ESTABLISHING SYSTEM AVAILABILITY REQUIREMENTS FOR CONCEPTUAL FACILITIES

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Paper for Presentation at the
Maintenance and Reliability CONference (MARCON 2000)
Knoxville, Tennessee
May 7–10, 2000

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*Managed by Lockheed Martin Energy Research Corp. Under contract DE-AC05-96OR22464 for the U.S. Department of Energy.

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1. INTRODUCTION

System design engineers must translate permitted overall facility downtime into detailed design and operating specifications for numerous systems and subsystems that make up a facility. The process of assigning overall facility reliability and maintainability requirements among systems is known as availability apportionment. Apportionment is normally required early in conceptual design when little or no hardware information is available. Apportionment, when coupled with availability prediction, enables the selection of viable alternative configurations, identifies problem areas, and provides redirection of the program into more productive areas, as necessary. A method for apportioning, or budgeting, overall facility availability requirements using characteristic factors and expert opinion is presented.

An example of applying this methodology to the Spallation Neutron Source (SNS) facility is given (ref. 1). The SNS is a new accelerator-based neutron scattering facility designed to provide special scientific and research capabilities serving the needs of the nation's universities, industry, private laboratories, federal laboratories, and others involved in the development and application of neutron-based research. The SNS effort is a collaboration among five national laboratories for the design, construction, installation, and commissioning of the facility. The SNS project is divided into systems according to the responsibilities of each national laboratory. The six major systems are the front-end ion source, the linear accelerator (linac), the ring and transfer lines, the target, the control system, and the conventional facilities (conv fac). Clearly, with responsibilities widely distributed around the country, it is essential that the 90% overall facility inherent availability requirement be apportioned among systems in order to have a clearly defined availability design criteria for each major system. Design and construction of the facility at Oak Ridge, Tennessee, are expected to be completed in the year 2005 and cost ~$1.3 billion.

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2. DETERMINATION OF WEIGHTING FACTORS

Characteristics that influence equipment reliability and maintainability are described in this paper. Experts, using engineering judgment, score each characteristic for each system whose availability design goal is to be established. The Analytic Hierarchy Process is used to produce a set of weighted ranks for each characteristic of each alternative system. Expert elicitation relies on a series of exhaustive judgments that compare pairs of characteristics.

Characteristics chosen that influence reliability are system complexity, design immaturity, and stressful operating environment. System complexity may be evaluated by considering the probable number of parts or components that make up the system—the higher the number of parts, the greater the likelihood of failures. The lack of a proven design increases the probable number of failures. Components operating in a stressful environment (e.g., high temperatures, vibration, and radiation fields) have more failures than do those operating in benign conditions.

Characteristics that influence maintenance are the elements of repair time: fault detection and diagnosis time, preparation time to conduct the repair, fault correction time itself, and time to restart the system once the fault is corrected.

3. PAIRED-COMPARISON METHOD OF DETERMINING WEIGHTING FACTORS

The Analytic Hierarchy Process is used to produce sets of weighting factors for each alternative. The paired-comparison procedure is implemented in two phases. During the first phase, the relative importances of "characteristics" are established. Experts are asked, for example, to compare complexity and design maturity with respect to their importance in apportioning reliability. An example of this comparison is shown in Table 1. The second phase compares pairs of systems for each characteristic. Table 2 shows a comparison of the complexity parameters for the six major systems of the SNS. All pairs are compared for each characteristic. The entire procedure is repeated twice—first for reliability and then for maintainability. Availability is allocated based on a joint consideration of reliability and maintainability. The Expert Choice™ commercial software package is used to assist experts in working through the Analytic Hierarchy Process method.

A principal technical expert is chosen to represent each system. A structured interview is conducted for each expert individually. Team aggregation and final adjustments of availability allocations are performed at the conclusion of the structured interviews, and results are reviewed.

4. EXAMPLE APPLICATION RESULTS

This method of apportioning overall 90% SNS facility availability gave the following results for the experts interviewed: front-end systems, 99.5%; linac, 97.5%; ring and transfer line systems, 96.9%; target, 96.3%; experimental systems, 100%; conv fac, 99.7%; and control systems, 99.7%.

Correlation analyses, as shown in Fig. 1, demonstrate a high consistency in weighted ranks of SNS systems. The range of correlations among expert pairs was from 0.685 to 0.985, with 73% of the correlations above 0.800. The correlations of the experts' weighted ranks with the aggregate scores ranged from 0.742 to 0.988. Availability scores for each expert were submitted to a principal components analysis in order to represent expert judgment in a lower dimensional space. Three natural clusters emerged. The largest cluster consisted of experts representing the ring, target, and conventional facilities as well as the aggregate scores. In summary, the aggregate apportioned availability among systems represents each individual expert's responses very well.

5. REFERENCES

1. Schryver, J. C. and M. J. Haire, *Spallation Neutron Source Availability 'Top-Down' Apportionment Using Characteristic Factors and Expert Opinion*, ORNL/TM-1999/206, SNS 102020000TR0002R00, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 1999.

Table 1. Comparison of mean-time-between-failure criteria

		Relative score																	
	Systems	**More**											**Less**						**Systems**
1	Complxty	9	8	7	6	5	**X**	3	2	1	2	3	4	5	6	7	8	9	Immature
2	Complxty	9	8	7	6	5	4	3	**X**	1	2	3	4	5	6	7	8	9	Stress-e
3	Immature	9	8	7	6	5	4	3	2	1	**X**	3	4	5	6	7	8	9	Stress-e

1 = equal, 3 = moderate, 5 = strong, 7 = very strong, and 9 = extreme.

Table 2. Compare subprojects with respect to complexity

		Relative score																	
	Systems	**More**											**Less**						**Systems**
1	Source	9	8	7	6	5	4	3	2	1	2	**X**	4	5	6	7	8	9	Linac
2	Source	9	8	7	6	5	4	3	2	1	2	**X**	4	5	6	7	8	9	Ring
3	Source	9	8	7	6	5	4	3	2	**X**	2	3	4	5	6	7	8	9	Target
4	Source	9	8	7	6	5	4	3	2	1	2	3	4	5	**X**	7	8	9	Controls
5	Source	9	8	7	6	5	4	3	2	**X**	2	3	4	5	6	7	8	9	Conv fac
6	Linac	9	8	7	6	5	4	3	2	**X**	2	3	4	5	6	7	8	9	Ring
7	Linac	9	8	7	6	5	4	**X**	2	1	2	3	4	5	6	7	8	9	Target
8	Linac	9	8	7	6	5	4	3	2	1	2	**X**	4	5	6	7	8	9	Controls
9	Linac	9	8	7	6	5	4	**X**	2	1	2	3	4	5	6	7	8	9	Conv fac
10	Ring	9	8	7	6	5	4	**X**	2	1	2	3	4	5	6	7	8	9	Target
11	Ring	9	8	7	6	5	4	3	2	1	2	**X**	4	5	6	7	8	9	Controls
12	Ring	9	8	7	6	5	4	**X**	2	1	2	3	4	5	6	7	8	9	Conv fac
13	Target	9	8	7	6	5	4	3	2	1	2	3	4	5	**X**	7	8	9	Controls
14	Target	9	8	7	6	5	4	3	2	**X**	2	3	4	5	6	7	8	9	Conv fac
15	Controls	9	8	7	**X**	5	4	3	2	1	2	3	4	5	6	7	8	9	Conv fac

1 = equal, 3 = moderate, 5 = strong, 7 = very strong, and 9 = extreme.

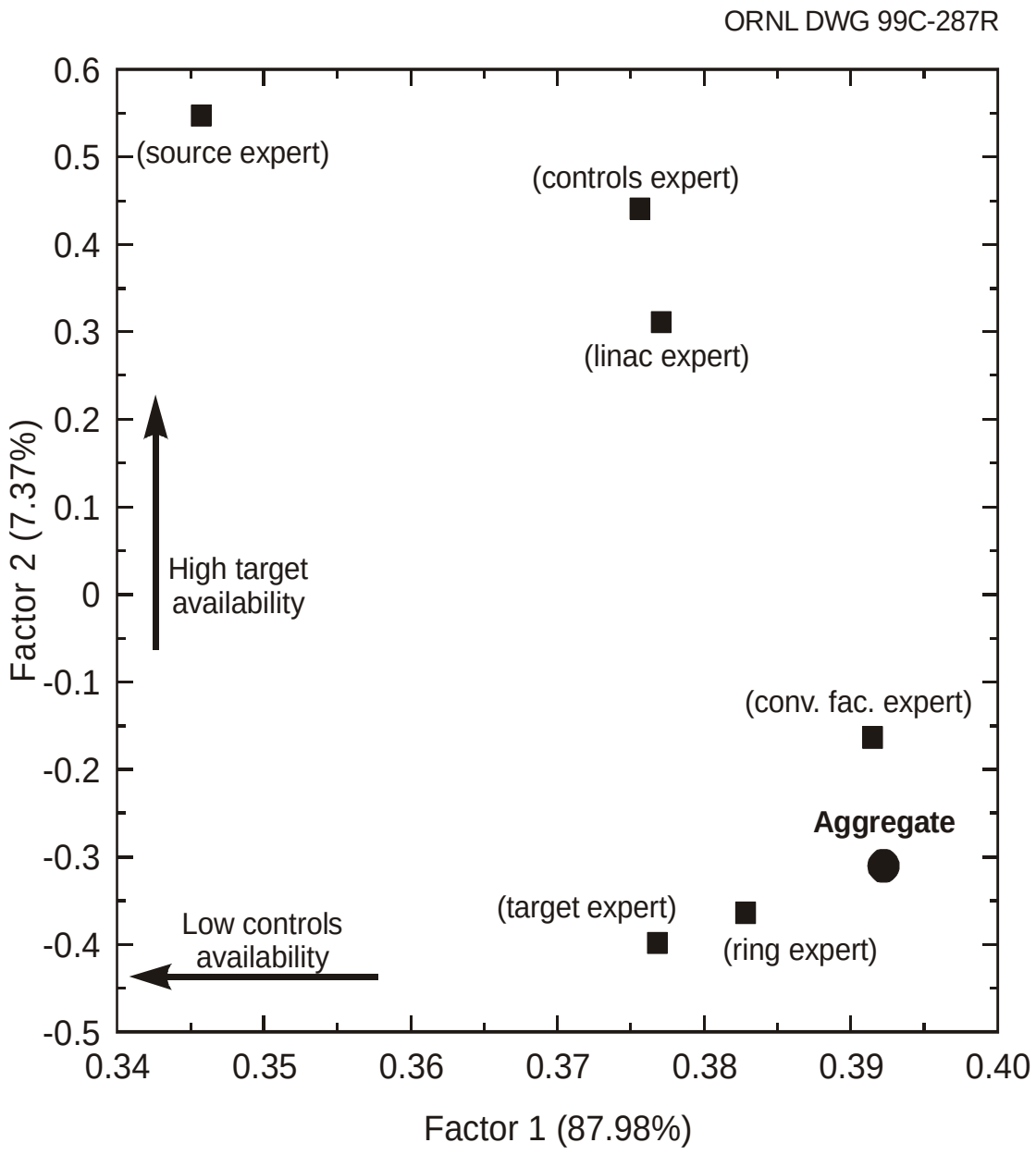

Fig. 1. Principal component analysis results showing agreement between experts and aggregate, apportioned availability.