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A Simple Model for RAM Analysis and Its Application to DUPIC Fuel Fabrication Facility

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Abstract

A simple model for RAM (Reliability, Availability and Maintainability) analysis and its computer code are developed for application to DUPIC fuel fabrication system. The approach is obtained by linking the allocation model (top-down method) to bottom-up method for RAM analysis. As a result, the availability requirement of subsystem, as well as the buffer storage requirement between processes, are evaluated for the DUPIC facility.

I. Introduction

One of the engineering system analysis to be done for manufacturing facility design is to develop performance criteria of equipment or processes in the facility. These criteria must satisfy the functional requirements and capacity of systems as well as constraints imposed by regulatory standards. As a tool for such analyses, the technique of RAM analyses can be used using probabilistic system assessment method including fault tree, event tree and/or Markov modeling methods[1, 2]. It is important in performance analysis to assure adequate "reliability" so that the facility is operating at its nominal capacity for an adequate fraction of its intended lifetime. Some reliability data of component based on operational experience are needed to quantify RAM in a facility. It is, however, substantially difficult to apply RAM analysis to the facility in conceptual design level and to first-of-a-kind plants (such as the DUPIC fuel fabrication facility) due to lack of appropriate reliability data of the component.

In this study, a simple approach for RAM analysis in pre-conceptual or conceptual design level and its computer code are developed for application in DUPIC fuel fabrication facility which is being designed conceptually. As a result, the availability requirement of subsystem as well as the buffer storage requirement between processes are evaluated for DUPIC fuel fabrication facility.

The simple approach which would fit to the plant in the conceptual design level is described in Figure 1. The approach is obtained by linking the allocation model (top-down method) into bottom-up method for RAM analysis. The top down methodology developed by D. D. Orvis[1] is used for apportioning an overall facility availability requirement. In addition, the buffer storage model developed in this study are linked into the allocation model using general reliability theory.

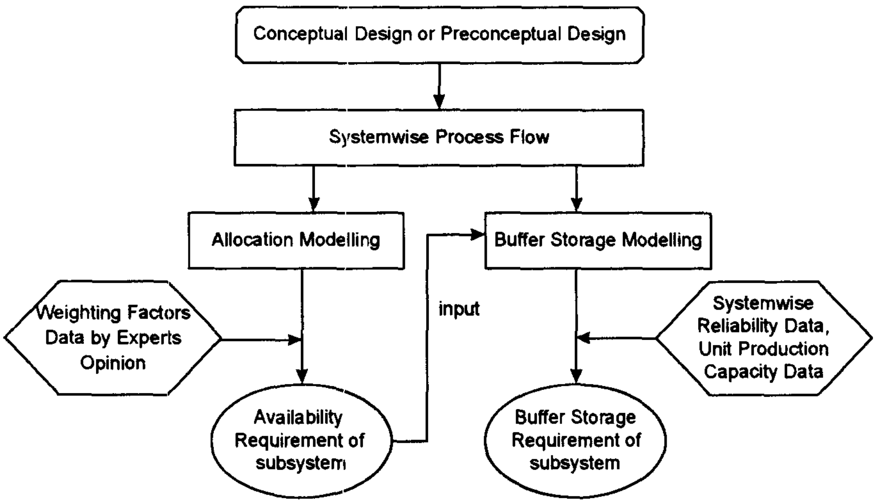

Figure 1. A Simple Model for RAM Analysis

II. Model Derivation

2. Availability Allocation Model

It is desirable to allocate tentative values to plant-level availability targets for the system or subsystem in early stages of facility development. The process of allocation serves as a means of assessing the feasibility of a design and to define problem areas that may require availability improvement.

The term " availability" usually refers to the time that equipment, a plant, or a system is available for operation out of a specified total time period as follows;

$$availability = \frac{uptime}{uptime + downtime} \tag{1}$$

The top down allocation method used in this study is well discribed in reference (1) and (3). The technique employs a weighting factor technique for estimating relative MTBFs (Mean Time Between Failure) and MTTRs (Mean Time To Repair) which can affords an advantage in the preconceptual and early conceptual design phase.

In this method, availability apportionment establishes the availability design goals or requirements at the system, subsystem, and/or component levels for a given plant level goal. The scores, combined into a weighting factor for each system, are incorporated into a mathematical model to provide a distribution of permitted plant downtime. The weighting factors are determined by the survey on opinions of experts who fill up questionnaire that ask assign values to a list of variables. By imposing high availability requirements on those units in which higher availability is easier to attain, and lower requirements on those in which higher availability is more difficult and costly, the overall cost of the system is minimized. The approach presented here is intended to accomplish this tradeoff objective.

2. Storage Requirement Model

The buffer storage in a manufacturing process can be used as a backup source of materials to the next downstream process unit when the unit in the previous stage are down. In this sense the storage is a potential availability improvement option, the cost of which must be balanced against adding more backup process unit which means redundancy of a system. In this study, 'redundancy at each stage is not considered because adding more system would yield substantially diminished benefits. .

The concept can be best explained by a system in Figure 2. Assuming that the system has no provision for intermediate process storage, the overall availability is the product of the individual reliability values.

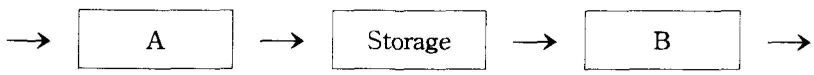

Figure 2. Process with buffer storage between processes

At the opposite extreme, we suppose that the inter-storage tank has infinite capacity. The unit reliability would equal the reliability of the second process unit. It means that the reliability of system A is 1.0. An inter-process storage unit can be coupled with the unit prior to it. The reliability of the combination of process unit A and storage unit S can be estimated by introduction of redundancy concept. Assume that equipment failures in A follow an exponential distribution and permit S to be large and failures in A to be scattered. It means that a failure in A will affect B if it is long enough to exhaust the capacity of S, but S will recover its proper capacity level before the next A failure.

If $MTTF_A$ equals the mean time to failure in unit A and process unit B will experience failures in A that last longer than s hours, then the reliability of the combination of A and S can be expressed as follows;

$$R_{A-S} = 1 - F_A H_S = 1 - F_A \mathrm{EXP}\left[\frac{-S}{MTTR_A} \right] \qquad (2)$$

where, R_{A-S} : the reliability of the combination of A and S

F_A : Failure probability of unit A (= 1 - R_A)

H_S : Probability not to recover the failed unit A for s hours

$$S = MTTR_A \ln[\frac{F_A}{1 - R_{A-S}}] \quad (3)$$

where, R_{A-S} can be derived from availability allocation by top down method. If mean time to repairs of unit A ($MTTR_A$) is known, in Equation (3), failure probability of unit A can also calculated by the following equation;

$$F_A = 1 - \frac{MTTF_A}{MTTF_A + MTTR_A} \quad (4)$$

From Equation (3), storage requirement between unit A and unit B can be calculated by multiplication the hour S by throughput requirement per hour of unit A. For n serial subsystem, storage requirement between (i-1)th and i-th subsystem is as follows;

Storage Requirement = S_{i-1} x Q_{i-1}

where Q_{i-1} means throughput requirement of (i-1)th subsystem.

III. Application of DUPIC Fuel Fabrication Facility

A computer program is developed to calculate the allocation of the overall system availability and buffer storage capacity by linking the top-down method into the bottom-up. The weighting factors, target availability and scheduled downtime are input to the computer program to calculate the allocation of availability. Failure rate, mean time to repairs and capacity rate of subsystems are also input to the program to calculate storage requirement.

DUPIC fuel fabrication facility has the capacity of 400 MTU/year, and consists of two parallel cells with two process lines per cell. Each line, therefore, shall have the capacity of 410 kgU/day. It means that there is no redundancy of cell or line of the facility. So only one line will be considered for simulation of the total system in this RAM analysis

To calculate the allocation of the target availability into each subsystem, main processes of DUPIC fuel fabrication system are divided up 10 subsystems considering each original function and area of the subsystem.

Support systems such as radwaste treatment systems and utility systems are not considered in this RAM analysis. It means that the failure of the support systems is assumed to have not an effects on the main process operation.

To obtain the weighting factors, foreign experts opinions are sought through weighting format. Some ORNL's experts including Dr. S. L. Schrock who are being involved in design of the main equipment of the DUPIC fuel fabrication are participated in this examination. Three persons filled the table out independently and then averaged the result. Reliability Data of system level are derived by referring the reliability data of system level in several similar facilities[5, 6]. The scheduled maintenance time is assumed to be 30 days, and the target system availability of 70 % referred to the conceptual design requirement of the DUPIC fuel fabrication facility is used.

Figure 3 ~ 5 show the results of availability allocation and buffer storage requirement for the

DUPIC fuel fabrication facility. It is inferred that the pellectization subsystem which include sintering and grinding process would be the lowest availability, while the spent fuel receiving and storage subsystem must have the highest availability. It is indicated from the results of buffer storage analysis subsystem that there is no need any storage capacity from subsystem 2 to subsystem 4, while space between subsystem 5 and subsystem 6 shall be equiped the largest capacity, 546 kg.

The buffer storage capacities derived in this study mean only minimum values to meet target availability of the facility, considering subsystems failure. However, in some spaces larger size capacity will be needed according to generic process characteristics. For example, in fuel powder and blending process, much larger size than 453 kg will be equipped to classify the fuel powder to meet appropriate fissile content of the fuel.

Reference

(1) O. D. Orvis et. al., Guidebook for reliability, Availability, and Maintainability Analysis of NWTS Repository Equipment, ONWI-334, General Atomic Company, 1981

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(3) M. J. Haire, A System Availability "Top-Down" Apportionment Method, CONF-850161-1, Oak Ridge National Laboratory, 1985

(4) N. D. Holder, et. al., Availability of Reprocessing System in an HTGR Fuel Recycle Facility, GA-A15028, General Atomic Company, 1978

(5) Final Design Report, prototypical Spent Nuclear Fuel Rod Consolidation Equipment Phase II, NWD-TR-002, Westinghouse Electric Corporation, 1987

(6) I. I. Zimmer et al., Secure Automated Fabrication System Analysis, DOE/SF/ 71031-T29 vol. I-1, US Department of Energy.

Figure 3. Availability and Storage Requirements of DUPIC Fuel Fabrication Facility

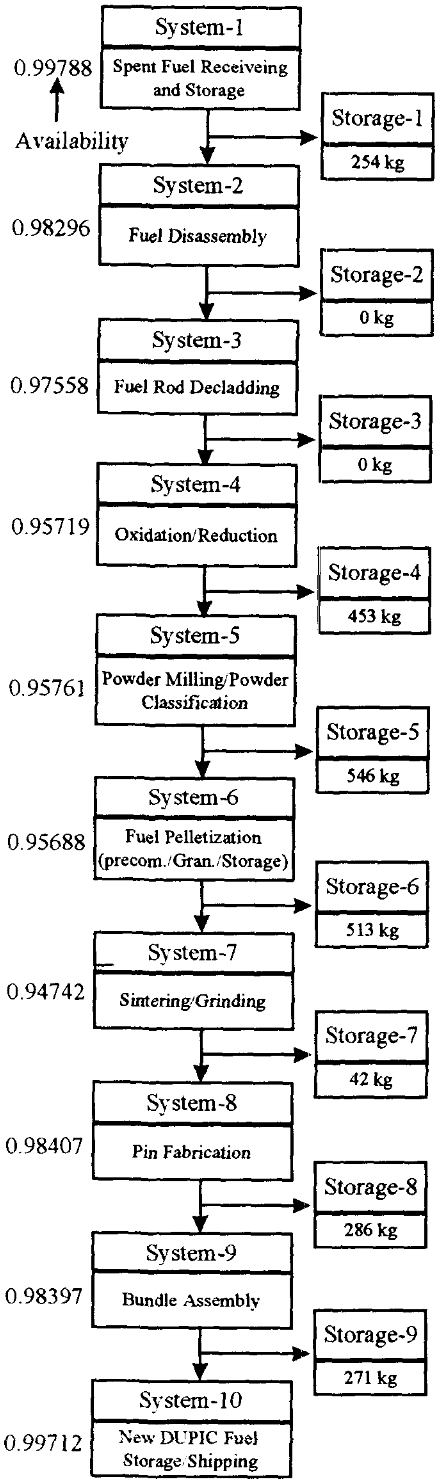

Figure 4. The Results of Availability Allocation

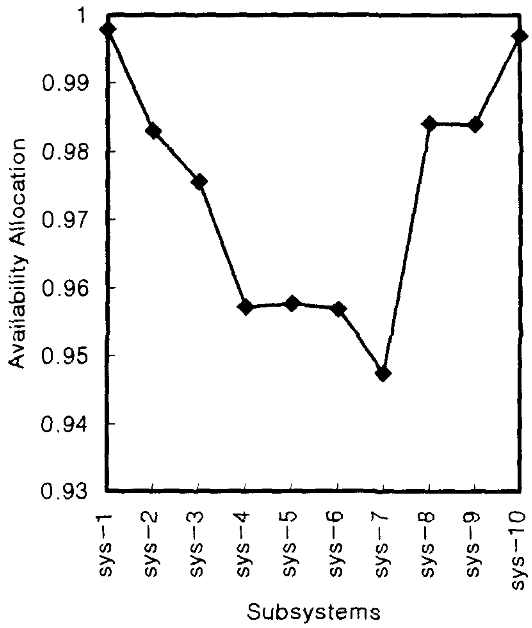

Figure 5. Buffer Storage Requirement of DUPIC Fuel Fabrication Facility