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A New Metric for Labor Productivity: Case Study of a Multi-Family Residential Project

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Abstract

The aim of this study is to present a labor productivity metric analysis with a case study. The objectives of this analysis include (1) to help project managers compare the project progress with labor productivity and take managerial actions quickly regarding the project performance; and (2) to fill the gap in the literature on case study-based labor productivity examinations of repeated construction units. In the first step of this research, a literature review was conducted on the productivity measurement of labor in the construction sector. After the literature review, the labor productivity metric was developed as a gap analysis that uses labor productivity to revise the schedule in project management and make quick decisions. A case study of a multi-family residential project involving multiple repetitiveprocesses was performed to identify challenges and lessons learned. According to the results of the case study, a delayed project was rescheduled using efficiency data. During the case study, interviews with experts involved in theproject were conducted, and relevant site reports were examined for data collection. The consensus of the experts is that the metric is useful and applicable. However, in order to increase the practicality of the metric, it is necessary to try it in more numbers, on a larger scale and in some specific projects, and to create a broad knowledge base.

Keywords

Worker Productivity, Case Study, Schedule Delay, Project Controls

1. Introduction

The construction sector contributes directly to the national economy. The sector fosters economic growth by increasing demand for the inputs that the industry needs to produce goods and services. The construction industry is a significant source of employment and a key driver of overall economic growth (Berk et al., 2017). Existing studies of the construction sector in developed countries have emphasized the industry's contribution to economic growth (Hillebrandt, 2000; Lean, 2001; Erol and Unal, 2015). Because of the construction industry's attractiveness to investors, competition is increasing, and as a result of being able to differentiate and stand out from competitors, today's projects can be carried out in larger scopes, with more complex structures, and using unconventional technologies. As a consequence, despite the construction industry's significant contributions to the economy, several studies show that the industry is frequently criticized for poor performance (Kagioglu et al., 2001; Bassioni et al., 2005; Durdyev et al., 2012; Barg et al., 2014; Hasan et al., 2018; Momade et al., 2021). Construction projects are labor-intensive (Shan et al., 2021). Internal and external variables such as socioeconomic culture, legal and environmental restrictions, improper management measures, extreme weather, excessive work hours, and transportation conditions all have a significant impact on the construction industry (Ghodrati et al., 2018; Durdyev et al., 2018; Tan et al., 2019). Worker performance and productivity are more difficult to measure than other sectors because they are dependent on so many factors.

2. Study Objectives

When the models for measuring construction project performance are examined, determining the factors and determining the impact of such factors requires intensive and long-term studies. In these intensive and time-consuming studies, while some factors can be expressed with measurable metrics, the values of some factors are collected subjectively through expert opinion. Considering that most of today's construction projects cannot be completed within the specified time, it is very important to quickly calculate the factors affecting the project performance and their impacts so that some remedial measures can be taken quickly while the projects continue. In those projects where use of a performance measurement model is not possible, a simple-to-use yet effective labor productivity metric will enable decision makers to take quick action in cases of lagging project performance.

Construction projects have many iterative processes, and all of these processes can be expressed as construction units. In other words, instead of separating a construction project into business activities or cost items, it is possible to divide it into repetitive processes, namely construction units. Studies on productivity calculations in the construction industry generally focus more on the use of materials and equipment to determine how efficiently a project uses its resources. And there are examples where work activities are handled individually, and efficiency is determined. However, in these studies, the use of manpower for the periodic completion amounts of the construction units and the determination of labor productivity are not studied in detail.

The aim of this study is to present a labor productivity metric analysis with a case study. The objectives of this analysis include (1) to help project managers compare the project progress with labor productivity and take managerial actions quickly regarding the project performance; and (2) to fill the gap in the literature on case study-based labor productivity examinations of repeated construction units. In the first step of this research, a literature review was conducted on the productivity measurement of labor in the construction sector. After the literature review, the labor productivity metric was developed to make quick decisions. A case study of a multi-family residential project involving multiple repetitive processes was performed to identify challenges and lessons learned. During the case study, interviews with experts involved in the project were conducted, and relevant site reports were examined for data collection. The focus group method was used to validate the case study results. The results of the interviews and document investigation were discussed with four experts. In focus group interviews, expert interviews were held and questions were asked about the applicability, usefulness, and practicality of the developed metric.

3. Literature Review on Labor Productivity

Low productivity in construction is most frequently accused of causing late delivery of the project and cost overruns (Lessing et al. 2017). As a result, productivity remains one of the most critical indicators for measuring and assessing the performance of a construction project (Shoar and Banaitis, 2019; Momade et al., 2021). Many studies have used different definitions of productivity. In general, productivity is the proportion of work completed by workers in a construction project (Griego and Leite, 2017) or the number of worker hours produced per unit of the finished product (Ibbs, 2012; Kazaz and Acıkara, 2015). There are many studies focusing on productivity in the construction industry (Park, 2006; Dolage and Chan, 2013; Fulford and Standing, 2014; Hasan et al., 2018; Kumar and Rana, 2021). When the available literature is examined, the topics of interest generally revolve around two concepts. The first one is the factors that affect productivity (Hasan et al., 2018), and the second one is measuring productivity or performance (Crawford and Vogl, 2006; Tekçe, 2010; Ilıcalı and Giritli, 2020). In addition to these, the available studies evaluated productivity at the industry level (Vogl and Abdel-Wahab, 2015), at the project level (Ayele and Fayek, 2019;Ilıcalı and Giritli, 2020; Park et al. 2005; Ellis and Lee 2006), at the firm level (Tekçe, 2010; Park et al. 2005; Ellisand Lee 2006), and at the activity level (Sonmez and Rowings, 1998; Tischer and Kuprenas, 2003; Zayed and Halpin,2005; Ayele and Fayek, 2019).

The majority of studies focusing on productivity in construction focused on factors affecting labor productivity (Jarkas and Bitar, 2012; El-Gohary and Aziz, 2014; Ghoddousi and Hosseini, 2012). The most popular method for measuring labor productivity is by measuring hourly outputs (Yi and Chan, 2014). Most researchers use labor hours to determine the completed work quantities (Thomas and Yiakoumis, 1987; Sonmez and Rowings, 1998; Hanna et al., 2008). This represents the actual work hours required to conduct the acceptable units of work. A lower productivityvalue represents greater productivity. Hourly output is broadly acknowledged as a reliable measure of productivity for construction operational activities.

The completed work quantities completed in the studies are generally evaluated in terms of concrete production (Yi and Chan, 2014), rebar production (Li et al., 2016), and similar specific work items. Dividing a project as a whole into meaningful segments and using the segments for efficiency measures is an often-undescribed process. However, measuring the labor productivity of a project is challenging. The performance of all work activities with a holistic approach is important for decision makers to make quick decisions. Labor productivity in construction is evaluated for comprehensive prediction and project scheduling by using labor hours as input and the produced quantities as output (Dozzi and AbouRizk, 1993). The S curves, which are often used in the construction industry to interpret financial values, can show the variable slope of the cost curve and the varying progress of work per unit of time (Chao and Chen, 2015). They can be used to interpret the results of labor performance metrics.

As a result, all construction projects, regardless of project type (e.g., residential, commercial, highway, etc.), necessitate an empirical method for tracking progress and effectiveness. The projects' success is determined by a number of factors, including cost, time, quality, health and safety, innovation, shareholder satisfaction, and environmental issues (Ilıcalı, 2020). The performance of field and management personnel, on the other hand, is regarded as one of the most important factors in the success of a project and/or an organization (Sherafat et al., 2013). Current performance measurement metrics can be used to measure employee productivity. However, these metrics should be applied to the calculated parts of the project as a whole, not to the specific work activities of the projects. In addition, the labor hours used in the metrics should be considered with modifications that will eliminate the time spent on construction sites other than performing work activities. Calculated labor productivity data can be interpretedquickly with the help of the S curve and can manage the actions of decision makers.

3. Application of Labor Productivity Metric

3. 1 Proposed Labor Productivity Metric

The type of construction is very important for determining the use of project performance metrics in construction projects. Vertical construction (architectural and other building-type projects) and horizontal construction (highways, railroads, bridges, etc.) are the two broad categories of construction projects (Runde and Sunayama, 1999). These two categories differ from each other in work schedule, payment procedures, and contract type. However, they can use similar performance measurement methods as they can be projects that include repeatable procedures. For example, work activities in a road project can be continued by repeating them for a certain distance (km). Either, in an apartment project with the same floor plan, the work activities determined for one floor might be repeated on the other floors. These iterative processes can be used to divide projects into logical units. This study focuses on construction projects that include large-scale repeatable processes. The case study in the study focuses on apartment complexes that have the same basic floor layout for large portions of the project.

To set a labor productivity measurement metric, the goal is to find out how many people are required in a progress payment period to generate one unit of progress value. In a payment period, it should be calculated how effectively manpower is used to achieve progress in the targeted unit. Therefore, two types of information need to be collected from the construction site. The first of these is how many units of work are produced in a specified payment period, and the other is how many people work for the completed work unit.

The first piece of information collected for efficiency analysis in construction projects is how many units of work are done on the site. For this purpose, the division of construction projects into logical units is very important in determining project efficiency. In order to determine the effect of worker productivity on the percentage of completion of the project in an apartment complex project, information on the completed project units is needed in each payment period (in general, the monthly progress payment is applied in construction projects). While determining the completion percentage, the ratio of the completed project units (for example, the structural work of the ground floor) to the total project units should be used. In this study, the term "unit metric" refers to the measurable units of the project that are included in the site reports or progress payment documents that are used to look at how efficient the project is.

Another piece of information collected for efficiency analysis in construction projects is how many resources are used for a unit of work. These resources are manpower, materials, equipment, and the resources for supporting processes such as testing and inspection. Since this study focuses on labor productivity, the concept of "manpower" is used to represent how many people work in the field for a unit of work. This information can be obtained from daily, weekly or monthly reports on the site. Using the direct average of on-site labor force data in productivity analysis can be misleading. It may be necessary to add an external factor in the calculations for the representation of non-working days at the construction sites in the productivity analysis. In order to use the exact time spent at the construction site in productivity analysis, "modifying the manpower" data in the field reports by considering the days without work will make the analysis error-free.

The metric proposed in this study is expressed by Formula (1): "LP" in the formula refers to labor intensity, "MP" refers to modified average manpower, "UN" refers to unit numbers, and "PC" refers to the percentage of complete. Having LP results close to 3 is considered a positive value for worker productivity. For this reason, the construction site's days off are taken into account when figuring out the average manpower. Modified manpower is used to avoid this problem.

$$LP = MP / (UN \times PC) \qquad (1)$$

Measuring labor productivity at the end of each payment period refers to periodic labor productivity. However, periodically, worker productivity depends on many factors such as project characteristics, firm financing, weather conditions, market conditions, etc., and productivity results can vary dramatically from period to period. For this reason, periodic productivity measurements can be misleading when evaluated for the total worker productivity of the project from a broader perspective. In addition, the decision makers need the average worker productivity information up to that period in order to delegate the resources for the next stages of the project and take the necessary actions. So, the results of the study are shown in terms of periodic labor productivity and average labor productivity.

A Case Study of and Multi-Family Residential Project

A multi-family residential project was chosen to use the proposed labor productivity metric and evaluate its results. The project consists of 216 repeating units. In general, the project consists of a 7-story residence and a 2-story precast concrete garage in South Florida, delivered in a lump-sum contract. The total cost of the project is $4.8 million. The number of the repeating units was determined according to the bedroom layout that spans one, two, and three-bedroom configurations. The first planned completion date for the project has been set for May 27 by the planning office.

Within the scope of the project, information about the work done and how many units were made was obtained from the subcontractors in the field, and this information was compiled with the productivity metric and conveyed to the field and management personnel. In the monthly coordination meetings, information about the progress of the project was shared with all stakeholders (main contractor, subcontractors, and consultant) along with the efficiency analysis (Table 1). In these meetings, labor productivity information at the time of realization of the activities on the critical path according to the work schedule was especially examined. These reviews use an S-curve to talk about monthly and average worker productivity and expectations for each month (Fig. 1).

The data from site reports is processed using the following parameters: The targeted unit number (TUN) is calculated by multiplying the targeted completion (TC) ratio by the project's unit. Similarly, the actual unit number (AUN) is calculated by the multiplication of the actual completion (AC) ratio and the unit of the project. Labor productivity is the result of dividing the modified manpower (MP) value by the actual unit number (AUN). Average labor productivity represents the mean productivity to date.

Table 1. Site reports data and calculated labor productivity

Months	TUN	TC	AUN	AC	MP	LP	ALP
September	0	0,00%	0,00	0,00%	2,43	NA	NA
October	0	0,00%	0,00	0,00%	2,13	NA	NA
November	1,08	0,50%	2,16	1,00%	1,47	0,6806	0,6806
December	2,16	1,00%	2,16	1,00%	1,55	0,7176	0,6991
January	2,16	1,00%	2,16	1,00%	5,42	2,5093	1,3025
February	6,48	3,00%	1,08	0,50%	10,1	9,3519	3,3148
March	12,96	6,00%	2,16	1,00%	15,82	7,3241	4,1167
April	17,28	8,00%	8,64	4,00%	26,32	3,0463	3,9383
May	19,44	9,00%	8,64	4,00%	38,89	4,5012	4,0187
June	21,6	10,00%	9,72	4,50%	43,65	4,4907	4,0777
July	21,6	10,00%	6,85	3,17%	48,93	7,1460	4,4186

August	20,52	9,50%	8,92	4,13%	52,24	5,8560	4,5623
September	17,28	8,00%	15,77	7,30%	55,42	3,5147	4,4671
October	15,12	7,00%	10,80	5,00%	64,55	5,9769	4,5929
November	12,96	6,00%	10,13	4,69%	51,94	5,1271	4,6340
December	12,96	6,00%	8,34	3,86%	45,86	5,5004	4,6959
January	10,8	5,00%	8,25	3,82%	48,29	5,8525	4,7730
February	8,64	4,00%	13,61	6,30%	65,08	4,7825	4,7736
March	6,48	3,00%					
April	4,32	2,00%					
May	2,16	1,00%					
Total	216	100,00%	119,38	55,27%			

TUN: Targeted Unit Number; TC: Targeted Completion According to Schedule; AUN: Actual Unit Number; AC: Actual Completion According to Site Reports; MP: Modified Manpower (Monthly); LP: Labor Productivity (Monthly); ALP: Average Labor Productivity.

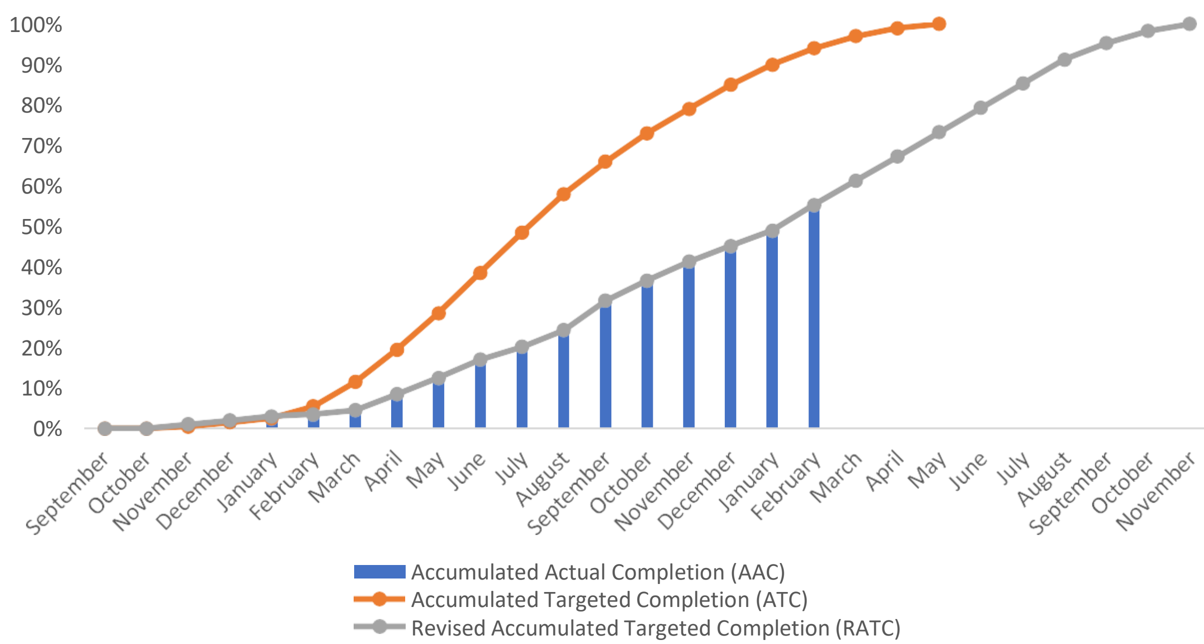

Fig. 1. S Curve for revised project schedule using the labor productivity

In the case study, field data from subcontractors was collected until March, and a worker productivity metric was calculated. The fact that the worker productivity metric values are quite high means that the actual productivity is low. As of February, the percentage of completed work is dramatically below the percentage of planned work. This is because, although construction has begun, the design is still ongoing and potential problems that arise are hampering field progress. The changes in the design and the inability to solve the incomprehensible issues on time prevented the project from reaching the targeted monthly amount of work. Although this provides a prediction that the project cannot be completed on time, it does not provide a clear idea of when the work can be finished. In addition to this, to avoid production delays, the manpower at the construction site has been gradually increased every month to keep up with the planned production and the project schedule. Thus, it aims to prevent delays by increasing production per unit time. However, since the contradictions related to the design and the design are still not completed and no problem can be solved with the increasing workforce, the worker productivity values could not be reduced and worker productivity could not be increased to the desired level. This has been interpreted as a wasteful use of resources and working hours by both the general contractor and subcontractors. It results in decreased worker productivity and profits for all parties. By using the worker productivity values, the amount of work remaining in the project was re-planned and the planned completion percentages were modified. According to the modified work schedule, the project is expected to be completed in November. The use of the worker productivity metric helped predict a delayed, albeit delayed, completion date for the project (Table 2).

Table 2. Revised project schedule using labor productivity metrics

Months	TC	ATC	RTC	RATC	AC	AAC
September	0,00%	0,00%			0,00%	0,00%
October	0,00%	0,00%			0,00%	0,00%
November	0,50%	0,50%			1,00%	1,00%
December	1,00%	1,50%			1,00%	2,00%
January	1,00%	2,50%			1,00%	3,00%
February	3,00%	5,50%			0,50%	3,50%
March	6,00%	11,50%			1,00%	4,50%
April	8,00%	19,50%			4,00%	8,50%
May	9,00%	28,50%			4,00%	12,50%
June	10,00%	38,50%			4,50%	17,00%
July	10,00%	48,50%			3,17%	20,17%
August	9,50%	58,00%			4,13%	24,30%
September	8,00%	66,00%			7,30%	31,60%
October	7,00%	73,00%			5,00%	36,60%
November	6,00%	79,00%			4,69%	41,29%
December	6,00%	85,00%			3,86%	45,15%
January	5,00%	90,00%			3,82%	48,97%
February	4,00%	94,00%			6,30%	55,27%
March	3,00%	97,00%	6,00%	61,27%		
April	2,00%	99,00%	6,00%	67,27%		
May	1,00%	100,00%	6,00%	73,27%		
June			6,00%	79,27%		
July			6,00%	85,27%		
August			4,00%	91,27%		

September	3,00%	95,27%
October	1,73%	98,27%
November		100,00%

TC: Targeted Completion According to Schedule; ATC: Accumulated Targeted Completion According to Schedule; RTC: Revised Targeted Completion According to Schedule; RATC: Revised Accumulated Targeted Completion According to Schedule; AC: Actual Completion According to Site Reports; ATC: Accumulated Actual Completion According to Site Reports.

Expert Opinion

The worker productivity metric and case study application were conveyed in focus group meetings held with the participation of four experts. The focus group meeting method evolved as a purposeful sampling strategy and a bridge strategy between scientific research and local knowledge (Cornwall & Jewkes, 1995). In participatory research, meetings are regarded as a "cost-effective" and "promising replacement" (Morgan, 1996), giving a basis for opposing concepts or ways of thinking (O. Nyumba et al., 2018). In these meetings, a questionnaire containing short, open-ended questions was given to the experts in order to understand the effectiveness, benefits, and limitations of the proposed labor productivity metric. Since some studies recommend more than or equal to four and less than or equal to fifteen participants (Fern, 1982; Mendes de Almeida, 1980), the minimum number of four participants was used in this study.

The first of the experts was a CEO with 30 years of experience in residential and commercial construction projects. This person is also an expert in using worker performance methods. Another expert interviewed was a construction director with 30 years of construction experience, mostly on large-scale residential and commercial projects, but with few actual uses of productivity tools. The given case study is selected from a complex project that includes more than one sub-construction project. For this reason, the first of the other two experts interviewed was the general superintendent of a complex project and had 35 years of professional experience. The other person was the senior superintendent of the construction project in the case study, who has worked in the field for 25 years. Expert evaluations were examined under the titles of usability, applicability and practicality. The effectiveness of the use of the metric in a case study according to current practices was evaluated.

Expert # 1 stated that the metric used and the case study were effective in understanding the progress of the projects and how the resources of this project would be used. It was stated that the experience gained from the case study could be used in the project development phase in the planning of future projects. While the usability and applicability of the relevant metric were found to be quite high, its practicality was evaluated at a relatively low level. The case study is thought to be incapable of providing specific data for specific project types. It was stated that the practicality of the worker productivity metric in the projects could be increased by conducting more case studies and including specific project types in these studies.

Expert # 2 stated that the metric and the case study allowed for a comprehensive review of construction management at a high level and that the usability was high. He noted that the metric used provides vital information to management personnel who are unable to visit the construction site on-site and personally analyze and judge it. The biggest obstacle to the effective implementation of the metric was interpreted as the fact that the company personnel using the metric did not understand how positive and beneficial it could be for the project.

Expert # 3 stated that the usefulness of the metric used in the case study was at a high level. He mentioned the potential of the labor productivity metric to become the main guideline for all workers in the field when delegating resources. Another positive use of the metric is that it will provide leverage to ensure that project subcontractors work diligently and effectively to help the project produce as much output as possible. He agreed with other experts that more data is needed to help figure out which subcontractors aren't producing well and quickly.

Expert #4 stated that the current situation, from the top management to the field personnel, is not well communicated according to which analysis and production are measured, and that the gap on this issue can be filled with the metric used. By giving workers information about how well or poorly they are doing on the project each month, it helps them keep morale high on the job site because they know that their work will still be done on time.

4. Conclusions and Recommendation

This paper provided a quantifiable labor productivity metric and a case study of a multi-house residential project. According to the results of the case study, a delayed project was rescheduled using efficiency data. In addition, the competencies of the workers in performing the project were provided to the project decision makers and enabled them to make inferences that could be used in future projects. The discussion of the metric and the case study was carried out with the experts working in the sector and on the project specified in the case study. The consensus of the experts is that the metric is useful and applicable. However, in order to increase the practicality of the metric, it is necessary to try it in more numbers, on a larger scale and in some specific projects, and to create a broad knowledge base. The obstacle to the applicability of the metric is the resistance of the field personnel to using the metric and their inability to transfer field data in a healthy way. The limitation of this study is that for the performance of the metric to be effective, the records from the field must be complete and accurate. For this reason, the operability of the metric should be effectively explained to field workers. In future studies, it is recommended to conduct more case studies on different types of projects and to manage these studies with defined processes by experienced construction professionals who use and learn the metric. In addition, the workload pressure factor can also be calculated if the activity standard for each construction unit is to be determined. This will assist with planning and scheduling.

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