Tools for Measuring Construction Materials Management Practices and Predicting Labor Productivity in Multistory Building Projects

Argaw Tarekegn Gurmu, Ph.D.[1]

Abstract: Planning, monitoring, and evaluating materials management practices are important for enhancing construction productivity. This study is designed to develop a tool for scoring materials management practices for building projects and, on that basis, build a tool for predicting productivity. The research was carried out in two phases. During Phase I, in-depth interviews were conducted with 19 experts and context-specific materials management practices were identified. During Phase II, questionnaires were used to collect quantitative data from 39 contractors. To prioritize the practices that were identified during Phase I, the quantitative data were analyzed. Based on the analysis, tools for measuring and planning the materials management practices and probability-based regression models were developed. Procurement plans for materials, long-lead materials identification, and materials delivery schedule are the three most significant practices. Contractors can use the scoring tool to measure the levels of implementation of the practices and assess the risk of having low productivity using the predictive models. This research contributes to the body of knowledge by developing construction materials management practices measuring, planning, monitoring, and evaluating tools in the context of building projects. In addition, the logistic and linear regression models can be used to assess whether a certain level of implementation of the construction materials management practice might be associated with higher or lower labor productivity. **DOI: 10.1061/(ASCE)CO.1943-7862.0001611.** © *2018 American Society of Civil Engineers.*

Author keywords: Labor productivity; Building construction projects; Materials management practices; Regression models.

Introduction

The construction industry makes a substantial contribution to the growth of an economy of a country. In 2015, the construction industry of Australia comprised about 8.29% of the gross value added (ABS 2016). However, the labor productivity growth in the construction industry is low as compared with other sectors. The Australian Productivity Commission (2015) report showed that the growth in labor productivity of the total economy in 2013/2014 was 1.4%. However, the construction industry's labor productivity was −1.0%. According to the Australian Productivity Commission (2013), labor productivity can be measured as an output per unit of labor input in *hours worked*. In this research, the output is the value of the completed building project (in AUD) and input is the project duration in days. Furthermore, *labor productivity* and *productivity* are used interchangeably, and multistory buildings refer to buildings having a rise in the story more than three.

A study conducted by the Australian Productivity Commission (2013) recommended that change in the management practices and the implementation of advanced technology can enhance productivity. Nonetheless, Rojas and Aramvareekul (2003) found that the adoption of the new technology could be useful but not adequate to improve productivity. The author suggested that management practice plays a vital role. Thus, this study focuses on the materials management practices that can improve the productivity of the building construction projects. Management practices that could increase productivity can be classified into preconstruction phase management practices, materials management practices, equipment management practices, management practices related to construction methods, safety and health practices, and human resource management practices (Nasir et al. 2015; Caldas et al. 2014; Gurmu and Aibinu 2017, 2018). In this research, materials management practices are studied because most of the building materials in the Victorian State of Australia are imported from other countries. Consequently, the absence of better construction materials management practices can considerably affect productivity.

To date, there is lack of a scoring tool that is used to measure, plan, monitor, and evaluate the implementation of construction materials management practices that enhance labor productivity of the building construction projects. Furthermore, no tool has been developed for predicting productivity based on the level of planning or implementation of the materials management practices. The scoring tool in conjunction with the prediction tools can help contractors to plan appropriate materials management practices that can be implemented during the construction of a certain building project. Therefore, the objectives of this research are as follows:

- To develop a scoring tool for measuring and planning the construction materials management practices.
- To develop a logistic regression model that can be used to predict productivity based on a score of the construction materials management practices.

Review of the Literature

Context of the Study

In the Victorian state of Australia, Construction, Forestry, Mining, and Energy Union (CFMEU) develops a calendar that can be used

[1]Lecturer in Construction Management, School of Architecture and Built Environment, Deakin Univ., Geelong, VIC 3220, Australia. ORCID: https://orcid.org/0000-0003-0750-4191. Email: argaw.gurmu@deakin.edu.au

Note. This manuscript was submitted on February 9, 2018; approved on August 20, 2018; published online on December 12, 2018. Discussion period open until May 12, 2019; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, © ASCE, ISSN 0733-9364.

in most construction sites (CFMEU 2016a). The minimum payments and working conditions can also be agreed between a contractor and the CFMEU. Under certain circumstances, the union also has the authority to suspend the construction works. The health and safety representatives can issue the provisional improvement notice to the contractor if there are unsafe working conditions, or they can suspend the construction work if there is an immediate threat to the workers (CFMEU 2016b). The Australian Fair Work Commission (2016) specifies ordinary working hours, minimum wages, and overtime rates during the construction of building projects. The ordinary working hours is 38 h/week, and it is between 7:00 a.m. and 6:00 p.m. Monday to Friday. According to the Commission, all the time worked beyond the ordinary working hours must be paid at the rate of one-and-half-time for the first 2 h and double time thereafter, and a minimum of 3 h should be considered for the payment purpose.

Project Evaluation Tools

Zavadskas et al. (2010) developed a risk assessment tool for construction projects. According to the authors, the assessment was based on the multiattribute decision, and the attributes were selected by considering the interests of stakeholders and factors influencing the construction process efficiency. Ngacho and Das (2014) prepared a multidimensional performance evaluation framework for development projects by considering various measures of performance. To demonstrate the applicability of the performance evaluation framework, the authors considered the case of Constituency Development Fund projects constructed between 2003 and 2011 in Kenya. Cao and Hoffman (2011) developed a project performance evaluation system using a case study approach. According to the authors, the project performance evaluation system would enable managers to audit a project and determine where improvements could be made. Tremblay and Badri (2018) built a tool for evaluating occupational health and safety performance in small- and medium-sized enterprises in Canada. Ali and Al Nsairat (2009) prepared a green building assessment tool for residential units in Jordan. The study reviewed international green building assessment tools such as Leadership in Energy and Environmental Design and defined new assessment items that consider the local conditions of Jordan. In this research, the tool for assessing the implementation of the construction materials management in the context of building projects is prepared based on the existing infrastructure and industrial projects' tools.

Prediction of Construction Labor Productivity Using Regression Models

Thomas and Sudhakumar (2014) developed multiple regression models to quantify the impact of the influential factors on masonry labor productivity. To develop the regression model, the study utilized quantitative data collected from two case study projects. The model identified excessive overtime and material delays as the major factors impacting productivity. Zayed and Halpin (2005) built and validated linear regression models that can be used to estimate productivity, cycle time, and cost during pile construction. Cottrell (2006) presented a regression model that relates job site productivity to process improvement initiatives such as design completeness, the definition of a project vision statement, testing oversight, and project manager experience and dedication. The model can be used to predict the expected value of labor productivity based on certain inputs related to preconstruction planning and construction execution. However, most of the construction materials management practices were not considered in the model.

Construction Materials Management Practices

Previous researchers mentioned that the practice *procurement plan for construction materials* can enhance labor productivity in construction projects. Arditi (1985) found that the use of construction materials procurement plan has the potential to improve construction productivity. Arditi and Mochtar (1996) concluded that the timely purchase of construction materials is vital for achieving maximum project efficiency. The survey carried out by the authors showed that the improvement of the materials procurement practices was given higher priority in enhancing productivity in Indonesia. According to Nasir (2013), materials procurement plan was found to be one of the best practices for increasing the productivity of infrastructure projects in the United States. Furthermore, Caldas et al. (2014) concluded that the use of materials procurement plan can improve the productivity of the industrial projects. Hence, the preparation and implementation of procurement plans for materials might increase the productivity of multistory building projects because the possibility of the project delay could be reduced.

The practice *long-lead materials identification* can enhance the productivity of the building construction projects (Gurmu 2018). Abdul Kadir et al. (2005) suggested that, to improve productivity, the project team needs to plan ahead to ensure the identification, procurement, and availability of the critical materials. Jergeas (2009) also recommended that the project team needs to check the presence of long-lead materials to increase the productivity of projects. The author explained that logistics and procurement plans for critical materials are important for increasing productivity. Nasir (2013) confirmed that identification of long-lead materials can increase the productivity of infrastructure construction projects.

Controlling the status of materials, assigning materials procurement team, and maintenance of the received materials can be some of the important practices that might increase the productivity of the building construction projects. Jergeas (2009) suggested that the dedicated follow-up of the procurement process of the construction materials is vital to enhance labor productivity. Nasir (2013) found that forming materials procurement team, tracking the quantity of the utilized materials, estimating materials required for completion of the remaining works, and preservation of materials on certain construction sites can increase the productivity of infrastructure projects. Caldas et al. (2014) also found that *materials status database* and *preservation of construction materials* are some of the practices that could improve the productivity of the industrial construction projects.

The use of tracking technology for construction materials might lead to gain in construction productivity. Grau et al. (2009) investigated the influence of materials tracking technology on crafts' productivity. The authors quantified the impacts of identifying, automating, and localizing engineered components on the productivity of industrial projects. The results of the study indicated that materials tracking technology can significantly improve productivity. Nasir et al. (2010) concluded that implementation of material tracking technology on power plants and refineries projects can enhance productivity. Likewise, the use of tracking technology for construction materials was confirmed to be an essential practice that can increase the productivity of industrial and infrastructure projects (Caldas et al. 2014; Nasir 2013). For building projects, the tracking technology might also help contractors to know the location materials on-site. Subsequently, the time spent by the workers in searching for the materials could be minimized, and productivity could increase.

Preparation of the schedule for the delivery of materials might also improve productivity in building construction projects. Arditi (1985) revealed that preparation and implementation of the delivery plan and schedule for materials can increase the productivity of construction projects in the United States. According to Bell and Stukhart (1987), materials planning is one of the essential materials management systems. Moreover, Nasir (2013) concluded that the preparation of materials delivery schedule can improve the productivity of the infrastructure construction projects. Caldas et al. (2014) also confirmed that the use of materials delivery schedule is important for increasing the productivity of industrial construction projects. El-Gohary and Aziz (2014) recommended that the use of materials delivery plan could increase productivity.

Formation of a team for inspecting materials and the development materials inspection process might be some of the practices that can increase productivity. Makulsawatudom et al. (2004) recommended that by carrying out thorough inspection of building materials, labor productivity gained could be achieved. According to Arditi (1985), standardization and checking the availability of materials play a vital role in enhancing productivity in construction projects. El-Gohary and Aziz (2014) suggested that preparation of detailed materials' documentation can minimize the negative effects of factors influencing labor productivity.

Methodology

This research adopted exploratory sequential mixed-methods research design, which involves the collection and analysis of the quantitative and qualitative data in two phases (Creswell 2013). The exploratory sequential mixed-methods design was used because the practices proposed by previous researchers may not be suitable in the Australian context (Gurmu et al. 2016). Therefore, this study was carried out, first, by collecting and analyzing qualitative data which were obtained from interviews during Phase I. On the basis of the qualitative data, appropriate materials management practices were identified, and their levels of implementations were refined to suit the building construction projects. To investigate the relationship between productivity and the practices, assign the weights to the materials management practices, validate the materials management practices' scoring tool for building projects, and develop as well as validate the productivity predicting tools, the quantitative data were collected and analyzed during Phase II.

During Phase I, the participants interviewed were 19 professionals having work experience in the construction of multistory buildings in the state of Victoria, Australia. The experts have 5–40 years' experience. Their positions include construction manager, general manager, project manager, project engineer, project coordinator, site engineer, and contract administrator. These experts were chosen on the basis of their experience in working for subcontractors as well as principal contractors that have been delivering multistory building projects in Australia. To select the experts, a snowballing technique was used. In this method, some of the experienced building construction experts were contacted, and they were requested to nominate other experts. The interviews were conducted until the data analysis reached a saturation point. According to Rose et al. (2014), saturation is the point where the participants gave similar reasons for accepting or rejecting a particular practice. See Appendix S1 for a list of interview questions.

Before choosing the sample projects for the second phase of the research, a list of contractors and their addresses were obtained from the Victorian Department of Treasury and Finance (2015) suppliers registry. Accordingly, 39 contractors that have experience in the delivery of multistory building projects were selected. The employees who were responsible for the construction of multistory building projects by these companies were then contacted. Site managers, project managers, and project coordinators were the respondents. The questionnaire consists of three parts. In the first part, the respondents were asked to provide information on a specific building project which they have completed within the last 5 years (2011–2016). See Appendix S2 for the contents of the questionnaire. The information includes project cost and project time among other things. In the second part of the questionnaire, the respondents were requested to rate the relative importance of the materials management practices which were identified during the first phase of the research. A scale of 1–5 is recommended to get better validity and reliability (Lozano et al. 2008; Jamieson 2004). Accordingly, to rate the practices, this research used a scale of 1 for not important; 2 for slightly important, 3 for somewhat important, 4 for very important, and 5 for extremely important. In the third part, the respondents were asked to choose the level of implementation of each of the practices on the building projects they nominated in the first part of the questionnaire. The levels of implementation of the materials management practices were measured on the basis of a survey instrument developed as part of Phase 1 of the study. In developing the measuring instrument, an existing instrument developed by the Construction Industry Institute (2013) was used as a starting point. On that basis, a new instrument (unweighted scoring tool) was developed and validated through interviews with local experts during Phase I of the study. The clarity, language, format, and the contents of the levels of the practices have been discussed during the validation process of the questionnaire.

Fig. 1 shows the procedures used in preparing the *unweighted* and *weighted* scoring tools. First, the qualitative data were analyzed, and materials management practices which are suitable to enhance productivity in building projects were identified. Then, the levels of implementation for the identified practices were prepared based on the existing tools developed by the Construction Industry Institute for industrial and infrastructure projects. The terms that are not commonly used in Australian building industry were deleted. For example, because the term *project turnover* is not commonly used in Australian building industry, it was deleted. Moreover, the practices and their levels which were not appropriate for building projects were deleted. For instance, the use of tracking technology for materials was found to be not suitable. Thus, the practice and its levels of implementation were excluded. Consequently, the *unweighted scoring tools* were prepared and validated by conducting interviews with local experts during Phase I of the study.

The validated and unweighted scoring tool (third part of a questionnaire) was used to collect the data regarding the implementation levels of the identified practices. During Stage I of the quantitative data analysis, the weight computed for each practice was used in the preparation of the *weighted scoring tool*. The weights were computed using the relative importance index (RII) technique. According to Lam et al. (2007), the mean value and the RII could be used for ranking variables. However, the RII technique is suitable for deriving relative indices between 0 and 1. Thus, it would be easy to compare various variables. Hence, the following RII equation is adopted (El-Gohary and Aziz 2014):

$$\mathrm{RII} = \frac{5(n5) + 4(n4) + 3(n3) + 2(n2) + n1}{5(n1 + n2 + n3 + n4 + n5)} \qquad (1)$$

where $n1$ = number of respondents who selected *not important*; $n2$ = number of respondents who selected *slightly important*; $n3$ = number of respondents who selected *somewhat important*; $n4$ = number of respondents who selected *very important*; and $n5$ = number of respondents who selected *extremely important*.

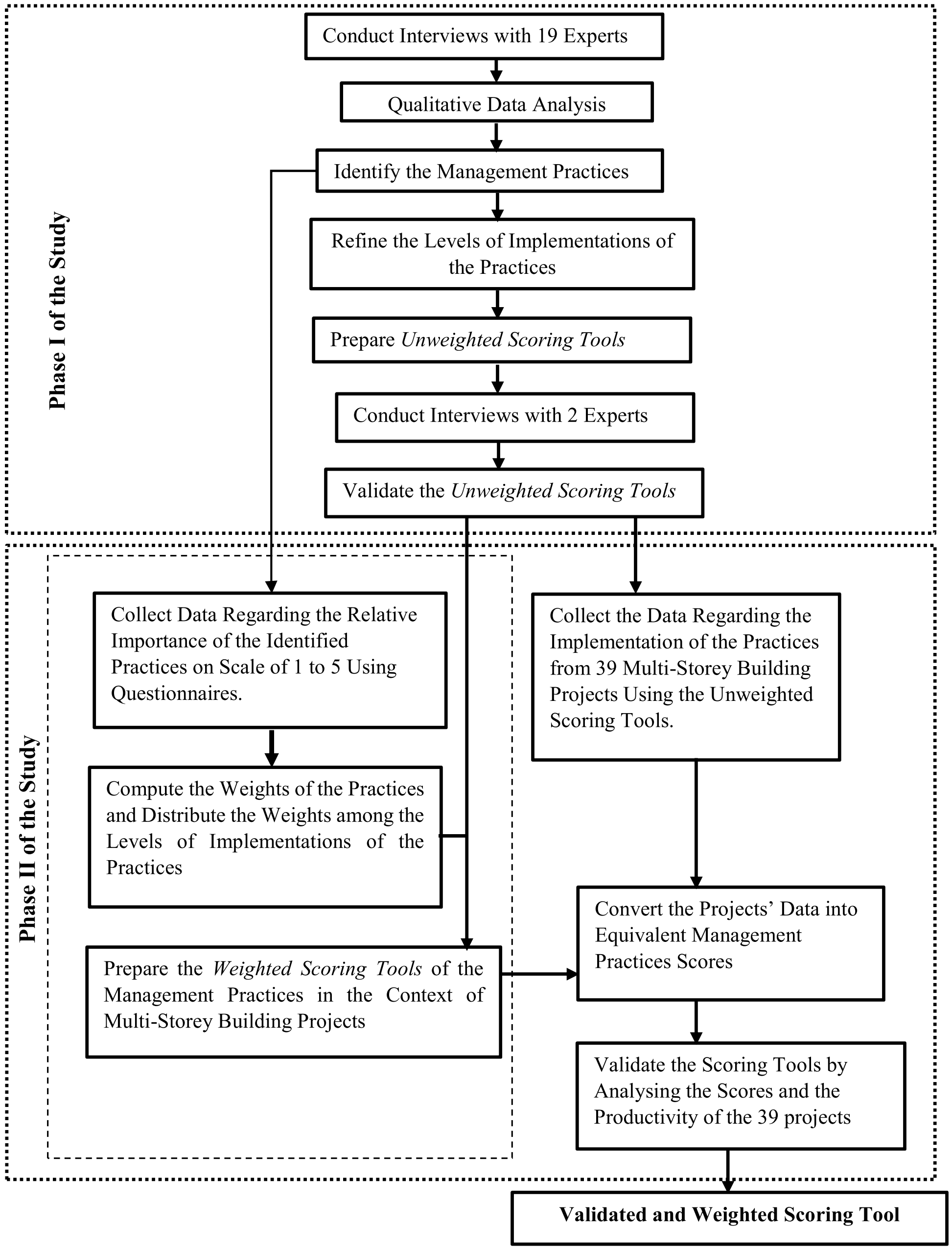

Fig. 1. Procedures of developing scoring tool.

The weights obtained using this equation were proportionally distributed among the five levels of the practices, and the weighted scoring tool was developed. During Stage II of the quantitative data analysis, the data collected from the building construction projects were transformed into equivalent scores using the weighted scoring tools, and projects' scores were computed. The analysis was then conducted to validate the weighted scoring tools.

Findings and Discussions

Materials Management Practices for Improving Labor Productivity of the Building Construction Projects

Interview results are summarized in Table 1. The practices which were not considered suitable for improving the productivity of the multistory building construction projects by all interviewees were rejected. Accordingly, *on-site materials tracking technology*, *procurement team*, and *postreceipt preservation and maintenance* were not found to be significant to enhance productivity in multistory building projects in the Victorian State of Australia. However, six materials management practices which can increase the productivity of multistory building construction projects were identified. These practices comprise *long-lead materials identification*, *procurement plans for materials*, *materials delivery schedule*, *material inspection process*, *materials inspection team*, and *materials status database*.

Productivity Factors of the Projects

Part one of the questionnaire was analyzed to compute the productivity factors (PFs) of the 39 building projects nominated by the 39 participating contractors. The productivity of construction projects can be measured in the relative or absolute term (Nasir 2013). In the

Table 1. Summary of the interview results of construction materials management practices

Construction materials management practices	Summary of the interview responses	Conclusion
Procurement plans for materials	Materials procurement plan is right on the front end. The potential suppliers are identified; the required materials are estimated upfront; the tracking sheets and charts are prepared; different stages of the procurement are represented using different colors on the chart; and any changes made during the procurement process are tracked.	Suitable
Long-lead materials identification	Usually the long lead items are façade materials, tiles and services such as lifts, generators, and boilers. All these key primary elements have long lead time. These items are identified earlier and tabulated. The approximate lead times for these materials are also estimated; for example, item = tiles, source = Italy, duration = 8 weeks. Most items imported from overseas are categorized as long lead items.	Suitable
Materials status database	The contractor's project manager get information regarding the work progress from supervisors or subcontractors and prepare the material status report which comprises the percentage of the materials utilized and the estimates of the quantities of materials required to complete the remaining works. The supervisors then monitor the work on a regular basis; they identify the remaining items and request the procurement of these materials if any.	Suitable
Materials delivery schedule	The materials delivery schedule is prepared based on the construction work program; the principal contractor's supervisors discuss the materials delivery dates with respective subcontractors/suppliers and prepare the schedule. The schedules are written on a whiteboard, and the materials delivery is tracked every day. Some materials such as façade are tracked during the manufacturing process; when they are on-site; and after their installation.	Suitable
Material inspection process	The inspection is made up front, the consultants are engaged in the inspection, and sometimes materials are inspected during the manufacturing stage. Inspection is made for various items such as reinforcement, formwork, glass, and concrete. The materials should be inspected before being installed. The subcontractors or suppliers provide the quality assurance documents for all items they bring to a site and the principal contractor's project management team conducts quality assurance checks.	Suitable
Materials inspection team	The project coordinators and specialist consultants are involved in the inspection process. For instance, façade expert and project coordinator or manager inspect the façade, and structural engineers take part in the inspection of reinforcement bars. Other consultants are also involved depending on the type of the materials or works.	Suitable
Procurement team for materials	A project coordinator or a project engineer or a contract administrator can oversee the procurement process. Forming the materials procurement team is not essential for productivity.	Not suitable
On-site materials tracking technology	The materials are not stored on-site; they are delivered to the site when required; thus, tracking technologies are not significant for productivity. When materials are brought to a building construction site, they are placed in a location that is very close to where they are installed.	Not suitable
Postreceipt preservation and maintenance	Most building materials are not stored on-sites due to the shortage of the storage areas, and the practice 'postreceipt preservation and maintenance' is not relevant for productivity improvement in multistory building construction projects.	Not suitable

case of the absolute term, the units of measurement of both the output and the input are indicated when presenting productivity value. PF, which is the relative measure, is the ratio of the actual productivity to the planned productivity. In this research, the actual productivity was calculated using a building project value as output and the actual project completion time as input, and the planned productivity was calculated using a building project value as output and planned project completion time as input (Gurmu et al. 2016). For instance, the project start date for one of the projects was February 1, 2012; its planned completion date was June 1, 2015; its actual completion date was March 1, 2016; and project cost was AUD 110 million. Thus, the planned duration (input) = (June 1, 2015) – (February 1, 2012) = 1,216 days; actual input = (March 1, 2016) − (February 1, 2012) = 1,490 days; actual productivity = (AUD 110 million)/(1,490 days) = AUD $0.07\ \text{million}/\text{day}$; planned productivity = (AUD 110 million)/(1,216 days) = AUD $0.09\ \text{million}/\text{day}$; and $\text{PF} = 0.07/0.09 = 0.82$. The PFs of the other projects were computed using a similar procedure.

According to Alby (1994), PF is a suitable measure for comparing the productivity of various projects. Nasir (2013) concluded that the use of PF as a metric to measure productivity is more beneficial than adopting the absolute measure. According to the study, the weighted average project productivities can be computed because PF is independent of the units of measurement. Caldas et al. (2014) validated the use of PF to measure productivity in industrial projects. In this research, PF is used as it is suitable to compare productivities of various building projects. The mean PF of the projects is 0.95, the minimum PF is 0.59, and the maximum PF is 1.14.

Materials Management Practices' Weights

Part two of the questionnaire was analyzed to assign weights to the construction materials management practices which were identified after conducting the interviews. Accordingly, the weights for the practices *materials inspection team*, *materials status database*, *material inspection process*, *materials delivery schedule*, *procurement plans for materials*, and *long-lead materials identification* are 0.569, 0.662, 0.697, 0.749, 0.846, and 0.918, respectively.

Weighted Scoring Tool of the Materials Management Practices

To prepare the weighted scoring tools, the weight of each practice is proportionally distributed among the five levels of implementation of a particular practice. The following formula is developed to compute the weight proportions of the practices.

$$\text{Level}\,(N+1) = \text{Level}\,N + \text{RII}/5 \tag{2}$$

where N ranges from 0 to 4; Level $0 = 0$; and RII denotes the weight of a practice.

As an example, for the practice *procurement plan for materials*, $\text{RII} = 0.85$; $\text{Level}\,0 = 0$; $N = 0$, $\text{Level}\,1 = 0 + 0.85/5 = 0.17$; $N = 1$, $\text{Level}\,2 = \text{Level}\,1 + 0.17 = 0.34$; $N = 2$, $\text{Level}\,3 = \text{Level}\,2 + 0.17 = 0.34 + 0.17 = 0.51$; $N = 3$, $\text{Level}\,4 = \text{Level}\,3 + 0.17 = 0.51 + 0.17 = 0.68$; and $N = 4$, $\text{Level}\,5 = \text{Level}\,4 + 0.17 = 0.68 + 0.17 = 0.85$.

J. Constr. Eng. Manage., 2019, 145(2): 04018139

Using a similar technique [Eq. (2)], the weight proportions of all the construction materials management practices were computed, and the results are provided in Table 2.

Validation of the Weighted Scoring Tool

To validate the scoring tool of the materials management practices, the projects are divided into high-score group (Group 1) and low-score group (Group 2) based on their construction materials management practices scores. If the projects with higher scores have low productivity, then the weighted scoring tool is not practical or valid and vice versa. To determine the baseline for classification, the mean score = 2.4, the median score = 2.34, the mode score = 1.53, the skewness = 0.37, the standard error (SE) of skewness = 0.38, and Z = (skewness)/(SE of skewness) = 0.98 were computed. As $Z = 0.98$ is less than 1.96, the mean materials management practices score (2.4) is considered for classification purpose (Kim 2013). Accordingly, 20 projects are grouped under

Table 2. Weighted scoring tool for construction materials

Level	Description	Score
	1. Procurement plan for materials	
0	A procurement plan for materials and equipment is not applicable.	0.00
1	There is no documented procurement plan for materials.	0.17
2	A procurement plan and schedule exist only for large materials and costly items.	0.34
3	Continuation of Level 2, plus plan includes all materials and consumables. Also, there is an established protocol for identifying reputation of potential vendors.	0.51
4	Continuation of Level 3, plus plan identifies necessary equipment and on-site resources to support delivery.	0.68
5	Continuation of Level 4, plus the procurement schedule is integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.	0.85
	2. Long-lead materials identification	
0	A separate procurement plan for long-lead materials is not applicable.	0.00
1	There is no documented procurement plan for long-lead materials.	0.18
2	A procurement plan and schedule exists for long-lead materials.	0.37
3	Continuation of Level 2, plus there is an established protocol for identifying reputation of potential vendors.	0.55
4	Continuation of Level 3, plus plan identifies necessary equipment and on-site resources to support delivery.	0.73
5	Continuation of Level 4, plus the procurement schedule is integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.	0.92
	3. Materials status database	
0	Material status database is not applicable.	0.00
1	There is no formal paper-based system used to track materials status.	0.13
2	There is a formal paper-based system to track materials status.	0.26
3	A proprietary internal materials status software tool is used, but it is not integrated with your company's project control systems or used by other contractors.	0.40
4	An available software tool is used but it is only integrated internally with your company's project control systems.	0.53
5	An available software tool is used by all stakeholders that is integrated with your supply chain and other project control systems.	0.66
	4. Materials delivery schedule	
0	Materials delivery schedule is not applicable.	0.00
1	There is no documented materials delivery schedule.	0.15
2	Materials delivery is planned early in the project and is integrated with a project schedule.	0.30
3	Continuation of Level 2, plus the schedule is automatically updated on receipt of new information as procurement proceeds.	0.45
4	Continuation of Level 3, plus the schedule is automatically linked with procurement, materials management, and overall project scheduling systems.	0.60
5	Continuation of Level 4, plus materials delivery planning and management is completely integrated with other automated project processes including automated materials tracking throughout the supply chain.	0.75
	5. Materials inspection process	
0	A material inspection process is not applicable.	0.00
1	There is no materials inspection process.	0.14
2	A materials inspection process is only utilized for large items or costly items on a project.	0.28
3	A materials inspection process is utilized that includes all items delivered to the site. There is a lack of organization of the process and materials are not separated into stages of the receipt process nor does it record the location of the materials and mark the materials for tracking.	0.42
4	A materials inspection process is used at the supplier and on-site, and organizes materials receipt inspections immediately upon delivery of materials, verifies that materials conform to standards, and organizes materials for tracking.	0.56
5	Continuation of Level 4, plus the process includes separation of material into categorical stages of the receipt process (e.g., awaiting inspection, storage area restocking, scrap, and/or awaiting for shipment, verification if the materials conform to specifications, standards, drawings, etc., record of the location of materials and marked materials for tracking, and prioritization for quality).	0.70
	6. Materials inspection team	
0	Materials inspection team is not applicable.	0.00
1	There is no materials inspection team.	0.11
2	There is a designated materials inspection team, but no training and qualifications of the individual's skill level is specified.	0.23
3	Continuations of Level 2, plus inspections are performed by project managers or workers rather than the team.	0.34
4	Continuation of Level 3, plus the inspection team can adequately inspect materials and understand the material specifications.	0.46
5	Continuation of Level 4, plus the members of the inspection team are experts at inspection processes and procedures, and know how to inspect materials and understand the material specifications.	0.57

Table 3. Outputs of the normality for projects grouped based on material management practices scores

Group	N	Mean PF	95% confidence interval		Shapiro–Wilk statistic	df	Significance
			Lower bound	Upper bound			
1	20	0.996	0.941	1.051	0.919	20	0.096
2	19	0.905	0.830	0.979	0.891	19	0.033

Note: df = degrees of freedom.

Table 4. Outputs of the N t-tests for projects grouped based on material management practices scores

Scenario	Levene's test for equality of variance		t	df	Significance for t-test for equality of means	Mean difference	Standard error difference	95% confidence interval	
	F-statistic	Significance						Lower bound	Upper bound
Equal variances assumed	0.922	0.343	2.09	37	0.044	0.091	0.044	0.003	0.19
Equal variances not assumed	—	—	2.07	33.57	0.046	0.091	0.044	0.002	0.18

Note: df = degrees of freedom; and $t = t$-statistic.

Group 1, and 19 projects are grouped under Group 2 based on their construction materials management practices scores.

Normality tests are conducted for the two independent groups, and the results are presented in Table 3. The Shapiro–Wilk test's hypotheses are Ho (null): the data in the group are normally distributed; and Ha (alternative): the data are not normally distributed. Accordingly, for Group 1, the null hypothesis is not rejected because the $P = 0.096 > 0.05$ and the data are normally distributed. The P value for Group 2 is 0.033, which is less than 0.05. However, $Z = \text{skewness}/\text{SE} = 0.27 < 1.96$, and the data in Group 2 can be considered as normally distributed. Test of homogeneity (Levene's test) is also conducted. The hypotheses for Levene's test are Ho (null): the variances of Groups 1 and 2 projects are equal; and Ha (alternative): the variances of Groups 1 and 2 projects are different. Accordingly, a $P = 0.343 > 0.05$ is obtained. This shows that the null hypothesis is accepted, and the variances of the data are homogeneous. Therefore, the parametric test (analysis of variance or t-test) could be used to check the difference between the means of two groups. Because there are only two independent samples (groups), the independent sample t-test is used in the analysis (Table 4).

Because the variances are equal, the results in the first row of the t-test output are considered. Accordingly, the null hypothesis for this t-test or the means of the groups are equal is rejected as $P = 0.04 < 0.05$. Therefore, there is a statistically significant difference between the Groups 1 and 2 projects, and the scoring tool for construction materials management practices is valid. In other words, the practicality of the weighted scoring tool is confirmed. The mean PF values for Groups 1 and 2 are found to be 0.996 and 0.899, respectively.

Reliability Test for the Weighted Scoring Tool

Before conducting correlation and regression analyses, the internal consistency of the scoring tools of the construction management practices was checked by running the reliability test using SPSS 24 (IBM, Armonk, New York). Cronbach alpha (α) is the most popular reliability statistic, which determines the consistency of items in a survey instrument, and the recommended acceptable minimum value of α is 0.70 (Santos 1999). In this research, the Cronbach α value of 0.84 is found, which indicates that the scoring tool is reliable.

Correlation Analysis

Correlation analysis was carried out to investigate the relationship between the labor productivity and construction materials management practices, and the results are presented in Table 5. Accordingly, all the practices have positive, medium strength and statistically significant ($r_s = 0.45$, $P = 0.005 < 0.05$) association with productivity. This implies that as the implementation level of the materials management practices increases, productivity also increases. Among the six practices, *long-lead materials identification* has the highest correlation coefficient ($r_s = 0.41$, $P = 0.009$). The finding shows that long-lead materials identification is the critical materials management practice to improve productivity in multistory building construction projects.

Linear Regression Analysis

To investigate the proportion of variance in the PF explained by the construction materials management practices, bivariate linear regression analysis was conducted, and the results are presented in Tables 6–8. Accordingly, an R^2 of 0.262 is found with a P value of 0.01, implying significant relationship, which means that 26.2% of the total variance in PF can be explained by construction materials management practices, and the remaining variance could be explained by other factors that are beyond the scope of this study, such as equipment management practices, advance in technology, and government regulations among others.

Based on the outputs presented in Table 8, the linear regression model of productivity and construction materials management practices can be represented by the following equation:

$$\mathrm{PF}_i = 0.09\mathrm{MMTS}_i + 0.74 \tag{3}$$

where PF_i = productivity factor of an ith project; and MMTS_i = materials management total score for an ith project.

Logistic Regression Model Building

Before conducting the logistic regression analysis, the 39 data points are divided into two: model building data sets and validation data set. Threefold and fourfold cross-validation techniques were used as they are less biased than the sample splitting method (Abou-Assaleh et al. 2014). To determine the baseline PF or the cutoff PF which is used to transform projects' PF into binary

Table 5. Spearman's correlation coefficients of the construction materials management practices and productivity

Materials management practices	Correlation coefficients/significance	PF	MMTS	PPM	LLM	MSD	MDS	MIP	MIT
PF	Correlation coefficient (r_s)	1.000	—	—	—	—	—	—	—
	Significance (two tailed)	—	—	—	—	—	—	—	—
MMTS	Correlation coefficient (r_s)	0.445[a]	1.000	—	—	—	—	—	—
	Significance (two tailed)	0.005	—	—	—	—	—	—	—
PPM	Correlation coefficient (r_s)	0.330[b]	0.816[a]	1.000	—	—	—	—	—
	Significance (two tailed)	0.040	0.000	—	—	—	—	—	—
LLM	Correlation coefficient (r_s)	0.414[a]	0.793[a]	0.644[a]	1.000	—	—	—	—
	Significance (two tailed)	0.009	0.000	0.000	—	—	—	—	—
MSD	Correlation coefficient (r_s)	0.367[b]	0.794[a]	0.534[b]	0.565[a]	1.000	—	—	—
	Significance (two tailed)	0.022	0.000	0.000	0.000	—	—	—	—
MDS	Correlation coefficient (r_s)	0.233	0.510[a]	0.336[b]	0.423[a]	0.345[b]	1.000	—	—
	Significance (two tailed)	0.153	0.001	0.037	0.007	0.032	—	—	—
MIP	Correlation coefficient (r_s)	0.143	0.585[a]	0.366[b]	0.201	0.437[a]	0.027	1.000	—
	Significance (two tailed)	0.386	0.000	0.022	0.219	0.005	0.868	—	—
MIT	Correlation coefficient (r_s)	0.263	0.839[a]	0.605[a]	0.496[a]	0.644[a]	0.399[b]	0.690[a]	1.00
	Significance (two tailed)	0.106	0.000	0.000	0.001	0.000	0.012	0.000	—

Note: LLM = long-lead materials identification; MDS = materials delivery schedule; MIT = materials inspection team; MIP = materials inspection process; MMTS = materials management total score; MSD = materials status database; N = number of samples (here, $N = 39$); and PPM = procurement plan for materials.

[a]Correlation is significant at 0.01.

[b]Correlation is significant at 0.05.

Table 6. Model summary for linear regression analysis

Parameter	Value
R	0.512
R^2	0.262
Adjusted R^2	0.235
Standard error of the estimate	0.012

Table 7. Analysis of variance for linear regression analysis

Parameter	Sum of squares	df	Mean square	F	Significance
Regression	0.139	1	0.139	9.594	0.005
Residual	0.391	27	0.014	—	—
Total	0.530	28	—	—	—

Note: df = degrees of freedom; and F = F-statistic.

equivalent, the three measures of central tendency (mean, mode, and median) and the skewness of the PF data were computed using SPSS 24. Accordingly, the mean PF $= 0.95$, mode PF $= 1.00$, median PF $= 1.00$, skewness $= -0.893$, SE $= 0.378$, and $Z = |(-0.893/0.378)| = 2.36$ were found. The mean value is the best measure of central tendency if the data are not highly skewed, and the median is the preferred value if the data are skewed (Lurd and Lurd 2013). According to Kim (2013), if Z-score for skewness is greater than 1.96, the distribution of the sample is not considered as normal. Thus, the median value of 1.00 is used as a cutoff PF value because the Z value $= 2.36$ is greater than the allowable Z value of 1.96.

Peduzzi et al. (1996) explained that, as the rule of thumb, before running the logistic regression analysis, the number of events per variable (EPV) needs to be greater than 10. However, Bowerman and Murphree (2014) argue that setting the minimum of 10 events per predictor is conservative. In this research, the number of positive events refers to the number of projects having PFs greater than the baseline PF, and there is one predictor (construction materials management practices). The EPVs are computed using median PF $= 1.00$, median PF $+$ (5% $\times$ median PF) $= 1.05$, median PF $-$ (5% $\times$ median PF) $= 0.95$, median PF $-$ (10% $\times$ median PF) $= 0.90$, and median PF $-$ (15% $\times$ median PF) $= 0.85$ as baseline PFs. In this research context, the number of events (positive events) refers to the number of projects whose PFs exceed the baseline PF, and the predictor (explanatory variable) is the construction materials management practices (one variable). Accordingly, using median PF as a baseline value, EPV $= (21)/(1) = 21 > 10$; using (median PF) + (5% $\times$ median PF) as a cutoff value, EPV $= 12 > 10$; using (median PF) $-$ (5% $\times$ median PF) as a baseline, EPV $= 23 > 10$; using (median PF) $-$ (10% $\times$ median PF) as a cutoff value, EPV $= 26 > 10$; and using (median PF) $-$ (15% $\times$ median PF) as a baseline EPV $= 31 > 10$ are obtained. Therefore, the data are suitable to run the logistic regression analysis.

Fifteen alternative logistic regression models of the six materials management practices and labor productivity are developed using the threefold cross-validation technique, and the results are presented in Tables 9 and 10. Accordingly, the model that has the highest predictive accuracy of 88.5% and statistically significant coefficient ($P = 0.03 < 0.05$) is chosen and assigned letter H (Table 11). Among the 20 alternative models developed using the fourfold cross-validation technique, two models with the highest predictive accuracy are selected. The first model (Model I) has the predictive accuracy of 89.7% and a P value of $0.03 < 0.05$; and the second model (Model J) has the predictive accuracy of 82.8%, and its coefficient of the independent variable (β) is significant ($P = 0.02 < 0.05$).

Table 8. Coefficients for linear regression analysis

Parameter	B	Standard error	β	t	Significance
Constant	0.741	0.073	—	10.201	<0.001
Construction materials management practices	0.09	0.029	0.512	3.097	0.005

Note: B = parameter estimate; and t = t-statistic.

Table 9. Validation and model building data set selection using threefold cross validation

Cutoff PF	Selection criteria	Trial 1[a]	Trial 2[b]	Trial 3[c]
Cutoff $PF_1 = 0.85$	Predictive accuracy	80.8	80.8	76.9
	Significance of β	0.19	0.34	0.24
Cutoff $PF_2 = 0.90$	Predictive accuracy	73.1	65.4	65.4
	Significance of β	0.04	0.57	0.46
Cutoff $PF_3 = 0.95$	Predictive accuracy	57.7	69.2	57.7
	Significance of β	0.07	0.35	0.21
Cutoff $PF_4 = 1.00$	Predictive accuracy	57.7	61.5	61.5
	Significance of β	0.09	0.16	0.08
Cutoff $PF_5 = 1.05$	Predictive accuracy	88.5[(H)]	80.8	73.1
	Significance of β	0.03	0.16	0.04

Note: β = parameter estimate; and H = model code.
[a]Validation data set (1–13 data points), model building data set (14–26 data points), and model building data set (27–39 data points).
[b]Model building data set (1–13 data points), validation data set (14–26 data points), and model building data set (27–39 data points).
[c]Model building data set (1–13 data points), model building data set (14–26 data points), and validation data set (27–39 data points).

Table 10. Validation and model building data set selection using fourfold cross validation

Cutoff PF	Selection criteria	Trial 1[a]	Trial 2[b]	Trial 3[c]	Trial 4[d]
Cutoff PF1 = 0.85	Predictive accuracy (%)	79.3	86.2	72.4	80.0
	Significance of β	0.08	0.58	0.24	0.24
Cutoff PF2 = 0.90	Predictive accuracy (%)	72.4	75.9	55.2	70.0
	Significance of β	0.03	0.62	0.27	0.48
Cutoff PF3 = 0.95	Predictive accuracy (%)	62.1	65.5	65.5	63.3
	Significance of β	0.04	0.33	0.12	0.29
Cutoff PF4 = 1.00	Predictive accuracy (%)	58.6	55.2	65.5	60.0
	Significance of β	0.06	0.15	0.06	0.12
Cutoff PF5 = 1.05	Predictive accuracy (%)	82.8[(J)]	69.0	89.7[(I)]	66.7
	Significance of β	0.02	0.09	0.03	0.06

Note: β = parameter estimate; and J, I = model codes.
[a]Validation data set (1–10 data points), model building data set (11–20 data points), model building data set (21–30 data points), and model building data set (31–39 data points).
[b]Model building data set (1–10 data points), validation data set (11–20 data points), model building data set (21–30 data points), and model building data set (31–39 data points).
[c]Model building data set (1–10 data points), model building data set (11–20 data points), validation data set (21–30 data points), and model building data set (31–39 data points).
[d]Model building data set (1–10 data points), model building data set (11–20 data points), model building data set (21–30 data points), and validation data set (31–39 data points).

The three selected models (H, I, and J) are compared based on the statistical significance of their coefficients, their area under the receiver operating characteristic (ROC) curves (AUCs), and their predictive accuracy (Table 11). All the three models have AUC > 0.5, their AUCs are statistically significant, the variables' coefficients are statistically significant at 5% level of significance, and the constants of the three models are also statistically significant. However, Model I is selected as it has the best predictive accuracy (89.7%). The data sets 16, 26, and 46 are used in model building, the data set 46 is used to validate the model, and PF = 1.05 is used as a cutoff PF.

The results of the logistic regression analysis conducted to develop the selected model (Model I or model in Block 1) are provided in Tables 11–19. In Block 0, the true negative percentage of 100.0%, the true positive percentage of 0.0%, and overall model accuracy of 82.8% are found. These imply that all projects with PFs less than 1.05 are correctly predicted, and that no project with PF greater than 1.05 is correctly predicted. The variable in the equation (−1.57) is significant ($P = 0.001 < 0.05$) and the variable not in the equation (7.03) is also significant ($P = 0.01 < 0.05$).

In Block 1, the chi-square (7.34) of the Omnibus test is significant ($P = 0.01 < 0.05$), which shows that the model is better than the null model (Block 0). The Hosmer and Lemeshow test shows $P = 0.42 > 0.05$, which implies that the model in Block 1 is good (Table 16). The overall prediction accuracy of the model is 89.7%, and the value is greater than the null model's prediction

Table 11. Comparison of the selected models

Model code	Overall accuracy (%)	Model AUC		B		β_o		Cutoff PF
		Value	Significance	Variable	Significance	Constant	Significance	
I	89.7	0.84	0.03	1.81	0.03	−6.46	0.01	1.05
H	88.5	0.91	< 0.01	1.58	0.03	−4.56	0.01	1.05
J	82.8	0.95	0.04	1.52	0.02	−4.62	0.01	1.05

Table 12. Classification table for Block 0

Description	Binary equivalent	Value
Observed PF	0	24
	1	5
Predicted PF	0	24
	1	0
Percent correct	0	100
	1	0
Overall percent	—	82.8

Table 13. Variable in equation in Block 0

Parameter	Value
Step 0	Constant
B	−1.569
Standard error	0.492
Wald	10.182
df	1
Significance	0.001
Exp(B)	0.208

Note: B = parameter estimate; and df = degrees of freedom.

Table 14. Variable in not equation in Block 0

Step 0	Score	df	Significance
Construction materials management practices	7.032	1	0.008
Constant	7.032	1	0.008

Note: df = degrees of freedom.

Table 15. Omnibus test for model coefficients

Step	Chi-square	df	Significance
Step	7.342	1	0.007
Block	7.342	1	0.007
Model	7.342	1	0.007

Note: df = degrees of freedom.

Table 16. Hosmer and Lemeshow test

Parameter	Value
Chi-square	7.125
df	7
Significance	0.416

Note: df = degrees of freedom.

accuracy (82.8%). The true negative prediction accuracy of the model is 95.8%, and the true positive prediction accuracy is 60.0%. Wald chi-square (5.04) for the variable in the equation is statistically significant ($P = 0.03 < 0.05$). Similarly, the Wald chi-square (6.76) for the constant is statistically significant ($P = 0.01 < 0.05$). The Exp(B) for the variable is 6.10, which indicates that for one unit increase in the score of the materials management practices, the odd of exceeding the PF of 1.05 increases by a factor of 6.10.

To test the reliability of the logistic regression model of the construction materials management practices and productivity, bootstrapping using 1,000 samples was conducted and the results are presented in Table 19. Accordingly, the P values of both the variable ($P = 0.021 < 0.05$) and the constant ($P = 0.016 < 0.05$) are

Table 17. Classification table for Block 1

Description	Binary equivalent	Value
Observed PF	0	24
	1	5
Predicted PF	0	23
	1	3
Percent correct	0	100
	1	0
Overall percent	—	89.7

found to be statistically significant. The coefficient and the constant obtained after bootstrapping are similar to the model's coefficient and constant. Therefore, the logistic regression model is reliable.

Finally, by using the variable's coefficient and the constant indicated in Table 18, the equation for the construction materials management practices and productivity model is developed as shown in Eqs. (4) and (5)

$$\mathrm{Log(Odds)} = \mathrm{Logit}(\mathrm{P}_i) = \mathrm{Ln}\left(\frac{\mathrm{P}_i}{1-\mathrm{P}_i}\right) = 1.81\,\mathrm{MMTS}_i - 6.46 \tag{4}$$

Eq. (4) can be simplified as follows:

$$\mathrm{P}_i = \frac{\mathrm{e}^{1.81\mathrm{MMTS}_i - 6.46}}{1 + \mathrm{e}^{1.81\mathrm{MMTS}_i - 6.46}} \tag{5}$$

where P_i = probability of exceeding PF = 1.05 for an ith project; and MMTS_i = materials management total score for an ith project.

Logistic Regression Model Validation

To validate the logistic regression model, probabilities of validation data sets were computed; PFs were predicted as binary values (1, 0) and compared with the actual PFs; the ROC curve was plotted and compared with the reference line; and AUC was computed. The ROC curve was drawn, and the curve of the graph is greater than the reference line, indicating that the model is good in prediction (Fig. 2). Furthermore, the AUC is computed to be 0.81, which is greater than the minimum acceptable value of 0.5. According to Hanley and McNeil (1982), if the graph is close to the left top boundary, the ROC curve is acceptable, and AUC ≤ 0.5 implies no accuracy and AUC = 1 indicates perfect accuracy.

After validation, the model's equation [Eq. (3)] is used to predict the probabilities of exceeding PF = 1.05, and the sigmoid graph is plotted.

Application of Scoring Tools and the Logistic Regression Model

The scoring tools of the construction materials management practices and the logistic regression model of productivity and the practices can assist the contractor's project manager to plan appropriate practices that can be implemented on a certain multistory building construction project. The project manager can make necessary decisions to improve the productivity of the project after assessing the risk of low productivity by using the tools and the model.

Suppose a project manager plans to implement the following practices (please refer to Table 2 for the weighted scoring tool). For the practice procurement plan for construction materials, the manager plans to implement *a procurement plan and schedule exists only for large materials and costly items* (Level 2 and equivalent score of 0.34). For the practice long-lead materials

Table 18. Variable in equation in Block 1

Step 1	B	SE	Wald	df	Significance	Exp(B)
Construction materials management practices	1.808	0.806	5.037	1	0.025	6.099
Constant	−6.461	2.484	6.764	1	0.009	0.002

Note: B = parameter estimate; df = degrees of freedom; and SE = standard error.

Table 19. Bootstrap for variables in the equation

Step 1	B	Bias	SE	Significance
Construction materials management practices	1.808	25.397	106.28	0.021
Constant	−6.461	−91.58	390.47	0.016

Note: B = parameter estimate; df = degrees of freedom; and SE = standard error.

identification, he/she plans *a procurement plan and schedule exists for long-lead materials* (Level 2 and score of 0.37); for materials status database, the manager plans *there is a formal paper-based system to track materials status* (Level 2 and score of 0.26); for the practice materials delivery schedule, *materials delivery is planned early in the project and is integrated with a project schedule* has been planned (Level 2 and score of 0.30); for materials inspection process, *materials inspection is made for all items delivered to the site, there is a lack of organization of the inspection process and materials are not separated into stages of the receipt process nor does it record the location of the materials, and the materials are not marked for tracking* is chosen (Level 3 and score of 0.42); and for the practice materials inspection team, the manager plans *materials inspections are performed by project manager or another worker rather than materials inspection team* (Level 3 and score of 0.34). Accordingly, the total score of the construction materials management practices or the materials management total score (MMTS) for the particular project is $0.34 + 0.37 + 0.26 + 0.30 + 0.42 + 0.34 = 2.03$. The following formula has been developed to compute the MMTS for a particular project:

$$\mathrm{MMTS} = \mathrm{PPMS} + \mathrm{LLMS} + \mathrm{MSDS} + \mathrm{MDSS} + \mathrm{MIPS} + \mathrm{MITS} \tag{6}$$

where MMTS = materials management total score; PPMS = procurement plan for materials score; LLMS = long-lead materials identification score; MSDS = materials status database score; MDSS = materials delivery schedule score; MIPS = materials inspection process score; and MITS = materials inspection team score.

The equivalent probability of exceeding PF = 1.05 for MMTS of 2.03 is 5% (Fig. 3). This implies that the actual productivity of a project can be less than the planned productivity, and the project could be delayed. Thus, corrective actions should be taken. The action could be increasing the levels of implementations of the materials management practices which are more crucial to improve the productivity of the building construction projects. Therefore, the model and the scoring tools can assist the project manager in planning suitable management practices that are to be implemented on a particular building project. Moreover, the PF of the project can be determined using the linear regression model [please refer to

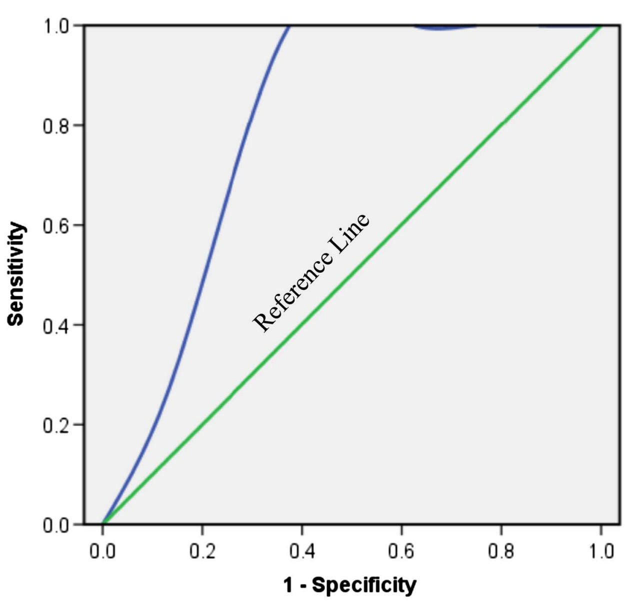

Fig. 2. ROC curve for validating the logistic regression model of the construction materials management practices and productivity.

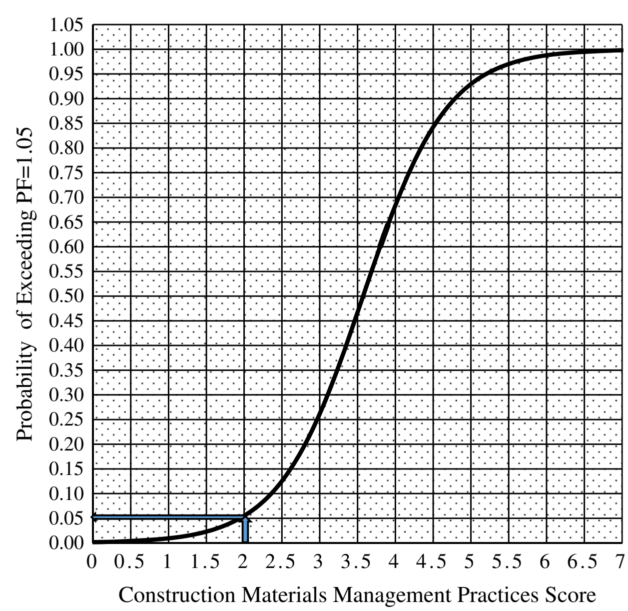

Fig. 3. Application of the sigmoid graph of the materials management practices.

Eq. (2)]. PF $= 0.09 \times 2.03 + 0.74 = 0.92$. This also indicates that the project could be delayed because PF is less than one.

Conclusion

The construction materials management practices' scoring tool which can be used to measure and plan the practices has been developed and validated for multistory construction building projects. Projects with materials management practices score of less than 2.4 are classified as low score, and the associated labor productivity would also be low. The practices *long-lead materials identification*, *procurement plans for materials*, and *materials delivery schedule* are the three most significant materials management practices which can enhance productivity in building projects. The model which integrates the probability, PF, and the score of the practices is also developed and validated. Future researchers can conduct further research to develop a new materials management practices' scoring tool for multistory building projects in other contexts based on the finding of this research. Moreover, the costs associated with each level of implementation of the materials management practices need to be investigated.

Contractors that are involved in the construction of the multistory building projects in the Victorian State of Australia can implement the materials management practices, which are identified in this research, to enhance the productivity of their projects. They can also score the implementation/planning levels of the practices and use the logistic regression model to estimate the probability of exceeding the baseline PF. On the basis of the predicted probability, the contractors can take corrective actions to increase the chance of achieving a higher level of productivity as compared to the baseline. Contractors in other countries can also implement the higher levels of the identified materials management practices to enhance the productivity of their building projects. Nonetheless, because the practices could vary from country to country, validation is required to adapt to any local context. For instance, the practice *long-lead materials identification* might not be the most critical practice in countries where most construction materials are locally produced or available.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

Supplemental Data

Appendixes S1 and S2 are available online in the ASCE Library (www.ascelibrary.org).

References

Abdul Kadir, M., W. Lee, M. Jaafar, S. Sapuan, and A. Ali. 2005. "Factors affecting construction labour productivity for Malaysian residential projects." *Struct. Surv.* 23 (1): 42–54. https://doi.org/10.1108/02630800510586907.

Abou-Assaleh, T., N. Cercone, V. Keselj, and R. Sweidan. 2014. "N-gram-based detection of new malicious code." In *Proc., 28th Annual Int. Computer Software and Applications Conf. (COMPSAC 2004)*, 41–42. New York: IEEE.

ABS (Australian Bureau of Statistics). 2016. *Australian national accounts: National income, expenditure and product.* Canberra, Australia: ABS.

Alby, V. 1994. "Productivity: Measurement and management." *AACE Int. Trans.* 38 (4): 1–7.

Ali, H. H., and S. F. Al Nsairat. 2009. "Developing a green building assessment tool for developing countries—Case of Jordan." *Build. Environ.* 44 (5): 1053–1064. https://doi.org/10.1016/j.buildenv.2008.07.015.

Arditi, D. 1985. "Construction productivity improvement." *J. Constr. Eng. Manage.* 111 (1): 1–14. https://doi.org/10.1061/(ASCE)0733-9364(1985)111:1(1).

Arditi, D., and K. Mochtar. 1996. "Productivity improvement in the Indonesian construction industry." *Constr. Manage. Econ.* 14 (1): 13–24. https://doi.org/10.1080/014461996000000003.

Bell, L. C., and G. Stukhart. 1987. "Costs and benefits of materials management systems." *J. Constr. Eng. Manage.* 113 (2): 222–234. https://doi.org/10.1061/(ASCE)0733-9364(1987)113:2(222).

Bowerman, B., and E. Murphree. 2014. *Regression analysis: Unified concepts, practical applications, and computer implementation*. New York: Business Expert Press.

Caldas, C. H., J.-Y. Kim, C. T. Haas, P. M. Goodrum, and D. Zhang. 2014. "Method to assess the level of implementation of productivity practices on industrial projects." *J. Constr. Eng. Manage.* 141 (1): 04014061. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000919.

Cao, Q., and J. J. Hoffman. 2011. "A case study approach for developing a project performance evaluation system." *Int. J. Project Manage.* 29 (2): 155–164. https://doi.org/10.1016/j.ijproman.2010.02.010.

CFMEU. 2016a. "Interim RDO calendar." Accessed May 9, 2016. https://vic.cfmeu.org.au/calendar-created/month/2016-02.

CFMEU. 2016b. "OHS information." Accessed November 7, 2017. https://vic.cfmeu.org.au/ohs/reps-info.

CII (Construction Industry Institute). 2013. *Best productivity practices implementation index for infrastructure projects: Implementation Resource 252-4d*. Austin, TX: CII.

Cottrell, D. S. 2006. "Contractor process improvement for enhancing construction productivity." *J. Constr. Eng. Manage.* 132 (2): 189–196. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:2(189).

Creswell, J. W. 2013. *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: Sage Publications.

Department of Treasury and Finance. 2015. "Construction supplier register." Accessed September 30, 2015. http://www.dtf.vic.gov.au.

El-Gohary, K. M., and R. F. Aziz. 2014. "Factors influencing construction labor productivity in Egypt." *J. Manage. Eng.* 30 (1): 1–9. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000168.

Fair Work Commission. 2016. "Building and construction general on-site award 2010." Accessed September 27, 2016. https://www.fwc.gov.au/documents/documents/modern_awards/pdf/ma000020.pdf.

Grau, D., C. H. Caldas, C. T. Haas, P. M. Goodrum, and J. Gong. 2009. "Assessing the impact of materials tracking technologies on construction craft productivity." *Autom. Constr.* 18 (7): 903–911. https://doi.org/10.1016/j.autcon.2009.04.001.

Gurmu, A. T. 2018. "Construction materials management practices enhancing labour productivity in multi-storey building projects." *Int. J. Constr. Manage.* 1–10. https://doi.org/10.1080/15623599.2018.1462447.

Gurmu, A. T., and A. A. Aibinu. 2017. "Construction equipment management practices for improving labor productivity in multistory building construction projects." *J. Constr. Eng. Manage.* 143 (10): 04017081. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001384.

Gurmu, A. T., and A. A. Aibinu. 2018. "Survey of management practices enhancing labor productivity in multi-storey building construction projects." *Int. J. Prod. Perform. Manage.* 67 (4): 717–735. https://doi.org/10.1108/IJPPM-02-2017-0032.

Gurmu, A. T., A. A. Aibinu, and T. K. Chan. 2016. "A study of best management practices for enhancing productivity in building projects: Construction methods perspectives." *Constr. Econ. Build.* 16 (3): 1–19. https://doi.org/10.5130/AJCEB.v16i3.4882.

Hanley, J. A., and B. J. McNeil. 1982. "The meaning and use of the area under a receiver operating characteristic (ROC) curve." *Radiology* 143 (1): 29–36. https://doi.org/10.1148/radiology.143.1.7063747.

Jamieson, S. 2004. "Likert scales: How to (ab)use them." *Med. Educ.* 38 (12): 1217–1218. https://doi.org/10.1111/j.1365-2929.2004.02012.x.

Jergeas, G. 2009. *Improving construction productivity on Alberta oil and gas capital projects.* A Rep. Submitted to Alberta Finance and Enterprise. Calgary, AB, Canada: Univ. of Calgary.

Kim, H.-Y. 2013. "Statistical notes for clinical researchers: Assessing normal distribution (2) using skewness and kurtosis." *Restor. Dent. Endod.* 38 (1): 52–54. https://doi.org/10.5395/rde.2013.38.1.52.

Lam, P. T., F. K. Wong, and F. W. Wong. 2007. "Building features and site-specific factors affecting buildability in Hong Kong." *J. Eng. Des. Technol.* 5 (2): 129–147. https://doi.org/10.1108/17260530710833185.

Lozano, L. M., E. García-Cueto, and J. Muñiz. 2008. "Effect of the number of response categories on the reliability and validity of rating scales." *Methodology* 4 (2): 73–79. https://doi.org/10.1027/1614-2241.4.2.73.

Lurd, A., and M. Lurd. 2013. "Measures of central tendency." Accessed June 13, 2016. https://statistics.laerd.com.

Makulsawatudom, A., M. Emsley, and K. Sinthawanarong. 2004. "Critical factors influencing construction productivity in Thailand." *J. KMITNB* 14 (3): 1–6.

Nasir, H. 2013. "Best productivity practices implementation index (BPPII) for infrastructure projects." Ph.D. dissertation, Dept. of Civil and Environmental Engineering, Univ. of Waterloo.

Nasir, H., C. T. Haas, C. H. Caldas, and P. M. Goodrum. 2015. "An integrated productivity-practices implementation index for planning the execution of infrastructure projects." *J. Infrastruct. Syst.* 22 (2): 04015022. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000275.

Nasir, H., C. T. Haas, D. A. Young, S. N. Razavi, C. Caldas, and P. Goodrum. 2010. "An implementation model for automated construction materials tracking and locating." *Can. J. Civ. Eng.* 37 (4): 588–599. https://doi.org/10.1139/L09-178.

Ngacho, C., and D. Das. 2014. "A performance evaluation framework of development projects: An empirical study of Constituency Development Fund (CDF) construction projects in Kenya." *Int. J. Project Manage.* 32 (3): 492–507. https://doi.org/10.1016/j.ijproman.2013.07.005.

Peduzzi, P., J. Concato, E. Kemper, T. R. Holford, and A. R. Feinstein. 1996. "A simulation study of the number of events per variable in logistic regression analysis." *J. Clin. Epidemiol.* 49 (12): 1373–1379. https://doi.org/10.1016/S0895-4356(96)00236-3.

Productivity Commission. 2013. *Productivity report.* Canberra, Australia: Productivity Commission.

Productivity Commission. 2015. *Productivity report.* Canberra, Australia: Productivity Commission.

Rojas, E. M., and P. Aramvareekul. 2003. "Labor productivity drivers and opportunities in the construction industry." *J. Manage. Eng.* 19 (2): 78–82. https://doi.org/10.1061/(ASCE)0742-597X(2003)19:2(78).

Rose, S., N. Spinks, and A. I. Canhoto. 2014. *Management research: Applying the principles*. New York: Routledge.

Santos, J. R. A. 1999. "Cronbach's alpha: A tool for assessing the reliability of scales." *J. Ext.* 37 (2): 1–5.

Thomas, A. V., and J. Sudhakumar 2014. "Modelling masonry labour productivity using multiple regression." In *Proc., 30th Annual ARCOM Conf.*, 1345–1354. Portsmouth, UK: Association of Researchers in Construction Management.

Tremblay, A., and A. Badri. 2018. "A novel tool for evaluating occupational health and safety performance in small and medium-sized enterprises: The case of the Quebec forestry/pulp and paper industry." *Saf. Sci.* 101: 282–294. https://doi.org/10.1016/j.ssci.2017.09.017.

Zavadskas, E. K., Z. Turskis, and J. Tamošaitiene. 2010. "Risk assessment of construction projects." *J. Civ. Eng. Manage.* 16 (1): 33–46. https://doi.org/10.3846/jcem.2010.03.

Zayed, T. M., and D. W. Halpin. 2005. "Productivity and cost regression models for pile construction." *J. Constr. Eng. Manage.* 131 (7): 779–789. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:7(779).