MIT 2.853/2.854
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.

Introduction

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

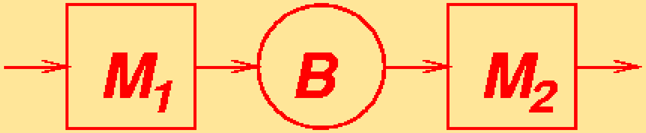
- *Quantity strategies* include optimizing local inventories, optimizing global inventory, other release/dispatch policies, make-to-order, etc.

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

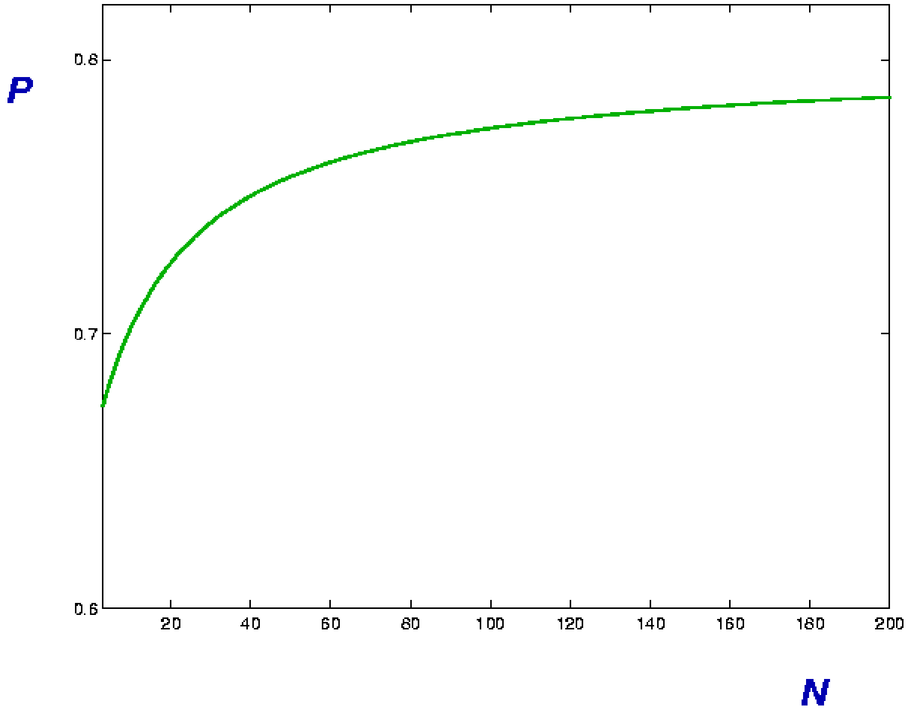
The problem is that, conventionally, ...

- 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

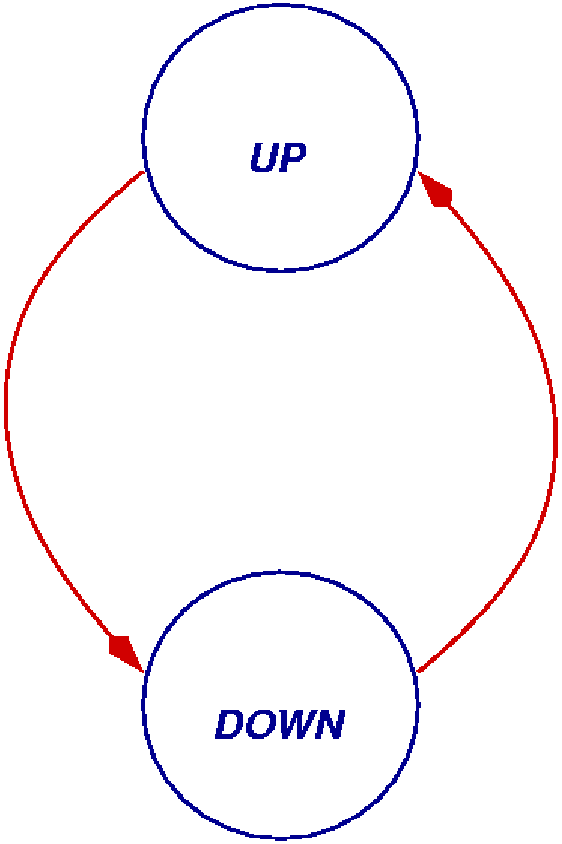


- Two-machine, one-buffer production line.
- All production is perfect quality.
- The machines are unreliable — they fail at random times and are repaired at random times.
- We vary the buffer size N and observe its effect on the production rate P.
- *Observation:* the production rate increases monotonically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



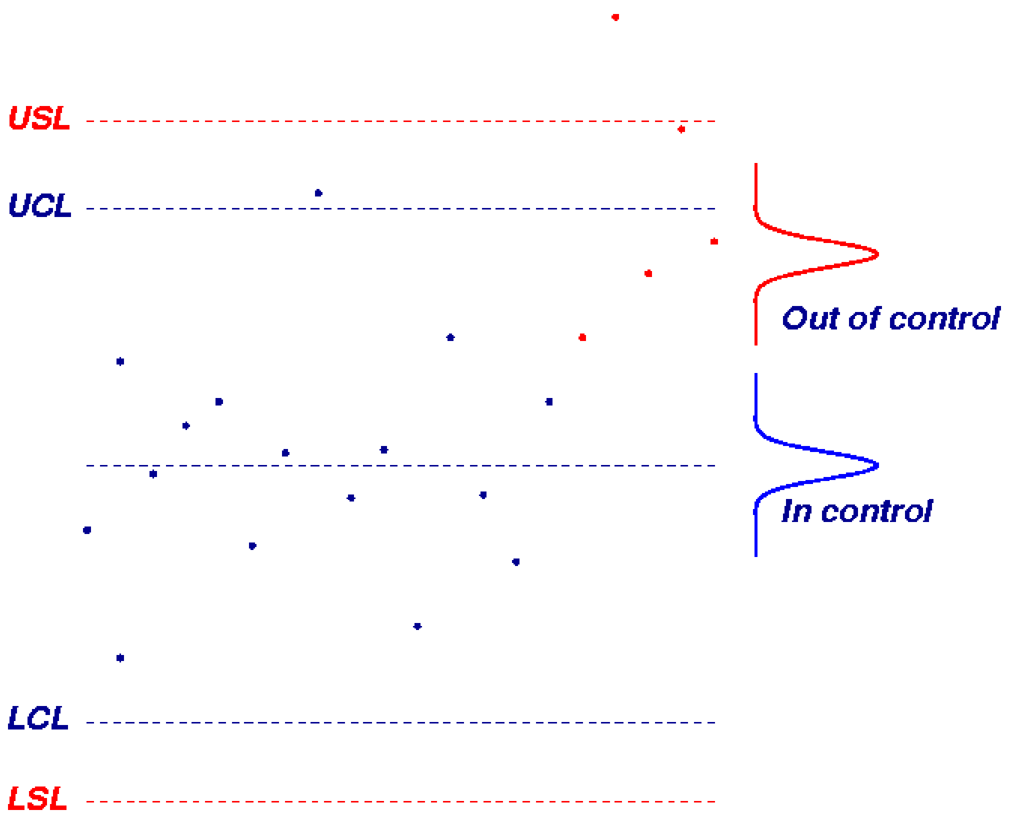
Machine Reliability Dynamics

Simplest model



Statistical Process Control

- Goal is to determine when a process has gone *out of control* .
- 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?



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.

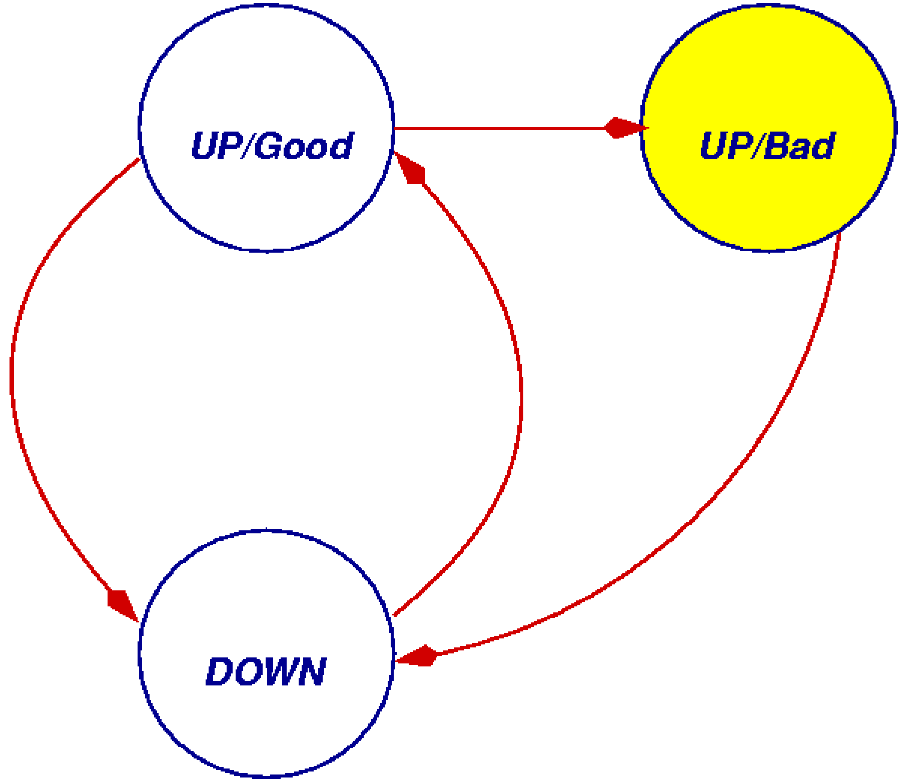
    GGGGGBGGGBGGGGGGGBGGBGGGGBBGGGGGGGG. . . . .
  - ⋆ Special cause: something happens to the machine, and failures become much more likely.

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

Quality Dynamics

Machine Quality Dynamics

Simplest model



Versions:

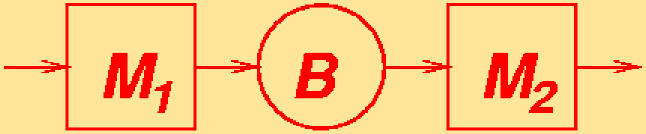
- The *Good* state has 100% yield and the *Bad* state has 0% yield.
- The *Good* state has high yield and the *Bad* state has low yield.

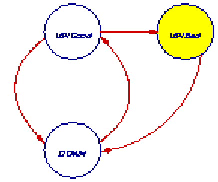
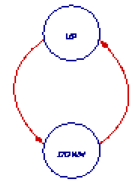
Separation of Operation and Inspection

Opinions

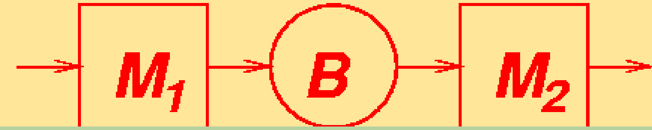
- Quantity-oriented people tend to assume that increasing a buffer *increases* the production rate.
- Quality-oriented people tend to assume that increasing a buffer *decreases* the production rate of good items.
- However, we have found that the picture is not so simple.

Separation of Operation and Inspection

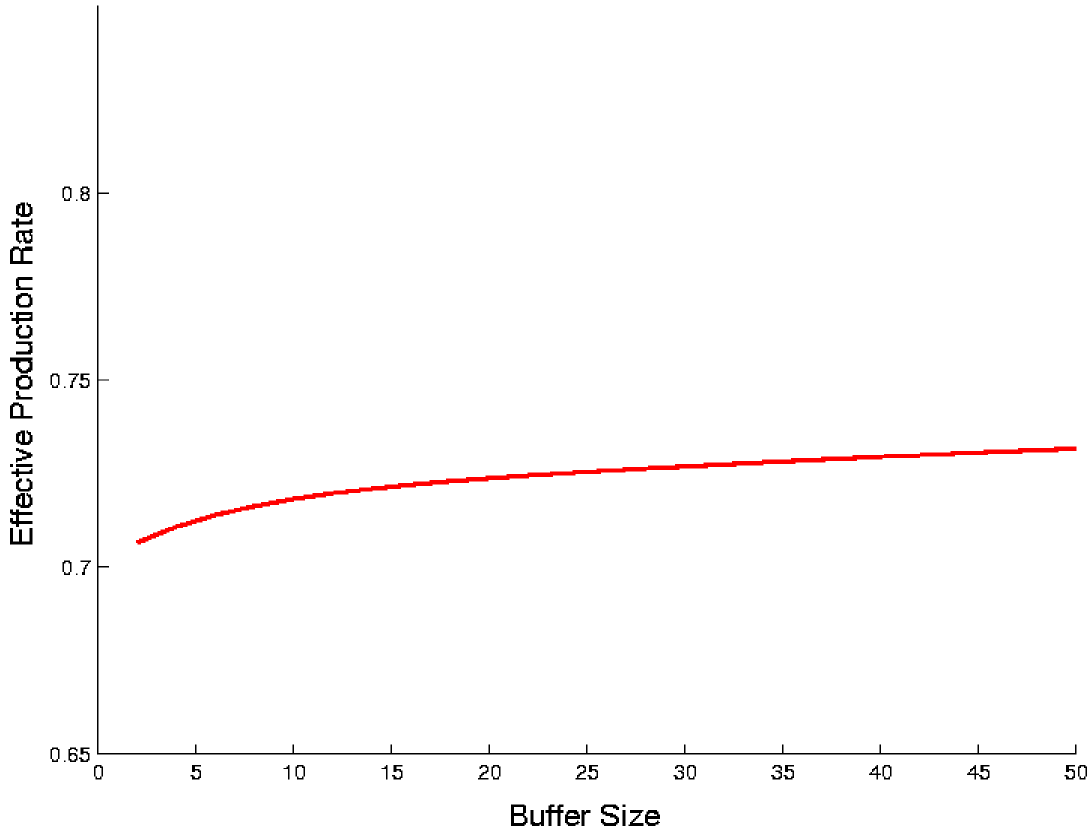


- Two-machine lines.
- The first machine sometimes does bad operations. 
- The second machine does inspection. 
- We look at three cases — ie, three sets of machines.
- We vary N and plot *effective production rate* — the production rate of good parts.

Separation of Operation and Inspection

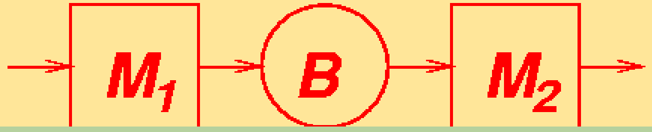


Beneficial Buffer

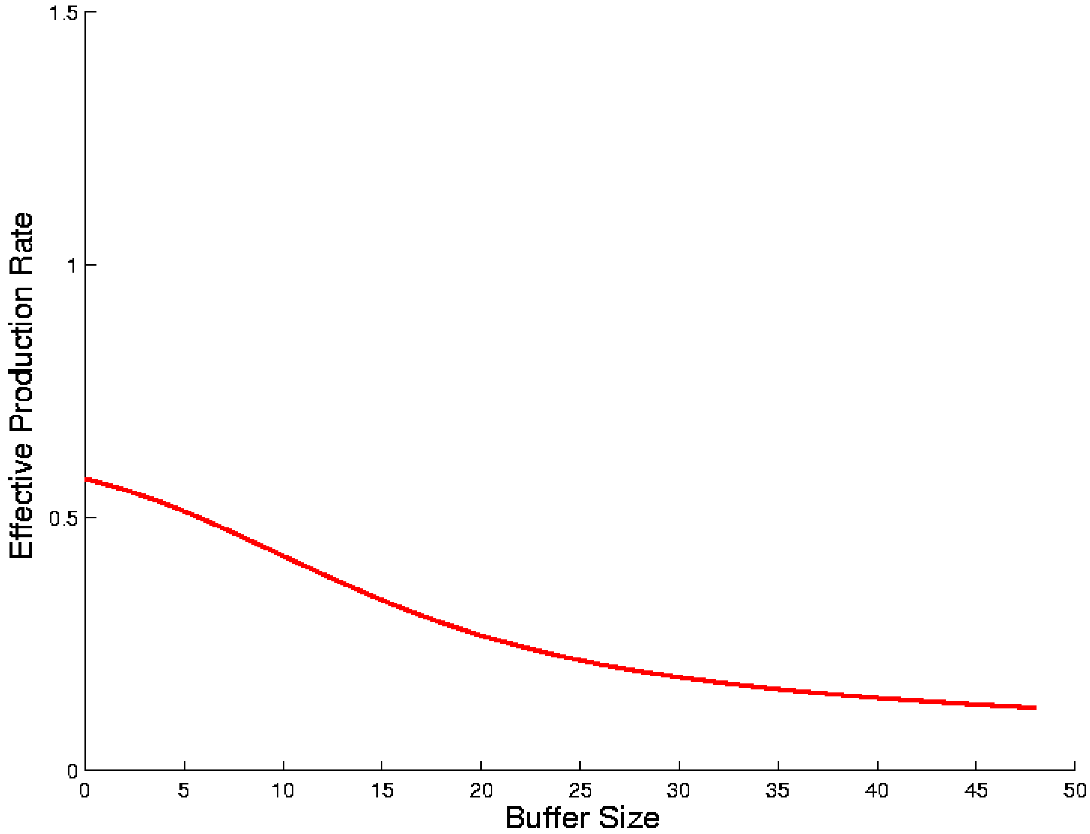


Effective production rate = production rate of good parts.

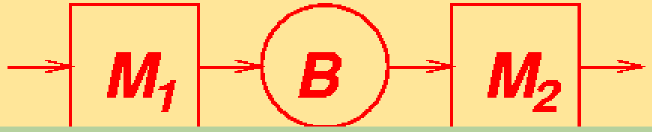
Separation of Operation and Inspection



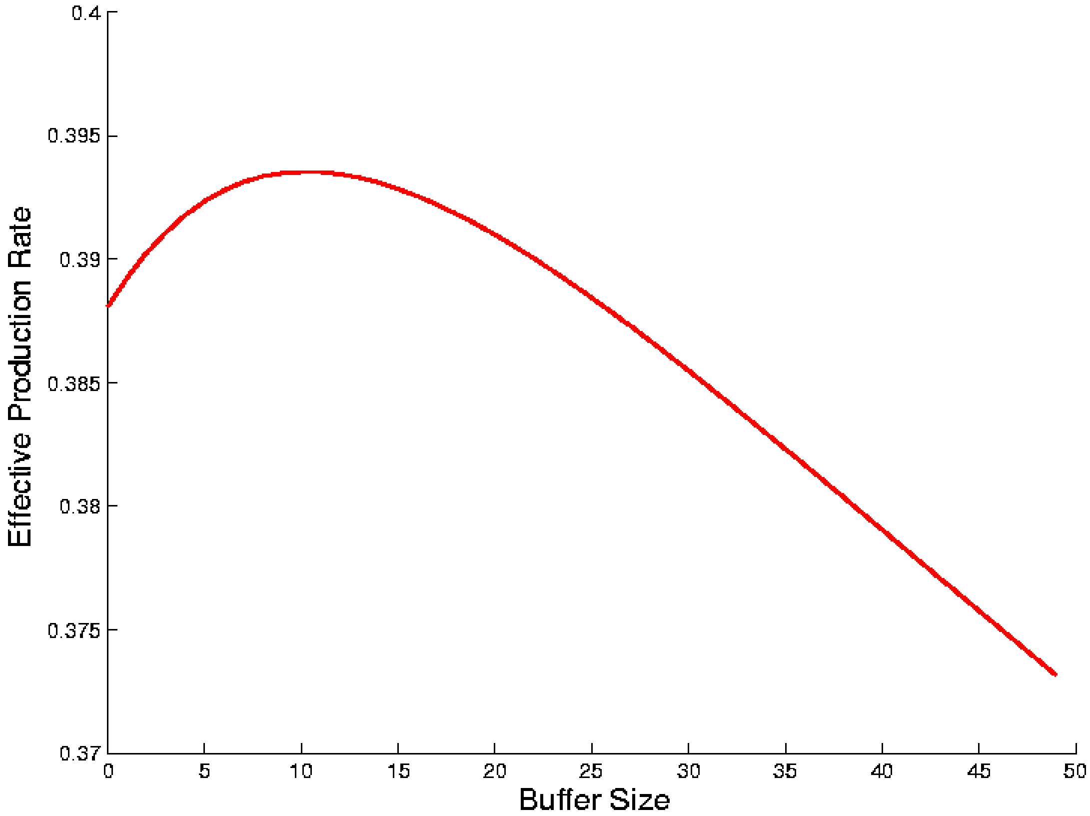
Harmful Buffer



Separation of Operation and Inspection



Mixed-Benefit Buffer



Inspections

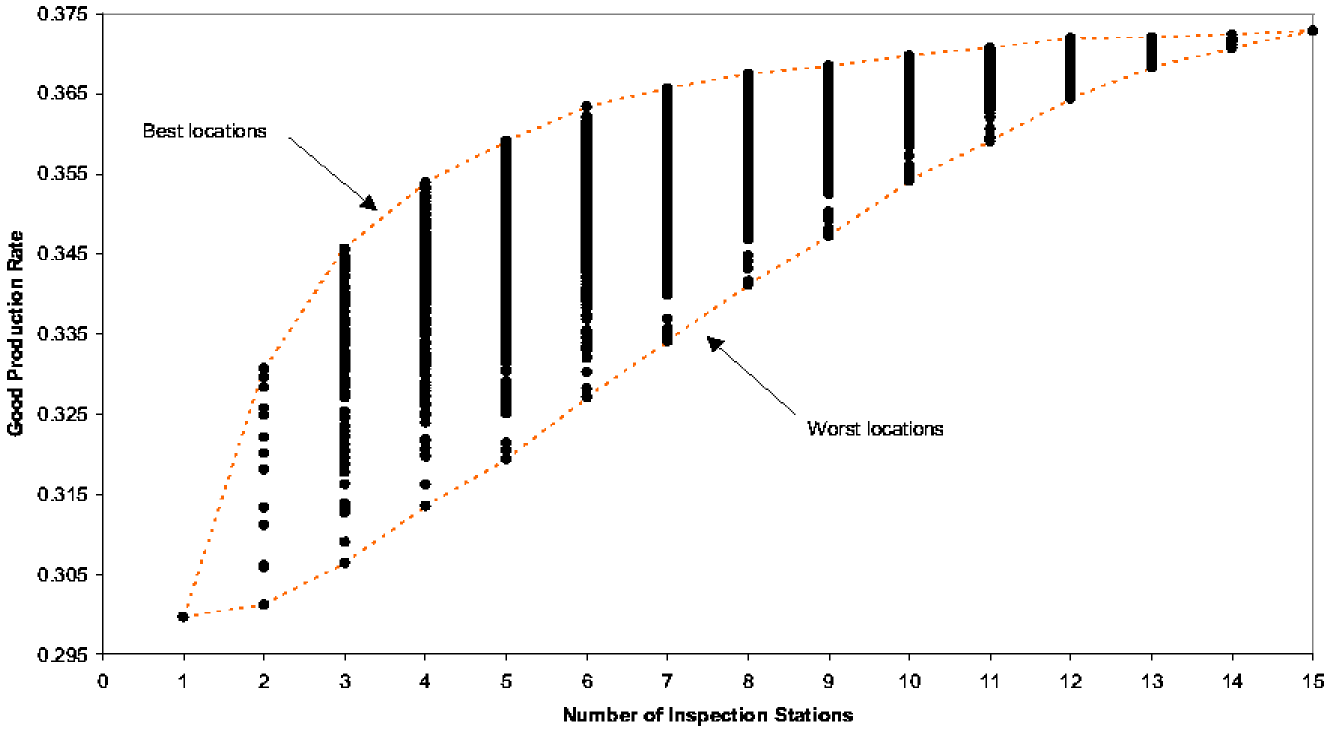
How many inspections should there be? And where?

- 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



Observations

- 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

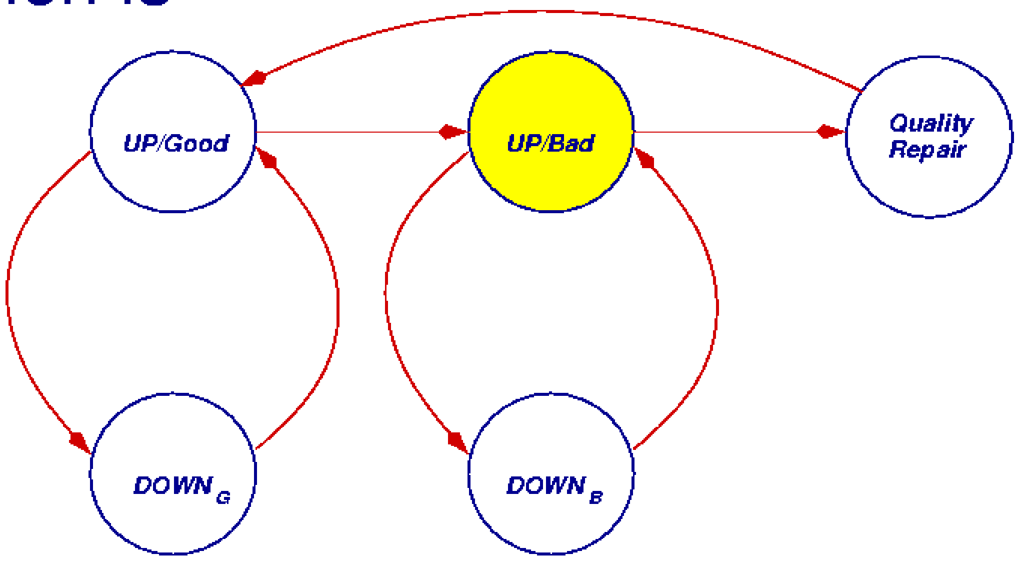
Inspection Strategy

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

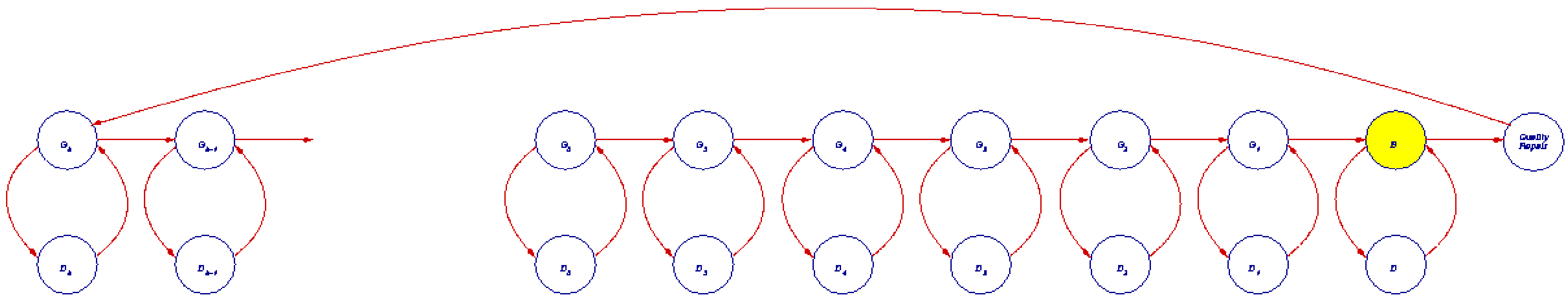
- The three-state machine model is much too simple.
- One extension is



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

Future Work

- Another extension is

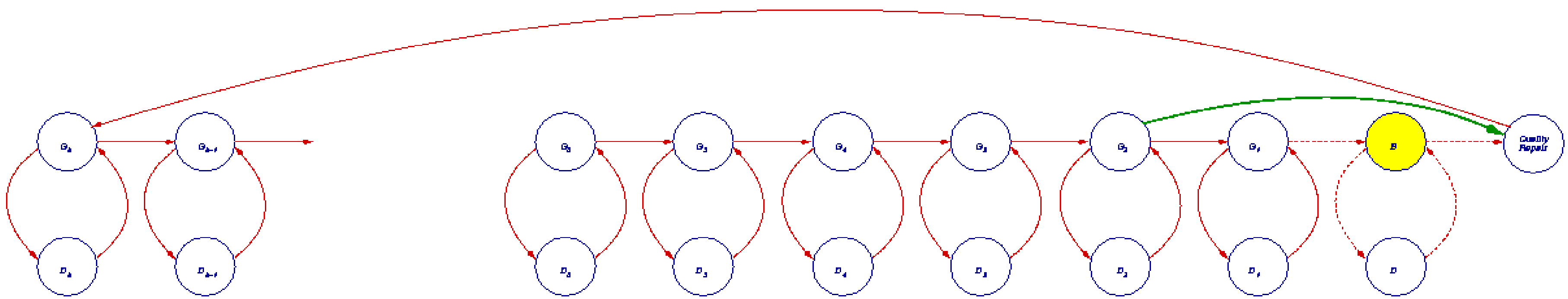


- This allows more general wear or aging models.

Future Work

Machine quality dynamics

- A maintenance strategy could be modeled as



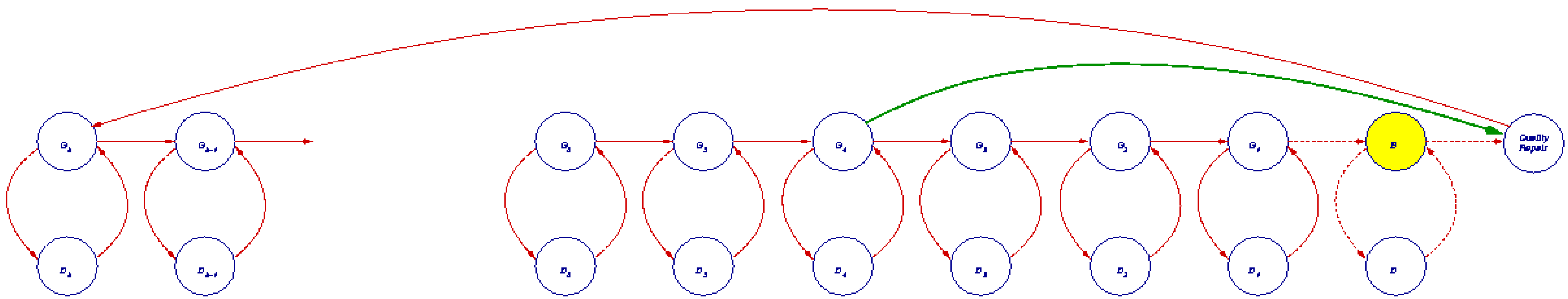
if we have perfect knowledge of the machine state.

Future Work

Machine quality dynamics

Bayesian statistics

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



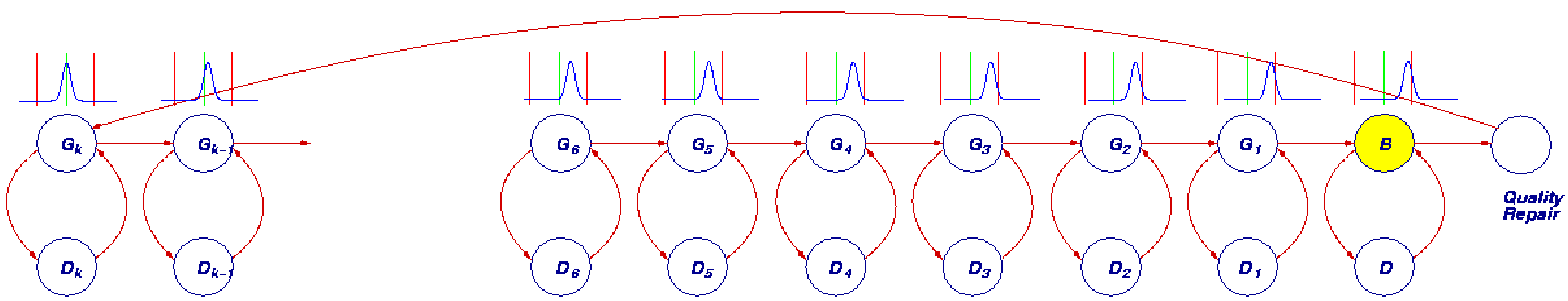
- Here, the machine quality state might be estimated according to the time since the last maintenance, *and/or* according to measurement data.

Future Work

Machine quality dynamics

Bayesian statistics

- Model with a parameter (eg, 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.*