Proposed Improvements to the MCAA Method for Quantifying Construction Loss of Productivity

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Abbreviations

AACE:	The Association for the Advancement of Cost Engineering
ASBCA:	Armed Services Board of Contract Appeals
BCA:	Board of Contract Appeals
BLS:	Bureau of Labor Statistics
BRT:	Business Roundtable
CO:	Change Order
GSBCA:	General Services Board of Contract Appeals
G&M:	Grimm and Wagner (1974)
IFC:	Issued for Construction
LOP:	Loss of Productivity
MCAA:	Mechanical Contractor's Association of America
NECA:	National Electrical Contractors Association
PR:	Productivity Ratio
SOFI:	Swedish Occupational Fatigue Inventory
T&J:	Thomas and Jansma (1985)
T&S:	Thomas and Smith (1990)
T&Y:	Thomas and Yiakoumis (1987)
VABCA:	Veterans Affairs Board of Contract Appeals
WBGT:	Wet-Bulb Globe Temperature

Glossary

Causation: One of three elements necessary to establish a LOP claim. It requires the plaintiff to prove that the loss of productivity was caused by the defendant's conduct or actions, rather than by the plaintiff's failure.

Change: Any addition, deletion, or other revision within the general scope of a contract. It may cause an adjustment to the contract price or contract time.

Damage (Quantum or Resultant injury): One of three elements the defendant needs to establish for a LOP claim. It requires the plaintiff to quantify LOP properly.

Factor Method: A general category of damage calculation method to calculate productivity or LOP by listing multiple factors, allocating a multiplier for each factor and adding them together.

Jury Verdict: A LOP quantification method relying on the discretion of the Court.

Labor Productivity: A measurement of rate of output per unit of time or effort.

Loss of Productivity: Less than anticipated productivity. Can be the result of interferences or events not the responsibility of the plaintiff.

Liability: One of three elements the plaintiff needs to establish for a LOP claim. It refers to the party responsible for a loss.

MCAA Method: A method to quantify LOP based on a table of factors that can impact labor productivity. This table was developed by the MCAA in its manual "change orders, overtime and productivity" since 1971.

Measured Mile Method: A method to calculate LOP by comparing the contractor's actual labor productivity during a relatively un-impacted period and its actual labor productivity during a period impacted by changes or other owner-caused events.

Modified Total Cost Method: A method similar to the total cost method except that the contractor subtracts known bid errors, excessive cost, and field problems for which it was responsible.

Productivity Percentage Loss: Percentage extra time spent per unit work.

Productivity Ratio: The ratio of actual productivity and expected productivity.

Total Cost Method: A method to calculate the LOP through the difference between total labor cost expended and total labor cost paid.

Proposed Improvements to the MCAA Method for Quantifying Construction Loss of Productivity

Executive Summary

Project changes are often encountered in construction industry. They can hurt construction craft labor productivity and can cause significant financial loss. Such losses are called loss of productivity (LOP). Calculating a project's LOP is one of the most important and contentious areas in construction disputes and claims.

Several ways to calculate productivity loss exist. One method is the MCAA (Mechanical Contractors Association of America) Factor method. Recognizing the importance and vulnerability of productivity to a wide array of project conditions and the value of having an easy-to-use method for calculating Loss of Productivity (LOP), MCAA developed a table of factors that can impact labor productivity. It has been in use for over forty years and has gained wide acceptance in the construction industry and before various Courts and Boards of contract appeals. But the model has been rejected in several recent claims.

The aim of this report is to investigate the reasons for those rejections and offer improvements to the existing MCAA model. We document the MCAA model's history, identify typical mistakes made in its application, and compare it with other LOP studies and previous legal case decisions.

The model's problems fall into two categories: 1) application problems, which are matters of how users apply the model, and 2) structural problems. The structural problems include 1) lack of guidelines to select factors and prove causation; 2) unclear definitions of what these factors mean and how they can affect labor productivity; and 3) the manual's recommendations of loss percentages are not verified by real project data. After analyzing those problems, we developed and now offer suggested improvements to the model.

Specifically, we found fourteen published board and court cases related to LOP that have used the MCAA Method. It has been used many times during the past twenty years, however the success rate for plaintiffs has generally declined in recent times. Prior to 2000 the model was successfully used in five of five published cases; since 2001 it has been successful in only two of nine cases. One possible explanation for this trend is that Boards and Courts have recently imposed a more stringent standard for proving LOP claims.

In terms of application problems, we found that:

1) Establishing causation is paramount in convincing triers-of-fact that a LOP claims exists.
2) Users of the MCAA model should not blindly rely on the single-point LOP damage percentages contained in the manual. Temper them with professional judgment and a full understanding of the project facts. Include testimony from experienced fact witnesses if they are available. Include testimony from expert witnesses who are familiar with LOP claims in general and the MCAA model in particular.

3) Use fewer Factors rather than more. Successful claims used an average of four factors while unsuccessful claims used nine. Season and Weather Change, Stacking of Trades, Site Access, and Overtime were the Factors most likely to be persuasive. Least likely to be persuasive were Errors and Omissions, Joint Occupancy, Ripple, and Logistics.

From the perspective of the model's structural problems, we recommend that:

1) Cause-Effect maps be used as a supplement to the MCAA model analysis to graphically depict causation and liability.

2) The MCAA Factors be more clearly defined. Some MCAA Factor definitions are vague, duplicative, and do not clearly explain how they affect labor productivity. We offer new language for all sixteen Factors that will address this deficiency.

3) The minor-average-severe single-point LOP percentages specified for the MCAA table need to be refined for some of the Factors, as detailed in Table 1 below. For instance:

    a. We analyzed weather data from previous research studies and developed a better formula for predicting LOP across a range of temperature and humidity values.
    b. We determined learning curve models should be used with caution, only for repetitive work, and for unit or moving average data. Avoid use of cumulative average productivity data.
    c. For overtime, the multiplier values presented in curvilinear fashion by The Business Roundtable, Bromberg, O'Connor, and other researchers are more realistic than the 10%, 20%, and 30% values contained in the current MCAA model.

In conclusion, the MCAA model is a valuable tool for parties trying to assess construction craft LOP. However, it has not fundamentally changed since its introduction forty years ago, and subsequent research and industry practice have advanced our understanding of loss of productivity. The work presented in this document is intended to help advance the model and make it more useful to contractors, owners, and consultants.

MCAA Original Definitions	Proposed Improvements on the Definition			MCAA Original Quantification Value			Proposed Quantification
	Definition	Effect on Productivity	Other Remarks	Minor	Average	Severe	
F1 STACKING OF TRADES: Operations take place within physically limited space with other contractors. Results in congestion of personnel, inability to locate tools conveniently, increased loss of tools, additional safety hazards, and increased visitors. Optimum crew size cannot be utilized.	STACKING OF TRADES: Stacking of several trades (the contractor's own work force or with those of other contractors) in the same working area, or work to be performed while facility occupied by other trades; Not anticipated in original bid.	1) Extra work or procedures needed when working with or right after other trades; 2) Site access and logistics problem: limited site access due to storage of materials /equipment; inability to locate tools conveniently; or another trade leaves the work incomplete, preventing the contractor from doing his own work; and 3) Congestion of personnel: more people working in the same area causing extra movement of people, physical conflict, constraints and extra standby time.	Related to Beneficial Occupancy, Crew Size Inefficiency, Site Access, and Logistics.	10%	20%	30%	See Figure 7.6.
MORALE AND ATTITUDE: Excessive hazard, competition for overtime, over-inspection, multiple contract changes and rework, disruption of labor rhythm and	MORALE AND ATTITUDE: Lower level of labor motivation and enthusiasm for achieving project objectives.	Lower work speed and extra errors and corrections.	Use is not recommended. Boards and courts have generally not accepted. Lower morale can be caused by other MCAA Factors and is	5%	15%	30%	Granted amounts in previous cases are small, typically 5%.

scheduling, poor site conditions, etc.			closely related to the contractor's management. Hard to establish liability and causation.				
REASSIGNMENT OF MANPOWER: Loss occurs with move-on, move-off men because of unexpected changes, excessive changes, or demand to expedite or reschedule completion of certain work phases. Preparation not possible for orderly change.	REASSIGNMENT OF MANPOWER: Transferring workers from one task to another due to blockages to current work. Workers need to jump frequently to other works and work on a stop-and-start basis.	Time spent on extra movement.	Related to out-of-sequence work and Learning Curve.	5%	10%	15%	Related to Learning Curve. Productivity level can be calculated based on number of units using Learning Curve model in Section 7.2.
CREW SIZE INEFFICIENCY: Additional workers to existing crews "breaks up" original team effort, affects labor rhythm. Also applies to basic contract hours.	CREW SIZE INEFFICIENCY: Adding more manpower to existing construction work.	1) Congestion of personnel: physical conflict and high density of labor; 2) Dilution of Supervision; and 3) Logistics problems such as material, tool and equipment shortage.	Related to Stacking of Trades, Dilution of Supervision, and Logistics.	10%	20%	30%	LOP can be calculated through overstaffing level; see Figure 7.5. Or crowding level; see Figure 7.6.
CONCURRENT OPERATIONS: Stacking of this contractor's own force. Effect of adding operation to an already planned sequence of operations. Unless	Suggest this Factor to be combined with Stacking of Trades.			5%	15%	25%	Suggest this Factor be combined with Stacking of Trades.

gradual and controlled implementation of additional operations is made, Factor will apply to all remaining and proposed contract hours.							
DILUTION OF SUPERVISION: Applies to both basic contract and proposed change. Supervision must be diverted to (a) analyze and plan change, (b) stop and replan affected work, c) take-off, order and expedite material and equipment, (d) incorporate change into schedule, (e) instruct foreman and journeyman, (f) supervise work in progress, and (g) revise punch lists, testing and start-up requirements.	DILUTION OF SUPERVISION: Refers to the situation that the supervisor(s) spending less time overseeing work; or a lower supervisor-labor ratio.	1) Extra Errors and Omissions due to lack of supervision; 2) Lower work speed of workers; and 3) Additional standby time waiting for supervisors to answer questions and solve problems.	Related to out-of-sequence work and Crew Size Inefficiency.	10%	15%	25%	When recognized, awards are typically less than 10%. Reimbursed amount should be smaller than the cost of adding more supervisors.
LEARNING CURVE: Period of orientation in order to become familiar with changed condition. If new men are added to project, effects more severe as they learn tool	LEARNING CURVE: Loss of learning due to disruptions, time and cost to familiarize with the work and work site, extra training cost, mobilization, and	1) Lower work speed during learning period to become familiar with work and work environment; 2) Extra training cost; and 3) Extra mobilization	Related to Reassignment of Manpower.	5%	15%	30%	Productivity level can be calculated based on number of units. See Eq. 7.4 and Eq. 7.5 in Section 7.2.

locations, work procedures, etc. Turnover of crew.	demobilization cost.	and demobilization cost.					
ERRORS AND OMISSIONS: Increases in errors and omissions because changes usually performed on crash basis, out-of-sequence, or cause Dilution of Supervision or other negative Factors.	ERRORS AND OMISSIONS: Increase in worker's work errors and omissions due to disruptions.	Extra correction work, including rework and cleanup.	Use not recommended. Extra errors can be caused by many other MCAA Factors, and thus may not be primary.	1%	3%	6%	No previous studies on LOP quantification were found. In general amount claimable is extra errors in excess of 1-4%. See Section 7.5.
BENEFICIAL OCCUPANCY: Working over in close proximity to owner's personnel or production equipment. Also badging, noise limitations, dust, and special safety requirements and access restrictions because of owner. Owner using premises prior to contract completion.	BENEFICIAL OCCUPANCY: Working over, around, or in close proximity to the owner or owner-created obstacles.	1) Site access problems; 2) Out-of-sequence work; 3) Logistical problems: including storage and protection of materials; and 4) Badging, noise limitations, dust, and special safety requirements.	Related to Stacking of Trades, Site Access, and Logistics.	15%	25%	40%	Congestion can be calculated through crowding level. See Figure 7.6.
JOINT OCCUPANCY: Change cause work to be performed while facility occupied by other trades and not anticipated under	Suggest this Factor be combined with Stacking of Trades.			5%	12%	20%	Suggest this Factor be combined with Stacking of Trades.

original bid.							
SITE ACCESS: Interference with convenient access to work areas, poor man-lift management, or large and congested worksite.	SITE ACCESS: Site partially restricted by the material or personnel onsite, or the site is not accessible so that the work is delayed.	1) Extra effort to get site access; 2) Extra movement of labor or equipment; and 3) Extra work such as cleaning up.	Related to Logistics.	5%	12%	30%	No previous studies were found. Highly dependent on project situations.
LOGISTICS: Owner furnished materials and problems of dealing with his storehouse people, no control over material flow to work areas. Also contract changes causing problems of procurement and delivery of materials and rehandling of substituted materials and rehandling of substituted materials at site.	LOGISTICS: 1) Problems with owner furnished materials; or 2) Other logistic problems caused by owner's change of materials or work schedule	1) Extra work for logistics coordination, materials movement and rehandling; 2) Storage cost: storage cost when no storage space; and 3) Standby time to wait for materials.	Logistics problem can be caused by many other MCAA Factors, it need to be used with caution.	10%	25%	50%	Cases and studies found have LOP percentage due to Logistics as much as 20%. Highly dependent on project characteristics.
FATIGUE: Unusual physical exertion. If on change order work and men return to base contract work, effects also affect performance on base contract.	FATIGUE: the worker's unusual physical conditions including lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness.	1) Lower work speed; and 2) Extra errors and omissions.	Use not recommended. Related to Weather and Overtime, hard to establish liability and causation. Low morale can be caused by Fatigue as well.	8%	10%	12%	Questionnaires have been used in other industries to determine Fatigue level. See Table 7.4.
RIPPLE: Changes in other trades' work	Suggest this Factor not be used in a LOP claim.			10%	15%	20%	Suggest this Factor not be used in a LOP

affecting our work such as alteration of our schedule. A solution is to request, at first job meeting, that all change notices/bulletins be sent to our Contract Manger.							claim. Usually the result of some other driving event or Factor, which is where the LOP should be computed.
OVERTIME: Lowers work output and efficiency through physical fatigue and poor mental attitude.	OVERTIME: Work more than forty hours per week, extended workdays, extended workweeks, night and weekend work.	1) Lower work speed and extra errors and omissions; and 2) Logistics problems.	Related to Fatigue, and Morale and Attitude.	10%	15%	20%	See multipliers listed in Table 7.2.
SEASON AND WEATHER CHANGE: Either very hot or very cold weather.	SEASON AND WEATHER CHANGE: Unexpected severe weather, work pushed to inferior work time or unexpected work environment change (e.g. lack of windows in winter). Possible problems include winter, rain and snow, wind, hot weather, and sun exposure, etc.	1) Impact to physiological conditions, lower work speed and extra errors; 2) Logistical and site access problem; and 3) Extra work such as cleanup.	Related to Fatigue, Logistics, and Site Access.	10%	20%	30%	See Eq. 7.3 and Figure 7.4.

Chapter 1. Introduction

1.1 Background: Changes, Loss of Productivity (LOP), and the MCAA Method

Project changes can hurt labor productivity, which in turn can jeopardize project success for all parties. Contractors and owners frequently fail to agree on the responsibility and quantification of productivity loss due to changes. This failure to agree becomes a major source of claims and litigation. The MCAA Method is one widely accepted approach to measure the damage in a LOP claim.

1.1.1 Changes in Construction

Ibbs (1994) defines change as "any addition, deletion, or revision to the general scope of a contract". Lee (2007) expands that definition of change as "any action, incidence of condition that makes differences to an original plan or what the original plan is reasonably based on."

Changes in construction can fall within two general categories: directed changes and constructive changes. A directed change can add to or reduce the contract price, and it may also involve a change in the construction sequence or schedule. Constructive changes "occur from any events that are not owner-directed or that have the effect of implicitly requiring the contractor to modify the scope set forth in the original contract" (MCAA 2016).

As defined by the Mechanical Contractors of America Association (MCAA) manual, some issues with changes include:

- *Owner-driven scope changes that cause an increase or decrease in the amount of work from the scope of work outlined in the original contract;*
- *Changes in the methods of performance or the materials or equipment to be installed;*
- *Changes that modify the planned sequence in which the work was to be performed;*
- *Differing site conditions not anticipated in the original contract price;*
- *Constructability issues;*
- *Changes in performance specifications;*
- *Changes to correct errors, omissions, or inconsistencies in the specifications or drawings;*
- *Changes in the time for performance;*
- *Changes resulting from extraordinary, unexpected natural events; and*

- *Changes due to the actions or inactions of other trades working on the project.*

In this report, change in construction refers to both directed change and constructive changes.

1.1.2 Productivity

Productivity is a measurement of rate of output per unit of time or effort. It is usually measured in units of work per labor hour or crew hour; for example, cubic yards concrete placed per crew hour (AACE 2004).

Productivity in construction sometimes includes both equipment productivity and labor productivity. Productivity in this paper refers to construction craft labor productivity. That is, equipment and material costs, indirect cost, profit and labor price will not be within the study scope of this report.

1.1.3 LOP Due to Changes

Not only is productivity important in projects, it is also vulnerable to change, which is common to projects. Less-than-anticipated productivity can cause significant financial loss. If these losses are the result of interference or events not the responsibility of the contractor, the contractor may be able to recover these costs from the responsible party through a loss of productivity claim (Harmon and Cole 2006). These losses are called loss of productivity (LOP). LOP calculation is one of the most important and contentious areas in construction claims.

In this report, LOP is measured by PR (productivity ratio) or percentage loss. Productivity ratio is defined by the ratio of actual productivity and optimal productivity. Productivity percentage loss is defined as the extra time spent per unit work. The relationship between PR and productivity percentage loss is thus:

$$Percentage\ Loss = 1/PR - 1 \qquad \text{(Eq. 1.1)}$$

1.1.4 LOP Claim

Simply experiencing labor inefficiency does not mean that the contractor is entitled to recover from the owner. In order for these damages to be recoverable, the contractor must prove three elements in a LOP claim: causation, liability, and resultant injury (*Appeal of Centex Bateson Construction Co.*); see Figure 1.1. In this report we will consider the contractor or subcontractor to be the plaintiff and the owner to be the defendant. It is possible for the reverse to be true.

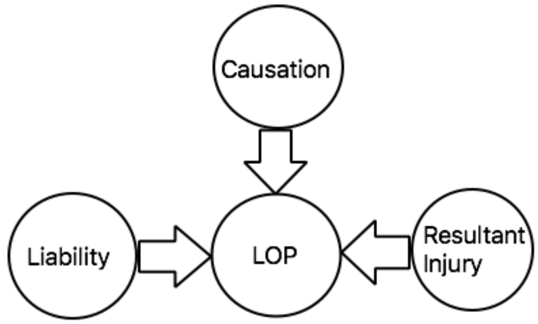

Figure 1.1: Three Elements to Establish LOP

Causation requires the contractor prove that the LOP was caused by the owner's conduct or actions, rather than by the contractor's failure to estimate the job properly, inability to properly schedule the work, or failure to coordinate the work. Liability has two components: 1) a legal right to recover based on either a "remedy-granting provision in the contract" or the owner's "breach of the contract" and (2) the owner did something that hindered the contractor's performance. The final element quantum requires the contractor to quantify the lost productivity and costs associated with LOP." (Jones 2003)

Both LOP causation and entitlement are hard to establish (AACE 2004).

1.1.5 LOP Measurement Methods

There are several ways to calculate productivity loss caused by changes. First and foremost is the actual, careful and contemporaneous measurement of the labor hours required to perform change work. However, such direct, real-time measurement is not always possible.

Measuring LOP is difficult. Standard cost account categories and standard monetary categories do not readily yield the necessary quantification of LOP. It is well recognized that a contractor does not have to prove its LOP with mathematical exactitude, and the MCAA Method, like any method, requires users to consider carefully the narrative facts and project events or milestones with the trends shown by the numbers (MCAA 2016).

A widely accepted approach is the measured mile analysis. It is a comparison between a contractor's actual labor productivity during a relatively un-impacted period and its actual labor productivity during a period impacted by changes or other owner-caused events (Long 2005).

However, measured mile cannot be applied to many projects because of the lack of a detailed productivity record and the lack of suitable or comparable un-impacted areas or time frames (MCAA 2016).

Total Cost Method is anther frequently used method for a productivity claim. It is simply “the difference between total labor cost expended and total labor cost paid” (AACE, 2004). This method is much easier to calculate and does not rely on detailed records. The Modified Total Cost Method is the same as the Total Cost Method except that “the contractor subtracts out known bid errors, excessive cost, field problems for which the contractor was responsible” (AACE 2004).

However, it assumes all the cost overrun is the fault of the defendant. This method is the least preferred, and according to *Servidone Constr. Corp. v. United States*, it only applies when:

1. The contractor’s actual losses are impractical to prove.
2. The contractor’s bid estimate was reasonable.
3. The contractor’s actual costs were reasonable.
4. The contractor was not responsible for any of the cost increases.

As mentioned, both measured mile and total cost methods have their limitations. Besides those two methods, published studies and manuals can also be used to prove losses. Harmon and Cole (2006) made a review of 21 manuals and studies, and for 16 of them there was no case or Board decision found that used those works. The Business Roundtable (BRT) Report “Scheduled Overtime Effect on Construction Project” has been accepted by Boards and Courts once in *Ace Constructors, Inc. v. U.S.*, and the MCAA Method has been accepted several times by the Boards and Courts, as discussed later.

Situations onsite are normally complicated. There might be many reasons for LOP, and some are possibly the defendant’s problems, while some are not. It is not easy to figure out the cause-effect chains that lead to productivity loss.

Multiple Factor methods are methods to calculate productivity or LOP by listing multiple factors and allocating a multiplier for each factor and combing those individual factor losses. They require the user to describe the problem through factors and therefore can presumably better explain the situation. The MCAA Method is a specific example of the factor method.

1.1.6 The MCAA Method

Recognizing the importance and vulnerability of productivity to a wide array of project conditions, the Mechanical Contractors of America Association (MCAA) developed a table of Factors that can impact labor productivity (MCAA 2016). The MCAA Factor descriptions "were developed by the MCAA Management Methods Committee beginning in the late 1960s and continuing into the early 1970s… to the best of MCAA's current knowledge, the information contained in the MCA Factors was gathered anecdotally from a number of highly experienced members of the MCAA's Management Methods Committee." The loss percentages in the table were provided by the MCAA member firms and finalized by the Management Methods Committee (MCAA 2016).

This approach can also be useful in estimating the LOP associated with different degrees of such change. The Construction Industry has, over the years, accepted that table as one approach for measuring LOP.

MCAA first offered "Factors affecting labor productivity" in its management methods manual in 1971 (MCAA 2016). The MCAA Factor model lists sixteen Factors that are believed to hurt labor productivity when they unexpectedly arise on a project. For each of those Factors there is a typical LOP percentage, depending on whether the Factor occurs in a minor, average, or severe degree. See Table 1.1.

Table 1.1: MCAA Factors

	% of Loss per Factor		
	Minor	Average	Severe
F1. STACKING OF TRADES: Operations take place within physically limited space with other contractors. Results in congestion of personnel, inability to locate tools conveniently, increased loss of tools, additional safety hazards and increased visitors. Optimum crew size cannot be utilized.	10%	20%	30%
F2. MORALE AND ATTITUDE: Excessive hazard, competition for overtime, over-inspection, multiple contract changes and rework, disruption of labor rhythm and scheduling, poor site conditions, etc.	5%	15%	30%
F3. REASSIGNMENT OF MANPOWER: Loss occurs with move-on, move-off men because of unexpected changes, excessive changes, or demand to expedite or reschedule completion of certain work phases. Preparation not possible for orderly change.	5%	10%	15%
F4. CREW SIZE INEFFICIENCY: Additional workers to existing crews "breaks up" original team effort, affects labor rhythm. Applies to basic contract hours also, adding more manpower to current construction work.	10%	20%	30%
F5. CONCURRENT OPERATIONS: Stacking of this contractor's own force. Effect of adding operation to already planned sequence of operations. Unless gradual and controlled implementation of additional operations made, factor will apply to all remaining and proposed contract hours.	5%	15%	25%
F6. DILUTION OF SUPERVISION: Applies to both basic contract and proposed change. Supervision must be diverted to (a) analyze and plan change, (b) stop and replan affected work, c) take-off, order, and expedite material and equipment, (d) incorporate change into schedule, (e) instruct foreman and journeyman, (f) supervise work in progress, and (g) revise punch lists, testing and start-up requirements.	10%	15%	25%
F7. LEARNING CURVE: Period of orientation in order to become familiar with changed condition. If new men are added to project, effects more severe as they learn tool locations, work procedures, etc. Turnover of crew.	5%	15%	30%
F8. ERRORS AND OMISSIONS: Increases in errors and omissions because changes usually performed on crash basis, out-of-sequence, or cause Dilution of Supervision or any other negative factors.	1%	3%	6%
F9. BENEFICIAL OCCUPANCY: Working over, around, or in close proximity to owner's personnel or production equipment. Also badging, noise limitations, dust and special safety requirements and access restrictions because of owner. Using premises by owner prior to contract completion.	15%	25%	40%
F10. JOINT OCCUPANCY: Change cause work to be performed while facility occupied by other trades and not anticipated under original bid.	5%	12%	20%
F11. SITE ACCESS: Interferences with convenient access to work areas, poor man-lift management, or large and congested worksite.	5%	12%	30%

F12. LOGISTICS: Owner furnished materials and problems of dealing with his storehouse people, no control over material flow to work areas. Also contract changes causing problems of procurement and delivery of materials and rehandling of substituted materials at site.	10%	25%	50%
F13. FATIGUE: Unusual physical exertion. If on change order work and men return to base contract work, effects also affect performance on base contract.	8%	10%	12%
F14. RIPPLE: Changes in other trades' work affecting our work such as alteration of our schedule. A solution is to request, at first job meeting, that all change notices/bulletins be sent to our Contract Manager.	10%	15%	20%
F15. OVERTIME: Lowers work output and efficiency through physical fatigue and poor mental attitude.	10%	15%	20%
F16. SEASON AND WEATHER CHANGE: Either very hot or very cold weather.	10%	20%	30%

The percentages for each category will be combined and then multiplied against the proposed craft hours for the change. An example of model application given by the manual is as follows (MCAA 2016):

Table 1.2: Use of the MCAA Method to Calculate LOP

Change Order estimated Craft Labor hours:	2,750 hours
MCAA Factor: Crew Size Inefficiency Learning Curve Reassignment of Manpower Total	 10% 5% 5% 20%
Estimated Loss of Productivity (2,750 * 20%)	550 hours
Subtotal, Craft Labor Hours:	3,300 hours

It is stressed by the model that "this primer is intended to be a planning tool and not a source for absolute percentages or costs." In other words, proper use of the model necessarily requires a judicious and informed understanding of the model by an analyst who understands both the assumptions and limitations of the model as well as the facts of the case.

1.2 Need of Study: Research Problem Statement

As useful and well intentioned as the MCAA Method is, it has many deficiencies.

Harmon and Cole (2006) criticized that the application of Factors is largely a subjective exercise because of 1) lack of information concerning the participants providing the information (in the MCAA Factor list) such as how many years they worked in the industry, title, experience, etc.; 2) lack of description of what constitute a minor, average or severe condition; 3) some Factors are duplicate and repetitive; and 4) if improperly applied, the use of this study to quantify the impact to productivity could unrealistically inflate the amount of lost labor-hours.

Dieterle and Gaines (2010) commented that 1) this method fails to differentiate or adequately define 'minor, average and severe'; and 2) the study was intended as a forward pricing tool to be used in change order evaluations. Simply applying the percentages to actual labor costs is expressively not recommended by the publication.

The result of those deficiencies is inconsistent application of the model, with contractors (generally in the plaintiff role) frequently overstating the severity of the impact to their project. This leads to skepticism and further dispute. Its success rate is uneven in large part because there are no reliable guidelines (Ibbs and Vaughn 2015). Thus there is a need for general guidance on the application of the MCAA Method, which this research address.

In addition, the Factor list was developed in 1971 and has remained unchanged during the past half century. During those years, many researchers and institutes have worked on LOP and published results with a stronger research base. Many LOP related cases has been decided and published, and those opinions contains important information that can improve the definitions and quantifications of the MCAA Method as well. Thus there is a need for improvement on the MCAA Method itself.

In this report we document the MCAA Method's history, identify typical mistakes made in its application, and compare it with other studies and previous legal case decisions. Suggested improvements to the model are then offered based on this analysis.

1.3 Target of Study

This report targets improvements to the existing MCAA Method based on a thorough study of the previous legal decisions and academic research. It will help parties to measure productivity loss caused by project change with clearer logic and less subjectivity.

The deficiencies of the MCAA Method are characterized as either in application or structural. The application problem is a matter of how users apply the model. Examples include applying too many Factors that overlap with each other. Another common problem is failure to provide causation proof for **EACH** Factor claimed. These problems will be discussed in Chapter 4.

The structural problems include 1) lack of guidelines to select Factors and prove causation; 2) unclear definition of what these Factors mean and how they can affect labor productivity; and 3) the manual's recommendations of loss percentages are not verified by real project data. In addition, with no guidance as to how frequently "severe" projects occur, it is left to the discretion of the user to decide whether his condition is minor, average, or severe. Chapter 7 address this issue.

This research aims to make improvements to the original method in both the application of the model and the structure of the model. By model structure we mean a more exact definition of what constitutes a narrative description of each Factor and its possible effect on productivity. The goal is to provide insights and recommendations on the quantification of each Factor's effect.

The audiences are contractors, owners, and other interested parties. The goal is to develop better LOP evaluations and help parties negotiate settlements quicker and with more fairness.

1.4 Report Structure

Chapter 1 of this report is the introduction about the background of LOP and the MCAA Method, the need of this study, and the target of this report.

Chapter 2 reviews the previous studies on this topic.

Chapter 3 introduces the research methodology used in this report.

Chapter 4 is an analysis of the legal appeals using the MCAA Method to quantify productivity loss. Improvement on application of the MCAA Method is proposed in this chapter.

Chapter 5 provides the improvements on causation establishment in a MCAA claim. The use of visualization tool is suggested. Existing visualization tools are reviewed and compared, how to use a visualization tool in a MCAA claim is discussed.

Chapter 6 discusses the improvement on the MCAA Factor definitions. Each Factor's definition, its effect on productivity, and the use of them in previous LOP case opinions are discussed.

Chapter 7 discusses the quantification of each Factor's effect on productivity. Credibility of existing academic studies and industry manuals is analyzed. Suggestions are proposed regarding using existing models. This chapter also discusses available legal case decisions on quantification of LOP for each Factor.

Chapter 8 summarizes the proposed improvements to the original MCAA Method and develops schema and procedures for using the improved model.

Chapter 9 is the conclusion and recommendations.

Chapter 2. Literature Review

This chapter summarizes previous studies regarding LOP. Section 2.1 summarizes initial productivity studies in construction industry. Section 2.2 introduces the existing work on Factors affecting productivity. Section 2.3 summarizes existing Factor methods to estimate productivity.

2.1 Initial LOP Studies in the Construction Industry

Early studies in productivity have mainly been developed for the estimation of the work speed. Standard estimating manuals such as RS Means, the Dodge Construction Cost Information System, and Richardson Engineering Services are first-hand materials for the contractor's schedule and work plan. Those studies give a normal baseline for each type of construction work's productivity.

Before 1967, productivity loss claim was barred by the Rice doctrine, which states that a "contractor that incurred costs associated with delays in performance or with disruption of contract work as the result of contract change was entitled, under the terms of the standard Changes clause, only to the increased costs of the changed work and to a time extension equal to the delay period." (*Rice v. United States*)

To avoid an inequitable result the doctrine was abolished in late 1967 by revising the standard federal contracts changes clause language to include new language. It currently reads as follows:

"If any such change causes an increase or decrease in the cost of, or the time required for, performance of any part of the work under this contract, whether or not changed by the order, the Contracting Officer shall make an equitable adjustment in the contract price, the delivery schedule or both, and shall modify the contract" (Jones, 2001).

This revision further legalized claim for productivity loss due to change order.

In the late 1970s the best way to improve productivity became a much-discussed topic in construction, since it was recognized that construction productivity had fallen dramatically (Oglesby et al. 1989). Subsequently, many institutes and researchers attempted to develop methods to help measure productivity loss.

Section 2.2 reviews works on reasons (factors) that cause LOP and quantification of their results. Previous studies regarding the cumulative factor method (the method that use multiple factors and allocates multipliers for each of those factors to calculate productivity or LOP) are reviewed in Section 2.3.

2.2 Existing Work on Individual Factor's Effect on Productivity

After the 1970s, researchers started to work on different reasons that might cause LOP and their effects.

Important works are summarized in Table 2.2, and details will be discussed in Chapter 5 and Chapter 6. As we can see in Table 2.1, most previous quantification studies on LOP focused on Weather, Learning Curve, Overtime, and Crew Size Inefficiency.

Table 2.1: List of Previous Work on Factor's Effect on Productivity

Factors Affecting Productivity	Previous Studies	Contains Quantification Method
Stacking of Trades	Not found	
Morale and Attitude	Schrader (1972)	No
	Borcherding (1981)	No
	Hardy (2009)	No
Crew Size Inefficiency	O'Connor (1969)	Yes
	Waldron (1968)	Yes
	Kappaz (1977)	Yes
	Corps (1979)	Yes
	US Army (1979)	Yes
	Thomas and Jansma (1985)	Yes
	Smith (1987)	Yes
	Thomas and Smith (1990)	Yes
Concurrent Operations	Not found	
Dilution of Supervision	Not found	
Learning Curve	UN (1965)	Yes
	Frantezolis (1984)	Yes
	Thomas et al. (1986)	Yes
	Everett & Farghal (1994)	Yes
	Everett & Farghal (1997)	Yes
	Couto and Teixeira (2005)	Yes
	Hinze and Olbina (2009)	Yes
	Thomas (2009)	Yes
	Gottlieb, S.C., and Haugbolle, K. (2010)	Yes
	Jarkas and Horner (2011)	Yes
Errors and Omissions	Cnuddle (1991)	No
	Hammarlund and Josephson (1991)	No
	Josephson (1990, 1994)	No
	Burati et al. (1992)	No
	Josephson and Hammarlund (1996)	No
	Josephson et al. (2002)	No
	Brown & Batie (2013)	No
Beneficial Occupancy	Not found	
Joint Occupancy	Not found	
Site Access	Not found	

Logistics	Harper (1982)	No
	Thomas et al. (1987)	Yes
	Thomas et al. (1989)	Yes
	Muehlhausen (1991)	No
Fatigue	Not found	No
Overtime	BLS (1947)	Yes
	NECA (1962, 1969, 1989)	Yes
	O'Connor (1969)	Yes
	US Army (1979)	Yes
	Adrian (1987)	Yes
	Bromberg (1988)	Yes
Weather	Clapp (1966)	Yes
	Johnson (1972)	Yes
	Grimm and Wagner (1974)	Yes
	Kuipers (1977)	Yes
	Brauer (1984)	Yes
	Koehn and Brown (1984)	Yes
	Abele (1986)	Yes
	Thomas and Yiakoumis (1987)	Yes
	Moselhi et al. (1997)	Yes
	Hancher and Abd-Elkhalek (1998)	Yes
	Srinavin and Mohamed (2003)	Yes
	NECA (2004)	Yes
Night Work	Kumar and Ellis (1994)	Yes
Shift Work	Hanna et al. (2005)	Yes
Availability of Skilled Worker	Not found	
Management Level	Not found	
Turnover	Not found	
Number and Timing of Change Orders	Leonard (1989)	Yes
	Ibbs et al. (2008)	Yes
Work Means and Methods	Related to specific work type	

2.3 Existing Cumulative Factor Method for Productivity Estimates

Except for the studies focusing on single factor effects on productivity, some other researchers tried to develop multiple factor methods to quantify LOP.

Sanders and Thomas (1991) described a methodology to identify and quantify the project-related factors that significantly affect the daily productivity of masonry. The study is based on data collected from eleven masonry projects in central Pennsylvania from 1986 to 1988.

Singh (2001) calculated expected durations with changes considering learning curve, effect of weather, overcrowding, and overtime. He used quantifying charts developed by the U.S. Army Corps of Engineers (1979) for individual factors such as overtime and overstaffing (overmanning), and then used a division method instead of multiplication in

MCAA Factors. The entire process can be clearly seen in the following table (Singh 2001).

Table 2.2: Singh's Productivity Quantification Process

Factors Used	Applied Quantification Methods
Learning Curve	$Y = A \times X^n$ (Straight-Line Learning Curve) Y: workhours used for doing the unit of work X: the units of work n: exponent (negative value) given the learning ratio A: Constant for each floor given the learning ratio
Weather	Grimm and Wagner (1974)'s Temperature-Humidity contour map
Overcrowding	Overcrowding Chart from the U.S. Army Corps of Engineering Guide (1979)
Overtime	Overtime Chart from the U.S. Army Corps of Engineering Guide (1979)

In his 2006 doctoral report, "Change Orders and Productivity Loss Quantification Using Verifiable Site Data," Serag developed and validated two factor models. For the first model, the dependent variable is increase in contract price due to change, and the predictor variables are timing for the change, reason for the change, the party implementing the change order (CO), work stoppage, the way CO is compensated, the way CO restricted access, the CO work season, approved CO hours and extension; and for the second model, the dependent variable is LOP, while the predictor variables are time factor (Learning Curve), number of rainy days, dewatering problem encountered, rework percentage, quantity installed etc.

It is observed that most of the factor methods use an approach similar to the MCAA Method. Singh's model seems to be very close to the one we want to construct, but it is based on a Learning Curve model. It is used to predict the productivity loss but not to quantify it afterwards. Sereg's model tries to determine why there is a decrease in productivity on a broader level. It may not be suitable to quantify the loss in a LOP claim.

2.4 Summary

From this chapter, we can see that LOP and Quantification of LOP has been a topic that attracted the attention of many researchers. Those studies include work on reasons of LOP and those factor's effect on productivity.

There exist some multiple factor methods to quantify LOP but they are generally used to predict the productivity loss but not to quantify it afterwards. Some of those studies only selected several factors that affected productivity.

The target of this report is to fill this research gap and develop a method to best describe and quantify LOP in a construction claim based on existing studies and related Board and Court decisions.

Chapter 3. Research Methodology

3.1 Introduction

This chapter presents the research methodologies used to perform the analysis and achieve the research objectives of this report. The MCAA Method was developed over forty years ago and has remained unchanged until the present day. The objective of this paper is to provide suggestions on its application and propose structural improvement, e.g., improvement on the definition of LOP Factors and quantification of those Factors.

This research does not attempt to collect new data and develop an entirely new model to quantify each Factor's impact on productivity. It attempts to find ways to improve the existing MCAA Model by incorporating existing methods and models and published LOP case opinions.

3.2 Review and Analysis of Existing Academic Studies

This report integrates the findings from previous studies and performs both qualitative and quantitative analysis to provide: 1) a more precise and complete description of each Factor; 2) reasons why those Factors might have an effect on productivity; 3) possible credible ways to quantify each Factor's impact on productivity; and 4) other suggestions on quantification of LOP.

3.2.1 Literature Review, Summaries, and Critiques

This research looks into the studies regarding each MCAA Factor and integrates all the possible reasons why those Factors can affect productivity. Those reasons collected are from different research's experience and analysis as introduced in Chapter 1. This research weaves those separate results into an integrated picture of all possible reasons. This summary intends to provide a starting point for the plaintiff and defendant to consider their own situations and possible reasons why their project's labor productivity has been negatively affected.

3.2.2 Previous Quantification Method Credibility Analysis

This report reviews each of the previous LOP quantification studies and methods for its source data and data processing method and accordingly evaluates the quantification method's credibility.

For instance, there is much published data available from previous models regarding weather's impact and Learning Curve. This research normalizes the data and compares the models provided by different researchers using consistent definitions of LOP loss and processing methods.

There are some previous studies containing models for estimating the effect of overtime and overstaffing (or overmanning), but no published real project data were found regarding those studies. This research converts all LOP metric into loss percentage defined in the MCAA manual (percentage extra time needed for completing the same work) and compares the results from different models to determine whether those models can validate one other.

3.2.3 Tools and Techniques

This report use statistical analysis, boxplot representation, and liner regression analysis as tools to analyze LOP in the reference studies.

3.2.3.1 Boxplot

A boxplot is a graphical display that shows a measure of location (the median), a measure of dispersion (the interquartile range), and the presence of possible outliers. The construction of a boxplot involves 1) drawing horizontal lines at the median and at the upper and lower quartiles and joining those lines by vertical lines to produce the box; 2) drawing a vertical line from the upper quartile to the most extreme data point that is within a distance of 1.5 interquartile range of the upper quartile; and 3) similarly drawing a vertical line down from the lower quartile (Rice 2007).

3.2.3.2 Linear Regression Model

The linear regression model shows the linear relationship between a dependent variable and independent variable. The linear regression model stipulates that the observed value of dependent variable is a linear function of independent variable plus random noise. Simple linear regression is the least squares estimator of a linear regression model. It fits the line by minimizing the sum of squared residuals of the model. Simple linear regression is used in this report to fit the weather and linear curve model.

3.3 Review and Analysis of Productivity-Related Cases

3.3.1 Analysis of Previous Legal Cases Involving the MCAA Method

Fourteen Board and Court cases have been found using the MCAA Method to claim for LOP. They were found by searching in the library system and search engines, reviewing previous studies commenting on the LOP legal cases, and looking at the citations in cases already found.

Each of these fourteen cases is studied in detail and key points regarding the MCAA Method are summarized (see Table 4.1). Based on the legal case opinions reviewed, this research identifies the strength and weakness of this method. This study also calculates the frequency and successful rates of each Factor in the claims and summarizes the explanation and rejection reasons for those Factors. Those analyses help us to further understand the research problem and the current use of MCAA Method. Finally, the application suggestions are developed based on the observations from those cases.

3.3.2 Analysis of Previous LOP Board Cases using the MCAA Method

Aside from the legal case opinions involving use of the MCAA Method, other LOP-related appeal Board cases were also reviewed so that we can understand each of the MCAA Factors' definitions, their effect on labor productivity, and the possible rejection reasons or allowed reimbursement amounts.

The cases were selected based on 1) searching terms "construction inefficiency," "construction productivity loss," and "construction efficiency loss" in databases; and 2) appeals referred or mentioned in previous studies or cases already found.

All the cases analyzed in this chapter are from the Board of Contract Appeals (BCA). Those disputes are between contractors and government agencies. For example, the ASBCA (Armed Services Board of Contract Appeals) hears certain claims arising from contract between contractors and agencies of the military (http://www.asbca.mil/index.html). The GSBCA (General Services Board of Contract) deals with disputes between contractors and executive agencies of the United States, including the Department of State, Treasury, Commerce and Education. The GSBCA was transferred to the newly established Civilian Board of Contact Appeals in 2007 (http://www.gsbca.gsa.gov/).

All the cases reviewed here are Board cases since 1) most of LOP cases are large projects with government involvement, and 2) the only case in which MCAA can successfully used were Board Cases.

We found 111 related Board cases through the above-mentioned process and carefully reviewed them. We then filtered and excluded the cases that: 1) are not directly related to productivity loss; and 2) have no specific LOP reason provided, for example, some plaintiffs tried to make the claim and failed since they claimed for LOP only based on the number of change orders. After this process, we found 53 cases that is closely related to LOP and have sufficient details to perform analysis.

We reviewed these 53 cases in details. This study analyzes the situation for each case and categorizes the cases into the MCAA Factors that can well describe them. Each Factor's possible effect on productivity as mentioned in those cases is summarized to improve the definitions provided by the MCAA. Available reimbursement amounts in those cases are provided to 1) compare with quantification method from academic studies; and 2) give the contractor a starting point to quantify its loss.

Table 3.1 shows the 53 cases reviewed and the MCAA Factors involved.

Table 3.1: List of Published Board Case Opinions on LOP

Case	Decision Year	Results	Causation Problems	MCAA Factors Involved (Not Necessary Successfully Claimed)
E. B. Bush Construction Co., Inc.	1963	Partially allowed, amount reduced.	No	Errors and Omissions, Site Access (share the site with other contractors), Acceleration, Weather, Stacking of Trades.
T. C. Bateson Construction Co.	1963	Partially allowed, amount reduced.	No	Errors and Omissions, Site Access (due to snow), Weather, Logistics (due to delay).
Lew F. Stilwell, Inc.	1964	LOP accepted by the Board.	No	Overtime, Crew Size Inefficiency, Logistics.
E. V. Lane Corporation	1966	The plaintiff claimed that acceleration order caused more overtime and the longer hours decreased the efficiency of workers. Rejected since the evidence did not support the plaintiff's assertion.	No	Overtime, Weather (Wet Season).
Zisken Construction Company	1967	Several weather related claims, mostly rejected.	No	Weather, Logistics.
ACME Missiles Amp Construction Corporation	1968	Not allowed, failed to show any cost resulting from the change.	Yes	Beneficial Occupancy, Site Access, Acceleration, Weather.
Continental Consolidated Corporation	1968	Partially allowed, amount reduced.	No	Overtime, Night Shift, Crew Size Inefficiency.
E.W. Bliss Company	1968	Disallowed since causal connection not established.	Yes	Overtime, Crew Size Inefficiency, Learning Curve.

International Builders of Florida Inc.	1969	Multiple claims, mostly rejected due to liability (the owner had the right to suspend the work). Causation problem also mentioned for some claims.	Yes	Stacking of Trades, Logistics, Reassignment of Manpower, Weather (Heavy Rains).
Blount Construction Company	1970	Partially allowed, amount reduced.	No	Overtime, Crew Size Inefficiency.
Continental Consolidated Corporation	1971	Rejected since the plaintiff failed to prove extra LOP caused by Joint Occupancy beyond that should be anticipated.	No	Stacking of Trades, Joint Occupancy, Site Access, Crew Size Inefficiency.
Pathman Construction Company	1971	Allowed.	No	Weather.
C & B Construction Company	1971	Rejected since the owner was not obligated to maintain the existing road for site access.	No	Site Access, Logistics.
Penn York Construction Company	1972	LOP due to Crew Size Inefficiency has been approved, but additional result was disallowed because of double counting.	No	Crew Size Inefficiency.
Fruehauf Corporation	1974	Partially allowed, amount reduced.	No	Reassignment of Manpower, Site Access, Logistics, Weather.
Flex-Y-Plan Industries, Inc.	1976	Partially allowed, amount reduced.	No	Beneficial Occupancy, Site Access, Logistics.
Ingalls Shipbuilding Division, Litton Systems, Inc.	1976	Partially allowed, amount reduced.	No	Learning Curve, Logistics, Reassignment of Manpower.
John E. Faucett	1976	Denied since LOP was largely due to the plaintiff's attempt to perform a concurrent contract without sufficient resources to handle both.	No	Site Access, Weather.
Algernon-Blair Incorporated	1976	LOP allowed, jury verdict.	No	Stacking of Trades, Morale and Attitude, Logistics, Reassignment

				of Manpower.
Ingalls Shipbuilding Division Litton System Inc.	1978	LOP allowed.	No	Reassignment of Manpower, Learning, Dilution of Supervision (extra supervision needed for less skilled workers).
Human Advancement, Inc.	1981	Allowed, jury verdict.	No	Excessive Supervisory Cost, Logistics, Extra Movement.
Excavation-Construction, Inc.	1982	Denied due to lack of understandable theory and supporting facts regarding LOP due to weather.	Yes	Weather.
Warwick Construction Inc.	1982	Partially granted.	No	Site Access, Weather.
Casson Construction Company, Inc.	1983	Partially allowed, amount reduced.	No	Overtime.
Ballenger Corporation Formerly Ranger Co.	1983	Time extension allowed for differing site condition.	No	Weather.
Hawaiian Dredging & Construction Co.	1984	LOP admitted but not allowed since it's already covered by total overtime hours.	No	Overtime, Lack of Skilled Worker (Learning).
Hugh Brasington Contracting Co.	1984	Denied since the evidence did not establish a cause-effect relationship.	Yes	Acceleration, Weather.
Fred A. Arnold, Inc.	1984	Multiple claims, mostly rejected.	Yes	Errors and Omissions, Site Access, Acceleration, Weather.
General Railway Signal Company	1985	Disallowed since LOP was "in the Board's judgment excessive and without foundation in the record."	Yes	Stacking of Trades, Overtime.
Space Age Engineering Inc.	1985	Several claims, mostly rejected.	Yes	Stacking of Trades, Morale and Attitude, Overtime, Site Access.
Santa Fe Engineers, Inc.	1986	Rejected since it was "not possible to identify any particular impact associated with any particular change."	Yes	Learning Curve, Dilution of Supervision, Crew Size Inefficiency, Morale and Attitude, Concurrent Operation, Reassignment of

				Manpower.
Essential Construction Co., Inc., and Himount Constructors Ltd	1989	Rejected since the plaintiff "failed to show that government-caused delays pushed the work into the winter season."	No	Acceleration, Logistics, Weather.
Charles G Williams Construction Inc.	1989	Appeal sustained.	No	Reassignment of Manpower.
Pittsburgh-Des Moines Corporation	1989	Denied since the evidence did not show LOP.	No	Overtime, Learning Curve, Crew Size Inefficiency.
Saudi Tarmac Company Ltd. and Tarmac Overseas Ltd. JV	1989	Mostly rejected since the impact had been settled by previous Modifications and agreements.	No	Overtime, Learning Curve, Dilution of Supervision, Crew Size Inefficiency, Reassignment of Manpower.
Bechtel National, Inc.	1989	Partially allowed, amount reduced.	Yes	Dilution of Supervision, Morale and Attitude, Errors and Omissions, Reassignment of Manpower.
Atlas Construction Inc.	1990	Allowed.	No	Beneficial Occupancy, Logistics.
McMillin Brothers Constructors	1990	Rejected since the plaintiff failed to prove the existence of LOP and causation.	Yes	Overtime, Crew Size Inefficiency.
Gerald Miller Construction	1991	LOP rejected since appellant failed to establish causation.	Yes	Dilution of Supervision, Logistics.
Rush Construction Inc.	1991	LOP denied since the plaintiff failed to allocate the loss to the owner's responsibility and failed to prove existence of loss.	Yes	Learning Curve, Morale and Attitude.
Community Heating & Plumbing Company	1992	Rejected due to causation not shown.	Yes	Overtime, Dilution of Supervision, Weather.
Dawson Construction Company	1993	Rejected due to causation not shown.	Yes	Crew Size Inefficiency, Logistics, Reassignment of Manpower.
Southwest	1994	Rejected since the	Yes	Learning Curve,

Marine, Inc.		plaintiff did not show that it experienced cumulative disruptions and the government caused the loss.		Dilution of Supervision, Crew Size Inefficiency.
Triad Mechanical, Inc.	1997	Partially allowed.	No	Overtime, Crew Size Inefficiency, Weather.
Danac, Inc.	1997	Allowed.	No	Acceleration, Logistics, Reassignment of Manpower.
Lamb Engineering and Construction Company	1997	Partially allowed.	No	Site Access, Weather.
Roberts, J.R. Corp.	1998	Denied since the plaintiff failed to substantiate the amount. Also there was no basis for the Board to apportion the amount of the loss.	No	Stacking of Trades.
Donohoe Construction	1998	Partially allowed for unusually severe weather.	No	Weather.
Centex Bateson Construction	1998	Denied since the plaintiff failed to prove impact and causation.	Yes	Logistics, Reassignment of Manpower.
J.A. Jones Construction Company	2000	Denied due to the plaintiff failed to prove cause-and-effect analysis.	Yes	Overtime, Learning, Dilution of Supervision, Weather.
Bay Construction Co.	2002	Rejected since the LOP was "wholly unsupported."	Yes	Learning Curve.
Fru-Con Construction Corporation	2005	Government's use of a winter inefficiency factor was denied because it was not based on the contractor's actual work experience.	NA	Weather.
Alderman Building Company	2013	Allowed.	No	Overtime, Crew Size Inefficiency.

3.4 Summary

In summary, this chapter previews the research methodology to develop improvements on the MCAA Method. In general this study is based on quantitative and qualitative analysis of previous academic studies' models and data, as well as LOP-related Board and Court cases. The following sections present the analysis results.

Chapter 4. Current Use of the MCAA Method and Application Suggestions

4.1 Introduction

The MCAA Method has been used many times during the past forty years. This chapter reviews the existing cases found using the MCAA Factors to quantify productivity loss.

We summarize and analyze those relevant legal case opinions and find the following observations: 1) no Board has ever rejected the MCAA Method because of inherent limitations in the model itself; 2) choosing fewer Factors is roughly correlated (not in strict statistical sense) with increased success in using the model; 3) contractors must provide detailed explanations and relevant evidence to establish causation for each Factor to ensure credibility; and 4) the LOP percentages provided in the MCAA Method are based on contractor opinions, not empirical studies, and Boards and Courts thus tend to be conservative in granting any LOP damage.

General suggestions on the use of the MCAA Method are provided in Section 4.4, based on analysis conducted and presented in Section 4.3.

4.2 Case Summary

Fourteen legal cases were found that used the MCAA Method to quantify LOP. The basic information about those cases is listed in Table 4.1. Seven of the fourteen cases were successful from the contractor's viewpoint: *Harmony, Fire Security–1991*, *Clark Concrete*, *Clark Construction*, *Hensel Phelps*, *Stroh,* and *Fire Security–2001*. Success in this setting means the contractor received financial compensation for its LOP using the MCAA Method. The other seven were not successful.

S and U in Table 4.1 represent "successful" and "unsuccessful." Details will be explained in the case summary that follows in chronological order.

Table 4.1: Basic Information Regarding the MCAA Cases

Case	Jurisdiction	Decision Time	S or U	Factors Claimed by Contractor
S. Leo Harmonay, Inc. v. Binks Mfg. Co.	U.S. Court for the Southern District of New York	1984	S	Unspecified
Appeal of Fire Security Systems, Inc.	VABCA	1991	S	Beneficial Occupancy, Stacking of Trades
Appeal of Stroh Corporation	GSBCA	1996	S	Crew Size Inefficiency, Weather
Appeal of Clark Concrete Contractors, Inc.	GSBCA	1999	S	Stacking of Trades, Concurrent Operations, Dilution of Supervision, Site Access, Reassignment of Manpower and Competition for labor, Overtime
Appeal of The Clark Construction Group, Inc.	VABCA	2000	S	Morale and Attitude, Reassignment of Manpower, Dilution of Supervision, Concurrent Operations, Errors and Omissions
Appeal of Hensel Phelps Construction Company	GSBCA	2001	S	Stacking of Trades, Morale and Attitude, Reassignment of Manpower, Concurrent Operations, Dilution of Supervision and Learning Curve
Norment Sec. Group, Inc. v. Ohio Dept. of Rehab. & Corr.	Ohio Court of Claims	2001	U	Morale and Attitude and unspecified others
Appeal of Sauer Inc.	ASBCA	2001	U	Stacking of Trades, Morale and Attitude, Reassignment of Manpower, Concurrent Operations, Dilution of Supervision, Beneficial Occupancy, Joint Occupancy, Ripple, Overtime
Appeal of P.J. Dick Incorporated	VABCA	2001	U	Morale and Attitude, Reassignment of Manpower, Concurrent Operations, Dilution of Supervision, Learning Curve, Errors and Omissions
Appeal of Fire Security Systems, Inc.	VABCA	2002	S	Morale and Attitude, Reassignment of Manpower and Dilution of Supervision
Appeal of Herman B. Taylor Construction Co.	GSBCA	2003	U	Morale and Attitude; Reassignment of Manpower; Concurrent Operations; and Dilution of Supervision
Sunshine Construction and Engineering v. The United States	United States Court of Federal Claims	2005	U	Stacking of Trades, Morale and Attitude, Reassignment of Manpower, Crew Size Inefficiency, Concurrent Operations, Dilution of Supervision, Learning Curve, Errors and Omissions, Site Access, Ripple effect
Appeal of AEI Pacific Inc.	ASBCA	2008	U	Stacking of Trades, Morale and Attitude, Reassignment of Manpower, Crew Size

				Inefficiency, Concurrent Operations, Dilution of Supervision, Learning Curve, Errors and Omissions, Beneficial Occupancy, Joint Occupancy, Site Access and Logistics
Appeal of States Roofing Corporation	ASBCA	2010	U	Unspecified

S. Leo Harmonay, Inc. v. Binks Manufacturing Company, 1984[1]

This appears to be the earliest legal case that used the MCAA manual to estimate LOP. Harmonay was a piping subcontractor working for general contractor Binks on expansion of an automobile assembly plant in New York. Harmonay claimed it was accelerated by Binks and as a consequence suffered at least a 30% productivity decline across its entire work force due to "excessive working hours, overly crowded conditions, the unavailability of tools, materials and storage, defendant's delay in supplying drawings and equipment, and the constant revision on the contract drawings."

Harmonay admitted in trial that its vice president read the MCAA manual but did not make detailed computations to arrive at the 30% LOP. He and the company's president both reviewed the project site and working conditions and the company's labor records. Binks countered that the 30% Factor was speculative because "the figure was not based on personal observation but on a formula developed in a manual not in evidence."

The Board decided that defendant did cause unreasonable and substantial delays to the plaintiff's work and was liable. The Board accepted the 30% LOP Factor because it was "persuaded by the testimony of Harmonay's president and vice president."

This case is the first case in which we see the MCAA manual being used, and it is a case where a MCAA-based LOP claim was successfully made. However, there is no evidence showing which Factors of the MCAA manual were used to compute the 30% LOP Factor. It seems that the manual was influential but not by itself decisive. Rather, the Board was heavily influenced by the experience and testimony of the appellant's president and vice president.

Appeal of Fire Security Systems, Inc., 1991

Automatic Sprinkler Corporation of America (ASCOA), a subcontractor of Fire Security Systems, Inc. (FSS), requested additional compensation for LOP for installing a fire sprinkler system in a psychiatric hospital. FSS had to work in various buildings and

[1] The subsections of this paper also contain the date of the Court or Board decision; e.g. Harmonay was decided in 1984. We have done that so that the reader can follow the emerging chronology of decisions about the MCAA method.

rooms under occupied conditions that had been depicted as vacant in the contract drawings. It also encountered another contractor working in the same areas. ASCOA used two MCAA Factors (Stacking of Trades and Beneficial Occupancy) to calculate a 20% productivity loss due to this unanticipated occupied area problem.

The Board decided that the government's continued occupation during construction of those areas was a differing site condition, and the contractor was entitled to recover additional labor costs. The Board agreed to use the MCAA manual as a starting point for the analysis because ASCOA had utilized the manual in its cost proposals, and "the government has provided no testimony or evidence that the MCA productivity Factors are flawed or unreasonable."

The government rejected the defendant's argument that ASCOA did not provide "a sufficient factual foundation in the record to support the 20% Factor."

However, the Board did not accept the ASCOA's claim of 20% LOP for all work. Rather it awarded 15% for some portions of the project and 20% for others due to Beneficial Occupancy and Trade Stacking.

Appeal of Stroh Corporation, 1996

The plaintiff, Stroh Corporation, was the contractor hired to replace the chillers in a cooling tower at a building in Iowa. Stroh alleged that the government delayed all field works from summer to winter because it refused to close the existing cooling system until the estimated end of the cooling season. In addition, the government insisted on completion within the planned period, and Stroh was forced to assign a larger overall crew to accelerate the job.

Stroh consulted the MCAA manual and estimated 30% LOP because of Weather impacts (severe degree) and 10% impact for Crew Size Inefficiency (minor degree). Stroh interviewed personnel onsite and provided causal explanation to support its allegation. For example, for the compression of work, the project superintendent testified that Stroh used a "larger than optimum" crew size, and his personal supervisory work was slowed because his duties increased with a larger work crew.

The Board agreed on the LOP resulting from delay and supported the contractor's estimate of 10% impact for non-optimal crew size conditions. But the Board was not persuaded that "the severity of the weather was shown to justify application of 30% Factor" and instead awarded 25% "representing a compromise between average and severe."

Appeal of Clark Concrete Contractors, Inc., 1999

Clark Concrete Contractors was awarded a contract for construction of a building for the Federal Bureau of Investigation (FBI). The work of its mechanical subcontractor, Poole & Kent Corporation (P&K), was delayed by the owner's redesign, and its labor productivity was adversely affected. P&K used the MCAA Method to claim LOP in three parts: 1) work in penthouse (six Factors, 60% LOP in total); 2) work on intermediate floors (four Factors, 33% LOP in total); and 3) Overtime throughout the entire project (15% LOP).

The government's expert objected to use of the MCAA Method for the penthouse LOP. Instead, he computed a "measured mile."

The Board disagreed with this method because the defendant's expert failed show that the "unimpacted period" chosen was really unimpacted, and consequently the Board supported the use of the MCAA Method. Application of MCAA for the damage alleged to have been suffered on intermediate floors resulted in a value greater than a total cost claim for those floors, and the Board awarded P&K a total cost value LOP.

The defendant did not challenge the LOP calculated for Overtime, and P&K received its full claim for such.

Appeal of the Clark Construction Group, Inc., 2000
Clark Construction Group (plaintiff) made this appeal on behalf of Pool and Kent (P&K, the principal plumbing/mechanical subcontractor) and United Sheet Metal Company (USM, P&K's principal subcontractor). This appeal involved construction of a 400-bed hospital and separate energy center.

Productivity of work was adversely affected due to site contamination and site dewatering problems. P&K used three methods (Measured Mile, the MCAA Method, and the Modified Total Cost) to estimate that inefficiency. P&K's project manager, P&K's expert, and USM's senior project manager applied the MCAA Method independently to quantify LOP. The defendant's expert questioned the utility of the MCAA Manual for quantifying LOP, basing his opinion on the ambiguity of the Factor definitions and the ambiguous instructions on how to apply them.

The Board rejected all three calculations provided by the plaintiff, because it thought that the measured mile analysis used an improper baseline; the MTC was a Total Cost variant, and the plaintiff's MCAA-based LOP calculation was unreasonably large.

A jury verdict method[2] was employed to arrive at an award. The Board used the MCAA manual itself to develop this jury verdict estimate and commented "despite the inherent subjectivity of the MCAA Factors, the record here demonstrated that the MCAA Method was a widely used industry standard method of accounting for the impact of inefficiency on mechanical work."[3] Dilution of Supervision, Site Access, and Morale and Attitude Factors were applied.

Appeal of Hensel Phelps Construction Company, 2001

Hensel Phelps Construction Company (HPCC) constructed a new building for the federal government and Trautman & Shreve, Inc. (T&S) was its mechanical subcontractor. During the contract, the government issued multiple change orders, which caused LOP for both HPCC and T&S.

T&S's expert used six MCAA Factors to access the LOP impact (Stacking of Trades, Morale and Attitude, Reassignment of Manpower, Concurrent Operations, Dilution of Supervision, and Learning Curve). He testified that his assessment was based on "his knowledge and the project documents, his analysis of an as-built schedule, his experience in the construction industry and his expertise in assessing labor productivity losses." He did not use the percentages contained in the manual but used his own knowledge of the circumstances to estimate the losses.

The defendant's expert spoke disparagingly of the use of the MCAA inefficiency Factors. In his opinion, the MCAA Method "lost credibility over the twenty years they were in use."

The Board, however, disagreed with the defendant's expert and pointed out that he had limited experience in mechanical construction and in the use of the MCAA Factors. The Board found T&S's expert's report and testimony highly credible and awarded T&S its claimed amount.

Norment Sec. Group, Inc. v. Ohio Dept. of Rehab. & Corr., 2001

Norment Security Group (Norment) was the contractor hired to build a detention and security work prison. It claimed LOP impact damage caused by the defendant's failure to

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[2] Jury Verdict: Jury verdict is an LOP quantification method. When a contractor cannot calculate its damage with any certainty, it leaves the computation to the discretion of the Court by way of the jury verdict method. This approach is typically employed when there is clear proof that the contractor was injured, but there is no reliable method for determining damages (Long 2005).

[3] The Board apparently believed that P&K's MCAA computations were "back-fit" to a total cost calculation. It discarded P&K's calculations using MCAA but computed and awarded a LOP damaged amount itself that utilized the MCAA framework.

provide a workable schedule, properly coordinate the project, and provide timely access to the jobsite. Norment's expert used the MCAA Method to calculate this impact at 25% LOP impact.

The Court rejected the LOP claim because "the testimony and evidence was insufficient to prove that the alleged damages proximately resulting from defendants' actions or inactions." Additionally, the Court found that plaintiff's MCAA-based calculations were "arbitrary and speculative" and did not represent a reliable measure of damages. The Court gave an example of Morale and Attitude, stating that plaintiff's estimate of the subjective Factors in the Manual were not supported by greater weight of the evidence.

Appeal of Sauer Inc., 2001

This contract at issue called for Sauer to finish the interior of a building at a submarine base. The claim arose from changes to another onsite contractor's schedule. Sauer's vice president consulted several Sauer employees and used the MCAA manual to calculate LOP impact. He testified that his estimate was based on reviewing "documents, photos and videos in conjunction with the MCA Bulletin items."

He applied nine Factors (Stacking of Trades, Morale and Attitude, Reassignment of Manpower, Concurrent Operations, Dilution of Supervision, Beneficial Occupancy, Joint Occupancy, Ripple, and Overtime), but found the result calculated was "astronomical." He then "melded documents and facts he was aware of into a reasonable value he had experienced."

This claim was rejected because the Board found that statements in the contract did not support the claim, and Sauer used the estimate of its own employee, not an independent expert. The Board also criticized Sauer's failure to explain how it formed its LOP estimates.

Appeal of P.J. Dick Incorporated, 2001

The project involved in this appeal was the construction of a clinical addition to a Veterans Affair medical center. P.J. Dick Incorporated's (PJD) performance was affected by electrical design deficiencies and acceleration ordered by the government. PJD claimed for inefficiency based on a "measured mile" analysis. There was no period during which branch circuits installation was not impacted, so the plaintiff's expert derived a measured mile based on feeder circuit work. PJD's expert used the MCAA Method as an alternative approach and applied six Factors (Morale and Attitude, Reassignment of Manpower, Concurrent Operations, Dilution of Supervision, Learning Curve, and Errors and Omissions) to calculate LOP.

The Board awarded the plaintiff damages based on his measured mile analysis, disregarding the MCAA-based claim.

Appeal of Fire Security Systems, Inc., 2002

Fire Security Systems constructed a fire safety project for the federal government. It claimed that its productivity was adversely affected because its crews encountered suspected asbestos almost as soon as pipe installation began. FSS used three MCAA Factors (Morale and Attitude, Reassignment of Manpower, and Dilution of Supervision) to estimate a 70% LOP.

The defendant's expert denied the existence of LOP based on observations that FSS's crews were "working at the same pace throughout the period of pipe installation" and had actually "achieved greater labor efficiency than it had estimated in its bid." The Board did not agree with his assertion. Based on the defendant expert's observations, the Board instead concluded that because the plaintiff reported asbestos almost as soon as the pipe installation began, there would be no useful "measured mile" analysis possible for this claim.

The Board adapted the use of the MCAA Method, but the requested amount was significantly reduced. "Morale and Attitude" was the only Factor recognized by the Board and considering "the amount of ambient air testing regularly performed and the defendant's prompt remediation," the impact was considered to be minor (5%).

Appeal of Herman B. Taylor Construction Co., 2003

Herman B. Taylor Construction Co. alleged LOP during construction of a US Courthouse and post office. Its LOP was due to additional crew moves caused by delay due to flawed drawings and delays in response to requests for information. The plaintiff estimated LOP using four MCAA Factors: Morale and Attitude, 20%; Reassignment of Manpower, 10%; Concurrent Operations, 5%; and Dilution of Supervision, 10%. However, these crew moves were not properly documented, and the plaintiff's consultant himself admitted that the productivity study applied only to mechanical trades and that Taylor's own forces were primarily "helpers for clean-up, set-up, that sort of thing."

The defendant's expert explained that the MCAA Bulletin was not intended to prove LOP but to illustrate what types of productivity loss might occur on a mechanical project.

The Board rejected Taylor's LOP impact claim. Reasons included 1) plaintiff underbid its labor cost, and thus it was unable to demonstrate the original staffing levels; 2) plaintiff did not submit adequate proof of labor inefficiency; the proof was based on "crew moves" that lacked substantiation; and 3) use of the MCAA Bulletin was inappropriate because the labor allegedly made inefficient by the government were “laborers, not mechanical workers”.

Sunshine Construction and Engineering v. The United States, 2005

Sunshine Construction and Engineering claimed LOP due to defective specifications on a government education project. The plaintiff’s expert planned to use the MCAA manual to quantify LOP, but the government’s expert preempted him by arguing that the MCAA manual “was not recognized as an accepted approach by his peers or any trade association.” That expert also cited the following passage in the manual: “the material contained in this manual is intended to assist you in planning and is not meant to provide absolute costs nor percentages which would be incurred. Each project, locale, situation is unique and variances will occur even within the same jurisdiction. These Factors listed are intended to serve as a reference only. Individual cases could prove to be too high or too low.”

The plaintiff in response adapted the defendant expert’s analysis and calculations, which were based on a modified total cost method. The Board did not support this claim, however, because the plaintiff failed to “sustain the predicate for LOP by showing that the Corps was responsible for the underlying causes of delay due to the defective plans and specifications.”

Appeal of AEI Pacific Inc., 2008

The dispute arose in a public school renovation project in which the contractor, AEI, alleged delay and other costs associated with numerous design clarification/variation requests. AEI’s expert had published an article in which he said that “the best method for estimating LOP is the measured mile technique and that if unimpacted productivity data are unavailable from a disputed project, a ‘similar’ project can be used for comparison purposes.”

However, he admitted in this case that he did not ask AEI for data from any similar project. Instead, he prepared a LOP damage claim based on the MCAA Method, using twelve Factors to perform his analysis. For each week he assigned a judgmentally derived percentage of loss to each Factor he deemed existed on the project. However, he never spoke to anyone from AEI, never visited the site, and kept no records explaining his rationale for assigning a particular percentage to a particular Factor. For example, one of the Factors he cited was “loss of morale”; however, AEI’s president testified that he did not believe morale was a problem on this project.

The government’s expert criticized the plaintiff’s use of the MCAA Method in this matter, pointing out that “the purpose of the bulletin is to help prepare original estimates and change orders, not to quantify damages.” He contended that the percentages of loss in the appendix are “both extremely generous and unsupported by studies of actual projects.” He argued that plaintiff misused the MCAA Method by applying all twelve Factors cumulatively to both base contract and change order hours. He also argued that the plaintiff’s expert failed to causally tie his analysis to actual events onsite and concluded that AEI was entitled to an equitable adjustment for LOP in the range of at most 2 to 5%.

The Board adapted the testimony of the government’s expert and awarded AEI 2% LOP damages.

Appeal of States Roofing Corporation, 2010
This appeal involved repair work to the roof cells on a building located in Norfolk, Virginia. States Roofing Corporation (SRC) argued that the owner’s design changes and differing site conditions significantly altered the original work and caused a decrease in crew productivity. SRC used the measured mile method to quantify LOP impact and offered an MCAA analysis as an alternative check.

The Board rejected the plaintiff's calculation, finding measured mile was of "marginal support" due to the use of estimated production rates and the plaintiff's lack of experience with such work. The MCAA Method was also rejected because the analysis was prepared by the plaintiff's president, not an expert, making it “impossible to disregard the inherent subjectivity” of this method. A jury verdict was finally used for estimating the quantum of the LOP impact.

Based on these fourteen cases, we can draw some general observations and conclusions about the nature and use of the MCAA Method. They are presented in the following subsections.

4.3 Discussion and Observations

4.3.1 There is a Decline in the Success Rate

The MCAA Method has been used many times during the past twenty years, but the success rate for plaintiffs has generally declined in recent times, as can be seen by an inspection of Table 4.1.

Prior to 2000, the model was successfully used in five of five published cases; since 2001 it has been successful in only two of nine cases. One possible explanation for this trend is that Boards and Courts have recently imposed a more stringent standard for proving LOP claims, requiring proof by either the actual cost or the measured mile technique. Training of field managers and advances in computer technology may have played a role in this trend, too, leading Courts to conclude that the state of the practice requires more pinpointed and contemporaneous damage calculation methodologies.

Opposing experts have over time become better informed about the model and its weaknesses and are thus better prepared to rebut its use. For instance, defense experts have noted that 1) the model is not intended to prove and quantify LOP retrospectively (*Herman, Sunshine, AEI*); 2) the model's Factors and instructions are ambiguous (*Clack Construction 2000)*; and 3) the loss percentages are generous and unsupported by empirical studies (*AEI*).

However, it is noteworthy that despite these defense objections, no Board or Court has overtly cited any of these arguments as a basis for rejecting a MCAA-based claim. That is, they have not questioned the inherent nature of the model. Rather, the overwhelming reason for MCAA-based claim rejection is plaintiff failure to prove causation, as discussed in a following section.

4.3.2 Boards Prefer Selecting Fewer Factors and Focusing on More Successful Factors

Another observation that emerges from this research is that the number of Factors claimed seems to be roughly and inversely associated with the likelihood of successful MCAA use.[4]

It is also observed that some Factors are more successful than others. Table 4.2 shows the number of times each Factor has been used in the fourteen cases, and the number of times that Factor was present in a successful claim.

Trade stacking, Site Access, and Overtime have the highest success rate (aside from weather, which was only cited in one case). Overtime and Weather have perhaps not been used as frequently because there are other research models that are specifically focused on Overtime and Weather effects (those studies will be discussed in next several chapters). Such models have a stronger research base and a singular focus, which makes them more credible and popular.

[4] Only fourteen cases were available for review in this article, so the sample size is small. Precise statistical analysis of the data is not possible. Therefore, all statistics reported in this paper must be viewed in that context.

Table 4.2: Frequency and Success Rate for Each Factor in the MCAA Cases

Factor	Number Cases in which Factor Asserted	Number of Successful Cases	Success rate	Rank
Reassignment of Manpower	9	2	0.22	11
Dilution of Supervision	9	3	0.33	6
Morale and Attitude	8	3	0.38	5
Concurrent Operations	8	2	0.25	9
Stacking of Trades	6	3	0.50	2
Learning Curve	4	1	0.25	9
Errors and Omissions	4	0	0.00	12
Site Access	4	2	0.50	2
Crew Size Inefficiency	3	1	0.33	6
Beneficial Occupancy	3	1	0.33	6
Joint Occupancy	2	0	0.00	12
Ripple	2	0	0.00	12
Overtime	2	1	0.50	2
Logistics	1	0	0.00	12
Season and Weather Change	1	1	1.00	1
Fatigue	0	0	0.00	12

Successful cases used four Factors on average, whereas unsuccessful cases typically used nine. One explanation for this is that use of more Factors may be overstating or be seen to be overstating the claim, which in turn impugns the credibility of the claim.

Sauer is an example. In this case, Sauer's expert used nine of the sixteen Factors, and the resulting LOP calculation was so "astronomical" that the expert himself even admitted under testimony that it was unrealistic. The Court thus ruled against the plaintiff.

In addition, Errors and Omissions has been used and rejected all four times used in these four cases, and Fatigue has never been used in this reported cases. A possible explanation is that these causal triggers are more distant from the construction workforce, and the linkage to LOP is accordingly more tenuous. Joint Occupancy, Ripple, and Logistics have been rarely used in these published decisions, perhaps because of the vagueness of the terms.

4.3.3 Need to Demonstrate Causation for Each Factor

Every LOP claim must show causation, liability, and damages. Demonstrating causation is especially important in the eyes of the Court. One advantage of the MCAA Method is that it contains a list of sixteen Factors that are well known and understood in the construction industry to cause LOP. However, it is not sufficient for the plaintiff to assert the mere presence of a Factor. A detailed linkage must be shown between some causal event and the resulting consequence.

Noteworthy MCAA cases that failed to demonstrate causation in sufficient detail are *Sauer, Norment, AEI,* and *Herman Taylor.* Broadly speaking, the claimant plaintiffs in these cases used the MCAA Method as a checklist of Factors that they believed impaired their labor productivity, but did not provide sufficient evidence explaining how the presence of a Factor (e.g., weather) impaired productivity.

Nowadays, the plaintiff needs to provide causation proof for **EACH** of the Factors it uses. For example the plaintiff in *Fire Security, 2002*, identified three Factors (Morale and Attitude, Reassignment of Manpower, and Dilution of Supervision). The Board checked fact witness testimony and daily logs, and determined that Reassignment of Manpower and Dilution of Supervision did not occur on this project. But it was convinced by extensive testimony of site supervisors that morale was damaged and productivity impaired and thus made an award to the plaintiff.

4.3.4 Estimates Allowed are Generally Conservative

The LOP percentages contained in the MCAA manual have been questioned by both defendant experts and Boards. In *AEI,* the owner's expert considered the percentage of loss in the MCAA list as both generous and unsupported by studies of actual projects.[5] He argued that no owner would consider paying a 25% premium for Dilution of Supervision when the plaintiff could easily bring in another field engineer and superintendent to accomplish the same thing.

The Board agreed with his assertion. In *Norment,* the plaintiff's expert estimated LOP due to inadequate scheduling and coordination based on data provided the manual. The Board rejected the claim partially because it believed that the plaintiff's use of the manual's percentages was "arbitrary and speculative" and did not "represent a reliable measure of damages."

The MCAA manual's LOP percentages are problematic in another way. Specifically, the manual does not provide guidelines on how to determine the severity level. As a result, Boards have been conservative when using MCAA and have **NEVER** used "severe" ratings in any of these published LOP awards.

For example, in *Stroh* the plaintiff provided substantial detail describing the Weather including: 1) the work that had to be performed outdoors and on the roof of the building, and argued that it was "significantly colder on top of a ten-story building than on the ground"; 2) the wind and other Weather elements necessitated the wearing of heavy

[5] MCAA admits that it "does not have any records indicating that a statistical or other type of empirical study was undertaken in order to determine the specific factors or the percentages of loss associated with the individual factors" (MCAA 2016).

clothing, which significantly slowed the work; and 3) interviews of people onsite.[6] Nevertheless, the Board reduced the plaintiff's claim for 30% LOP (which is "severe" in the manual) to 25%, which represented "a compromise between average and severe seasonal conditions."

This pattern of awarding LOP rates that are lower than those requested by the plaintiff can be seen by reviewing the successful cases, which are listed in Table 4.3. Of course plaintiffs are undoubtedly asking for higher-than-justified rates as part of their bargaining strategy knowing that the LOP percentages will eventually be bargained downwards.

However, in most of the successful cases the plaintiff's requested percentages fell into minor and average slots. The only counter example was *Fire Security, 2001*, in which the plaintiff applied a "severe" LOP impact for all three Factors it requested. As a result the Board significantly reduced the estimated LOP and only awarded Morale and Attitude with a "minor" impact.

[6] The contractor's foreman reported that "there were days we had to step in an out of wind to warm up when your hands get so cold you can't hang onto tools and stuff."

Table 4.3: Percentages Used for Successful MCAA Cases

Factors	Requested	Awarded
Appeal of Fire Security Systems Inc.-1991		
Beneficial Occupancy	20% (minor-average),	15% (minor)
Stacking of Trades	20% (average)	15% (minor-average)
Appeal of Fire Security Systems Inc.-2001		
Morale and Attitude	30% (severe)	5% (minor)
Reassignment of Manpower	15% (severe)	0% (none)
Dilution of Supervision	25% (severe)	0% (none)
Hensel Phelps Construction Co. v. General Services Administration[7]		
Period two building D as an example		
Reassignment of Manpower	10% (average)	10% (average)
Appeal of Clark Concrete Contractors[8]		
Penthouse		
Stacking of Trades	20% (average)	20% (average)
Concurrent Operations	15% (average)	15% (average)
Dilution of Supervision	5% (less than minor)	5% (less than minor)
Site Access	5% (minor)	5% (minor)
Reassignment of Manpower	10% (average)	10% (average)
On floors		
Concurrent Operations	10% (minor-average)	Not available (NA)
Dilution of Supervision	10% (minor)	NA
Reassignment of Manpower	10% (average)	NA
Overtime		
Overtime	10-15% (minor-average)	10-15% (minor-average)
Appeal of Stroh Corporation		
Crew Size Inefficiency	10% (minor)	10% (minor)
Weather	30% (severe)	25% (average-severe)
Appeal of Clark Construction Group[9]		
Dilution of Supervision	See endnote	10% (minor)
Site Access		5% (minor)
Morale and Attitude		5% (minor)

4.4 General Recommendations

[7] For *Hensel Phelps,* the detailed information about the percentages is not publicly available. But the Board has concluded that "the percentages which he (the contractor) used, when compared to those recommended by MCAA, tend, on the whole, to be conservative. By far the majority of his estimates fall between the percentages recommended on the MCAA chart for either 'minor' or 'average' disruptions."

[8] The Court ruled that the contractor was responsible for 29% of the delay to part of the project and held the owner responsible for the balance, 71%.

[9] For *Appeal of Clark Construction Group*, estimates were developed by three different experts, and that information would be too voluminous to recap here. Details can be found in the decision. The allowed amount is in general to the lower side of the estimates.

Based on the observations and analysis presented above, we recommend the following when using the MCAA Method:

1) Use fewer Factors rather than more. Successful claims averaged four Factors, while unsuccessful claims averaged nine. Choose Factors that are closer in terms of causal link to owner actions and are more definitive (e.g., Overtime or Weather). It may be difficult to allocate responsibility in Factors such as Fatigue and Errors and Omissions, because they are more distant and thus are not easily linked to owner action or inaction. Avoid vague Factors such as Fatigue, Logistics, and Joint Occupancy;

2) Establishing causation is paramount in convincing triers-of-fact that a LOP claims exists. Establish causation for **EACH** Factor. Explain clearly when, where, who, and how productivity was affected. Evidence that may help support a causation argument can come from project documents, witness interviews, and expert opinions. Failing to provide detailed explanations can doom a claim. In *Sauer*, as an example, the Board rejected the LOP claim, explaining that there was too little evidence on how and why productivity was lost. It also volunteered that the claim would have been strengthened by using an expert to conduct the analysis; and

3) Users of the MCAA model should not blindly rely on the single-point LOP damage percentages contained in the manual. Temper them with professional judgment and a full understanding of the project facts. Include testimony from experience fact witnesses if they are available. Include testimony from expert witnesses who are familiar with LOP claims in general and the MCAA model in particular.

Chapter 5. Proposed Improvements for Demonstrating Cause-Effect Links

5.1 Introduction

An observation of able 3.1 shows that among 27 LOP cases we found that have been denied by the Board, eighteen of them failed at least partially because of the plaintiff's failing to establish causation. The MCAA Method has been shown to require the users to consider carefully the narrative facts and project events.

Many Factors in the MCAA list are correlated; For example, Overtime can cause a worker's fatigue and cause lower work speed and extra work errors. If both such Factors are chosen (Overtime and Fatigue), there may be a double count (or redundant calculation) in the LOP calculation. Therefore, it is important to clearly explain the relationship and avoid that may duplicate another factor.

A causal visualization tool has been used by many previous researchers and practitioners to describe events and the cause-effect relationship between these events. It can clearly show the relationship between Factors and help the plaintiff link change conditions to the resultant damage.

Long (2005) suggests use of a causal visualization tool to establish causation in a LOP claim, compared with a causal visualization tool used by other researchers, Long's matrix as we will show later, is more organized and structured than other tools. However, Long does not suggest a way to organize and categorize the Factors.

We believe that a causal visualization tool can be used with the MCAA Method, since it can help the plaintiff to identify the relationship between Factors. The events or the factors can be categorized into root factor (which is the change defined in the MCAA manual; the root factor can be easily linked to the responsible party); intermediate factors (most of the MCAA Factors); and ultimate factors (factors that can be linked to damage to the plaintiff).

In this chapter, Section 5.2 explains the importance of causation establishment and cause-effect visualization tool for a LOP claim. Section 5.3 introduces and compares different visualization tools used by previous researchers, and Section 5.4 explains how a visualization can be used in a MCAA case.

5.2 Importance of Causation Establishment and Cause-Effect Visualization Tools

Causation is one of the three elements in the triad of proof. The other two are liability and resultant injury. It requires the plaintiff to prove that the LOP was caused by the owner's conduct or actions, rather than by the plaintiff's failure (Jones 2003).

It is well recognized that a contractor does not have to prove its LOP with mathematical exactitude, however this does not relieve the contractor from making a compelling case as to the specific causes of the impacts and to connect then with a logic effect (MCAA 2016). Many LOP claims are denied, at least in part, because the contractor fails to show the causal link between the owner-caused changes and the contractor's LOP (Long 2005).

MCAA Factors have been found to require the users to consider carefully the narrative facts and project events (MCAA 2016). However as we discussed in Chapter 4, the plaintiff needs to provide causation proof for each of the Factors it uses and to explain why there is a loss.

MCAA cases that failed to demonstrate causation in sufficient detail are *Sauer*, *Norment*, *AEI*, and *Herman Taylor*. Broadly speaking, the claimant plaintiffs in these cases used the MCAA Method as a checklist of Factors that they believed impaired their labor productivity, but did not provide sufficient evidence explaining how the presence of a Factor (e.g. Weather) impaired productivity, or that was the owner's fault.

The backbone of the cause-effect linkage in the LOP claim is a cause-effect map (Long 2005). A cause-effect map can graphically trace the LOP of the plaintiff's work to the changes and the responsible parties. Combined with the MCAA Factors, it can help the plaintiff to determine and explain the relationship between Factors.

5.3 Existing Cause-Effect Visualization Tools

A visualization tool explains cause-effect relationship using variables to describe events and links to denote the influence among the variables (Sterman 2000). Different researchers, however, use different names, notations, and styles (Lee 2007).

Previous important cause-effect visualization tools include the causal diagram in Jansma (1998), causal loops introduced in Sterman (2000), influence diagram in Eden et al. (2000), and causal matrix introduced by Long (2005). Most of those researchers used such tools to explain the situations but did not introduce those tools as a general method to prove causation in a LOP claim.

Jansma (1998) used a causal diagram to show that productivity is difficult to measure due to the multitude of factors influencing craft efficiency. He used bubbles to express the events or factors that related to productivity loss. Five ultimate reasons (traveling, waiting or idle, slow work, rework, and ineffective time) were allocated in the center of the graph. See Figure 5.1 for Jansma's causal diagram.

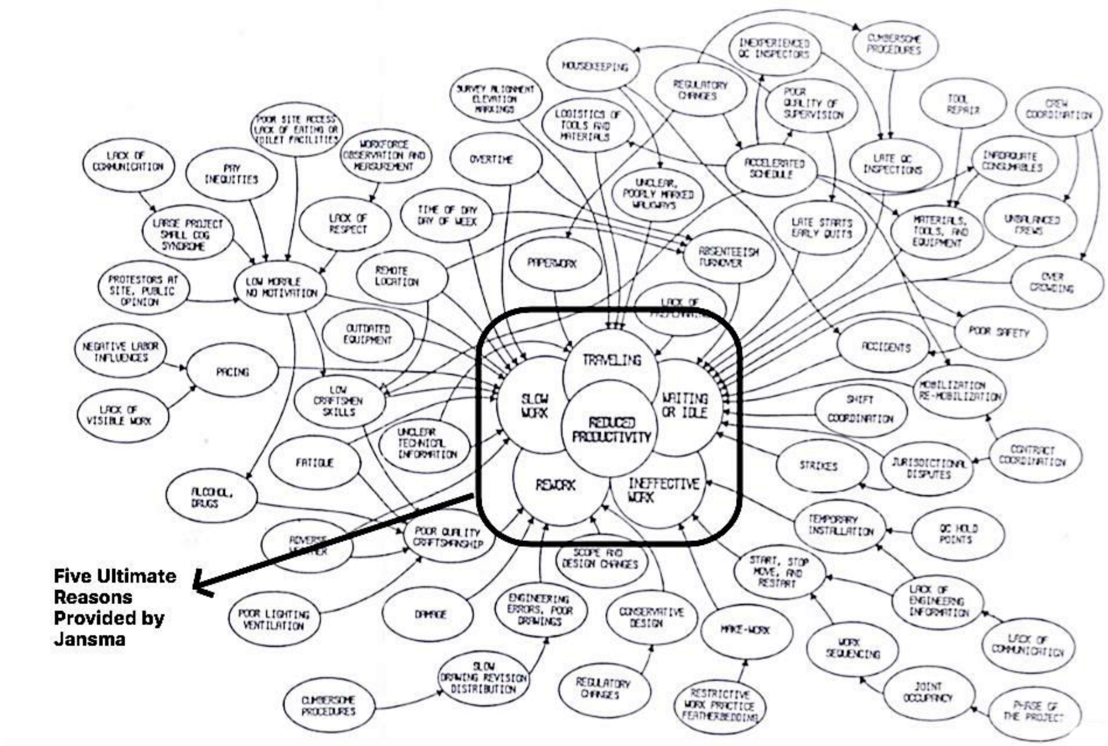

Figure 5.1: Jansma's Causal Diagram

The advantage of Jansma's diagram is that it defines five root reasons that clearly and directly cause LOP. In addition, the layout of the sample diagram looks very professional. However, Jansma did not plan to introduce this diagram as a general tool to visualize the connection between parties' responsibility to productivity loss. It does not clearly show the allocation of responsibility. The factors are not structured and organized well. To use this kind of chart in their own project, people need to use their own judgment to describe the situation and arrange the events' location.

Sterman's (2000) causal loops denoted the factors by squares and used positive (+) to show the increase effect and negative links to show the negative effect. See Figure 5.2 for Sterman's causal loop. Sterman showed the negative and positive impact between different events and considered the managerial actions' effect on the disruptions. For example, the acceleration will increase the disruption and thus be represented by a positive sign; and decrease the delay, shown with a negative sign.

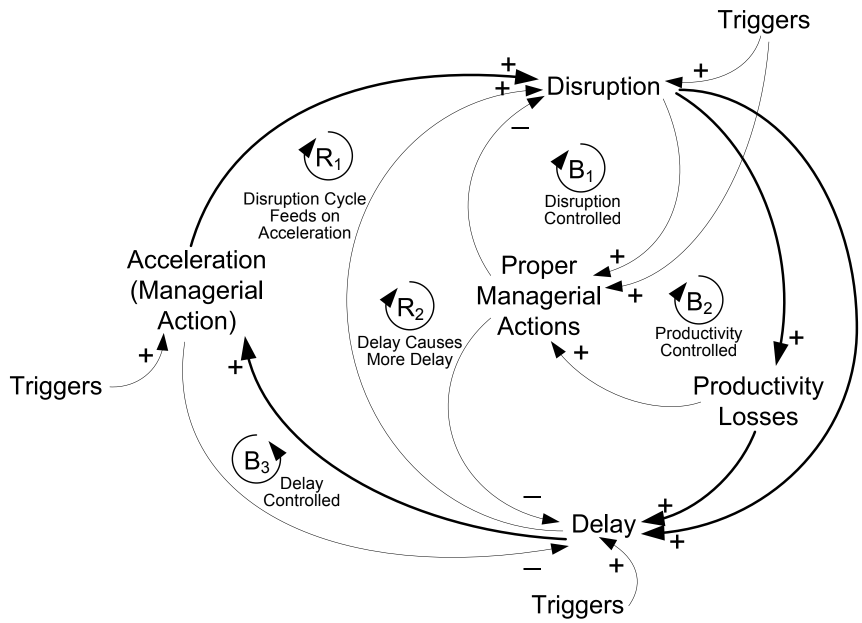

Figure 5.2: Sterman's Causal Loops

However, Sterman's causal loops are not clear in how the responsibility is distributed to the involved parties. They also lack details: since the loops, negative and positive effect increase the complexity of the chart, more high level and might not be sufficient to explain how disruption can cause productivity loss. Those two aspects, are important in a LOP claim.

Eden et al. (2000) used an influence diagram to show acceleration's effect on productivity. Their influence diagram was close to Sterman's causal loops. Similarly, it used arrows to express the positive and negative effect of factors. It had a simpler style and thus was able to provide more details on why there is a LOP. However, they did not intend to introduce this as a tool for causation establishment and thus did not clearly shown the responsibility allocation and factors' structure. See Figure 5.3 for Eden's influence diagram.

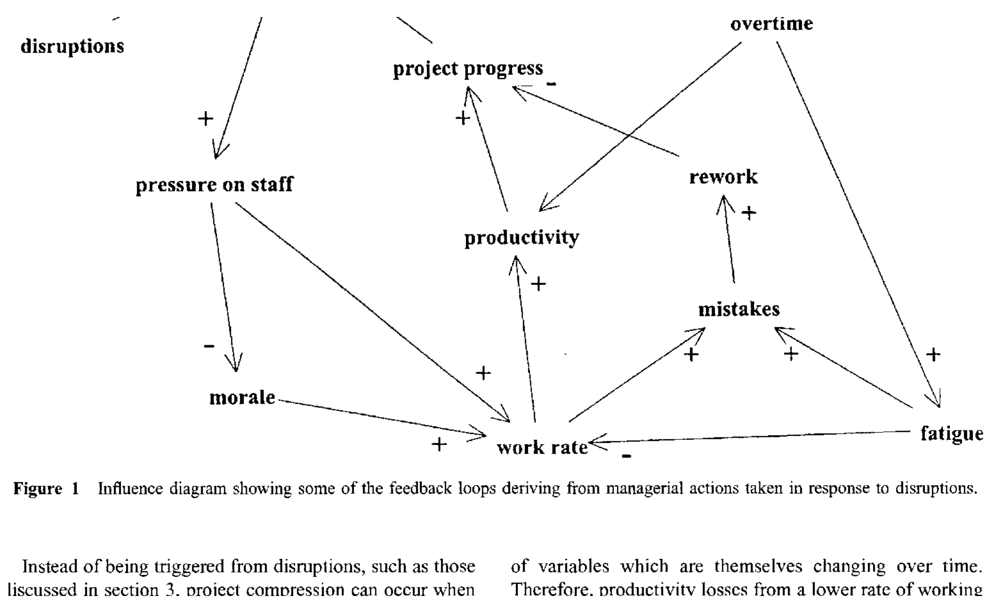

Figure 5.3: Eden's Influence Diagram

Long (2005) used squares to describe things that happened and hinges the matrices together to show the causal relationship. Long (2005) suggested using this matrix to establish causation in a construction claim. Long divided the events into levels, including primary causes and secondary causes (that can be directly allocated to the project's parties), productivity loss, and ultimate causes (that directly cause a loss). See Figure 5.4.

Unfortunately, except for the factors listed in the sample causal matrix, Long did not suggest how to organize and categorize the factors and provides no information on possible situations. In addition, Long did not give persuasive explanations about the ultimate cause of loss. The ultimate causes he gave include direct labor-hour growth, indirect labor-hour growth, and increased equipment and manpower quantities. He linked the factors such as "congestions" and "Dilution of Supervision" directly to the ultimate factors he provided. His "ultimate effects" are general and insufficient because the plaintiff normally needs to provide more detail regarding how those factors cause a loss.

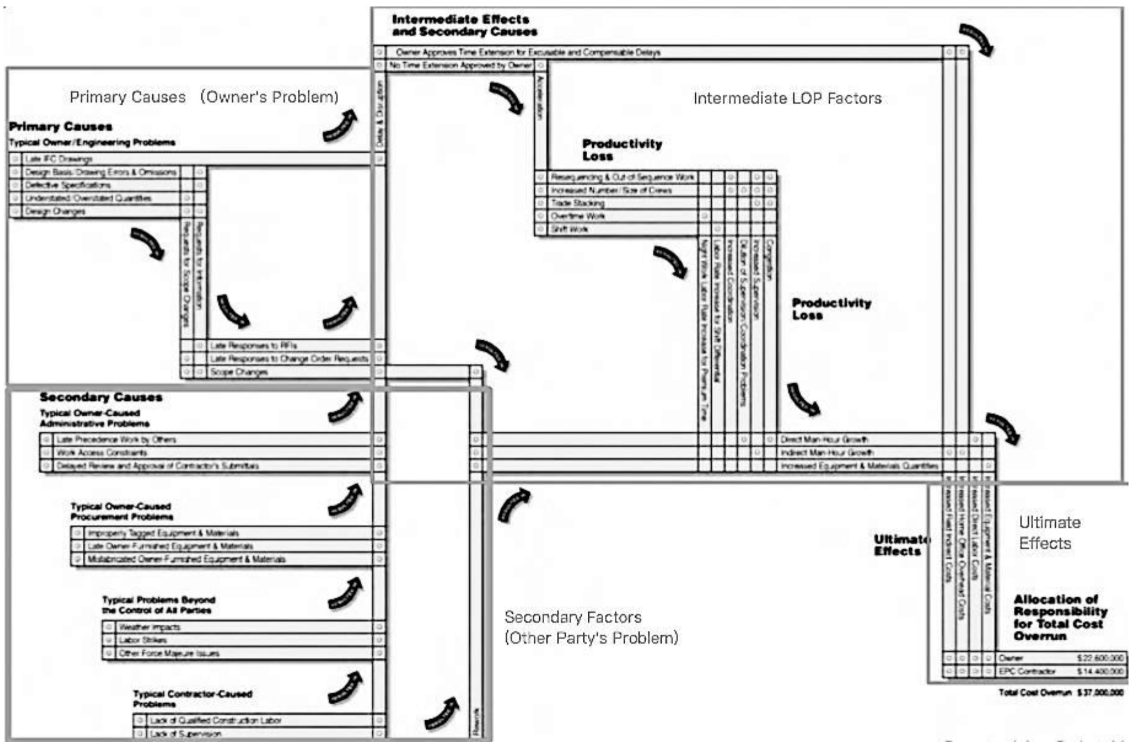

Figure 5.4: Long's Causal Matrix

The features of previous cause-effect visualization tool are shown in Table 5.1.

Table 5.1: Comparison of Existing Cause-Effect Visualization Tools

	Jansma (1998)	Sterman (2000)	Eden et.al (2000)	Long (2005)
Intent to be used in a LOP claim	No	No	No	Yes
Contains the responsible party	No	No	No	Yes
Contains the direct reason for loss	Yes	No	No	Yes
Symbols to show the event	Bubble	None	None	Matrix
Symbols to show the link	arrow	arrow	arrow	hinge
Differentiate positive and negative effect	No	Yes	Yes	No
Contains loops or cycles	No	Yes	Yes	No

We can see that those models differ in some detail such as the symbols they use to show the events and the link. In addition, some methods differentiated the positive and negative effects; and contain loops and cycles to show that the "effect" can deteriorate the situation and further cause delay and impact. These models were generally not developed to be used in a LOP claim so they do not meet the needs of a claimant.

Since we intend to use the cause-effect visualization tool to prove the causation, we suggest that users think about their own situation, make the graph as clear as possible, and focus on the causal link between responsible party and resultant loss.

Among those tools listed above, Long's casual matrix is the only one that identifies the responsible party and ultimate loss.

5.4 Using Cause-Effect Visualization Tools in an MCAA Case

To clearly show how the responsible party caused the resultant loss, an organized structure and specification about responsible party and loss are recommended.

Based on our understanding of the LOP claims and the reviews of previous cause-effect visualization tool, we believe any causation visualization structure should contain the primary cause (the responsible party's action or inaction), productivity loss factors (intermediate factors that connect the parties' action to possible productivity loss), and ultimate factors (resultant loss). The contractor can use the notations and styles they prefer to build visualization maps (methods introduced in Section 5.2), as long as the causal relationship and factor structure are shown.

This section suggests the use of three levels to categorize the factors and proposes typical factors for each category. The categorization of factors, however, will still depend on the individual project. The levels should be determined based on 1) whether the event is directly related to responsible party's action or inaction (root factor); 2) whether the event is directly related to the cost and time loss of the contractor (ultimate factor); and 3) whether the factor causally linked the root reasons to the ultimate reasons (intermediate factor).

5.4.1 Three Levels of LOP Causes: Primary Cause, Intermediate Cause and Ultimate Cause

As explained in previous sections, we suggest using cause-effect visualization tools to help explain the situations on site and establish causation. The target of such a tool is to explain the link between the responsible party and the damage in a more intuitive and transparent way. Therefore in order to achieve this target, it is important for each single link of events in the graph to 1) start with a responsible party and 2) end with a loss that can be proved and quantified.

We thus suggest categorizing the factors into primary causes (the reasons that can be directly connected to party/parties' action or inaction), ultimate factors (factors that directly cause a damage or loss) and intermediate productivity factors that link the above two together. Figure 5.5 shows the procedures to draw a causal map.

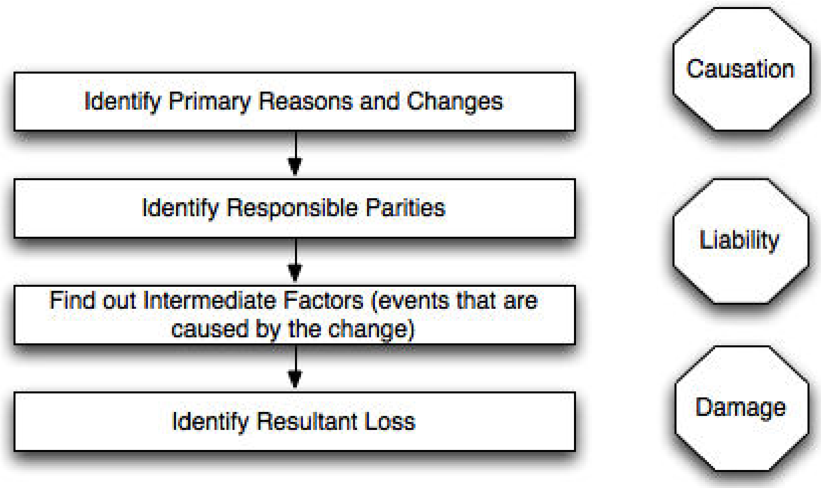

Figure 5.5: Procedure to Draw a Cause-Effect Map

5.4.2 Typical Primary Reasons: Changes

This section summarizes the typical primary causes. The primary causes involve the establishment of the liability. The change that essentially causes the problems defined in the MCAA include (see Section 1.1.1):

- Owner-driven scope changes that cause an increase or decrease in the amount of work from the scope of work outlined in the original contract;
- Changes in the methods of performance or the materials or equipment to be installed;
- Changes that modify the planned sequence in which the work was to be performed;
- Differing site conditions not anticipated in the original contract price;
- Constructability issues;
- Changes in performance specifications;
- Changes to correct errors, omissions, or inconsistencies in the specifications or drawings;
- Changes in the time for performance;
- Changes resulting from extraordinary, unexpected natural events; and
- Changes due to the actions or inactions of other trades working on the project.

According to Long (2005), typical primary causes (owner/engineering problems) include late Issued for Construction drawings, design basis/drawing Errors and Omissions, detective specifications, understated/overstated quantities, and design changes.

Secondary factors typically include owner-caused administrative problems (e.g. late precedence work by others, work access constraints, delayed review, and approval of contractor's submittals), owner-caused procurement problems (improperly tagged equipment and materials, and late owner-furnished equipment and materials), problems beyond control of all parties (weather impacts, labor strikes, and other force majeure issues), and contractor-caused problems (lack of qualified construction labor, lack of supervision, defective construction, vendor/supplier delivery delays, poor planning, and scheduling problems).

Based on the examples provided by Long and changes summarized by MCAA (2016), we provide a list of the possible primary causes of the LOP and the responsible party. This information is summarized as follows in Table 5.2.

Table 5.2: Typical Primary Causes and Responsible Party

Primary Causes	Responsible Party
1. Change of scope outlined in the contract 2. Changes in the design or specifications (including error correction) 3. Change in the method of performance or the materials and equipment used 4. Site Access problem or change in the time for performance 5. Delay in review or approval of submittals 6. Logistical problem: late owner-furnished equipment or materials 7. Acceleration requested by the owner 8. Other owner-caused delay	Owner and Designer
1. Logistical problem: late owner-furnished equipment or materials 2. Lack of supervision 3. Poor planning or scheduling problems 4. Defective construction 5. Other contractor-caused delay	Contractor
1. Change due to actions or inactions of other parties 2. Late equipment or material due to supplier's problem 3. Other delays caused by third party	Other Party
1. Unexpected natural event or weather impact or geographical conditions 2. Labor strike 3. Lack of qualified in market or increase of labor cost 4. Constructability issues 5. Other force majeure issues	Beyond Control of All Parties (Responsibility Depends on How the Contract Allocates it)

5.4.3 Typical Intermediate Productivity Factors

In Long's matrix the intermediate productivity loss factors include out-of-sequence work, increased size of crews, trade stacking, overtime work and shift work, resultant congestion, increased supervision, increased coordination, and night work. The listed factors are similar to MCAA productivity loss Factors. Typical intermediate LOP factors are summarized in Table 5.3.

Table 5.3: Typical Intermediate Productivity Loss Factors

Intermediate Productivity Loss Factors
Stacking of Trades
Morale and Attitude
Reassignment of Manpower
Crew Size Inefficiency
Dilution of Supervision
Learning Curve
Beneficial Occupancy
Site Access (Congested or partially blocked site)
Logistics problems onsite
Fatigue
Overtime or Nighttime Work

5.4.4 Typical Ultimate Factors: Direct Reason for Loss

Long, in his cause-effect matrix, gives examples of ultimate loss, including increased direct costs (including labor cost, equipment cost, etc.) and indirect cost. However, the way factors such as Congestion and Dilution of Supervision can cause a direct labor cost was not explained in his chart. Based on the legal cases reviewed, the plaintiff is required to explain in detail how the problems it encounters will ultimately cause a time or money loss.

Based on the 53 legal case decisions reviewed, the reasons that have been recognized by the Board and Court as a reason for labor productivity loss are summarized in Table 5.4.

Table 5.4: Typical Ultimate Factors

Ultimate factors	Examples
Lower work speed	Workers may move and work slower in cold weather.
Higher error rates and excessive correction work	More errors in night work.
Extra standby time	Non-work time waiting for other workers, materials, or further instructions.
Extra movement	The workers need to spend time on extra movement if the site is partially blocked.
Additional tasks or additional procedures	For example, additional procedures to remove water when encountering excessive rains or additional work or requirement of work directed by the owner.

5.5 Summary

In summary, a causal visualization tool can help MCAA Method users show the relationship between factors more clearly and help them to link change conditions to the resultant damage.

It is suggested that a better structured map be used in a LOP claim in order to establish liability, causation, and damage. Based on existing causation visualization tools and a review of previous LOP cases, it is suggested that the events or the factors be categorized into three levels:

1) Root factor (which is the changes defined in the MCAA manual; the root factor can be easily linked to the responsible party)

2) Intermediate factors (most of the MCAA Factors), and

3) Ultimate factors (factors that can be easily linked to damage to the plaintiff).

It is noteworthy that the factors listed for root, intermediate, and ultimate can only be used as reference. Individual project circumstances may differ. The most important rule is to link causation to the responsible parties and then to the time or money loss.

Chapter 6. Proposed Improvements to Factor Definitions

6.1 Introduction

It is argued in Chapter 1 that the original MCAA productivity method can be improved in terms of the following three structural deficiencies: 1) the definitions provided in the original MCAA Method are unclear; and 2) the loss percentage provided by the MCAA is not supported by real project data; and 3) there is no guidance on how to determine the severity level for each Factor. The first problem, the unclear definitions and improvements regarding them is addressed in this chapter.

The first target of this chapter is to improve the existing Factor definition provided by MCAA. One of the main problems of the MCAA Method addressed in Chapter 4 is that the claimant frequently does not provide sufficient evidence to prove the existence of Factors or to explain how the presence of such Factors can impair productivity. One reason for causal linkage failure is the vague definition of the MCAA Factors. This vagueness in the definitions causes inconsistency in applying those Factors and decreases the credibility of the MCAA Method's use.

With a thorough review of previous academic studies related to the Factors and previous legal case opinions, this chapter will improve each Factor's definition by explaining what each Factor means and how that Factor affects labor productivity. It also discusses the original source of the MCAA Factors and analyzes the definition and scope for each Factor in detail. Stacking of Trades, Concurrent Operations, and Joint Occupancy are closely related. They were not clear in the original definitions provided by the MCAA, and each can easily be a result of another. Thus, it is suggested those three Factors be combined. Ripple is a Factor defined on the basis of its affected work. It provides no specific information on how the problem is caused by the change and how it causes LOP. In addition, Ripple is rarely used in claims because of its imprecision, and therefore we recommend it not use in a LOP claim.

6.2 Existing Factor Definitions

The ambiguity of the MCAA's definitions inhibits consistent use of the MCAA Method, and the source of the MCAA Factors has been questioned from time to time (Harmon and Cole, 2006). According to MCAA (2016), the definitions of those Factors were developed by the Management Method Committee in 1971. Those definitions have remained unchanged during the past half century. The definitions for MCAA Factor that are commonly cited by researchers and used in LOP cases are cited from a table contained in the MCAA manual. See Table 1.1 of this report.

However another set of definitions was provided in the text (located in the first section "change orders") in the earlier versions of the MCAA manual (2005 or before). In that section, another sixteen Factors (mostly the same, but not exactly) were listed with slightly different explanations. Those two sets of definitions are compared in Table 6.1.

Table 6.1: Comparison of Definitions in the MCAA Manual

Definitions in Text (MCAA Version 2005 or Before)	Definitions in Table (MCAA All Versions)
Delayed, completion, escalation of costs, financing charges, other direct and indirect job costs	None
Fatigue: Overtime may be required to complete the base contract work within the allotted contract time because of a change order. Overtime breaks the established rhythm of a project and lowers work output and efficiency through physical fatigue.	FATIGUE: Unusual physical exertion. If on change order work and men return to base contract work, effects also affect performance on base contract.
Morale and Attitude: Skilled workers have intense pride in their work, in its progress, and in the final result. Change orders, if not properly planned, may cause interruptions in the work schedule, require adjustments in size and makeup of crews, or require moving personnel to other parts of the project prior to completing the one they are currently working on and with which they are intimately familiar. Frequently, work is required on a phase for which detailed plans have not been completed. If overtime is required on a part of the project because of a change order, workers on another part of the project not requiring overtime will compete for some part of it. The competition for overtime may contribute to poor Morale and Attitude, which reduces productivity and lowers efficiency.	MORALE AND ATTITUDE: Excessive hazard, competition for overtime, over-inspection, multiple contract changes and rework, disruption of labor rhythm and scheduling, poor site conditions, etc.
Stacking of Trades: Delays in the planned activities of a project result in a deterioration of the construction schedule. A change order, if not properly integrated in the average schedule, can transform an orderly, sequenced work plan into one in which many operations must be performed concurrently. The workers of several trades could be stacked in a limited work area, creating a situation in which work cannot be done efficiently. A contractor who was the low bidder and who scheduled its performance on an optimum time-minimum	STACKING OF TRADES: Operations take place within physically limited space with other contractors. Results in congestion of personnel, inability to locate tools conveniently, increased loss of tools, additional safety hazards and increased visitors. Optimum crew size cannot be utilized. CONCURRENT OPERATIONS: Stacking of this contractor's own force. Effect of adding operation to already planned sequence of operations. Unless gradual and controlled

cost program may find itself faced with a minimum time-maximum cost fiasco.	implementation of additional operations made, Factor will apply to all remaining and proposed contract hours.
Reassignment of Manpower: Reassignment of workers is generally required when changes to work in progress come unexpectedly, when changes are major, or when a demand is made to expedite or reschedule completion of certain phases of the work. Productivity could decrease if sufficient time is not allowed to plan an orderly effort to ensure work proceeds smoothly and efficiently.	REASSIGNMENT OF MANPOWER: Loss occurs with move-on, move-off men because of unexpected changes, excessive changes, or demand to expedite or reschedule completion of certain work phases. Preparation not possible for orderly change.
Dilution of Supervision: Field activities necessary to, and associated with, the integration of change order work into the work of the basic contract requires a diversion of supervisory attention from the basic contract work. While the superintendent is engaged in analyzing the change, organizing and assigning workers, procuring the additional material, equipment, and tools, etc., productivity on the basic contract could be adversely affected.	DILUTION OF SUPERVISION: Applies to both basic contract and proposed change. Supervision must be diverted to (a) analyze and plan change, (b) stop and replan affected work, c) take-off, order, and expedite material and equipment, (d) incorporate change into schedule, (e) instruct foreman and journeyman, (f) supervise work in progress, and (g) revise punch lists, testing, and start-up requirements.
Learning Curve: When workers are added to perform additional work because of change orders, a period of familiarization will be required until they are oriented to the job, plans, specifications, tool locations, work procedures, etc. If more than one crew is required to do certain installation work, the Learning Curve productivity is correspondingly multiplied.	LEARNING CURVE: Period of orientation in order to become familiar with changed condition. If new men are added to project, effects more severe as they learn tool locations, work procedures, etc. Turnover of crew.
Errors and Omissions: When additional work is required because of a change order being issued, often the impact on the basic contract work is not properly considered. This gives rise to possible Errors and Omissions, which can be very costly to correct.	ERRORS AND OMISSIONS: Increases in Errors and Omissions because changes usually performed on crash basis, out-of-sequence, or cause Dilution of Supervision or any other negative Factors.
Beneficial or Joint Occupancy: A change order which delays completion of the project could result in work having to be performed after the area is occupied by the owner's employees. Security or badging requirements, restrictions from certain areas, noise limitations which must be observed, etc., all adversely affect productivity and efficiency. Access to the project areas becomes congested or restricted at the time the work is scheduled for that area.	BENEFICIAL OCCUPANCY: Working over, around, or in close proximity to owner's personnel or production equipment. Also badging, noise limitations, dust, and special safety requirements and access restrictions because of owner. Using premises by owner prior to contract completion. JOINT OCCUPANCY: Change cause work to be performed while facility occupied by other

Time in gaining access is costly.	trades and not anticipated under original bid.
Logistics: Delay can occur because of problems in procurement and delivery of materials, equipment, etc., due to a change in scope. Prolonged overhead and escalation of material and equipment prices and projection of labor into a new and higher wage period also contribute to additional costs.	LOGISTICS: Owner furnished materials and problems of dealing with his storehouse people, no control over material flow to work areas. Also contract changes causing problems of procurement and delivery of materials and rehandling of substituted materials at site.
Ripple: A change order issued to one contractor more often than not has a profound effect on the work of other contractors. The other contractors may find themselves faced with additional costs due to having to change the schedule or sequence of operations.	RIPPLE: Changes in other trades' work affecting our work such as alteration of our schedule. A solution is to request, at first job meeting, that all change notices/bulletins be sent to our Contract Manager.
Not Included	SITE ACCESS, SEASON, AND WEATHER CHANGE, CREW SIZE INEFFICIENCY

From this table, we can observe that though in general the definitions are similar, there are also some inconsistencies between the two sets of definitions:

1) Errors and Omissions in the MCAA table (all versions) means extra Errors and Omissions due to disruptions such as change of sequence or Dilution of Supervision, but in the text (2005 version or before), it is described as a result of the basic contract work not properly considered when there is a change;

2) In the MCAA table (all versions), "Stacking of Trades" is between the contractor and other contractors, the consequent problems include "crowding" and "working with other trades". But in the text (2005 version or before), Stacking of Trades is caused by out-of-sequence work. It is a combination of "Concurrent Operation" and "Stacking of Trades" in the MCAA table (all versions); and

3) In the MCAA Factor table (all versions), the beneficial and Joint Occupancy are separated into two Factors by working with the owner and working with other trades. In the text (version 2005 or before), "Beneficial and Joint Occupancy" is one Factor and it means working with the owner.

Those inconsistencies mentioned above reflect the uncertainty/vagueness in those Factors' definitions. In addition, many definitions are not defining the Factors, for example, in both the text and Factor list, the definitions for the Factor Morale are describing the possible causes of lower morale, but not what is morale and how low morale might affect productivity. Similar problems happen to other Factors as well.

6.3 Proposed Improvements to Factor Definitions

The Factors' definitions, including what those Factors mean and how those Factors affect labor productivity, were investigated in this research. The results based on previous academic studies and legal case opinions are discussed in the following subsections.

Ripple is defined as one trade's problem affecting other trade's work, such as change of schedule or others. This is vague in nature and is not suitable for a LOP claim since a claiming contractor needs to describe the problem in details and causal link clearly to get reimbursed. Thus Ripple is a consequence of some underlying primary Factor and is not treated separately here.

6.3.1 Stacking of Trades, Concurrent Operations, and Joint Occupancy

According to MCAA (2016), trade stacking refers to the problem that multiple trades (contractors) are working in the same workplace; Concurrent Operation is defined as "stacking of this contractor's own force," and it is the "effect of adding operation to already planned sequence of operations." Joint Occupancy is one of possible consequences of trade stacking, and it is defined as "work to be performed while facility occupied by other trades and not anticipated under original bid."

Stacking of Trades, Concurrent Operations, and Joint Occupancy overlap in their definitions. Stacking of Trades can possibly cause Joint Occupancy. And the difference between stacking of staff from different contractors (Stacking of Trades) and the contractor's own staff (Concurrent Operation's consequence) is not obvious. Stacking of Trades and Concurrent Operations both cause LOP through congestion, extra work and sharing of working space and tools (as described). In addition, as discussed in Section 5.2.1, those Factors were not consistent in different versions of definitions provided by the MCAA. Thus, we believed these Factors should be considered together.

We thus combined those Factors and generalized the definition as "stacking of several trades (the contractor's own crews or with other contractors) in a limited area or work to be performed while facility occupied by other trades that not anticipated under original bid."

Based on a review of previous legal decisions, it is observed that Stacking of Trades can cause LOP by:

1) When working with or right after other trades, some other work or procedures such as cleanup work might be needed;[10] and

2) Site access and logistics problems: It is observed that one trade can be affected by other trades due to lack of access or congestion if they share the same work place. For example, there might be limited site access due to storage of other trades' materials /fixtures /equipment;[11] it is also possible that other trades leave their work incomplete, preventing the contractor doing his own work;[12] And more workers working on a congested area will cause LOP by extra movement of people and standby time.[13]

One of the rejection reasons provided by the Boards is that the Stacking of Trades were not due to the fault or negligence of the owner (or it has already been agreed in the contract); that is, Joint Occupancy can be frequently seen, the appellant will have to show that it suffered greater labor inefficiency as a result of Joint Occupancy than its contract required of it.[14]

Stacking of Trades and Crew Size Inefficiency can both cause similar problems such as high density of labor, congestion, and extra coordination. Stacking of Trades and Beneficial Occupancy can both cause logistics and site access problems. When the plaintiff chooses Factors, those Factors should be used together with caution.

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[10] See *Appeal of International Builder of Florida,* where the plaintiff claimed that unexpectedly working with dust-generating spray fireproofing work caused extra work for dust control.

[11] See *Appeal of General Railway Signal Company,* where the other contractor had blocked the contractor's excavation path by parking an earth grader and by dumping truckloads of sand. And in *Appeal of Space Age Engineering Inc.*, the contractor claimed that it had to work with paving operation and it became a safety problem with mixed cargo and it could not store or stage cargo in places it had become accustomed to using.

[12] See *Appeal of Roberts J R Corp.*, where the contractor claimed their work areas were congested, one reason provided is that "other trades [other contractors] have left their work incomplete thus stopping us [the contractor] from doing ours".

[13] See *Appeal of Continental Consolidated Corporation,* where the appellant's claim is based on LOP due to overcrowding in narrow underground spaces to a greater extent than could have been anticipated.

[14] See *Appeal of Continental Consolidate Corporation*: The Board decided that while the diaries of the inspectors show many incidents connected with the Joint Occupancy of the site, they are generally minor and many conflicts were resolved in favor of appellant. The government fully performed any duty incumbent upon it to coordinate its contractor's work. It did not establish facts with sufficient accuracy to what degree, if any, appellant here suffered LOP as a result of Joint Occupancy than its contract required it. Similarly see *Appeal of Fruehauf Co.* regarding the owner's coordination responsibility.

6.3.2 Morale and Attitude

"Morale and Attitude" is defined as a result of "excessive hazard, competition for overtime, over-inspection, multiple contract changes and rework, disruption of labor rhythm and scheduling, [and] poor site conditions." (MCAA, 2016) This definition provides no information about what it meant by Morale and Attitude, but instead the reason why lower Morale and Attitude might occur.

Hardy (2009) looked into the historical definitions of morale and concluded that morale is regarded as related to a goal, enthusiasm to achieve that goal, and cohesion within a group. Thus, it can be inferred that morale means labor's level of motivation and enthusiasm for achieving group objectives (completion goals of the construction project).

The construction industry has long recognized that motivation and morale of workers is important, but we found no study that clearly quantifies their effect. It is not easy to prove the existence of "lower morale." It is even harder to identify its cause (that is, why there is lower morale) and effect (that is, how much lower morale negatively affects the labor productivity).

According to the previous studies reviewed, lower morale can take place in many situations. Possible causes include:

- The worker's need has not been satisfied (sufficient earnings, belongings) (Schrader 1972).
- Unfavorable nature of work, coworker relationships, bad orientation, or bad safety programs (Borcherding and Garner 1980).
- Poor foreman or supervisor's management (Borcherding and Garner 1980).
- Excessive rework or work delays (Borcherding and Garner 1980).

Lower morale is in many cases related to the contractor's management. Of course, it is necessary to prove that the owner, not the contractor, caused the morale problem if a contractor wants to recover LOP.

On the other hand, most academic studies and legal case decisions do not provide explanations regarding how low morale can cause LOP. It can be inferred that lower morale will cause the workers to be unwilling to work or work hard, and thus it will impair the work speed and increase the error and rework rate. But it is hard to quantify the effect and prove the loss is caused by low morale.

Based on the published morale-related LOP case opinions, the two most common rejection reasons found in the legal opinions are:

1) The Board did not find any evidence showing that there is a loss related to lower

morale;[15] and

2) The impact is very difficult to measure and cannot be specifically identified by reviewing productivity.[16]

It is noteworthy that even though it is difficult to establish the cause of low morale, in *Appeal of Fire Security System Inc.*, LOP caused by low Morale and Attitude was the only Factor accepted by the Board. In that case suspect material was discovered at the early stage of pipe installation. The Board decided that Fire Security System was qualified for extra cost due to lower morale, since this Factor best described the situations. But the allowed amount was only 5%, which represents the "minor" LOP effect in the MCAA Method.

6.3.3 Reassignment of Manpower

Reassignment of Manpower may be a reaction of the contractor under a change condition; e.g., when there is limited access to current work, crews are reassigned to new work to minimize loss. Reassignment of Manpower means transferring workers from one task to another due to blocks to current work; this means workers need to jump to another task and this may create a LOP.

Reassignment of Manpower in some cases was regarded same as "out-of-sequence work."[17] However, change of work sequence (or out-of-sequence work) is one of the "changes" listed in the MCAA manual, and is defined as the change of planned work sequence.

In this report, we treat Reassignment of Manpower as one possible consequence of out-of-sequence work because out-of-sequence work can cause many other problems such as Stacking of Trades, Crew Size Inefficiency, etc. Reassignment of Manpower here refers

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[15] See *Appeal of Space Age Engineering*: According to the contractor's expert, the announcement of the change impacted morale and generated a number of retirements, luncheons award ceremonies and job interviews. However, The government's evidence supports the belief that morale was impacted but it suggests that only a few of the younger workers were very agitated because of it.

[16] See *Appeal of Bechtel Nation*: The contractor's expert himself admitted that the impact on morale is difficult to measure and cannot be specifically identified. It was thus not allowed by the Board.

[17] For example, in *Appeal of Hensel Phelps*, Reassignment of Manpower is described as "the need to constantly move members of T&S's plumbing and HVAC piping crews from location to location and floor to floor to work on 'hot spots.' These were the areas where work could be performed because the design was sufficiently complete, or where work had to be performed to avoid interference with other on-going work." And see also *Appeal of Clark Concrete Contractors.*

to the situation where people need to move between different tasks so that the workers cannot work on a continuous pattern. The works may consequently be divided into smaller pieces affecting Learning Curve.

Two reasons were found in previous legal decisions as to how Reassignment of Manpower can cause LOP:

1) Loss of learning: performing out-of-sequence, off-schedule on a stop-and-start basis, time needed to familiarize oneself with the work and work site, extra mobilization and demobilization;[18] and

2) Movement and disruption: transfer and movement of workers, materials, or equipment, imbalance of crews, disruptions and coordination effort will cause losses.[19]

Learning is another MCAA Factor. When learning is the main reason why Reassignment of Manpower causes LOP, those two Factors should be used together with caution. In this report, to avoid the overlap between Learning Curve and Reassignment of Manpower, we suggest avoiding inclusion of the learning effect when using "Reassignment of Manpower".

In addition, some Reassignment of Manpower in some cases should be expected on every project, especially when the contract contains a "change" clause and a "pay for delay" clause. Those clauses may give the owner some limited rights to suspend work, and the contractor may not be reimbursed for the loss due to Reassignment of Manpower.[20]

6.3.4 Crew Size Inefficiency

Crew Size Inefficiency represents adding more manpower to current construction work. It is one of the acceleration methods. It differs from Stacking of Trades in that Stacking of Trades represents stacking more people from different labor trades whereas Crew Size Inefficiency is a non-optimally-sized crew, possibly of the same trade.

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[18] See *Appeal of Dawson Construction Inc.*: Appellant's project manager testified that "you got to stop, put your people in other areas… and when you come back you're losing labor, losing time, because your people have got to get familiar with the areas again."

[19] See *Appeal of International Builders of Florida Inc.,* where the government's indecision on removing the stop order made it impossible to schedule and sequence work, requiring the contractor to "maintain some degree of readiness" during the period the stop order was in effect). *See also Appeal of Saudi Tarmac Company Ltd and Tarmac Overseas Ltd. (JV).*

[20] See *Appeal of International Builders of Florida Inc.*

Problems associated with Crew Size Inefficiency include LOP due to physical conflict, high density of labor, congestion, and Dilution of Supervision. Material tool and equipment shortages may occur due to an increased number of workers. Coordination and control may become more difficult. In addition, the demand for additional labor may introduce less productive workers (Hanna et al. 2007).

Stacking of Trades and Crew Size Inefficiency can cause similar problems such as high density of labor, congestion, and extra coordination. Those two Factors should be used together with caution.

6.3.5 Dilution of Supervision

Dilution of Supervision refers to the situation in which the supervisor-worker ratio is out of balance and workers don't receive the attention and guidance they need.

Dilution of Supervision is closely related to the contractor's own management. Extra effort will be needed to prove that Dilution of Supervision is caused by the owner's change and is not caused by the contractor's own management problem.

Two causes of Dilution of Supervision/additional supervision are found in the previous legal case opinions:

1) Change of the work sequence makes more craft works and activities happen simultaneously, or more crews are recruited while the number of supervisors keep the same;[21]

2) more supervision needed due to unskilled labor (when there are no enough skilled workers in the market or unskilled labor were hired to accelerate the work, etc.);[22] and

3) An abnormal amount of the foreman's time was spent identifying problems and bringing them to the attention of the management staff and the Corps of Engineers.[23]

In *Appeal of Southwest Marine Inc.*, the contractor claimed that Dilution of Supervision caused a LOP because:

1) With less time available for supervisory responsibilities, the lead men were unable to check the progress and quality of the work with sufficient frequency;

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[21] See *Appeal of Santa Fe Engineers*: The contractor claimed to increase their labor forces and escalated the work and that action necessitated in additional supervision.

[22] See *Appeal of Ingalls Shipbuilding Division Litton System Inc.(1978), Appeal of Southwest Marine Inc.*

[23] See *Appeal of Santa Fe Engineers,* Santa Fe Engineers and its subcontractors claimed Dilution of Supervision was due to time spent identifying problems and solving problems.

2) Workers tended to work less harder without closer supervision, and therefore the less the supervisors circulated, the less effort the craft workers expended; and

3) Supervisors were far less available to answer questions and solve problems, and consequently when their help was essential to the job, the workers interrupted their work either by leaving the job site to find the supervisors or by waiting to proceed until they came to the job site.

The main rejection reasons found in the previous cases were that the plaintiff could not allocate the responsibility to the owner, or Dilution of Supervision was at least partially the plaintiff's responsibility.[24]

Dilution of Supervision problem can be solved by adding more supervisors to the site. The costs for additional supervisors can then be treated separately.[25] But a claim for Dilution of Supervision will be rejected if there is double counting of the cost of Dilution of Supervision and the cost of extra supervisors.

6.3.6 Learning Curve

The Learning Curve Factor represents loss of learning due to disruptions, extra time to familiarize with the work, extra training time, mobilization, and demobilization.

It is widely accepted that production rates or productivity for performing repetitive construction tasks will improve with additional experience and practice. There are several reasons for this learning effect: 1) increased worker familiarization; 2) improved equipment and crew coordination; 3) improved job organization; 4) better engineering support; 5) better day-to-day management and supervision; 6) development of more efficient techniques and methods; 7) development of more efficient material supply systems; and 8) clarified and stabilized design leading to fewer modifications and rework (Thomas 1986).

Accordingly, loss of learning can be due to stoppage/interruption of work. That is, the original learning effect was affected so that the workers cannot achieve optimal efficiency as planned.[26] Related costs that have been cited in previous cases by the plaintiff include:

1) Extra work time and labor cost to familiarize with the work and site;

2) Extra training cost when returning to the original work[27] and recruiting new/unskilled labor (a new Learning Curve);[28] and

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[24] See *Appeal of Santa Fe Engineers*: Contractor used total cost method, and it was not able to allocate the loss to the owner's changes.

[25] See *Appeal of Clark Concrete, and Appeal of Hensel Phelps Construction Co.*

[26] See *Appeal of Ingalls Shipbuilding Division Litton System, Inc.(1976)*: Loss of learning resulted from government-caused disruption of series production and the Board allowed that claim.

3) Extra mobilization and demobilization cost due to extra movement from one task to another, such as the equipment mobilization, training fees, and preparation work.[29]

For the second and third categories, evidence such as receipt of training fee and payroll for mobilization and demobilization may be needed to prove the loss.

The extra cost needed to familiarize a worker with the work is not easy to quantify. Some researchers have worked on a mathematical way to quantify the productivity versus the number of units produced. Details will be further discussed in the Section 7.4.

Learning Curve theory and the regression model used to simulate it were found in two cases to estimate productivity (not the LOP).[30] In both cases, the Board was unsure about the correctness of the Learning Curve model.

One case was allowed (10% of the requested amount was awarded) since the plaintiff successfully proved that there was a loss related to learning. That is, the interruption in the production caused a frequent hire and rehire, and the plaintiff was forced to employ unskilled workers in the market. The other case was rejected since the plaintiff failed to link the owner's change to the loss of learning and the Board believed that the requested amount has been reimbursed in previous agreements.

6.3.7 Errors and Omissions

Errors and Omissions in the design and specifications can be a major reason for change. Errors and Omissions in the MCAA list referred to the problems in the construction work such that the workers are affected by disruptions in the work. Errors and Omissions (and correction work) can be directly caused by the incorrect specifications[31].

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[27] See *Appeal of James P. Purvis:* The job superintendent testified that when the work was stopped and restarted, the crews had to go through a learning period (he described the situation as "the crew would be disoriented and perhaps it might even be a completely new task and yet another period of training would be necessary to reorient them").

[28] See *Appeal of Algernon-Blair Incorporated, Appeal of Southwest Marine, and Appeal of E. W. Bliss Company.*

[29] See *Appeal of Excavation-Construction Inc., and Appeal of Santa Fe Engineers:* Extra mobilization and demobilization due to disruptions of Change claimed by the contractor.

[30] See *Appeal of Ingalls Shipbuilding Division Litton System, Inc. (1976), and Appeal of E. W. Bliss Company.*

[31] See *Appeal of E B Bush Construction Co Inc.*: Correction work repairing physical damage caused by earth fill failure due to government's faulty specifications.

Errors and Omissions is hereby defined as worker's mistakes or omissions in the constructed work. It can be caused by bad weather, worker's fatigue, etc. Errors and Omissions were frequently seen as a result of many other Factors, and it is comparatively easy to quantify the loss (cost of correction work). It is one of the Factors that directly causes extra work (correction and rework), and therefore is one of the ultimate Factors defined in Section 5.4.

6.3.8 Beneficial Occupancy

Beneficial Occupancy happens if 1) the site is occupied by the owner; or 2) the owner left some obstacles onsite.

The liability of Beneficial Occupancy is comparably easy to establish, since obviously it is directly related to the owner's action. Two cases were found regarding Beneficial Occupancy (*Appeal of Flex-Y-Plan* and *Appeal of International Builder of Florida*), and the plaintiff was reimbursed for both of them.

Based on those two LOP cases, it is observed that besides badging problems, noise limitations, dust problems, and special safety requirements, Beneficial Occupancy can also cause:

1) Site access problems with extra movement of workers;[32]
2) Out-of-sequence work;[33] and
3) Logistical problems: storage and protection of materials.[34]

Site Access problems (partially or completely blocked by the owner) can be a reason why Beneficial Occupancy causes LOP. Those two Factors should be used together with caution to avoid overstating the LOP.

6.3.9 Site Access

There are in general two types of Site Access problems found in previous cases:

1) Access to the site is partially blocked by the material or personnel onsite. Extra

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[32] See *Appeal of Flex-Y-Plan*: The government failed to evacuate personnel from the barracks. The presence of personnel during working hours and the use of the barracks at night (included the movement of furniture) disrupted the contractor's schedule.

[33] See *Appeal of Flex-Y-Plan*: The contractor's schedule was disrupted since the government failed to evacuate personnel from the barracks.

[34] See *Appeal of Flex-Y-Plan:* A claim based on furniture and personnel in the barracks was not accepted since the contract did not indicate the premises would be vacant. Also, see *Appeal of Atlas Construction Co., Inc.* in which storage of the owner's supplies was also an issue.

movement will be needed when working onsite;[35] and

2) The site is not accessible at all, and all work is delayed.[36] The site inaccessibility can be caused either by weather (snow, etc.) or an inaccessible road or bridge.

For instances of partial blockage of the site such as working around partially completed partitions, the plaintiff needs to offer proof regarding specific work practice inefficiencies (such as extra movement or cleaning) to prove LOP. Reimbursement may be denied without reasonable explanation, even though the Board agrees that the work site was partially blocked.[37]

Liability can be a problem for a situation where the site is completely inaccessible. It is possible that the owner is obligated to maintain the access (for example, the existing road), while the plaintiff is required by some contract clause to inspect the site prior to bidding and assumes the risk and responsibility for the access road.[38] In addition, site access is not regarded as a direct reason for extra cost; most of the time it only causes a suspension or delay for the project. That suspension or delay is, in turn, the actual triggering event for LOP. Thus, it is necessary to refer to other MCAA Factors and show why there is a LOP. In this case, it can be seen as "changes" in Section 5.4.

6.3.10 Logistics

The first kind of logistic problem is when the defendant is responsible for purchasing the material. In such case, delay or disruptions happen when 1) the delivery is delayed; 2) the quality is not good; or 3) the approval of the material is delayed. This logistic problem is a root reason for LOP (delay of work) that is defined as "changes" in Section 5.4. The plaintiff needs to further prove why this delay will cause a LOP.

Another kind of logistic problem is the case that owner's changes in the project cause changes in the contractor's logistic plan. Those Logistics problems include:

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[35] See *Appeal of International Builder of Florida* in which the contractor claimed "it was necessary for the contractor to work around partially completed partitions." Its claim was rejected however since it did not clearly explain the consequences of these partially completed partitions. *See also Appeal of Flex-Y-Plan.*

[36] See *Appeal of Excavation-Construction Inc.* in which government failed to issue a timely notice to proceed.

[37] See *Appeal of International Builders of Florida, Inc.*: Board concluded that some disruption must be expected when the contract contains a change clause and a pay-for-delay clause giving government the right to suspend work.

[38] See *Appeal of C & B Construction Company*: C&B claimed for increased costs due to poor condition of an existing access road. This claim was not allowed since the government was not obligated to either build a new road or to maintain the existing one. The contractor was required to inspect the site prior to bidding.

1) Extra manpower for material or equipment coordination: when the work was delayed, but the material and equipment were still sent to the site;[39]

2) Storage cost: when the materials and equipment unexpected accumulated but there is not enough storage space provided;[40]

3) Standby time to wait for materials (delay in procurement or material movement due to changes in the plan);[41]

Establishing liability in a logistic-related LOP claim is often difficult. Logistics are usually not the government's responsibility, but contractor caused or the third-party caused.[42] In previous legal cases, logistical problems have been proposed by owners as a defense.[43]

6.3.11 Fatigue

Fatigue refers to the worker's unusual physical conditions including lack of energy, physical exertion, physical discomfort, lack of motivation, and sleepiness (Ahsberg et al., 1997). Fatigue will cause the worker to work slower and make more errors and hence rework.

In the Board cases found by this research, Fatigue has not been used as a sole reason for productivity loss. In two cases it has been mentioned with other Factors. One was claimed to be a result of Overtime ("overtime fatigue", *Appeal of Blount Construction Company*), and the other is the result of severe weather ("fatigue from the heat", *Appeal of Fru-Con Construction Corporation*).

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[39] See *Appeal of T. C. Bateson.*

[40] See *Appeal of Fruehauf Co.* in which material was delivered to site during suspension of work at a time when no space was available in the building being constructed. Also, *Appeal of Flex-Y-Plan industries Inc.*

[41] See *Appeal of Centex Bateson*: Contractor claimed that when the original completion schedule was extended for a considerable period of time, it did not permit proportionate reduction of forces. That allegedly caused the total manpower utilized to be the same as planned. For example, it was necessary to maintain crews of workmen to release for shipment material and equipment required for the work in progress, and men were required to receive and store these items when delivered.

[42] See *Appeal of Zisken Construction Company*: Appellant's work was delayed into winter due to delay of material. Claim was rejected since responsibility for obtaining materials was appellant's and contractor did not provide enough evidence to show that government unduly delayed permission for use of material.

[43] See *Appeal of Essential Construction Co., Inc., and Himount Constructors Ltd., Joint Venture*: LOP due to winter work was denied partially because "much of appellant's problem, by its own admission, was caused by lumber shortage and site problems [the contactor's responsibility]".

6.3.12 Overtime

Overtime is one method to accelerate the project when there was a delay, and no or insufficient time extension was grated. Possible Overtime includes more than eight hours work per day, night shifts, and work during weekends. In the LOP claims found, fatigue and night work ("overtime fatigue and reduced productivity on night shift" in *Appeal of Continental Consolidated Corporation*) are the main reasons mentioned for Overtime that have an effect on productivity.

Previous academic studies have shown that Overtime can cause physical fatigue, lower morale, and increased errors (Lee 2007). Some researchers also found that Overtime work might cause an inability to provide materials, tools, equipment, and information in a timely manner and further cause the workers to wait or to work out-of-sequence. Absenteeism and turnover rates may increase because of Overtime period which affects productivity (Lee 2007).

A LOP claim due to Overtime will fail if the acceleration is not due to the owner.[44] In addition, if the parties have an agreement about acceleration before construction, the contractor should be prepared for the Overtime, and the inefficiency due to Overtime may not be reimbursed.[45] Another common reason for rejection in the legal cases found is lack of records showing loss due to Overtime.[46]

In addition, a contractor has erroneously claimed for both Overtime fees and LOP due to Overtime. This contractor claims were denied partially because of cost double counting.[47]

6.3.13 Season and Weather Change

Adverse weather is considered one of the main Factors causing delays and overruns on construction projects (Moselhi & El-Rayes 2002). Typically, there are three situations related to weather:

1) Unexpected severe weather that a reasonable contractor cannot predict in its initial plan and estimate.[48] It is not the mere presence of bad weather per se; it is the presence of

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[44] See *Appeal of Hawaiian* in which owner had inquired about possible delays during performance, and the contractor's failure to respond deprived the government of the opportunity of offering a time extension. *Also, Appeal of Community Heating* where overtime was not necessary.

[45] See *Appeal of Space Age Engineering:* Contractor should have expected overtime.

[46] See *Appeal of E.V. Lane:* No evidence shows that a loss occurred due to acceleration order). Also *Appeal of Pittsburgh-Des Moines Corporation:* No evidence of inefficiency.

[47] See *Appeal of Hawaiian:* Overtime was not allowed. The Board also stated that even though overtime was allowed, the LOP calculated by contractor was a double counting with overtime fees.

bad weather that could not have been reasonably foreseen (Ibbs & Razavi, 2014). Unfavorable weather normally includes hot weather,[49] cold weather,[50] and excessive rain.[51] A claim based on unexpected severe weather can be rejected if the weather is deemed not to be unusually severe.[52] In addition, contracts generally support time extensions caused by unusually severe weather but in some instances do not provide for equitable cost adjustments for such delays;[53]

2) The project was moved out of a favorable weather period into an unfavorable weather time due to changes or other reasons.[54] Contractors need to show that they did not undertake contract performance in unfavorable weather for their own reasons.[55] Another possible rejection reason is that the delay pushed as much or even more work into milder weather;[56] and

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[48] See *Appeal of Zisken Construction Company, J.D. Hedin Construction Co. Inc. v. United States, Edge Construction Company v. United States, Appeal of Triad Mechanical Inc*., *Daewoo Engineering and Construction Co. v. United States*.

[49] See *Fru-Con Construction Corporation v. United States.*

[50] See *Appeal of E.B. Bush Construction, Luria Brothers & Company v. United States, Appeal of Fruehauf Corporation:* Contractor did not expect to work in winter and that winter was "cold and erratic and there were several sizable snowstorms." Also, *Appeal of Excavation-construction Inc., Appeal of Pathman Construction Co.,* and *Appeal of Triad Mechanical Inc.*

[51] See *Appeal of Zisken Construction Company, J.D. Hedin Construction Co. Inc. v. United States, Appeal of International Builders of Florida Inc., Appeal of John E. Faucett, Appeal of Lamb Engineering and Construction Company*, and *Daewoo Engineering and Construction Co., LTD. v. United States*.

[52] For example, in *Appeal of Zisken Construction Company*, the appeal was rejected because the weather was not unusually severe. The Court noted that though "it rained more often than normal, the amount of each rainfall was below normal; there was a cold snap but there were 21 mild days which gave Zisken some advantages." See also *Appeal of Fruehauf Corporation, Appeal of Community Heating and Plumbing Company, Appeal of Triad Mechanical Inc., Appeal of Lamb Engineering and Construction Company*.

[53] For example, in *Edge Construction Company v. United States*, Edge was entitled to an extension of project time for weather-related delays, but the cost reimbursement was not supported.

[54] See *Luria Brothers & Company v. United States, Appeal of International Builders of Florida Inc., Appeal of Fruehauf Corporation, Appeal of Essential Construction Co. and Himount Contractors Ltd., Joint Venture, Kit-San-Azusa v. the United States, Appeal of Donohoe Construction Company, George Sollitt Construction Co. v. United States, Appeal of Pathman Construction, Appeal of Excavation-Construction Inc.*

[55] For example, in *Appeal of John E. Faucett*: Plaintiff's claim was rejected, since it voluntarily undertook contract performance during an anticipated period of normally heavy rainfall due to Faucett's desire to start work on another project immediately after the disrupted project would finish. *See also Appeal of Fred A. Arnold, Inc.*

[56] See *Appeal of Excavation-construction Inc,, Appeal of J.A. Jones Construction Company.*

3) Unexpected work environment change. A typical example of this kind is where building windows and temporary heat were unexpectedly not provided during winter construction.[57]

Two commonly seen problems are winter work and work in wind, rain or snow. Other Weather Factors such as hot weather, winter, exposure to sun, etc. can also cause LOP.

Reasons for winter-based productivity loss found in reviewed cases include:

1) Cold weather can have an impact on physiological conditions and also cause some "unknown additional loss due to behavioral reasons".[58] Cold weather can slow the laborer's work;[59]

2) Labor time is lost in morning start-ups and during breakdowns. For example, workers would not be inclined to stay onsite and handle tools until their fingers got (too) numb to hold onto them;[60]

3) Materials cannot be used or installed in cold weather;[61] and

4) Extra costs for mobilization, demobilization, and logistical cost such as storage and other cost for idle equipment (for winter shutdown).[62]

Reasons for productivity loss due to rain and wetness that have been cited in previous cases include:

1) Earth work can be heavily affected. Paving is performed less efficiently or not at all during wet season[63] and causes extra work (such as removing and replacing unsuitable soil);[64] and

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[57] See *Appeal of E.B. Bush construction:* Adequate winter heat unavailable. And *Appeal of Acme Missiles & Construction Corporation,* and *Appeal of Hugh Brasington Contracting Co.*

[58] See *Appeal of Fruehauf Corporation.*

[59] See *Appeal of E.B. Bush Construction Co.*

[60] See *Appeal of E.B. Bush Construction Co.*

[61] For example, frozen paint mentioned in *Appeal of E.B. Bush Construction Company* and extra protection of material during cold days (*Appeal of Triad Mechanical Inc.*).

[62] See *Appeal of Gerald Miller Construction Co.*

[63] See *Appeal of E.V. Lane.*

[64] *See Appeal of John E. Faucett, Appeal of International Builders of Florida:* Contractor had to remove rainwater from the work place.

2) Rainfall might cause site access and logistical problems (a road or bridge is unavailable).[65]

6.4 Summary

Table 6.2 shows the original definitions provided by the MCAA and proposed improvements based on existing academic studies and legal case opinions. This table is a summary of explanations in Section 6.3.

There proposed definitions are intended to better explain the meaning of each Factor, the possible situations, its effect on productivity, and the Factors is closely related to.

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[65] See *Appeal of John E. Faucett.*

Table 6.2: Improved MCAA Definitions

MCAA (all versions)	Proposed Improvements		
Original Definition	Definition	Effect on Productivity	Other Remarks
STACKING OF TRADES: Operations take place within physically limited space with other contractors. Results in congestion of personnel, inability to locate tools conveniently, increased loss of tools, additional safety hazards, and increased visitors. Optimum crew size cannot be utilized. CONCURRENT OPERATIONS: Stacking of this contractor's own force. Effect of adding operation to an already planned sequence of operations. Unless gradual and controlled implementation of additional operations is made, Factor will apply to all remaining and proposed contract hours. JOINT OCCUPANCY: Change cause work to be performed while facility occupied by other trades and not anticipated under original bid.	STACKING OF TRADES: Stacking of several trades (the contractor's own work force or with those of other contractors) in the same working area, or work to be performed while facility occupied by other trades; Not anticipated in original bid.	1) Extra work or procedures needed when working with or right after other trades; 2) Site access and logistics problem: limited site access due to storage of materials /equipment; inability to locate tools conveniently; or another trade leaves its work incomplete, preventing the contractor from doing his own work; and 3) Congestion of personnel: more people working in the same area causing extra movement of people, physical conflict, constraints and extra standby time.	Related to Beneficial Occupancy, Crew Size Inefficiency, Site Access, and Logistics.
CREW SIZE INEFFICIENCY: Additional workers to existing crews "breaks up" original team effort, affects labor rhythm. Also applies to basic contract hours.	CREW SIZE INEFFICIENCY: Adding more manpower to existing construction work.	1) Congestion of personnel: physical conflict and high density of labor; 2) Dilution of Supervision; and 3) Logistics problems such as material, tool and equipment shortage.	Related to Stacking of Trades, Dilution of Supervision, and Logistics.
BENEFICIAL OCCUPANCY: Working over, around, or in close proximity to owner's personnel or production equipment. Also badging, noise limitations, dust, and special safety requirements and access restrictions because of owner. Using premises by owner prior to contract completion.	BENEFICIAL OCCUPANCY: Working over, around, or in close proximity to the owner or owner-created obstacles.	1) Site access problems; 2) Out-of-sequence work; 3) Logistical problems: including storage and protection of materials; and 4) Badging, noise limitations, dust, and special safety requirements.	Related to Stacking of Trades, Site Access, and Logistics.
REASSIGNMENT OF	REASSIGNMENT OF	Time spent on extra	Related to out-of-sequence

MANPOWER: Loss occurs with move-on, move-off men because of unexpected changes, excessive changes, or demand to expedite or reschedule completion of certain work phases. Preparation not possible for orderly change.	MANPOWER: Transferring workers from one task to another due to blockages to current work. Workers need to jump frequently to other works and work on a stop-and-start basis.	movement.	work and Learning Curve.
LEARNING CURVE: Period of orientation in order to become familiar with changed condition. If new men are added to project, effects more severe as they learn tool locations, work procedures, etc. Turnover of crew.	LEARNING CURVE: Loss of learning due to disruptions, time and cost to familiarize with the work and work site, extra training cost, mobilization, and demobilization cost.	1) Lower work speed during learning period to become familiar with work and work environment; 2) Extra training cost; and 3) Extra mobilization and demobilization cost.	Related to Fatigue, Logistics, and Site Access.
SEASON AND WEATHER CHANGE: Either very hot or very cold weather.	SEASON AND WEATHER CHANGE: Unexpected severe weather, work pushed into inferior work time or unexpected work environment change (such as lack of windows in winter). Possible problems include winter work, rain and snow, hot weather, wind and sun exposure, etc.	1) Impact to physiological conditions, lower work speed and extra errors; 2) Logistical and site access problem; and 3) Extra work such as cleanup.	Related to Fatigue, Logistics, and Site Access.
SITE ACCESS: Interference with convenient access to work areas, poor man-lift management, or large and congested worksite.	SITE ACCESS: Site partially restricted by the material or personnel onsite, or the site is not accessible so that the work is delayed.	1) Extra effort to get site access; 2) Extra movement of labor or equipment; and 3) Extra work such as cleaning up.	Related to Logistics.
LOGISTICS: Owner furnished materials and problems of dealing with his storehouse people, no control over material flow to work areas. Also contract changes causing problems of procurement and delivery of materials and rehandling of substituted materials and rehandling of substituted materials at site.	LOGISTICS: 1) Problems with owner furnished materials; or 2) Other logistic problems caused by owner's change of materials or work schedule	1) Extra work for logistics coordination, materials movement and rehandling; 2) Storage cost: storage cost when no storage space; and 3) Standby time to wait for materials.	Logistics problem can be caused by many other MCAA Factors. Needs to be used with caution.
OVERTIME: Lowers work output and efficiency through physical fatigue and poor mental attitude.	OVERTIME: Work more than forty hours per week, extended workdays, extended workweeks, night and	1) Lower work speed and extra errors and omissions; and 2) Logistics problem.	Related to Fatigue, morale, and attitude.

	weekend work.		
DILUTION OF SUPERVISION: Applies to both basic contract and proposed change. Supervision must be diverted to (a) analyze and plan change, (b) stop and replan affected work, c) take-off, order and expedite material and equipment, (d) incorporate change into schedule, (e) instruct foreman and journeyman, (f) supervise work in progress, and (g) revise punch lists, testing and start-up requirements.	DILUTION OF SUPERVISION: Refers to the situation that the supervisor(s) spending less time overseeing work; or a lower supervisor-labor ratio.	1) Extra Errors and Omissions due to lack of supervision; 2) Lower work speed of workers; and 3) Additional standby time waiting for supervisors to answer questions and solve problems.	Related to out-of-sequence work and Crew Size Inefficiency.
MORALE AND ATTITUDE: Excessive hazard, competition for overtime, over-inspection, multiple contract changes and rework, disruption of labor rhythm and scheduling, poor site conditions, etc.	MORALE AND ATTITUDE: Lower level of labor motivation and enthusiasm for achieving project objectives.	Lower work speed and extra errors and corrections.	Use is not recommended. Boards and courts have generally not accepted. Lower morale can be caused by other MCAA Factors and is closely related to the contractor's management. Hard to establish liability and causation.
ERRORS AND OMISSIONS: Increases in errors and omissions because changes usually performed on crash basis, out-of-sequence, or cause Dilution of Supervision or any other negative Factors.	ERRORS AND OMISSIONS: Increase in worker's work errors and omissions due to disruptions.	Extra correction work, including rework and cleanup.	Use not recommended. Extra errors can be caused by many other MCAA Factors, and thus may not be primary.
FATIGUE: Unusual physical exertion. If on change order work and men return to base contract work, effects also affect performance on base contract.	FATIGUE: the worker's unusual physical conditions including lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness.	1) Lower work speed; and 2) Extra errors and omissions.	Not recommended. Related to Weather and Overtime, hard to establish liability and causation. Low morale can be caused by Fatigue as well.

Chapter 7. Proposed Improvements for Quantifying LOP

In Chapter 4 the current use of the MCAA Factor was analyzed and it was observed that loss percentages provided by MCAA are not supported by empirical studies. In addition, the MCAA has provided minor, average, and severe levels for each Factor's effect on productivity. However, no explanation has been published regarding how to determine the severity level for each Factor.

The MCAA Method was developed in 1971 and has remained unchanged. During the past 40 years, there have been many studies on labor productivity in the construction industry. Those studies obtained data from real projects or experiments and provided detailed information about how to quantify productivity loss. They have not been compared with the MCAA Factor method. This study does so.

Reliable studies found were focused on Weather, Overtime, Overstaffing, and Learning Curve's effect on productivity loss. The target of this chapter is to 1) examine the credibility of using those studies in a LOP claim and 2) develop a more definitive and applicable way to calculate productivity loss due to those Factors based on existing data and method, if possible.

The results are:

1) For Weather, available published data are studied, and a regression model based on temperature and humidity versus labor productivity is presented;

2) For a Learning Curve model, it is found that based on published data Learning Curve model should be used with caution. It can only be used on repetitive work and we suggest use of unit data or moving average data as opposed to cumulative data and selection of model based on prediction performance;

3) For Overtime, no published original project data were found. However, the multiplier provided by previous researchers and institutes has been widely accepted by the industry; and

4) For Reassignment of Manpower, no published original project data were found. The published models vary widely and need to be used with caution.

During this research we exhaustively reviewed the published research literature and court decisions searching for information on all sixteen MCAA Factors. However we found reliable quantitative modes on only four of those factors. But we also discussed the other factors' use in a LOP case.

Those results include:

1) For Dilution of Supervision, the Board allowed amounts have mostly been smaller than 10%, also the allowed amount should not exceed the cost to bring in extra supervisors.

2) For Errors and Omissions, we need to calculate the error rate beyond that should be normally expected (the typical project's general error rate). According to previous studies, the general rate is from 1 to 4%.

3) For Fatigue, we suggest use of the Swedish Occupational Fatigue Inventory (SOFI) for measure of the Fatigue levels.

Previous legal case opinions that included information on LOP quantifications are also summarized in this chapter.

7.1 Weather

7.1.1 Previous Studies Regarding Weather

Weather's effect on productivity is an important topic and has been the subject of a considerable amount of research. Several researchers have published their original data on Weather's effect.

Grimm and Wagner (1974) and The National Electrical Contractors Association (NECA 1969, NECA 2004) conducted experiments to measure productivity under different weather conditions. Grimm and Wagner (1974) collected and analyzed masonry productivity data from a series of experimental test stations and published a contour graph showing the impact of temperature and humidity on productivity ratio (PR herein after).

Grimm and Wagner called it productivity, but it is actually a ratio of actual productivity divided by optimal productivity). The data were collected hourly and grouped according to temperature and humidity. Their original data were published in Johnson (1972) and showed that productivity is very sensitive to temperature. See Appendix B. We investigate this study in more detail later in this paper.

NECA (2004) collected productivity data from an experiment on installing test receptacles with the temperature and humidity controlled. However, it only studied two electricians and did not consider Learning Curve, which was also the case in the Grimm study. NECA did not provide the raw data. It merely provided an inefficiency table with productivity normalized against different temperatures and humidity based on their data. No information has been provided as to how the optimal productivity and productivity percentages were calculated.

Clapp (1966) and Thomas and Yiakoumis (1987) also collected real project data. Clapp studied five semi-detached home building sites in the United Kingdom and determined when construction work would stop given different temperature and rainfall levels. But these results were based on monthly temperature averages and work stoppages, not diminished productivity rates.

Thomas and Yiakoumis (1987) developed a regression model using temperature and humidity to predict PR (in their work, they called it predicted efficiency). They studied masonry, steelwork, and formwork. See Appendix C. We explore this study in more detail later in this section.

Brauer (1984), Koehn and Brown (1984), Srinavin and Mohamed (2003), and Moselhi et al. (1997) developed models based on previously published data. Brauer et al. (1984) developed a diagram showing Wet-Bulb Globe Temperature (WBGT) versus PR with climate zone adjustment (multipliers for different regions and countries) based on previously published data. Koehn and Brown (1985) developed a table showing productivity versus temperature and humidity.

Abele (1986) presented a figure showing the relationship between temperature and productivity for both manual work and equipment work. This work focused on cold weather and was based on various previous studies from the construction industry and military (Lee, 2007). They state their analysis is based on previously published studies but do not identify those studies.

Mosehi et.al (1997) developed an automatic decision support system named WEATHER. The system was designed to help the contractor make decisions based on weather information and possible effect. They calculated productivity loss based on existing models (NECA 1974, Grimm and Wagner 1974, Sanders and Thomas 1991, U.S. Army 1986, Koehn and Brown 1985, see El-Rayes and Moselhi, 2001).

Hancher and Abd-Elkhalek (1998) focused on adjustment Factors (such as trades) and developed a figure showing productivity loss versus temperature and tables of multipliers with adjustment Factors. Their model is, in general, based on NECA (1974).

Besides the above studies, Kuipers (1977) developed an equation and a series of look-up tables for PR, considering temperature, humidity, solar radiation, wind, clothing, etc. This model was based on the theory that the human being is a heat-producing organism operating in a thermal environment, and a thermal imbalance (imbalance of heat production and heat loss) will cause inefficiency. The model is comprehensive in considering various Factors related to weather conditions, work being performed, and human relations to the work environment. It is too complex to be used in a practical context, and it is based on very small data set, which makes it questionable (Lee, 2007).

Srinavin and Mohamed (2003) developed a model similar to the Kuipers model, considering temperature, humidity, radiant temperature, wind velocity, the nature of construction task, and clothing based on previous data. They then tested the model with data collected from four construction sites in northeast of Thailand. They concluded that their model worked better on light (painting) and moderate work (brick laying) than heavy work (manual excavation). However, they did not explain how they addressed unavailable data, including wind, task type, clothing, metabolic rate, etc.

Of all the studies reviewed above, only the Grimm and Wagner study (labeled G&W herein) and the Thomas and Youkiamous (T&Y) provided their source data. The availability of that source data allowed us to conduct a meta-analysis.

Grimm and Wagner (1974) and Thomas and Yiakoumis (1987)'s estimates of temperature's impact on productivity are shown in the following Figure 7.1. Even though the NECA (1974, 2004) studies did not provide raw data, we also include such in the figure, because NECA's discussion of its findings is compelling. The other studies discussed above are excluded because they did not explain how they normalized and processed their data.

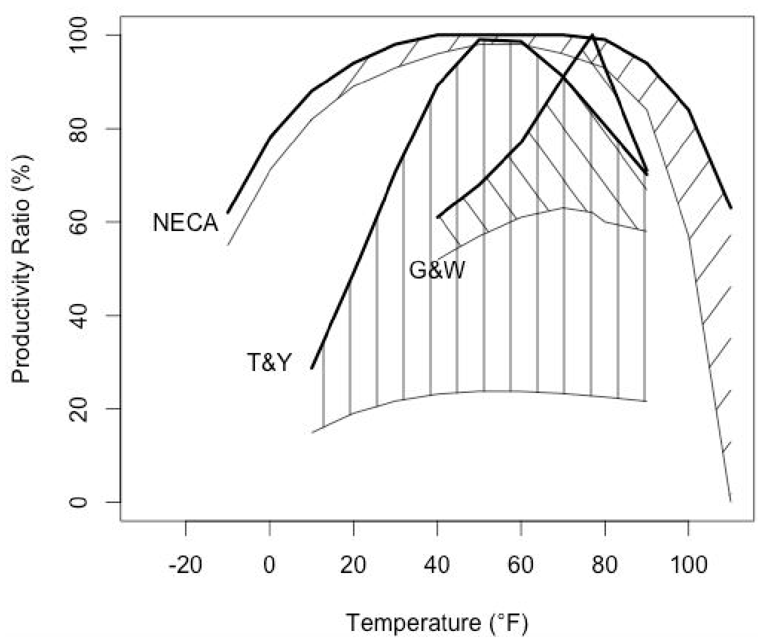

Figure 7.1: Temperature Versus Productivity (NECA, T&Y, and G&W)

The Productivity Ratio (PR) in Figure 7.1 represents the ratio of actual productivity divided by "optimal" productivity. These prior works, however, have different definitions of optimal productivity, which we will discuss in detail in the next section of this paper.

The hashed areas shown the solid curves in Figure 7.1 represent the range of each study's estimate of temperature's impact on productivity for different humidity levels. For example, Thomas reports 100% PR at 50°F and 0% humidity vs. 25% PR at 50°F and 85% humidity.

Note that the models shown in Figure 7.1 have their peak PRs at different temperature ranges. G&W's optimal temperature was approximately 80°F, T&Y's was around 45°F, and NECA had a wider range, in general 40-80°. The figure also reveals that NECA's model was less sensitive to temperature and G&W's model was more sensitive.

Upon detailed examination these models were found to have been developed using different definitions of PR. Figure 7.2 shows the PRs provided by G&W and T&Y (not yet normalized with a common definition). Data were grouped by temperature into 10°F bins. We can see that the PRs used by G&W are in general lower than T&Y's, with most PRs below 80%. T&Y's PRs varied from 25% to 175%, and many were larger than 100%.

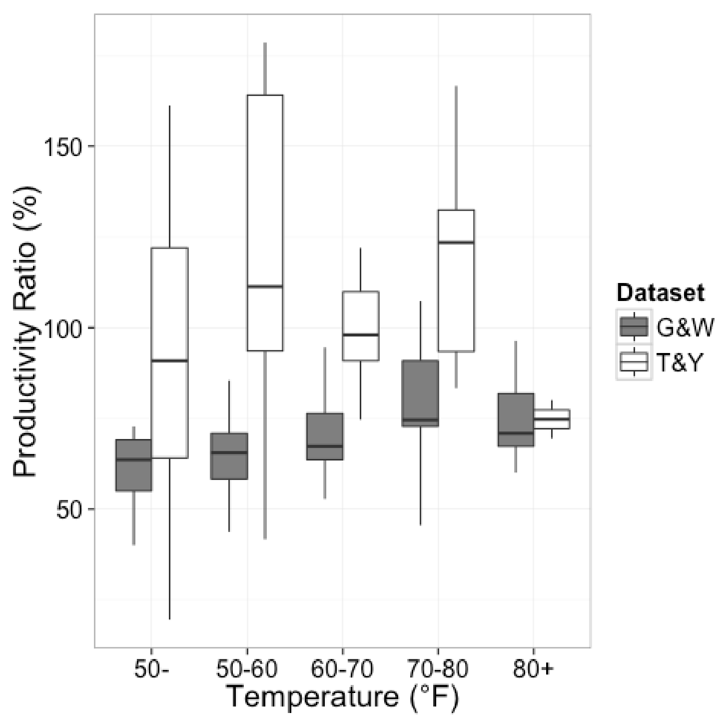

Figure 7.2: Temperature Versus Productivity (G&W versus T&Y)

The G&W curve is developed by computing the individual, actual productivity for a series of tasks and dividing such by the best actual productivity for those tasks overall. For example, if a mason installed three brick walls at a rate of 10 labor-hours, 15 labor-hours, and 20 labor-hours, the G&W values would be 1.0 (10/10), 0.67 (10/15), and 0.5 (10/20).

T&Y, on the other hand, compares the actual productivity rate for each of these walls against the planned rate for each wall. If the mason planned to work at 15 hours/wall, but actually spent 10 hours, 15 hours, and 20 hours respectively, then the PRs would accordingly be 1.5 (15/10), 1 (15/15), and 0.75 (15/20). Thus, the models are not directly comparable unless the underlying definitions are harmonized.

T&Y's definition relies on the contractor's estimate, using the planned rate in the denominator of the PR calculation. G&W's estimate, on the other hand, uses the very best actual productivity experience in the denominator for all PR calculations, and the estimated productivity rate is not used in the PR calculation.

We believe that the normalization methods used in these studies are not reliable, and thus a more definitive way is developed and presented in next section.

7.1.2 Use of Existing Weather Studies in a LOP Claim

To get reasonable results, we have to base our result on consistent definitions of productivity ratio, and we believe that the expected productivity should be an average over a range of optimal temperatures. Therefore we used the raw data provided by each researcher to compute the average productivity achieved in the 50-80°F range. That average was used as the denominator in our normalized PR calculation. Then the actual productivity for all temperature ranges was divided by that average optimal value. We then fit a quadratic model for each dataset and the two datasets combined. The normalized data from two datasets and the resulting regression lines of PR versus temperature are shown in Figure 7.3.

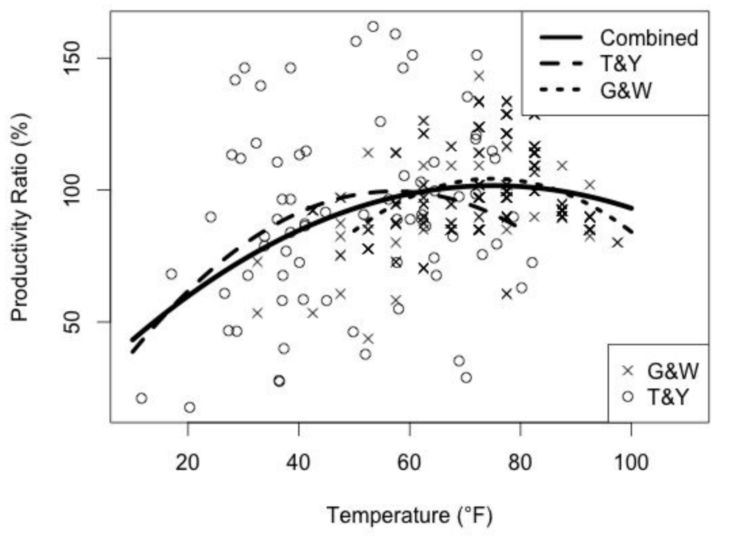

Figure 7.3: Temperature Versus Normalized Productivity Ratio

The solid line represents the regression line based on combined data, and the dotted lines represents the regression line based on T&Y and G&W, respectively. The combined model is as follows:

$$Estimated\ Productivity\ \ Ratio = 23.92 + 2.07T - 0.014T^2 \qquad \text{(Eq. 7.1)}$$

In this equation, T represents Temperature in °F.

In the t-test for this model, all coefficients have p-values smaller than 0.05. The F-statistic is very close to 0. This means that the model is quite significant, and the probability that the temperature does not have effect on productivity is almost 0%. The R2, which is the statistical coefficient of determination, is only 0.1238, which means that only about 12% variation in the productivity can be explained by this model. Inspection of Figure 7.3 shows large scatter in the original data, which substantiates the low R^2.

Based on the combined dataset of T&Y and G&W, we conclude that the effect on productivity of temperature is significant, but it is only one factor among many others that may have an impact.

Similarly, we were able to normalize and analyze the T&Y and G&W data to evaluate humidity's impact on productivity. Figure 7.4 shows the result, with 60% humidity being optimal.

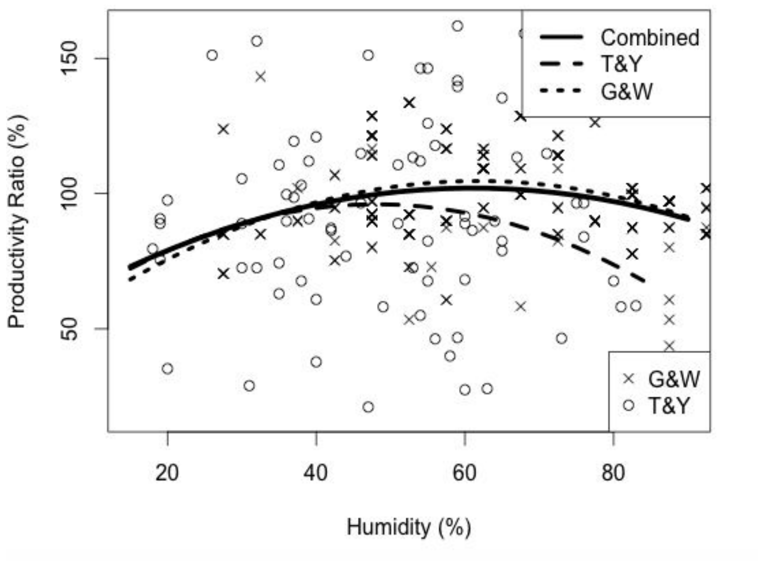

Figure 7.4: Humidity Versus Normalized Productivity Ratio

The statistical fit for these data are represented in Equation 7.2:

$$Estimated\ Productivity\ Ratio = 51.02 + 1.67H - 0.014H^2 \qquad \text{(Eq. 7.2)}$$

In this model, H represents humidity in %.

Applying the t-test for this model, all coefficients are determined to have p-values smaller than 0.05, and the F-statistic is very close to 0. That means the model is very significant, and the probability that humidity does not affect productivity is close to 0. The R^2 is 0.05, which is smaller than the temperature equation, Eq. 7.1. This means that humidity is a contributor to productivity but less of a contributor than temperature, because humidity's R^2 is less than temperature's R^2.

From this we conclude that humidity itself also has a significant effect on productivity, but its effect is smaller than temperature's. Since temperature and humidity might have an interactive effect on productivity, we developed a combination of temperature and humidity's effect on productivity, Eq. 7.3:

$$Estimated\ Productivity\ Ratio = -27.02 + 2.38T - 0.022T^2 + 1.82H - 0.021H^2 + 0.011HT \qquad \text{(Eq. 7.3)}$$

This model reflects temperature, humidity, and the two-way interaction between temperature and humidity's effect on PR. All coefficients are significant, and R^2 is 0.2445 for this model, which means, if we consider the combination of temperature and humidity, this model can explain around 1/4 of the variation in the data.

We suggest use of this updated formula to calculate the productivity loss, since it is based on a more reasonable definition of productivity ratio. The resultant model is significant as well. According to the MCAA Manual, the LOP due to Weather are 10% (minor), 20% (average), and 30% (severe). Our suggested quantification method are based on the temperature and humidity and are more scientific and based on real project data.

7.1.3. Legal Case Decisions Regarding LOP Quantification of Weather's Impact

Some of the LOP cases reviewed provide details regarding the LOP claimed and granted:

1) In *Luria Brothers & Company v. United States*, the witness testified that the plaintiff had to work outside on trench excavations and foundation construction in winter weather. He estimated the loss to be 33.33%, 25%, and 20% for different time periods. The Board allowed 20%, 10%, and 10%, respectively;

2) In *Appeal of Pathman Construction Co.*, the performance of concrete and masonry work was delayed into a winter season because of a strike. The plaintiff requested 25% LOP, which was accepted by the Board;

3) In *Appeal of Fruehauf Corporation*, the plaintiff was forced to work into the winter. It claimed for 50% LOP, and 25% was allowed; and

4) In *Appeal of Hugh Brasington Contracting Co.*, the government failed to provide adequate heat. Half of the building was affected, and 50% LOP was allowed for the affected part of the plaintiff's work.

From the four legal cases above, it is clear that Courts recognize that weather impacts productivity, and a contractor can successfully lodge a claim if that claim is properly prepared and presented. Generally, the Courts granted around 25% LOP to these impacted contractors.

7.2 Learning Curve

Loss of learning is closely related to the MCAA Factors "Reassignment of Manpower" and "Learning Curve." It is noteworthy that the Learning Curve in the MCAA Factor list is different from the mathematical Learning Curve model in the academic area. The learning Curve problem in the MCAA list include the extra time to arrange for the logistics, mobilization and demobilization, extra training fees as well as time to get familiar with the site and work. The first several problems can be quantified through onsite records, it may just be a matter of effect judgment. But the loss due to the familiarity problem is not easy to quantify.

Learning Curve quantification models in the academic area in general deal with the familiarity problem and have attracted researcher attention in the construction industry. Such models are discussed in the next subsection.

7.2.1 Previous Studies Regarding Learning Curve

Learning Curve is a mathematical description of worker performance in repetitive tasks. It was first empirically developed by Wright (1936) after observing the way assembly costs of airplanes decreased as repetitions were performed.

It states that whenever the production quantity of a new or changed product doubles, the unit or cumulative average cost will decline by a certain percentage. Unit cost represent the time or cost spent for completing each unit of work (for example, time used per cubic yard of concrete placed). Cumulative average cost is the average time or cost to complete units up to and including the given unit versus the unit number.

The formula is as below:

$$t_x = t_1 x^{-k} = \frac{t_1}{x^k} \qquad \text{(Eq. 7.4)}$$

where t_x is the cumulative average cost or unit cost for the time needed for the first x units; and –k is a parameter characterizing the improvement

$$k = -\frac{\log(1-\Phi)}{\log 2} \qquad \text{(Eq. 7.5)}$$

where Φ is the reduction in productivity per unit cost/time/etc.

Wright's formula can be rewritten in the form as

$$\log t_x = a + b(\log x) \qquad \text{(Eq. 7.6)}$$

It is therefore also named straight-line model or linear log model.

There are several variations of Wright's formula, which changes the general form of Wright's model to describe the learning effect. Examples include the cubic model

$$\log t_x = a + b(\log x) + c(\log x)^2 + d(\log x)^3 \qquad \text{(Eq. 7.7)}$$

and the Stanford B Model

$$t_x = t_1(x + A)^{-k} \qquad \text{(Eq. 7.8)}$$

introduced by Carlson (1973) and Thomas et al. (1986).

Table 7.1 summarizes the more prominent Learning Curve research.

Table 7.1: Comparison of Learning Curve Studies

Learning Curve Study	Data Source	Main Conclusions
UN, 1965	Data provided by governmental research organizations in western Europe.	The data shows improvement from repetition and that productivity can be affected by disruptions.
Frantezolis, 1984	Six activities on a multistory reinforced concrete building in Worchester, Mass.	Improvements from repetition and productivity losses before and after the interruption depended on 1) the length of the interruption; 2) the number of repetitive unites completed; 3) the degree of complexity of the operation; and 4) the rate of personnel turnover.
Thomas et al., 1986	Published historical data and data collected from a six-story apartment building construction.	Other nonlinear models such as cubic model have higher coefficient of determination.
Everett and Farghal, 1994	60 construction field operations gathered from published sources.	1) Cubic models give the highest correlation but are poor predictors of future performance; and 2) Linear log Learning Curve model (Wright's model) is the most reliable predictor.
Everett and Farghal, 1997	54 construction activities published by previous studies.	1) Unit data gives the most accurate prediction of the time or cost required to complete the remaining cycles; 2) Cumulative-average data is an unreliable predictor; and 3) Using exponentially weighted average data with a relatively large weighting Factor or smoothing parameter gives a slightly less accurate prediction at the early stage of the activity, but more accurate later.
Couto and Teixeira, 2005	Concrete form work for buildings in the Porto Area.	1) The linear model adequately fits the data collected; and 2) learning process depends on a number of Factors including project characteristics, project variations, changes in the work crew, and management level.
Hinze and Olbina, 2009	148 Concrete piles cast at a project site.	Learning Curve method applies well to large numbers of repeated items such as concrete

		pile fabrication and pile driving. The learning rate could change for different phases of the work.
Thomas, 2009	Actual project data.	Cumulative data gives a distorted view of performance. Three things are needed for a Learning Curve to take place: 1) the task need to be sufficiently complex; 2) there should be repetition in the units; and 3) management must create a stable work environment.
Jarkas and Horner, 2011	Formwork labor productivity data collected from building project in Kuwait.	Findings show little evidence of the applicability of the Learning Curve theory to formwork labor productivity of building floors.

It is accepted by most of the previous studies that 1) Learning Curve modeling provides a valid method for estimating the costs of work that continues in a repetitive manner; and 2) disruptions in the planned workflow may result in LOP.

7.2.2 Use of Existing Learning Curve Studies in a LOP Claim

Many previous studies have investigated the learning model and confirmed the positive correlation between productivity and cycle number and concluded that the Learning Curve was a reliable tool to make prediction (UN 1965; Thomas 1986; Everett & Farghal 1994; Couto & Teixeira 2005, etc.).

However, in order to use the Learning Curve successfully in a LOP claim, the calculation needs to be reasonable and realistic. Based on the published work and data, we make the following suggestions for use of Learning Curve model:

1) Check the work involved, it needs to be at least approximately similar and repetitive.

Construction activities normally take place under different and unique site conditions, and the tasks are typically varied. Learning does not occur on all construction tasks. It is agreed by most researchers that in order to use Learning Curve models to approximate the learning effect, the task needs to be sufficient complex and mostly identical (UN 1965; Couto & Teixeira 2005; Thomas 2009, etc.).

In addition, a distinction between productivity improvement due to "trade learning" and "site acquaintance" should be made. The former represent the learning process of the operatives' trade, the latter is a result of skilled labors getting acquainted with particular site conditions. Improvement related to site acquaintance can be significant within the first few cycles, but not progressive throughout the whole projects (Jarkas and Horner 2011).

2) Select model based on prediction performance.

There are several variations of Wright's formula, which change the general form of Wright's model to describe the learning effect. To select the best general form of Learning Curve model, the plaintiff needs to test the predictive power of different models (as discussed below). Unfortunately many previous researchers focused on the mathematical models and model fittings, but in practice, it is important to select a model based on their prediction performance.

Statistically how the model performs on the training set (known data on which the model is fit) is not a useful estimator of model performance on predictions. Ideally the model needs to be tested based on its performance on testing set (an independent dataset for test only). Thus statistical metrics such as the coefficient of correlation cannot be used as the only measure to compare models.

Everett and Farghal (1994) evaluated different models by testing on the previously published data and concluded that Wright's model remains the best fit for the prediction in practical. This conclusion might not be suitable for all projects, but it can be used as a starting point when there are no enough data available for a cross validation.

3) Calculate the learning rate based on the project involved. Project data need to be examined before the model is used.

Several recent studies on Learning Curve show that there is no consistent learning rate. Especially when the initial several units are disrupted, the Learning Curve may be badly distorted.

Gottlieb and Haugbolle (2010), in an overview of previous Learning Curve studies, concluded that the reported learning rates differ substantially from dataset to dataset, and that anything from 68 to 100% learning rate (corresponding 0 to 32% reduction of the accumulated mean value of operational time when doubling the number of operations) can be accomplished.

Hinze and Olbina (2009) found that the Learning Curve rate can be different for different phases of work. That is, sometimes the initial learning is quite substantial, but once the first several units are completed, the learning rates typically drop to a smaller but constant rate.

4) Use unit data or moving average data (or exponentially weighted average) to fit the Learning Curve model.

The unit data show the actual performance of the repetitive activities exactly as they happened, when it happened. Cumulative average data is the average time or cost to complete units up to and including the given unit versus the unit number. Moving average data calculate the average time with only the most recent data included. Exponentially weighted average (studied by Everett and Farghal 1997) is a smoothing method that in which past units will receive progressively less weight as more units are performed.

Cumulative Average Data:

$$s_x = \frac{t_1 + t_2 + t_3 + \cdots + t_x}{x} \quad \text{(Eq. 7.9)}$$

Moving Average of 3:

$$s_x = \frac{t_{x-2} + t_{x-1} + t_x}{3} \quad \text{(Eq. 7.10)}$$

Exponentially Weighted Average:

$$s_x = \alpha t_x + (1 - \alpha) s_{x-1} \quad \text{(Eq. 7.11)}$$

Learning Curve data have traditionally been represented in unit data and cumulative-average data. Many researchers have discussed which type of data we should use. Thomas et al. (1986) stated that 1) cumulative average curve can be deceptive because it is a "smoothing process whose power increases as the cumulative quantity increases", and it "has a tendency to make the basic data appear better"; and 2) unit curve or moving average curve contains more relevant information and allows the manager to detect the short-term changes. Other authors disagree, noting that cumulative averaging filters short-term noise.

Among all those studies, Everett and Farghal (1997) evaluate unit data, cumulative-average form, moving average data and exponentially weighted average data based on their performance in prediction. They concluded that 1) unit data gives the most accurate prediction, 2) cumulative-average data is an unreliable predictor of future performance, and 3) moving average data or exponentially weighted average data with a relatively large weighting Factor ($\alpha = 0.5$) "gives a less accurate prediction early in the activity but is more accurate later compared to unit data". We found Everett and Farghal's results credible and therefore suggest use of unit data or moving average data (exponentially weighted average data) for fitting a Learning Curve model.

According to the MCAA Manual, the LOP caused by the Learning Curve will be 5% for minor, 15% for average and 30% for severe. Proper application of Learning Curve will be based on specific project work experience and may give a more accurate estimate of LOP.

7.2.3 Legal Case Decisions Regarding LOP Quantification of Learning's Impact

Whether the Courts and Boards will accept Learning Curve data as a basis for a quantum judgment in a LOP case remains unanswered. Among the cases studied, there are only two cases in which the plaintiff argued LOP using Learning Curve before the Boards.

In *Appeal of Ingalls Shipbuilding Division Litton Systems, Inc. (1976)*, the plaintiff alleged its submarine construction was disrupted by the government. The interruption of production and loss of skilled workers caused a measureable LOP due to the lack of familiarity. The appellant calculated the loss based on the Learning Curve theory and argued that a 90% Learning Curve was demonstrated.

For months, a loss of learning was calculated, at an average of 0.445% increase per month. It used the total number of labor-hours x the number of months where learning was affected (17.5 months *0.445%) to calculate the loss. In this case, the government argued that a least square method was more appropriate for plotting a Learning Curve than the linear method used by the appellant. But the government also admitted that this method is not ideal.

Since there were many problems in the plaintiff's method (such as, the data were general, number of months unsure, calculation not based on a statistical significant model), the Board decided to user jury verdict and grant 10% of the requested amount.

Appeal of E.W. Bliss Company involved the eight sets of ship equipment produced under various contracts. The two problematic submarines were the fourth and fifth sets. Bliss projected an 85% Learning Curve and determined that it suffered a total loss of $169,035.94 (The labor-hours should have been 40,662 and 38,000 according to Learning Curve, but actually 50,771 and 50,779 respectively).

The ASBCA ruled that Bliss did not prove that it used a reasonable and realistic number of labor-hours per ship set, hence the Board was unable to verify the correctness of this calculation. The claim was also rejected because the Board believed that the additional labor-hours had been granted through a previously agreed price increase and the contractor failed to show that the amount shown as Learning Curve effect loss was LOP caused by change orders.

In those two cases the data sizes were small and the data were general (monthly data or data per ship). It is also unclear whether their work was sufficiently complex and sufficiently similar to use Learning Curve. It seems that both contractors failed to properly explain and examine their data. There is no information about how they made the estimate of the learning rate.

Therefore in both cases, the Board was unsure about the correctness of the Learning Curve model. In *Appeal of Ingalls Shipbuilding Division Litton Systems, Inc. (1976)*, the Board allowed part of the requested amount based on the agreement that there was a loss regarding learning. The allowed amount was very conservative and was essentially jury verdict (only 10% based on a conservative learning rate of 90%).

7.3 Overtime

7.3.1 Previous Studies Regarding Overtime

The standard work time in the US is five days per week, eight hours per day. Hours in excess of eight hours per day or forty hours per week are considered Overtime. Some researchers have provided Overtime's productivity multipliers according to the method of exercising Overtime.

The Bureau of Labor Statistics published Bulletin 791 in 1947 (Kossoris, 1947), which is seen as the earliest credible study on this topic. It did not focus on any construction companies however, and the data size is small; for each situation, the number of cases is no more than 10, and the result is not statistically significant.

NECA's Overtime study (1962, 1969, 1989) was based on interviews of the members of the Southeastern Michigan Chapter of NECA in Detroit. Smith (1975) studied a project located 50 miles from medium-sized metropolitan and provided efficiency values for four different overtime types. The US Army Corps of Engineers (1979) provided a graph showing Overtime versus efficiency. But information regarding the data source was not disclosed. Adrian (1987) was based on data collected from concrete work in Chicago, Illinois. But Adrian did not explain the data source. Business Roundtable (1974, 1980) claimed their results were based on records from a project in Green Bay, Wisconsin, but the validity of their results was questioned by many researchers. The original data was not published, and no details regarding the data source were given. Haneiko and Henry (1991) studied a backfit project in Texas and provided a figure for overtime's effect. Construction Industry Institute (CII) (1994) analyzes 120 weeks of productivity data from four industrial projects that were constructed between 1989 and 1992.

Though most of those studies claimed that their results were based on real project and data, no published source data were included in those studies.

Figure 7.5 and Figure 7.6 (adapted from Lee 2007) provides the LOP percentages according to these different studies for 5-10's and 6-10's.

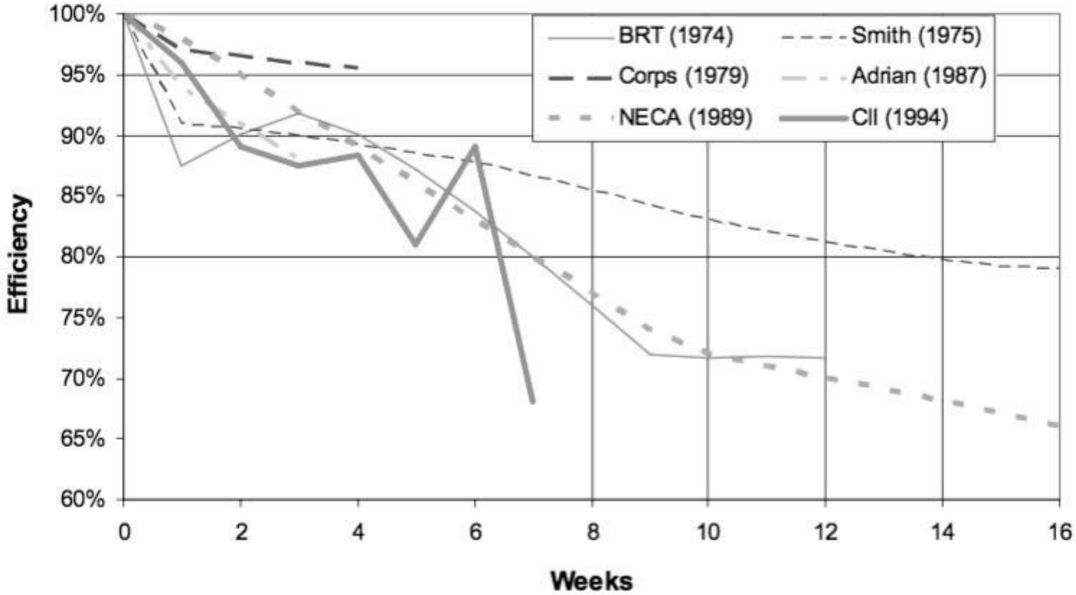

Figure 7.5: Comparison of Different Studies' Result for 5-10's

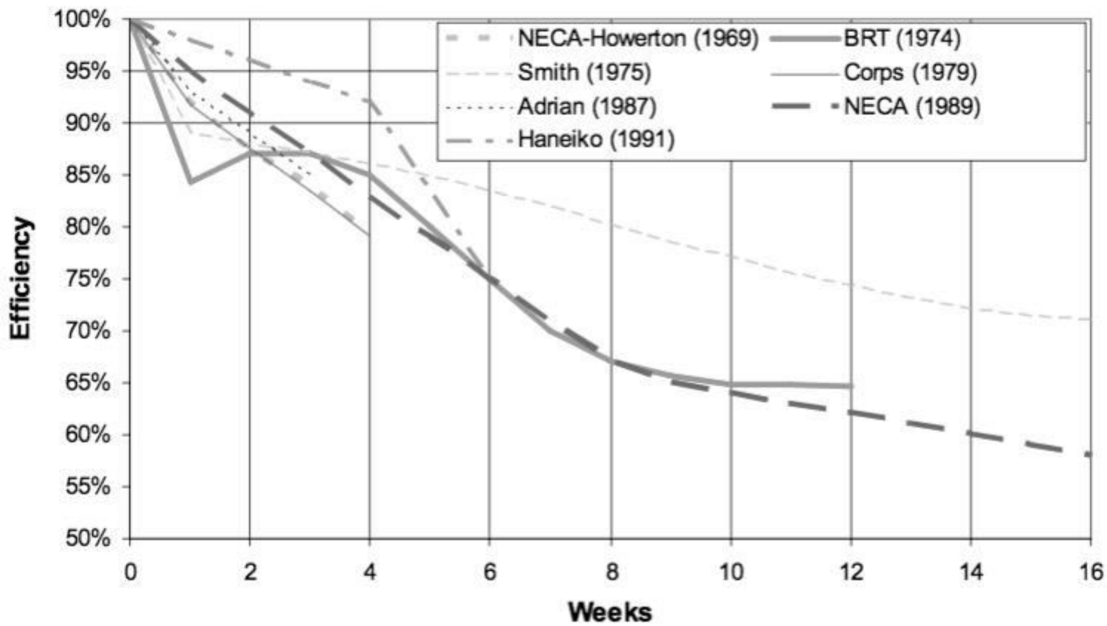

Figure 7.6: Comparison of Different Studies' Result for 6-10's

7.3.2 Use of Existing Overtime Studies in a LOP Claim

There is no published data set to validate these numbers. If the results from previous studies are from independent studies, they might be used to validate each other. Unfortunately, most of them did not provide a clear explanation about their data sets, and many of those studies are suspected to have used, in whole or part the BLS data.

On the other hand, overtime of more than 60 hours (from 6x11 to 7x12 in the table above) per week is rarely seen on a construction project. It seems that the data for those situations have larger variance and are not very consistent with each other. Thus, the credibility of such data in the table above is unproven.

However, even though those multipliers might not have reliable data sources, it is true that those Factors have commonly been used in the industry in the past many years, e.g., for claims or for other purposes (Larew 1988).

Thus, we believe that those multipliers can be used as supplementary materials to support the existence and quantification of overtime's effect on productivity. The plaintiff will also need to prepare other evidence (such as payroll, expert opinion, or interviews with onsite personnel) to confirm their calculation. The tables for overtime of 60 or more hours per week should be applied judicious.

The MCAA manual suggests 10%-20% for Overtime, we believe estimate LOP base on the overtime type (for example, 5x10 or 6x8), and the length of time overtime will be more reasonable and thus suggest the use of multipliers provided by previous studies.

7.3.3 Legal Case Decisions Regarding LOP Quantification of Overtime's Impact

Two LOP cases with details regarding quantification of Overtime's effect have been found:

1) In *Ace Constructors, Inc. v. U.S.*, the contractor used the Business Roundtable Report to claim for the loss due to Overtime over a long term. The Court held that the Business Roundtable report was credible and relevant, and the LOP was awarded accordingly.

2) In *Appeal of Continental Consolidated Corporation*, 17% LOP was granted due to night work and 60-hour work weeks. Compared to the multipliers in Table 6.1, it seems that the awarded amount is close to those provided in the table.

3) In *Appeal of Lew F Stilwell Inc.*, the Board accepted efficiency loss due to Overtime and allowed around 40% extra cost for several trades.

4) In *Appeal of Blount Construction Company*, the contractor claimed 16% LOP for acceleration. The Board did not question that part, but only allowed 11% of claimed amount due to other liability problems.

Thus we conclude that these multipliers have industry acceptance because of their use by the boards and courts.

7.4 Crew Size Inefficiency

7.4.1 Previous Studies Regarding Crew Size Inefficiency

Adding more people onsite is one method to accelerate the construction progress. Lee (2007) and Thomas and Smith (1990) are two studies that have discussed this topic. In summary, two methods have been found to quantify overstaffing's effect on productivity: One is to quantify LOP through overstaffing level (percentage of additional people added onsite), and the other is to quantify LOP through space per person.

7.4.1.1 Quantification through Overstaffing Level (Percentage More People)
In general, this method refers to crew-size inefficiency in the MCAA Factors. It determines the LOP based on percentage more people added to the project.

The determination of whether a project is overstaffed can be based on an increase in peak numbers or the average number of workers (optimal versus actual). Many previous studies showed that when the crew size increases, efficiency decreases. Most of those studies simulated the effect with a linear curve or a regression model close to linear.

However, no published data were found on this topic and most of the previous studies did not provide any information regarding the normalization and processing of their data. It is thus not possible to determine the credibility based on the quality of the data and the correctness of the data processing. However, it seems that most of the previous studies were based on independent data and could be used to validate each other.

O'Connor (1969) and Waldron (1968) used the same data set. The study was based on the construction of large central station boilers in the Ohio Valley. The line they gave in their published diagram for overstaffing versus productivity is quite smooth, and there is no further explanation of that figure.

Kappaz (1977) provided graphs showing productivity versus overstaffing. Kappaz did not explain the data source of his graph. Corps (1979) provided a figure showing the crew size increase versus productivity loss. Similarly there was no information about the data source or data processing.

Thomas and Jansma (1985) studied a nuclear power plant project, and the overstaffing was measured for peak manpower (actual peak over planned peak). Thomas and Smith (1990) claimed to have used unpublished data provided by some general contractors. No further details regarding the data size or data processing for either of these Thomas studies was provided.

Figure 7.7 compares the Overstaffing Percentage versus Productivity ratio based on the previous studies. This figure is adapted from (Lee 2007).

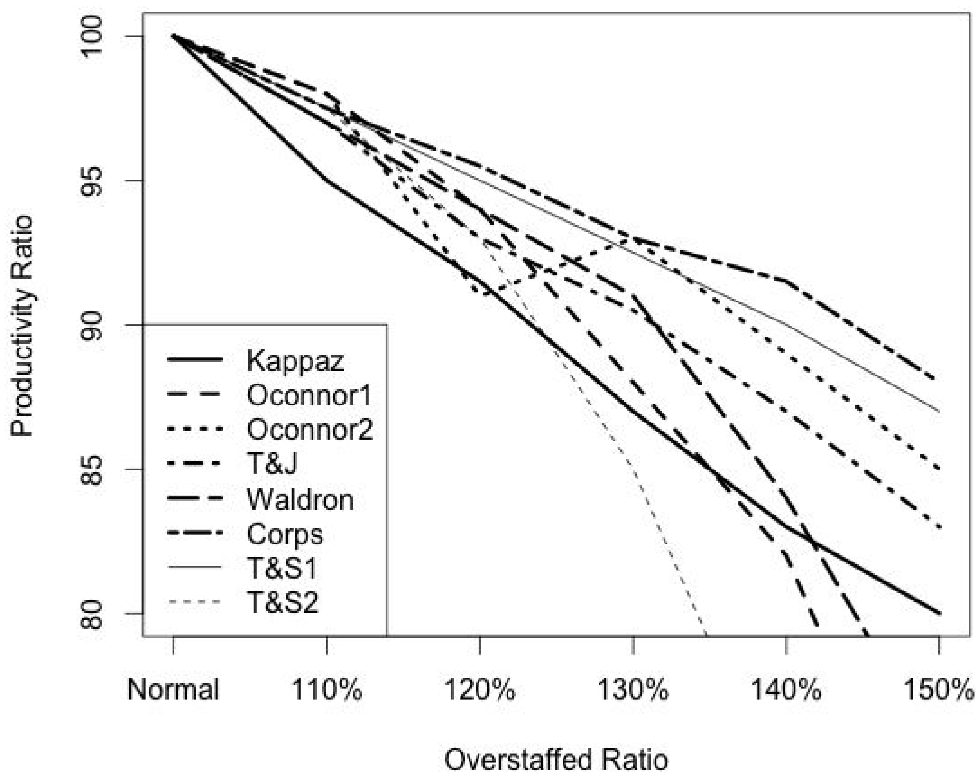

Figure 7.7: Comparison of Previous Overstaffing Models

In this graph, Oconnor1 is for a 300-men project and Oconnor2 is for a 100 men-project. T& J represents Thomas and Jansma (1985). T&S1 and T&S2 represent two contractors in Thomas and Smith (1990). It is observed that previous studies in general gave a range for overstaffing's effect on productivity. Corps (1979) seems to be the most conservative work among all the works.

7.4.1.2 Quantification Through Crowding (Percentage Additional Person Per Space)

The second method to quantify the effect of overstaffing is to quantify through crowding. Such studies include Kappaz (1977), US Army (1979), Smith (1987), and Thomas and Smith (1990).

Optimal work space per person is estimated differently in those studies. But all of them in general indicate that 200–350 sf/person is optimal (Kappaz, 225 sf/person; Smith, 323 sf/person and Thomas and Smith 200, 250 sf/person).

Thomas and Smith (1990) provide a comparison graph by collectively drawing the curves from Kappaz (1977), Corps (1979), A.G. Smith (1987), and Mobil (Thomas and G.R. Smith, 1990). See Figure 7.8 (adapted from Lee 2007).

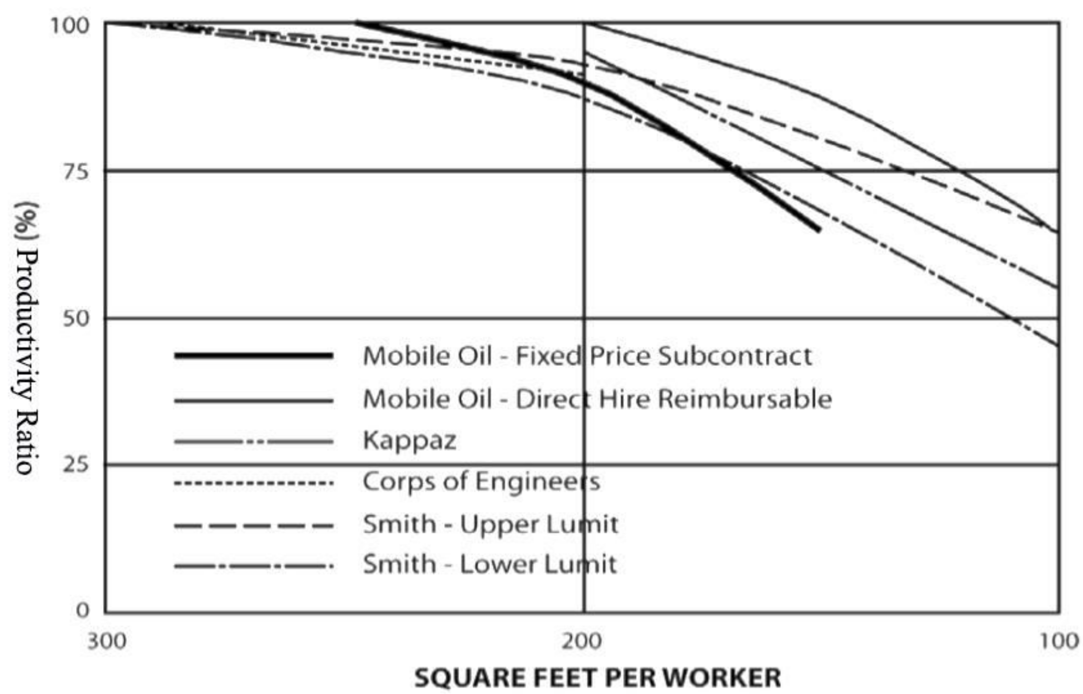

Figure 7.8: Comparison of Previous Congestion Models

Results of those studies seem to validate each other. They provided a reasonably small range for estimate of multipliers. However, the reliability of those studies is a problem.

Kappaz (1977) Corps (1979), and Smith (1987) did not provide any information regarding their data source and data processing. They also failed to provide how they calculated the productivity ratios or multipliers. Kappaz (1977) clearly stated that the curve is not intended to be "a cookbook approach or a mathematical formula that would solve the problem". It can only be used as a systematic guide or framework for analysis.

7.4.2 Use of Existing Crew Size Inefficiency Studies in a LOP Claim

Studies regarding crowding, similarly, have reliability problems with a lack of information about source data and how the data were processed. It is widely accepted that the congestion will have a negative effect on productivity loss, but more work will be needed on this topic to further confirm how to quantify that effect. We believe this range can only be provided a starting point for the contractor to estimate its own LOP.

However, the MCAA Manual suggest the LOP due to Crew Size Inefficiency from 10% to 30% but there is no further information regarding how to determine the severity level of minor, average and severe. The curves provided in Section 7.4.1 are based on the overstaffed ratio and space per person.

7.4.3 Legal Case Decisions Regarding LOP Quantification of Crew Size Inefficiency's Impact

In *Appeal of Danac, Inc*., the Board denied the LOP claim, which was based on the Corps (1979) results. The Board believed that the principle included in the guide was too general of a statement, and the plaintiff failed to link the described phenomenon in the guide to the project in question.

In the *Appeal of Continental Consolidated Corporation*, the plaintiff used a method called the "mountain home" formula, which "seeks to establish the optimum manning patterns of contractors in Joint Occupancy as well as the percentage of overload." The consultant computed monthly overloads of from 74% to 150% and monthly labor inefficiency Factors of 30 to 60% per month.

The method was not allowed by the Board. The Board commented that because "such an inaccurate and speculative attempt to marshal the facts does not permit us to make the findings requisite here nor does it even create the basis for a jury verdict in appellant's favor."

In the *Appeal of Penn York Corporation and Acro-v Builders Corporation*, there is an 10.8% increase of manpower loading, and the contractor was allowed for LOP award 3%.

In *Appeal of Stroh Corporation*, the contractor was forced to use a less efficient four-man crew instead of its planned two-man crew. Stroh was awarded 10% for the crew-size inefficiency problem.

From the above cases it is observed that the LOP caused by overstaffing has been recognized and admitted by the Board. But we found no legal cases to support the use of previous academic work or experience formula.

The Boards seem to trust expert opinion rather than the existing formula or studies. The academic studies seem to be reasonable supplementary materials to support the quantification of LOP due to overstaffing.

7.5 Other Conclusions Regarding LOP Impact Quantification

7.5.1 Dilution of Supervision

As defined in Chapter 5, Dilution of Supervision refers to the situation in which the supervisor(s) has to spend more time on other work and less time on direct supervision of craft labor.

No academic study was found regarding quantification of Dilution of Supervision's effect on productivity; more research is needed on this topic.

However, in some legal case opinions reviewed, there were several points brought up regarding "Dilution of Supervision."

Firstly, it seems that the allowed amount of Dilution of Supervision tends to fall into "minor" or an even smaller category provided by the MCAA:

1) In *Appeal of AEI*, as an example provided by the government to prove its statements that the MCAA list gives an inflated value of impact, the government's expert argued that "no owner would consider paying a 25% premium for Dilution of Supervision for all base contract and change order labor…";

2) In *Appeal of Clark Concrete*, Dilution of Supervision is estimated as 5% (half of minor, since the plaintiff believes they mitigated this problem by adding more supervisors);

3) In *Clark Construction Group Inc.*, the plaintiff successfully used Dilution of Supervision, but the allowed amount is minor, e.g. 10%.

Secondly, the Dilution of Supervision problem obviously can be solved by adding more supervisors. Therefore, the allowed amount will reasonably not be larger than the cost to bring in extra field engineer and/or superintendent to accomplish the same thing.

7.5.2 Errors and Omissions

Some studies show that rework is related to many Factors (see Table 6.2 and Section 6.3.7). But no study was found to estimate the error rate based on those Factors.

However, previous researchers did find that there exists a “general error rate”, which is the cost incurred by rework due to errors on average for a normal construction project. It is meaningful to determine LOP since the contractor must compare the general error rate to its own projects’ error rate to determine if it spent more time on errors and rework. Table 7.2 shows the related results of previous studies (adapted from Josephson et al 2002):

Table 7.2: Rework Cost Percentages by Previous Studies

Previous study	Error and rework costs of total project cost	Percentage for construction errors	Costs incurred because of construction errors
Cnuddle (1991)	10% - 20%	22%	2.2-4.4%
Burati et al. (1992)	12.4%	17%	2.1%
Hammarlund and Josephson (1991)	4%	26%	1.1%
Josephson (1990, 1994); Josephson and Hammarlund (1996)	2.3-9.4%	50%	1.2-4.8%
Josephson et al. (2002)	7.1%	45%	3.195%

The cost incurred by rework (Errors and Omissions) is reasonably consistent, generally from 1–4%.

It is also noteworthy that general error rate is highly dependent on the complexity of work. Research on errors in pipeline construction (Brown & Batie 2013) showed that most errors occurring in pipeline construction include “improperly calculating the grade, slope and/or elevations, improper alignment and/or incorrect layout, improper installation resulting in leaks in the pipeline.” Accordingly, the mistakes can vary from 20% to 130%, which is significant larger than a general construction project.

In conclusion, no study was found providing project data and error rates, but there seems to be a consensus that even normal project have some amount of error, probably 1-4%. It also depends on the complexity of a specific task.

In addition, in the *Appeal of T C Bateson Construction Co.*, the contractor claimed 20% inefficiency in backfilling operations during winter. Because of frost in the ground it did not achieve satisfactory results. The owner did not question the 20% inefficiency claimed.

7.5.3 Morale and Attitude

The effect of morale is very hard to quantify. No quantitative study was found regarding the measure of morale’s impact on productivity (Hardy 2009).

There are some studies of how job satisfaction will affect job performance, and the conclusions are very vague regarding the relationship between those two. For instance, according to Iaffaldano and Muchinsky (1985), satisfaction and performance are only slightly related to each other. The amount of empirical support for the satisfaction-performance relation does not approximate the degree to which this relation has been espoused in theories of organizational design. It is almost as if the satisfaction-performance relation is itself an illusory correlation, a perceived relation between two variables that we logically or intuitively think should interrelate, but in fact may not.

According to Borcherding and Oglesby (1974), an inverse relationship exists between productivity and job satisfaction. It is proposed that satisfaction comes about because each workman is producing a highly visible physical structure. That is, when production is poor, the worker tends to have lower job satisfaction. How job satisfaction can affect productivity was not clearly stated though the authors admit that it was one of the targets in the early stages of their study.

Corps (1979) commented that "morale does exert an influence on productivity, but so many Factors interact on morale that their individual effects defy quantification… The degree to which this may affect productivity, and consequently the cost of performing the work, would normally be very minor compared to the other causes of productivity loss. A contractor would probably find that it would cost more to maintain the records necessary to document productivity loss from lowered morale than justified by the amount he might recover."

"Morale and Attitude" have not been accepted in most of the cases due to its inherent vagueness, but in *Appeal of Security System Inc*. and *Appeal of Hensel Phelps*, the Board agreed to the use of Morale and Attitude as one Factor in the MCAA Factor list, allocating 5% (a minor effect) in both cases.

7.5.4 Fatigue

No study was found regarding Fatigue's effect on productivity, but the level of Fatigue is normally measured physically or subjectively. For physical measurement, different variables have been used as indicator of Fatigue, such as changes in blood pressure and heart rate (Absberg 1998; Shinmi 1999; Shiomi & Hirose 2000). However, contractors rarely perform such physical tests on a construction site.

Subjective evaluation is generally based on questionnaires and is probably more suitable. The Swedish Occupational Fatigue Inventory (SOFI) appears in most peer-reviewed academic publications that attempt to measure Fatigue in an occupational setting. In most studies, participants are asked to rate on the basis of five dimensions which it best describes their feelings at the specific moment. Feelings of being tired are graded from 0 (no feelings at all) to 6 (high feelings to a very high degree) (Ahsberg et al. 1997). How the level of Fatigue quantified by SOFI is related to LOP is unknown and requires more studies in the future. See Table 7.3 (adapted from Hallowell 2010).

Table 7.3: SOFI Provided Categories to Quantify Fatigue

SOFI category	Scale (0~6)
Lack of Energy	
Worn out	
Spent	
Drained	
Overworked	
Physical exertion	
Palpitations	
Sweaty	
Out of breath	
Breathing heavily	
Physical discomfort	
Tense muscles	
Numbness	
Stiff joint	
Aching	
Lack of motivation	
Lack of concern	
Passive	
Indifferent	
Uninterested	
Sleepiness	
Falling asleep	
Drowsy	
Yawning	
Sleep	

7.5.5 Site Access

Site Access is a vague concept. It can either be complete blocked site (which will probably result in a work delay and cause other problems) or partially blocked site (which cause extra time to move the labor or materials). No academic studies were found to quantify the LOP caused by Site Access. The likely explanation is that it is difficult to quantify and standardize site logistic descriptions.

In the LOP cases we found, Site Access problems generally occurred when the access is blocked so that the contractor encountered a delay in work. However, no cases were found regarding the quantification of the loss.

Accordingly there is insufficient evidence to either support or oppose the MCAA provided percentages (5% to 30%). More research is needed regarding this topic.

7.5.6 Logistics

Similar to Site Access, Logistics is a general problem that needs further research.

When the Logistics problem represents the situations that the owner furnished materials or equipment is delayed, it serve as a root cause for delay. We suggest using other Factors to calculate the loss (such as Weather, Learning Curve, etc.).

In Thomas et al. (1989), the authors estimated a LOP due to Logistics for their project (18% overrun) and believed this percentage can serve as an order-of-magnitude assessment for other single commercial construction project.

Two LOP case opinions contained the quantification loss information:

1) In *Appeal of Human Advancement Inc.*, the delay in obtaining an approval for heat tape after the government rejected the contractor's first substitute tape resulted in inefficiency and the Board allowed a 20% loss using jury verdict.

2) In Appeal of Algernon-Blair incorporated, the plaintiff claimed that late arrival of the equipment and delays in receiving relocation instruction caused a 30% LOP and 8% was finally allowed.

It is noteworthy that the percentage allowed will largely depend on the physical onsite characteristics.

In a related case a contractor was awarded extra handling and storage costs using relevant invoice and payroll information (*Appeal of Fruehauf Corporation*).

7.6 Summary

Regarding the quantification of LOP, we draw the following conclusions:

1) For Weather, available published data were studied and we present a new regression model based on temperature and humidity versus labor productivity. Instead of determining the loss based on three single severity level points, we suggest developing estimates of LOP based on our temperature and humidity formula.

2) For Learning Curve, we found that the Learning Curve models need to be used with caution. It can only be used on repetitive work. We suggest using unit data or moving average data and select the model based on prediction performance.

3) For Overtime, the multipliers provided by previous researchers and institutes have been widely accepted by the industry. We suggest making estimate based on the overtime type (for example, 6 days per week with 9 hours per day).

4) For Crew Size Inefficiency, the published models need to be used with caution. But we believe the studies can be referred to calculate LOP based on overstaffing percentage or space per person.

5) For Dilution of Supervision, the amounts awarded by courts have mostly been smaller than 10%, and the allowed amount should not exceed the cost to bring in extra supervisors.

6) For Errors and Omissions, the contractor should recognize that most projects have some inherent errors and omissions, and the contractor should only pursue an amount that is greater than that typical amount. According to previous studies, the error rate for the typical project is between 1% to 4%.

7) For Fatigue, we suggest use of the Swedish Occupational Fatigue Inventory (SOFI) to measure Fatigue levels.

Chapter 8. Summary of Proposed Improvements

This chapter summarizes the previous chapters' application and structural suggestions for using the MCAA Method in a LOP claim. Section 8.1 summarizes the definitions and quantification methods studied in this research. Section 8.2 proposes procedures for contractors to use the revised MCAA Factor list.

8.1 Revised MCAA Factor List

A revised MCAA Factor list is shown in Table 8.1. This table contains updated Factor definitions, reasons why those Factors may possibly affect labor productivity and the sections discussing quantification of its effect on productivity.

Table 8.1: Proposed MCAA Factor List and Quantification Suggestions

MCAA Original Definitions	Proposed Improvements on the Definition			MCAA Original Quantification Value			Proposed Quantification
	Definition	Effect on Productivity	Other Remarks	Minor	Average	Severe	
F1 STACKING OF TRADES: Operations take place within physically limited space with other contractors. Results in congestion of personnel, inability to locate tools conveniently, increased loss of tools, additional safety hazards, and increased visitors. Optimum crew size cannot be utilized.	STACKING OF TRADES: Stacking of several trades (the contractor's own work force or with those of other contractors) in the same working area, or work to be performed while facility occupied by other trades; Not anticipated in original bid.	1) Extra work or procedures needed when working with or right after other trades; 2) Site access and logistics problem: limited site access due to storage of materials /fixtures /equipment; inability to locate tools conveniently; or another trade leaves the work incomplete, preventing the contractor from doing his own work; and 3) Congestion of personnel: more people working in the same area causing extra movement of people, physical conflict, constraints and extra standby time.	Related to Beneficial Occupancy, Crew Size Inefficiency, Site Access, and Logistics.	10%	20%	30%	See Figure 7.8.
MORALE AND ATTITUDE: Excessive hazard, competition for overtime, over-inspection, multiple contract changes and rework, disruption of labor rhythm and scheduling, poor site conditions, etc.	MORALE AND ATTITUDE: Lower level of labor motivation and enthusiasm for achieving project objectives.	Lower work speed and extra errors and corrections.	Use is not recommended. Boards and courts have generally not accepted. Lower morale can be caused by most other MCAA Factors and is closely related to the contractor's management. Hard to establish liability and causation for low	5%	15%	30%	Granted amounts in previous cases are small, typically 5%.

			morale.				
REASSIGNMENT OF MANPOWER: Loss occurs with move-on, move-off men because of unexpected changes, excessive changes, or demand to expedite or reschedule completion of certain work phases. Preparation not possible for orderly change.	REASSIGNMENT OF MANPOWER: Transferring workers from one task to another due to blockages to current work. Workers need to jump frequently to other works and work on a stop-and-start basis.	Time spent on extra movement.	Related to out-of-sequence work and Learning Curve.	5%	10%	15%	Related to Learning Curve. Productivity level can be calculated based on number of unit using Learning Curve model in Section 7.2.
CREW SIZE INEFFICIENCY: Additional workers to existing crews "breaks up" original team effort, affects labor rhythm. Also applies to basic contract hours.	CREW SIZE INEFFICIENCY: Adding more manpower to existing construction work.	1) Congestion of personnel: physical conflict and high density of labor; 2) Dilution of Supervision; and 3) Logistics problem such as material, tool and equipment shortage.	Related to Stacking of Trades, Dilution of Supervision, and Logistics.	10%	20%	30%	LOP can be calculated through overstaffing level (see Figure 7.7); or crowding level. See Figure 7.8.
CONCURRENT OPERATIONS: Stacking of this contractor's own force. Effect of adding operation to an already planned sequence of operations. Unless gradual and controlled implementation of additional operations is made, Factor will apply to all remaining and proposed contract hours.	Suggest this Factor to be combined with Stacking of Trade.			5%	15%	25%	Suggest be combined with Stacking of Trade.
DILUTION OF SUPERVISION: Applies to both basic contract and proposed change. Supervision must be diverted to (a) analyze and	DILUTION OF SUPERVISION: Refers to the situation that the supervisor(s) spending less time overseeing work; or a lower	1) Extra Errors and Omissions due to lack of supervision; 2) Lower work speed of workers; and 3) Additional standby	Related to out-of-sequence work and Crew Size Inefficiency.	10%	15%	25%	When recognized, typical awards are less than 10%. Reimbursed amount should be smaller than the cost of adding more

plan change, (b) stop and replan affected work, c) take-off, order and expedite material and equipment, (d) incorporate change into schedule, (e) instruct foreman and journeyman, (f) supervise work in progress, and (g) revise punch lists, testing and start-up requirements.	supervisor-labor ratio.	time to waiting for supervisors to answer questions and solve problems.					supervisors.
LEARNING CURVE: Period of orientation in order to become familiar with changed condition. If new men are added to project, effects more severe as they learn tool locations, work procedures, etc. Turnover of crew.	LEARNING CURVE: Loss of learning due to disruptions, time and cost to familiarize with the work and work site, extra training cost, mobilization, and demobilization cost.	1) Lower work speed during learning period to become familiar with work and work environment; 2) Extra training cost; and 3) Extra mobilization and demobilization cost.	Related to Reassignment of Manpower.	5%	15%	30%	Productivity level can be calculated based on number of unit. See Eq. 7.4, 7.5 in Section 7.2.
ERRORS AND OMISSIONS: Increases in errors and omissions because changes usually performed on crash basis, out-of-sequence, or cause Dilution of Supervision or any other negative Factors.	ERRORS AND OMISSIONS: Increase in worker's work errors and omissions due to disruptions.	Extra correction work, including rework and cleanup.	Not recommended. Extra errors can be caused by many other MCAA Factors.	1%	3%	6%	No previous studies on LOP quantification were found. In general amount claimable is extra error in excess of 1-4%. See Section 7.5.
BENEFICIAL OCCUPANCY: Working over, around, or in close proximity to owner's personnel or production equipment. Also badging, noise limitations, dust, and special safety requirements and access restrictions because of owner. Using	BENEFICIAL OCCUPANCY: Working over, around, or in close proximity to the owner or owner-created obstacles.	1) Site access problems; 2) Out-of-sequence work; 3) Logistical problems: including storage and protection of materials; and 4) Badging, noise limitations, dust, and special safety requirements.	Related to Stacking of Trades, Site Access, and Logistics.	15%	25%	40%	Congestion can be calculated through crowding level. See Figure 7.8.

premises by owner prior to contract completion.							
JOINT OCCUPANCY: Change cause work to be performed while facility occupied by other trades and not anticipated under original bid.	Suggest this Factor be combined with Stacking of Trades.			5%	12%	20%	Suggest this Factor to be combined with Stacking of Trade.
SITE ACCESS: Interference with convenient access to work areas, poor man-lift management, or large and congested worksite.	SITE ACCESS: Site partially restricted by the material or personnel onsite, or the site is not accessible so that the work is delayed.	1) Extra effort to get site access; 2) Extra movement of labor or equipment; and 3) Extra work such as cleaning up.	Related to Logistics.	5%	12%	30%	No previous studies were found. Highly dependent on project situations.
LOGISTICS: Owner furnished materials and problems of dealing with his storehouse people, no control over material flow to work areas. Also contract changes causing problems of procurement and delivery of materials and rehandling of substituted materials and rehandling of substituted materials at site.	LOGISTICS: 1) Problems with owner furnished materials; or 2) Other logistic problems caused by owner's change of materials or work schedule	1) Extra work for logistics coordination, materials movement and rehandling; 2) Storage cost: storage cost when no storage space; and 3) Standby time to wait for materials.	Logistics problem can be caused by many other MCAA Factors, it need to be used with caution.	10%	25%	50%	Cases and studies found have LOP percentage due to Logistics as much as 20%. Highly dependent on project characteristics.
FATIGUE: Unusual physical exertion. If on change order work and men return to base contract work, effects also affect performance on base contract.	FATIGUE: the worker's unusual physical conditions including lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness.	1) Lower work speed; and 2) Extra errors and omissions.	Use not recommended. Related to Weather and Overtime, hard to establish liability and causation. Low morale can be caused by Fatigue as well.	8%	10%	12%	Questionnaires have been used in other industries to determine Fatigue level. See Table 7.3.

RIPPLE: Changes in other trades' work affecting our work such as alteration of our schedule. A solution is to request, at first job meeting, that all change notices/bulletins be sent to our Contract Manger.	Suggest this Factor not be used in a LOP claim.			10%	15%	20%	Suggest this Factor not be used in a LOP claim. Details regarding causation required.
OVERTIME: Lowers work output and efficiency through physical fatigue and poor mental attitude.	OVERTIME: Work more than forty hours per week, extended workdays, extended workweeks, night and weekend work.	1) Lower work speed and extra errors and omissions; and 2) Logistics problem.	Related to Fatigue, and Morale and Attitude.	10%	15%	20%	See multipliers listed in Figure 7.5 and Figure 7.6.
SEASON AND WEATHER CHANGE: Either very hot or very cold weather.	SEASON AND WEATHER CHANGE: Unexpected severe weather, work pushed into inferior work time or unexpected work environment change (such as lack of windows in winter). Possible problems include winter work, rain and snow, hot weather, wind and sun exposure, etc.	1) Impact to physiological conditions, lower work speed and extra errors; 2) Logistical and site access problem; and 3) Extra work such as cleanup.	Related to Fatigue, Logistics, and Site Access.	10%	20%	30%	See Eq. 7.3 and Figure 7.4.

8.2 Suggested Procedures for Use of the MCAA Method in a LOP Claim

The MCAA's success rate in LOP claims is uneven in large part because there are no reliable guidelines (Ibbs and Vaughn 2015). This section proposes procedures for use of the MCAA Method in a LOP claim. Hopefully this can be a starting point to use the MCAA Method in a more consistent and transparent way.

In general, use of the MCAA Method is suggested to be a four step process: 1) list all the possible Factors that apply, 2) establish causation and liability, explain the relationship between Factors, 3) select Factors and determine who are affected and for how long, and 4) calculate LOP. Those procedures are explained in the following sections.

8.2.1 Step 1: List All Possible Factors that Apply

The first step is to use the definitions provided in Table 8.1 and identify the Factors that occurred in the contractor's project.

8.2.2 Step 2: Establish Causation and Liability

The second step is to establish causation and liability based on the Factors listed in Step 1, That is, to determine who should be responsible for the problems and how those Factors cause a productivity loss. The contractor can look at the Factor's possible cause-and-effect in Chapter 5 and consider its own situations. A causation map (or other causal visualization tool) is suggested to help clearly show the relationship between Factors. It is suggested that development of the causation map started with responsible party and root reasons, and ends with ultimate Factors that are directly related to the loss; see Section 5.3.

See Figure 8.1 for an example of a causation map.

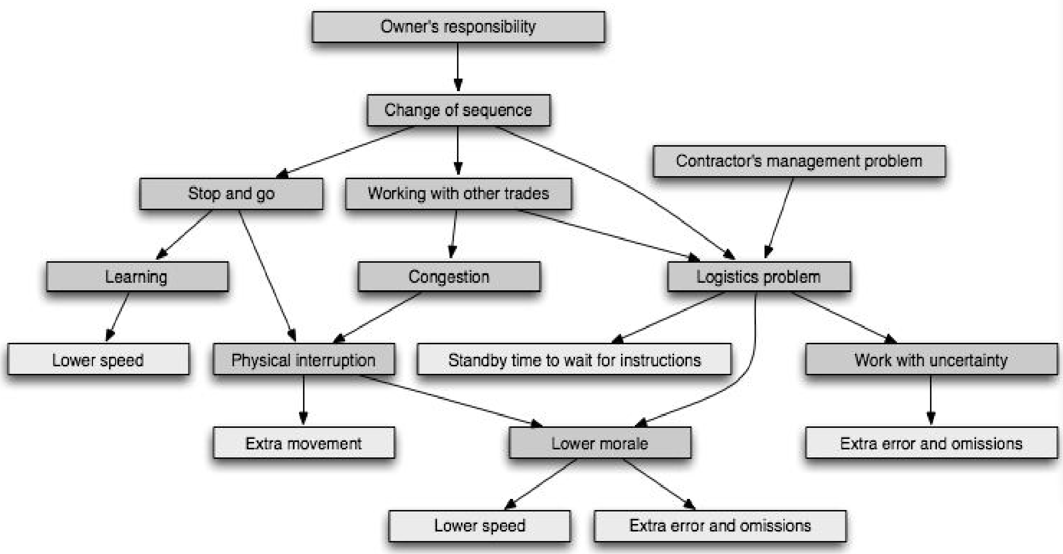

Figure 8.1: Example of a Causation Map

It is concluded in Chapter 4 that contractors need to establish causation for **EACH** Factor used in a MCAA Method. In this causation map above, every causal link starts with a party's responsibility and ends with ultimate reasons that directly cause a LOP and cost.

A causation map can clearly show what kind of problem is caused by the changes, who should be responsible for that problem, and how that problem causes a loss.

8.2.3 Step 3: Select Factors

The third step is to select suitable Factors, and find out who (which crew) has been affected by those Factors and for how long.

For Factor selection, we recommend, as explained in Chapter 4, that fewer Factors should be used rather than more. Avoid choosing overlapping Factors.

In the example of Figure 8.1, for instance, if we choose both Reassignment of Manpower and Learning Curve, we may double-count the effect since Reassignment of Manpower may cause a loss mainly because of Learning Curve interruption.

In addition, we should choose Factors that are closer in terms of causal link to owner actions and more definitive, and avoid vague Factors and vague assertions about causal linkages. For example, in Figure 8.1, we might focus on Reassignment of Manpower, Stacking of Trades (working with other trades), and Logistics. See Table 8.2 for an example of Factors selected.

Table 8.2: Selected Factor List Example

Involved Factors	Crews affected	Time period
Reassignment of Manpower	3 mechanical workers	Feb. 1, 2016 – Feb. 29.2016
Stacking of Trades	6 mechanical workers	Jan. 1, 2016 – Mar. 31, 2016
Logistics problems (owner responsible for 30%)	6 mechanical workers	Jan. 1, 2016 – Mar. 31, 2016

8.2.4 Step 4: Quantify LOP

The final step is to calculate the affected labor hours and loss according to Factors selected and materials. The affected labor hours can be calculated through Table 8.2.

Quantification of each Factor's impact can be based on available materials such as payroll and daily log, and interviews on workers and supervisors. Experts' opinions are very valuable for quantification of LOP. Previous academic studies and industry work (listed in Table 8.1) can also be used as a starting point, as well as complementary materials.

Chapter 9. Conclusions and Future Research

This chapter summarizes the findings and contributions of this research. It also discusses limitations of this work and gives recommendations to future researchers.

9.1 Conclusions

The MCAA Method has been used many times during the past twenty years. However, the success rate for contractors has generally declined in recent times. Based on the MCAA cases we found, prior to 2000, the model was successfully used in five of five published cases; since 2001 it has been successful in only two of nine cases.

One possible explanation for this trend is that Boards and Courts have recently imposed a more stringent standard for proving LOP claims, requiring proof of either the actual cost or use of the measured mile technique. Despite these defense objections, no Board or Court has overtly cited any of these arguments as a basis for rejecting a MCAA-based claim. That is, the inherent nature of the model has not been questioned by them. Rather, the overwhelming reason for MCAA-based claim rejection is contractor failure to prove causation as discussed in a following section.

Regarding the application of the MCAA Method, we first found the following when using the MCAA Method:

1) Successful claims use fewer Factors rather than more Factors. Based on the cases we found, successful claims used four Factors while unsuccessful claims used nine. It is also observed that some Factors are more successful than others. Trade Stacking, Site Access, and Overtime have the highest success rate (aside from Weather, which was only cited in one case); Overtime and Weather have not been used as frequently; Errors and Omissions has been used and rejected four times, and Fatigue has never been used; Joint Occupancy, Ripple, and Logistics have been rarely used in these published decisions.

2) Establish causation for **<u>EACH</u>** Factor. The contractor were required to explain clearly when, where, who, and how productivity was affected. Evidence that may help support a causation argument can come from project documents, witness interviews, and expert opinions. Failure to provide detailed explanations can doom a claim. In *Sauer*, as an example, the Board rejected the LOP claim explaining that there was too little evidence on how and why productivity was lost. It also volunteered that the claim would have been strengthened by using an expert to conduct the analysis; and

3) Blindly relying on the LOP damage percentages contained in the MCAA manual is not a good strategy. Those percentages were developed by surveying contractors who had a vested interest in assigning larger percentages to these Factors. Moreover, there are no

definitions for the three severity levels suggested and some of the Factor definitions are ambiguous. Two different people applying the MCAA Method to the same disrupted project could arrive at very different LOP percentages because of this lack of definition.

Then secondly, we investigated the structure of the existing MCAA Method based on the existing academic studies regarding Loss of Productivity and propose improvement based on the findings.

We found that a causal map can help to establish causation and liability. This report reviews the existing cause-effect visualization tools. Long's casual matrix was designed for LOP claims. Based on this matrix and the three elements a contractor needs to establish in a LOP claim (causation, liability and damage), we suggest carefully organizing the structure of a causal map and include the responsible party, primary reasons, intermediate productivity loss reasons, and ultimate reasons.

In addition, this report reviews the LOP related cases and discusses the definition of each MCAA Factor, how they hinder labor productivity, and their previous use before boards and courts.

This report discusses quantification of LOP impact for each Factor as well:

1) For Weather, available published data were studied and we developed a regression model based on temperature and humidity versus labor productivity. Instead of determining the loss based on three individual severity level data points, we recommend use of the temperature and humidity equation we developed.

2) For Learning Curve, we found that the Learning Curve models need to be used with caution. It can only be used on repetitive work. We suggest using unit data or moving average data and selecting the model based on prediction performance.

3) For Overtime, the multipliers provided by previous researchers and institutes have been widely accepted by the industry. We suggest making estimate based on the overtime type (for example, 6 days per week with 9 hours per day).

4) For Crew Size Inefficiency, the published models need to be used with caution. But we believe the studies can be referred to calculate LOP based on overstaffing percentage or space per person.

5) For Dilution of Supervision, the amounts awarded by courts have mostly been smaller than 10%, and the allowed amount should not exceed the cost to bring in extra supervisors.

6) For Errors and Omissions, the contractor should recognize that most projects have some inherent errors and omissions, and the contractor should only pursue an amount that is greater than that typical amount. According to previous studies, the error rate for the typical project is between 1% to 4%.

7) For Fatigue, we suggest to use Swedish Occupational Fatigue Inventory (SOFI) to measure Fatigue levels.

Finally, this report proposes procedures and guidelines to use the MCAA Method in a LOP claim: 1) compare the project situations with the MCAA Factor definition and list all the Factors that apply; 2) organize the relationship between Factors and establish causation with a cause-effect map; 3) select Factors and explain who was affected and for how long; and 4) estimate the loss according to labor hours calculated through Step 3.

9.2 Contributions

This report proposes application and structural improvements for using the MCAA Method to quantify productivity loss in construction claims. It organizes the Factor structure, refines the definition of the Factors, and analyzes possible reasons why each Factor may cause productivity. It also reviews existing LOP quantification models for each Factor, normalizes their data, compares their models based on normalized data, and tests their credibility.

This report develops procedures to standardize the use of this revised method to reduce the inherent subjectivity. One step in this standardization procedure is use of causation maps. A causal map is a visualization tool used by many previous academic researchers to explain the cause-effect relationship between change and productivity loss. We found no evidence that it has ever been used with the MCAA Method in a LOP claim. This report reviews and compares the existing causal maps technique and makes suggestions on properly using it in an MCAA claim based on study of previous cases. We also suggest criteria to choose proper Factors. In addition, a table to clearly show the affected people and time period for each Factor is recommended.

Another step in this standardization process is use of reliable studies or LOP data (rather than surveyed opinions of MCAA contractors). This report collects and evaluates available studies and legal opinions in previous construction claims. These can be referred to when contractors attempt to demonstrate their problems and make their claims. Individual summaries and critiques are important parts of this report since such information will help contractors to determine whether this method is appropriate and how reliable those studies are.

9.3 Limitations and Future Research

This research is based on the assumption that the philosophy of MCAA Factor Method is acceptable and that it can be improved to a more acceptable level. The assumption is supported by the fact that MCAA has been successfully used before Courts and Boards several times. Future research can further examine the reliability of this assumption by applying the ideas provided in this report to a real case.

This study did not intend to collect productivity data and develop new models. Instead it integrated previous studies and quantification models. Those previous studies on Factor effects on productivity are limited to Weather, Learning Curve, Overtime, and overstaffing. Many other Factors such as Dilution of Supervision, Reassignment of Manpower, and Stacking of Trades have been recognized and admitted by Boards and Courts, but there is little credible research regarding those Factors. Those Factors' effects on productivity remain unverified and deserve detailed, scientific study.

Currently productivity data collection is generally erotic and unsophisticated. The correlation of different Factors and the use of other advanced models to parse the effects multiple factors have on productivity need further study.

Finally, some new technologies are under research. Automated project progress tracking includes Wireless Real-time Productivity Measurement System to provide pictorial data via a wireless network to the construction field office (Su and Liu, 2007) and 3D site laser scans to capture comprehensive and detailed 3D as-built information and link it to a 3D Building Information Modeling (BIM) system (Bosche et.al, 2009). Future adaptation of these new technologies will provide detailed productivity information for future estimate and research.

Based on such advances in data collection and analysis technology, each Factor's impact and the interplay between those Factors will be more clearly understood over time.

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Appendices

Appendix A: Cases Reviewed and Cited

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Appendix C: Original Data of G&W[66]

	Temperature (°F)													
Relative Humidity (%)	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100
90-95						39 (4)	42 (2)	36 (1)	35 (11)	42 (3)				
85-90			22 (1)	25 (1)	18 (1)	33 (1)	36 (2)	36 (1)	40 (11)	40 (10)				
80-85					32 (6)	36 (7)		36 (1)	42 (8)	41 (9)	57 (2)			
75-80				34 (1)			52 (2)		37 (2)	37 (6)	37 (1)			
70-75					35 (3)		50 (3)	39 (3)	45 (1)	55 (4)	47 (9)			
65-70						24 (1)		45 (1)		53 (7)	41 (7)	45 (1)		
60-65				36 (1)	47 (1)		45 (1)	46 (1)	47 (3)	48 (2)	45 (13)	39 (3)		
55-60	30 (1)				36 (4)				51 (4)	25 (2)	48 (5)	37 (8)		
50-55	22 (1)					30 (2)			55 (6)	35 (1)		38 (12)	35 (6)	
45-50			38 (4)	40 (2)		47 (4)	40 (2)	48 (1)		50 (9)	53 (5)	38 (5)	37 (10)	33 (2)
40-45				31 (2)			39 (3)				44 (2)		34 (1)	
35-40							37 (3)							
30-35							35 (1)	35 (2)	59 (1)					
25-30							29 (4)	35 (5)	51 (2)					

Note:
(6) – Number of Data Used to Calculate Average
45 – Average Hourly Productivity (2 Masons, Square Feet per Hour)

66 From (Johnson 1972).

Appendix D: Original Data of T&Y

Data Point	Calendar	Activity	Performance Ratio	Temperature (°F)	Relative Humidity (%)
1	February 05	Steel	0.79	41.3	71
2	February 06	Steel	0.65	33.1	59
3	February 10	Steel	0.80	27.9	67
4	February 11	Steel	1.95	28.8	73
5	February 12	Steel	0.64	28.5	59
6	February 13	Steel	1.01	24.1	64
7	February 14	Steel	1.33	17.0	60
8	February 20	Steel	0.94	37.0	75
9	February 24	Steel	0.77	32.3	56
10	February 25	Steel	1.49	26.6	40
11	February 26	Steel	0.62	30.2	54
12	February 27	Steel	1.94	27.3	59
13	February 28	Steel	0.81	29.5	54
14	March 03	Steel	1.18	37.7	44
15	March 04	Steel	5.13	20.3	85
16	March 05	Steel	0.62	38.5	70
17	March 06	Steel	1.34	30.8	80
18	March 07	Steel	4.30	11.6	47
19	March 10	Steel	2.40	52.0	40
20	March 11	Steel	3.25	36.4	63
21	March 12	Steel	3.30	36.5	60
22	March 13	Steel	1.56	37.0	81
23	March 14	Steel	1.55	40.8	83
24	March 17	Steel	2.27	37.3	58
25	March 18	Steel	1.56	45.0	49
26	April 03	Masonry	0.58	50.3	32
27	April 04	Masonry	0.62	58.8	55
28	April 07	Masonry	0.72	54.7	55
29	April 10	Masonry	0.86	59.0	30
30	April 11	Masonry	1.25	40.1	53
31	April 12	Masonry	1.02	36.1	51
32	April 13	Masonry	1.15	33.8	65
33	April 14	Masonry	1.02	57.7	30
34	April 17	Masonry	0.99	44.8	60
35	April 18	Masonry	1.22	64.4	35
36	April 22	Masonry	1.08	38.5	76
37	April 23	Masonry	1.05	41.1	42
38	April 24	Masonry	1.00	62.2	19
39	April 25	Masonry	0.93	68.9	20
40	April 28	Masonry	0.92	71.9	37
41	May 13	Masonry	0.88	62.0	38
42	May 14	Masonry	1.00	51.7	39
43	May 15	Masonry	0.94	56.2	46
44	April 09	Formwork	0.80	40.1	53
45	April 10	Formwork	0.82	36.1	51
46	April 11	Formwork	1.10	33.8	65
47	April 14	Formwork	1.25	57.7	30
48	April 15	Formwork	0.15	44.8	60
49	April 18	Formwork	0.82	64.4	35
50	April 21	Formwork	1.96	49.8	56
51	April 22	Formwork	0.94	38.5	76
52	April 23	Formwork	1.04	41.1	42
53	April 24	Formwork	1.02	62.2	19

54	April 25	Formwork	2.57	68.9	20
55	April 28	Formwork	0.76	71.9	37
56	April 29	Formwork	0.91	64.5	36
57	April 30	Formwork	1.20	73.1	19
58	May 01	Formwork	0.75	72.0	40
59	May 02	Formwork	1.34	37.1	55
60	May 05	Formwork	1.14	75.7	18
61	May 06	Formwork	1.01	78.7	36
62	May 07	Formwork	0.81	75.4	39
63	May 08	Formwork	0.60	72.1	26
64	May 09	Formwork	3.13	70.2	31
65	May 12	Formwork	0.47	67.1	34
66	May 13	Formwork	1.34	64.8	38
67	May 14	Formwork	0.56	53.4	59
68	May 15	Formwork	0.57	57.4	68
69	May 16	Formwork	0.41	77.5	38
70	May 19	Formwork	0.67	70.4	65
71	May 20	Formwork	1.10	67.8	55
72	May 21	Formwork	1.02	60.1	60
73	May 22	Formwork	0.60	60.5	47
74	May 23	Formwork	1.65	58.0	54
75	May 27	Formwork	1.05	62.9	61
76	May 28	Formwork	0.79	74.9	46
77	May 29	Formwork	1.25	82.1	32
78	May 30	Formwork	1.44	80.2	35