# Choosing the Optimal Intervention Method to Reduce Human-related Machine Failures

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# Introduction/Main Idea

Overall goal:

- To provide a decision model that incorporates human-related factors as dynamic variables which can be influenced to positively affect system performance

# Analyzing the Risk of Failure

Quantification of Human-Related (HR) factors

Qualitative measurements turned to quantitative ones

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Develop risk model that includes HR factors

How much risk of failure is the system facing?

↓

Provide cost-benefit analysis for choosing among risk reduction intervention methods

What is the best proactive step I should take?

# Main Tool for Risk Model

Proportional Hazards Model (PHM):

$$h(t,z) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{\gamma_1 z_1(t)+\ldots+\gamma_n z_n(t)}$$

- A failure prediction model, comprising of:
  - Baseline hazard, dependant on age, and
  - A functional term, capturing effects of specific characteristics (covariates)
- Covariates may be:
  - Machine-related: ex. Iron content in lubrication oil
  - Human-related: ex. skill level

# Cost-benefit Analysis

- PHM provides decision maker with idea of failure risk based on current conditions
- DM has a decision to make: intervene or do nothing
  - Also important to know which intervention method makes the most sense
- Decision is made on a financial basis

# Revenue Function

Expected net revenue for each intervention method =
Expected revenue – expected cost

$$E\left(\mathrm{C}_{\mathrm{t,t+s}} | T > t, Z, A\right) = \boxed{\text{revenue}}$$

$$- \boxed{\text{cost}}$$

Revenue component:
expected machine uptime

$$E\left(\min\{T - t, s\} | T > t, Z, A\right) = \int_{t}^{t+s} e^{-\psi(Z,A)\left[\left(\frac{t+u}{\eta}\right)^{\beta} - \left(\frac{t}{\eta}\right)^{\beta}\right]} du$$

Cost component:
probability of failure

# Empirical Study

- HR factors considered:
  - Skill
    - Experience: general manufacturing knowledge, and specific gear manufacturing
    - Analytical: technical skill, specific to particular machine
    - Social: social interaction, willingness to receive/provide help
  - Shift work
  - Day of the week

# Sample Data for Developing PHM

| Working Age | Experience | Social | Analytical | X1 | X2 | Y1 | Y2 | V1 | V2 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 42.86 | 70.83 | 27.12 | 0 | 1 | 1 | 0 | 1 | 0 |
| 8 | 100.00 | 77.08 | 78.67 | 0 | 0 | 1 | 0 | 1 | 0 |
| 16 | 42.86 | 41.15 | 23.05 | 1 | 0 | 1 | 0 | 1 | 0 |
| 24 | 42.86 | 70.83 | 27.12 | 0 | 1 | 1 | 0 | 0 | 0 |
| 32 | 100.00 | 77.08 | 78.67 | 0 | 0 | 1 | 0 | 0 | 0 |
| 40 | 42.86 | 41.15 | 23.05 | 1 | 0 | 1 | 0 | 0 | 0 |
| 48 | 42.86 | 70.83 | 27.12 | 0 | 1 | 1 | 0 | 0 | 0 |
| 56 | 100.00 | 77.08 | 78.67 | 0 | 0 | 1 | 0 | 0 | 0 |
| 7.5 | 42.86 | 70.83 | 27.12 | 0 | 0 | 1 | 0 | 1 | 0 |
| 15.5 | 100.00 | 77.08 | 78.67 | 1 | 0 | 1 | 0 | 1 | 0 |
| 23.5 | 42.86 | 41.15 | 23.05 | 0 | 1 | 1 | 0 | 0 | 0 |

X1: afternoon shift or not
X2: night shift or not

Y1: "A" machine or not
Y2: "B" machine or not

V1: first day of the week or not
V2: last day of the week or not

# PHM obtained

$$h(t,z)=\frac{1}{2.511}e^{(-0.065z_1-0.029z_2+2.490z_3+2.210z_4-0.865z_5-1.301z_6+0.977z_7)}$$

- $z_1$ : Social
- $z_2$ : Analytical
- $z_3$ : Afternoon shift or not
- $z_4$ : Night shift or not
- $z_5$ : “A” machine or not
- $z_6$ : “B” machine or not
- $z_7$ : First day of the week or not

# Intervention Methods

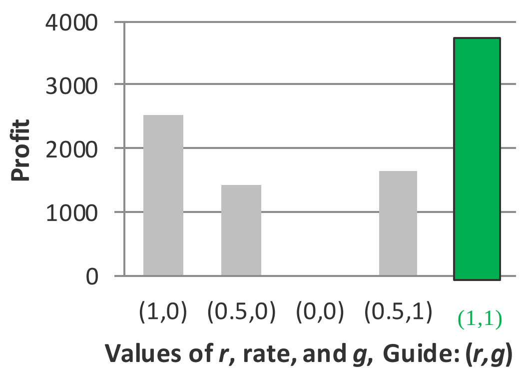
1. Running the production process at a slower speed
2. Adding a highly skilled person to the shift to provide expertise, a “Guide”

$$E\left(C_{t,t+s} \middle| T > t, Z, A\right) = \omega(g_1, g_2, \ldots, g_p) \times \int_t^{t+s} e^{-\psi(Z,A)\left[\left(\frac{t+u}{\eta}\right)^{\beta} - \left(\frac{t}{\eta}\right)^{\beta}\right]} du - C_F \times \left(1 - e^{-\psi(Z,A)\left[\left(\frac{t+s}{\eta}\right)^{\beta} - \left(\frac{t}{\eta}\right)^{\beta}\right]}\right) - \vartheta(g_1, g_2, \ldots, g_p)$$

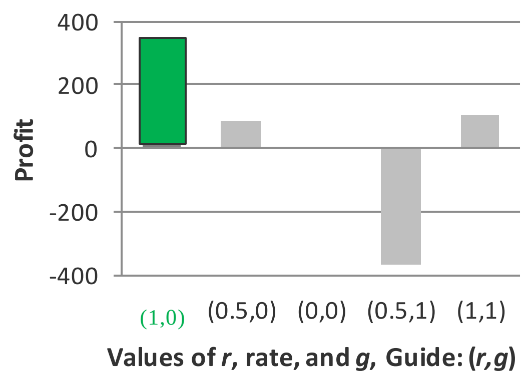
$$\psi(Z, A) = a_0 \times \exp\left(\sum_{j=1}^{m} \gamma_j A^{(j)} Z_j\right)$$

# Sample Results

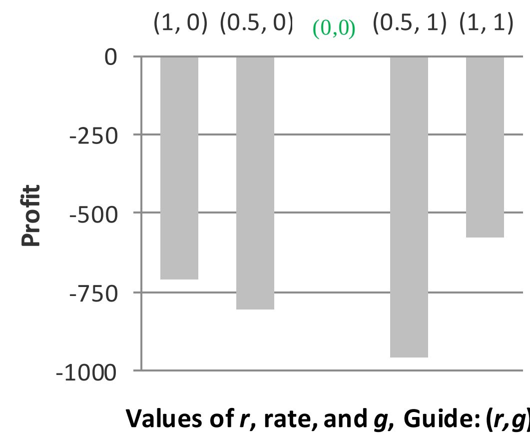
First afternoon shift of the week, $z_1$=62 and $z_2$=64, machine C, $t$ =40, operator's average production rate=33 pcs/hr, process rate at 50%→ 0.5*$h(t,z)$, Guide presence → 1.25*$z_2$ , Guide cost=$800/shift




**Scenario 1**: run at rate, add a Guide




**Scenario 2**: Run at rate, no Guide




**Scenario 3:** Stop Machine

- (1,0): run at normal rate, no Guide ("Do nothing" option)
- (0.5,0): run at half rate, no guide
- (0,0): shut machine down
- (0.5,1): run at half rate, add Guide
- (1,1): run at normal rate, add Guide

# Final thought

Human-related factors can have a significant impact on system performance (both positive and negative).

It is necessary to pay attention to them just as much as focusing on equipment reliability and uptime.

Thank you

Questions? Comments?