POWERPLANT PRODUCTIVITY IMPROVEMENT STUDY

PROJECT SUMMARY REPORT

ERRATA

Page	Change
15	"Net Present Value of Project (NPV): $2,922,000"
	should read
	"Net Present Value of Project (NPV): -$2,922,000"
16	"Net Present Value of Project (NPV): $1,213,000"
	should read
	"Net Present Value of Project (NPV): -$1,213,000"
22	The following line should be removed:
	"Estimated Project Benefits (Present Worth) $119,740,580"

DISCLAIMER

POWERPLANT PRODUCTIVITY IMPROVEMENT STUDY

Project Summary Report

December 21, 1979

Prepared for:

Economic Regulatory Administration

U.S. Department of Energy

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Illinois Commerce Commission

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U.S. Department of Energy

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Energy Resources Center,
University of Illinois at Chicago Circle

Trident Engineering Associates, Inc.

Illinois Power Company

Commonwealth Edison Company

Central Illinois Public Service Company

Central Illinois Light Company

Illinois Commerce Commission Staff

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I. INTRODUCTION

A. DOE Powerplant Productivity Improvement Program

Electric utilities in the United States are major consumers of oil and natural gas used in the generation of electrical energy. Over the past several years, this consumption has averaged approximately three million barrels per day of oil and gas equivalent. The National Electric Reliability Council's projections of fuel use for electric power generation show oil and gas consumption continuing at current levels through 1985. Even modest improvements in the productivity of generating units using coal or uranium are likely to yield substantial oil and gas savings nationally. In 1974, the Federal Energy Administration (FEA) led an interagency Task Group which investigated the then current status of powerplant productivity. Through that study, it was determined that large coal fired and nuclear generating units were operating below expectation and that substantial improvements in performance were possible. The U.S. Department of Energy initiated a Powerplant Productivity Improvement Program to encourage a reduction in the use of oil and gas by the electric utility sector. Some of the significant elements of that program were:

- A study which identified some underlying causes of lost productivity and defined possible corrective actions.

- Development by Mechanics Research, Inc. (MRI) of analytic methods for the routine systematic analysis of the cost-effectiveness of specific plant improvement programs.

- Estimates by the General Electric Company Center for Energy Systems of the benefits of improved powerplant productivity in terms of deferred additions of new capacity, reduced scarce fuel consumption, reduced capital requirements, and reduced energy costs to consumers.

- Cooperative projects with state public utility commissions demonstrating the DOE methodologies and directed toward exploring mechanisms by which productivity improvements might be encouraged.

The systematic methodology developed for the analysis of the cost effectiveness of productivity improvement projects is based on standard reliability engineering principles. It employs a reliability model tailored to each generating unit together with component performance data and translates expected changes in component reliability resulting from component improvements or equipment configuration into expected changes in unit reliability. These unit reliability changes are expressed in terms of Equivalent Availability (EA), a standard industry measure of performance. The cost of achieving changes in unit EA can then be evaluated, together with the benefits to the utility system, to provide estimates of an improvement project's cost effectiveness. Use of these analytical techniques is supported by detailed procedures which were developed by MRI for the determination of root causes of lost productivity to assist utility personnel in identifying candidate improvement projects. The development of this methodology by MRI was done with the participation of Duke Power, Florida Power & Light, and Tennessee Valley Authority and was substantiated through application to specific improvement projects at one coal fired and one nuclear unit.

Potential benefits from improved powerplant productivity were found by the General Electric Company to be substantial. Assuming a five percentage point improvement both in planned and forced outage rates of 400 MW and larger coal and nuclear units, GE performed an in-depth assessment of the potential savings in utility oil consumption, generation costs, and capacity expansion for Detroit Edison Company, the New England Power Pool, and the Northeast Utilities Company taking into account all of the practical constraints to which operation of these systems are subject. For the Northeast and East Central Regions (representing approximately 25% of the US utility industry capacity) potential annual savings by 1985 of 54 million barrels per year of oil and approximately one billion dollars per year fuel costs were reported. Subsequently a regionalized study by GE indicated economic benefits (1975$) of 1.40 to 1.64 dollars per year per Kw of capacity improved for each percentage point improvement in forced and planned outage rates for the MAIN and MARCA National Electrical Reliability Council (NERC) regions. These are potential gross benefits and do not consider the costs of achieving the improved performance.

In order to demonstrate and further validate the methodologies and to encourage state efforts toward increased powerplant productivity, in 1977 the U.S. Department of Energy sponsored cooperative study projects with the Ohio Public Utilities Commission and the Illinois Commerce Commission (ICC). A key DOE objective of both projects is to demonstrate approaches for assessing costs and benefits of powerplant performance improvements. This objective has involved demonstration of the MRI and GE methodologies by application to specific problem areas at a number of powerplants in each state. In addition, an examination was conducted of methodologies currently in use by Illinois utilities to provide a comparison with the MRI and GE methodologies for the purpose of identifying strengths and weaknesses in each, and for identifying the essential steps in any systematic approach to the problem. A second DOE objective has been to obtain a detailed assessment of the past performance of nuclear and large coal-fired units in each state in order to gain a perspective of the opportunities for performance improvements. A third DOE objective has been to identify potential regulatory and incentives policies that would give utilities added motivation to undertake plant performance improvements.

B. Scope of This Report

This report provides a brief description of each of the individual tasks followed by a summary of the task reports. It also includes an analysis of overall results, a list of key findings and conclusions, and recommendations and resource needs based on information obtained in the conduct of the individual task reports.

C. Scope of DOE/ICC Cooperative Effort

This effort consisted of two projects divided into six tasks. Individual reports were prepared for each of the tasks as they were completed. A brief description of each task together with the task report references are given below in their project/task or numerical sequence. In the next section these tasks are described in more detail and in a sequence that relates to the key DOE objectives previously described.

PROJECT I

Task 1 (P1T1) Current Practices in Illinois Utilities Towards Powerplant Productivity

Identification and documentation of approaches and practices of Illinois electric utilities in improving plant productivity. Management philosophy toward productivity, performance measures, analytical tools and procedures, internal organization for productivity, and representative case studies were examined for the four largest investor-owned electric utilities in Illinois.

Task 2 (P1T2) Demonstration of DOE Methodology

The systematic methodology developed by DOE was applied to the analysis of eight plant improvement projects at the Illinois Power Wood River 5 coal unit and the Commonwealth Edison Quad Cities 1 and 2 nuclear units. Estimates of improved unit equivalent availability were calculated for each project.

Task 3 (P1T3) Analysis of Costs and Benefits for Eight Power plant Productivity Improvement Projects

Estimated improvements in unit equivalent availability from Task 2 above were translated into economic benefits resulting from reduced replacement power costs. Project costs were estimated and benefit-to-cost ratios and net present values were calculated for each project.

PROJECT II

Task 1 (P2T1) Historical Performance of Illinois Investor-Owned Electrical Generating Powerplants Over 200 MW

Equivalent availability of large generating units in Illinois was reported and compared with national performance data.

Task 2 (P2T2) Benefits of Improved Reliability

The procedures developed by General Electric for estimating the potential benefits of improved productivity were applied to the Commonwealth Edison and Illinois Power systems. Four scenarios of improvements in planned and forced outage rates were examined to determine benefits (exclusive of costs) in terms of savings in generation costs and oil consumption.

Task 3 (P2T3) Policy Analysis and Incentive Assessment

Current regulatory practice in Illinois was examined to identify any existing incentives or disincentives to the undertaking of plant improvement projects by electric utilities. Other state public utility commissions were contacted to determine their experiences with productivity improvement incentives, and candidate incentive mechanisms were discussed and presented for consideration by the Illinois Commerce Commission.

Project I Task 2, Demonstration of DOE Methodology, was performed by Trident Engineering Associates, Inc. (Trident) under subcontract to the Illinois Commerce Commission. Technical assistance was provided to the Commission in this study by the Energy Resources Center, University of Illinois at Chicago Circle. The four investor-owned electric utilities which participated in this cooperative study were:

Commonwealth Edison Company

Illinois Power Company

Central Illinois Light Company

Central Illinois Public Service Company

The main involvement of Central Illinois Light Company and Central Illinois Public Service Company was in P1-T1 and P2-T1 with comments also being submitted on other task reports. Only Illinois Power Company and Commonwealth Edison Company participated in P1-T2 and these utilities provided the data upon which P2-T2 is based.

II. SUMMARY OF TASKS

A. Demonstration of the DOE/MRI Methodology (P1T2)

The systematic methodology developed for DOE by MRI for the analysis of productivity improvement projects consists of the following phases:

Phase A - Identification of root causes of lost productivity and development of effective corrective actions to eliminate or mitigate the problem.

Phase B - Prediction of the changes in unit equivalent availability due to changes in equipment reliability and maintenance practices.

Phase C - Determination of the cost effectiveness of specific improvement projects.

Phase D - Tracking the costs and resulting productivity improvements of specific improvement projects.

Due to time and resource limitations, this study focused on demonstrations of Phases B and C. Demonstration of Phase B was done by Trident Engineering Associates under contract to the Illinois Commerce Commission.

Objectives & Approach Taken

The objectives of the Trident study were:

- Apply the methodology to two different improvement projects at each of three units in Illinois.
- Simplify the method where possible.
- Develop reliability models of the three units.
- Demononstrate the validity of the models.
- Estimate changes in equivalent availability resulting from each improvement project.
- Critique the methodology.

Trident's approach to meeting these objectives consisted of the following steps:

- Selection of units and problems to be studied.
- Collection of necessary unit design information, operation and maintenance procedures and outage data.
- Development of functional diagrams for each unit at the generic function, sub-function, and equipment function levels.

- o Analysis of each unit using the DOE/MRI Phase B methodology.
- o Analysis of each of the improvement projects.

Unit and Problem Selection

Unit selection was determined in part by DOE's powerplant productivity program being focused on nuclear and coal units, 400 Mwe and larger. Selection was narrowed further by the availability of utility participation which turned out to be Commonwealth Edison and Illinois Power. Units having less than 3 years commercial operation were excluded to avoid unit immaturity effects. A total of nine coal and five nuclear units met these selection criteria. Because all five nuclear units belong to CECO, and because of the DOE/ICC desire that the two units to be studied include one coal and one nuclear, the selection list was narrowed to 3 coal and 5 nuclear units. Selection from this list of the units to be studied was done by Trident based upon a detailed analysis of unit performance over the five year period 1973-1977 measured against seven factors related to the DOE/MRI methodology.

1. Number of loss-of-function outages.
2. Total hours per year of loss-of-function outage.
3. Number of systems or components experiencing loss-of-function outages.

4. Average number of loss-of-function outages per system.

5. Statistical distribution of loss-of-function outages among systems.

6. Number of loss-of-function outages exceeding two weeks duration.

7. Contribution of loss-of-function outages to total unit unavailability.

Using this approach, Trident selected the following units for a demonstration of the DOE/MRI methodology:

Unit	Utility	Unit Size	Unit Type
Wood River 5	IP	398 MW	Coal
Quad Cities 1	CE	809 MW	Nuclear
Quad Cities 2	CE	809 MW	Nuclear

Due to project resource and time constraints, selection of the improvement projects was not based upon the type of detailed root cause investigation described in Phase A of the DOE/MRI methodology. Instead the projects were chosen by listing potential improvement projects identified by the utility and selecting those which best met criteria developed by ICC, Trident, and the Energy Resources Center (ERC). These criteria are reproduced below.

IMPROVEMENT PROJECT

SELECTION CRITERIA

Essential Criteria	Desirable Criteria*
1. Hardware problem	1. Significant to plant operation
2. Repetitive problem	2. Undertaken or about to be undertaken by utility
3. Suitable to Department of Energy methodology	3. Outage cause well understood
4. Technically and economically feasible	4. Availability of outage cost data
	5. Studied or recommended by utility
	6. Analyzed by a utility improvement project method

*Not necessarily in order of priority.

A total of ten potential projects was identified for Wood River 5 of which four met the selection criteria. Six projects were identified for Quad Cities 1 of which three met the criteria. Thus, a total of eight improvement projects were selected for application of the DOE/MRI methodology.

Unit	Improvement Project
Wood River 5	1. Add sixth pulverizer coal system
	2. Install new tube bundles in all high pressure heaters
	3. Use three shift maintenance to repair pulverizer outages
Quad Cities 1	1. Modification of Electromatic relief valve
	2. Construct Cooling Towers
	3. Modify Moisture Separator Drain Tank
Quad Cities 2	1. Install Amertap System
	2. Modify Feedwater Regulating valve.

On the following pages a brief description of each improvement project studied by Trident is presented along with results of the Benefit Cost analyses.

Addition of Sixth Pulverizer

Wood River 5

Project Description:

Wood River 5 currently uses five pulverizers to attain its maximum dependable capacity of 390 MW. Maximum unit output falls to approximately 340 MW if any of the pulverizers fails. Although environmental restrictions now limit output to 360 MW, addition of a sixth pulberizer would remove an historical source of unit load curtailments and increase unit equivalent availability if and when environmental constraints are lifted. This project involves adding a sixth pulverizer which would supply coal to the boiler in a dense phase (ten to one coal/ air ratio) and thus require only a small diameter pipe with little boiler modification. Technical feasibility of this project is claimed by Combustion Engineering, although there appear to be some uncertainties associated with it. Assuming no failures of the sixth pulverizer, Trident Engineering Associated Inc. has estimated a maximum improvement in equivalent availability (ΔEA) for the project of 0.0234.

Estimated Project Costs (Present Worth): $4,004,000

Estimated Project Benefits (Present Worth):

Due to ΔEA: $1,082,000

Benefit/Cost Comparison:

Net Present Value of Project (NPV): $2,922,000

Benefit to Cost Ratio (B/C): 0.27

Three Shift Maintenance of Mills

Wood River 5

Project Description:

Current practice at Wood River 5 is to use one or two shift maintenance for the repair of mill outages. This causes greater than minimum outage duration. When repairs are postponed over holidays and weekends, outage durations are further extended. This project involves continuous repair of mills, extending into three shifts and weekends and holidays when necessary. Trident Engineering Associates, Inc. has estimated an improvement in unit equivalent availability (ΔEA) of 0.0194 for this project.

Estimated Project Cost (Present Worth): $2,423,000

Estimated Project Benefits (Present Worth):

Due to ΔEA: $1,210,000

Benefit/Cost Comparison:

Net Present Value of Project (NPV): $1,213,000

Benefit to Cost Ratio (B/C): 0.5

Installation of New Tube Bundles in High Pressure Heaters

Wood River 5

Project Description:

High pressure feedwater heater tube leaks have degraded unit performance and have resulted in outages for repairs. This project consists of installing new tube bundles in the high pressure heaters. Assuming an equivalent meantime-to-outage equal to the expected tube lifetime, Trident Engineering Associates, Inc. has estimated a maximum improvement in unit equivalent availability (ΔEA) of 1.00106. This project is currently under serious consideration by Illinois Power Company. Analysis assumes replacement after 14 years.

Estimated Project Cost (Present worth): $464,000

Estimated Project Benefits (Present Worth):

Due To ΔEA:	$209,000	
Due to Improved Heat Rate:	458,000	
Total		$667,000

Benefit/Cost Comparison:

Net Present Value of Project (NPV):	$203,000
Benefit to Cost Ratio (B/C):	1.44

Moisture Separator Drain Tank Modification

Quad Cities 1

Project Description

Instrumentation currently mounted on the moisture separator drain tank is subject to intense vibration and has on previous occasions fallen off, resulting in faulty level signals being given to drain valves, causing them to close. This results in water backing up into the moisture separator itself, causing a turbine trip. The improvement project involves locating the transmitters elsewhere and installing new, faster acting valves. The upper limit on equivalent availability improvement (ΔEA) was estimated by Trident Engineering Associates, Inc. to be 0.00131, for the case in which no further outages occur in connection with the moisture separator drain tank instrumentation.

Estimated Project Cost (Present Worth): $ 25,568

Estimated Project Benefits (Present Worth):

Due to ΔEA $1,180,769

Benefit/Cost Comparison:

Net Present Value of Project (NPV):	$1,155,201
Benefit to Cost Ratio (B/C):	46

Modification of Electromatic Relief Valves

Quad Cities 1

Project Description:

The electromatic relief valves are components of the main steam line piping and suffer from two design problems. On some of the valves, the locking arm has broken off or fallen off. Also, the disc retainer threads have shown minor indications of fretting, which may have caused nonoperation of the valves. This project differs from the others examined in that although several engineering fixes have been identified, none is certain to correct the problem. As a result, analysis of this project is limited to estimation of potential EA benefits in dollar terms. Knowing the potential economic payoff will assist plant personnel in searching for a fix which does not exceed the value of the benefits. Assuming that electromatic relief valve related outages can be eliminated by the fix, a unit improvement in equivalent availability (ΔEA) of 0.0108 was estimated by Trident Engineering Associates, Inc.

Estimated Project Cost (Present Worth):

Unknown. Technical fix for problem has not yet been identified.

Estimated Project Benefits (Present Worth):

Gross benefits only, due to ΔEA: $9,734,580

Benefit/Cost Comparison:

N/A

Modification of Feedwater Regulating Valves

Quad Cities 2

Project Description:

Each Quad Cities unit has two feedwater regulating valves to maintain reactor vessel water levels within prescribed limits. The original valves have a short (2") stroke and produce high turbulance with poor flow regulation. This problem has resulted in reactor scrams at both units. One of the short-stroke valves has been replaced with a drag valve at each unit. Drag valves, consisting of a series of discs and orifices, produce smooth flow characteristics. This project involves replacement of the remaining short-stroke valve at Quad Cities 2 with a drag valve. The maximum potential improvement in unit equivalent availability (ΔEA) from this project was estimated by Trident Engineering Associates, Inc. to be 0.0155. That estimate assumes a very large equivalent meantime-to-outage for the drag valve, which is confirmed by experience at Quad Cities. Plant personnel are currently evaluating performance of hydraulic and pneumatic actuated drag valves before changing the short-stroke valves.

Estimated Project Cost (Present Worth): $ 351,979

Estimated Project Benefits (Present Worth):

Due to ΔEA: $ 970,925

Benefit/Cost Comparison

Net Present Value of Project (NPV): $13,618,946

Benefit to Cost Ratio (B/C): 40

Install Amertap System

Quad Cities 2

Project Description:

Scale build-up fouling of condenser tubes has resulted in numerous unit derating at Quad Cities 2. The Amertap system reduces condenser fouling with the continuous circulation of sponge balls through the condenser tubes. This improvement project consists of installing a commercial Amertap system. The improvement in unit equivalent availability estimated by Trident Engineering Associates for the Amertap system is 1.00374. This estimate assumes no outage hours or deratings due to the Amertap installation, since the Amertap equipment can be serviced with the unit on line without any deratings of the unit. It is noted that the Amertap system must be installed below all condenser lines and a major component of its cost is excavation and concrete work in an area dense with underground lines. Plant personnel are currently examining a chemical water treatment approach to the reduction of condenser tube fouling as an alternative to the Amertap system.

Estimated Project Cost (Present Worth): $ 371,232

Estimated Project Benefits (Present Worth):

Due to ΔEA:	$3,371,049	
Due to Reduced O&M Costs:	100,650	
Total		$3,471,699

Benefit/Cost Comparison:

Net Present Value of Project (NPV):	$3,100,467
Benefit to Cost Ratio (B/C):	9.4

Installation of Cooling Towers

Quad Cities 2

Project Description:

Currently, the Quad Cities plant is cooled through a spray canal. As a result of non-emergency environmental restrictions on direct Mississippi River water cooling, Quad Cities 2 has suffered numerous deratings due to poor performance of the spray canal. This project involves installation of cooling towers to provide additional cooling. Assuming that no unit deratings occur due to the cooling towers (a reasonable assumption given the spray canal and river as backup), Trident Engineering Associated Inc. estimated a maximum improvement in equivalent availability (ΔEA) of 1.0317. It may be noted that an in-depth examination of the option of installing cooling towers at Quad Cities is currently underway by Commonwealth Edison.

Estimated Project Cost (Present Worth): $119,740,580

Estimated Project Benefits (Present Worth): $119,740,580

Estimated Project Benefits (Present Worth):

Due to ΔEA: $ 28,572,795

Benefit/Cost Comparison:

Net Present Value of Project (NPV): -$91,167,785

Benefit to Cost Ratio (B/C): 0.24

Reliability Model Development & Verification

Reliability models were developed for the Wood River and Quad Cities units. Because of design similarities, a single model sufficed for the Quad Cities 1 and 2 units. The generic functional diagram for both units was identified, consisting of five principal functions; i.e., power conversion, steam condensation, feedwater, steam generation, and shared systems. At the sub-functional level, the Wood River and Quad Cities units were modeled by 16 functions and 23 functions respectively. At the equipment function level, the Wood River and Quad Cities units were modeled by 35 and 45 functions together with the number and arrangement (i.e., parallel/series) of each equipment item within a function.

Failure mode and effects analyses were conducted on each unit to establish the degree to which a loss-of-function outage at the equipment level resulted in a unit derating or complete outage.

Detailed compilations of equipment loss-of-function were prepared. Due to the inadequacy and unavailability of the data reported by the utilities to EEI, it was necessary to glean the data by a search of unit operating logs and maintenance records to obtain the basic component performance data needed as an input to the reliability model.

Verification of the model validity was done by using the model and the individual component performance data to "simulate" an overall equivalent availability for the unit and comparing this "simulated" value with the actual measured value. Excellent agreement was obtained for both Wood River and Quad Cities units.

Reliability Model Application

Application of the DOE/MRI methodology is dependent upon the loss-of-function outages as being in a "steady-state" condition, i.e., occurring at random. The methodology can handle unsteady state conditions provided there is an accurate record of all external events that could be changing the outage experience, e.g., changes in maintenance or operating procedures, equipment changes, etc. To test the degree to which the Wood River and Quad Cities units were in steady-state, Trident used the experience of a prior year (or years) to predict unit performance for a subsequent prior year. Although good agreement was found for some years, in some years the predicted and actual equipment availabilities differed substantially. No attempt was made in this project to find an explanation for these differences.

Using the reliability models and the equipment performance data, Trident then used the methodology to make estimates of the improvement in unit equivalent availability that would be expected to result if the improvement projects were implemented. At this step in the methodology, application, a key input is required which cannot be obtained by the methodology, i.e., the expected improvement in equipment reliability resulting from the improvement. This is a very important consideration. Experience and judgement alone can provide this key input. For this project, this input was obtained in close consultation with the utility plant and engineering personnel. The following tabulation lists the predicted improvement in unit equivalent availability (ΔEA) for each of the improvement projects, expressed as a decimal; e.g., ΔEA = 0.0234 corresponds to a 2.34 percentage point change in EA -- not a 2.34% change.

MAXIMUM CHANGE IN EQUIVALENT AVAILABILITY FOR IMPROVEMENT PROJECTS EVALUATED

Unit	Improvement Project	ΔEA (Maximum)
Wood River 5	Install sixth pulverizer	.0234
	Continuous pulverizer maintenance	.0194
	Addition of new tube bundles	.00106
Quad Cities 1	Moisture drain tank modification	.00131
	Electromatic relief valves modification	.0108
Quad Cities 2	Install drag valve	.0155
	Install Amertap system	.00374
	Install cooling tower	.0317

To put these values in perspective it is noted that the average equivalent availability of all nuclear and 400 Mw and larger coal units is about 0.65. Thus the range of improvements is from a low of 0.1 to a high of 3.2 percentage points. Trident points out that there are significant uncertainties in some of these values due to the statistically small number of outages from which some of the model input coefficients are derived.

Critique of Methodology

Based on the experience gained in this project, Trident made the following observations about the methodology:

- It is a valid methodology.
- Estimates of unit performance improvement have a high statistical uncertainty.
- Some of the statistical uncertainty can be eliminated through further development of the methodology.
- There are many limitations and deficiencies which could be eliminated through further development.
- It is unnecessarily complex.
- Hand calculations are tedious and time consuming. Automation would help greatly.

- The DOE report is too lengthy to be used as a manual. It is extremely difficult to use by individuals without a background in reliability, statistics, and powerplants.

- The methodology focuses only on equipment functional outages whereas a significant fraction of outage time is due to other causes.

- The existing industry data bases are inadequate to supply the generic outage data in a usable format.

- The manpower resources required to implement the methodology on this project compared favorably with the 3 to 6 man months per unit suggested in the DOE report.

Trident recommended the following actions to improve the methodology:

- Modification of the methodology to handle multiple failures;

- Modification of the methodology to handle non-identical parallel components;

- Modification of the methodology to handle components not repairable with the unit on line;

- Modification of the methodology to incorporate details of outage duration;

- Modification of methodology to incorporate simplifications in U_F calculations;

- Refinement of methodology to quantitatively define procedures to handle such areas as the statistical analysis and meantime-to-outage and meantime-to-restore trend projections;

- Development of a handbook type format for presentation of methodology which concisely describes the equations and procedures to be followed in a step-by-step manner;

- Development of procedures for implementation of the DOE methodology into a computer-based system;

- Modification of methodology to model administrative and conditional outages.

B. Analysis of Costs and Benefits for Eight Powerplant Productivity Improvement Projects

The determination of the cost effectiveness of specific improvement projects (Phase C of the DOE/MRI Methodology) is essential to any program of powerplant productivity improvements. Projects to improve the productivity of a generating unit by increasing either its reliability or some other performance measure are attractive only if the value of improved performance exceeds the cost of the project.

Objectives and Approach Taken

The objectives of this task were to determine the cost of undertaking each of the eight projects studied by Trident and the economic value of the unit performance improvements predicted by Trident for each project.

Project cost estimates were developed largely by utility engineering personnal familiar with the problems, the units, and prevailing rates for making engineering modifications. In many cases, estimates were preliminary since utilities had not previously examined some projects. For several projects, however, benefits so greatly exceeded estimated costs that even large errors in cost estimation would not alter the attractiveness of the project.

In order to translate improved plant availability benefits into dollar benefits it was necessary to make assumptions and projections concerning future unit loading and other variables, such as fuel costs and labor escalation rates. This is usually done through a production cost simulation model, which was used to estimate benefits for the Illinois Power Company Wood River 5 unit. For Commonwealth Edison's Quad Cities units, a straightforward estimate of replacement power costs (based on cost of power from the system's fossil units) was made.

Results

The estimates of cumulative benefits per percentage point improvement in unit equivalent availability are provided below in Table B1.

Table B1

Unit	Project	Cumulative Present Worth of a 1% Point Improvement in Equivalent Availability (1978$)*
Quad Cities 1	All	$9,013,500
Quad Cities 2	All	$9,013,500
Wood River 5	Heater Bundle	$1,971,968
Wood River 5	Sixth Pulverizer	$ 462,393
Wood River 5	Three Shift Maintenance	$ 623,711

*Exclusive of cost of achieving the improvement.

Table B2
Summary of Benefit/Cost Analyses

Project (Unit)	Performance Impacts	Economic Benefits (Pres. Worth)	Project Cost (Pres. Worth)	Net Present Value	Benefit/ Cost Ratio
Moisture Separator Drain Tank Modification (Quad Cities 1)	ΔEA = 0.00131 (maximum)	$ 1,180,769	$ 25,568	$ 1,155,201	46
Electromatic Valve Modification (Quad Cities 1)	ΔEA = 0.0108 (maximum)	$ 9,734,580	Unknown	Unknown	Unknown
Cooling Towers (Quad Cities 2)	ΔEA = 0.0317 (maximum)	$28,572,795	$119,740,580	-$91,167,785	0.24
Amertap System	ΔEA = 0.00374 (maximum)	$ 3,371,049			
(Quad Cities 2)	ΔOMC= $6,700/yr (typical)	$ 100,650 $ 3,471,699	$ 371,232	$ 3,100,467	9.4
Feedwater Regulating Valve Modification (Quad Cities 2)	ΔEA = 0.0155 (maximum)	$13,970,925	$ 351,979	$13,618,946	40
Add Sixth Pulverizer (Wood River 5)	ΔEA = 0.0234 (maximum)	$ 1,082,000	$ 4,004,000	-$ 2,922,000	0.27
Replace Heater Tube	ΔEA = 0.00106 (typical)	$ 209,000			
Bundle (Wood River 5)	ΔHR = 0.1% (minimum)	$ 458,000 $ 667,000	$ 464,000	$ 203,000	1.44
Shift Pulverizer Maintenance (Wood River 5)	ΔEA = 0.0194 (typical)	$ 1,210,000	$ 2,423,000	-$ 1,213,000	0.5

Key:

ΔEA = Change in Unit Equivalent Availability
ΔHR = Change in Unit Heat Rate
ΔOMC = Change in Unit O & M Costs

The analyses yielded benefit to cost ratios ranging from 46 to 0.24, reflecting the influence of project selection criteria as well as opportunities for cost justifiable improved productivity. A summary of the results of the analysis is presented in Table 2.

In the case of the Electromatic Relief Valve Modification, a technical "fix" for the problem was not identified during the course of the study. Therefore, potential benefits only were calculated for that project. Such information is useful to plant engineering personnel by providing them with an upper limit on the justifiable cost of a solution.

Standard engineering economic practices were employed in the calculation of net present values and benefit/cost ratios for the projects.

C. Current Practices in Illinois Utilities Towards Powerplant Productivity (PlT1)

Sharply rising fuel and new plant construction costs have made the issue of powerplant productivity improvement a pressing one for Illinois electric utilities. Current practices of these utilities are of interest to determine whether adequate tools exist to effectively exploit opportunities for improved productivity.

Objectives and Approach Taken

The objective of this task was to identify and document the various approaches and practices currently in use in Illinois electric utilities for the analysis of powerplant productivity related questions. These questions include evaluating current levels of productivity as well as estimating future levels. The productivity aspects of only base load (large) coal and nuclear generating units were considered. Four of the major investor-owned utilities in the state cooperated in this task.

Current practices towards productivity analysis were documented by gathering data and information on:

- Measures of productivity and performance in use at large powerplants.
- Methods of determining current levels of productivity.
- Identification of causes and magnitudes of lost productivity.
- Selection of projects for improving historic plant performance.
- Representative case studies of productivity analysis at each utility.
- Internal organization and responsibilities for productivity and performance.

It has been recognized by the utility industry that accurate measurement of powerplant productivity is a complex task. A variety of performance indices such as availability factor, capacity factor, forced outage rates, etc., are in use in the industry to measure different aspects of powerplant productivity. Hence, the approach taken in this task was to document several cases (i.e., projects) that involved improvements to different productivity indices. The overall organization for productivity analysis and improvement at each utility was also documented.

The principal source of information was the utilities themselves. Generally, the contacts with the utilities consisted of the following:

- o Briefing top utility management on the overall goals of the DOE/ICC project.
- o Discussion with senior technical and managerial personnel regarding practices towards productivity improvement.
- o Study of various internal documents to establish organization and responsibilities for productivity studies.
- o Visits to powerplants to discuss site procedures with operating personnel.

The identification and documentation was not pursued to the same level of detail at each utility. Two of the utilities participated in other tasks of this project and as a result, it was possible to present procedures used by them in greater detail. The other two utilities were also preoccupied with the coal strike problems during the early parts of 1978 and were able to devote less time to this task.

Results

Responsibility for productivity improvement is diffuse in all four utilities. None has a centrally focused responsibility at a high level, such as vice-president for productivity improvement, or an equivalent corporate level position. Most such responsibilities rest with power production personnel who focus more on maintaining powerplant performance than on improving it. The distinction is between a reactive rather than an active approach to improvements.

Utilities in Illinois use industry-wide measures of performance, such as capacity factor, availability factor, forced and planned outage rates, etc. Equivalent availability as a measure of productivity is not generally used at any of the four utilities, even though it is one of the four key performance indices adopted by the utility industry through the Equipment Availability Task Force of the EEI Prime Movers Committee. Recently, however, Commonwealth Edison developed a procedure for utilizing Edison Electric Institute outage data in the analysis of productivity related questions at nuclear plants. This procedure employs unit non-operating hours as a performance measure. Causes of outages are ranked by the company in terms of their contribution to non-operating hours. This provides engineering personnel with a candidate list of improvement opportunities, but has not been used thus far to produce estimates of economic benefits which would flow from elimination of the cause of non-operating hours.

The identification of immediate causes of lost productivity is relatively straightforward and is done routinely. That is, if an outage is due to a broken seal, that fact will be quickly determined. The determination of root causes, however, is not done routinely. In the case of the broken seal, for example, the root cause of the outage might have been faulty installation, maintenance, design, or manufacture of the seal. Engineering personnel sometimes address the question of root causes quantitatively. Commonwealth Edison has on one occasion employed formal fault tree analysis as an aid to the identification of root causes of outages.

The selection of improvement projects for analysis, as well as the evaluation of future performance improvement, is generally based on operating experience and engineering judgement. Currently, no utilities employ formal analytical or statistical reliability models to analyze improvement projects. Project costs and benefits are subjected to traditional engineering economic analyses.

No attempt was made in this task to directly evaluate the adequacy of internal organization, performance measures, procedures, or analytical tools currently applied by utilities in the analysis of candidate performance improvement projects.

D. Historical Performance of Illinois Investor-Owned Electric Generating Powerplants Over 200 MW (P2T1)

An essential prerequisite to the improvement of powerplant productivity in Illinois is an analysis of historical performance including a comparison with national trends.

Objectives and Approach Taken

The objectives of this task, which analyzes the historical performance of electrical powerplants in Illinois, are threefold: 1) Evaluate the strengths and weaknesses of the various powerplant performance indices presently used by the electrical industry and select a comparative index for this study; 2) Characterize the historical performance of both large and small electrical generating units in Illinois; and, 3) Determine the potential for improvements in productivity by examining the performance of Illinois units relative to national trends.

The common electric utility powerplant performance indices are defined by the Equipment Availability Task Force of the Prime Movers Committee of the Edison Electric Institute (EEI). This group is comprised primarily of utility representatives and seeks to provide nationally accepted definitions for powerplant productivity indices. Nevertheless, many utilities have found it necessary to modify the EEI definitions for thier own in-house use. In this study, both the EEI definitions and the utility's version of the definitions were reviewed, with the equivalent availability being deemed the most suitable comparative index for the purposes of this study.

The most uniform data base for national powerplant productivity is that provided by the Edison Electric Institute. However, there remains a long lag time between the actual submission of data by utilities and the publication of the information by the Edison Electric Institute. As a consequence, the Edison Electric Institute data available for this study extend only to the end of calendar year 1976. Although information for 1977 and 1978 has been submitted by the utilities to the Edison Electric Institute, there has been no comprehensive compilation of that data.

For electrical generating units in Illinois, the productivity using equivalent availability was compared to that of the historic performance of similar units throughout the nation. For units 400 megawatts and larger the national data base included 40 nuclear units and 109 primarily coal fired units. For the primarily coal fired units in the range of 300 to 399 megawatts nameplate capacity, 126 units comprised the national data base, while for the primarily coal fired units in the range of 200 to 299 megawatts nameplate rating, 169 units were utilized in the national data base.

For the larger units, the performance of the Illinois units on a life year basis was compared to that of comparable national averages. For the smaller size units the productivity of these plants was compared to the ten year average as published by the Edison Electric Institute. Only one of the smaller units sampled had data for less than ten years of operation.

Results

The major findings of this task are:

- For the purposes of evaluating the historical performance of Illinois electricity generating units, the equivalent availability was judged to be the most appropriate measure.

- In terms of powerplant productivity one Illinois investor-owned utility, Illinois Power, is among the best in the nation, and in terms of productivity from large coal units it ranks in the top five nationally. This illustrates that high powerplant performance is achievable in Illinois.

- In general, the performance of coal-fired units of Central Illinois Public Service Company and Commonwealth Edison Company have been below national averages and in some cases significantly below the national averages.

- A review of the trends in powerplant production of all Illinois units reveals that Illinois units as a group have been generally below the national averages for the respective powerplant unit classes. (See Figure D1).

- As noted in this and other studies, the productivity of the nuclear plants in Illinois has been below the national average for all comparable nuclear plants. (See Figure D2).

- This analysis should be updated when national 1977 and 1978 Edison Electric Institute data becomes publicly available.

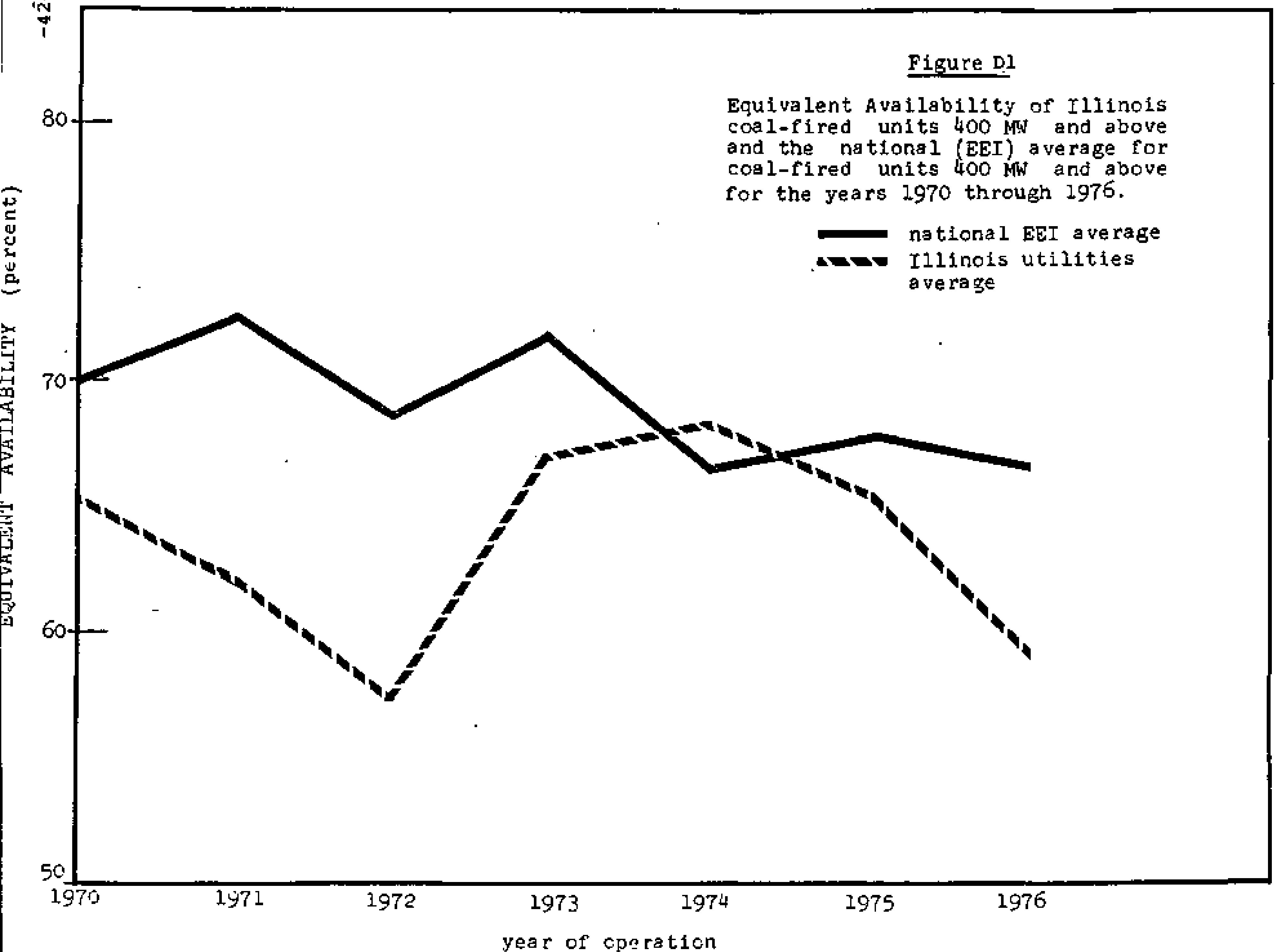

Figure D1

Equivalent Availability of Illinois coal-fired units 400 MW and above and the national (EEI) average for coal-fired units 400 MW and above for the years 1970 through 1976.

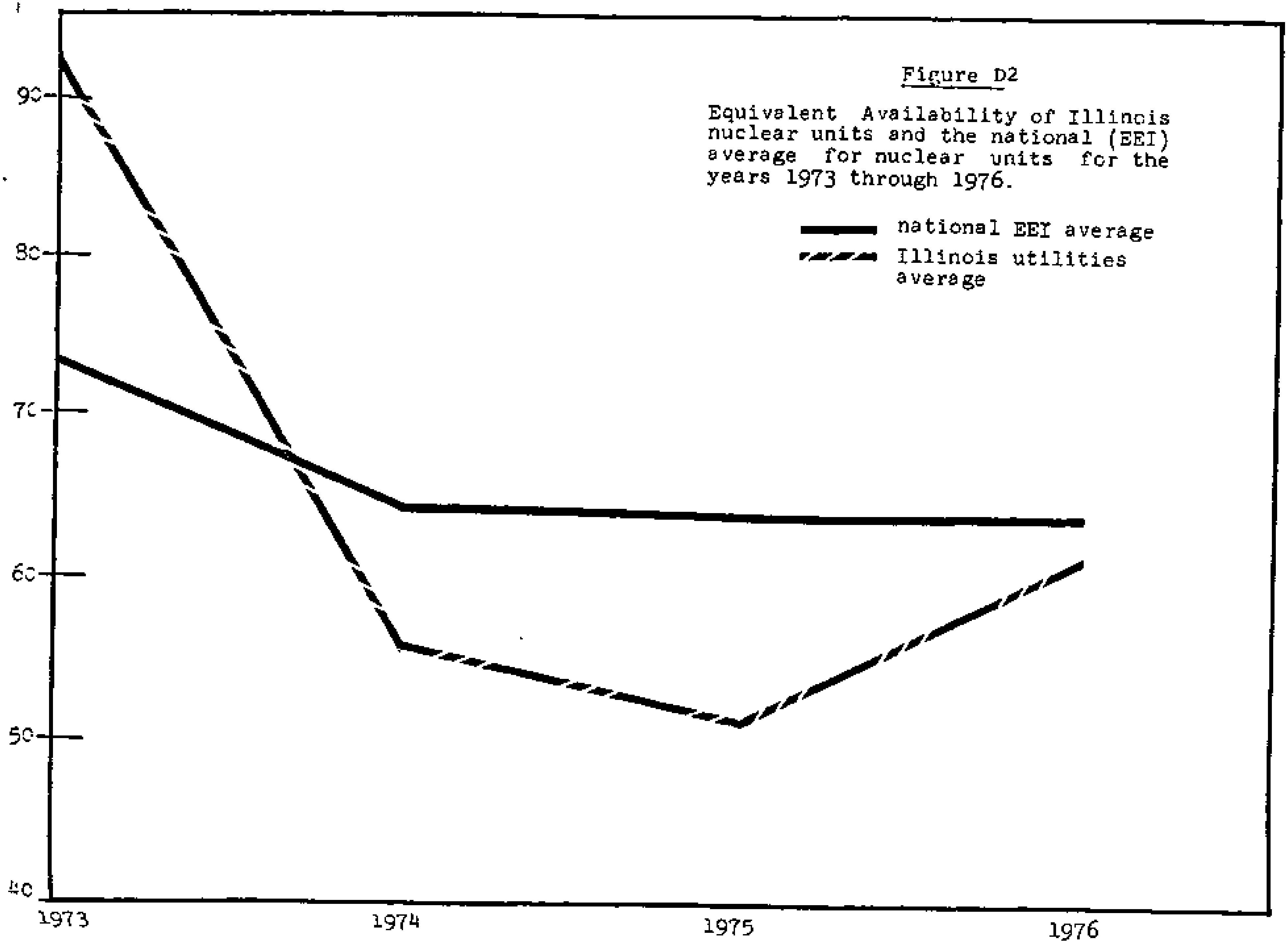

Figure D2

Equivalent Availability of Illinois nuclear units and the national (EEI) average for nuclear units for the years 1973 through 1976.

E. Benefits of Improved Powerplant Reliability (P2T2)

Under this task, estimates were made of the potential benefits of improved base loaded unit reliability for the Illinois Power and Commonwealth Edison systems. These companies are the two largest investor-owned electric utilities in the state and together account for approximately 80% of total electrical generation within Illinois.

Objectives and Approach Taken

The objective of this task was to provide an order of magnitude estimate of the potential benefits which would result from modest improvements in the planned and forced outage rates of large base loaded coal and nuclear units in the Commonwealth Edison and Illinois Power systems. Four hypothetical improvement scenarios were examined over the period 1979-1990 to determine effects on consumption of various fuels.

The selection of forced and planned outage rate improvement scenarios for this study was accomplished through discussions with utility representatives. A simultaneous improvement in both outage rates of 5 percentage points as used in the General Electric Study was considered to be unlikely for the Commonwealth Edison and Illinois Power systems. Instead, a maximum improvement of 2 percentage points in both planned and forced outage rates was selected. Although there is no analytical basis for this assumption, it was judged by both utilities to be close to the upper limit of attainable improvement. The scenarios examined were as follows:

Case A-

Base case analysis using currently projected planned and forced outage rates.

Case B-

1 percentage point improvement in forced outage rates for base loaded units. Improvement implemented over a two year period.

Case C-

1 percentage point improvement in planned outage rates for base loaded units. Improvement implemented over two years.

Case D-

1 percentage point improvement in both planned and forced outage rates for base loaded units. Improvement implemented over a two year period.

Case E-

2 percentage point improvement in both planned and forced outage rates for base loaded units. Improvement implemented over a two year period.

In all cases, the study horizon for benefits calculation was 1990. Some departures were made from the methodology employed by General Electric in their study of benefits of improved reliability and productivity for FEA. GE used an optimal generation planning model in conjunction with a financial simulation model to perform their analysis. However, neither of the two participating utilities currently has an optimizing generation planning model on line. Instead, proprietary production cost simulation models were used by the utilities to examine the differential production costs for each of the four improvement scenario cases. The primary output of these models is fuel consumption by fuel type and fuel costs. General Electric found that, assuming an improvement in outage rates, a utility could either (1) accept a reduced (i.e., improved) loss of load probability (LOLP) and hold the scheduling of future base load generation additions fixed, or (2) hold LOLP constant and defer future base load generation additions. The use of a production cost simulation model to explore such alternatives, however, is unwieldy. For this study, each utility manually examined the possible deferral of future base load generation additions and found that none existed. This finding may be the result of using a 2 percentage point improvement scenario instead of 5 percentage points as assumed by General Electric.

The approach followed in this task was to estimate benefits of improved productivity only. The cost of projects and plant improvements required to bring about the four scenarios was not considered in the results presented. Although the costs of seven candidate projects were estimated in a separate part of the ICC/DOE study, it is not feasible to extrapolate those estimates. Since it has not yet been determined that the improvement scenarios themselves are realizeable, no information can be provided on the magnitude of net benefits (gross benefits minus costs). Estimates of gross benefits are nevertheless useful in demonstrating the relationship between small, realistic improvements in the planned and forced outage rates of base loaded units and total system generation costs. Such information could assist utility personnel in better structuring internal programs to improve unit reliability.

Results

In terms of reduced scarce fuel consumption, results were greatest under scenario E (2 percentage point improvement in FOR and POR) as was expected. For the Commonwealth Edison system, a reduction in peaking fuel consumption of 42% over the base case was reported. In addition, #6 oil consumption was reduced by 25% over the base case level. These percentages refer to total consumption over the period 1979-1990. The peaking and #6 oil fuels were displaced by coal and nuclear generation in the Edison system.

Under scenario E the Illinois Power system achieved a cumulative (through 1990) reduction in peaking fuel consumption of more than 17% over the base case. Consumption of #6 oil was reduced by almost 8% over the base case level. Because the Clinton nuclear unit has not been completed, it was not improved in the scenario runs. The coal units in the Illinois Power system which were improved are subject to minimum loading constraints. Operation below these minima is technically undesirable. As a result, improvements in the availability of the coal units produce more frequent invoking of minimum loading constraints. When such constraints are encountered, the effect is to increase coal unit loading and decrease nuclear unit loading, even though average nuclear generation costs may be lower. This effect is also partially due to the fact that the nuclear unit availability was not improved in the scenario runs.

For both utilities combined, the estimated value of the scarce fuels saved is approximately $346 million in 1978 dollars for the 2 percentage point FOR and POR improvement scenario. Of this total, approximately $308 million is attributable to the Commonwealth Edison system and $37 million to the Illinois Power system. The results obtained under this task are remarkably close to those estimated for the MAIN/MARCA Region by General Electric.

These are presented below for the Commonwealth Edison system for the year 1990.

Base Case (1990)

#6 Oil Consumed $= 3{,}253 \times 10^3$ BBL

#2 Oil Consumed (in #6 equivalent)

$$\frac{43{,}929\ (5.8)}{42\ (6.2)} \times 10^3 = \underline{978 \times 10^3 \text{ BBL}}$$

$$4{,}231 \times 10^3 \text{ BBL}$$

Case "E" (1990)

#6 Oil Consumed $= 2{,}116 \times 10^3$ BBL

#2 Oil Consumed (in #6 equivalent)

$$\frac{22{,}732\ (5.8)}{42\ (6.2)} \times 10^3 = \underline{500 \times 10^3 \text{ BBL}}$$

$$2{,}616 \times 10^3 \text{ BBL}$$

A total of 10,894,000 KW were improved by 4 percentage points.

$$\text{Oil Savings Rate} = \frac{(4{,}231 - 2{,}616) \times 10^3 \text{ BBL/yr}}{(4\%)\ (10{,}894{,}000\text{KW})} = \frac{0.37 \text{ BBL}}{\text{yr} - \text{KW} - \%}$$

$$\text{GE result for MAIN/MARCA Region in 1990} = \frac{0.5 \text{ BBL}}{\text{yr} - \text{KW} - \%}$$

Improvement scenario results are summarized for each company in Tables E-1 through E-5.

Table E1

Commonwealth Edison Company

Baseload Unit Fuel Consumption

Cumulative Differences through 1990*

(1,000's)

Case	Fuel	Nuclear (mmBTU)	HS Coal (tons)	LS Coal (tons)	#6 Oil (BBLS)	Peaking (Gals)
B 1% FOR Improvement		65,577	117	(1,218)	(4,174)	(49,804)
C 1% POR Improvement		59,442	95	(1,073)	(4,016)	(36,858)
D 1% FOR + 1% POR Improvement		124,712	216	(2,341)	(8,154)	(81,869)
E 2% FOR + 2% POR Improvement		248,950	369	(4,997)	(15,191)	(139,912)

*Parentheses indicate decreases.

Table E2

Commonwealth Edison Company

System Fuel Costs

($ x 1,000)

Case	System Fuel Cost	Difference from Base Case*	% Change from Base Case*
B 1% FOR Improvement	11,595,196	($89,546)	(0.8%)
C 1% POR Improvement	11,609,770	(74,972)	(0.6%)
D 1% FOR + 1% POR Improvement	11,522,960	(161,782)	(1.4%)
E 2% FOR + 2% POR Improvement	11,376,230	(380,512)	(2.6%)

Note:

Above costs represent cumulative estimated fuel costs for the period 1979-1990. Amounts are in 1978$.

*Parentheses indicate decreases.

Table E3

Illinois Power Company

Baseload Unit Fuel Consumption

Cumulative Differences Through 1990*

(1,000's)

Case	Fuel	Nuclear (mmBTU)	HS Coal (tons)	LS Coal (tons)	#6 Oil (BBLS)	Peaking (Gals.)
B 1% FOR Improvement		(3,762)	407	(475)	(682)	(125,262)
C 1% FOR Improvement		(3,610)	398	(545)	(617)	(14,549)
D 1% FOR and 1% POR Improvement		(4,723)	1,587	(1,265)	(1,547)	(39,333)
E 2% FOR and 2% POR Improvement		(4,021)	(380)	(796)	(943)	(23,545)

*Parentheses indicate decreases.

Table E4

Illinois Power Company

System Fuel Costs

($ x 1,000)

Case	System Fuel Cost	Difference from Base Case*	% Change from Base Case*
B 1% POR Improvement	2,198,070	($10,500)	(0.5%)
C 1% POR Improvement	2,199,800	(8,770)	(0.4%)
D 1% FOR + 1% POR Improvement	2,188,880	(19,690)	(0.8%)
E 2% FOR + 2% POR Improvement	2,169,050	(39,520)	(1.8%)

Note:

Above costs represent cumulative estimated fuel costs for the period 1979-1990. Amounts are in 1978$.

*Parentheses indicate decreases.

F. Policy Analysis and Incentive Assessment (P2T3)

The improvement of powerplant productivity by regulatory policies and incentives may be a viable option for some state public utility commissions.

Objective and Approach Taken

The objective of this task was to identify and analyze policy options which the Illinois Commerce Commission might adopt in order to promote improved powerplant productivity for existing units in Illinois. These policy options would generally involve either removing existing disincentives and/or adding direct incentives through the regulatory process.

The approach followed in this task consisted of the following activities:

- In-depth review of existing theoretical and empirical literature in the areas of powerplant reliability, regulated utility efficiency and performance incentives, and impacts of various regulatory mechanisms such as the Fuel Adjustment Clauses on productivity. Results of this literature search have been incorporated into an annotated bibliography as a part of the task report.

- Contacts with other state public utility commissions known to be investigating or implementing productivity improvement incentive mechanisms.

- Documentation and analysis of incentive mechanisms adopted or under consideration in other states.

- Analysis of current regulatory practice in Illinois as it relates to powerplant productivity incentives and disincentives.

- Identification of candidate incentive mechanisms for consideration by the Illinois Commerce Commission.

- Analysis and evaluation of these candidates.

Results

Because of the exploratory nature of this task, definitive results and recommendations were not developed. The following observations summarize the findings of this task.

The current regulatory environment in Illinois is such that clear-cut statements about existing incentives and disincentives to the undertaking by utilities of productivity improvement projects cannot be made. Normal regulatory lag, whether or not the allowed rate of return is being earned, and whether a project is expensed or capitalized, all affect the economic incentive structure in complex, case-dependent ways.

Because of the above, there is reason to believe that utilities generally respond to indirect rather than direct incentives when they undertake plant improvement projects. Under an indirect incentive, the utility usually cannot make a direct link between project costs and benefits and earnings. This arrangement is considered by the authors to be less desirable than one involving direct incentives, in which earnings are directly related to the net improvement as seen by consumers.

Although several state public utility commissions are currently experimenting with various incentive mechanisms directed at improving productivity, none of these has been in operation long enough to permit an empirical assessment of effectiveness. All such mechanisms brought to the attention of the Illinois study team appear to have the potential for improving powerplant performance in some specific area (such as capacity factor) at the cost of cost-effective improvements in other areas of performance. It should be made clear that this is a "theoretical" concern at this time and no empirical evidence is yet available which would provide a basis for a conclusion on the overall effectiveness of single measure incentives.

There appears to be little evidence at the present time on how effectively the single measure incentive mechanisms being implemented in other states will achieve the desired objective of improving performance in that measure. This is due entirely to the fact that most such mechanisms have been implemented fairly recently; empirical data should become more abundant with time.

Currently, the most desirable incentive mechanism appears to be one which is direct, as discussed above, and which provides an incentive for the utility to undertake (and to search out opportunities for) productivity improvement projects in all areas. This would include such areas as availability, capacity factor, and heat rate. Although other elements of this project have confirmed that improvement in unit equivalent availability appears to be the most effective approach to the improvement of overall powerplant productivity, it should probably not be pursued in such a manner as to discourage cost-effective improvements in other areas.

The following specific mechanisms were suggested for consideration by the Illinois Commerce Commission:

A. Improve Information Flows Regarding Potential Productivity Improvements

The Commission could focus utility attention on productivity issues not only by publicly proclaiming their importance but also by facilitating the dispersal of information to utilities regarding possible productivity improvements such as technical R&D supported by the Department of Energy and trade associations such as EPRI.

B. Institution of Efficiency Incentives Tied to Rate of Return

A mechanism by which the allowed rate of return would be adjusted in accordance with overall productivity may be implemented with changes in the Public Utilities Act. Rate of return would be partially based on changes in a utility's performance as measured against its own historical performance or national averages. This would require consensus on the choice of an overall productivity measure, which may constitute a substantial obstacle. But many of the potential adverse side effects of single measure incentives would be avoided.

C. Modification of the Fuel Adjustment Clause

Any fuel adjustment clause carries with it a potential for inefficient operation which could act as a disincentive to certain productivity improvement projects. Although no empirical data are available which support this concern, it may be possible to counter disincentive effects. One mechanism for doing so is a Cost and Efficiency Adjustment clause which guarantees recovery of only a portion of increased costs (such as fuel costs). The balance of increased costs would have to be recovered through improved productivity.

Except for A, considerably more analysis appears to be needed to thoroughly evaluate these mechanisms. Substantial changes in regulation can only be achieved through legislation or formal hearings. Mechanisms B and C require further study before they can be subjected to this process.

III. ANALYSIS OF RESULTS

A. Potential for Improved Productivity in Illinois

Taken as a whole, large powerplants in Illinois have been performing below national averages in terms of equivalent availability. Some units, however, are performing above the national average and nuclear units appear to be close to the national average at the present time. Assuming that there is no reason to consider Illinois units as different from other units nationally, it would seem reasonable to expect the improvement potential to be on the order of two to five percentage points. Some units may be improved by more than this amount and some by less. But in general, Illinois units would then be performing closer to national average performance.

Opportunities for improved equivalent availability appear to exist in the following general areas:

- Standardization of generic components
- Improved inventory methods for stocking spares
- Modifications to existing plant, including the addition of redundant components and systems
- Upgrading of component reliability
- Reduction of outage hours through streamlined maintenance operations

These opportunities will certainly increase in number as the alternatives to improved productivity, such as new plant construction and scarce fuel consumption, become more costly.

There is little question that utilities in Illinois are currently pursuing productivity improvement projects, and many projects will be implemented in the course of time even in the absence of additional external pressures. In view of the consistency of below-average performance in the period 1970-76, the question of whether improvement projects will be pursued with sufficient vigor must be raised. It may be noted that the expected potential improvement in equivalent availability of 2 to 5 percentage points does not assume the use of sophisticated tools and procedures since these are not yet in general use in the industry. It was not possible to estimate the additional improvement which could result from the application of such tools.

Although there are ample opportunities for productivity improvements, there are numerous obstacles as well. Poor coal quality, environmental constraints, inherent limitations in the design of existing plants, and the uncertainty of ultimate performance of many projects all contribute to the problem. Yet, it is difficult to argue that Illinois has been disproportionately afflicted with these obstacles.

B. Benefits of Improved Productivity

Cumulative benefits from a two percentage point improvement in both planned and forced outage rates were estimated to be approximately

$346 million in constant dollars through 1990. This estimate is based on Commonwealth Edison and Illinois Power data only, and would be greater if the other Illinois utilities were included.

However, it is exclusive of the costs of achieving the improvement. If the actual improvement were as high as 5 percentage points, total gross benefits for the state could approach $1 billion (cumulative). Because of project risk and competing uses of funds, it is reasonable to expect that only projects with benefit-to-cost ratios in excess of two would be viewed by utilities as attractive. If so, net benefits (cumulative through 1990) could be on the order of $500 million (1978$). When spread among all ratepayers in the state, over 12 years, the net effect on electricity bills would be small but not unworthy of consideration.

In addition to direct monetary benefits to Illinois ratepayers, considerable quantities of oil and natural gas would be released for other uses. This would total approximately 40 million barrels of oil (cumulative through 1990) for a 5 percentage point improvement in planned and forced outage rates, roughly equivalent to the total petroleum consumption in Illinois in 1974.

The magnitudes of these potential benefits justify commitments by the Illinois Commerce Commission and the utilities in Illinois that they will be pursued. Since only cost-effective projects would be considered, these benefits do not require the expenditures of public monies or financial sacrifices by the regulated utilities.

C. Enhancement of Utility Practices

Current utility approaches to the improvement of powerplant productivity were documented in PlTl, but no formal assessment of the adequacy of those practices was made. One measure of adequacy is actual unit performance, which has generally been below national average performance. It must be recognized, however, that utilities in Illinois have recently strengthened their efforts in productivity improvement, and recent performance has concomitantly improved.

The basic productivity improvement process involves the following general steps:

1. Aggressive pursuit of opportunities for improved productivity.

2. Analysis of candidate solutions to include projection of costs and improved unit performance.

3. Management decision and implementation.

4. Performance monitoring.

Regardless of the adequacy of current analytical tools and procedures, many opportunities will not be identified unless they are aggressively sought. Commonwealth Edison has recently put into operation a computerized system for the routine analysis of nuclear unit non-operating hours. This approach concentrates attention on the most serious immediate causes of lost productivity, which are subsequently examined individually by engineering personnel. This appears to be the type of approach which must be systematically applied to all large units in the state on a regular basis. Once immediate causes of non-operating hours have been identified, they can be subjected to further analysis to determine root causes and appropriate corrective actions. Although Commonwealth Edison envisions extension of their system to fossil units in the future, this systematic pursuit of productivity improvement opportunities is not currently standard practice in Illinois. Outages are universally recorded, documented, and analyzed to be sure. But more aggressive management approaches are likely to yield greater opportunities for cost-effective improvements. This view is consistent with, if not confirmed by, the improvements in Commonwealth Edison's nuclear unit performance in the last three years.

In discussing analytical tools and procedures, it is useful to separate engineering economic analysis from that employed in the prediction of future unit performance. The internal analyses of costs and benefits examined in this study were found to follow generally accepted industry practices. However, there appear to be opportunities for improving the quality of such analyses at all four utilities. A standard format is not employed and a reader has no way of knowing, for example, whether the omission of some cost or benefit category was due to error or insignificant estimates. Industrial trade associations have developed numerous standard forms for such analyses, of which that published by the Machinery and Allied Products Institute (MAPI) is an excellent and widely adopted example. Adoption of such a "standard" would help ensure that all relevant costs and benefits have been considered and would promote better capital budgeting decisions by management since all projects would be presented in comparable format. These comments are not motivated by a desire for standardization for its own sake. Nor is it known how significant these considerations will be in terms of effecting greater improvements in powerplant productivity. For clear-cut projects which involve returning a unit to operational status or which involve benefits which greatly exceed costs, more detailed analyses are probably not justified. The thrust of this study, however, is toward the consideration of more projects requiring a higher level of analysis and in such cases, more thorough engineering economic analyses may be inevitable.

Whereas utilities can and will upgrade engineering economic analyses when necessary, the adequacy of current approaches to the prediction of project effects on unit performance is much less certain. For a large number of projects, no sophisticated tools are required. A combination of engineering judgement and operating experience will provide entirely adequate estimates of how these projects will influence future unit performance. There appears to be no reason to consider the replacement of this process with one that is less direct and more complex for projects in that category. There is reason to believe, however, that many projects cannot be addressed quantitatively when exclusive reliance is placed on judgement and experience. One utility indicated, for example, that it was considering the addition of a redundant component to a unit but that it simply did not know how to estimate the effect of that addition on unit availability. The PlTl survey of four utilities produced no evidence that any utility currently applies formal reliability engineering principles to the analysis of unit performance. By reliability engineering is meant the use of statistics and probability theory in describing and predicting the failure distributions of components, systems, and units. There is, of course, growing interest in the application of such principles to the electric utility industry as is evidenced by research activities conducted by EPRI and DOE.

It is indeed true that a large powerplant, and in particular one which is custom designed, is a less appropriate candidate for reliability engineering than NASA and aerospace applications involving large numbers of identical electronic components. A more realistic comparison might be with the production lines in large manufacturing operations. These tend to be more analogous to a powerplant and yet have accommodated reliability engineering analyses for many years. There are certainly some real difficulties associated with the reliability engineering analysis of powerplants. In particular, failure modes are numerous and each tends to have a different and often unknown probability distribution. Moveover data quality at present is inadequate to support much formal analysis. On the other hand, all analysis benefits from high data quality, and improvement is certainly possible.

It appears likely that electric utilities in Illinois will look toward more sophistication in the analysis of candidate improvement projects as more experience and information concerning available tools are obtained. It is conceivable that substantial improvements in equivalent availability will not be achieved if current practices are not complemented by reliability engineering tools.

D. Evaluation of the DOE Methodology

In two tasks of this study (P1T2 and P1T3), the essential elements of the DOE systematic methodology were applied to the analysis of eight projects at Commonwealth Edison Quad Cities Nuclear units and Illinois Power Wood River 5 coal unit. The most important conclusion from that demonstration was that the methodology can be used to generate estimates of improved unit performance for various projects. No attempt was made to estimate the accuracy of the predictions, but several observations can be made concerning its usefulness.

1. One of the first steps in applying the DOE method is development of a reliability model of each unit (powerplant). This is undoubtedly a useful exercise for plant personnel even if no further formal reliability analysis is contemplated. It would appear difficult to seriously discuss the overall reliability of a powerplant without access to an analytical or schematic model of this type.

2. Existing data banks proved inadequate for the application of the DOE method. However, it was possible to upgrade data by reference to operating logs and other documents and by interviewing plant personnel. Since previously, little use was made of data such as that supplied to EEI, there was no motivation to tailor it to specific applications. Poor existing data quality does not appear to be a permanent obstacle to the use of formal analytical models.

3. Numerous occasions arose in which it was necessary to make key assumptions about variables for which no data existed. In some cases, these assumptions concerned future events. It has been suggested that this is a deficiency of the DOE method which renders it unuseful. Admittedly, it would be preferable if the DOE method were a black box which yielded unambiguous results and replaced all human judgement. On the other hand, the method provides the user with an explicit statement of all key assumptions. As with any formal model, fuzzy thinking and uncertainties are laid bare in simple analytical form. The more substantive response to such an argument, however, is that the DOE method enables the user to perform sensitivity analyses to identify those assumptions which are critical to the results and those which are less important.

4. DOE appears to have developed their methodology as a "cookbook" approach to modeling and analysis. While it is true that many of the activities required in applying the method do not require special training (beyond that needed to master the method), the Illinois study team is reluctant to endorse its application without assistance from an individual well versed in reliability engineering practices. In particular, professional guidance seems warranted in the fitting of unit and component outage histories to an appropriate failure distribution. This does not suggest, however, that only a team of experts can routinely apply the method.

5. The entire DOE Phase B activity required approximately 2,000 professional person hours to model eight projects at three units, two of which were "sister" units, identically configured. It is difficult to extrapolate such information. Nonetheless, it should be mentioned that a considerable portion of that time was devoted to unit modeling which is a one-time exercise. Analysis of additional projects would require far less time once unit modeling had been completed. It would be more realistic to view the unit model as analogous to an econometric model used in load forecasting in the sense that it is more or less continually being refined, improved, and updated. The overall cost of applying the DOE method does not appear to be excessive.

6. It was not possible to compare the results of the DOE method with utility estimates of unit performance changes due to the eight projects. Although the utilities indicated some disagreement with results, neither an alternative answer nor a preferred analytical approach was provided.

Taken as a whole, the DOE methodology appears to offer considerable advantages over current utility practice for certain types of projects. The Illinois study team does not feel it appropriate to endorse or recommend any specific methodology, and the DOE methodology is viewed only as a representative model. Other systematic approaches exist which also rely on reliability engineering principles. The application of such approaches complements the wealth of operating experience which utilities can bring to bear on productivity problems.

E. Regulator Options for the Improvement of Powerplant Productivity

The incentive structure faced by electric utilities in Illinois is complex and uncertain. In general, utilities evaluate projects in terms of their effect on revenue requirements rather than on earnings. Since the effect of a reduction in revenue requirements on earnings is usually unknown, this incentive mechanism may be inadequate to ensure an aggressive management approach to productivity improvements.

Other state public utility commissions have recently begun experimentation with various "formula" incentive mechanisms in which a relatively clear and identifiable reward is provided in exchange for the achievement of some predetermined performance level. Others are considering penalties when some performance measure falls below a pre-established limit. Both of these mechanisms appear to have the potential for distorting a utility's allocation of resources in such a way as to increase rates. Careful monitoring of these approaches over the next several years will permit an accurate assessment of their viability.

Ideally, however, an incentive mechanism should provide a reward which is related in magnitude to the ultimate savings secured for consumers. Because actual savings over the lifetime of a project can never really be known in advance, this ideal may be unattainable in practice.

There are numerous options which the Illinois Commerce Commission may consider which do not involve such "formula" incentive mechanisms. For example, recent powerplant productivity relative to the company's historical performance as well as national average performance can be a consideration in normal rate case hearings. It could also be a consideration in the hearing process for certification of new unit construction. These _ad hoc_ approaches to the provision of incentives would be more effective if they were implemented through a formal policy statement by the Commission. Their advantage over formula mechanisms is that they are flexible and better able to take into account any special circumstances which may arise. Moreover, to the extent that the Fuel Adjustment Clause provides any disincentives to improved productivity, the suggested mechanism would provide a cost-effective stimulus to avoid such lost productivity. The combination of the Fuel Adjustment Clause and a productivity incentive policy would result in fairness to utilities through recognition of rising fuel prices, and would also ensure fairness to ratepayers through monitoring of powerplant performance to avoid any abuse of the FAC.

As a further step, the Commission might institute an investigation into the reasonableness and appropriateness of methods used by Illinois utilities in attempting to improve powerplant productivity. As noted previously, P1T1 addressed the problem of documenting and identifying utility practices. No attempt was made at evaluation or in-depth analysis. This may be a fruitful area for further pursuit.

The potential of cost-effective improvements in productivity, the potential benefits which would stem from those improvements, and the availability of tools and analytical procedures all confirm the merits of a Commission Productivity Incentive Policy.

IV. KEY FINDINGS AND CONCLUSIONS

1. The historic performance (equivalent availability) of large generating units in Illinois is below national average performance. Some units and some companies perform above national averages, however.

2. Cost-effective opportunities to improve performance exist, and utilities pursue many of these.

3. There are no strong regulatory disincentives to the undertaking of productivity improvement projects, but no strong incentives either.

4. Current utility practices, procedures, and management philosophy toward improved productivity are being strengthened.

5. Areas in which immediate attention is warranted include application of reliability engineering tools to the analysis of powerplant availability and more vigorous pursuit of opportunities for performance improvements.

6. The U.S. Department of Energy systematic methodology for the analysis of productivity improvement projects was demonstrated at three units in Illinois and found to be a useful approach.

7. The potential for improved productivity was estimated by Commonwealth Edison and Illinois Power to be on the order of 2 percentage points in planned and forced outage rates. If Illinois utilities attained national average performance, the potential would be closer to 5 percentage points.

8. If a five percentage point improvement is attained, cumulative (through 1990) constant dollar benefits would be approximately $500 million. Cumulative oil savings could equal the total consumption of oil in Illinois in 1974. Benefits for a two percentage point improvement would be proportionally less.

9. Based on a survey of state public utility commissions, it was determined that "formula" regulatory incentive mechanisms are presently in a developmental or experimental phase. Results of these activities should be monitored closely, but adoption by the State of Illinois does not appear warranted at this time.

10. The Illinois Commerce Commission can encourage improved power-plant productivity by explicitly considering recent unit performance during normal rate case proceedings.

V. RECOMMENDATIONS AND RESOURCE NEEDS

A. Recommendations

1. The Illinois Commerce Commission staff should begin to collect powerplant performance data from utilities on a regular basis. It is recommended that unit equivalent availability as defined by Edison Electric Institute be the primary performance measure monitored.

2. The Illinois Commerce Commission should adopt a formal policy of encouraging improved powerplant productivity. Major elements of this policy would include:

   a. Written communication to each utility urging the adoption of aggressive management policies toward the identification of improvement opportunities, the consideration of appropriate new analytical tools and procedures, and the development of realistic target performance levels for each large generating unit.

   b. Monitoring by staff of powerplant performance on a regular basis.

c. Consideration of recent productivity levels during normal rate case proceedings as a significant factor.

d. Investigation of the reasonableness and appropriateness of methods used by Illinois utilities in attempting to improve powerplant productivity.

3. The Illinois Commerce Commission staff should continue to keep abreast of developments in the field of powerplant productivity. These include studies undertaken by other state public utility commissions, the Department of Energy, NARUC, NRRI, EPRI, and major utilities.

B. <u>Resource Needs</u>

Total time commitments by staff for these recommendations is estimated to be two to four person months per year. No further significant resources can be identified.

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