Background

In the last decade, the explosion of the Internet of Things (IoT) and the sensors that came with it created a large amount of sensor data. The interpretation of this data has driven the development of so-called prescriptive maintenance tools, e.g., Si et al. (2011). These tools aim to transform raw data into some information about when a piece of equipment may fail. This has driven the formulation of integrated production and scheduling models, e.g., Basciftci et al. (2018). These models aim to build holistic schedules that incorporate sensor data to drive maintenance actions while taking into account traditional scheduling concerns.

Purpose

Currently all proposed models assume that the cost of a maintenance action is independent of other maintenance actions. This means that if a plant has ten identical pieces of equipment the cost to repair a single one is simply the cost to repair one times ten. This does not take into account built in costs in maintenance. For example a flat fee that a maintenance worker may charge for their onsite arrival. The cost maintenance in which maintenance cost is a function of the type of task and the amount of coupling. However the extent that a change in a single attribute would impact the amount of coupling was varied and clearly the result of a complex relationship.

Citations


Model

Min $\sum_{j} \sum_{t} P_{j,t} \times PS_{j} + S_{j,t} \times CS_{j}$

1) $R_{j,t} = R_{j,t-1} + \sum_{k} \sum_{t} m_{j,k,t} \cdot N_{k,t-1} + m_{j,k,t} \cdot \delta_{k,t} + P_{j,t} - DM_{j,t} \cdot \varphi_{j,t}$

2) $R_{j,t} \leq \text{Rmax} \cdot \varphi_{j,t}$

3) $E_{j,t} \leq \text{Emax} \cdot N_{j,t} \cdot \varphi_{j,t}$

4) $P_{j,t} \leq \text{Pmax} \cdot \varphi_{j,t}$

A modified resource task network was used. The sample problem used was the steel mill problem described in Kondili et al. (1992) values were used from Biondi, et al. (2017) so comparisons could be made. To couple costs a flag to allow repair was added. This flag has a fixed cost and allows the conversion of purchasable repair token to the consumable repair token. This can only be done in a single time frame. None of these flags or tokens are storable. This models a discounted price for grouped maintenance as if maintenance is scheduling individually the flag must be repurchased incentivizing coupling. Important resources, tasks, mu and nu values are defined below.

Graph based representation of the problem (Biondi, et al., 2011)

Sets

- J - number of resources
- K - number of tasks
- T - number of timeslots in planning horizon

Variables

- $P_{j,t}$ - number of resource $j$ purchased in time $t$
- $R_{j,t}$ - amount of resource $j$ in time $t$
- $S_{j,t}$ - amount of resource $j$ in time $t$ stored
- $N_{j,t}$ - binary variable for each task in time $t$
- $P_{j,t}$ - extent of each task $j$ in time $t$

Datasets

- $DM_{j,t}$ - demand of resource $j$ in time $T$
- $PS_{j}$ - cost to purchase resource $j$
- $R_{j,t}$ - initial values of each resource $j$
- $CS_{j,t}$ - cost to store each resource $j$
- $N_{j,t}$ - resource parameters associated with $E$
- $M_{j,t}$ - resource parameters associated with $E$
- $Emax_{k}$ - max extent for each task $k$

Value

- $K$ - number of resources
- $J$ - number of tasks
- $T$ - number of timeslots in planning horizon
- $nu$ - value related to maintenance

Methods and Results

The model was implemented in the programming language Julia using the framework JuMP. The model was solved with Gurobi. The model was solved on a machine with an Intel i7-4600U and 8GB of RAM. The time complexity drastically varied with demand. High demand models took 12hrs to solve to a optimality gap of 2% with a twenty period time horizon. A standard model was made and run with and without coupling the comparison is shown below. A series of experiments in which the demand, number of repair actions and discount was varied. These all showed a general trend in the direction they impacted the amount of coupling. However the extent that a change in a single attribute would impact the amount of coupling was varied and clearly the result of a complex relationship.

Conclusions

Coupled Cost of maintenance actions can be effectively modeled in a resource task network. It has a large impact on time complexity. It is hard to predict the extent of coupling. How changes made to the model will impact the level of coupling are also hard to predict. This work can be extended to further explore integrated maintenance and production scheduling.

Resource Levels Over Time - Coupled

Component Health Over Time - Coupled

Resource Levels Over Time - Non Coupled

Component Health Over Time - Non Coupled