# WORKLOAD RATIO AS AN INDICATOR OF SCHEDULE ACCELERATION AND ITS RELATIONSHIP WITH LABOUR EFFICIENCY

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There has been no clear indicator to determine if a project has experienced schedule acceleration or not. Schedule acceleration occurs when a contractor is required to do a certain amount of work in shorter period of time than the normal experienced time or optimal time typical for the type and size of project in a given set of circumstance, or to do more works in a given time frame. From this fundamental aspect of schedule acceleration, the concept of *Workload Ratio* was developed. Workload Ratio can be considered as a measure to represent if the project schedule has been accelerated or not, and how much the project was accelerated. Workload can be understood as the amount of works a contractor or a subcontractor should perform in a certain period. By dividing actual weekly workload by planned weekly workload, Workload Ratio can be obtained, where Workload is defined as total man-hours divided by project duration in week. To determine the impact of Workload Ratio on construction labour efficiency, the relationship between Workload ratio and labour efficiency were quantified by analyzing 96 projects collected from sheet metal and mechanical contractors across the United States.

Keywords: efficiency, labour, schedule acceleration.

## INTRODUCTION

The construction industry is highly competitive and operates within a volatile market. Disputes often arise out of this environment. The dominant factor that seems to be prevalent in construction disputes is time. Tension between owners and contractors often escalates when the issue of time arises. Driving this tension is the fact that time inevitably equals money. Time savings can greatly improve profits, while a loss of time can lead to financial distress.

As a result, time conservation is a prime concern for both the owners and contractors on construction projects. If substantial loss of time is encountered during a project, late completion will become a significant issue. If a project is extended beyond the original completion date, the owner may lose business opportunities or income derived from the use of a facility. Simultaneously, to the extent to that the contractor is responsible for the delay, the contractor may be charged a penalty for late completion based on the liquidated damages clause in the contract. Therefore, timely

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Chang, C-K and Sullivan, K T (2006) Workload ratio as an indicator of schedule acceleration and its relationship with labour efficiency. *In:* Boyd, D (Ed) *Procs 22nd Annual ARCOM Conference,* 4-6 September 2006, Birmingham, UK, Association of Researchers in Construction Management, 21-27.

completion is one of the basic objectives of the construction project, along with cost and quality.

However, timely completion can often be accompanied by its own impacts. Frequently, the owner will require the contractor to complete a project in a less than normal time frame originally needed or will require additional work to be completed within the original time frame. Furthermore, unforeseeable circumstances outside the control of the contractor may cause a reduction of time available for completing the work. When these circumstances arise, the contractor is forced to speed up its work progress in order to accomplish a “timely” completion for the owner.

It may seem that schedule acceleration would be an effective solution for construction problems associated with time. Unfortunately, schedule acceleration negatively impacts the contractor’s labour efficiency. Furthermore, the occurrence of disputes and claims between owners and contractors arises when the labour efficiency of the contractor is impacted. Therefore, understanding how and why schedule accleration impacts labour efficiency is essential for improving labour efficiency, avoiding disputes, and maintaining sound financial status of one’s company.

Although many studies have been conducted on the issue of schedule acceleration, most of the studies deal with schedule acceleration as a trade-off between time and cost with the objective of minimizing cost escalation while achieving schedule acceleration. Many mathematical and optimization models have been developed as a means of calculating the required acceleration of individual activities on the project schedule. However, these methods are quite complex in nature and provide little practical use on the project site due to their complexity (Noyce and Hanna 1998). Relatively little effort has been made to determine the effects of schedule acceleration on labour efficiency.

In 1967, the so-called Mathews Curve was developed after evaluating a contractor’s claim arising out of a freeway construction project in Seattle (Heather 1989). The rationale behind the Mathews Curve is that if the work is either delayed or accelerated so that the contractor is required to perform substantially the same work in a different length of time, the cost will necessarily increase. In other words, if a project is delayed, accelerated, or disrupted, the amount of the delay or acceleration will also affect the unchanged work by an amount identified on the developed curve (Heater 1989). The model was empirically derived after studying industrial machinery, and assessing the life of the equipment. Horner and Talhouni (1995) analyzed previously published studies quantifying the effects of acceleration on productivity in order to see how the acceleration affected jobsite conditions and site operations. The jobsite factors affected by schedule acceleration included working hours, shift pattern, pay, absenteeism, size of labour force, congestion, source of labour, learning curve effect, quality, efficiency, and delay. Thomas (2000) analyzed how labour efficiency is affected by disruption of work flow caused by schedule acceleration. The study estimated productivity loss during a schedule acceleration from 250 weeks of data from 3 electrical projects which experienced schedule acceleration. It was found that inefficient work hours resulting from the uneven work flow, which is common during schedule acceleration, is estimated in the range of 20~45%. However, his finding is hard to be generalized due to small sample size.

Although several studies have been conducted on the issue of schedule acceleration, there has been no clear indicator to determine if a project has experienced schedule acceleration or not.

## OBJECTIVE OF STUDY

The prime objective of this study is to introduce workload ratio as an indicator of schedule acceleration. This paper also addresses how workload ratio impact labour efficiency and quantify its relationship with labour efficiency by analyzing real project data.

## WORKLOAD RATIO

**Workload ratio as an indicator of schedule acceleration**

Schedule acceleration occurs when a contractor is required to do a certain amount of work in shorter period of time than the normal experienced time or optimal time typical for the type and size of project in a given set of circumstance, or to do more works in a given time frame. From this fundamental aspect of schedule acceleration, the concept of workload ratio was developed. *Work Load Ratio* can be considered as a measure to represent if the project experienced schedule acceleration and how much the project was accelerated.

Workload can be understood as the amount of works which contractor or subcontractor should perform in a certain period. Workload is defined as total manhours divided by project duration in week. Estimated workload can be calculated as estimated total manhours divided by estimated project duration in weeks, and actual workload can be calculated by dividing actual total manhours and actual project duration in weeks to complete the project. By dividing actual workload by planned workload, workload ratio can be obtained. This ratio can be used as an indicator to judge whether the project accelerated or not, and if impacted, how much the project schedule was accelerated. As for the period in calculation of workload, since some contractors or subcontractors use different crew scheduling method such as 5-8 (8 hours per day and 5 days per week), 4-10 (4 days per week, 10 hours per day) , etc. Therefore, weekly workload will be more effective than daily or monthly workload in comparing projects in terms of schedule acceleration. Since workload ratio can consider all the following factors, estimated workload per week, actual workload per week, estimated manhour, actual manhour, project size, estimated project duration, actual project duration, whether time extension granted or not (and how much), average crew size, hours per week, workload ratio can avoid any bias caused by project size, work hours per week from different crew scheduling methods, the number of workers involved in the project, and whether time extension was granted or not.

$$\textbf{Workload Ratio} = \frac{\textbf{Actual Weekly Workload}}{\textbf{Estimated Weekly Workload}} \qquad (1)$$

Where

$$\textbf{Actual Weekly Workload} = \frac{\textbf{Actual Total Manhour}}{\textbf{Actual Project Duration in weeks}} \qquad (2)$$

$$\textbf{Estimated Weekly Workload} = \frac{\textbf{Estimated Total Manhour}}{\textbf{Estimated Project Duration in weeks}} \qquad (3)$$

**Interpretation of Workload ratio**

When the workload ratio is higher than 1, we can say the project schedule was compressed or the project was accelerated by any reason. Workload ratio of 1 represents the project was completed as scheduled, or enough time extension was granted for the increased work scope or changed work. Less than 1 of workload ratio indicates much time was granted than increased work scope, the project experienced time overrun, the project was delayed during implementation of the project, or the work scope was reduced while project duration remained as planned.

Some projects may experience both delay and acceleration during project implementation. For instance, a project manager found the project is delayed due to some reasons without any addition or deduction of work scope in the middle of project. During that period of delay, no manhour was spent. And then the project manager decided to accelerate the schedule to meet the project completion date. All estimated manhours were spent the rest of time in project duration. Finally, the project was completed on time with estimated manhour. (Actually, actual manhour may be more than estimated due to productivity loss caused by overtime, shift work or overmanning whatever the contractor used. Anyway suppose that the project was completed within estimated manhour). In this case, workload ratio for the whole project is meaningless. Instead, estimated workload and actual workload only for the period when the work was accelerated should be used to calculate the effect of schedule acceleration on labour productivity.

## QUANTIFICATION OF THE IMPACT OF WORKLOAD RATIO ON LABOUR EFFICIENCY

**How schedule acceleration affects labour efficiency**

Schedule acceleration can impact labour efficiency in various ways. First, schedule acceleration can alter the planned sequence of activities and flow of resources, including labour, materials, equipment, and subcontractors. Research shows that when the orderly plan of a project is impacted by schedule acceleration, labour productivity can be seriously affected (Peles 1977, Borcherding 1980, Marchman 1988, Long 1988, Haneiko and Henry 1991, Thomas 1997). Secondly, schedule acceleration often requires activities to be accomplished concurrently in a limited working space. Frequently, more workers will be added to achieve completion, and oftentimes the work area will not be able to accommodate the increased number of workers or activities. A high density of workers in a limited work space results in site congestion, and thereby causes a labour productivity loss (US Army Corp. of Engineers 1979, Peles 1977, Marchman 1988, Long 1988). Thirdly, as the number of on-site workers increases, it is critical that a corresponding increase be made to the supervisory staff, materials, tools, and equipment. If the proper increases are not made, labour productivity may decrease. It is widely accepted in the construction industry that a dilution of supervision and a shortage of materials, tools, and equipment may lead to a productivity loss. (Peles 1977, Thomas 1997). There are many additional ways that schedule acceleration can affect labour productivity that have not been mentioned.

**Data collection**

66 mechanical and 37 sheet metal projects were analyzed. The project data were gathered from contractors of various size and geographic location in the U.S. To avoid location bias, which could occur with the use of contractors from only a certain region of the country, data were solicited on projects from contractors with headquarters in 20 states, with the projects themselves being worked in 28 different states. The value of construction put-in-place per year by these companies ranged from $3.9 million to $ 170 million and these contractors worked a range of total manhours of direct labour (averaged over the last three years) from 9,690 manhours to 1,977,300 manhours. The

work entailed new construction (43%), addition or expansion construction (19%), renovation (19%), and combinations of these three (13%). Construction project types that compose the database are commercial (Banks, retail, office buildings, etc.: 12%), institutional (hospitals and correctional facilities: 35%), industrial (manufacturing or process plants, paper mills, wastewater treatment plants, etc.: 38%), manufacturing (line, factory, etc.: 6%), residential (multi-unit housing: 2%), and others (arenas, etc.: 8/%). The types of work performed on these projects are Heating, Ventilating, and Air-conditioning (HVAC: 43 %), plumbing (22 %), process piping (24%), fire protection (4 %), and others (7%).

**Efficiency loss**

Loss of Efficiency is defined as the difference between actual hours utilized from budgeted hours including approved manhours for change orders as a percent of actual total actual hours utilized. Lost Efficiency may result from a contractor's poor performance or the impact of productivity related factors such as overmanning, overtime, shift work, and work interruptions. The strength of this method is its representation of the direct effects, as well as the indirect effects, on efficiency since actual labour hours are calculated after the completion of project. To compare projects of varying size, Percent Lost Efficiency (%LostEff) is defined as given in Equation 4:

$$\%\ Lost\ Efficiency = \frac{Actual\ \ Total\ \ Manhours - (Estimated\ \ Total\ \ Manhours + Approved\ \ Change\ \ Order\ \ Hours)}{Actual\ \ Total\ \ Man\ hours} \quad (4)$$

**Predict variable: Workload ratio**

As shown in figure 1, the majority (68%) of projects in the dataset had workload ratio greater than 1, this means there was some kind of schedule acceleration during project. The average workload ratio of collected data was 1.38, and the maximum is 3.7. This means the contractor worked 3.7 times of workload than estimated workload in a given period, or did same amount of work in 3.7 times shorter than estimated duration.

**Relationship with labour efficiency**

It was found that as workload ratio increase, labour efficiency significantly decreased. This can explain how much schedule acceleration affects labour efficiency. Following equation (Equation 5) was developed from analysis of collected data. The $R^2$ of the equation is 44%. Considering that the collected data contains human aspects and only one factor was investigated, 44% for $R^2$is good enough to explain the relationship between workload ratio and efficiency loss.

***% Lost Labour Inefficiency = -0.194 + 0.239 * Workload Ratio*** (5)

The relationship between Work Load Ratio and labor efficiency loss is well shown in Figure 1. Lost efficiency due to schedule acceleration steeply increases up to 50% as workload ratio increases up to 3. From the figure 1, efficiency loss due to schedule acceleration can be easily obtained. For instance, if the workload is doubled as planned or the estimated duration is cut by half, workload ratio is 2, and the lost efficiency caused by schedule acceleration would be about 30%. Equation 5 provide more accurate amount of lost efficiency caused by schedule acceleration. By inserting workload ratio of 2 in the equation 5, we will get 31% as lost efficiency due to schedule acceleration.

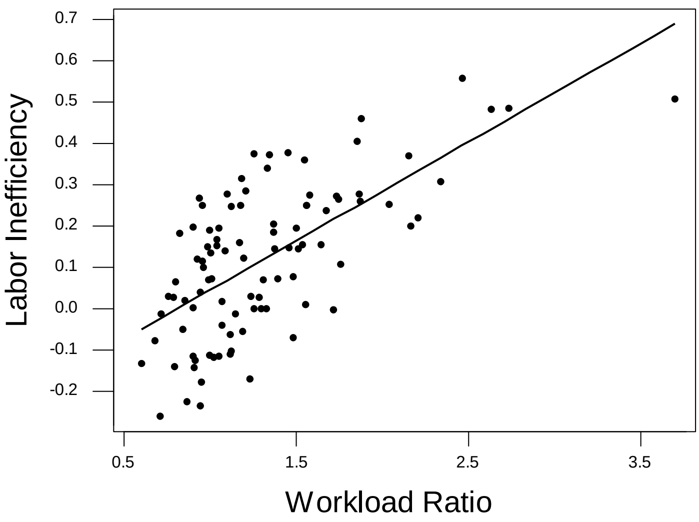


**Figure 1:** The Impact of Workload Ratio on Labour efficiency

**Table 1:** Analysis of Variance for Workload Ratio Regression Equation

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 1.3908 | 1.3908 | 74.25 | 0.000 |
| Residual Error | 94 | 1.7606 | 0.0187 | | |
| Total | 95 | 3.1514 | | | |

**Table 2:** Hypothesis Testing Result for Workload Ratio Model Predictor Variables

| Coefficient Tested | Null Hypo-thesis | Alternative Hypo-thesis | P-Value | Result |
|---|---|---|---|---|
| Workload Ratio | Equal to Zero | Not equal to Zero | 0.000 | Not equal to Zero |

**Scope of the model**

This study is limited to mechanical and sheet metal projects with lump sum contracts and a traditional project delivery system. Off-project costs may accrue when contractors are forced to reallocate resources from other projects to a project that is experiencing schedule acceleration. Further more, the commitment of schedule acceleration on a certain project will tie up important resource and hence limit the company's ability to undertake other work. Consequently, the loss of efficiency or even profit from a secondary project is not considered in the analysis of the losses of an impacted project under the Delta approach.

## CONCLUSION

Unfortunately, schedule acceleration is a common problem in the construction industry. Its implementation negatively impacts labour efficiency. Through this paper "workload ratio" was introduced as an indicator of schedule acceleration and its relationship with labour efficiency was quantified. The data analysis shows as workload ratio increases, labour efficiency decreases.

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