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SIMULATION AS A SOFT DIGITAL TWIN FOR MAINTENANCE RELIABILITY OPERATIONS

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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.

Metric	Process	Simulation
Average TIS	94	93
TIS Standard Deviation	146	136
Median TIS	58	62
Average Throughput	6578	6382

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

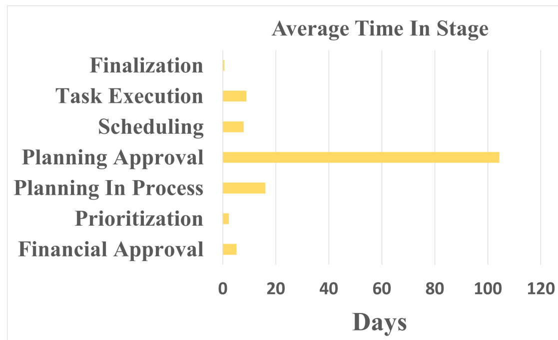

Figure 1: Average time in stage comparisons

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