LEVERAGING PHM IN CONJUNCTION WITH INTELLIGENT SCHEDULING TO IMPROVE MANUFACTURING RESILIENCE

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Rob Richards, PhD
Jim Ong
Stottler Henke Associates, Inc.
Prognostics & Health Management (PHM)

• Technology to enhance the effective reliability and availability of a product in its life cycle conditions by detection of current and approaching failures.

• Prognostics is the real-time enhancement of reliability and availability and the prediction of the remaining useful life of the product by assessing the extent of deviation or degradation of a product’s monitored parameters from its expected normal operating conditions.

• Prognostics can yield an advance warning of impending failure in a system, thereby enabling more efficient and effective maintenance and corrective actions.
Scheduling

The process of assigning resources to tasks over time, with the goal of optimizing the result according to one or more objectives: Usually includes minimizing project duration maximizing throughput.

Temporal relationships: Tasks may have predecessors and successors relationships that must be respected; other temporal constraints include start no earlier than dates.

Resources: Each task can require that specific resources are required for the task to be scheduled. Examples of resources include people with specific skills, equipment, and physical space.

Calendars: Resources, both human and equipment have calendars associated with them. Resources can only be scheduled on tasks when their calendar shows the resource is available.
Intelligent Scheduler Architecture

- Stottler Henke Associates, Inc. uses the general heuristics gleaned from top experts, over a wide array of circumstances, to enhance our intelligent scheduling system.
Resilience

- The ability of a system to withstand potentially high-impact disruptions, and it is characterized by the capability of the system to mitigate or absorb the impact of disruptions, and quickly recover to normal conditions.
Resource Scheduling: NP-Complete Problem

Ordering options scale as $N!$

<table>
<thead>
<tr>
<th>$N$</th>
<th>Options</th>
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<tbody>
<tr>
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<td>10</td>
<td>3628800</td>
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</tbody>
</table>
Why Order Matters?

The example below involves jobs using two resources. Different colors represent each resource.

Schedule 1: B before C

Schedule 2: C before B
Intelligent Scheduling vs Resource-Leveling

REFINERY TURNAROUND 2500+ TASKS

Aurora saves over 10 days versus Primavera P6

Critical Path 46

Primavera P6: 67.13 days
Aurora: 56.27 days

All tests done by third party
MS Project results (START of animation)
VS. Aurora results (END)
Equipment and all other Resources have Calendars
Intelligent Scheduling Adapts to Changes to Human & Machine Calendars
PHM Determines Timespan when Maintenance Must Occur
Histogram Analysis: Timeframes when Equipment was not Scheduled to be Used
Intelligence Scheduling Determines when best to Actually Schedule the Maintenance
Intelligent Scheduling Adapts to Changes to Human & Machine Calendars

Intelligent scheduling adapts optimally to any updates to calendars during execution, each time the scheduler is updated (e.g., after each shift).

- Consider status updates of tasks,
- Changes known per future availability of people and equipment (via updates to their calendars).

PHM helps improves the accuracy of each machine’s calendar

- Allowing for the intelligent scheduling engine to adapt sooner, and thus better, to future conditions.
Visualizations to Clarify Effects of Downtime
Equipment Outage: Production Blockage, Starvation

Throughput and Queue Lengths by Process Step vs. Date

Day 0: T4 is operational

Queued Blades vs. Day

- Acquirer
- Btch
- Ultrasone Screw Hole Inspection
- Mag Particle Inspection
- Visual and Eddy Current Inspection

- Oversize Bushing and Outer Taper
- Eddy Current Inspection
- Glass Bond Blast
- Borescope Inspection
- Robotic Oil Blast

- Btch and Btch and
- Fluorescent Penetrant Inspection
- Measuring and Rating Magnetometry
- Legacy Repair Processes
- Bushing Bore Size Cut Off Step Peer

- Bushing Bore and Bushing
- Apply Permalloy
- Prime Inner Bore and Install Bushing

Legend:
- numBladesProcessed
- inputQueueLength
- outputQueueLength
- starved
- blocked
- failed
Aids intelligent scheduling systems by discovering mishaps before they occur.

Provides more time so the intelligent scheduling system can reduce the impact, either alongside human schedulers, or autonomously.
Leverage PHM to take Advantage of Supply Chain or other Disruptions

Supply Chain or other disruptions may cause certain equipment to become idle.

Intelligent scheduling will leverage PHM knowledge and the idle time to determine if advantageous to perform maintenance during unexpected idle time.
PHM & Timeframes to Perform Maintenance

PHM is the early warning system providing the intelligent scheduling system with options of when to perform maintenance to minimize disruption.

Intelligent scheduling solutions combine this information with the established deadlines, to create new scenarios to lower the impact of identified disruptions.
Conclusion

SCHEDULING, EVEN UNDER IDEAL SITUATIONS IS INCREDIBLY CHALLENGING, UNEXPECTED EVENTS, SUCH AS UNPLANNED EQUIPMENT DOWNTIME FURTHER COMPLICATES SCHEDULING

PHM IN CONJUNCTION WITH INTELLIGENT SCHEDULING & HUMAN SCHEDULERS, CAN MAXIMIZE THE EFFICIENCY AND THE EFFECTIVENESS OF LIMITED RESOURCES TO MAXIMIZE THROUGHPUT AND MINIMIZE COST