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Introduction to Manufacturing Systems
Quality/Quantity Interactions

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Goals of Talk

• To show that there is great advantage in treating quality and quantity *simultaneously* in the design and operation of manufacturing systems.

• To report on MIT research.  
  *Collaborators:* Irvin C. Schick, Jongyoon Kim.

• To enlist additional industry assistance.  
  *General Motors R & D has generously contributed to the support of this work.*
In manufacturing,

- *Quantity* is about how much is produced, when it is produced, and what resources are required to produce it.

- *Quality* is about how well it is made, and how much of it is made well. Production quality is about not giving customers what they do not want.
Introduction

- *Quantity measures* include production rate, lead time, inventory, utilization.

- *Quality measures* include yield and output defect rate.
Introduction

- *Quantity strategies* include optimizing local inventories, optimizing global inventory, other release/dispatch policies, make-to-order, etc.

- *Quality strategies* include inspection, statistical process control, etc.
The problem is that, conventionally, ...

- Quantity strategies are selected according to how they affect quantity measures, and

- Quality strategies are selected according to how they quality measures, but ...

- in reality, *both affect both*.
Quantity

- Two-machine, one-buffer production line.
- All production is perfect quality.
- The machines are unreliable — they fail at random times and are repaired at random times.
- We vary the buffer size \( N \) and observe its effect on the production rate \( P \).
- Observation: the production rate increases monotonically up to a limit.
Quantity

Machine Reliability Dynamics

Simplest model

UP

DOWN
Quality

- Goal is to determine when a process has gone *out of control*.
- Upper and lower control limits (UCL, LCL) usually chosen to be $6\sigma$ apart.
- Basic idea: which is the most likely distribution that sample comes from?

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Inspection

• Motivation — why inspect?
  ★ To take action on parts (accept, rework, or scrap).
  ★ To take action on machines (leave alone or repair).

• Effects of perfect inspection:
  ★ Bad parts rejected or reworked.
  ★ Machine maintained when necessary.

• Effects of inspection errors:
  ★ Some good parts rejected or reworked; some bad parts accepted.
  ★ Unnecessary downtime and/or more bad parts.
Quality Dynamics

- **Definition:** How the quality of a machine changes over time.
- The quality literature distinguishes between *common causes* and *special causes*. (Other terms are also used.)
  - ★ Common cause: successive failures are equally likely, regardless of past history.
    
    GGGGBGGGBGGGGGGGBGGBGGGGBBGGGGGGG.GGGG.GGGG.GGGG.

  - ★ Special cause: something happens to the machine, and failures become much more likely.
    
    GGGGBGGGGGBGGGGGGGGGBBBBGBBBBGBBBBGBBGBBGB.

- We use this concept to extend quantity models.
Versions:

- The *Good* state has 100% yield and the *Bad* state has 0% yield.

- The *Good* state has high yield and the *Bad* state has low yield.
Quantity-oriented people tend to assume that increasing a buffer *increases* the production rate.

Quality-oriented people tend to assume that increasing a buffer *decreases* the production rate of good items.

However, we have found that the picture is not so simple.
Separation of Operation and Inspection

- Two-machine lines.
- The first machine sometimes does bad operations.
- The second machine does inspection.
- We look at three cases — ie, three sets of machines.
- We vary $N$ and plot effective production rate — the production rate of good parts.
Separation of Operation and Inspection

Beneficial Buffer

![Graph showing effective production rate vs buffer size]

*Effective production rate* = production rate of good parts.

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Separation of Operation and Inspection

Harmful Buffer

Effective Production Rate vs Buffer Size

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Separation of Operation and Inspection

Mixed-Benefit Buffer

![Graph showing the relationship between buffer size and effective production rate.]

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Inspections

How many inspections should there be? And where?

- Intuition: more inspection improves quality.

- Reality: increasing inspection can actually reduce quality, if it is not done intelligently.
Inspections

- We simulated a 15-machine, 14-buffer line.
- All machines and buffers were identical.
- We looked at all possible combinations of inspection stations in which all operations were inspected.
  
  ★ Example: Inspection stations just after Machines 6, 9, 13, and 15.
  ★ The first inspection looks at the results from Machines 1 – 6; the second looks at results from Machines 7 – 9; the third from 10 – 13; and the last from 14 and 15.
  ★ There is always one inspection after Machine 15.

- A total of $2^{14} = 16,384$ cases were simulated.
Inspections
Choosing the optimal set of locations for 3 inspection stations is better than the worst set of locations for 9 stations.

Having 15 stations is only marginally better than having 8 stations, if the 8 stations are located well.
Conclusions

- Combining Q/Q produces unexpected behavior.
- Yield is a function of the system (including the sizes of buffers) and not just of the machines.
- System yield is not a simple function of machine yields.
- This is an important area with many kinds of problems to be studied.
Current Work

- When should we maintain a machine?
- If we repair a machine immediately after seeing one bad part, we may repair machines when they are good.
- If we wait until we see $n$ bad parts, we may make unnecessary bad parts.
- Common *ad hoc* methods:
  - Repair for some fixed $n$.
  - Repair after inspection measurement has $k$ successive increases or decreases.
Current Work

Inspection Strategy

Bayes risk methods

- *Bayesian statistics* allows us to update the probability of each machine state after each inspection.

- Bayes risk methods use Bayesian statistics to determine the best time to take an action — such as starting a repair — after obtaining measurement information.

- This leads to a *closed-loop* strategy.
Future Work

- The three-state machine model is much too simple.
- One extension is

... but even this leaves out important features.
Future Work

- Another extension is

- This allows more general wear or aging models.
Future Work

- A maintenance strategy could be modeled as

\[ a_1, a_2, \ldots, a_n \]

- if we have perfect knowledge of the machine state.

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Future Work

- If the machine state is not known perfectly, a better strategy might be:

- Here, the machine quality state might be estimated according to the time since the last maintenance, and/or according to measurement data.
Future Work

- Model with a parameter (e.g., tool diameter) that varies with the time since the last maintenance (tool change).
Future Work

- Collect data from factories to assess the realism of our models and methods.

- Apply our results to factory design.

- *This activity is already under way with GM.*