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Input-output benefit evaluation of major projects based on DEA

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Abstract: The data envelopment analysis DEA method is used to calculate the input-output ratio of some major projects in terms of annual funds, equipment, fixed assets, personnel, etc., and evaluate the comprehensive benefits and economies of scale of some projects. The analysis results show that there is redundancy in the input of most projects, so the input value can be further optimized. The optimal value and saving value of different input types are calculated for specific projects. This model provides technical support for future major project planning of military construction.

1. INTRODUCTION

Entering the new stage of the new century, the situation and tasks faced by the PLA have undergone profound changes. The increase in our national defense expenditure is in harmony with the level of economic development, and our country is accelerating the military reform, so it is necessary to support many national defense projects to further advance the strategy of strengthening the army in science and technology and strengthening the army with talents. With large scale, long construction period and high investment, major projects in the construction of the Chinese People's Liberation Army (PLA) occupy an important proportion in the investment of military expenditure, personnel and equipment, etc. Therefore, the calculation of the input-output ratio of major projects is helpful for the PLA to formulate reasonable project investment policies, and is of great significance for controlling the macro-control of project investment and strengthening the management of the PLA. It is a complex systematic project to improve the evaluation ability of the input-output of major projects. Efficient, reasonable and accurate calculation model is the key to improve the input-output of PLA [1-4].

The input-output ratio model of major projects takes the implementation process and results of major projects as the evaluation object, and realizes the input-output ratio analysis of the comprehensive benefits of major projects by analyzing the factors that affect and reflect the funds, equipment, quantity and expected benefits of major projects. This model mainly carries out quantitative evaluation and display of the input-output ratio of major projects according to the investment and input of annual funds, equipment, fixed assets and personnel of major projects, and provides comprehensive benefit assessment [5-7]. It is of great significance to provide technical support for major project planning to better serve military construction in the coming period.

Data enveloping analysis is an efficiency evaluation method proposed by the famous American operations research scientist A. Charnes and W-W. Cooper based on the concept of ‘relative efficiency evaluation’[8]. This method extends the concept of single input and single output to quantitative evaluation of effectiveness of multi-input and multi-output Decision making Unit (DMU), and has the characteristics of objectivity, simple calculation and small error. Since the establishment of CZR model, the first DEA model, in 1978, DEA method has made rapid development in both theoretical research and practical application, and has become a common and important analysis tool and research means in the fields of operations research, management, systems science and mathematical economics [9-12].

2. DEA MODEL INTRODUCTION

With $n$decision making unitsDMU_i $(i = 1,2,\cdots n)$, each decision-making unit has $m$kind of nonnegative input and output p kind of nonnegative, Among them, the input vector of the i^{th} decision unit DMU_i is expressed as $x_i = (x_{i1}, x_{i2},\cdots, x_{i3})'$, output variable is expressed as $y_i = (y_{i1}, y_{i2},\cdots, y_{it})'$, the input weight vector is expressed as $v_i = (v_1, v_2,\cdots, v_m)'$, the output weight is $u_i = (u_1, u_2,\cdots, u_t)'$, Among them $x_{si} \geq 0$, $y_{ti} \geq 0$ $(s = 1,2,\cdots,m;\ t = 1,2,\cdots,p;\ i = 1,2,\cdots,n)$.

Set $h_i = \frac{u'y_i}{v'x_i}$ as the efficiency evaluation index of the i^{th} decision making unit DMU_i to evaluate the efficiency of DMU_i . The weight coefficient u, v can always be selected. Under the condition that the efficiency evaluation index of each DMU_i does not exceed 1, h_i is maximized, and the following optimization model—— C[2]R model is obtained:

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$max\, h_i = \frac{u' y_i}{v' x_i}$ (1)

s.t. $\begin{cases} h_i \leq 1, i = 1,2,\cdots,n \\ u \geq 0, v \geq 0 \end{cases}$ (2)

By Charess-Cooper transformation, the fractional programming form of C²R model is equivalent to linear programming form:

$max\, \mu'^{y_0}$ (3)

s.t. $\begin{cases} \omega' x_i - \mu' y_i \geq 0, i = 1,2,\cdots,n \\ \omega x_0 = 1 \\ \omega \geq 0, \mu \geq 0 \end{cases}$ (4)

$\omega = tv, \mu = tu, t = \frac{1}{v' x_0}$ (5)

Its dual programming model is:

$min\, \theta$ (6)

s.t. $\begin{cases} \sum_{i=1}^{n} \lambda_i x_i \leq \theta x_0 \\ \sum_{i=1}^{n} y_i \lambda_i \geq y_0 \\ \lambda_i \geq 0, i = 1,2,\cdots,n \end{cases}$ (7)

SE-DEA model:

Introduce a new relaxation variable, linear programming model with non-Archimedean infinitesimal and relaxation variable super efficiency Data Enveloping analysis model (SE-DEA):

$min\, \theta - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{i=1}^{m} s_i^+)$ (8)

s.t. $\begin{cases} \sum_{i=1}^{m} x_i \lambda_i + s^- = \theta x_0 \\ \sum_{i=1}^{m} y_i \lambda_i + s^+ = y_0 \\ \lambda_i \geq 0 (1 \leq i \leq n) \\ s^- \geq 0, s^+ \geq 0 \end{cases}$ (9)

Where ε is a non-Archimedean infinite small quantity, a number greater than zero but less than any positive number, the general value is 10^{-6}, $\lambda_i (i = 1,2,\cdots,n)$ is the optimal solution; s^-, s^+ are the input-output relaxation vectors respectively.

Effectiveness analysis of the model:

Set the optimal solution for $\lambda^0, s^{-0}, s^{+0}, \theta^0$, then:

(1) If $\theta^0 \geq 1$, and $s^{-0} \neq 0$ or $s^{+0} \neq 0$, then the decision unit DMU_i is DEA efficient, that is, the decision unit is both technology efficient and scale efficient, indicating that the input reaches the best combination and the output reaches the maximum.

(2) If $\theta^0 \geq 1$, and$s^{-0} = 0, s^{+0} = 0$, the decision unit DMU_i is DEA weak and efficient, indicating that the decision is not simultaneously technology efficiency or scale efficiency, and the input of part of the unit is excessive or the output of the department is insufficient.

(3) If $\theta^0 < 1$,then the decision unit DMU_i is called DEA invalid.

Scale economy determination of the mode

Let $k = \frac{1}{\theta^0} \sum_{i=1}^{n} \lambda_i^0$, call k the size gain of the DMU_i , have:

(1) When$k = 1$ indicates that the DMU_i reaches the maximum output scale point when the scale gain of the DMU_i remains unchanged;

(2) When$k < 1$, it means that when the scale gain of DMU_i is increasing, and the smaller the value of$k$ the larger the scale increasing trend, indicating that DMU_i will have a higher proportional increase in the output quantity by appropriately increasing the input quantity on the basis of the inputx_0;

(3) When$k > 1$, it means that when the diminishing returns to scale of DMU_i , and the larger the value of $k$the larger the diminishing trend, indicating that DMU_i on the basis of inputsx_0 increase the amount of inputs is unlikely to bring a higher proportion of output, at this time there is no need to increase the inputs of the decision unit.

The model flow chart is shown in Figure 1.

3. EXAMPLE ANALYSIS

The input-output values of an army in terms of number of personnel, funding, and equipment for certain major projects are shown in Table 1:

3.1 DEA validity analysis

As calculated by the model,s^-, s^+ The results are shown in Table 2:

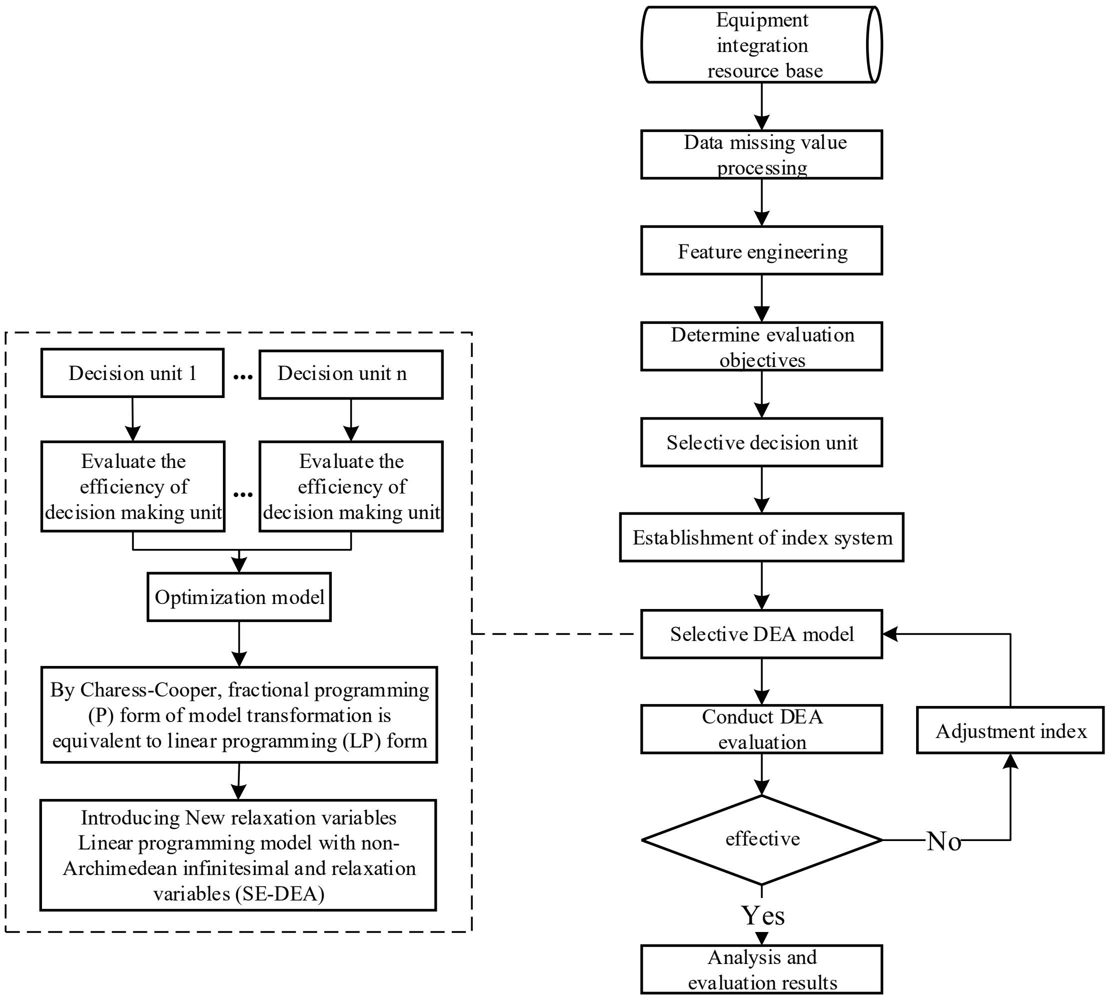

Figure 1. Flow chart of input-output ratio model for major projects

Table 1. Input-output ratio of each major project

Projects	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10
Number of personnel	196	107	145	94	194	175	131	169	106	108
Funding	8	1.1	3.1	4.7	2.9	2.2	1.9	0.87	0.7	1.23
Equipment	14350	5645	17000	16000	26269	8364	27495	8021	10850	7238
Fixed Assets	1100	1238	2246	1750	2500	1750	11640	898	4100	5500
Prototypes/Prototype Systems	2	5	4	4	2	3	1	2	3	4
New theories/new principles/new methods	3	5	2	4	2	5	4	2	1	3
Papers / Publications / Research (Consulting) Reports	20	32	28	21	17	19	35	34	22	23
Number of independent intellectual property rights	52	30	50	18	25	13	20	23	41	10
Standards / Specifications	5	7	8	4	6	5	8	4	6	7
Awards	7	10	8	12	6	5	4	6	7	7
Income from transfer of results	7000	11100	3500	3700	3000	2600	1800	8900	7500	11200
Technology maturity enhancement	2	3	4	3	4	2	3	2	3	3
Equipment system contribution	0.415	0.36	0.317	0.617	0.859	0.621	0.794	0.256	0.345	0.401
Team Building	5	6	2	3	4	2	4	6	5	2

Table 2. DEA validity analysis table

Projects	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10
s_1^-	0.000	0.000	0.000	0.000	0.000	32.341	0.000	0.000	0.000	0.000
s_2^-	12.883	0.000	0.758	6.205	0.000	0.603	0.000	12.883	0.000	0.758
s_3^-	9273.940	0.000	8363.57	13830.7	16577.2	0.001	20819.4	9273.94	0.000	8363.57

s_4^-	0.000	0.000	0.000	0.000	0.000	0.000	14884.2	0.000	0.000	0.000
s_1^+	2.910	0.000	1.768	1.707	4.043	5.449	4.167	3.313	3.833	1.118
s_2^+	1.910	1.278	3.349	2.031	5.818	3.449	1.167	3.313	5.833	2.231
s_3^+	54.866	14.188	11.269	19.392	21.775	34.804	0.000	0.000	21.733	10.703
s_4^+	0.000	1.499	0.000	20.159	6.540	37.343	17.694	8.875	0.000	21.066
s_5^+	4.333	1.768	1.089	5.295	3.082	6.735	0.870	3.438	3.567	0.369
s_6^+	6.918	0.666	4.465	0.000	6.094	12.132	7.788	4.625	6.667	3.424
s_7^+	13039.2	0.016	10093.3	8657.67	6058.77	15853.5	8424.72	2893.75	7670	0.000
s_8^+	2.585	0.946	0.000	1.201	0.000	3.104	1.705	1.188	1.1	0.178
s_9^+	0.167	0.445	0.191	0.000	0.000	0.000	0.000	0.122	0.142	0.000
s_{10}^+	8.269	0.508	5.893	4.447	1.698	8.033	2.932	0.375	3.200	4.196

The ordering of θ^0 calculated by SE-DEA is shown in Table 3:

Table 3. θ^0 Sorting

Projects	**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**
θ^0	1.856	2.717	1.158	1.723	1.170
Sort by	3	1	9	4	8
Validity	DEA is weakly effective	DEA is weakly effective	DEA is weakly effective	DEA is weakly effective	DEA is weakly effective
Projects	**Project 6**	**Project 7**	**Project 8**	**Project 9**	**Project 10**
θ^0	1.221	1.490	1.465	2.148	1.055
Sort by	7	5	6	2	10
Validity	DEA is weakly effective	DEA is weakly effective	DEA is weakly effective	DEA is weakly effective	DEA is weakly effective

(1) From the SE-DEA calculation of θ^0 , it is concluded that among the 10 major projects, Project 1 has the best overall effectiveness, followed by Project 9, Project 1, Project 4, and the last in the list are Project 10, Project 3, Project 5, and the others are in the middle;

(2) Based on the values of θ^0 and the slack variabless_1^- ,s_2^- , s_3^- , s_4^- , s_5^-, s_6^-, s_7^-, s_8^-, s_9^-, s_{10}^-, it is concluded that under the current input and each unit level conditions, all projects are weakly DEA efficient and are on the production frontier of technically efficient and scale efficient, and the various resources invested are relatively fully utilized and the output achieved is maximized.

3.2 Scale benefit analysis

λ^0Calculation:

Table 4. λ^0 Calculation table

Projects	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10
	0.000	0.000	0.205	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.162	0.000	0.884	1.046	0.553	1.643	0.742	1.063	1.367	0.993
λ^0	0.000	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.059	0.000	0.000	0.189	0.059	0.086	0.000	0.000	0.028
	0.000	0.000	0.000	0.185	0.000	0.000	0.555	0.000	0.000	0.000

	0.000	0.781	0.000	0.000	0.828	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.108	0.040	0.000	0.000	0.000	0.000	0.038
	2.049	0.712	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.312	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.214	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\sum_{i=1}^{10} \lambda_i^0$	2.211	1.801	1.402	1.339	1.609	1.701	1.383	1.063	1.367	1.059

Table 5. k value calculation

Projects	**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**
k	1.192	0.663	1.210	0.777	1.375
Scale efficiency	Diminishing economies of scale	Incremental scale benefits	Diminishing economies of scale	Incremental scale benefits	Diminishing economies of scale
Projects	**Project 6**	**Project 7**	**Project 8**	**Project 9**	**Project 10**
k	1.394	0.929	0.725	0.636	1.005
Scale efficiency	Diminishing economies of scale	Incremental scale benefits	Incremental scale benefits	Incremental scale benefits	Diminishing economies of scale

Based on the k values, there are three types of scale benefits among the 10 units, as shown in Table 4 and Table 5:

(1) Increasing scale benefits, Project 2, Project 4, Project 7, Project 8, Project 9, k smaller, with larger marginal outputs within certain limits, indicating that by increasing inputs appropriately, outputs will increase in a larger proportion;

(2) The decreasing scale benefit type, which are Project 1, Project 3, Project 5, Project 6, and Project 10, indicate that increasing the input will not result in a higher proportion of output and there is no need to increase the input.

3.3 Projection analysis of non-effectiv DMU

Using the formula$\hat{x}_0 = \theta^0 x_0 - s^{-0}$, $\hat{y}_0 = y_0 + s^{+0}$, the non-valid DMU_idecision unit is turned into a valid DMU_i and The results are shown in Table 6:

Table 6. Projection analysis of non-effective DMU

Projects	Project 1			Project 2			Project 3		
	Actual value	Optimum value	Input saving	Actual value	Optimum value	Input saving	Actual value	Optimum value	Input saving
Number of personnel	196	363.683	-167.683	107	290.749	-183.749	145	167.925	-22.925
Funding	8	1.961	6.039	1.1	2.989	-1.889	3.1	2.832	0.268
Equipment	14350	17352.900	-3002.900	5645	15339.100	-9694.060	17000	11324.200	5675.830
Fixed Assets	1100	2041.080	-941.082	1238	3364.000	-2126.000	2246	2601.100	-355.098

Projects	Project 4			Project 5			Project 6		
	Actual value	Optimum value	Input saving	Actual value	Optimum value	Input saving	Actual value	Optimum value	Input saving
Number of personnel	94	161.942	-67.942	194	226.988	-32.988	175	181.298	-6.298
Funding	4.7	1.892	2.808	2.9	3.393	-0.493	2.2	2.082	0.118
Equipment	16000	13733.900	2266.120	26269	14158.600	12110.400	8364	10210.800	-1846.760

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Fixed Assets	1750	3014.880	-1264.880	2500	2925.110	-425.105	1750	2136.400	-386.397

Projects	Project 7			Project 8			Project 9		
	Actual value	Optimum value	Input saving	Actual value	Optimum value	Input saving	Actual value	Optimum value	Input saving
Number of personnel	131	195.160	-64.160	169	113.688	55.313	106	146.233	-40.233
Funding	1.9	2.831	-0.931	0.87	1.169	-0.299	0.7	1.503	-0.803
Equipment	27495	20141.900	7353.070	8021	5997.810	2023.190	10850	7714.830	3135.170
Fixed Assets	11640	2456.800	9183.200	898	1315.380	-417.375	4100	1691.930	2408.070

Projects	Project 10		
	Input saving	Actual value	Optimum value
Number of personnel	108	113.890	-5.890
Funding	1.23	1.297	-0.067
Equipment	7238	7095.280	142.724
Fixed Assets	5500	1717.630	3782.370

According to the above calculation and analysis, the optimization of the number of personnel input, the optimization of financial input, the optimization of equipment input and the optimization of fixed assets input are shown in Figure 2, Figure 3, Figure 4 and Figure 5 respectively.

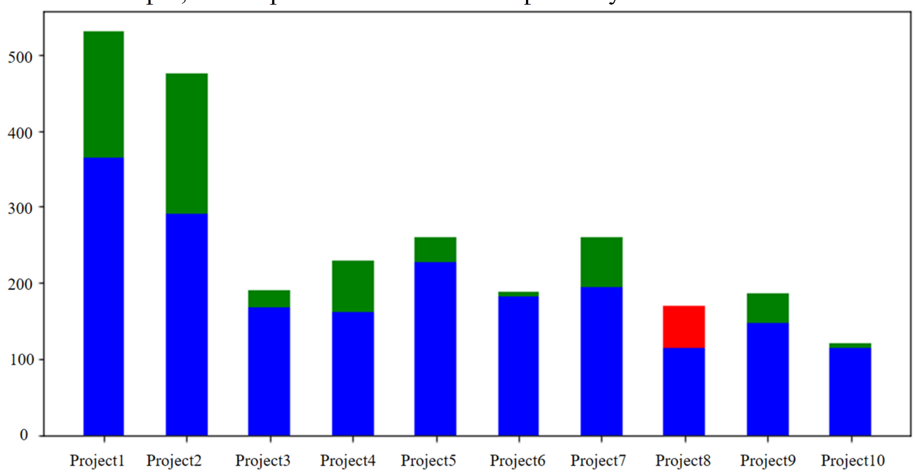

Figure 2. Optimization chart of the number of personnel input

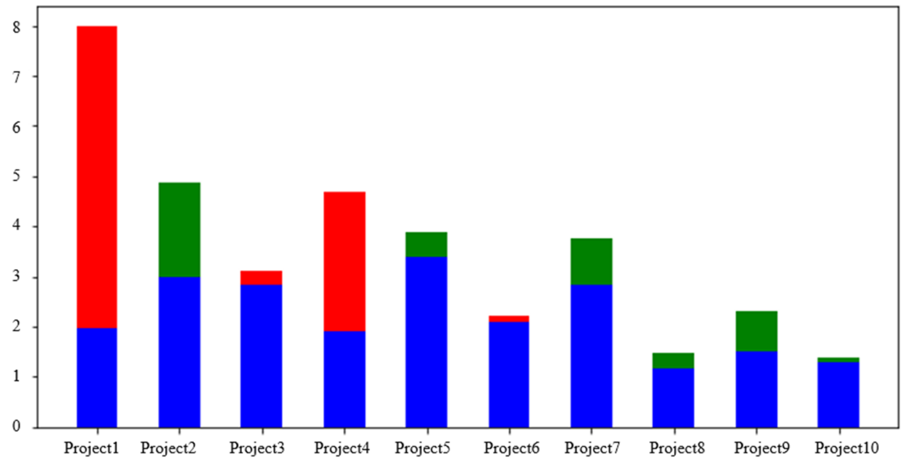

Figure 3. Optimization chart of funding input

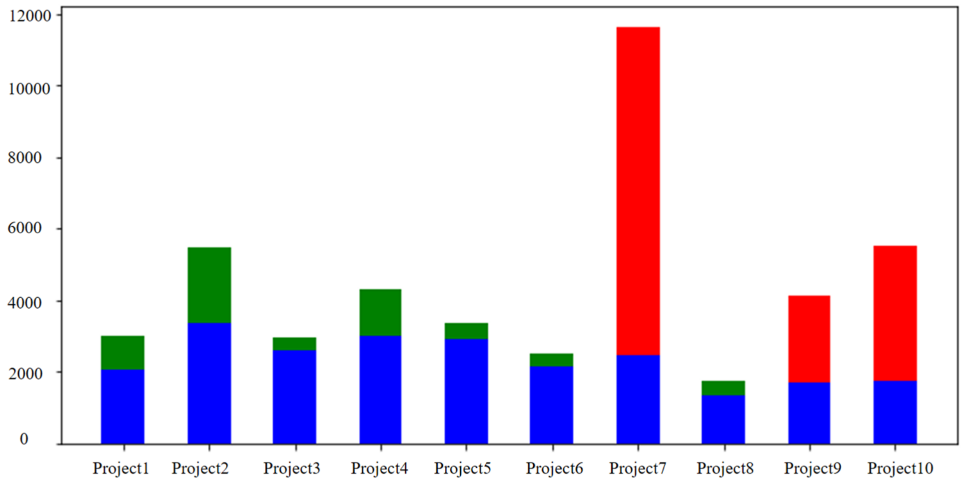

Figure 4. Equipment input optimization chart

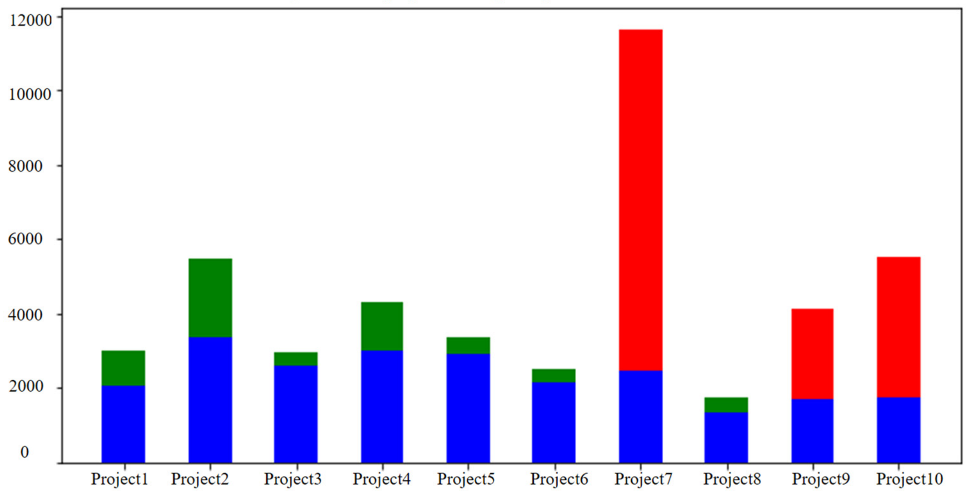

Figure 5. Fixed asset input optimization chart

It can be seen that, except for Project 2 and Project 6, all other projects have different degrees of resource wastage in terms of the number of personnel, funding, equipment and fixed assets.

4. CONCLUSION

In this paper, by establishing a data envelopment analysis DEA model, we calculated and analyzed the input-output ratios of certain large projects of the army in terms of the number of personnel, equipment, funds, and fixed assets, and made an objective evaluation of the input-output ratio of each project, and gave reasonable suggestions for the input optimization of projects that could be optimized.

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