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A Novel DEA Based on Construction Productivity Calculation Method †

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Abstract: Construction is a labor-intensive industry. Each construction project involves aspects of execution complexity, construction records, management objectives, evaluation benchmarks, and construction productivity. In order to complete a construction project on time, on budget, and with high quality, construction productivity is a key factor. Construction productivity involves various working groups (reinforcement, template, concrete, plastering, water, electricity, furnishing, and heavy machinery). All working groups must execute their daily tasks, including corresponding work items and schedules. To calculate the productivities of all working groups, many input and output factors must be considered, which is related to multi-attribute decision making (MADM). The traditional productivity calculation method is use single outputs/single inputs, but such method cannot solve the problems of multiple outputs/multiple inputs of construction productivity. For solve the above-mentioned problem, this paper integrates technique for order preference by similarity to the ideal solution (TOPSIS) and data envelopment analysis (DEA) method to handle the issue of construction productivity. The paper further uses the data of three cases in a construction project, namely the installations of windows and blinds, concrete slabs, and sheet metal pipes, to verify the effectiveness and feasibility of the proposed novel construction productivity calculation method. The test results show that the proposed novel construction productivity calculation method could be widely used to evaluate the problems related to construction productivity, as well as to rank and to compare the daily labor productivity regardless of efficiency values. The findings can provide a direction for construction managers to improve labor productivity.

Keywords: construction productivity; data envelopment analysis; TOPSIS

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1. Introduction

The requirements of construction projects are to complete a project on time, on budget, and with high quality. Construction productivity is the key factor that determines the success or failure of a project and influences the project quality and business earnings. Robles et al. (2014) [1] proposed that the traditional method to calculate productivity is to use outputs/inputs; however, there are many factors influencing construction productivity, including conditions of the construction site, workers' competence, material suitability, climatic conditions, workers' motivations, and the supervisory mechanism, which is a multi-attribute decision making (MADM) problem. Hence, the actual performance or productivity cannot be calculated by the traditional method.

As there are many factors that must be considered in construction productivity, Enshassi et al. (2007) [2]proposed that the most important factor to improve productivity is to solve the following problems: (1) the complicated characteristics of the construction industry, (2) the difficultly of collecting complete records during project execution, (3) the uncertainty of the productivity of working groups, (4) the difficulty of defining the benchmarking management objectives of construction projects, and (5) the difficulty of integrating effective evaluation standards. Furthermore, there are many indicators that influence the productivity of working groups, which is a complicated problem with multiple inputs and multiple outputs; therefore, it is necessary to calculate productivity based on these influencing indicators. Elwakil, E and Zayed, T (2018) [3] A knowledge management knowledge base system was developed using a fuzzy approach to integrate analytical data and infer any underlying patterns to predict the time and productivity of the construction process. Mlybari and EA (2020) [4] Using different soft computing techniques to evaluate and compare labor productivity in construction. Larsson and Rudberg (2021) [5] using Analytic Hierarchy Process (AHP) analysis and assessment to survey practitioners of concrete construction projects in Sweden about the productivity loss of work tasks exposed to different weather types. Ofori et al. (2021) [6] Strengthen the government's policies and supervision methods to improve the productivity of public works.

To effectively solve problems with multiple inputs and multiple outputs related to data attributes, Charnes et al. (1978) [7] first proposed the data envelopment analysis (DEA) to solve problems with multiple inputs and multiple outputs. Due to its simple calculation and the ability to solve problems with multiple inputs and multiple outputs, DEA has been popularly used. Numerous studies have adopted DEA to solve problems related to decision making. For example, Wang and Lan (2011) [8] proposed a novel method of double frontiers data envelopment analysis (DFDEA) to measure MPI productivity indicators, and evaluate, analyze, and verify the changes in productivity of the Chinese industrial economy over time. Chen (2017) [9] proposed the multifunctional DEA model for multi-activity data envelopment analysis (MADEA), which overcomes the uncertainty of data output, and shares inputs, environmental variables, and inter-temporal efficiencies. The model can be applied to measure the performance of prefectural/municipal departments and entire regions in Taiwan. Fan et al. (2017) [10] used the DEA model to evaluate the ecological efficiencies of Chinese industrial parks, and took park resources, industrial structures, environmental policies, and development scale as the indicators influencing ecological efficiencies to reflect the characteristics of the ecological efficiencies of sustainable development. In addition to the original inputs and outputs of DEA, Kao (2018) [11] considered three intermediate products, e.g., independent, relational, and cooperative, and efficiency reductions to improve the influence of DEA on the evaluation of network performance by decision making units (DMUs), thereby helping internal managers to identify inefficient departments for improvement. To ensure the flight safety of Iran, Barak and Dahooei (2018) [12] integrated fuzzy data envelopment analysis (FDEA) and fuzzy-multi attribute decision making (F-MADM) to evaluate and select the safest airlines of Iran. Amin et al. (2019) [13] proposed a novel method of establishing merger targets by integrating goal programming (GP) and inverse data envelopment analysis (InvDEA). Decision-makers can thus reserve the inputs of specific merger units and preferentially produce specific outputs. More specifically, GP InvDEA is a novel decision support system. Lai et al. (2019) [14] used the novel DEA-based method to evaluate the dredging productivity of the national army and found that the novel method can effectively solve the complicated MADM problem of dredging productivity. Hermoso et al. (2019) [15] By exhaustively examining the efficiency of major airlines in European airspace using the novel input/output parameters of Data Envelope Analysis (DEA), a more complete picture of their operations can be obtained. Papatheodorou et al. (2021) [16] Using the DEA Method to Evaluate the Efficiency of 3D Printers. Abbasi et al. (2021) [17] DEA-based interaction and expansion approach combined with multiple technologies to improve drug sales performance. Zhou et al. (2021) [18] Combine goal-oriented methodology (GO methodology) to

integrate dynamic Bayesian networks (DBNs) and apply DEA methodology to improve smart meter reliability and accuracy. Alidrisi, H. (2021) [19] A model for improving the productivity of warehouses and logistics distribution centers using the PROMETHEE II and DEA methods.

DEA can overcome the limitation of the traditional labor productivity method, and thus, can deal with multi-input and multi-output problems. However, the DEA produces calculation results with equal efficiency, and cannot solve problems that involve equal efficiency. Hwang and Yoon (1981) [20] developed a technique for order preference by similarity to the ideal solution (TOPSIS), which can effectively solve equal efficiency. Zyoud and Fuchs-Hanusch (2017) [21] integrated AHP and TOPSIS to explore the contributions of academic papers under four topics, namely geographic information system, risk model, supply chain management, and sustainability, to the management field of China. Xu et al. (2018) [22] proposed an intelligent TOPSIS method for image segmentation, which utilizes the Neutrosophic set (NS). By using the TOPSIS method and improved fuzzy c-means (FCM) for segmentation of images, the simulated images and actual images can be roughly consistent, thereby proving that the proposed method is very effective and accurate in image segmentation. Zhang et al. (2018) [23] used the improved TOPSIS method to evaluate the performance of Wuhan's public transportation, as based on the four factors of overall development level, infrastructure construction, public transportation service standards, and policy support. The results showed that infrastructure construction needed to be improved first. Kacprzak (2019) [24] used the quadratic ordered fuzzy numbers of the TOPSIS in group decision-making, which first determines the decision makers' various weights, then uses these weights to calculate the sum of the decision matrix, and lastly, applies the TOPSIS on the summed matrix to rank and select the best plan. Li et al. (2019) [25] used sensor fusion neural network and TOPSIS to rank the mechanical operations of the machining of carbon fiber reinforced polymer composites (CFRPs). They found that the mechanical operation decisions were accurate. When the sensor data were fused into the input quantities, the neural network structure (NN) model provided better results. They also verified that the TOPSIS could obtain the optimal conditions. Tang et al. (2019) [26] comprehensively evaluated public blockchains from multiple dimensions and designed three first-grade indicators and 11 s-grade indicators to evaluate the public blockchains. They adopted the TOPSIS to rank the blockchains and proved that the method could objectively evaluate and calculate the weights of various public blockchain indicators for ranking. Their results provided reference for relevant studies and management personnel on decision-making. Ali et al. (2021) [27] Adopted (TOPSIS) technology to improve the best choice of canal lining and related building materials, reducing water loss due to leakage. Ortiz-Barrios et al. (2021) [28] Combining Fuzzy Analytic Hierarchy Process (FAHP) and TOPSIS calculation method, improve the optimal configuration of workshop production scheduling in Industry 4.0, and improve the production efficiency of products. Lim et al. (2021) [29] Analyze and compare the application of AHP and TOPSIS to help the case company select the anchor and increase the sales amount of the online sales company. Huang, D and Han, M (2021) [30] Using TOPSIS's scientific and accurate method for the transportation route of oversized goods, it solves the time cost problem that is difficult to deal with subjective factors and multiple influencing factors. Tamosaitiene et al. (2021) [31] Using multi-criteria decision-making and TOPSIS technology to assess and rank key risk factors (CRFs) can effectively grasp construction risks and alleviate financial pressures. Liang et al. (2022) [32] Using the TOPSIS method to improve the eddy current losses around the coupler in a wireless power transfer (WPT) system. And the effectiveness of the optimization process is verified. Many of the above methods are aimed at solving the difficult and complex problem of labor productivity.

In order to solve complicated problems with multiple inputs and multiple outputs in construction productivity, this paper proposes an improved method that integrates DEA and TOPSIS to establish a more reliable, objective, and accurate novel evaluation model.

The remainder of this paper is organized as follows. Section 2 reviews literature related to traditional productivity and TOPSIS. Section 3 proposes a novel productivity evaluation method based on DEA and TOPSIS. Section 4 adapts the data from the case of Thomas and Sanvido (2000) [33] to verify the effectiveness of the proposed method. Finally, Section 5 provides conclusions and future research directions.

2. Related Works

2.1. Traditional Productivity Method

A construction project is indeed a complicated problem with multiple inputs and multiple outputs that involves the operations of many types of work to complete the project. However, the traditional method to calculate productivity can only solve problems with single input and single output and cannot solve problems with multiple inputs and multiple outputs. A construction project involves many aspects, mainly includes working groups, machines and tools, materials, climate, quality, and safety. However, such data may not be recorded or measured. In traditional productivity, only the completed work items and the work hours of working groups are considered; hence, productivity is defined as the ratio of "outputs" and "inputs" of an item in unit time, as shown in Eq. (1) (Robles et al., 2014[1]).

$$\text{productivity} = \frac{\text{Output quantity}}{\text{Labor hour}} \tag{1}$$

2.2. Topsis Method

Hwang and Yoon (1981) [20] developed the TOPSIS, which has been widely applied on MADM problems. TOPSIS mainly focuses on the definition and application of the positive ideal solution (PIS) and negative ideal solution (NIS). The PIS has the maximum output value (benefit criteria) and the minimum input value (cost criteria), while the NIS has the minimum output value (benefit criteria) and the maximum input value (cost criteria). Its basic principle is that the optimal solution is closest to the PIS and farthest from the NIS in calculation. The advantages of TOPSIS are that it is simple, easy to calculate and understand, and able to avoid the situations that the calculation result is simultaneously closest to or the farthest from the PIS and NIS, meaning completing the most work items or achieving the best efficiency with the least time or minimum costs. The calculation steps of TOPSIS are described as follows (Zhang et al., 2018; Zyoud & Fuchs-Hanusch, 2017 [23]):

Step 1: Construct the normalized decision matrix

In units of each input and output item, calculate the ratio of the sum of squares of n evaluation items and all m working days to their square root, as shown in Equation (2).

$$\delta_{ij} = \frac{x_{ij}}{\sqrt{\sum_j^J x_{ij}^2}}, j = 1,2,3, \dots \dots, J, i = 1,2,3, \dots \dots, n \tag{2}$$

δ_{ij} is the coefficient after normalization with the value between [0,1], and x_{ij} is the value of various work items.

Step 2: Calculate the normalized decision matrix

In units of each input and output item after normalization, multiply all indicators by their own objective weights, as shown in Equation (3).

$$\rho_{ij} = w_i * \delta_{ij}, j = 1,2,3, \dots \dots, J, \ i = 1,2,3, \dots \dots, n \tag{3}$$

ρ_{ij} is the evaluation value after the consideration of objective weights, w_i is the objective weight of all evaluation indicators. It must be noted that the sum of the objective weights of the inputs and outputs shall be 1.

Step 3: Determine the best ideal solution and the worst ideal solution

Calculate the PIS V^+ and the NIS V^- in each input and output item. If the output item is a benefit criterion, the PIS is the maximum normal weighted value of all output indicators under the same criterion, while the NIS is the minimum normal weighted value of all output indicators under the same criterion; for the cost criterion, the PIS is the minimum normal weighted value of all input indicators in the input items, while the NIS is the maximum normal weighted value of all input indicators in the same input item, as shown in Equations (4) and (5). V^+ denotes benefit criterion and V^- denotes the cost criterion.

$$V^+ = \{V_1^+, V_2^+, \dots\dots, V_m^+\}, V_j^+ = max\{V_{ij}\}, i = 1,2,3, \dots\dots, m \quad (4)$$

$$V^- = \{V_1^-, V_2^-, \dots\dots, V_m^-\}, V_j^- = min\{V_{ij}\}, i = 1,2,3, \dots\dots, m \quad (5)$$

Step 4: Calculate the separation measures from the PIS and the NIS

Calculate the sum of squares of all the normal weighted values of each evaluation indicator and the sum of the PIS of all criteria, and then, take its square root, as shown in Equation (6), to obtain D_i^+; calculate the sum of squares of the difference between all daily normal weighted values and the NIS of all criteria, and then, take its square root, as shown in Equation (7), to obtain D_i^-.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^+\right)^2}, j = 1,2, \dots, J \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2}, \ j = 1,2, \dots, J \quad (7)$$

Step5: Calculate the relative closeness to the PIS

Consider the best solution C_i^+ for the distances between the performance of all evaluation indicators and the PIS and NIS; calculate the relative closeness of all evaluation indicators to the PIS by simultaneously considering D_i^+ and D_i^-. The farther from the NIS, the better, and larger D_i^- and C_i^+ values are better, but must be between 0 and 1, as shown in Equation (8).

$$C_i^+ = \frac{D_i^-}{D_i^- + D_i^+}, \ 0 < C_i^+ < 1 \quad (8)$$

3. The Proposed Novel Construction Productivity Calculation Method

The productivity of a construction project requires an accurate method to measure the performance of working groups, and the productivity of such working groups is a complicated MADM problem. The traditional method can only solve productivity problems with single input and single output, cannot solve construction productivity problems with many inputs and output. DEA can directly solve productivity problems with multiple inputs and multiple outputs; however, DEA may generate many productivity values of 1, and cannot compare or rank productivities that equal 1. Therefore, this study proposes a method that can solve problems with multiple inputs and multiple outputs and rank the calculation results, where the calculation results are consistent with the trends of inputs and outputs. The procedures of the novel productivity calculation method, as proposed in this paper, include the following 8 steps:

Step 1. Observe and record the daily work hours and completed work items.

Step 2. Establish a formalized performance matrix for the recorded input and output data.

Step 3. Use the calculation results of the formalized performance matrix to respectively calculate the weights of inputs and outputs, and the sum of the weights should be 1.

Step 4. Confirm the PIS and NIS of inputs and outputs after weight calculation, where smaller input items and larger output items are better.
Step 5. Calculate the sum of the squares of the difference between all daily normal weighted values and the sum of and the difference between the PIS and NIS of all criteria, and then, take their square roots to obtain the distance between the PIS and NIS.
Step 6. Consider the best solution for the distances between the daily performance and the PIS and NIS, and then, calculate the relative closeness of the daily productivity to the PIS to obtain the relative performance indicator values.
Step 7. Rank the calculation results.
Step 8. Compare the calculation results of each method.

The flowchart of the novel construction productivity calculation is shown in Figure 1.

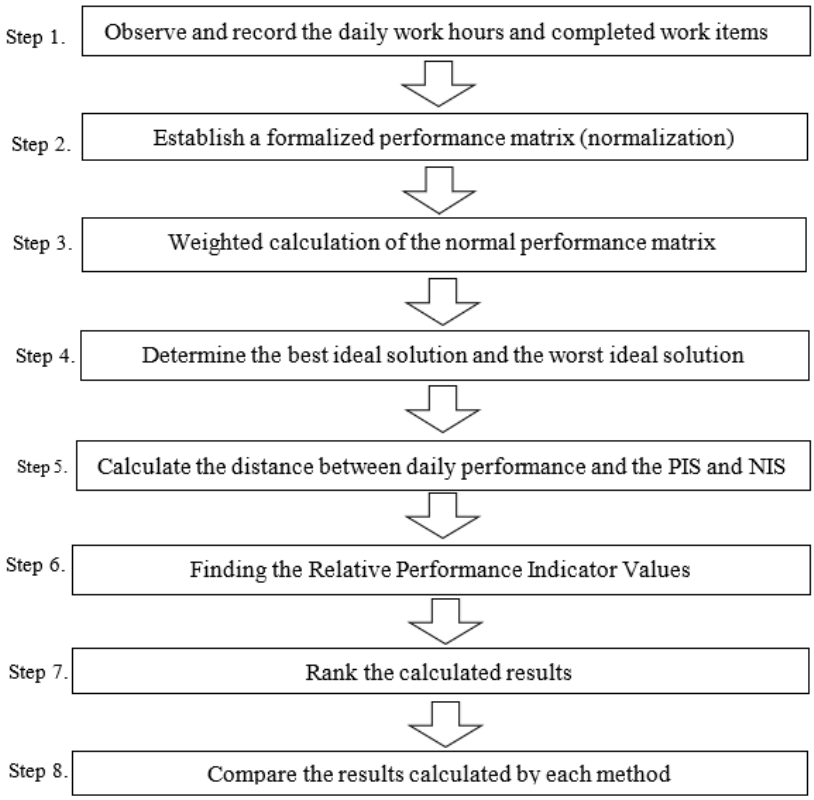

Figure 1. Flowchart of the proposed novel construction productivity calculation method.

4. Case Study

4.1. Overview

To verify the accuracy of the proposed method, this study adapted the case data of Thomas and Sanvido (2000) [33]. This case was the observations and records of a construction project of a three-story reinforced concrete research building located in Pennsylvania State University. The building consisted of offices, classrooms, and laboratories, covering an area of 92,000 sq.ft. (8850 sq.m.), and with a value of. USD 12 million. Data analysis was performed on the 36-day pipe installation work, during which three types of pipes were installed: 1) branch ducts, which are less than 30 in (75.9 cm), and 1492 ft (455 m) were installed; 2) main feeder ducts, which are between 30–50 in (75.9–126.5 cm), and 220 ft (67 m) were installed; 3) large feeder ducts, which are larger than 50 in (larger than 126.5 cm),

and 118 ft (36 m) were installed. In addition, 43 fire dampers were installed. The detailed records are shown in Table 1.

Table 1. Data from adapted case.

Workday	Input	Output			
	Work Hours	Fire Damper	Branch Duct	Small Feeder Duct	Large Feeder Duct
1	40	1.200	30.630	0.000	0.000
2	40	0.000	55.060	0.000	0.000
3	40	0.000	86.250	0.000	0.000
4	40	3.000	40.000	0.000	0.000
5	24	0.000	67.440	0.000	0.000
6	24	0.000	93.560	0.000	0.000
7	24	0.000	45.880	0.000	0.000
8	24	1.600	23.250	0.000	0.000
9	24	0.000	0.000	17.250	2.250
10	24	0.000	27.190	4.500	1.500
11	24	2.000	28.690	0.000	0.000
12	40	0.000	41.690	0.000	3.000
13	40	0.000	80.130	0.000	0.000
14	40	0.1	54.630	5.130	0.000
15	24	2.000	25.130	0.000	0.000
16	24	0.000	90.880	6.750	0.000
17	24	1.400	16.430	1.500	1.500
18	24	0.000	26.310	0.000	0.000
19	24	2.000	57.940	0.000	0.000
20	24	0.000	0.000	30.000	0.000
21	24	0.000	60.000	0.000	0.000
22	40	0.000	24.310	22.340	12.000
23	40	0.000	65.310	19.000	29.880
24	40	0.000	18.750	0.000	20.250
25	40	0.000	47.000	11.310	20.690
26	40	0.000	34.500	7.130	2.250
27	40	0.000	39.630	5.440	23.630
28	32	0.000	0.000	37.700	0.750
29	40	0.000	11.940	35.190	0.000
30	40	0.000	56.720	16.160	0.000
31	40	0.000	33.880	0.000	0.000
32	40	10.000	49.380	0.000	0.000
33	40	9.000	16.880	0.000	0.000
34	40	10.000	13.880	0.000	0.000
35	24	0.000	76.810	0.000	0.000
36	24	0.000	49.500	0.000	0.000

4.2. Solution by the Traditional Productivity Method

Due to the traditional productivity calculation method just only solve the problem of single input and a single output, there is no way to directly calculate the problem of single input and multiple outputs, multiple inputs and single outputs, or multiple inputs and multiple outputs. The data must be converted before calculations. The case a quote from the case presented in Thomas and Sanvido (2000) [33] is the actual record data of 1 input and 4 outputs (see Table 1). In order to make the traditional method can be solved, we use

Equation (2) to standardize the input and output of the data in Table 1. The converted data is shown in Table 2.

Table 2. Establish a formalized performance matrix from the adapted case data.

Workday	Input	Output			
	Work Hours	Fire Damper	Branch Duct	Small Feeder Duct	Large Feeder Duct
1	0.198	0.066	0.105	0.000	0.000
2	0.198	0.000	0.189	0.000	0.000
3	0.198	0.000	0.297	0.000	0.000
4	0.198	0.166	0.138	0.000	0.000
5	0.119	0.000	0.232	0.000	0.000
6	0.119	0.000	0.322	0.000	0.000
7	0.119	0.000	0.158	0.000	0.000
8	0.119	0.088	0.080	0.000	0.000
9	0.119	0.000	0.000	0.236	0.045
10	0.119	0.000	0.094	0.061	0.030
11	0.119	0.111	0.099	0.000	0.000
12	0.198	0.000	0.143	0.000	0.061
13	0.198	0.000	0.276	0.000	0.000
14	0.198	0.000	0.188	0.070	0.000
15	0.119	0.111	0.086	0.000	0.000
16	0.119	0.000	0.313	0.092	0.000
17	0.119	0.077	0.056	0.020	0.030
18	0.119	0.000	0.091	0.000	0.000
19	0.119	0.111	0.199	0.000	0.000
20	0.119	0.000	0.000	0.410	0.000
21	0.119	0.000	0.206	0.000	0.000
22	0.198	0.000	0.084	0.305	0.242
23	0.198	0.000	0.225	0.260	0.603
24	0.198	0.000	0.064	0.000	0.408
25	0.198	0.000	0.162	0.155	0.417
26	0.198	0.000	0.119	0.097	0.045
27	0.198	0.000	0.136	0.074	0.477
28	0.159	0.000	0.000	0.529	0.015
29	0.198	0.000	0.041	0.481	0.000
30	0.198	0.000	0.195	0.221	0.000
31	0.198	0.000	0.117	0.000	0.000
32	0.198	0.553	0.170	0.000	0.000
33	0.198	0.553	0.058	0.000	0.000
34	0.198	0.553	0.058	0.000	0.000
35	0.119	0.000	0.264	0.000	0.000
36	0.119	0.000	0.170	0.000	0.000

After the formalized conversion of all output items (Table 2), the daily output weights after conversion can be summed to calculate daily productivity by using Eq. (1). The calculation results are shown in Table 3.

Table 3. Calculation productivity results by the traditional productivity method.

Work day	Input	Output	Daily Productivity
	Work Hours	Sum All Job	Output/Input

1	0.198	0.172	0.865
2	0.198	0.189	0.955
3	0.198	0.297	1.495
4	0.198	0.304	1.530
5	0.119	0.232	1.949
6	0.119	0.322	2.703
7	0.119	0.158	1.326
8	0.119	0.168	1.415
9	0.119	0.281	2.361
10	0.119	0.185	1.556
11	0.119	0.209	1.758
12	0.198	0.204	1.028
13	0.198	0.276	1.389
14	0.198	0.258	1.300
15	0.119	0.197	1.655
16	0.119	0.405	3.401
17	0.119	0.184	1.548
18	0.119	0.091	0.760
19	0.119	0.310	2.603
20	0.119	0.410	3.443
21	0.119	0.206	1.734
22	0.198	0.631	3.180
23	0.198	1.087	5.478
24	0.198	0.473	2.384
25	0.198	0.734	3.697
26	0.198	0.261	1.318
27	0.198	0.687	3.464
28	0.159	0.544	3.426
29	0.198	0.522	2.630
30	0.198	0.416	2.096
31	0.198	0.117	0.587
32	0.198	0.723	3.643
33	0.198	0.611	3.080
34	0.198	0.611	3.080
35	0.119	0.264	2.219
36	0.119	0.170	1.430

4.3. Solution by the Thomas (1999) [34] Method

Thomas (2000) used the multiple regression techniques to calculate the daily productivity of single-input and multi-output. In the three-story reinforced concrete research case, Thomas (2000) applied the work hours as the dependent variable, and the fire damper, branch duct, small feeder duct, large feeder duct as the independent variables. The coefficient calculation results of multiple regression techniques for the independent variables (fire damper, branch duct, small feeder duct, large feeder duct) as the 3.101, 0.446, 0.843 and 0.563, respectively.

Thomas (2000) used the small feeder duct as a benchmark, the coefficient of independent variables (fire damper, branch duct, small feeder duct, large feeder duct) divided by the coefficient of small feeder duct to obtain the conversion factors, as shown in Table 4. Sum of output are the products of independent variables multiply conversion factors.

Table 4. Daily productivity calculation results by the Thomas (2000) method.

Workday	Input	Output					Daily Productivity
	Work Hours	Fire Damper	Branch Duct	Small Feeder Duct	Large Feeder Duct	Sum	Input/Output
Regression coefficient		**3.101**	**0.446**	**0.843**	**0.563**		
Conversion factors		**3.680**	**0.529**	**1.000**	**0.668**		
1	40	1.200	30.630	0.000	0.000	20.626	1.939
2	40	0.000	55.060	0.000	0.000	29.139	1.373
3	40	0.000	86.250	0.000	0.000	45.645	0.876
4	40	3.000	40.000	0.000	0.000	32.209	1.242
5	24	0.000	67.440	0.000	0.000	35.690	0.672
6	24	0.000	93.560	0.000	0.000	49.513	0.485
7	24	0.000	45.880	0.000	0.000	24.280	0.988
8	24	1.600	23.250	0.000	0.000	18.192	1.319
9	24	0.000	0.000	17.250	2.250	18.753	1.280
10	24	0.000	27.190	4.500	1.500	19.891	1.207
11	24	2.000	28.690	0.000	0.000	22.543	1.065
12	40	0.000	41.690	0.000	3.000	24.066	1.662
13	40	0.000	80.130	0.000	0.000	42.406	0.943
14	40	0.000	54.630	5.130	0.000	34.041	1.175
15	24	2.000	25.130	0.000	0.000	20.659	1.162
16	24	0.000	90.880	6.750	0.000	54.845	0.438
17	24	1.400	16.310	1.500	1.500	16.285	1.474
18	24	0.000	26.310	0.000	0.000	13.924	1.724
19	24	2.000	57.940	0.000	0.000	38.023	0.631
20	24	0.000	0.000	30.000	0.000	30.000	0.800
21	24	0.000	60.000	0.000	0.000	31.753	0.756
22	40	0.000	24.310	22.340	12.000	43.219	0.926
23	40	0.000	65.310	19.000	29.880	73.517	0.544
24	40	0.000	18.750	0.000	20.250	23.446	1.706
25	40	0.000	47.000	11.310	20.690	50.000	0.800
26	40	0.000	34.500	7.130	2.250	26.890	1.488
27	40	0.000	39.630	5.440	23.630	42.193	0.948
28	32	0.000	0.000	38.700	0.750	39.201	0.816
29	40	0.000	11.940	35.190	0.000	41.509	0.964
30	40	0.000	56.720	16.160	0.000	46.177	0.866
31	40	0.000	33.880	0.000	0.000	17.930	2.231
32	40	10.000	49.380	0.000	0.000	62.933	0.636
33	40	10.000	16.880	0.000	0.000	45.734	0.875
34	40	10.000	16.880	0.000	0.000	45.734	0.875
35	24	0.000	76.810	0.000	0.000	40.649	0.590
36	24	0.000	49.500	0.000	0.000	26.196	0.916

4.4. Solution by the DEA Method

Lin and Huang (2010) [35] used DEA (CCR) method to calculate the daily productivity of pipe installation work in the three-story reinforced concrete research case. The DEA method can handle complicated data problems with multiple inputs and multiple

outputs. Applied the CCR model of DEAP software to calculate the daily productivity of pipe installation work, the daily productivity calculation results as shown in Table 5.

Table 5. Daily productivity calculation results by the DEA method.

	Input	Output				DEA (CCR)
Workday	Work Hours	Fire Damper	Branch Duct	Small Feeder Duct	Large Feeder Duct	Daily Productivity
1	40	1.200	30.630	0.000	0.000	0.278
2	40	0.000	55.060	0.000	0.000	0.353
3	40	0.000	86.250	0.000	0.000	0.553
4	40	3.000	40.000	0.000	0.000	0.462
5	24	0.000	67.440	0.000	0.000	0.721
6	24	0.000	93.560	0.000	0.000	1.000
7	24	0.000	45.880	0.000	0.000	0.490
8	24	1.600	23.250	0.000	0.000	0.431
9	24	0.000	0.000	17.250	2.250	0.653
10	24	0.000	27.190	4.500	1.500	0.406
11	24	2.000	28.690	0.000	0.000	0.534
12	40	0.000	41.690	0.000	3.000	0.326
13	40	0.000	80.130	0.000	0.000	0.514
14	40	0.000	54.630	5.130	0.000	0.382
15	24	2.000	25.130	0.000	0.000	0.496
16	24	0.000	90.880	6.750	0.000	1.000
17	24	1.400	16.310	1.500	1.500	0.387
18	24	0.000	26.310	0.000	0.000	0.281
19	24	2.000	57.940	0.000	0.000	0.847
20	24	0.000	0.000	30.000	0.000	1.000
21	24	0.000	60.000	0.000	0.000	0.641
22	40	0.000	24.310	22.340	12.000	0.696
23	40	0.000	65.310	19.000	29.880	1.000
24	40	0.000	18.750	0.000	20.250	0.678
25	40	0.000	47.000	11.310	20.690	0.704
26	40	0.000	34.500	7.130	2.250	0.341
27	40	0.000	39.630	5.440	23.630	0.791
28	32	0.000	0.000	38.700	0.750	0.987
29	40	0.000	11.940	35.190	0.000	0.765
30	40	0.000	56.720	16.160	0.000	0.613
31	40	0.000	33.880	0.000	0.000	0.217
32	40	10.000	49.380	0.000	0.000	1.000
33	40	10.000	16.880	0.000	0.000	1.000
34	40	10.000	16.880	0.000	0.000	1.000
35	24	0.000	76.810	0.000	0.000	0.821
36	24	0.000	49.500	0.000	0.000	0.529

4.5. Solution by the Proposed Novel Productivity Calculation Method

Construction engineering is a complex MCDM problem with multiple data inputs and multiple data outputs. However, traditional productivity methods deal only with a single input and output data problem. On the other hand, although the DEA method can solve the problem of multiple inputs and multiple outputs, because the results calculated by the DEA method have the same efficiency (the efficiency is equal to 1), it is impossible to know which is more efficient and which is less efficient.

In order to efficiently solve DEA there are many computations with an efficiency equal to 1. This paper proposed an integrated TOPSIS and DEA novel construction productivity calculation method. The solution steps are as follows.

Step 1: Observe and record the daily work hours and completed work items

Observation and record of the installation time of Fire damper, Branch duct, Feeder duck Small and Feeder duck Large, etc. adapted from the case data of Thomas and Sanvido (2000) [33], as shown in Table 1.

Step 2: Establish a formalized performance matrix (normalization)

According to the data recorded in Table 1 and using Equation (2) calculation results are shown in Table 6.

Table 6. Establish a formalized performance matrix from the adapted case data.

Work day	Input	Output			
	Work Hours	Fire Damper	Branch Duct	Feeder Duck Small	Feeder Duck Large
1	1	0.030	0.766	0.000	0.000
2	1	0.000	1.377	0.000	0.000
3	1	0.000	2.156	0.000	0.000
4	1	0.075	1.000	0.000	0.000
5	1	0.000	2.810	0.000	0.000
6	1	0.000	3.898	0.000	0.000
7	1	0.000	1.912	0.000	0.000
8	1	0.067	0.969	0.000	0.000
9	1	0.000	0.000	0.719	0.094
10	1	0.000	1.133	0.188	0.063
11	1	0.083	1.195	0.000	0.000
12	1	0.000	1.042	0.000	0.075
13	1	0.000	2.003	0.000	0.000
14	1	0.000	1.366	0.128	0.000
15	1	0.083	1.047	0.000	0.000
16	1	0.000	3.787	0.281	0.000
17	1	0.058	0.680	0.063	0.063
18	1	0.000	1.096	0.000	0.000
19	1	0.083	2.414	0.000	0.000
20	1	0.000	0.000	1.250	0.000
21	1	0.000	2.500	0.000	0.000
22	1	0.000	0.608	0.559	0.300
23	1	0.000	1.633	0.475	0.747
24	1	0.000	0.469	0.000	0.506
25	1	0.000	1.175	0.283	0.517
26	1	0.000	0.863	0.178	0.056
27	1	0.000	0.991	0.136	0.591
28	1	0.000	0.000	1.209	0.023
29	1	0.000	0.299	0.880	0.000
30	1	0.000	1.418	0.404	0.000
31	1	0.000	0.847	0.000	0.000
32	1	0.250	1.235	0.000	0.000
33	1	0.250	0.422	0.000	0.000
34	1	0.250	0.422	0.000	0.000
35	1	0.000	3.200	0.000	0.000
36	1	0.000	2.063	0.000	0.000

Step 3: Weighted calculation of the normal performance matrix

The output data (Fire damper, Branch duct, Feeder duck Small and Feeder duck Large) are assumed equal weight. Using Equation (3) to calculations, the normal matrix weighted performance matrix as shown in Table 7.

Step 4: Determine the best ideal solution and the worst ideal solution

Using Equations (4) and (5), to determine the best ideal solution and the worst ideal solution, the results are shown in Table 7.

Table 7. Calculate normal matrix weighted objective weights for input and output items.

Work day	Input		Output		
	Work Hours	Fire Damper	Branch Duct	Feeder Duck Small	Feeder Duck Large
Weight	**1**	**0.25**	**0.25**	**0.25**	**0.25**
1	1.000	0.016	0.019	0.000	0.000
2	1.000	0.000	0.034	0.000	0.000
3	1.000	0.000	0.054	0.000	0.000
4	1.000	0.040	0.025	0.000	0.000
5	1.000	0.000	0.070	0.000	0.000
6	1.000	0.000	0.097	0.000	0.000
7	1.000	0.000	0.048	0.000	0.000
8	1.000	0.035	0.024	0.000	0.000
9	1.000	0.000	0.000	0.078	0.019
10	1.000	0.000	0.028	0.020	0.013
11	1.000	0.044	0.030	0.000	0.000
12	1.000	0.000	0.026	0.000	0.015
13	1.000	0.000	0.050	0.000	0.000
14	1.000	0.000	0.034	0.014	0.000
15	1.000	0.044	0.026	0.000	0.000
16	1.000	0.000	0.095	0.031	0.000
17	1.000	0.031	0.017	0.007	0.013
18	1.000	0.000	0.027	0.000	0.000
19	1.000	0.044	0.060	0.000	0.000
20	1.000	0.000	0.000	0.136	0.000
21	1.000	0.000	0.062	0.000	0.000
22	1.000	0.000	0.015	0.061	0.060
23	1.000	0.000	0.041	0.052	0.150
24	1.000	0.000	0.012	0.000	0.102
25	1.000	0.000	0.029	0.031	0.104
26	1.000	0.000	0.022	0.019	0.011
27	1.000	0.000	0.025	0.015	0.119
28	1.000	0.000	0.000	0.132	0.005
29	1.000	0.000	0.007	0.096	0.000
30	1.000	0.000	0.035	0.044	0.000
31	1.000	0.000	0.021	0.000	0.000
32	1.000	0.132	0.031	0.000	0.000
33	1.000	0.132	0.011	0.000	0.000
34	1.000	0.132	0.011	0.000	0.000
35	1.000	0.000	0.080	0.000	0.000
36	1.000	0.000	0.052	0.000	0.000
V^+(Hope)	**1.000(min)**	**0.132(max)**	**0.097(max)**	**0.136(max)**	**0.150(max)**
V^-(Hope)	**1.000 (max)**	**0.000(min)**	**0.000 (min)**	**0.000 (min)**	**0.000 (min)**

Step 5: Calculate the distance between daily performance and the PIS and NIS

In this step, we used Equations (6) and (7) to calculate the distance between daily performance and the PIS(D_i^+) and NIS(D_i^-), respectively, as shown in Table 8.

Table 8. Calculate the distance between daily performance and the PIS and NIS.

Work Day	D_i^+	D_i^-
1	0.246	0.025
2	0.250	0.034
3	0.246	0.054
4	0.234	0.047
5	0.244	0.070
6	0.242	0.097
7	0.247	0.048
8	0.236	0.043
9	0.218	0.080
10	0.234	0.037
11	0.231	0.053
12	0.244	0.030
13	0.247	0.050
14	0.243	0.037
15	0.232	0.051
16	0.226	0.099
17	0.229	0.038
18	0.252	0.027
19	0.224	0.075
20	0.223	0.136
21	0.245	0.062
22	0.195	0.087
23	0.167	0.164
24	0.214	0.102
25	0.188	0.112
26	0.237	0.031
27	0.196	0.122
28	0.220	0.132
29	0.223	0.096
30	0.229	0.056
31	0.254	0.021
32	0.213	0.136
33	0.220	0.133
34	0.220	0.133
35	0.243	0.080
36	0.246	0.052

Step 6: Finding the Relative Performance Indicator Values

To find relative performance indicator values, we used Equation (8) to calculate the relative Performance Indicator Values (C_i^+), the calculation results are shown in Table 9.

Step 7: Rank the calculated results

According to the productivity calculation method proposed in this study, the results are ranked to find the best and equivalent dates, as shown in Table 9.

Table 9. Calculate relative Performance Indicator Values (C_i^+) and rank.

Work Day	Ci^+	Rank
1	0.09	35
2	0.12	31
3	0.18	22
4	0.17	25
5	0.22	17
6	0.29	13
7	0.16	26
8	0.15	27
9	0.27	14
10	0.14	29
11	0.19	20
12	0.11	33
13	0.17	24
14	0.13	30
15	0.18	21
16	0.31	11
17	0.14	28
18	0.10	34
19	0.25	15
20	0.38	4
21	0.20	18
22	0.31	10
23	0.50	1
24	0.32	9
25	0.37	8
26	0.12	32
27	0.38	3
28	0.37	7
29	0.30	12
30	0.20	19
31	0.08	36
32	0.39	2
33	0.38	5
34	0.38	5
35	0.25	16
36	0.17	23

Step 8. Compare the results calculated by each method

Rank the results obtained by all productivity calculation methods, and the calculation results are shown in Table 10.

Table 10. Compare the results calculated by each method.

Workday	Traditional Method		Thomas Method		DEA Method		TOPSIS Method		Propose Method	
	Output/input	Ranking	Input/Output	Ranking	Performance	Ranking	C_i^+	Ranking	Performance	Ranking
1	1.273	28	1.280	6	0.278	35	0.09	35	0.277	35
2	2.255	13	0.726	25	0.353	31	0.12	31	0.353	31
3	3.533	5	0.464	35	0.553	20	0.18	22	0.554	20
4	1.684	20	0.963	17	0.462	26	0.17	25	0.463	26
5	1.718	18	0.689	28	0.721	13	0.22	17	0.72	13
6	2.383	12	0.497	33	1.000	1	0.29	13	1	1
7	1.168	31	1.013	13	0.490	25	0.16	26	0.491	25
8	1.452	26	1.231	8	0.431	27	0.15	27	0.429	27
9	1.630	21	1.218	9	0.653	17	0.27	14	0.652	17
10	1.301	27	1.190	11	0.406	28	0.14	29	0.405	28
11	1.806	17	0.992	14	0.534	21	0.19	20	0.535	21
12	0.999	34	1.613	3	0.326	33	0.11	33	0.326	33
13	1.224	30	0.967	16	0.514	23	0.17	24	0.515	23
14	1.045	33	1.200	10	0.382	30	0.13	30	0.383	30
15	1.715	19	1.074	12	0.496	24	0.18	21	0.495	24
16	2.775	8	0.447	36	1.000	1	0.31	11	1	1
17	1.572	23	1.325	5	0.387	29	0.14	28	0.384	29
18	0.670	35	1.767	2	0.281	34	0.10	34	0.283	34
19	2.551	11	0.611	30	0.847	9	0.25	15	0.846	9
20	2.048	15	0.800	22	1.000	1	0.38	4	1	1
21	1.528	25	0.775	23	0.641	18	0.20	18	0.64	18
22	2.734	9	0.833	20	0.696	15	0.31	10	0.695	15
23	5.380	1	0.469	34	1.000	1	0.50	1	1	1
24	2.729	10	1.258	7	0.678	16	0.32	9	0.677	16
25	3.677	4	0.688	29	0.704	14	0.37	8	0.703	14
26	1.091	32	1.460	4	0.341	32	0.12	32	0.341	32
27	3.678	3	0.774	24	0.791	11	0.38	3	0.791	11
28	2.094	14	0.810	21	0.987	8	0.37	7	0.985	8
29	1.624	22	0.967	15	0.765	12	0.30	12	0.766	12
30	1.529	24	0.880	19	0.613	19	0.20	19	0.614	19
31	0.518	36	2.287	1	0.217	36	0.08	36	0.218	36
32	3.981	2	0.553	32	1.000	1	0.39	2	1	1
33	3.484	6	0.720	26	1.000	1	0.38	5	1	1
34	3.484	6	0.720	26	1.000	1	0.38	5	1	1
35	1.956	16	0.605	31	0.821	10	0.25	16	0.82	10
36	1.261	29	0.939	18	0.529	22	0.17	23	0.528	22

4.6. Comparison and Discussion

In order to verify that the proposed productivity calculation method can improve the disadvantages in productivity calculation, this study adapted the data from the case presented in Thomas and Sanvido (2000) [33]. To calculate productivity by the traditional calculation method, it is necessary to change the output items into one item after conversion of the formalized performance matrix. Thomas (1990,1994) [36,37] used this regression method to identify the conversion factors, and c converted the output items w to one item before calculation; however, both the traditional method and the Thomas method can only solve problems with single input and single output. DEA calculates the daily productivity based on the input and output coefficients entered into the DEAP software, and the values closer to 1 are considered better. Although DEA can solve problems with multiple inputs and multiple outputs, it cannot further compare the advantages and

disadvantages of productivities when the values are all 1. The novel multi-input and multi-output productivity calculation method can solve, compare, and rank the largest and equal productivity calculation results. The main differences of the above four methods are compared, among them, to solve the problem of productivity with single input and multiple outputs, only the traditional calculation method cannot solve it. The remaining three methods can deal with related problems; the problem of productivity calculation with multiple inputs and multiple outputs can only be solved by DEA and proposed method, as for solving the effectively resolve performance duplication of multiple inputs and multiple outputs, only the proposed method can solve it. For the above four methods, the relative problems can be summarized the results are shown in Table 11.

Table 11. Comparing the main differences of the above four methods.

Method / Solve Problem	Traditional	Thomas	DEA	Proposed Method
Multiple inputs and single outputs	No	Yes	Yes	Yes
Multiple inputs and multiple outputs	No	No	Yes	Yes
Effectively resolve performance duplication	Yes	Yes	No	Yes

5. Conclusions and Future Work

In addition to material costs, the largest expense in construction is labor cost. As different working groups are equipped differently, the quality of labor productivity influences the capital expenditures, thus, how to improve management efficiency and reduce personnel cost through labor productivity calculation is very important. There are many items to be considered when evaluating labor productivity, such as machines and tools, climate, work complexity, material supply, and material stacking, which constitute a MADM problem. However, the traditional method can only solve problems with single input and single output, can not solve construction productivity problems with many input and output. Although the DEA method can solve the multi-input and multi-output productivity calculation problem; however, DEA is unable to compare the calculation results when the efficiencies are equal.

For calculation of labor productivity, this study integrated TOPSIS to solve the disadvantages of the traditional method (only able to solve problems with single input and single output) and DEA (unable to compare equal efficiencies). A real case was used to verify the effectiveness and feasibility of the proposed method, and the simulation results showed that the extended TOPSIS method proposed in this study is more suitable for labor productivity evaluation.

In the future studies, more consideration can be given to man-made and natural risk evaluations, the proficiency of working groups, and management methods, to conduct further exploration. In terms of calculation methods, soft set and fuzzy TOPSIS can be integrated to evaluate labor productivity.

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