Development of an Availability Contribution Assessment Framework for Plant Modifications in Nuclear Power Plants

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1. Introduction

Stable operation of nuclear power plants (NPPs) requires continuous maintenance of equipment performance and reliability and the reduction of unplanned plant shutdowns and power reductions. According to the World Nuclear Association, high-performing NPPs maintain high capacity factors, and effective management of outage duration and production losses is important for maintaining good plant performance [1]. In Korea, plant availability is also used as an important performance indicator for NPPs. Improving equipment reliability, optimizing maintenance, and reducing outage duration through plant modifications are important factors in improving plant availability [2].

During long-term operation, NPPs perform plant modifications to address repeated equipment failures, performance degradation, aging, and obsolescence. Plant modification is an important engineering activity for correcting equipment vulnerabilities identified from operating experience and improving safety, reliability, and maintainability. The effects of a modification also need to be reviewed for related systems, operation, maintenance, and testing activities [3].

In Korean NPPs, proposed plant modifications are first evaluated based on their necessity and technical feasibility. After a proposal is accepted, a separate priority evaluation determines the order for preparing design change documents and carrying out subsequent activities. The current process gives high priority to safety, legal and regulatory requirements, equipment importance, and urgency. It also considers factors related to plant availability, including the operational impact of equipment failure and the expected reduction in maintenance or recovery time.

This approach is reasonable because safety and regulatory requirements must have the highest priority in NPPs. It also considers the availability impact of a modification as part of the overall prioritization process. However, the current process mainly focuses on the necessity, importance, and urgency of each modification when determining its implementation priority. Therefore, availability-related benefits are considered together with other priority factors rather than being evaluated separately in detail.

An analysis of plant modification activities at a case NPP over the most recent five-year period showed that approximately 53% of the accepted modifications were waiting for preparation of design change documents. This indicates that all accepted modifications cannot be implemented at the same time because engineering and implementation resources are limited. Therefore, a continuous decision-making process is required to determine the order of design change implementation.

From the plant operator's point of view, plant availability can provide an additional basis for this decision. In particular, the availability benefit of a plant modification can be considered from two aspects: reducing the possibility of an unplanned plant shutdown or power reduction and shortening the time required for diagnosis, maintenance, testing, and restoration to normal operation [2]. In addition, improving obsolescence management, spare part availability, and vendor support can reduce the time required for equipment recovery.

Therefore, this study does not replace the availability-related factors already considered in the current priority evaluation. Instead, it proposes a more detailed assessment of the availability contribution of accepted plant modifications. Existing operational impact information is first used for identifying modifications related to plant shutdown or power reduction. The expected benefits of these modifications are then evaluated by considering Supply Chain, Maintenance Engineering, and Regulatory and Operational Factors. AHP (Analytic Hierarchy Process) is also applied to reflect the relative importance of the three evaluation areas.

2. Availability Contribution Assessment Framework

2.1 Comparison with the Current Priority Evaluation

The current design change priority evaluation considers safety, legal and regulatory requirements, equipment importance, urgency, and availability-related factors when determining the priority of accepted plant modifications. In particular, availability-related items, such as reductions in maintenance time and outage duration, are included in the current evaluation. However, their weighting is relatively low compared with safety, legal, and regulatory requirements. Table 1

summarizes the main differences between the current evaluation and the proposed framework.

Table I: Comparison of the Current Evaluation and the Proposed Framework

Item	***Current Evaluation***	***Proposed Framework***
Primary Focus	*Safety, legal and regulatory requirements*	*Plant availability*
Availability Assessment	*Limited items included with relatively low weighting*	*Detailed assessment of shutdown/power reduction and recovery time*
Method	*Priority scoring*	*Screening + three-area assessment + AHP*

The proposed framework focuses on plant availability while using the existing priority evaluation as the basis for design change decision-making. It first screens modifications related to plant shutdown or power reduction using existing operational impact information and then evaluates their expected availability contribution in three areas. This approach considers both reducing the possibility of shutdown or power reduction and shortening the time required for equipment recovery and return to normal plant operation.

2.2 Availability Impact Screening

Not all improvements resulting from plant modifications directly contribute to plant availability. For example, a modification may improve maintainability or resolve an obsolescence issue, but its direct contribution to plant availability may be limited when failure of the equipment does not cause a plant shutdown or power reduction.

Therefore, before conducting the detailed assessment, this study performs availability impact screening, identifying modifications related to plant shutdown or power reduction. Korean NPPs already use information such as Single Point Vulnerability (SPV), Potential Single Point Vulnerability (PSPV), and Trip Criticality for managing the operational impact of equipment failures. SPV refers to equipment whose single failure can cause a reactor trip, turbine-generator trip, or a power reduction of 50% or more [4]. PSPV refers to equipment that may temporarily become an SPV when another redundant channel or train becomes unavailable due to equipment failure, maintenance, or other causes.

In this study, these existing classifications are not used for establishing a new equipment importance system. Instead, they are used as screening information for identifying accepted plant modifications that require further evaluation from the viewpoint of plant availability. Modifications without a direct relationship to plant shutdown or power reduction are excluded from the detailed availability contribution assessment.

2.3 Evaluation Areas and Items

The contribution of a plant modification to plant availability is evaluated from two main aspects: reducing the possibility of an unplanned plant shutdown or power reduction and shortening the time required to restore normal plant operation. After an equipment failure, several activities may be required before restoring normal operation, including failure diagnosis, work preparation, maintenance, functional testing, and plant restoration.

This study identifies evaluation factors by considering the process from equipment failure to recovery and restoration of normal plant operation. Equipment obsolescence, spare part availability, and vendor support can affect the time required for starting maintenance and restoring equipment. During maintenance, failure diagnosis, maintenance work, and functional testing directly affect the recovery time. The possibility that equipment failure leads to a plant shutdown or power reduction, the scope of its impact, and the activities required for plant restart also affect plant availability.

Based on these considerations, the evaluation factors are classified into three areas: Supply Chain, Maintenance Engineering, and Regulatory and Operational Factors. The Supply Chain area focuses on spare parts, obsolescence, and long-term equipment support. The Maintenance Engineering area focuses on failure diagnosis, maintenance, functional testing, and equipment recovery. The Regulatory and Operational Factors area focuses on the possibility and scope of plant shutdown or power reduction and the activities required for plant restart and return to normal operation.

Table II: Evaluation Areas and Items for Availability Contribution

Evaluation area	**Evaluation item**
Supply Chain	Obsolescence Management
	Spare Part Availability
	Vendor Dependency
Maintenance Engineering	Failure Diagnosis Time
	Maintenance Time
	Functional Testing and Recovery Verification Time
	Maintenance Resources
Regulatory and Operational Factors	Possibility of Plant Shutdown or Power Reduction
	Common Cause Failure (CCF) and Scope of Impact
	Restart and Operational Recovery Burden

The Supply Chain area evaluates whether a plant modification can reduce recovery delays caused by obsolescence, lack of spare parts, or vendor dependency. The Maintenance Engineering area evaluates whether the modification can reduce the time and resources required for diagnosis, maintenance, testing, and equipment recovery. The Regulatory and Operational

Factors area evaluates whether the modification can reduce the possibility or scope of a plant shutdown or power reduction, including the impact of Common Cause Failure (CCF), where multiple components may fail due to a shared cause, and reduce the activities required for plant restart and operational recovery.

2.4 Relative Importance of the Evaluation Areas

The three evaluation areas may not have the same level of importance for plant availability. Therefore, this study applies the Analytic Hierarchy Process (AHP), a structured decision-making method that determines the relative importance of evaluation criteria through pairwise comparisons. [5].

In this study, Supply Chain, Maintenance Engineering, and Regulatory and Operational Factors are used as the upper-level criteria of the AHP structure. Pairwise comparison determines the relative importance of the three areas. The resulting weights are combined with the checklist-based evaluation results for assessing the expected availability contribution of each plant modification.

2.5 Proposed Framework

The proposed framework consists of five main steps: acceptance of a plant modification, availability impact screening, detailed availability contribution assessment, application of relative weights, and overall evaluation.

First, SPV, PSPV, and Trip Criticality information is reviewed for an accepted plant modification to determine whether the target equipment is related to a plant shutdown or power reduction. If a relationship with plant shutdown or power reduction is identified, the expected improvement effects of the modification are evaluated using the detailed items in the Supply Chain, Maintenance Engineering, and Regulatory and Operational Factors.

The checklist evaluates the expected improvement from each plant modification, and the relative weights obtained from AHP are applied to the three evaluation areas. The results are then combined to compare the expected availability contribution of each plant modification. The final result can be used as additional information to support the existing decision-making process for design change implementation priority.

3. Conclusions

This study proposes a framework for evaluating the expected contribution of accepted plant modifications to NPP availability. The current design change priority evaluation already considers availability-related factors together with safety, regulatory requirements, equipment importance, urgency, and other factors. However, these factors are considered as part of the overall process for determining implementation priority.

The proposed framework focuses specifically on plant availability, using existing SPV, PSPV, and Trip Criticality information for identifying modifications related to plant shutdown or power reduction. It then evaluates the selected modifications by considering three areas: Supply Chain, Maintenance Engineering, and Regulatory and Operational Factors. These areas consider both reducing the possibility of plant shutdown or power reduction and shortening the time required for equipment recovery and return to normal plant operation.

AHP reflects the relative importance of the three evaluation areas, and the resulting weights are combined with the checklist-based assessment. In this way, the framework provides additional information on the expected availability contribution of each plant modification.

The proposed framework does not replace the current priority evaluation. Instead, it provides additional availability-focused information for supporting design change prioritization. The framework may also have potential for broader application to areas such as the Maintenance Rule (MR) and risk-informed decision-making processes, as it evaluates plant modifications based on their impact on plant operation, equipment recovery, and availability. Further studies are needed to examine how the framework can be integrated with these existing management processes.

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