SIMULATION AS A SOFT DIGITAL TWIN FOR MAINTENANCE RELIABILITY OPERATIONS

Xueping Li
Thomas Berg
Gerald Jones
Kimon Swanson
University of Tennessee, Knoxville
851 Neyland Drive
Knoxville, TN 37996, USA

Vincent Lamberti
Luke Birt
Pugazenthi Atchayagopal
Consolidated Nuclear Security, LLC
Y-12 National Security Complex
Oak Ridge, TN 37831, USA

ABSTRACT
A critical facility’s reliability relies heavily on its maintenance process’s effectiveness. This process involves numerous sub-processes, which can be challenging to model due to uncertainties and complexities. System managers often seek a predictive tool, and this work extends a previous study that developed a digital twin of a nuclear facility’s maintenance task process using data-driven and stochastic modeling, along with expert input. The authors extended the project’s previous iteration by enhancing the bootstrapping technique and improving the model’s fidelity.

1 INTRODUCTION & PROBLEM DESCRIPTION
Ensuring reliable operation and minimal downtime for critical facilities is crucial. These facilities employ systematic maintenance processes with multiple sub-processes requiring human resources. The interplay between these sub-processes creates challenges to model complex systems. To assist system managers in making optimal decisions for configuring the Maintenance Task Process (MTP), they desire a “crystal ball” to predict how changes will impact maintenance outcomes. The authors’ previous work developed an MTP digital twin (MTPDT) that closely mimicked the system’s statistical behavior for predictive optimization. This work extends the original study to enhance the MTPDT by refining uncertainty modeling and expanding the planning stage model.

2 METHODS
The original MTPDT was developed iteratively, incorporating data analysis and discussions with experienced individuals familiar with the process. Over six thousand sample MTs were generated to replicate real-world nuclear facility distributions for location, priority, maintenance type, and activity. Insights from discussions helped modelers understand the logic behind prioritizing preventative maintenance over corrective tasks. They revealed the time-consuming nature of the planning process, which was divided into planning in-process and planning approval components to explore the stage further. The updated model provided descriptive statistics for the time in the system (TIS) and throughput, resulting in even closer alignment with real-world MTP behavior (see Table 1).

3 RESULTS AND DISCUSSION
The higher fidelity modeling methodology allows for a precise model and simulation approximating objective attributes like average TIS and throughput based on raw data (Table 1). The average and median...
TIS shows minimal one to five-day discrepancies between the real-world data and DT simulation, with higher differences in the standard deviation in Average TIS and throughput. The improvements in the DT’s performance are attributed to the extended empirical distribution modeling and the incorporation of stakeholder-driven logic, prioritizing different maintenance types. This enhanced simulation instills more confidence in the experiment outcomes and provides a more detailed understanding of the time-consuming aspects of the MT process. The expanded planning stage model provided insights into the main causes of the extended duration of the planning stage. Figure 1 illustrates that the average time spent in the planning process stage, although significant, is overshadowed by the time consumed in the planning approval stage. This finding prompted an analysis of the data used to generate the simulations, confirming the observed behavior. This discovery initiated discussions among stakeholders to mitigate this delay in the maintenance process.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Process</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average TIS</td>
<td>94</td>
<td>93</td>
</tr>
<tr>
<td>TIS Standard Deviation</td>
<td>146</td>
<td>136</td>
</tr>
<tr>
<td>Median TIS</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td>Average Throughput</td>
<td>6578</td>
<td>6382</td>
</tr>
</tbody>
</table>

Table 1: MTP vs. simulation statistics, TIS in days

**DISCLAIMER**

This work of authorship and those incorporated herein were prepared by Consolidated Nuclear Security, LLC (CNS) as accounts of work sponsored by an agency of the United States Government under Contract DE-NA-0001942. Neither the United States Government nor any agency thereof, nor CNS, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility to any non-governmental recipient hereof for the accuracy, completeness, use made, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency or contractor thereof, or by CNS. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency or contractor (other than the authors) thereof.

**COPYRIGHT NOTICE**

This document has been authored by Consolidated Nuclear Security, LLC, under Contract DE-NA-0001942 with the U.S. Department of Energy/National Nuclear Security Administration, or a subcontractor thereof. The United States Government retains and the publisher, by accepting the document for publication, acknowledges that the United States Government retains a nonexclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this document, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, or allow others to do so, for United States Government purposes.