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A RISK BASED APPROACH TO IMPROVING BEAM AVAILABILITY AT AN ACCELERATOR FACILITY*

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Abstract

This paper describes a risk-based approach to improving beam availability at an accelerator facility. Los Alamos Neutron Science Center (LANSCE), like many other accelerator facilities, was built many years ago and has been repurposed when new missions were adopted. Many of the upgrades to the accelerator and beamlines allowed partial improvements but large-scale, system-wide improvements were never accomplished. Because of this, the facility operates with a mix of old and new equipment of varying conditions. Limited budgets have constrained spending for spare part procurement making it vital to prioritize those items predicted to have the highest impact to availability, should they fail. A systematic approach is described where equipment is inventoried, condition assessed, rated for potential failure and finally compiled into a risk-based priority list.

Introduction

The LANSCE facility operates a proton accelerator originally built in the late 60s and early 70s to deliver beam to five experimental areas. The facility has done very well over the years delivering beam at an overall 80-85% availability [1] even as the original mission has changed and expanded by several other Experimental Areas (EAs). Accelerator availability is a measure of uptime divided by total time so the Mean-Time-To-Repair (MTTR) metric lowers available beam time to each of the EAs. The Availability metric is calculated weekly during production runs to each EA and then combined into an overall total for the accelerator.

It is the objective of Accelerator Operations and Technology (AOT) Division management, the organization operating and maintaining LANSCE, to improve the availability metric to 90% or greater using a risk-based approach for identifying and purchasing adequate operational spares to lower the unscheduled down time (MTTR). To achieve this goal, risks of failure shall be identified and prioritized from the top level down, from systems to structures to components (SSCs). Downtime (MTTR) data for the past history of failures along with the trends associated with particular equipment has already been captured for the availability metric. By mining this data, performing equipment assessments and assigning risk by subject matter experts, the most appropriate spares procurement list can be created.

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Unscheduled Down Time

An intricate set of systems operate in unison to produce and deliver particle beam to EAs at LANSCE. In fact, AOT division is organized such that key disciplines are grouped according to areas of specialty. Each of these AOT groups is populated with Subject Matter Experts (SMEs) that are intimately familiar with the details of their respective systems and can troubleshoot and repair issues arising that cause unscheduled downtime. The key to dealing with the unscheduled downtime lies in the recognition that the systems have single point failures that will turn off all or part of the entire machine if not functional. These single point failures are partially depicted, at a high level, in Fig. 1:

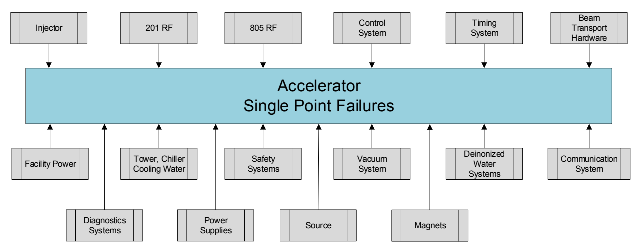

Figure 1: Single point failure diagram of the LANSCE accelerator.

As a 24 hour, 7 day a week operation, the LANSCE accelerator is attended by an excellent Operations staff that resolves many of the unscheduled downtime issues themselves with only small impacts to MTTR. For issues beyond their expertise or knowledge base, staff rotate on-call schedules to address the more difficult or complex issues that arise. The use of on-call staff affects the availability metric in terms of wait time for personnel to arrive on site, of proper diagnosis of the problem and whether the right person or persons have been called. These times contribute to the MTTR metric.

Maintainability

The maintainability for LANSCE is measured as the Mean Time to Repair [2]:

$$MTTR_i = RT + AD + LD \qquad (1)$$

where *RT* is the repair time, *AD* is the administrative delay and *LD* is the logistical delay or lead time waiting for parts and/or people. Repair times for unscheduled events have been mined from the Operator Logs and categorized into specific SSCs that caused the failure. The

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logistical delay will typically dominate this expression if the parts to be replaced are not readily available but need to be procured, designed and/or fabricated.

It is the logistical delay that is of particular interest to AOT Management. From the limited budget used to operate the accelerator, it is not possible to procure a spare for every SSC. And it is not necessary since many of the SSCs will probably last the lifetime of the LANSCE facility. Therefore, the knowledge and experience of SMEs along with historical data, guides the selection of SSCs that are more prone to or at risk for failure, thus causing unscheduled downtime.

Availability

The system availability for LANSCE is a known quantity that has been tracked and recorded for many years. Availability is a measure of the accelerator's ability to deliver beam to the experimental areas and is usually expressed as a percentage. It does not necessarily mean the accelerator is delivering beam but is available to do so.

$$A = \frac{MTBF}{(MTBF + MTTR)} = \frac{Uptime}{Total\ Time\ (Uptime + Downtime)} \quad (2)$$

where $MTBF$ is the Mean-Time-Between-Failure and $MTTR$ is as before. For a system made up of many single point failures, the system availability is defined as:

$$A_{sys} = \left(\frac{MTBF_{sys}}{MTBF_{sys} + MTTR_{sys}}\right) \quad (3)$$

where

$$MTBF_{sys} = \left(\frac{1}{MTBF_1} + \frac{1}{MTBF_2} + \cdots + \frac{1}{MTBF_n}\right)^{-1} \quad (4)$$

and

$$MTTR_{sys} = \sum_{i=1}^{m} MTTR_i \quad (5)$$

A_{sys} is the system availability, $MTBF_{sys}$ is the system $MTBF$ and $MTTR_{sys}$ is the system $MTTR$. $MTTR_i$ are the subsystem $MTTRs$. The future $MTBF$ is obtained from SME predictions, which can be derived from data trends, manufacturer data and/or comparable accelerator facilities. This data provides a baseline and trend for specific issues but does not predict future availability and performance. It is these predictions that help to determine the prioritized list for spares procurement.

Interrelationships

Each Experimental Area (EA) at LANSCE is dependent on the upstream status of the systems that precede it (Fig. 2). For example, if the H+ source is down, the Isotope Production Facility (IPF) will be down. If the H-Source is down, all other EAs will be down except IPF. As one imagines, the SSCs that are integrated into each upstream section affect the Availability of the downstream EAs. Therefore, the $MTBF_i$ and $MTTR_i$ of Eqs. (4) and (5) are those particular SSCs that are upstream of the EA. Obviously, if these upstream SSCs are down, the EA is down.

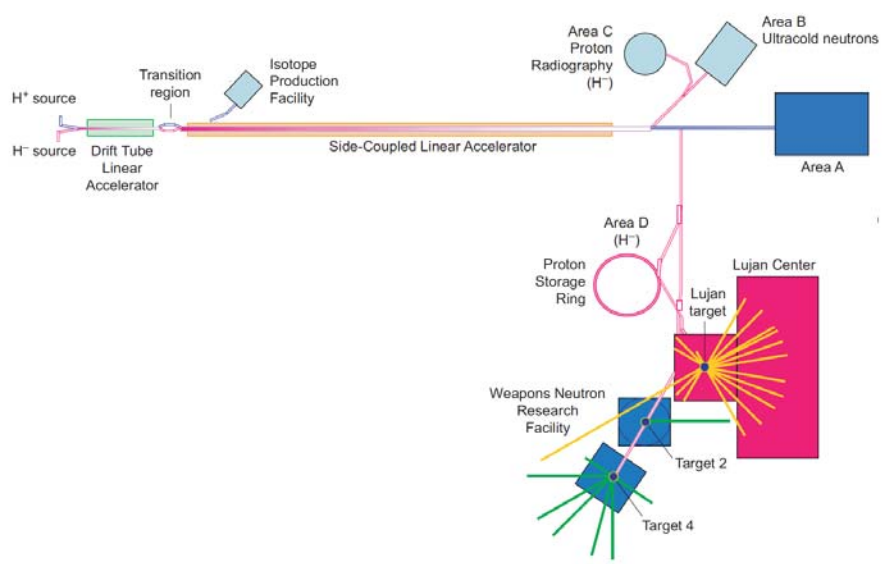

Figure 2: Graphical representation of the LANSCE accelerator.

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Table 1: Equipment Assessment Criteria

	Safety	Environment	Security	Reliability	Availability	Maintainability	System Physical Condition	Aging Degradation	Equipment Obsolescence	Spares	Mission Opportunity
3	Imminent Safety Issue	Severe environmental risk	Compromise of security	Greater than 20 failures during a ~5000 h Run Cycle; incl. machine turn on & beam tune	Overall downtime of more than 1 week in a run cycle	Greater than 1 days of Mean Time To Repair	System provides frequent evidence of not performing to its design requirements	System shows significant evidence of ageing	System is past End-Of-Life. Spare Parts are Unavailable for purchase	No spares in stock	Strong business case for upgrade
2	Code issue, Engineered Controls Issues, Potential for Adverse Safety from Failure Modes	Minor environmental risk, of compliance issues	Security incident	Greater than 5 but less than 20 failures during a ~5000 h Run Cycle, incl. machine turn on & beam tune	Overall downtime of less than 1 week but more than 1 day in a run cycle	More than 2 hour but less than 1 days of Mean Time To Repair	System provides occasional evidence of not performing to its design requirements	System shows evidence of ageing that will increasingly affect performance	System is approaching end of life and it is difficult to obtain Spare Parts	Limited spares in stock	Moderate business case for upgrade
1	No Safety Issue	Negligible environmental impact	Inconsequential impact to security	Less than 5 failures during a ~5000 h Run Cycle, incl. machine turn on & beam tune	Overall downtime of less than 1 day in a run cycle	Less than 2 hours of Mean Time To Repair	System provides no evidence of performance degradation	System shows no evidence of ageing	System is available for purchase - No End-Of-Life date	No spares issue	No business case for upgrade

Equipment Assessment

Each operational group at LANSCE tasked SMEs in their individual organizations to generate an SSC equipment list, rolled up to an appropriate replacement level, and assess each of these with a set of criteria as agreed to by the AOT management team. Table 1 lists the criteria with accompanying boundaries for scoring such that a number (1, 2 or 3) could be assigned to each individual criteria.

The equipment assessment includes categories that affect safety, security, the environment and mission. By including these factors, the intent of the LANL guiding document "Conduct of Research and Development" is addressed [3]. This policy document provides the architecture for structuring approaches to engineering endeavors, such as this one, in an R&D environment. Note that the equipment assessment is somewhat qualitative since it is partially objective.

The broad category of mission in the assessment criteria does take into account the metrics for a production facility such as reliability, availability and maintainability (RAM). Such categories are carefully considered when proposing upgrades to the accelerator [4].

Furthermore, the equipment assessment is augmented with categories that include performance degradation, signs of ageing and the subject of spare parts. Because spares are not kept in stock for every SSC, the vulnerability to increased MTTR is obvious. For those SSCs that are not readily available as Commercial off the Shelf (COTS) parts, the Logistical Delay can be quite long in duration, especially for long-lead items such as klystrons or magnets. For this reason, a weighting system was devised to put more emphasis on the two categories of whether the SSCs are COTS and whether or not spares are available and/or serviceable.

As seen from Table 1, the rating of 1, 2 or 3 with its weighting factor is assigned to each SSC for each category listed based on the descriptions in the columns. This rating task results in a cumulative total score for each SSC by adding the scores in each column of the table. Although thousands of SSCs were rated during this undertaking, a definite breaking point or gap could be identified in each discipline's equipment assessment. This gap produced a Top 10-15 SSCs in the list that showed the most vulnerability to generating unscheduled downtime.

Risk Register

As explained earlier, AOT Management's goal is to reduce the risks leading to unscheduled downtime and to optimize risk mitigation strategies to lower the highest risks. Starting with the equipment assessment, the Top 10-15 for the four disciplines compiled into a list of ~50 which became the basis for the risk register.

As was originally proposed, the risk register is a list of risks that lead to exceptional unscheduled downtime should they occur, thereby substantially affecting the availability metric. Each risk is evaluated for probability and consequence with availability (or schedule) as one of the major factors in the risk consequence (Table 2).

Table 2: Consequence Criteria

Rating	Mission	Schedule	Safety/Environment/Security
Low	Production beam (Criteria) to all areas not affected	Overall downtime of less than 1 day in a run cycle	No safety impact / Negligible environmental impact / Inconsequential impact to security
Moderate	Production beam to one or more areas affected	Overall downtime of less than 1 week but more than 1 day in a run cycle	Code issue, Engineered Controls Issues, Potential for Adverse Safety from Failure Modes / Minor environmental risk, of compliance issues / An IMI 3 or 4 security incident
High	Production beam to all areas affected	Overall downtime of more than 1 week in a run cycle	Imminent Safety Issue / Severe environmental risk / Compromise of national security due to the release of classified information. Compromise of Personally Identifiable Information (PII). A security incident having an Impact Measurement Index (IMI) of 1 or 2.

Risk Analysis

Modern and well tested methods of risk-based analysis and planning are regularly applied to complex systems in industry to ensure maximized performance within imposed constraints. Such methodologies, strategic maintenance planning, can also be applied to a large and complex expert-based scientific infrastructure such as the LANSCE proton accelerator system. AOT SMEs assign probability and consequence to the SSCs on the risk register, prioritize the results, and then optimize the overall list. The resulting list would then allow AOT division to strategically fine tune its operational, maintenance, and improvement priorities based on the risks and the available resources. The goal of this endeavor has been to generate a pilot program that can be carried forward, refined, and fully-implemented in future years.

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