Quantified Impacts of Project Change

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Abstract: Changes almost always occur on construction projects. Among other things, they can hurt labor productivity. The relationship between change and labor productivity, though commonly acknowledged, is not well understood. In this paper, such causal linkages are illustrated to capture the interactions of changes, disruptions, productivity losses, and the responsible parties. They go an extra step from the current mechanism of changes, disruptions, and inefficiency to underline the critical role of causing parties in cumulative impacts. From these causal linkages it is visible that: (1) even when disruptions are initially caused by one party (e.g., the owner), the other party (e.g., the contractor) may be able to reduce or escalate the disruptions and inefficiency throughout the course of work; and (2) productivity losses rarely result from a single causing factor but multiple and concurrent ones for which both parties can be responsible. Also, the methods available for quantifying lost productivity are systemized in this paper to visualize relationships among uncertainty, effort and expertise to use, and the level of contemporaneous project documentation required of these methods. A conceptual framework is also proposed herein to help project participants match the relevant quantifying analysis with their project circumstances.

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Introduction

Construction projects are typically undertaken in ever-fluctuating natural and business environments. Changes therefore normally occur in these projects for various reasons. These changes can lead to inefficiency or lost labor productivity. As a result, identification of factors causing inefficiency and quantification of the productivity loss has concerned a number of professionals and researchers. Unfortunately, the impact of changes is not sufficiently understood and quantified (Thomas and Napolitan 1995; Moselhi et al. 2005).

In this paper, we review and systematize current lost productivity estimating methods so that each method can be properly utilized in certain specific circumstances. In addition, we explain some insights into the interrelationships of changes, disruptions, productivity losses, and causing parties by employing the "feedback" concept from system dynamics methodology. The benefit of this review and analysis is that contractors and owners can choose the lost productivity analysis method that is best suited to their circumstance. They can further understand their role and responsibility in cumulative impacts of changes through the proposed causal mechanism. Future analyses and studies are able to more accurately quantify labor inefficiency induced by each party by elaborating this mechanism into quantitative cause-and-effect models.

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Background

Project change, disruptions, cumulative impacts, and factors affecting labor productivity have strong relationships. They are also playing a vital role in establishing liability, causation, and resultant injury in lost productivity claims. Change is one crucial factor in a range of factors influencing labor productivity. The following is brief discussion of these concepts.

Factors Affecting Labor Productivity

Labor productivity is a function of various controllable and uncontrollable factors. Schwartzkopf (1995) listed these factors in six groups: (1) schedule acceleration; (2) change in work; (3) management characteristics; (4) project characteristics; (5) labor and morale; and (6) project location/external conditions. Borcherding and Alarcon (1991) present a comprehensive review of quantitative information on factors influencing productivity. In addition, they categorized the major components of productivity loss as waiting or idle, traveling, working slowly, doing ineffective work, and doing rework. Specific factors and their descriptions are available in Borcherding and Alarcon (1991), MCAA (1994), Schwartzkopf (1995), and AACE (2004).

Project Change

Change is normally defined as any event that results in a modification of the original scope, execution time, cost, and/or quality of work (Ibbs and Allen 1995; Revay 2003). There are generally five types of changes; namely, change in scope, differing site conditions, delays, suspensions, and acceleration. Some discussion about the types of changes can be found elsewhere (e.g., Orczyk 2002).

Change may not only directly add, subtract, or change the type of work being performed in a particular area but also affect other areas of the work for which the change order is not accounted (Jones 2001). The Armed Services Board of Contract Appeals once stated that the costs of performing changed work consist of both (1) those costs directly related to the accomplishment of the changed work; and (2) those costs arising from the interaction between the changed work and unchanged work (*Triple "A" South*, ASBCA No. 46866, 94-3 BCA ¶27,194, at 135,523). This was also used by the other Boards of Contract Appeals such as the Veterans Affairs Board of Contract Appeals in Coates Industrial Piping (*Coates Industrial Piping, Inc.*, VABCA No. 5412, 99-2 BCA ¶30,479, at 150,586, 1999).

Extent of Project Change

The degree of project change varies per project but is frequently significant. An overall additive change rate for 22 federally funded and administered projects during the 1979–1983 period was 6% on the dollar due to design errors, owner initiated changes, differing site conditions, etc. (Diekmann and Nelson 1985). Among 24 construction projects in western Canada, project costs increased by at least 30 and 60% for more than half and a third of projects, respectively (Semple et al. 1994). Several projects suffered delays over 100%. A recent study of the Joint Legislative Audit and Review Commission (JLARC 2001) on approximately 300 road construction projects in Virginia revealed that average project change in dollars was more than 11%.

The amount and timing of change are also significant factors affecting productivity. From 90 construction disputes in 57 independent projects, Leonard (1987) showed that there was a significant direct correlation between percentage of change order hours to contract hours and percentage of lost productivity. Ibbs (1997, 2005) found that: (1) the greater the amount of change, the less the efficiency is; and (2) late project change more adversely affects labor productivity than early change. This finding was also confirmed by later studies (e.g., Hanna et al. 1999a).

Disruptions and Cumulative Impacts

The definition of disruption varies in literature. In *Coastal Dry Dock & Repair Corp.*, disruption is noted as the "cost effect upon, or the increased cost of performing, the unchanged work due to a change in contract" (*Coastal Dry Dock & Repair Corp.*, ASBCA No. 36754, 91-1 BCA ¶23,324, at 116,989, 1990). In some studies (Thomas and Napolitan 1995; Thomas and Raynar 1997), disruptions are defined as the occurrence of events that are acknowledged to negatively impact on labor productivity. More broadly, a Recommended Practice standard (AACE 2004) defines "disruptions as an action or event which hinders a party from proceeding with the work or some portion of the work as planned or as scheduled."

Disruptions can be caused by change. They can reduce labor productivity and extend the project duration (Hanna et al. 2002). Change-caused disruptions can be both foreseeable and unforeseeable. The foreseeable or local disruptions can occur at the same time and either the same place or within the same resource as the changed work, whereas unforeseeable or cumulative disruptions can also occur at a time or place, or within resources, different from changed work (Finke 1998a). The words "cumulative disruption" and "cumulative impact" can be used interchangeably. The Veterans Affairs Board of Contract Appeals recently described "cumulative impact is the unforeseeable disruption of productivity resulting from the 'synergistic' effect of an undifferentiated group of changes. Cumulative impact is referred to as the 'ripple effect' of changes on unchanged work that causes a decrease in productivity and is not analyzed in terms of spatial or temporal relationships" (*Centex Bateson Construction Co.*, VABCA No. 4613, 99-1 BCA ¶30,153, at 149,259, 1998). Jones (2001) argued that when the Board states that cumulative impact cannot be analyzed in terms of spatial or temporal relationships, it means that cumulative impact costs cannot be secured in individual contract changes.

Pricing of the direct impact due to local disruptions and cumulative impacts due to cumulative disruptions is different. The direct impact costs are prepared on a forward pricing basis. The cumulative impact costs, on the other hand, are more often priced on a backward-pricing basis as a contractor cannot foresee or readily quantify, if can foresee, the impact. In other words, a cumulative impact claim addresses the changed work's effect on working conditions that will indirectly influence the unchanged work, whereas a direct impact claim covers the impact of changed work on unchanged work (Jones 2001).

Causal Linkages of Labor Inefficiencies

The impacts of changes on labor productivity are extremely complicated to analyze. Quantifying the impacts of changes on labor efficiency is burdensome as there are the interconnected nature of the construction work and the difficulty in isolating factors to quantify them (Hanna et al. 2004). Although there are various interacting factors present at all times under practical conditions in the field, very few studies provide a method to address the combined effect of different factors that are existing simultaneously (Borcherding and Alarcon 1991). Also, there have been no definitive research works disseminating in quantitative terms the impacts of changes and why they occur (Thomas and Napolitan 1995; Hanna et al. 1999b). Importantly, the answer to which project party causes lost productivity is difficult to establish. For instance, factors that are not related to the number of owner-directed changes could be responsible for schedule delays and lost productivity on a construction project (Jones 2001). The Recommended Practice (AACE 2004) notes: "contractors tend to blame such losses on owners and ask to be compensated. Owners, on the other hand, often blame a bad bid or poor project management and thus deny additional compensation for lost productivity. Given this situation the root cause of lost productivity is frequently a matter in dispute between owners, contractors and subcontractors."

Although there are a few studies (e.g. Borcherding and Alarcon 1991; Thomas and Sakarcan 1993; Thomas and Napolitan 1995; Finke 1998a) which focus on how changes cause losses of productivity, these studies mainly focus on the relationship between changes, disruptions, and lost productivity, not the role of the project parties. For instance, Thomas and Napolitan (1995) present a factor model which explains that changes themselves do not directly cause productivity loss but cause other disruptive influences to be activated instead. Unfortunately, this model's neglect of the responsible party makes this model incomplete, especially since "causation," together with "liability" and "resultant injury," is a prerequisite for the success of cumulative impact claims. Proving the cause and the cost of the lost productivity so

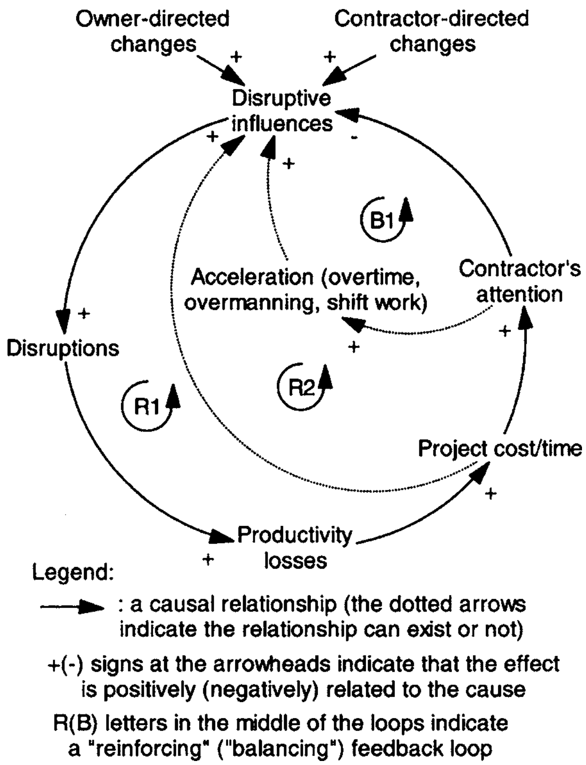

Fig. 1. Causal loops of inefficiency

that the proper party bears responsibility is the key challenge when presenting an inefficiency claim (Klanac and Nelson 2004).

Fig. 1 illustrates the causal loops and extends the above studies in order to capture the interactions among changes, disruptions, productivity losses, and causing parties. Because these loops describe such interactions for a given project, two groups of factors that affect labor productivity as previously discussed, namely project characteristics and project location/external conditions, are excluded for simplification. In other words, these two groups should be known for the given project. Other groups are not explicitly modeled. For instance, one may model "overtime," which is currently labeled in a general variable—"acceleration," separately (e.g., Nguyen and Ogunlana 2005). By doing this, some group of factors affecting labor productivity such as labor and morale can be explicitly included.

In Fig. 1, the arrows indicate causal relationships and + (or −) signs at the arrowheads indicate that the effect is positively (or negatively) related to the cause. Dotted arrows indicate that the corresponding causal relationships can exist or not. "R" in the middle of each loop represents a "reinforcing" (or positive) feedback loop, whereas "B" in the middle of each loop represents a "balancing" (or negative) one. These concepts can be found in Sterman (2000). Loops R1, R2, and B1 interact dynamically. Mathematically speaking, the behavior of the variables in the loops changes over time or during the course of project work. Changes can be classified as owner-directed and contractor-directed changes. They both cause disruptive influences and disruptions. Disruptions then cause productivity losses. This mechanism was proposed by previous research (e.g. Thomas and Napolitan 1995; Finke 1998a).

The feedback structure of Fig. 1 goes an extra step to relate inefficiency to the responsible party. Productivity loss generally increases project cost, time, or both. The delay, if any, likely amplifies disruptions if the work performed has to be shifted from

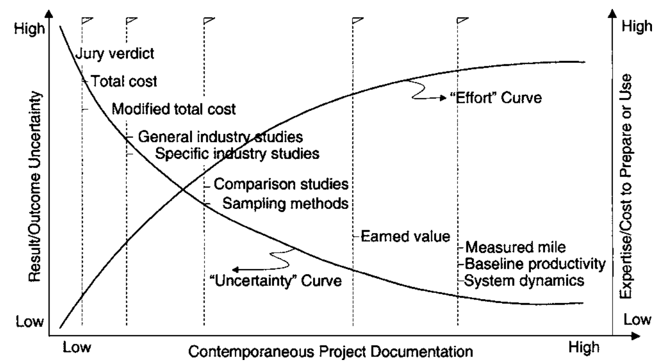

Fig. 2. Reliability of lost productivity quantifying methods

good weather season to a bad one. Any delay provides greater opportunities for all types of disruptions to occur. This cause is presented as a dotted arrow from "project cost/time" to "disruptive influences." The contractor, as the party responsible for managing project cost and schedule, will increase the attention when the project suffers cost and/or time overruns. As a result decisions can be made to either avoid further disruptions by reducing disruptive influences or unintentionally increase disruptions by acceleration in response to less-than-expected project status. This syndrome implies that even when disruptions are initially caused by owner-directed changes, the contractor is able to reduce or escalate those disruptions and inefficiency due to project management factors. This also underscores the idea that productivity losses rarely result from a single factor but instead multiple, concurrent, or intertwined factors.

Importantly, it is inferred that proper project management can minimize disruptive effects of changes. This is in agreement with the conclusions of Thomas and Napolitan (1995) that it is crucial to avoid disruptions in order to manage change work for improved efficiency. Similarly, Halligan et al. (1994) confirmed that proper management actions during the course of a project are crucial to mitigate lost productivity. To sum, the quantification of the impacts of project changes is undoubtedly arduous in terms of their quantum, causing factors and causing parties.

Lost Productivity Quantifying Methods

The construction industry has developed and employed many methodologies for estimating lost labor productivity in cumulative impact cost claims. Similar to the Recommended Practice (AACE 2004) and based on necessary data input, these methods can be classified into three major groups; namely project practice based, industry based, and cost based methods. The data requirements and the judicial acceptance generally increase as we move from the cost based to the project practice based methods.

Fig. 2 conceptually outlines the relationships between the levels of contemporaneous project documentation, verifiability of the project data required, reliability of the methods, and cost and expertise to record, prepare, and document the quantum of damages. The horizontal axis refers to the attributes of the project data, whereas the two vertical axes refer to attributes of the quantification methods for lost productivity. The methods listed typically increase in precision as they move from top to bottom in the graph. This also reflects the order of preference in the research literature (AACE 2004). On the contrary, the cost, effort, and expertise required for quantifying the loss normally increase as we progress from left to right. Horizontally the level of the contemporaneous documentation increases as the more detailed methods are used. The following discusses the concepts, merits, and limitations of specific methods. This is a basis to effectively match project practice and quantifying methods employed in labor productivity loss claims.

Project Practice-Based Methods

Measured mile analysis, baseline productivity analysis, system dynamics modeling, earned value analysis, sampling studies, and comparison studies are in this group as they require project records available for the calculations. As such, they are expected to be more credible. Courts, Boards of Contract Appeals and other legal bodies therefore prefer estimations of damages that are directly linked to the disputed project and supported by its contemporaneous documentation (AACE 2004). Types of the contemporaneous documentation required are generally different from this method to another. That is, the right method can only be recognized based upon available project data.

Measured Mile Analysis

The measured mile approach (differential studies or measured productivity comparisons) is widely acknowledged as the most favorable method for calculating lost productivity costs. The analysis compares identical tasks in impacted and nonimpacted periods of the project to estimate the productivity loss caused by the impact of a known series of events (Schwartzkopf 1995). It is based on an extrapolation of actual work hours spent (Zink 1986). The measured mile calculation might include comparison of similar work activities and achieve court acceptance (Jones 2003; Calvey and Zollinger 2003; AACE 2004). The allure of the measured mile is that the actual contract performance rather than the initial estimate is used for the calculations.

There are several assumptions and prerequisites underlying the measured mile technique. First, there must be an unimpacted or least impacted period (so-called the “measured mile” period) for the specific type of work being assessed. The adverse factors affecting productivity during the measured mile period, if any, must be solely attributable to the contractor. Second, the length of this period should be significant compared to the impacted period and the course of work. In other words, it would be unreasonable to extrapolate 2% of progress into 80% of expected costs (Zink 1986). Third, sufficient amounts of contemporaneous project data should be available for the analysis. At most the physical units of work completed have to be periodically recorded so that the cumulative labor hours can be plotted through the course of work. Fourth, the project data are assumed to be error free. That is, the contemporaneous documentation must be accurately recorded by the contractor. Finally, all disruptions during the impacted period are due to one party’s (say, the owner’s) actions or inactions. It is extended that other factors unrelated to the claimed impacts have to be accounted for and removed from the impacted period analysis to the degree these factors occurred during the measured mile period (AACE 2004).

Considerable limitations are embedded in these assumptions. The measured mile analysis becomes unreliable or even impossible when either an unimpacted period does simply not exist or this period is not sizeable. The fact that the analysis requires identical or substantially similar activities for comparisons can hamper its applicability as the method is inappropriate for unique and complex tasks (Loulakis and Santiago 1999). The reliability of the method is challenged if inaccurate contemporaneous project data are used for the analysis. Unfortunately reporting errors are commonplace in the current practice (Thomas and Sanvido 2000).

Other limitations are more implicit. Projected cumulative labor hours can be extrapolated differently due to different options of the time frame. Gulezian and Samelian (2003) pointed out that: (1) different time frame and segments selected within the measured mile period may produce different numbers; and (2) variation of daily productivity is concealed to varying extents by the cumulating nature of the measure mile analysis. They also argue that the measured mile does not necessarily reflect the productivity normally achieved by the contractor due to the smoothing effect of successive cumulative data and the nature of variation in unit productivity values. In addition, the two average productivity rates, which are readily calculated and compared for unimpacted and impacted periods, may mask the fact that a contractor generally does not attain a single rate of productivity throughout a time period (Finke 1998b).

Baseline Productivity Analysis

This approach was recently proposed in order to avoid some of the substantial limitations and impractical assumptions of a current measured mile analysis. Similar to the measured mile method, baseline analysis relies on the contractor’s actual performance of the project being analyzed. A central point of this analysis is to establish the baseline productivity. It represents the best and most consistent productivity the contractor was able to achieve on the project (Thomas and Završki 1999). Analyzing a 42-project database, Thomas and Završki (1999) revealed that the baseline productivity mainly depends on the complexity of the design and the work methods used. Unlike the measured mile analysis, a baseline analysis neither needs defined unimpacted and impacted periods nor be consecutive reporting periods in the baseline time frame (Thomas 2005a). In other words, the baseline analysis can be more flexible and hence more applicable in current practice.

A determining process of the baseline productivity can be found in Thomas and Završki (1999), Thomas and Sanvido (2000), and Gulezian and Samelian (2003). However, the process has not obtained consensus among studies though it is generally agreed that using individual productivity values is better than cumulative productivity for the calculations. This may be due to varying views on the baseline productivity. Unlike Thomas and Završki (1999), Gulezian and Samelian (2003) noted that the baseline productivity reflects the normal operating performance of a contractor. Thomas and Završki (1999) and Thomas and Sanvido (2000) determine the baseline productivity as “the median of the individual productivity values in the baseline subset.” Gulezian and Samelian (2003) calculate it as “the mean productivity of the points falling within the control limits” after applying an iterative process of an individuals’ control chart to deal with different sources of variation of periodically reported productivity values.

Although the baseline analysis solves several problems of the measured mile approach, it is still limited. The way of calculating the baseline productivity should be more scientific and straightforward, subject to properly dealing with reliability of reported data, variation of productivity values, and casual linkages to disruptions and inefficiency. Some shortcomings are related to the establishment of the baseline sample as in Thomas and Završki (1999) and Thomas and Sanvido 2000). They are: (1) the baseline sample is identified according to the best daily output instead of the best daily productivity; and (2) the 10% requirement for the baseline sample size is arbitrary and not based upon scientific principles (Ibbs and Liu 2005a). In addition it is agreed that the baseline analysis is a cause–effect analysis, yet it is qualitative or very roughly approximate in nature as in Thomas (2005b). There has been no sound method for which damages induced by the owner and contractor are classified and quantified during a disputed period. Especially, multiple and/or simultaneous owner- and contractor-caused disruptions are not uncommon in real life.

System Dynamics Modeling

System dynamics (SD) methodology has been employed to understand the behavior of various natural, social, and engineered systems. Its principles, concepts, and tools can be found in Forrester (1961), Richardson and Pugh (1981), and Sterman (2000). Specifically, a number of delay and disruption claims have been successfully settled with extensive support of SD modeling. One such successful story was the development and application of a SD computer simulation model to resolve a $500 million shipbuilder claim consisting of the direct impact and the "ripple effects" between Ingalls Shipbuilding and the U.S. Navy in the 1970s (Cooper 1980). Other successful applications of SD modeling in delay and disruption claims and lawsuits have been also reported recently (Ackermann et al. 1997; Eden et al. 2000; Williams et al. 2003).

By using SD modeling quantification of cumulative impacts can overcome one of the major limitations of the measured mile and baseline analyses. As discussed earlier the two methods are not able to properly handle the multiple and/or concurrent disruptions caused by different project parties. SD models can correctly quantify owner-responsible delay and disruption impact costs and demonstrate the cause–effect relationship of the cumulative impacts (Cooper 1980). A key feature of SD simulation modeling is that it allows and directs answering a pool of "what if" questions such as: What if one particular category of disruptions had not occurred but all others had? What if the owner interventions had not occurred? (Cooper 1980; Eden et al. 2005). In addition, it visualizes causality and allows for validation of causal logic in quantitative terms and against actual data at any period of the project in dispute (Eden et al. 2005).

SD modeling has not achieved much popularity in construction disputes compared to the measured mile analysis. One main reason is that SD simulation models are not readily understood by all litigation audiences (e.g., contractors, owners, judges, . . .) due to the dynamic complexity and quantitative nature of those models (Howick 2005). Also, unless the SD model is properly validated, it is meaningless, incredible, and therefore useless. Validation of a SD model is very problematic and time consuming and requires extensive expertise of the SD methodology. In some circumstances, it is assumed that the reasonableness of the original estimate in SD modeling can draw inaccurate and unpersuasive quantum of damages. Also, though the causal coefficients indicating the relationships between activities are very important to the accuracy of a SD model, they are not easy to estimate (Ibbs and Liu 2005b).

Earned Value Analysis

An earned value analysis can also be used to estimate the cumulative impacts, especially when the physical units of work completed have not been recorded adequately for employing a more reliable method like the measured mile and baseline analyses. For a project the difference between earned hours determined from the earned value analysis method and actual hours expended for an impacted period can be used to compute the inefficiency suffered (AACE 2004). As an earned value analysis is based on the percent complete and the budget, the credibility of the method can be questionable. The reasons are that (1) the percent complete method is not as detailed and accurate as the physical units of work completed method (Schwartzkopf 1995) used in the previous quantifying methods; and (2) the original estimate is likely unsubstantiated. Any earned value analysis relying on an unreasonable budget is very doubtful (AACE 2004).

Sampling Methods

Two sampling methods used for estimating lost productivity are work sampling and craftsmen questionnaire sampling methods. Introduction to these methods can be found elsewhere (e.g., Oglesby et al. 1989). The sampling methods are typically simple and inexpensive to analyze labor productivity. Although they can be used for lost productivity claims, their trustworthiness is not high as they are only a sampled measure of labor productivity. For instance, an assumption of work sampling that there is a positive relationship between productive time and labor productivity was found to be false (Thomas 1991).

Comparison Studies

Comparison studies can be classified as comparable work and comparable project studies. AACE (2004) also classifies the comparable work studies in two forms: (1) the contractor estimates lost productivity on the impacted period, and then locates an analogous or similar work activity on the same project, which was unimpacted and calculates its productivity; and (2) the contractor compares productivities during the impacted period and of similar but unimpacted work performed by another contractor on the same project. Comparable project studies are used to contrast the productivities of similar work activities on the project being analyzed and a similar project.

The success of the comparison studies is difficult to achieve as the definition of similar work or a similar project are typically impossible and therefore rarely agreed by project parties and/or different litigation audiences in court cases. As such it is recommended that the baseline productivity analysis or system dynamics modeling should be used for sizable claims when there is no clear unimpacted period. The other methods can be complementary and substantiating, and should not be discarded. There may be times when they are the best alternative available.

Industry-Based Methods

Specialty industry and general industry studies are called the industry based methods. As their names implied a specialty, industry study employs results of specific studies directly related to the cause of damages, whereas a general industry study is based on industry-wide manuals and/or reports. The specific studies can be about acceleration, learning curve, overtime, weather, and so forth. Sources of these qualitative and/or quantitative studies for various subjects can be found in Borcherding and Alarcon (1991) and AACE (2004). The industry based analyses may be employed when there is insufficient project documentation. They can also be used with another method to augment supportive evidence of damages. The industry based and craftsmen questionnaire sampling methods worked well in a recent case ruled by the General Services Board of Contract Appeals (*Hensel Phelps Construction Co.*, GSBCA No. 14,744 & 14,877, 01-1 BCA ¶31,249, 2001). In general, though the industry based methods are quick and inexpensive, their use in calculating lost productivity is not the first preference.

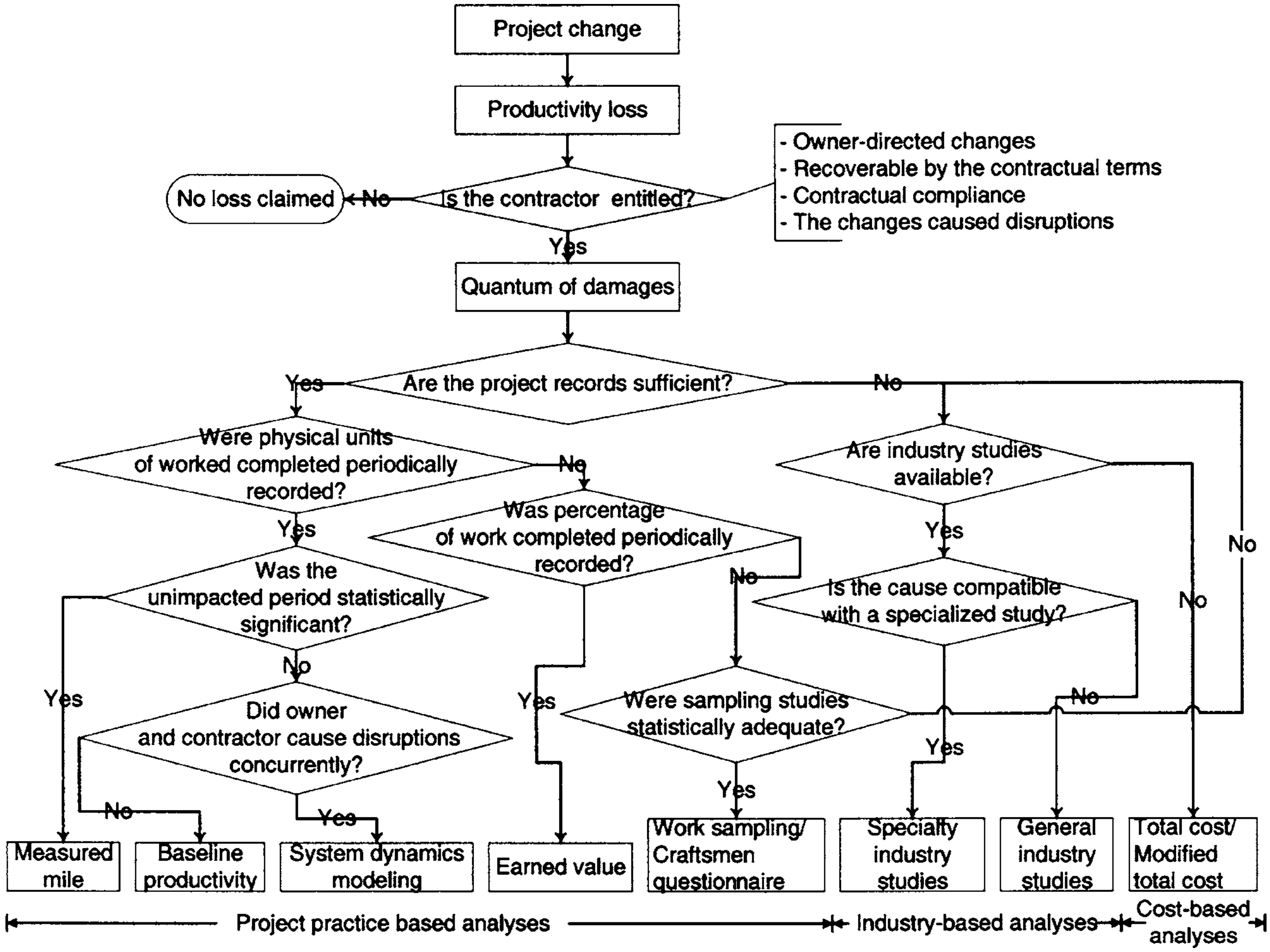

Fig. 3. Matching the quantifying methods and project practice

Cost-Based Methods

Total cost and modified total cost methods are grouped into cost based methods. AACE (2004) further divides a total cost method into a total unit cost and a total labor cost method. Under the total cost method, the contractor subtracts its estimated labor costs from the costs actually incurred to arrive at the resulting overrun as the basis for its inefficiency claims (Jones 2003; Klanac and Nelson 2004). The major difference between the total cost and modified total cost methods is that damages quantified by modified total cost calculation takes into account unreasonable estimates and/or inefficiencies due to contractor's problems. Thus, the second method is preferable.

Successful use of the cost based methods is today limited. In order to employ a total cost analysis, a contractor has to prove the following requirements: (1) the impracticability of proving actual losses directly; (2) the reasonableness of its bid; (3) the reasonableness of its actual costs; and (4) lack of responsibility for the added costs (*Centex Bateson Construction Co.*, VABCA No. 4613, 99-1 BCA ¶30,153 at 149,261, 1998). The requirements for the use of the modified total cost method are similar but the bid and actual costs should be reasonable after adjusted.

Other Quantifying Methods

There are other inefficiency estimations such as expert testimony and jury verdict. A considerable portion of lost productivity calculations is based primarily upon an expert's testimony (Sanders and Nagata 2003). Though this method might work, it is extremely uncertain due to no supporting analysis in-hand. Similarly, the jury verdict that is occasionally applied by boards, courts, and other legal bodies to determine damages has no ground on which a contractor should rely.

Matching the Quantifying Methods and Project Practice

Although more than one method may be employed under a certain circumstance at an acceptable standard of accuracy, the most appropriate method is normally predicted in a given project practice. Based on the extent of information available in a particular case, all ways of estimating cumulative impacts try to be as objective as possible (Gulezian and Samelian 2003). Thus, a guideline on which method should be adopted for inefficiency claims is necessary.

Fig. 3 presents a conceptual framework for which a contractor can figure out a proper analysis for quantifying damages. This selection process is primarily based on availability and characteristics of information and degree of reliability of quantifying methods. Available information can be from particular project practice and/or industry studies.

The contractor has to ask himself a series of questions to select the right quantifying method. Accordingly, the matching process structures critical questions by various decision points. These decision points are organized in such a way that more general questions regarding project practice arise first so that available methods can gradually be classified in terms of their feasibility. Finally, the most advantageous method emerges among the feasible set for a certain type of project data and industry studies. The relative advantages and disadvantages of the lost productivity quantifying methods are discussed in the previous section.

The framework recommends the most favored approach rather than a set of possible ones. This means that, for example, an earned value analysis can also be used in case a measured mile study is not available. However, the measured mile method is most favored in that circumstance and hence is recommended. In addition, comparison studies do not appear in the possible outcomes of the framework since such more credible methods as baseline productivity analysis and system dynamics modeling are preferred when time, available documents, and resources permit.

Conclusions

To reliably quantify and successfully claim lost productivity, damages have to be associated with causes. This paper proposes causal loops or causal linkages to capture and explain the interactions among changes, disruptions, productivity losses, and causing parties when changes occur. These causal relationships extend the current mechanism of changes, disruptions and inefficiency in order to emphasize the critical role of the project parties in cumulative impacts. From the feedback structure of labor inefficiency proposed, it is apparent that: (1) even when disruptions are initially caused by owner-directed changes, the contractor can potentially reduce or escalate the disruptions and inefficiency during the course of work; and (2) losses of productivity rarely result from a single causing factor but multiple and concurrent ones for which both parties can be responsible.

Resultant injury goes hand-in-hand with liability and causation to form the "triad of proof." For that reason, this paper systematizes the proven lost productivity quantifying methods as well as the other emergent methods. The comments are also made for each method in terms of its credibility, effort and expertise to prepare or use, and the level of contemporaneous project documentation required. The relationships among these components of the quantifying methods available are also discussed.

A conceptual framework is proposed here for matching the right quantifying method and its particular project practice. Availability and characteristics of information and degree of credibility of the quantifying methods are focused for the matching process. Together with employing qualified experts, the framework proposed herein can be used to find the most favored quantifying method in accordance with its circumstance to effectively recover the damages.

The quantification of cumulative impacts of project changes is indisputably formidable in terms of their quantum, causing factors and causing parties. Credibility of analysts, explicit connections between damages and causes, and an acceptable level of accuracy for measuring lost labor productivity are the keys to successfully achieve cumulative impact claims.

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