MIT 2.852

Manufacturing Systems Analysis

Lectures 22–?

Quality and Quantity

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Spring, 2007

Quality and Quantity

- *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.
  - ⋆ *Design quality* is about giving customers what they would like.
  - ⋆ *Production quality* is about not giving customers what they would not like.

Quality and Quantity

- Most literature is all quantity or all quality.
- *Quantity measures* include production rate, lead time, inventory, utilization.
- *Quality measures* include yield and output defect rate.

Quality and Quantity

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

- *Quality strategies* include inspection, statistical process control, etc.

Quality and Quantity

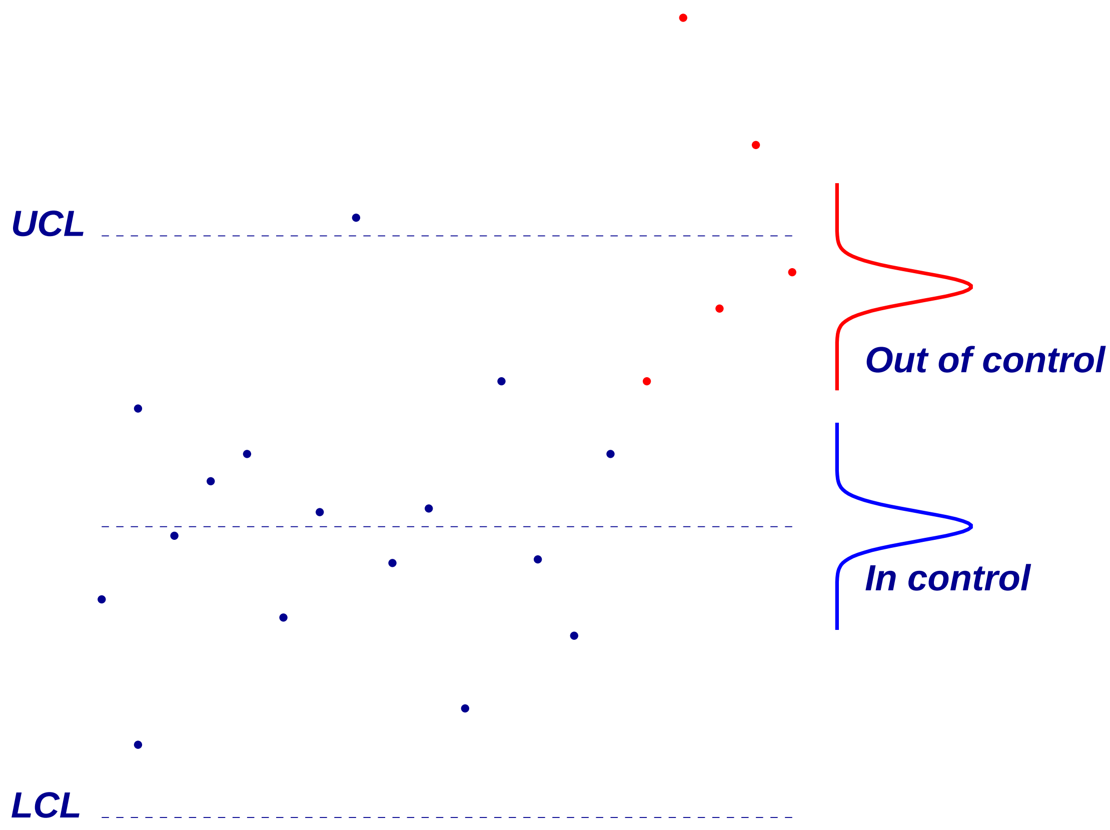
The Problem

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* .

Example: Statistical Process Control

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



Quality and Quantity

Example:

Everything we have been discussing so far.

Taxonomy of Issues

- Failure dynamics
- Inspection
  - ⋆ Binary (good/bad) vs. measurement
  - ⋆ Accuracy (false positives and negatives)
  - ⋆ Spatial and temporal frequency
- Actions on parts and machines
- Topology of system
- Performance measures

Taxonomy of Issues

Failure 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.

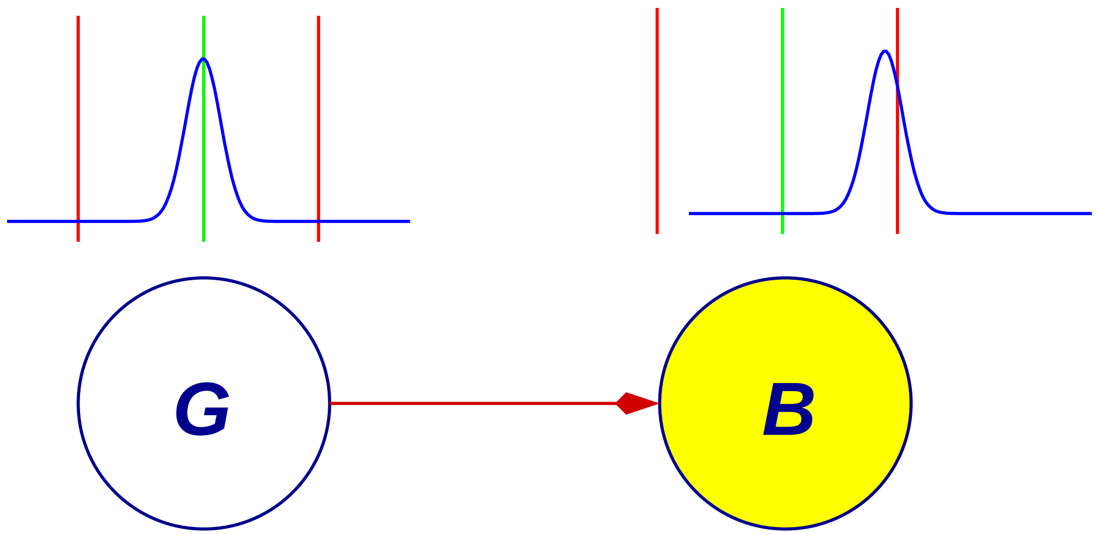
    GGGGGBGGGBGGGGGGBGGBGGGGBBGGGGGGGG. . . . .
  - ⋆ Special cause: something happens to the machine, and failures become much more likely.

    GGGGBGGGGGBGGGGGGGBBBBBBGBBBBGBBGB. . . . .
- We use this concept to extend quantity models.

Taxonomy of Issues

- *Bernoulli or common cause:* independent.
- *Persistent or special cause:* all parts after the first bad part are bad, until the repair.
- *Multi-Yield* : generalization of persistent.

The relationship between quality dynamics and statistical process control:

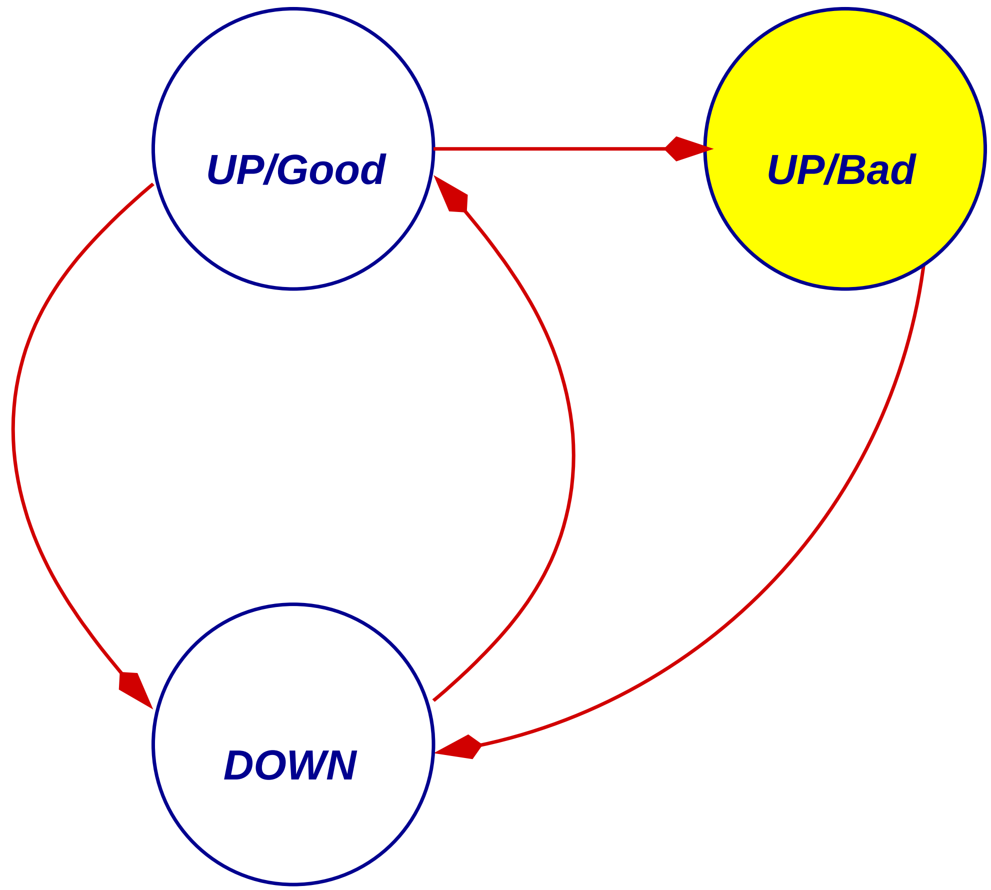


Note: The operator does not know when the machine is in the bad state until it has been detected.

Taxonomy of Issues

Failure Dynamics

Simplest model

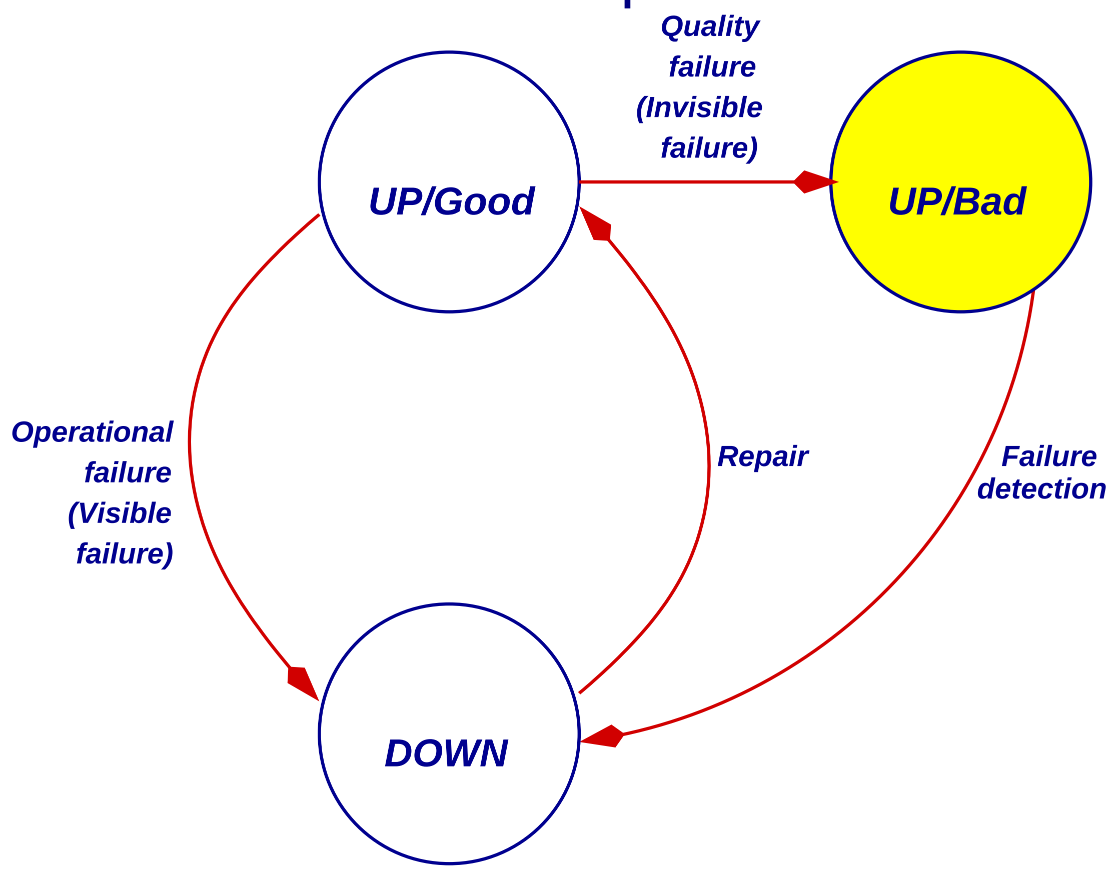


Versions:

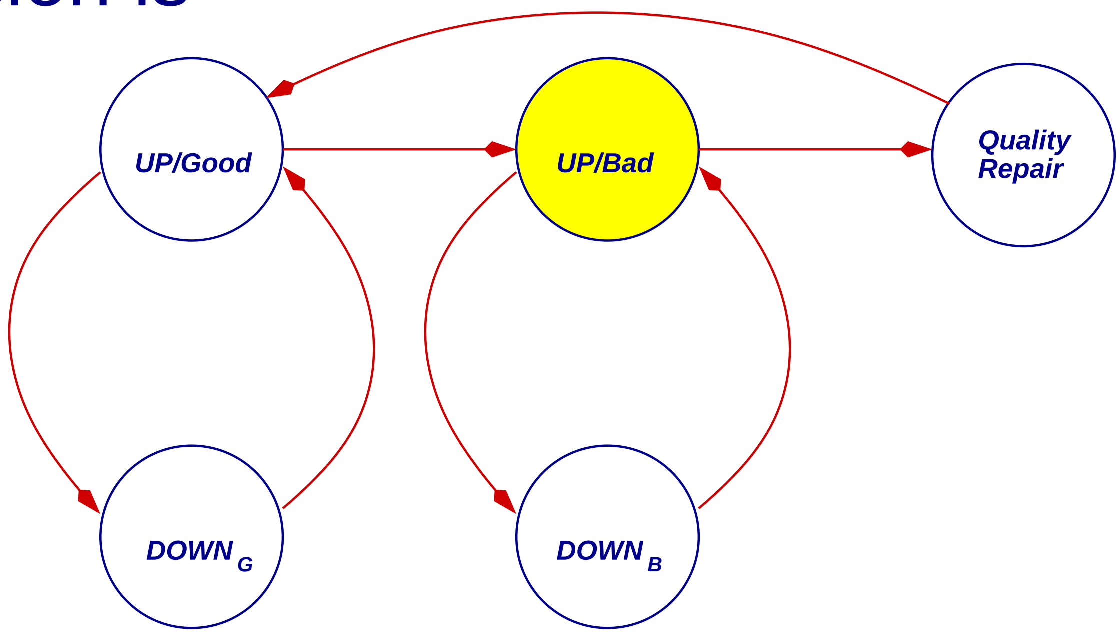
- The *Good* state has 100% yield and the *Bad* state has 0% yield.
- The *Good* state has high yield and the *Bad* state has low yield.

The three-state machine model is much too simple.

- No matter how the machine arrived at the *DOWN* state, it gets the same repair. Since the next state is always the *UP/Good* state, there must have been a quality repair.
- Quality repairs are expensive, and not necessary for operational failures.



- One extension is



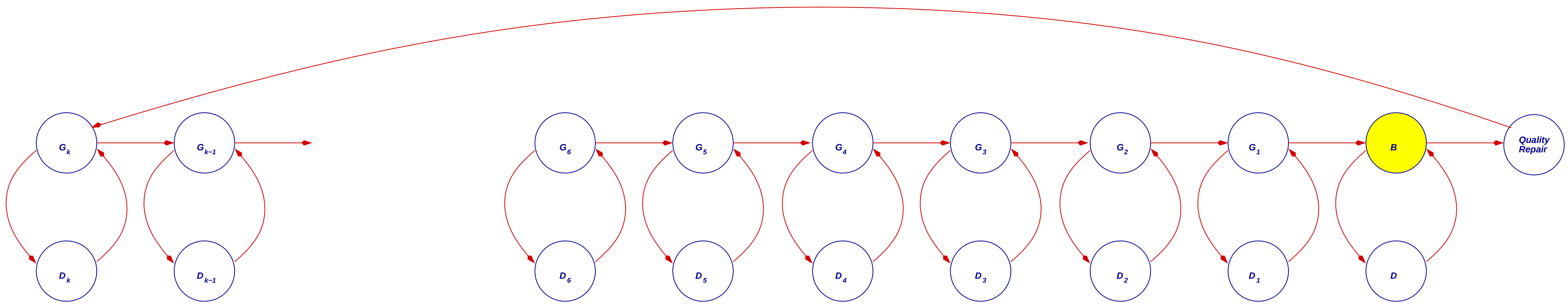
- ... but even this leaves out important features.

Taxonomy of Issues

Failure Dynamics

Simplest model

- Another extension is



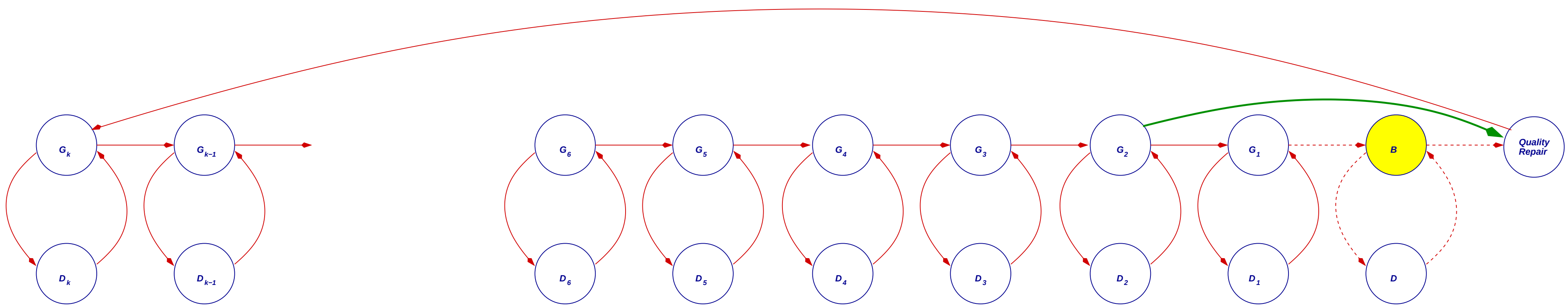
- This allows very general wear or aging models.

Taxonomy of Issues

Failure Dynamics

Simplest model

- A maintenance strategy could be modeled as



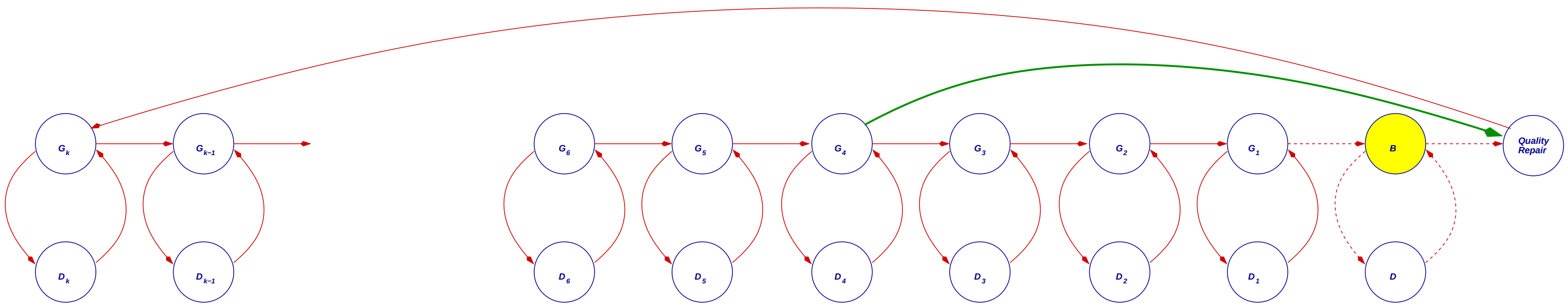
if we have perfect knowledge of the machine state.

Taxonomy of Issues

Failure Dynamics

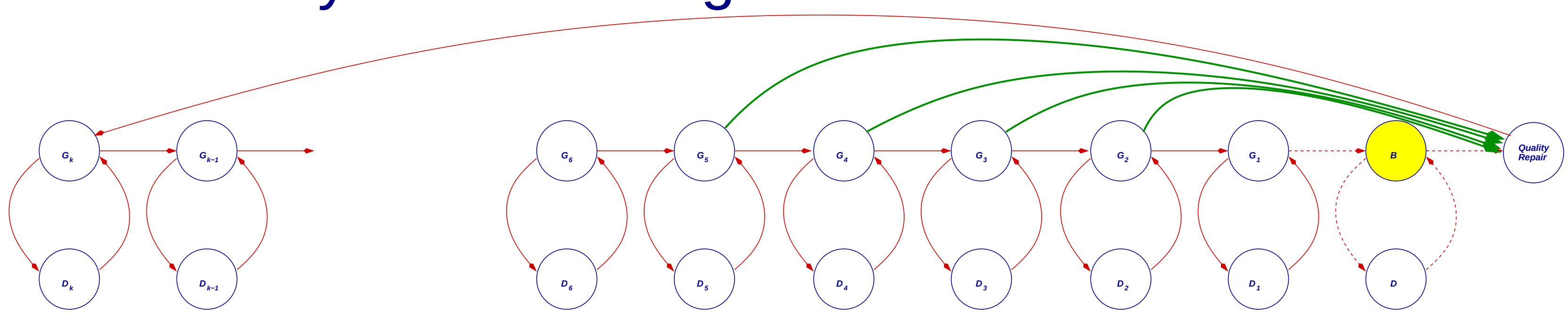
Simplest model

- A maintenance strategy could be *implemented* as



if we do not have perfect knowledge of the machine state.

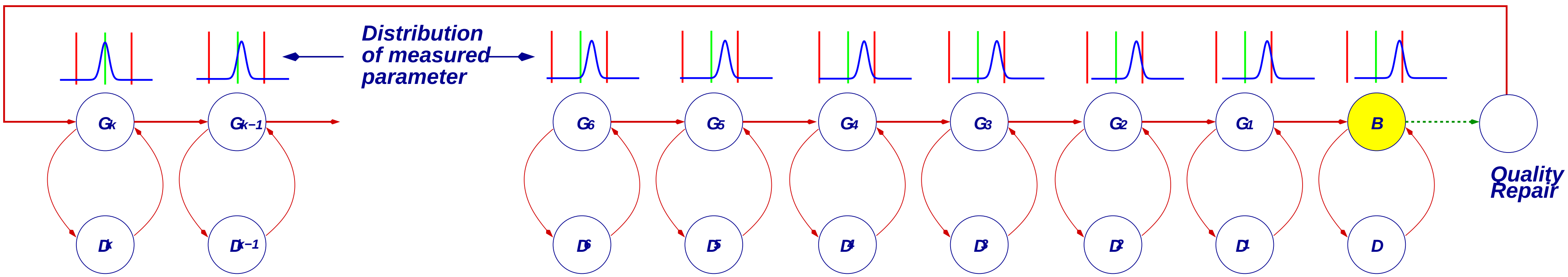
- It would be analyzed according to



Taxonomy of Issues

Failure Dynamics

Simplest model



Taxonomy of Issues

- Motivation — why inspect?
  - ⋆ To take action on parts and machines.
- Objectives of 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.

Taxonomy of Issues

- Destructive vs. non-destructive
- Domain
- Sampling
- Inspection time
- Accuracy (and goal of inspection)

Taxonomy of Issues

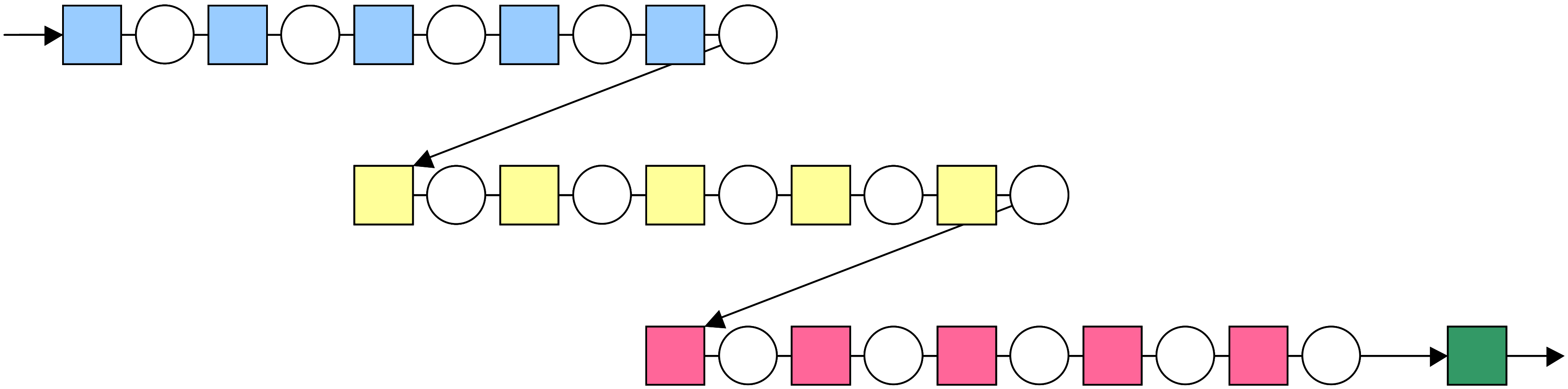
Actions on parts and machines

- Actions on parts: accept, rework, or scrap.

- Actions on machines: leave alone or repair.

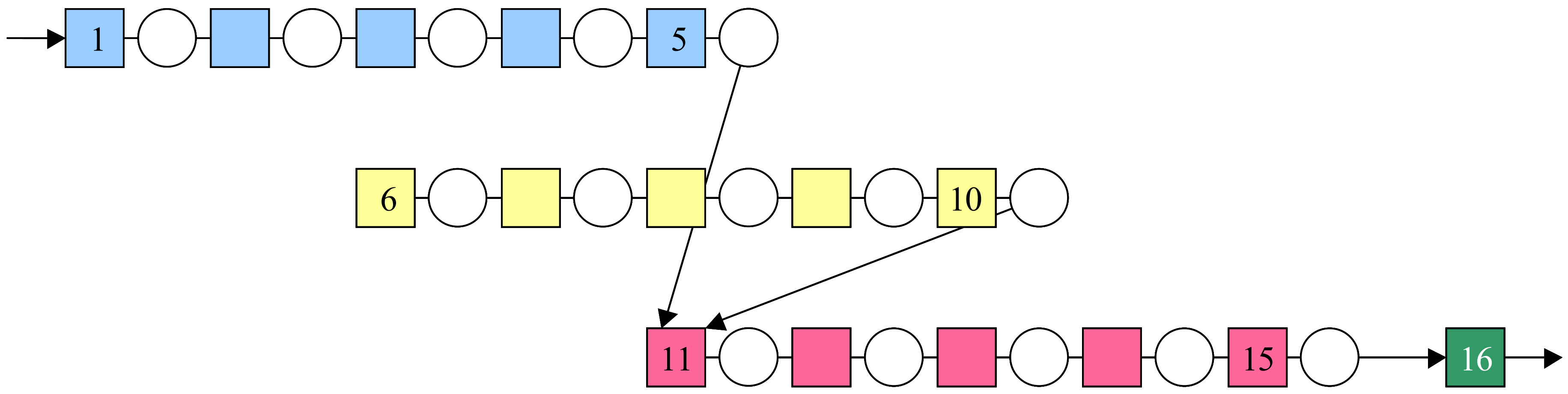
Taxonomy of Issues

Topology of system



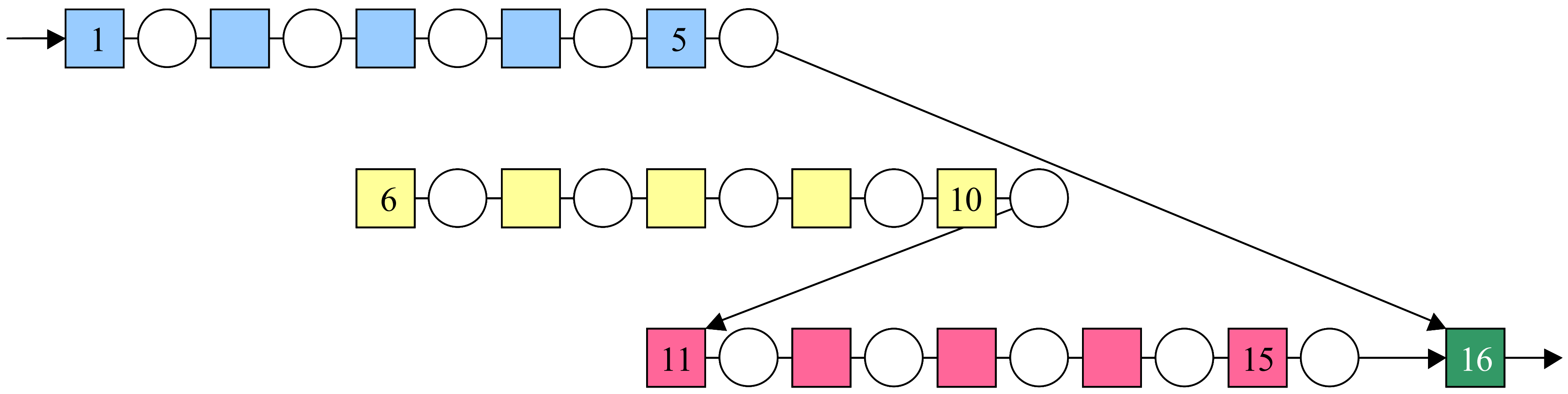
Taxonomy of Issues

Topology of system



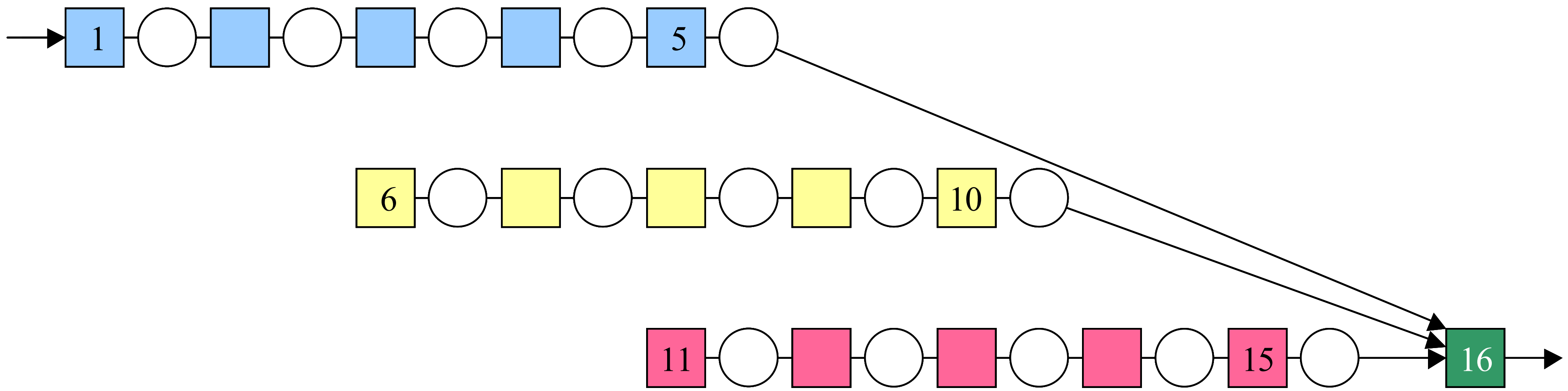
Taxonomy of Issues

Topology of system



Taxonomy of Issues

Topology of system



Performance Measures

- Expected total production rate
- Expected good production rate
- Yield
- Expected inventory.
- Miss and waste
- Production lead time

They are easy to calculate in a single-machine model.

One- and Two-Machine Systems

Note:

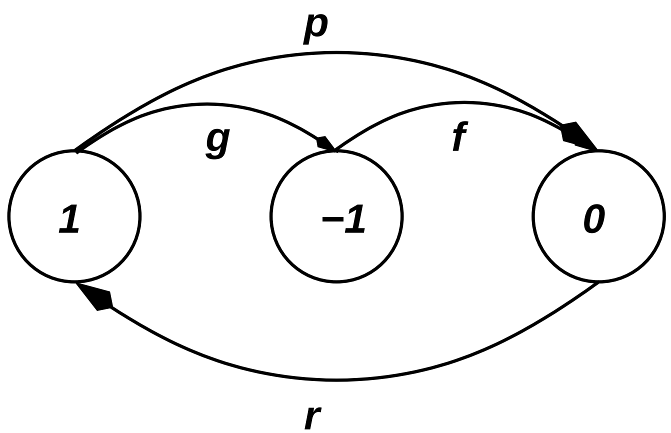
All the material up to Slide 43 is taken from

Kim and Gershwin, "Integrated Quality and Quantity Modeling of a Production Line," *OR Spectrum*, Volume 27, Numbers 2-3, pp. 287–314, June, 2005.

and

Jongyoon Kim, "Integrated Quality and Quantity Modeling of a Production Line," Ph. D thesis, MIT Mechanical Engineering, November, 2004.

Single Machine



$$(g+p)P(1) = rP(0)$$

$$fP(-1) = gP(1)$$

$$rP(0) = pP(1) + fP(-1)$$

$$P(0) + P(1) + P(-1) = 1$$

$$P(1) = \frac{1}{1 + (p+g)/r + g/f}$$

$$P(0) = \frac{(p+g)/r}{1 + (p+g)/r + g/f}$$

$$P(-1) = \frac{g/f}{1 + (p+g)/r + g/f}$$

The *total production rate*, including good and bad parts, is

$$P_T = \mu(P(1) + P(-1)) = \mu \frac{1 + g/f}{1 + (p + g)/r + g/f}$$

The *effective production rate*, the production rate of good parts only, is

$$P_E = \mu P(1) = \mu \frac{1}{1 + (p + g)/r + g/f}$$

(This quantity is also called the *good production rate.*) Since there is no scrapping, the rate at which parts enter the system is equal to the rate at which parts leave the system, so that the *yield* is

$$Y = \frac{P_E}{P_T} = \frac{P(1)}{P(1) + P(-1)} = \frac{f}{f + g}$$

Two-Machine, Infinite-Buffer Line:

$$P_T^\infty = \min\left[\frac{\mu_1(1+g_1/f_1)}{1+(p_1+g_1)/r_1+g_1/f_1}, \frac{\mu_2(1+g_2/f_2)}{1+(p_2+g_2)/r_2+g_2/f_2}\right]$$

$$P_E^\infty = \frac{f_1 f_2}{(f_1+g_1)(f_2+g_2)} P_T^\infty$$

One- and Two-Machine Systems

Lines with Zero Buffers

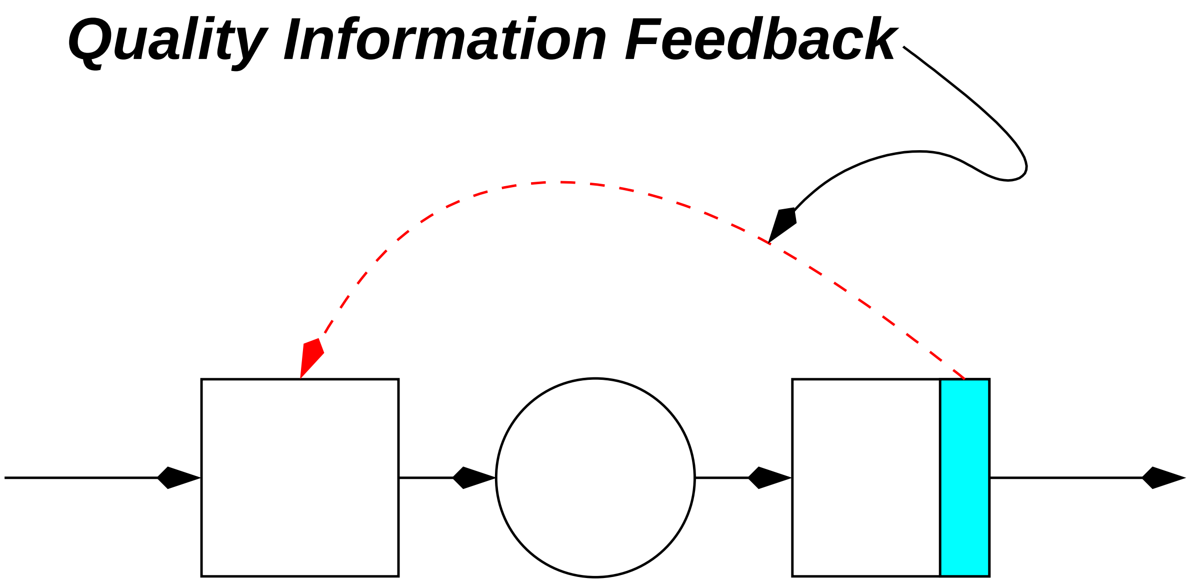
Two-Machine, Zero-Buffer Line:

$$P_T^0 = \frac{\min[\mu_1, \mu_2]}{1 + \dfrac{f_1^b(p_1^b + g_1^b)}{r_1(f_1^b + g_1^b)} + \dfrac{f_2^b(p_2^b + g_2^b)}{r_2(f_2^b + g_2^b)}}$$

$$P_E^0 = \frac{f_1^b f_2^b}{(f_1^b + g_1^b)(f_2^b + g_2^b)} P_T^0$$

Two-Machine-One-Buffer Lines

- Continuous material
- Three-state machine
- *Quality information feedback*
  - ⋆ Defects produced by the first machine are detected, after a delay, by the second machine.
  - ⋆ The length of the delay depends on the number of parts in the buffer.
- As buffer size increases, total production rate increases and yield decreases. But good production rate behavior is harder to predict.


Quality Information Feedback

The two-machine, one-buffer line with known parameters can be solved using standard methods.

All parameters of the two-machine, one-buffer line are known except h_{12}, the transition rate from the bad quality state of M_1 to the down state due to the inspection at M_2. This depends on the number of parts in the buffer $\bar{x}$.

Procedure:

- Guess $\bar{x}$.
- Calculate h_{12}.
- Solve the two-machine line. Recalculate $\bar{x}$ and iterate.

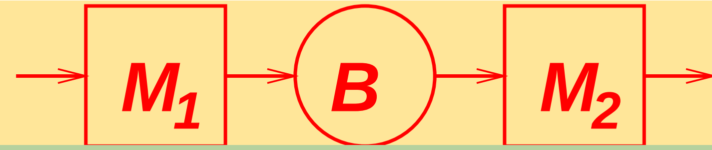
Intuition

- 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.

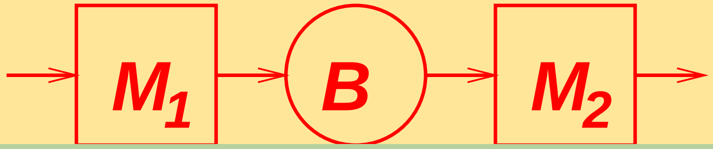
One- and Two-Machine Systems



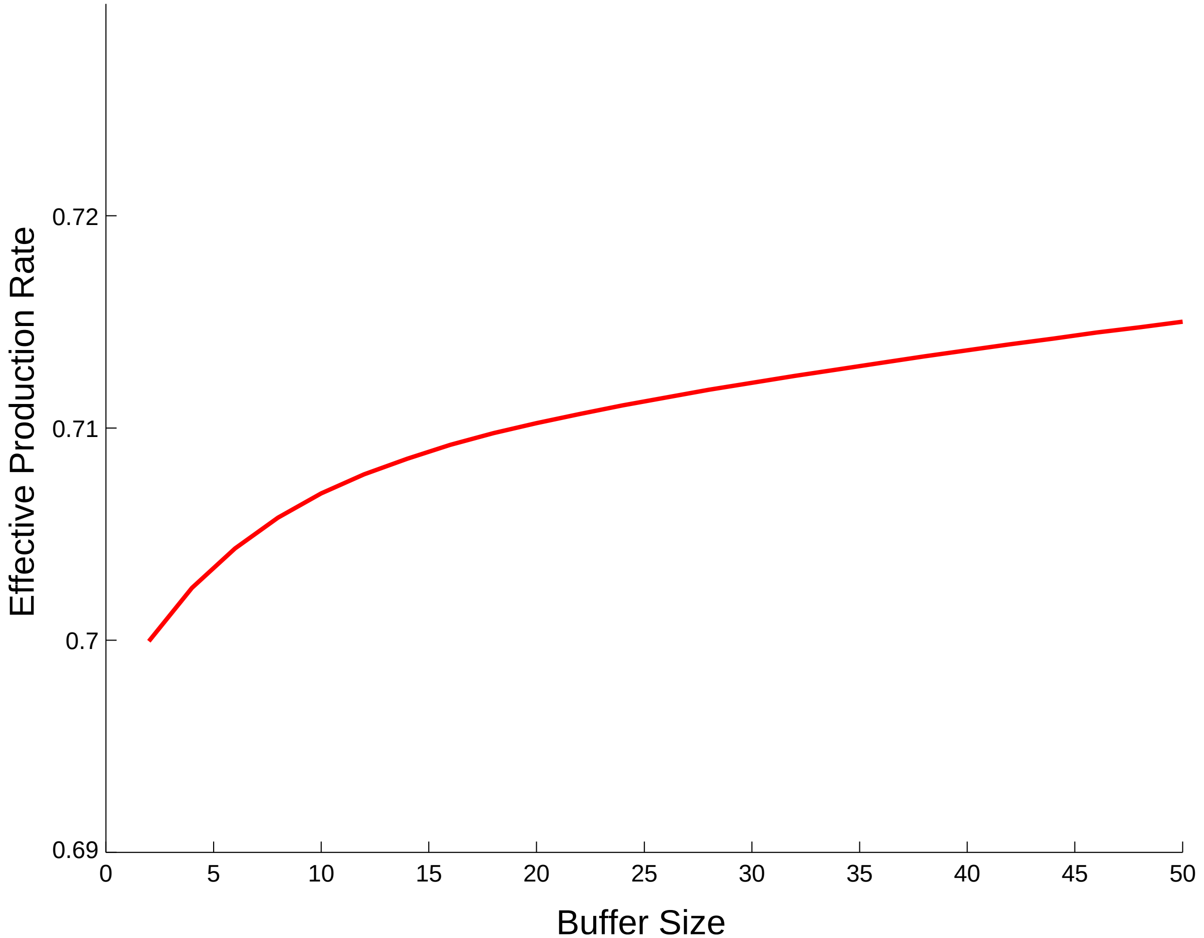
Assumptions

- M_1 has variable quality; the inspection occurs at M_2.
- M_1 makes only good parts in the G state and only bad parts in the B state.
- Stoppages occur at both machines at random times for random durations.
- The buffer is operated according to FIFO.
- Detection of the M_1 state change cannot take place until a bad part reaches M_2.

One- and Two-Machine Systems

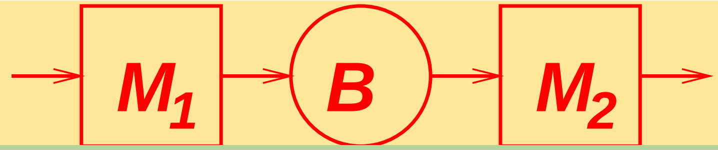


Beneficial Buffer

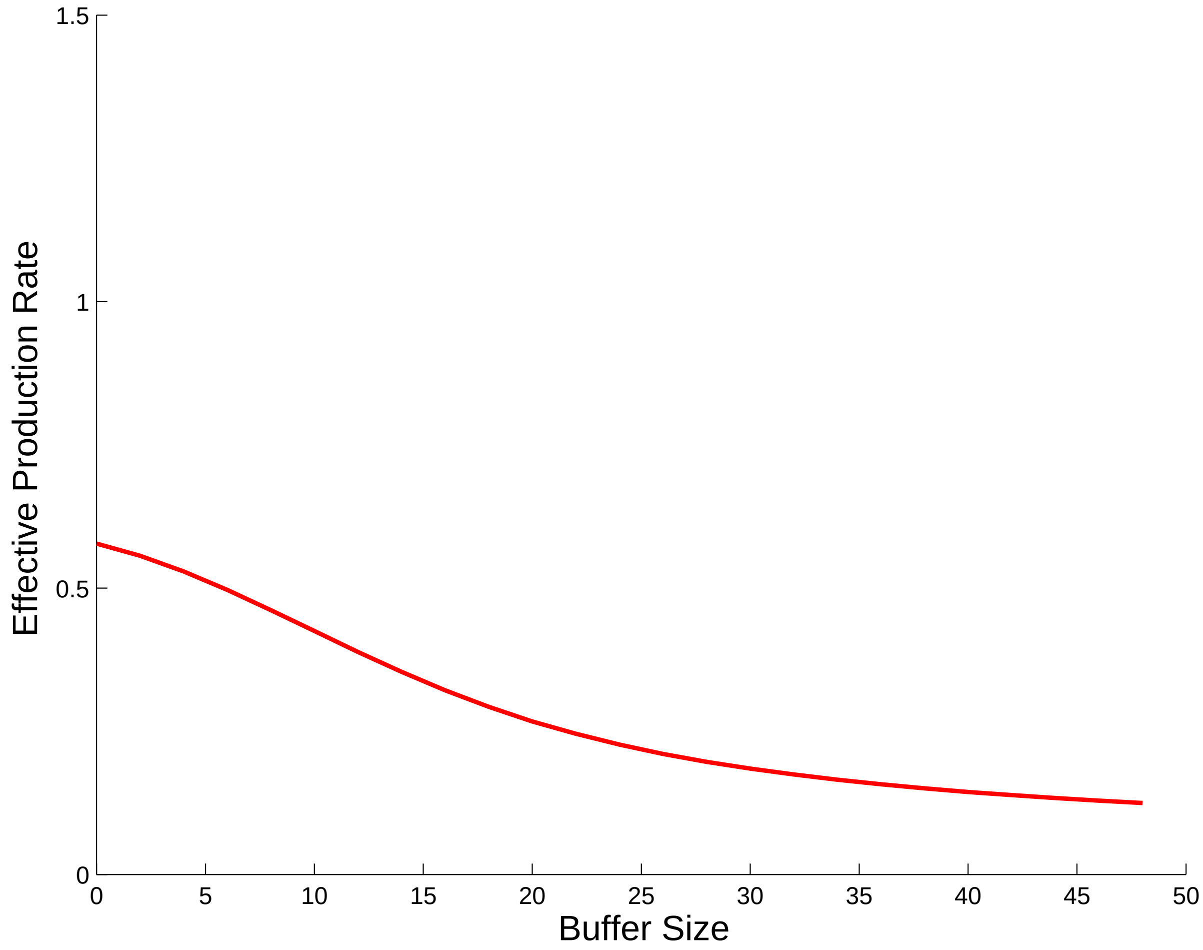


Effective production rate = production rate of good parts.

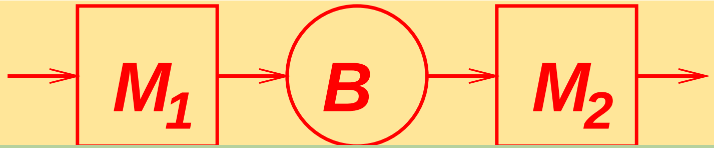
One- and Two-Machine Systems



Harmful Buffer

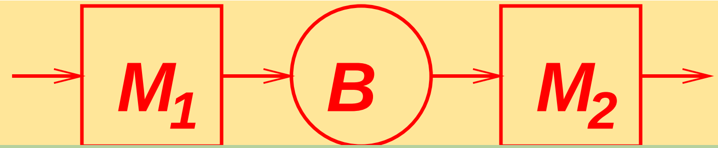


One- and Two-Machine Systems



Intuition

- When the inspection detects the first bad part after a good part, the buffer contains *only* bad parts.
- In the harmful buffer case, the first machine has a higher isolated total production rate than the second. Therefore, the buffer is usually close to full, *no matter how large the buffer is*.
- Increasing the size of the buffer increases the number of bad parts in the system when the M_1 state change is detected.
- It also increases the total production rate, but not as much as it increases the production rate of bad parts.



Intuition

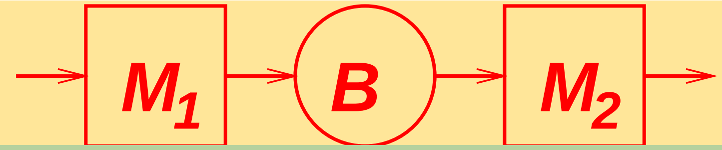
- In the beneficial buffer case, the first machine has a smaller isolated production rate than the second.

- Therefore, even if the buffer size increases, the number of parts in the system is almost always small.

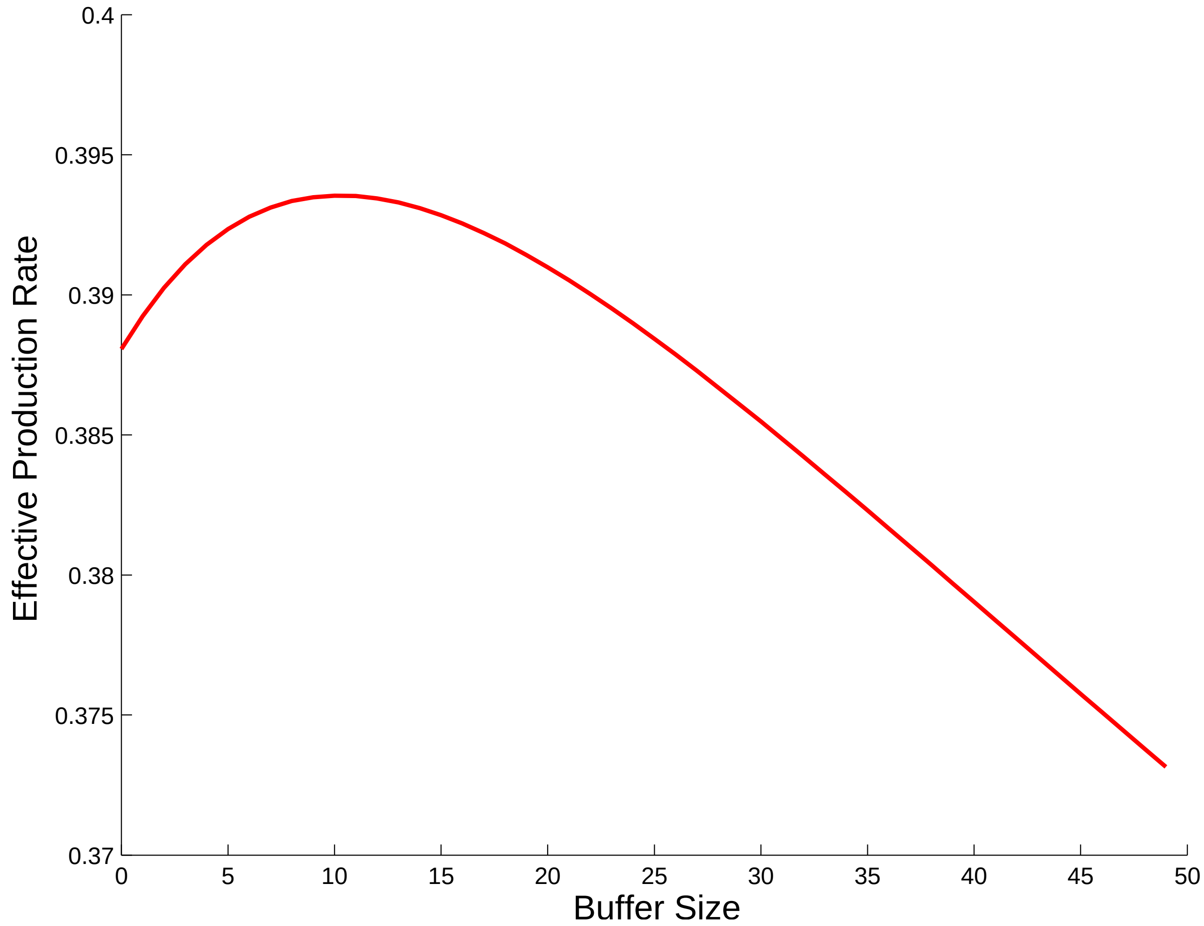
- Therefore it is rare for there to be many bad parts in the buffer when the first bad part is inspected.

- Consequently, the production rate of bad parts remains limited even as the buffer size increases.

One- and Two-Machine Systems



Mixed-Benefit Buffer



Long Lines with Finite Buffers

Simulation

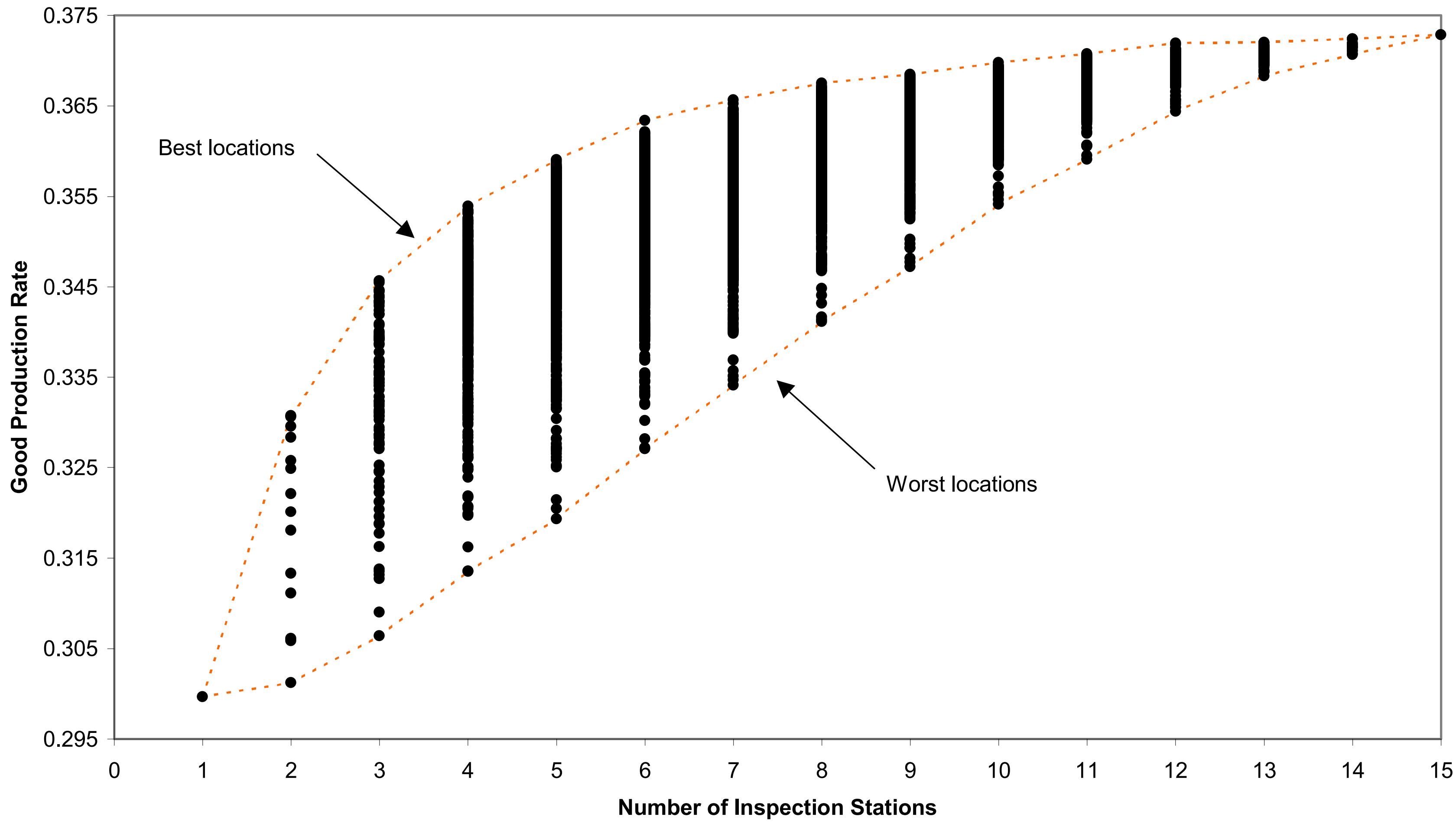
- Intuition: more inspection improves quality.
- Reality: increasing inspection can actually reduce quality, if it is not done intelligently.

Long Lines with Finite Buffers

- 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, 8, and 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.

Long Lines with Finite Buffers

Simulation



Observations

A few inspection stations deployed well can do as well or better than many stations deployed poorly.

- The best distribution of *3* stations has a higher effective production rate than the worst distribution of *7* stations.

- The best distribution of *8* stations performs almost as well as *15* inspection stations.

Long Lines with Finite Buffers

Decomposition

Three structures analyzed

Details are in

Jongyoon Kim, “Integrated Quality and Quantity Modeling of a Production Line,” Ph. D thesis, MIT Mechanical Engineering, November, 2004.

and

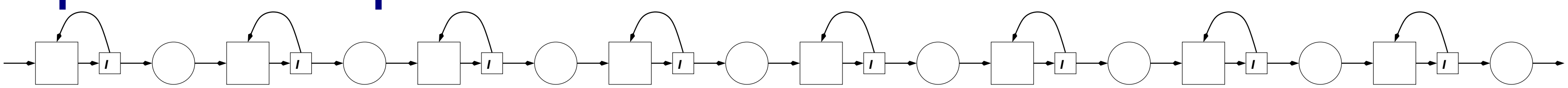
Kim and Gershwin, “ Modeling and analysis of long flow lines with quality and operational failures,” *IIE Transactions*, to appear.

Long Lines with Finite Buffers

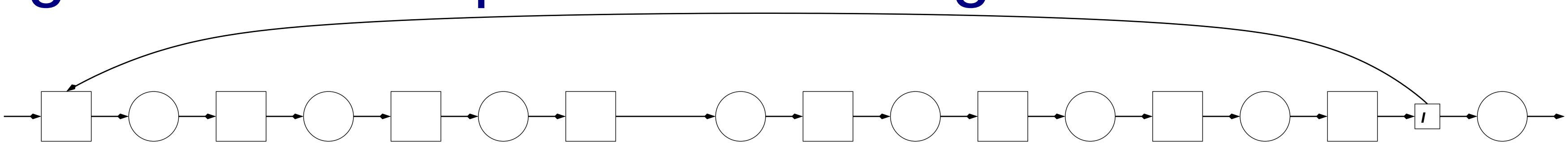
Decomposition

Three structures analyzed

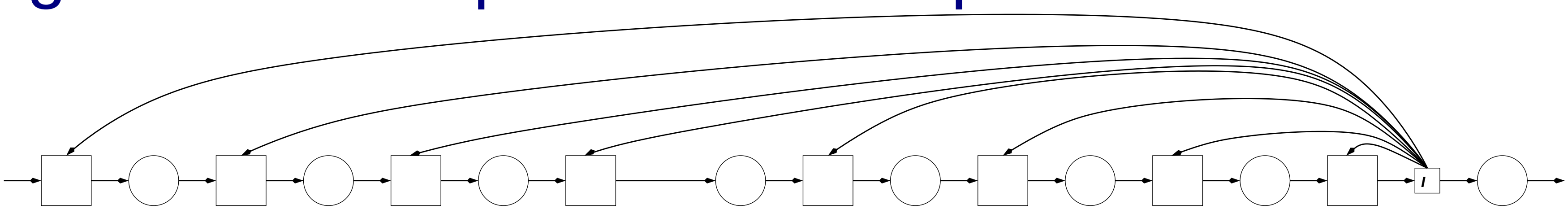
Ubiquitous inspection:



Single remote inspection of a single machine:



Single remote inspection of multiple machines:



- Procedure:
  - ⋆ Guess $\bar{x}_i$.
  - ⋆ Calculate required h_{ij} parameters.
  - ⋆ Transform the 3-state machines into approximate 2-state machines.
  - ⋆ Solve the resulting line by a standard decomposition technique.
  - ⋆ Recalculate $\bar{x}_i$ and iterate.
- Comparison with simulation is reasonable.

Long Lines with Finite Buffers

Decomposition

The system yield is the product of individual machine yields *using the final* h_{ij} *values* .

The effective production rate is the total production rate times the system yield.

Conclusions

- *Yield* is a system attribute. It is not a simple function of machine yields. It depends on the operation policy, the buffer sizes, etc.

- The Q/Q area is important but has not been studied systematically with engineering rigor as much as other areas have. Much work remains to be done.

- Factory designers and operators must use intuition and simulation.

2.852 Manufacturing Systems Analysis
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