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ANALYSIS ON THE EVALUATION OF PROJECT EFFICIENCY BASED ON BUDGET EXECUTION: PLANNED OUTAGE MAINTENANCE (POM) FOR ELECTRICITY POWER PLANT

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ABSTRACT: With rapid industrialization, electric power consumption has been increasing every year in Korea and in other countries. The provision of additional power stations to produce more electricity is one possible response to this steady increase in consumption. Another alternative is to improve the efficiency of existing stations through timely and effective maintenance works. Since the construction of a new power plant involves a large amount of capital as well as difficulties in the selection of sites, the improvement of existing power stations' efficiencies is often a preferred solution. Therefore, this paper focuses on maintenance project management to address this issue.

Among several types of maintenance works, this paper concentrates on planned outage maintenance (POM). This focus arises from the critical impact of POM on other maintenance work, as well as the entire process of electricity production. Unlike other maintenance work, POM is done on the basis of mid and long-term plans. In addition, only POM works are conducted during the outage of all power plants.

To evaluate the efficiency of POM works, budget data relating to 164 POM projects between 2001 and 2008 was collected from 7 sites in South Korea. Data envelopment analysis (DEA) was selected as a methodology for evaluation. From this analysis, comparative study was used to determine the categories of projects that had performed well, and those with the most optimized budget structures. Moreover, through discussion with industry, this research develops a feasible proposed method by which to enhance the efficiency of POM projects.

Keywords: Electric Power Plant; Efficiency; Planned Outage Maintenance; DEA: Data Envelopment Analysis

1. INTRODUCTION

1.1 Background of Research

Electric power plays a very important role in productivity growth of overall industries and national economics [1]. Hence, a sufficient supply of electric power is critical. However, paradoxically due to the development of industrialization, it has become increasingly challenging to consistently provide the required quantity of electric power. In addition, the recent unpredictable status of climate change has increased the complexity of this issue because electric consumption is highly correlated with the rate of economic growth and weather fluctuation (Director General for Energy Industries, Ministry of Knowledge Economy, Republic of Korea, 2010).

In order to provide stable electric power, initially it is important to have a sufficient quantity of power stations. However usually the expenses associated with such power stations is an extremely large sum. Furthermore, it is difficult to find an appropriate site to build new station, and a long-term construction period is required (Director General for Energy Industries, Ministry of Knowledge Economy, Republic of Korea, 2010). This is the main reason for the need to focus on maintenance work to optimize the efficiency of power plants, and thus provide the greatest quantity of electricity. Normally in the product life cycle management, the most effective activity for maintaining the functional level of a product above the level required is maintenance [2]. Timely maintenance tasks can contribute to ensuring a reliable supply of electricity regardless of systems and kinds of power plants. On the other hand, unsuitable planned maintenance leads to lost revenue or obstructs our economic application. This also degrades performance, potentially de-rates the unit permanently in the longer term, and exposes the unit to higher risk of forced outages [3].

Although there are a wide variety of types of maintenance activities, this paper focuses on planned outage maintenance (POM) for the following reasons. (1) POM is executed by mid and long-term plans while routine or emergency maintenance are only executed as necessary. (2) Planned outage maintenance (POM) is conducted during the outage of all power generating facilities to disassemble and inspect most components. For this reason, effective management of POM can contribute to improving plant availability and efficiency, by shortening the outage period [13] and all performance

indexes should be improved after POM work [9]. (3) Furthermore, as verified through interviews with engineers and experts of power plant maintenance, POM can have a tremendous impact on 'success or failure' of general operation of power station units. POM works can improve performance and reduce the expense attributed to power generation, as well as expand the life of a station [27].
POM maintenance work is further complicated by the following environmental issue: Because of the outage period, POM cannot be carried out when the electricity demand is volatile and higher than average, and for this reason POM can be practiced only during the off-season. Unfortunately, anomaly atmospheric conditions (such as global warming, unforeseen continuous rainy spells, unforeseen cold and so on) makes electricity demand unpredictable, along with the peak and off-seasons. In this context, one simple example can be found. A result of global warming is that summer and winter (which represent periods of peak power demand) are growing longer. This means not only an increase in power consumption but also a reduction in the time available each year for POM. Therefore more efficient management of POM projects has been is an important requirement.

1.2 Scope of Research

Maintenance work consumes a significant amount of money spent on power generation [4]. This applies in particular to POM work, because it is broad by nature. According to the budget data collected between 2001 and 2008 relating to Korean power plants, the annual budget was generally in the order of millions of USD. As POM is a repeated process, variable technologies and knowhow have accumulated and improved, however according to the data, there has not been significant innovative change or development to reduce maintenance cost and duration. Thus, through this research, the authors analyse the budget structure and determine the empirical efficiency frontier. The optimized budget structure is then established through comparative study.

Budget data was collected relating to 164 POM projects conducted across seven sites in South Korea between 2001 and 2008. The sites were selected based on obtaining a variety of plant attributes to prevent the distortion of data. The data relates to 164 POM projects, and consists of budget structure and performance. The cost factors were indexed to a 2008 equivalent according to the Korean Construction Cost Index (CCI) which is officially provided every month by the Korean government. The data envelopment analysis (DEA) method and Efficiency and Productivity Analysis System (EnPAS) software was selected to evaluate the efficiency of the POM projects. The projects were divided by efficiency level into 22 groups, which were used to conduct a comparative analysis.

This paper reports the latest developments of ongoing research efforts regarding efficient project management in the area of budget execution.

2. THEORETICAL REVIEW

2.1 Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a mathematical programming approach to provide a relative efficiency assessment (called DEA efficient) for a group of decision making units (DMU) with multiple inputs and outputs [5]. Generically, a DMU is regarded as the entity responsible for converting inputs into outputs and whose performances are to be evaluated [6]. In this research, DMUs are POM projects within power plants.

DEA is a principle method for extracting information about a population of observations. In contrast to parametric approaches whose object is to optimize a single regression plane through the data, DEA optimizes on each individual observation with the objective of calculating a discrete piecewise frontier determined by the set of Pareto-efficient decision-making units (DMUs) [1]. For each DMU, a virtual input and output was formed by weights which were derived from the data instead of being fixed in advance [6], since the weights generally vary from one DMU to another DMU. For example, consider m input and s output, with the following data matrix (1). Using the primitive equation (2), the weights are determined by linear programming in order to maximize the ratio in equation (2)

$$X = \begin{bmatrix} x_{11} & x_{12} & & x_{1n} \\ x_{21} & x_{22} & \cdots\cdots & x_{2n} \\ x_{31} & x_{32} & & x_{3n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots\cdots & x_{mn} \end{bmatrix}$$

$$Y = \begin{bmatrix} y_{11} & y_{12} & & y_{1n} \\ y_{21} & y_{22} & \cdots\cdots & y_{2n} \\ y_{31} & y_{32} & & y_{3n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{s1} & y_{s2} & \cdots\cdots & y_{sn} \end{bmatrix} \tag{1}$$

$$\theta_{ratio} = \frac{Virtual\ output = \sum_{k=1}^{s} u_k y_{kj}}{Virtual\ input = \sum_{k=1}^{m} v_k x_{kj}},$$

$$j = 1, 2, 3, \ldots\ldots, n \tag{2}$$

θ = Efficiency of DMU_0
u = Weight of output
v = Weight of input
x = Input of DMU
y = Output of DMU

Each DMU is assigned a best set of weights (v_k, u_k) with values that may vary from one DMU to another [6]. In general, two of the most widely used DEA models are CCR (Charnes, Cooper and Rhodes) and BCC (Banker, Charnes and Cooper). In 1978, Charnes, Cooper and Rhodes proposed the first DEA model (CCR) [7]. The original CCR model was applicable only to technologies characterized by constant returns to scale globally [8]. For this reason, the CCR model has limitations in terms of unrestricted weight flexibility, and also in that it does not consider issues relating to capacity and location constraints and deployment plans [9]. The BCC (Banker, Charnes and Cooper) model was developed in 1984 to overcome these drawbacks of the CCR model [10]. The BBC model extended the CCR model to accommodate technologies that exhibit variable returns to scale [8]. Equation 3 shown below presents the general BCC model.

$$Max\ \theta_{ratio} = \frac{\sum_{k=1}^{s} u_k y_{kj} \ + \ u_j}{\sum_{k=1}^{m} v_k x_{kj}} \qquad (3)$$

$$subject\ to\ \ \frac{\sum_{r=1}^{s} u_r y_{rj} + u_j}{\sum_{r=1}^{m} v_r x_{rj}} \le 1,$$

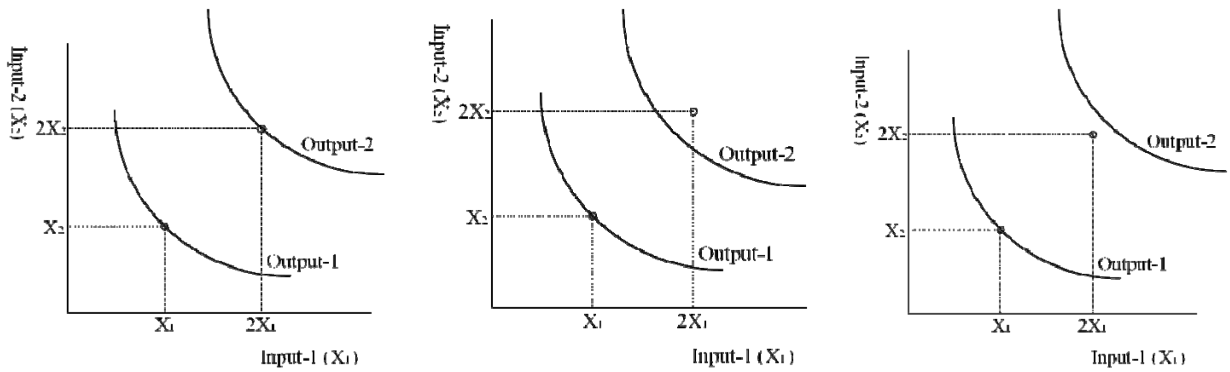
$$j = 1, 2, 3, \ldots\ldots, n$$

θ = Efficiency of DMU_0
u = Weight of output
v = Weight of input
x = Input of DMU
y = Output of DMU
u_j free,

2.2 Returns to scale

Returns to scale (RTS) can be defined as how output fluctuates by variable scales. The CCR model assumes constant returns to scale (CRS). This CRS assumption is appropriate when all firms are operating at an optimal scale [11]. On the other hand, BBC model assumes variable returns to scale (VRS) exist. Decreasing returns to scale (DRS) occur when output decreases as all input factors increase. The reverse situation is increasing returns to scale (IRS). These CRS and VRS scale models can be used to establish which DMU determines the frontier of the envelopment surface [12]. Figure 1 presents an explanation of RTS with the geometric production curve.

Figure 1. Graphs regarding return to scale (RTS)



(1) CRS (2) DRS (3) IRS

3. EFFICIENCY ANALYSIS OF POM PROJECTS

3.1 Overview of Korean power plants

This research is based on data relating to POM projects across seven power plants, operated by the Korea East-West Power Co. Ltd (EWP). The power produced by these plants account for 12.9% of power generation facilities in Korea. In total, 37 power units were studied, consisting of 12 thermal-coal fired power units (4,900MW), 15 thermal-LNG and oil fired power units (3,000MW), 8 cogeneration power units (900MW) and 2 pumped storage power units (700MW). The total capacity of these units is 9,500MW. To prevent distortion of the data, seven sites were selected by variable attributes and criterions. According to data provided by the Korean government (Director General for Energy Industries, Ministry of Knowledge Economy), the thermal power system accounts for almost 70% of the Korean power generation system. For this reason, this research focuses on the thermal power system, with the inclusion of two other systems to ensure the objectivity of the study.

3.2 Establishment of criterion for evaluation

To determine which sorts of projects tend to have a higher efficiency rates, the criterion used to measure the efficiency of POM projects is set. Although plants and stations may appear to use the same process for generating electric power, there are several differences among their principles of power generation. One of the distinctive differences is the capacity of each unit. Therefore, POM projects should be divided according to their characteristics to obtain reliable results in this study. The criterion for grouping is based on the technical report by EWP. For several decades, engineers and managers have accumulated their technical skills and knowhow, and they organize their reports based on their own categories. This categorization provides the basis of grouping of this research and the result is shown in Table 1 below. DEA analysis has been performed for each group.

Table 1. Criterions of Korean power stations

Main Category	Types	N	Code
Year	Over 20 years	30	Y-1
	Over 15 years	62	Y-2
	Over 10 years	39	Y-3
	Less than 10 years	33	Y-4
Capacity (Generation system and fuel)	100 MW, (LNG)	60	C-1
	150 MW, (LNG)	27	C-2
	200 MW, (Anthracite)	32	C-3
	250 MW, (Bituminous)	10	C-4
	350 MW, (Pumped Storage)	5	C-5
	400 MW, (Oil)	14	C-6
	500 MW, (Bituminous)	16	C-7
Level of maintenance	Major	39	L-1
	Normal	42	L-2
	Minor	77	L-3
	Temporary	6	L-4
Site (Location)	A	16	S-1
	B	10	S-2
	C	13	S-3
	D	25	S-4
	E	36	S-5
	F	59	S-6
	G	5	S-7

3.3 Result of Efficiency Analysis

3.3.1 Time in Operation

Table 2 presents the first analysis result regarding the relationship between 'time in operation' and efficiency. Y-2 group (greater than 15 years; less than 20 years) outperformed the other groups in both CRS and VRS efficiency analyses (mean returns to scale of 0.5759 and 0.7617 respectively. In addition to this, relatively low efficiencies were seen for the Y-1 group (greater than 20 years) and Y-4 group (less than 10 years). This is attributed to the assumption that POM work on units that have been used for more than 20 years increased costs are incurred due to the wear and tear of components. Based on the relatively high standard deviation shown for the units in operation for less than 10 years, it appears that unforeseen problems may cause this low efficiency. By contrasting the maximum (Y-2) and minimum (Y-1) mean returns to scale, we find that 'time' has approximately 0.32 and 0.38 degrees of leverage over POM project efficiency according to CRS and VRS respectively. Along with this result, it is noted that there is a serious fluctuation in efficiency as time in operation increased beyond 20 years.

Table 2. Analysis result 1- Time in Operation

Code	Time in Operation	N	Constant Return to Scale		Variable Return to Scale		Return to Scale (N)		
			Mean	SD	Mean	SD	DRS	CRS	IRS
Y-1	> 20 years	30	0.2554	0.2133	0.3808	0.3001	19	1	11
Y-2	15 to 20 years	62	0.5759	0.2401	0.7617	0.2089	9	9	44
Y-3	10 to 15 years	39	0.4476	0.2303	0.5436	0.2327	5	3	31
Y-4	<10 years	33	0.3079	0.3316	0.3716	0.3687	16	4	13

□ Shadowed space refers to each maximum figure

SD: Standard Deviation
DRS: Decreasing Return to Scale
CRS: Constant Return to Scale
IRS: Increasing Return to Scale

3.3.2 Capacity Group

Table 3. Analysis result 2- Capacity of Unit (Generation System and Fuel)

Code	Capacity (Fuel)	N	Constant Return to Scale		Variable Return to Scale		Return to Scale (N)		
			Mean	SD	Mean	SD	DRS	CRS	IRS
C-1	100 MW (LNG)	60	0.5836	0.2437	0.7698	0.2418	8	10	42
C-2	150 MW (LNG)	27	0.4027	0.2450	0.5028	0.2426	4	0	23
C-3	200 MW (Anthracite)	32	0.3793	0.2836	0.4762	0.3168	13	2	17
C-4	250 MW (Bituminous)	10	0.4687	0.2827	0.5615	0.3155	3	1	6
C-5	350 MW (Pumped Storage)	5	0.8135	0.3370	0.8948	0.3754	2	3	0
C-6	400 MW (Oil)	14	0.1639	0.2203	0.3539	0.3103	9	0	5
C-7	500 MW (Bituminous)	16	0.1192	0.3369	0.1292	0.3746	10	1	5

□ Shadowed space refers to each maximum figure

SD: Standard Deviation
DRS: Decreasing Return to Scale
CRS: Constant Return to Scale
IRS: Increasing Return to Scale

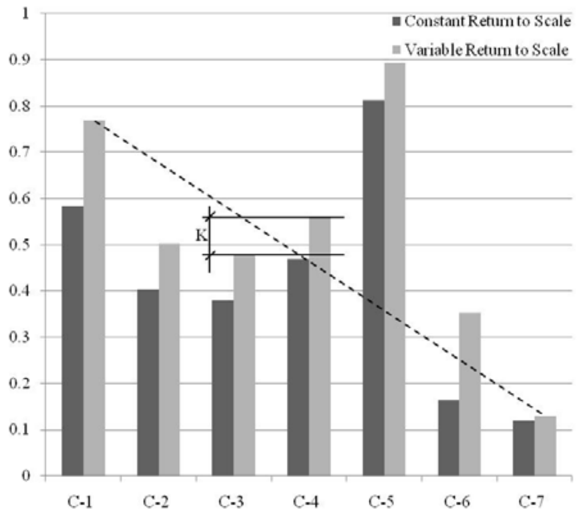
Table 3 presents the analysis result regarding the relationship between unit capacity and efficiency. It should be noted here that the generation system and fuel used varies from one unit to another, and this has a significant impact on these results. The highest efficiency was seen in C-5 group (350 MW unit) with CRS and VRS of 0.8135 and 0.8948 respectively. With the except C-4 and C-5 groups, capacity and efficiency appear to be related in inverse proportion as shown in the figure 2. From this result, it can also be said that C-5 group (350 MW: Pumped Storage) can be operated very efficiently in terms of POM work.

As mentioned above, C-4 and C-5 groups perform outside the general trend. This may be an indication that the fuel and generation system used has a significant impact on these cases. In other words, although the influence of capacity is generally correlated with efficiency, the impact of 'Bituminous' and 'Anthracite' fuels interrupted the trend based on capacity that is the 'K' in the figure 2.

In return to scale (RTS) regard, it is concluded that 200 MW~ 350 MW units is the most efficient, since at this level, decreasing return to scale (DRS), constant return to scale (CRS) and increasing return to scale (IRS) represent a uniform distribution. Units with capacity greater than 350 MW are dominated by DRS and those with less than 200 MW are dominated by IRS.

Furthermore, the difference in returns to scale between the best and worst performing groups reveals a leverage of up to approximately 0.73 and therefore it can be said that the 'capacity' factor has a greater impact on efficiency than that of 'time'. In addition, it is evident that the impact of fuel used on the efficiency of POM projects should not be overlooked.

Figure 2. Bar chart of analysis result 2 – Capacity of Unit



3.3.3 Level of Maintenance Group

The relationship between 'level of maintenance' and efficiency of POM projects is analyzed in Table 4. L-1 group reveals relatively low efficiency. L-2, L-3 and L-4 groups show similar efficiencies to one another. Based on these results, the progress of L-1 group should be analyzed circumstantially to enhance this work. The Return to Scale (RTS), of L-1 group is 30-DRS which are 76.92% of the L-1 group result. This implies that the scale of L-1 group is larger than optimal in terms of efficiency. In response to this limitation, one possible solution is to divide the process of L-1: 'Major work' and to perform it as separate tasks. The L-3 and L-4 groups displayed the opposite tendency, indicating that this work was performed more frequently than necessary. In this 'level of maintenance' case, there is only 0.17 difference between the best and worst groups. Therefore, it is concluded that ‘level’ exhibits less leverage than other factors.

Table 4. Analysis result 3- Level of Maintenance

Code	Types	N	Constant Return to Scale		Variable Return to Scale		Return to Scale (N)		
			Mean	SD	Mean	SD	DRS	CRS	IRS
L-1	Major	39	0.3661	0.2855	0.4910	0.3185	30	3	6
L-2	Normal	42	0.4678	0.2836	0.5583	0.3168	12	7	23
L-3	Minor	77	0.4437	0.2844	0.5870	0.3165	7	6	64
L-4	Temporary	6	0.4830	0.3031	0.7205	0.3307	0	1	5

□ Shadowed space refers to each maximum figure

SD: Standard Deviation
DRS: Decreasing Return to Scale
CRS: Constant Return to Scale
IRS: Increasing Return to Scale

3.3.4 Site Group

Table 5. Analysis result 4- Site (Location)

Code	Types	N	Constant Return to Scale		Variable Return to Scale		Return to Scale (N)		
			Mean	SD	Mean	SD	DRS	CRS	IRS
S-1	A	16	0.1192	0.3369	0.1292	0.3746	10	1	5
S-2	B	10	0.4687	0.2827	0.5615	0.3155	3	1	6
S-3	C	13	0.3491	0.2878	0.4746	0.3126	3	1	9
S-4	D	25	0.2007	0.2133	0.3383	0.3001	17	0	8
S-5	E	36	0.4456	0.2441	0.5461	0.2415	6	2	28
S-6	F	59	0.5886	0.2449	0.7741	0.2443	8	9	42
S-7	G	5	0.8135	0.3370	0.8949	0.3754	2	3	0

□ Shadowed space refers to each maximum figure

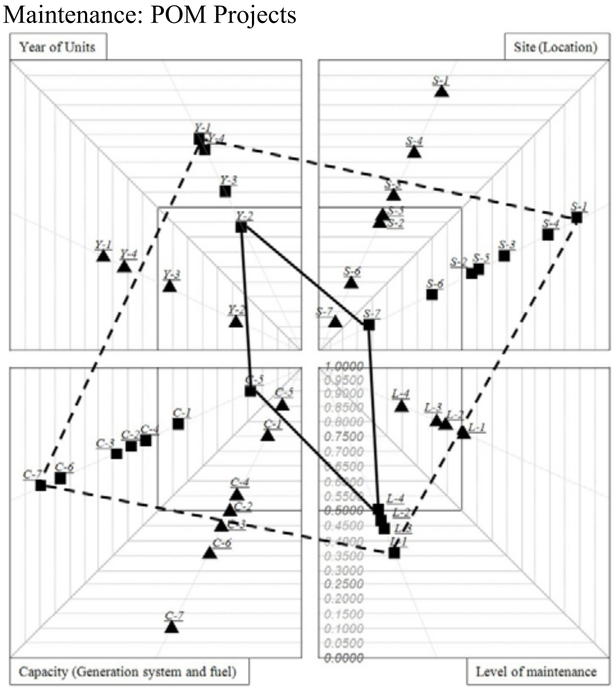
SD: Standard Deviation
DRS: Decreasing Return to Scale
CRS: Constant Return to Scale
IRS: Increasing Return to Scale

Table 5 shows the results of site (location) analysis. Both CRS and VRS rank the groups in the following order: S-7 > S-6 > S-2 > S-5 > S-3 > S-4 > S-1. These distinctly evident points would result from variations in generation system, the unit’s capacity and the fuel type. Based on the relatively high standard deviation, the progress of S-7 group and S-1 group should be checked. Generally, S-6 group had performed the largest number of projects with high CRS (0.5886) and VRS (0.7741). On the other hand, S-1 group and S-3 group exhibit the opposite trend. The ‘site’ factor exhibits approximately 0.73 degrees of leverage to POM project efficiency. Based on detailed research and interview with engineers and experts, it is concluded that this influence is derived from variations in generating units rather than location.

3.4 Visualization of group DEA efficiency analysis

Figure 3 illustrates where POM projects sit in terms of the decision making units (DMUs). The four quadrants refer to ‘year of establishment’, ‘capacity (generation system and fuel)’, ‘level of maintenance’ and ‘site (location)’. The centre of each plane represents the maximum efficiency: 1.0000 and efficiency decreases with distance from this point. The following conclusions are drawn based on this figure.

Figure 3. Trend Analysis of Planned Outage Maintenance: POM Projects



□ Toward the centre, it represents higher efficiency
CRS: Constant Return to Scale
VRS: Variable Return to Scale

Based on CRS analysis, the ‘best curve’ (black bold connecting line) and ‘worst curve’ (black dotted bold connecting line) form two different diamonds aligned on opposite axes. The ‘Capacity (generation system and fuel)’ and ‘Site (location)’ are far more vital factors than ‘time in operation’ or ‘level of maintenance’ in POM projects. Furthermore, both CRS and VRS analyses produced very similar trends. Therefore, it can be said that the scale variability cannot influence positively on the efficiency of POM project.

4. CONCLUSION AND FUTURE WORK

It goes without question that a stable supply of electric power is one of the most important factors for industry and national sustainability. For this reason, numerous studies exist regarding power supply and its optimal production. Although there are already diverse approached to this issue, this research focuses on optimizing the efficiency of maintenance work.

Firstly it was established that planned outage maintenance (POM) work is the most crucial work among a broad variety of maintenance works. Thus, data was collected relating to 164 POM projects conducted across seven sites in South Korea between 2001 and 2008. Using this data, efficiency of these projects was evaluated, based on data envelopment analysis (DEA) and Efficiency and Productivity Analysis System (EnPAS). Through this research, many valuable results were discovered as mentioned above. From this research, it was possible to conclude which factors have the greatest impact on the efficiency of POM project. Therefore, a more detailed approach to predicting and evaluating the efficiency of POM projects should be studied to attain more effective maintenance project management.

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