Discussion Paper

CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH

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A Priority Service Program and Power Outage Costs: The Case of Taiwan's Cement Industry

by
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ABSTRACT

This paper examines the quantitative relationship between the electricity priority service program and customers' outage costs. Taiwan's cement industry is as a study case. Based on the survey data of factories subject to ANOVA and ANCOVA models, we conclude that an appropriate priority service rate should be designed to meet the curtailable load covering the cement mill and raw mill stage, which represents 68% of the customers' contracted load. The corresponding outage costs of the cement factory is $1.05/KWH. Areas for further research are also suggested in this paper.

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I. Introduction

Priority service, which offers customers a selection of service options at a range of prices for all, or a portion of their loads, allows for utility flexibility and relaxes the power shortage problem. A central element in the implementation of priority service would be the design of a menu that offers customers choices and combinatons in service reliability and rates. Such a menu of priority service rates is normally determined by the customers' outage costs and the utility's cost; including power production cost and the transaction cost of the priority service program. The outage costs used for designing a feasible priority service program should contain information concerning of various outage conditions including prior notification, duration time, frequency and depth of power outage. Among these, outage depth or load portions of customers' contracted capacity are the most important for setting a fair priority service program. As pointed out in EPRI(1989), most of the outage cost literature is focused on measuring the impact of total power interruptions, without investigating how outage costs change with the depth of the outage (i.e., the ratio of curtailed capacity vs. contracted capacity). The lack of partial outage costs information is a significant shortcoming in the literature and is the focus of the present study.

In Taiwan, power shortage has been a critical problem for the past few years. In the last five years, Taiwan Power Company (Taipower) has experienced an annual 10.75% rate of growth in demand during the peak-load periods. Moreover, many power plant development programs have been postponed due to the opposition of the local people near the proposed plant sites. As a result, the reserve margin of Taipower's generating capacity has dropped and several power outages occurred during the summers of 1989, 1990, and 1991. This problem is likely to continue since there won't be enough generating units on-line to meet the projected growth in peak-load demand. Therefore, the implementation of priority service is most critical, other than power plant development, to mitigate the problem of power shortage.

The purpose of this study is to formulate a feasible priority service program for Taiwan. In order to achieve this objective, the cement industry was selected as a case study. The reason for choosing the cement industry is because of the following. First, cement manufacturing can be divided into several stages and the power supply can be interrupted without significant loss. Second, most cement factories have experts for managing their power network and they know how to conduct load management. Third, it is one of the major industries in Taiwan in terms of electricity consumption (4.1% of the total in 1990) and GDP contribution (5.4% of the total in 1990).

This paper is organized as follows. Section two illustrates the analytical framework. Section three presents the empirical results. Concluding remarks are presented in the last section.

II. Analytical framework

Conceptually, other things being equal, power outage costs will increase when the outage depth increases. This is because customers curtail their load, starting from switching off the least costly end-use first, the next least costly, etc., so as to minimize their outage costs. In other words, the higher portion of the customers' load demand, the smaller the outage costs. This can be illustrated by Figure 1 and Figure 2. From Figure 1, there is a positive relationship between average outage costs (OC) and service reliability (R) (quadrant I). This is because the higher the outage costs of the load share, the higher their service relisbility for customers' requirements in order to minimize the loss of the power outages. The customers, of course, are willing to pay a higher price (P) to avoid the loss (quadrant IV). Moreover, given a normalized load duration curve, we have the negative slope of the electricity demand function L(P) (quadrant III), corresponding to the negative relationship between outage costs (OC) and its load demand (L) (quadrant II). In addtion, since a higher customers' load demand means a smaller outage depth (A) and vise versa, we can derive an upward trend relationship between customers' outage costs and power outage depth as shown in Figure 2. For the example of the cement industry, the manufacturing process can be divided into four stages:

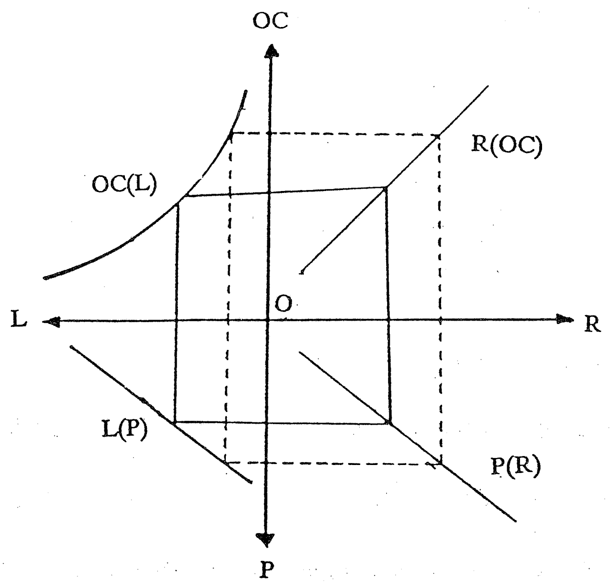

Figure 1: The Relationship Between Outage Costs and Related Vareables

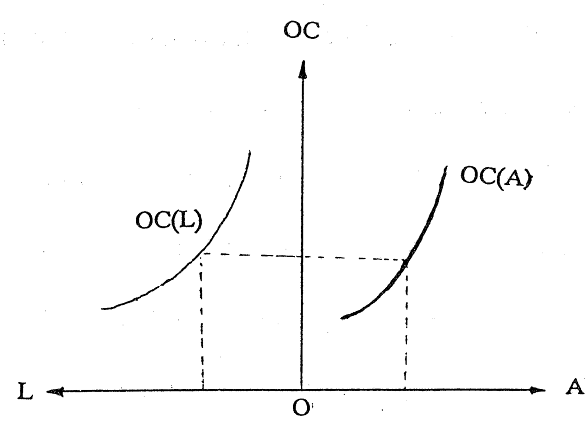

Figure 2: The Relationship between Outage Costs and Outage Depth

limestone crushing; raw mill; clinker; and cement mill. The cement mill stage, is the most electricity-intensive and can be interrupted with short-time notification. Therefore, its outage costs are relatively low. In general, this stage is first considered for load curtailing when power supplies are short. On the contrary, the clinker stage has less electricity-intensity and is most sensitive to power outage. Therefore, it is the last step to curtail its power supply.

In the present study, outage costs of the cement industry are represented by the production loss due to power outage. The first step of the analysis is to calculate the average outage costs (AOC) per KWH of each machine and of the four manufacturing stages. Based on the AOC, we can derive a priority service program for each load slice (the amount of outage depth). The calculating process of the AOC contains three stages. First, measure the total outage reduction (TOR) of each machine. The formula is as follows:

TOR = (daily output/daily operation hours) x (outage hours + 1/2 x turn-off hours of each machine + 1/2 x re-start hours of each machine)

Note that actual and hypothetical lotus of turned-off and re-start curves for each machine (as shown in Figure 3) are different and this paper, for simplicity, uses 1/2 as a proxy of the total load curtailed.

Second, calculate total outage costs (TOC) of each machine, i.e., the value of total production. The formula is as follows:

$$TOC = TOR \times (\$91.63/\text{per MT cement}) \times (1- \text{gross profit rate}) \times (\text{cost share in a specific manufacturing stage})$$

Also note that "cost share" in the formula is defined as the percentage of the cost in a specific stage (e.g., limestone crushing or raw mill) divided by the cost of final product (i.e., the retail prices of cement). In other words, it is the marginal cost of each manufacturing stage.

Third, average outage costs (AOC) is derived as follows:

$$AOC = TOC \,/\, (\text{outage hours} \times \text{electricity-consumed capacity of each machine})$$

After estimating the outage costs, we conducted analyses of variance (ANOVA) and covariance (ANCOVA) to examine the relationship between the estimated outage costs and their attributes (i.e., outage depth and plant size). The former (ANOVA) is to test if there are any significant differences among those two attributes, the latter (ANCOVA) is to identify the quantitative relationship between the outage costs and those two attributes. The ANCOVA model formulated as follows:

$$Y_{ijkl} = U + A_i + B_j + AB_j + C_k + \epsilon_{ijkl}$$

Where

Y_{ijkl}	represents the sample observations, i.e., the lth outage costs under the kth plant size and of the jth outage stage of the ith outage depth; i=10,12,14,...,90, j=1,...,4, k=1,2, l=1,2,3,...,598, referred to Figure 4 for the notation;
U	represents the population mean;
A_i	represents the effect of outage depth;
B_j	represents the effect of outage stage;
AB_j	represents the interactive effect between outage depth and outage stage;
C_k	represents the effect of plant size;
ϵ_{ijkl}	represent the error term, ϵ_{ijkl} -- $NID(0,\sigma^2)$

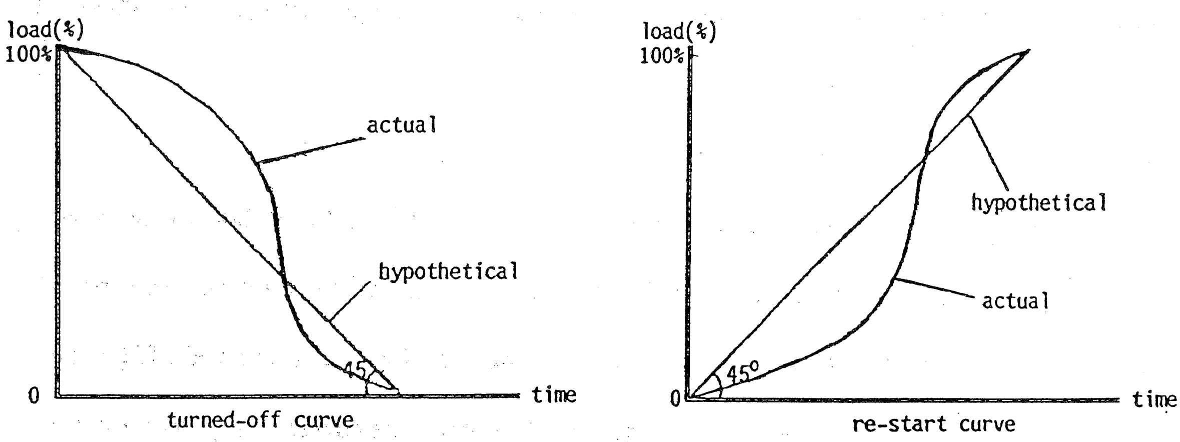

Figure 3: Actual and Hypothetical Lotus of Cement Machines' Turned-off and Re-start Curves

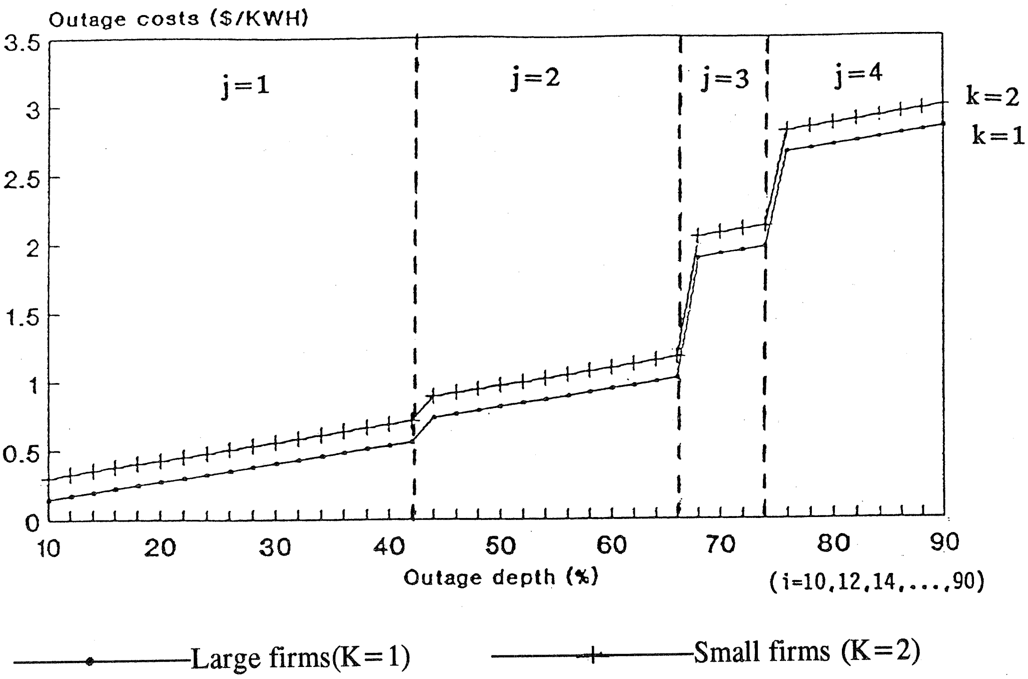

Figure 4: The Relationship Between Outage Costs and Outage Depth, Outage Stage, Plant Size

It should be noted that the curve in Figure 4 describing the relationship between outage costs and outage depth, in reality, should be in a discrete parametric form, not a continuous derivative form. Because in most cases, equipments are turned-off by the same switch, that is, runs on the same system. Therefore, the curves in Figure 4 are just proxy.

III. Empirical Results

Based on the above analytical framework, we conducted a survey in March 1991 on 15 cement factories with 4,000KW usage or above. The questionnaires were mailed and followed-up by telephone cross checks. A total of 13 factories replied and constructed the effective sample of the study. The main contents of the questionnaires included partial outage costs of each manufacturing stage and outage conditions, i.e., partial outage for a seven-hour duration from 10:00 a.m. to 5:00 p.m. during the summer peak period, i.e., between July 1 and September 30. Also, a sixteen-hour prior notification of each outage is implemented and the maximum outages are limited to eight times per month.

The results show that surveyed customers would shut down each machine of each manufacturing stage according to the scale of outage costs (see Table 1) from the least costly one to the most costly one. The average outage costs of each machine and of each manufacturing stage are listed in the last row in Table 1. It shows that in most cases those machines' outage costs in the cement mill stage are smaller than those in the raw mill stage. It also reveals that the cement mill has the least average outage costs of \$0.36/KWH, followed by the raw mill (\$0.61/KWH), limestone crusher (1.92/KWH) and rotary kiln (\$2.46/KWH).

Table 1: The Average Outage Costs of Each Machine and of Each Manufacturing Stage

Unit:$/KWH

Customers' number / Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	Averge
Limestone Crusher														
#1	1.35	2.25	2.03	1.75	1.56	2.43	0.91	2.04	2.07	1.70	1.45	1.49	1.42	
#2	1.71	2.26	2.04	2.11	1.60	2.48	1.45	2.81	-	-	-	-	2.06	1.937
#3	2.11	2.95	-	-	2.15	-	-	-	-	-	-	-	-	
Raw mill														
#1	0.40	0.48	0.51	0.50	0.87	0.46	0.29	0.60	1.05	0.51	0.58	1.02	0.73	
#2	0.47	0.50	0.65	0.68	1.05	0.48	0.30	0.61	-	-	1.04	1.34	-	0.609
#3	0.51	-	-	-	-	0.69	0.32	-	-	-	-	-	-	
#4	0.51	-	-	-	-	0.70	0.35	-	-	-	-	-	-	
Rotary kiln														
#1	2.34	1.93	2.82	2.95	1.45	3.03	1.81	3.74	2.69	2.04	1.93	1.95	2.08	
#2	2.93	2.65	3.16	3.35	1.95	3.27	1.88	3.76	-	-	-	-	-	2.509
#3	3.02	-	-	-	-	-	-	-	-	-	-	-	-	
Cement mill														
#1	0.25	0.29	0.18	0.20	0.29	0.40	0.33	0.36	0.24	0.36	0.18	0.54	0.47	
#2	0.40	0.30	0.19	0.21	0.30	0.41	0.35	0.39	-	-	0.19	0.55	0.47	
#3	0.44	0.32	0.21	0.23	0.36	0.49	0.36	-	-	-	0.23	0.57	0.49	0.358
#4	0.44	0.34	0.21	0.23	-	0.49	-	-	-	-	-	0.57	0.49	
#5	-	0.40	-	0.25	-	-	-	-	-	-	-	-	0.50	
#6	-	0.41	-	-	-	-	-	-	-	-	-	-	0.51	
#7	-	0.41	-	-	-	-	-	-	-	-	-	-	0.51	
Contracted Capacity (KW)	28500	26900	24936	23500	21350	20700	19428	17500	13100	12800	10350	9850	4000	17916

Note: "#" means each machine of each stage, "-" means lack of the pertaining machine.

With regards to the ANOVA process (see Table 2), since the overall F-value (900.03) is significant, it means that the formulated model is valid. Also, the attribute test (i.e., outage depth and plant size) shows that respective F-values are 1191.93 (outage depth attribute) and 24.30 (plant size attribute), which are significantly different from zero. As to the pair-wise test, it shows that each of the outage depths are significantly different in outage costs (see Table 3). The result implies that a different priority service program could be constructed based on each different stage.

Table 2: The Results of the Overall and Individual Factor Tests

Sources	SSE	DF	MSE	F-Value	P-Value
Model	577.05	4	144.26	900.03	0.001*
Error term	103.38	645	0.16		
Total	680.43	649			
Outage depth	573.15	3	191.05	1191.93	0.001*
Plant size	3.89	1	3.89	24.30	0.001*

Note: "*" represents significant different at 5%.

Table 3: The Results of Pair-wise Test among Outage Stage

P-value	stage 1	stage 2	stage 3	stage 4
stage 1	.	0.0215	0.0001	0.0001
stage 2	0.0215	.	0.0001	0.0001
stage 3	0.0001	0.0001	.	0.0001
stage 4	0.0001	0.0001	0.0001	.

Note: All significant at 5% level.

Next, we also utilize an ANCOVA model demonstrated in the previous section to identify the quantitative relationship among the estimated outage costs and their attributes. Table 4 shows the definitions of each variable in the ANCOVA model. Based on the survey data, we proceeded the ANCOVA model and found that all coefficients of the ANCOVA parameters are significantly different from zero except for the ones of interactive effects between outage stage and outage depth, i.e., AB_j. Therefore, we revised the ANCOVA model by substracting the parameters of interactive effects. Table 5 presents the estimated results of the revised model. From the empirical process of the ANCOVA model, we can derive two economic implications. First, since AB_j is indifferent, it means that to curtail the load profile within each manufacturing stage is not wise because by doing that, it will obviously not minimize consumers' outage costs. Second, since the coefficients of parameters B1, B2 and B3 are all significantly different from the reference case B4 as shown in Table 5, it means that the priority service program should be designed by cutting at the turning points between any two stages. In other words, for the case of Taiwan's cement industry, an appropriate priority service program could include three different curtailable loads, i.e., 42%, 68% and 74%. Note that the coefficients of the dummy variables B1, B2 and B3 are all negative. This implies that, other things being equal, the smaller the coefficients of these variables, the smaller the outage costs of the pertaining manufacturing stages. It also shows that an apparent upward parametric curve with the average outage costs increases as the outage depth increases.

In addition, for making a better rate schedule for a priority service program, one should select the largest "gap" between any two coefficients of B_j. In this study, the gap between B2 and B3 is the largest (-0.6618-(-1.5086)=0.8482). Therefore, the level of the curtailable load of the priority service program should be set at 68% of the consumers' total contracted load. At this point, the corresponding outage costs of the cement factory is about $1.05/KWH (see Figure 4).

Table 4: Definitions Used in the ANCOVA Model

Variables	Definitions
OC	The average outage costs
A	Outage ratio (depth)
B1	Outage stage 1, when A is ranging from 10% to 41.9%, if the observations belong to B1, then B1=1; otherwise B1=0.
B2	Outage stage 2, when A is ranging from 42% to 67.9%, if the observations belong to B2, then B2=1; otherwise B2=0.
B3	Outage stage 3, when A is ranging from 68% to 73.9%, if the observations belong to B3, then B3=1; otherwise B3=0.
B4	Outage stage 4, when A is ranging from 74% to 90.0%, if the observations belong to B4, then B4=1; otherwise B4=0.
AB1	Interactive items of A and B1, if the observations belong to AB1, then AB1=1; otherwise AB1=0.
AB2	Interactive items of A and B2, if the observations belong to AB2, then AB2=1; otherwise AB2=0.
AB3	Interactive items of A and B3, if the observations belong to AB3, then AB3=1; otherwise AB3=0.
AB4	Interactive items of A and B4, if the observations belong to AB4, then AB4=1; otherwise AB4=0.
C1	Plant size 1 (Capacity < 18000), if the observations belong to C1, then C1=1; otherwise C1=0.
C2	Plant size 2 (Capacity > 18000), if the observations belong to C2, then C2=1; otherwise C2=0.

Table 5: The Estimated Results of the Revised ANCOVA Model

Variables	Parameters	t-Statistics	P-Value
Intercept	0.0271	2.29	0.0014*
A	0.0129	5.66	0.0001*
B1	-1.6628	-2.47	0.0075*
B2	-1.5086	-12.59	0.0001*
B3	-0.6618	-2.24	0.0039*
C1	0.1553	2.11	0.0107*

Notes:
1. Since the P-Value of AB1, AB2 and AB3 items are insignificant, we revised the model and omitted all interactive variable items.
2. B4 and C2 are the reference cases, their coefficients are zero and do not show.
3. $R^2 = 0.8553$; F=167.07.
4. "*" means significant at 5%.

The above analysis focuses on a one-level priority service rate. In the case that the utility desires to design two or more curtailable load levels, further analysis is need. For the second load slice to be curtailed, there are two possible alternatives to be considered, i.e., 42% and 74% of the customers' total contracted load. The former has the advantage of its larger amount of curtailable load, while its disadvantage are less rate incentives due to the similar scale customers' outage costs to the two manufacturing stages. In contrast, the latter has more favorable and attractive conditions to customers for rate incentives, while unfavorable to utility for its smaller amount of curtailable load. Alternatively speaking, the decision-maker of the utility should evaluate other factors such as the seriousness of the power shortage problem (which has to do with the expected amount of load to be curtailed), the rate incentive (which the utility is willing to give) and so on, to determine which alternatives should be adopted.

IV. Concluding Remarks

This paper examines the quantitative relationship between the electricity priority service program and customers' outage costs. Taiwan's cement industry is used as a study case. Based on the survey data of 13 factories subject to ANCOVA models, it reveals that there is a positive relationship between the average outage costs and outage depth. In reality, such a relationship is shown as an upward parametric curve. The empirical results conclude that an appropriate priority service rate should be designed to meet the curtailable load covering the cement mill and raw mill stages, which represent 68% of the customers' contracted load. At this point, the corresponding outage costs of the cement factory is $1.05/KWH. It also shows that the proportional increases of outage costs is magnified by each depth increment. To describe it as a smooth curve, it would be a concave one.

In conclusion, a priority service rate should be designed by cutting at the turning points between any two stages. For a reasonable curtailable load of Taiwan's cement industry, there could be 3 kinds of cutting level loads. For one-level priority service program, 68% of the total consumers' contracted load would be most appropriate. For the two-level priority service program, either 42% and 68%, or 68% and 74% would be appropriate. For the three-level program, 42%, 68% and 74% load would be appropriate.

Finally, this study was conducted from a short-run viewpoint; a long-term viewpoint may lead to different results. Also, for simplicity, the calculation of the outage costs were only based on production loss, while in reality other outage costs should be included, such as the cost components that are associated with quality deterioration, clean-up and restarting expenses after the power outages and, the categories of "others" such as the costs associated with damage to the environment or to people's health and other transaction costs, e.g., administration cost. Moreover, an appliable priority service program should be expanded to all industries. Since each industry has different curtailable load attributes, the results derived from the cement industry are not necessarily applicable to other industries. Therefore, other important industries should be studied and an inter-industry relationship should be considered before a comprehensive priority service program could be realized. All of these areas need further research.

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