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Combining Novel Integration and the DEA Technique to Compute Dredging Productivity

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Abstract: Construction productivity entails a wide range of work combinations. When human resources are scarce, it is critical to replace manpower with machinery, and calculating machinery productivity is crucial. Traditional labor productivity methods, however, cannot address dredging complex multi-attribute decision-making (MADM) problems. Aiming to address the limitations of the traditional labor productivity method, this paper extends the data envelopment analysis (DEA) and proposes a new dredging productivity evaluation method. The proposed method can solve the problem of evaluating various combinations of factors (single-input, multiple-input, single-output, and multiple-output) and the problem suggesting that the efficiency of the DEA method'scalculation results is equal to 1. The effectiveness of the proposed method was verified using reservoir dredging examples. The simulation results show that the proposed method has broad applicability, can accurately evaluate the related dredging performance issues, and provide directions for construction managers to improve labor productivity.

Keywords: dredging productivity; data envelopment analysis

1. Introduction

Completing a construction project on time, on budget, and with excellent quality is critical to a project's success. Construction efficiency (productivity) is also a key factor determining the success or failure of a project, affecting project quality and revenue. Many factors influence construction productivity, such as construction site conditions, worker capabilities, material suitability, climatic conditions, worker motivation, and supervisory mechanisms. The emergence of such issues is referred to as a multiple-attribute decision-making (MADM) problem. Therefore, traditional methods cannot calculate actual performance or productivity.

Many scholars evaluate productivity using different methods. Some scholars used soft computing techniques to evaluate and compare labor productivity in construction [1]. Others used the Analytic Hierarchy Process (AHP) analysis to investigate the productivity losses of practitioners in concrete construction projects in Sweden and assessed the impacts of their exposure to different weather types while performing work tasks [2]. Some scholars experimented with strengthening government policy and regulatory tools to increase productivity in public works [3].

The significant increase in the frequency of natural disasters due to extreme climate change has increased the risk of natural disasters. Floods induced by heavy rainfall create reservoir sedimentation, reducing reservoir capacity by 1% per year worldwide, which has become a major problem globally. Many scholars also proposed using engineering methods to address flooding issues, such as building dams, dredging rivers, and heightening and strengthening buildings.

Dredging, a planned and systematic excavation activity, is a critical issue in water resource management. Many scholars have investigated the issues related to dredging. For example, some scholars developed a river dredging management model in South Korea using multi-criteria decision analysis techniques, which assigns weights to various dredging-related factors, such as dredging costs and social and environmental impacts, to address river dredging problems [4]. Other scholars discussed the problem definition and model formulation for optimal dredging fleet scheduling to

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improve the efficiency of dredging projects initiated by the United States Army Corps of Engineers (USACE) [5]. Decision-makers can use this approach to boost dredger productivity. Some scholars also asserted that proper planning and scheduling could significantly reduce waiting times and address delays, making earthworks more efficient while reducing cost overruns risks[6].

Dredging performance (productivity) is a major research area in construction engineering and management science. Dredging requires the transportation of large volumes of soil, necessitating combined transportation methods and complex machinery. Therefore, reservoir dredging is classified as a complex multi-attribute decision-making (MADM) problem.

Traditional methods for assessing dredging productivity use a labor productivity method to evaluate the issues related to dredging performance. Productivity is defined as "the work hour (WH) required to complete a unit of work." Some researchers stated that productivity research should focus on labor-intensive, repetitive, and important crew work [7]. They used the latest version of the world's largest corporate financial database to identify three statistical properties related to manual labor productivity [8].

To efficiently address the multiple-input and multiple-output (MIMO) problems associated with data attributes, Data Envelope Analysis (DEA) was first proposed [9]. Due to its simple calculation and ability to solve MIMO problems, many scholars employed DEA to address decision-related problems.

The proposed multifunctional DEA model for multi-activity data envelopment analysis (MADEA) can overcome data output uncertainty and share inputs, environmental variables, and inter-temporal efficiencies [10]. The model can measure the performance of prefectural/municipal departments and the entire Taiwanese. On the other hand, the integrated fuzzy data envelopment analysis (FDEA) and fuzzy-multi attribute decision-making (F-MADM) were used to evaluate and select the safest airlines in Iran [11]. Some scholars used the novel DEA-based method to evaluate the dredging productivity of the national army and found that it can effectively address the complicated MADM problem of dredging productivity [12]. A complete picture of major airlines' operations can be achieved by exhaustively examining their efficiency in European airspace using the novel input/output parameters of the Data Envelope Analysis (DEA) [13].

Moreover, the efficiency of 3D printers can also be assessed using the DEA method [14]. Combined with multiple technologies, DEA-based interaction and expansion approach can also improve drug sales performance [15]. The application of combined goal-oriented methodology (GO methodology), integrated dynamic Bayesian networks (DBNs), and the DEA methodology can improve smart meter reliability and accuracy [16]. A certain model was developed for improving the productivity of warehouses and logistics distribution centers using the PROMETHEE II and DEA methods [17]. Since appropriate organizational changes were made in terms of infrastructure, human resources, and technology, efficiency and productivity assessments were incorporated into hospital decision-making [18].

To address complicated problems related to multiple inputs and multiple outputs of dredging productivity, this study proposes an improved method involving novel integration and DEA 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 DEA. Section 3 proposes a novel productivity evaluation method based on novel integration and DEA. Section 4 adapts the data from the case of Lai (2019) [12] to verify the effectiveness of the proposed method. Lastly, Section 5 provides conclusions and future research directions.

2. Related works

2.1. Traditional productivity method

A dredging project is a complex problem requiring productivity, quality, safety, and timeliness operations of many types of work needed for project completion. However, traditional methods used in calculating productivity can only solve problems related to a single input and a single output. It cannot address problems involving multiple inputs and multiple outputs. In traditional productivity, only the completed work items and the groups' working hours are considered; hence, productivity is defined as the ratio of "outputs" and "inputs" of an item in unit time, as shown in Equation 1. [19]. The unit of C pertains to one thousand US dollars per employee. Due to physical labor productivity, the researchers of this study denoted the number of employees (NE) as L, while the operating revenue (OR) was denoted as Y. The unit of L pertains to the employee. The unit of Y is one thousand US dollars.

$$C = \frac{Y}{L} \tag{1}$$

Since the traditional calculation method of productivity cannot address the MIMO problem, the data must be converted before calculation. Equation 2 was used for standardization.

$$N_{ij} = \frac{[X_{ij} - min(X_{ij})]}{max(X_{ij}) - min(X_{ij})} \tag{2}$$

Dredging productivity is a complex MCDM problem. Traditional productivity methods can only address problems with single data input and output. While the DEA method can solve the MIMO problem, its results have the same efficiency (efficiency is equal to 1), making it difficult to identify which efficiency is better. This study utilized the multiple regression equation shown in Equation 3 to calculate the regression coefficient value.

$$Y = a + b_1x_1 + b_2x_2 + \varepsilon \tag{3}$$

2.2. DEA method

Charnes et al. [12] initially introduced the DEA method as a mathematical programming method that can evaluate the relative efficiency of decision-making units (DMUs) (first-mode CCR model). DEA is a method that uses multiple inputs to produce multiple outputs to measure the relative efficiencies of a group of DMUs. This non-parametric technique was originally conceived to analyze a set of units. Since the DEA method can solve multiple-criteria decision analysis (MCDA) problems with single-input–single-output, single-input–multi-output, or multi-input–multiple-output, this theoretical approach can be applied to a wide range of real-world problems. The results of this study were obtained using the software "DEA.P version 2.1 for Windows" [20].

3. The proposed novel construction productivity calculation method

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

Step 1. Observe and record the number of equipment and earthwork dredged every day.
Step 2. Establish a formalized performance matrix (multiple regression).
Step 3. Perform the weighted calculation of the normal performance matrix.
Step 4. Obtain the solution using the DEA method
Step 5. Rank the calculated results.
Step 6. Compare the results calculated using each method.
Figure 1 shows the flowchart of the novel construction productivity calculation.

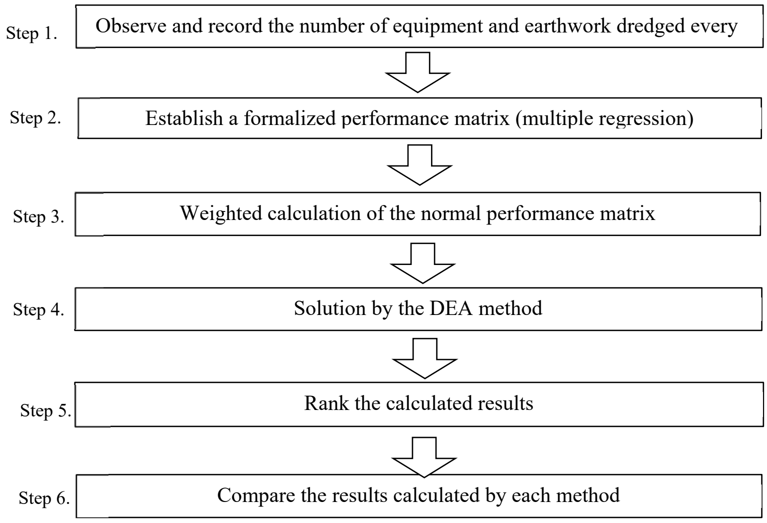

Figure 1. Flowchart of the proposed novel construction productivity calculation method.

4. Case study

4.1. Overview

To verify the correctness and effectiveness of the proposed method in this study, the researchers adapted one of the case data from Lai, Chang, and Lin's study [00] to demonstrate how the traditional method of calculating dredging productivity is a special case of the proposed method. Records from the Nanhua Reservoir dredging located in Taiwan at that time were used. The Nanhua Reservoir is about 104 square kilometers and was completed in 1994. After its completion, the water storage capacity reached about 158.05 million cubic meters. At present, it can provide domestic water for Tainan and Kaohsiung. It also serves as a reservoir for sightseeing and leisure. The collected data from the Nanhua Reservoir dredging case was for 54 working days, from April 8 to May 31, 2011. Table 1 shows the record per day for hydraulic excavators (SL-330 and 320B) and trucks as input items, including the number of dispatches, while the output is the amount of daily dredging.

Table 1. Data adapted from the chosen case.

Record day	Output	Input		
	Daily dredging (M^3)	Number of trucks	Excavator SL-330	Excavator 320B
1	1668	98	1	5
2	1683	98	1	5
3	1701	100	2	3
4	1702	100	2	3
5	1700	100	1	4
6	1696	99	1	5
7	1665	98	2	3
8	1701	100	2	4
9	1716	101	1	5
10	1720	101	1	5
11	1706	91	2	4
12	1717	93	2	4
13	1729	94	1	5
14	1737	95	1	5
15	1747	96	2	5
16	1759	98	2	5
17	1770	99	1	6
18	1782	100	1	6
19	1792	101	2	5
20	1798	102	2	5
21	1826	104	1	6
22	1855	106	1	6
23	1871	107	2	5

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24	1895	108	2	6
25	1925	110	2	6
26	1950	112	2	6
27	1985	114	2	6
28	2041	117	2	6
29	2093	120	2	6
30	2089	116	2	6
31	2083	113	2	6
32	2076	109	2	6
33	2067	106	2	6
34	2058	103	2	6
35	2047	100	2	6
36	2036	97	2	6
37	2024	94	2	6
38	2012	92	2	6
39	1999	89	2	6
40	1986	87	2	6
41	1973	85	2	6
42	1959	83	2	6
43	1946	81	2	6
44	1932	79	2	6
45	1918	78	2	6
46	1905	76	2	6
47	1891	74	2	6
48	1877	73	2	6
49	1863	71	2	6
50	1850	70	2	6
51	1836	68	2	6
52	1823	67	2	6
53	1809	66	2	6
54	1796	65	2	6

4.2. Solution using the traditional productivity method

Since the traditional productivity calculation method can only solve problems involving a single input and a single output, directly calculating the problem of single input and multiple outputs, multiple inputs and single outputs, or multiple inputs and multiple outputs is quite challenging [19]. Data must be converted before calculations. To make the traditional method applicable in addressing problems involving multiple inputs and outputs, the researchers of this study used Equation 2 to standardize the input of the data in Table 1. After formalizing the conversion of all input items, the researchers proceeded to calculate the aggregated input value using the traditional method productivity (output/input) and the dredging productivity result/one-day high dredging productivity. Table 2 illustrates the calculated result.

Table 2. Established formalized performance matrix from the adapted case data and calculation results.

Record day	Output	Input			Aggregated input value	Traditional method productivity(output/input)	Dredging productivity result/One-day high dredging productivity
	Daily dredging	Number of trucks	Excavator SL-330	Excavator 320B			
1	1668	0.817	0.500	0.833	2.150	775.814	0.913
2	1683	0.817	0.500	0.833	2.150	782.791	0.921
3	1701	0.833	1.000	0.500	2.333	729.000	0.858
4	1702	0.833	1.000	0.500	2.333	729.429	0.858
5	1700	0.833	0.500	0.667	2.000	850.000	1.000
6	1696	0.825	0.500	0.833	2.158	785.792	0.924
7	1665	0.817	1.000	0.500	2.317	718.705	0.846
8	1701	0.833	1.000	0.667	2.500	680.400	0.800
9	1716	0.842	0.500	0.833	2.175	788.966	0.928
10	1720	0.842	0.500	0.833	2.175	790.805	0.930
11	1706	0.758	1.000	0.667	2.425	703.505	0.828
12	1717	0.775	1.000	0.667	2.442	703.208	0.827
13	1729	0.783	0.500	0.833	2.117	816.850	0.961
14	1737	0.792	0.500	0.833	2.125	817.412	0.962
15	1747	0.800	1.000	0.833	2.633	663.418	0.780
16	1759	0.817	1.000	0.833	2.650	663.774	0.781

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17	1770	0.825	0.500	1.000	2.325	761.290	0.896
18	1782	0.833	0.500	1.000	2.333	763.714	0.898
19	1792	0.842	1.000	0.833	2.675	669.907	0.788
20	1798	0.850	1.000	0.833	2.683	670.062	0.788
21	1826	0.867	0.500	1.000	2.367	771.549	0.908
22	1855	0.883	0.500	1.000	2.383	778.322	0.916
23	1871	0.892	1.000	0.833	2.725	686.606	0.808
24	1895	0.900	1.000	1.000	2.900	653.448	0.769
25	1925	0.917	1.000	1.000	2.917	660.000	0.776
26	1950	0.933	1.000	1.000	2.933	664.773	0.782
27	1985	0.950	1.000	1.000	2.950	672.881	0.792
28	2041	0.975	1.000	1.000	2.975	686.050	0.807
29	2093	1.000	1.000	1.000	3.000	697.667	0.821
30	2089	0.967	1.000	1.000	2.967	704.157	0.828
31	2083	0.942	1.000	1.000	2.942	708.102	0.833
32	2076	0.908	1.000	1.000	2.908	713.811	0.840
33	2067	0.883	1.000	1.000	2.883	716.879	0.843
34	2058	0.858	1.000	1.000	2.858	720.000	0.847
35	2047	0.833	1.000	1.000	2.833	722.471	0.850
36	2036	0.808	1.000	1.000	2.808	724.985	0.853
37	2024	0.783	1.000	1.000	2.783	727.186	0.856
38	2012	0.767	1.000	1.000	2.767	727.229	0.856
39	1999	0.742	1.000	1.000	2.742	729.119	0.858
40	1986	0.725	1.000	1.000	2.725	728.807	0.857
41	1973	0.708	1.000	1.000	2.708	728.492	0.857
42	1959	0.692	1.000	1.000	2.692	727.802	0.856
43	1946	0.675	1.000	1.000	2.675	727.477	0.856
44	1932	0.658	1.000	1.000	2.658	726.771	0.855
45	1918	0.650	1.000	1.000	2.650	723.774	0.851
46	1905	0.633	1.000	1.000	2.633	723.418	0.851
47	1891	0.617	1.000	1.000	2.617	722.675	0.850
48	1877	0.608	1.000	1.000	2.608	719.617	0.847
49	1863	0.592	1.000	1.000	2.592	718.842	0.846
50	1850	0.583	1.000	1.000	2.583	716.129	0.843
51	1836	0.567	1.000	1.000	2.567	715.325	0.842
52	1823	0.558	1.000	1.000	2.558	712.573	0.838
53	1809	0.550	1.000	1.000	2.550	709.412	0.835
54	1796	0.542	1.000	1.000	2.542	706.623	0.831

4.3. Solution using the DEA method

The data envelopment analysis (DEA) method proposed by Androutsou et al. (2022) [18] is one of the critical tools for performing productivity measurements. The DEA method can deal with complex data problems involving multiple inputs and multiple outputs. This study used the CCR model of the DEAP software to calculate the daily productivity of the dredging work in the Nanhua Reservoir shown in Table 2. The calculation results are shown in Table 3.

Table 3. Daily productivity calculation results using the DEA method.

Record day	Output	Input			DEA (CCR)
	Daily dredging	Number of trucks	Excavator SL-330	Excavator 320B	Daily productivity
1	1668	0.817	0.500	0.833	0.952
2	1683	0.817	0.500	0.833	0.960
3	1701	0.833	1.000	0.500	0.999
4	1702	0.833	1.000	0.500	1.000
5	1700	0.833	0.500	0.667	1.000
6	1696	0.825	0.500	0.833	0.965
7	1665	0.817	1.000	0.500	0.992
8	1701	0.833	1.000	0.667	0.920
9	1716	0.842	0.500	0.833	0.971
10	1720	0.842	0.500	0.833	0.973
11	1706	0.758	1.000	0.667	0.968
12	1717	0.775	1.000	0.667	0.963
13	1729	0.783	0.500	0.833	1.000
14	1737	0.792	0.500	0.833	1.000
15	1747	0.800	1.000	0.833	0.892
16	1759	0.817	1.000	0.833	0.890
17	1770	0.825	0.500	1.000	0.993
18	1782	0.833	0.500	1.000	0.994

19	1792	0.842	1.000	0.833	0.893
20	1798	0.850	1.000	0.833	0.892
21	1826	0.867	0.500	1.000	0.995
22	1855	0.883	0.500	1.000	1.000
23	1871	0.892	1.000	0.833	0.906
24	1895	0.900	1.000	1.000	0.853
25	1925	0.917	1.000	1.000	0.859
26	1950	0.933	1.000	1.000	0.863
27	1985	0.950	1.000	1.000	0.871
28	2041	0.975	1.000	1.000	0.885
29	2093	1.000	1.000	1.000	0.896
30	2089	0.967	1.000	1.000	0.909
31	2083	0.942	1.000	1.000	0.918
32	2076	0.908	1.000	1.000	0.931
33	2067	0.883	1.000	1.000	0.939
34	2058	0.858	1.000	1.000	0.947
35	2047	0.833	1.000	1.000	0.955
36	2036	0.808	1.000	1.000	0.963
37	2024	0.783	1.000	1.000	0.971
38	2012	0.767	1.000	1.000	0.973
39	1999	0.742	1.000	1.000	0.981
40	1986	0.725	1.000	1.000	0.984
41	1973	0.708	1.000	1.000	0.987
42	1959	0.692	1.000	1.000	0.989
43	1946	0.675	1.000	1.000	0.992
44	1932	0.658	1.000	1.000	0.995
45	1918	0.650	1.000	1.000	0.993
46	1905	0.633	1.000	1.000	0.996
47	1891	0.617	1.000	1.000	0.999
48	1877	0.608	1.000	1.000	0.997
49	1863	0.592	1.000	1.000	0.999
50	1850	0.583	1.000	1.000	0.998
51	1836	0.567	1.000	1.000	1.000
52	1823	0.558	1.000	1.000	1.000
53	1809	0.550	1.000	1.000	1.000
54	1796	0.542	1.000	1.000	1.000

4.4. Solution using the proposed novel productivity calculation method

Dredging productivity is a complex MCDM problem involving multiple data inputs and multiple data outputs. However, traditional productivity methods can only deal with a single input and output data problem. While the DEA method can solve problems involving multiple inputs and multiple outputs, its calculated results have the same efficiency (the efficiency is equal to 1), making it challenging to determine which is more efficient and which is less efficient.

Several computations with an efficiency equal to 1 can be used to solve DEA efficiently. Some scholars used the multiple regression (ML) method to adopt farming techniques that significantly impact the integration of dairy cows and goats and create smallholder employment[21]. This study proposes an integrated and novel DEA construction productivity calculation method. This method considers the objective weights in obtaining the regression coefficient and selects an input as a conversion benchmark to calculate the conversion factors for each input. The solution steps are as follows.

Step 1: Observe and record the number of equipment and earthwork dredged daily.

Observation and records of the hydraulic excavators (SL-330 and 320B) and trucks as input items include the number of dispatches. The output is the amount of daily dredging output adapted from the case data of [12], as shown in Table 1.

Step 2: Establish a formalized performance matrix (multiple regression).

The regression coefficient value was calculated based on the data recorded in Table 1 and using a multiple regression formula shown in Equation 3. The results are shown in Table 4.

Table 4. Established formalized performance matrix (normalization).

Record day	Output	Input		
	Daily dredging	Number of trucks	Excavator SL-330	Excavator 320B
Regression coefficient		3.767	156.43	110.981

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Step 3: Perform the weighted calculation for the normal performance matrix.

To solve the issue concerning the efficiency is equivalent to 1, the researchers of this study used the number of trucks as the conversion benchmark, divided all the regression coefficient values by the number of trucks in the regression results to obtain the conversion factor, and summarized the total input value. Table 5 shows the calculation results.

Table 5. Calculated normal matrix weighted objective weights for input and output items.

Record day	Output	Input			Aggregated total input value after conversion
	Daily dredging	Number of trucks	Excavator SL-330	Excavator 320B	
Regression coefficient		3.767	156.43	110.981	
Conversion factors		1	41.523	29.459	
1	1668	98.000	41.523	147.295	286.818
2	1683	98.000	41.523	147.295	286.818
3	1701	100.000	83.046	88.377	271.423
4	1702	100.000	83.046	88.377	271.423
5	1700	100.000	41.523	117.836	259.359
6	1696	99.000	41.523	147.295	287.818
7	1665	98.000	83.046	88.377	269.423
8	1701	100.000	83.046	117.836	300.882
9	1716	101.000	41.523	147.295	289.818
10	1720	101.000	41.523	147.295	289.818
11	1706	91.000	83.046	117.836	291.882
12	1717	93.000	83.046	117.836	293.882
13	1729	94.000	41.523	147.295	282.818
14	1737	95.000	41.523	147.295	283.818
15	1747	96.000	83.046	147.295	326.341
16	1759	98.000	83.046	147.295	328.341
17	1770	99.000	41.523	176.754	317.277
18	1782	100.000	41.523	176.754	318.277
19	1792	101.000	83.046	147.295	331.341
20	1798	102.000	83.046	147.295	332.341
21	1826	104.000	41.523	176.754	322.277
22	1855	106.000	41.523	176.754	324.277
23	1871	107.000	83.046	147.295	337.341
24	1895	108.000	83.046	176.754	367.800
25	1925	110.000	83.046	176.754	369.800
26	1950	112.000	83.046	176.754	371.800
27	1985	114.000	83.046	176.754	373.800
28	2041	117.000	83.046	176.754	376.800
29	2093	120.000	83.046	176.754	379.800
30	2089	116.000	83.046	176.754	375.800
31	2083	113.000	83.046	176.754	372.800
32	2076	109.000	83.046	176.754	368.800
33	2067	106.000	83.046	176.754	365.800
34	2058	103.000	83.046	176.754	362.800
35	2047	100.000	83.046	176.754	359.800
36	2036	97.000	83.046	176.754	356.800
37	2024	94.000	83.046	176.754	353.800
38	2012	92.000	83.046	176.754	351.800
39	1999	89.000	83.046	176.754	348.800
40	1986	87.000	83.046	176.754	346.800
41	1973	85.000	83.046	176.754	344.800
42	1959	83.000	83.046	176.754	342.800
43	1946	81.000	83.046	176.754	340.800
44	1932	79.000	83.046	176.754	338.800
45	1918	78.000	83.046	176.754	337.800
46	1905	76.000	83.046	176.754	335.800
47	1891	74.000	83.046	176.754	333.800
48	1877	73.000	83.046	176.754	332.800
49	1863	71.000	83.046	176.754	330.800
50	1850	70.000	83.046	176.754	329.800
51	1836	68.000	83.046	176.754	327.800
52	1823	67.000	83.046	176.754	326.800
53	1809	66.000	83.046	176.754	325.800
54	1796	65.000	83.046	176.754	324.800

Step 4: Obtain the solution using the DEA method

This study used the CCR model of the DEAP software to calculate the daily productivity of the dredging work in Nanhua Reservoir shown in Table 5. The calculation results are depicted in Table 6.

Table 6. Calculated daily productivity and rank.

Record day	Output	Input	DEA(CCR)	Rank
	Daily dredging	Total input	Daily productivity	
1	1668	286.818	0.887	13
2	1683	286.818	0.895	10
3	1701	271.423	0.956	3
4	1702	271.423	0.957	2
5	1700	259.359	1.000	1
6	1696	287.818	0.899	9
7	1665	269.423	0.943	4
8	1701	300.882	0.863	30
9	1716	289.818	0.903	8
10	1720	289.818	0.905	7
11	1706	291.882	0.892	11
12	1717	293.882	0.891	12
13	1729	282.818	0.933	6
14	1737	283.818	0.934	5
15	1747	326.341	0.817	49
16	1759	328.341	0.817	49
17	1770	317.277	0.851	39
18	1782	318.277	0.854	37
19	1792	331.341	0.825	47
20	1798	332.341	0.825	47
21	1826	322.277	0.864	28
22	1855	324.277	0.873	16
23	1871	337.341	0.846	43
24	1895	367.800	0.786	54
25	1925	369.800	0.794	53
26	1950	371.800	0.800	52
27	1985	373.800	0.810	51
28	2041	376.800	0.826	46
29	2093	379.800	0.841	45
30	2089	375.800	0.848	41
31	2083	372.800	0.852	38
32	2076	368.800	0.859	33
33	2067	365.800	0.862	31
34	2058	362.800	0.865	26
35	2047	359.800	0.868	24
36	2036	356.800	0.871	21
37	2024	353.800	0.873	16
38	2012	351.800	0.873	16
39	1999	348.800	0.874	14
40	1986	346.800	0.874	14
41	1973	344.800	0.873	16
42	1959	342.800	0.872	20
43	1946	340.800	0.871	21
44	1932	338.800	0.870	23
45	1918	337.800	0.866	25
46	1905	335.800	0.865	26
47	1891	333.800	0.864	28
48	1877	332.800	0.860	32
49	1863	330.800	0.859	33
50	1850	329.800	0.856	35
51	1836	327.800	0.855	36
52	1823	326.800	0.851	39
53	1809	325.800	0.847	42
54	1796	324.800	0.844	44

Step 5: Rank the calculated results.

Based on the productivity calculation method proposed in this study, the results are ranked to find the best and equivalent dates, as shown in Table 6.

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Step 6: Compare the results calculated using each method.

This step involves ranking the results obtained using both productivity calculation methods. Table 7 shows the calculation results.

Table 7. Comparison of the sorted calculated results calculated using each method.

Record day	Traditional method		DEA method		Propose method	
	Output/input	Ranking	Performance	Ranking	Daily productivity	Ranking
1	0.913	9	0.952	37	0.887	13
2	0.921	7	0.96	35	0.895	10
3	0.858	13	0.999	10	0.956	3
4	0.858	13	1	1	0.957	2
5	1	1	1	1	1.000	1
6	0.924	6	0.965	32	0.899	9
7	0.846	30	0.992	21	0.943	4
8	0.8	46	0.92	41	0.863	30
9	0.928	5	0.971	29	0.903	8
10	0.93	4	0.973	27	0.905	7
11	0.828	40	0.968	31	0.892	11
12	0.827	42	0.963	33	0.891	12
13	0.961	3	1	1	0.933	6
14	0.962	2	1	1	0.934	5
15	0.78	52	0.892	47	0.817	49
16	0.781	51	0.89	49	0.817	49
17	0.896	12	0.993	19	0.851	39
18	0.898	11	0.994	18	0.854	37
19	0.788	48	0.893	46	0.825	47
20	0.788	48	0.892	47	0.825	47
21	0.908	10	0.995	16	0.864	28
22	0.916	8	1	1	0.873	16
23	0.808	44	0.906	44	0.846	43
24	0.769	54	0.853	54	0.786	54
25	0.776	53	0.859	53	0.794	53
26	0.782	50	0.863	52	0.800	52
27	0.792	47	0.871	51	0.810	51
28	0.807	45	0.885	50	0.826	46
29	0.821	43	0.896	45	0.841	45
30	0.828	40	0.909	43	0.848	41
31	0.833	38	0.918	42	0.852	38
32	0.84	35	0.931	40	0.859	33
33	0.843	32	0.939	39	0.862	31
34	0.847	28	0.947	38	0.865	26
35	0.85	26	0.955	36	0.868	24
36	0.853	23	0.963	33	0.871	21
37	0.856	18	0.971	29	0.873	16
38	0.856	18	0.973	27	0.873	16
39	0.858	13	0.981	26	0.874	14
40	0.857	16	0.984	25	0.874	14
41	0.857	16	0.987	24	0.873	16
42	0.856	18	0.989	23	0.872	20
43	0.856	18	0.992	21	0.871	21
44	0.855	22	0.995	16	0.870	23
45	0.851	24	0.993	19	0.866	25
46	0.851	24	0.996	15	0.865	26
47	0.85	26	0.999	10	0.864	28
48	0.847	28	0.997	14	0.860	32
49	0.846	30	0.999	10	0.859	33
50	0.843	32	0.998	13	0.856	35
51	0.842	34	1	1	0.855	36
52	0.838	36	1	1	0.851	39
53	0.835	37	1	1	0.847	42
54	0.831	39	1	1	0.844	44

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4.5. Comparison and Discussion

To ensure that the proposed productivity calculation method can improve the disadvantages of traditional productivity calculation, this study adapted the data from the case presented in [12]. To calculate productivity using the traditional calculation method, it is necessary to change the output items into one item after converting the formalized performance matrix. Some scholars used this regression method to identify the conversion factors and converted the output items w to one item before calculation. However, the traditional and Thomas methods can only solve problems involving single input and output [22,23]. DEA calculates the daily productivity based on the input and output coefficients entered into the DEAP software, and the values closer to 1 are deemed better. Although DEA can solve problems with multiple inputs and outputs, it cannot compare the advantages and disadvantages of the productivities when the values are all 1. The novel multi-input and multi-output productivity calculation methods proposed in this study can solve, compare, and rank the largest and equal productivity calculation results. Comparing the main differences between the above three methods, the researchers discovered that only the traditional calculation method could not solve the productivity problem of productivity involving single input and multiple outputs. The remaining two methods can deal with related problems; DEA and the proposed method can solve productivity problems with multiple inputs and outputs. As for effectively resolving performance duplication of multiple inputs and multiple outputs, only the proposed method can solve it. Table 8 summarizes the relative problems for the above three methods.

Table 8. Comparison of the main differences between the above four methods.

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

5. Conclusions and future work

In addition to trucks and excavators being the most expensive in dredging, other factors must be considered, such as weather, soil conditions, transportation distance, and so on. Since the productivity of different machines and tools can vary, the quality of productivity influences capital expenditure. Therefore, improving management efficiency and reducing costs through productivity measurement is particularly important initially. In addition, many items must also be considered when evaluating productivity. These include machines and tools, climate, job complexity, material supply, material stacking, and other elements constituting the MADM problem. Since the traditional method can only solve the problem of single input and single output, it cannot solve construction capacity problems with multiple inputs and outputs. Although the DEA method can solve the productivity calculation problem involving multiple inputs and multiple outputs, it cannot compare the calculation results when the efficiencies are equal.

This study combined multiple regression and regularization to solve the shortcomings of traditional methods (which can only solve the problem of single input and single output) and DEA (which cannot compare equal efficiencies) to calculate the productivity results. The researchers of this study used examples to confirm the validity and feasibility of the proposed method, and the simulation results revealed that the novel integration and the DEA technique are more suitable for the evaluation and calculation of productivity.

Future research may further explore this research topic by considering man-made and natural risk assessments, working group proficiency, and management methods. Future studies may evaluate productivity by combining a soft set and fuzzy TOPSIS for the calculation method.

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