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Introduction to Manufacturing Systems

Toyota Production System

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Toyota Production System
Historic context

- Developed by Toyota after World War II:
  - ⋆ In the postwar period, the West (especially the U.S.) was relatively prosperous. It was important to U.S. manufacturers to satisfy high post-war demand.
  - ⋆ Japan was poor. Cost minimization and efficiency were most important to Japanese manufacturers.
  - ⋆ TPS is low tech, not dependent on computers (when they became available in the 1960s). All required actions had to be easily understood and executed.
- TPS has been highly influential and widely imitated.

Toyota Production System

Framework and Goals

- Profit through cost reduction
- Elimination of waste:
    - ⋆ Excessive production resources
    - ⋆ Overproduction
    - ⋆ Excessive inventory
    - ⋆ Unnecessary capital investment

Toyota Production System
Framework and Goals

- Quantity control
- Quality assurance
- Respect for people

Toyota Production System
Framework and Goals

- Just in time
- "Autonomation" — *jidoka*
- Flexible workforce — *stotinka*
- Creative thinking — *seiko*

Toyota Production System
Just in time

- In the assembly of car subsystems and in the final assembly of a car, the parts and subassemblies arrive just when they are needed.
- Inventories are therefore not needed.
- Cannot be achieved by central planning.
- People at each process withdraw from the previous process only what they need.
- People at each process produce what is necessary to replenish what has been taken by the next process.

Toyota Production System
Systems and methods

- Kanban
- Production smoothing
- Reduction of setup time
- Standardization of operations to attain line synchronization
- Machine layout
- Visual control
- *... and many more*

Toyota Production System

"DNA"

Spear and Bowen: *"We found that, for outsiders, the key is to understand that the Toyota Production System creates a community of scientists."*

The Four Rules:

1. All work shall be highly specified as to content, sequence, timing, and outcome.

2. Every customer supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.

Toyota Production System

"DNA"

3. The pathway for every product and service must be simple and direct.

4. Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

Toyota Production System
"DNA"

Toyota's notion of the ideal: A common vision

The output of an *ideal* person, group of people, or machine:

- is defect free (features, performance the customer expects);
- can be delivered one request at a time (a batch size of one);
- can be supplied on demand in the version requested;
- can be delivered immediately;
- can be produced without wasting any materials, labor, energy, or other resources (such as costs associated with inventory);
- can be produced in a work environment that is safe physically, emotionally, and professionally for every employee.

Kanban

- Kanban is *not* TPS. Kanban is a *subsystem* of TPS.
- Kanban is an information system for controlling production quantity and timing.
- Kanban: a card in rectangular vinyl envelope.
  - ⋆ Withdrawal kanban: describes quantity that subsequent process must withdraw.
  - ⋆ Production-ordering kanban: describes quantity that preceding process must produce.
- Kanbans circulate within factories...
  - ⋆ as low level shop floor control

... and between factories.

Kanban
Non-kanban systems

- In other production control systems, schedules are issued to all processes *(push)*.
- Push systems cannot easily adapt to demand fluctuations, disruptions, etc.
- This leads to excessive inventory.

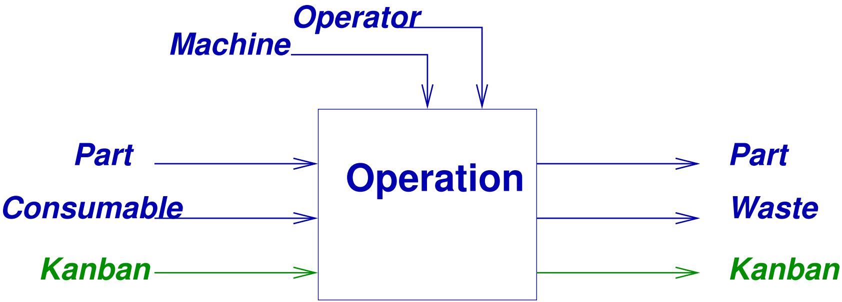
Kanban
Pull

- Kanban is a *pull* system.
- When demand changes occur, it is enough to notify final assembly.
- All preceding stages learn about schedule changes through the kanban system.
- It is not necessary to issue updated detailed schedules to each stage.

Kanban
Pull

- Kanbans coordinate production without disruption propagation caused by scheduling changes.
- Kanbans allow systems to operate based on local real-time information.
- The number of kanbans at each stage determines the maximum inventory at that stage.

Kanban
Pull

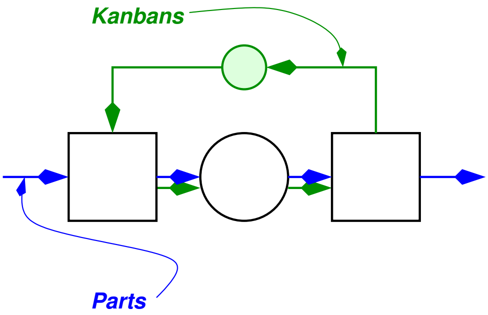


Nothing happens until <u>everything</u> is present.

Kanban
Pull

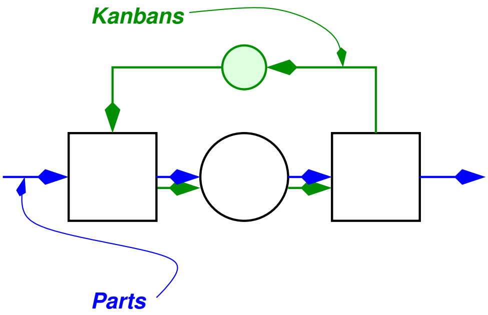
- In the following discussion of kanban systems, each square can represent an individual machine, a multi-machine work cell, or a sub-process, consisting of several cells.
    - ⋆ It could be an entire factory.
- Flow into and out of a square need not be the same as that of any other square at the same time.
- The movement of kanbans can be more complex than described here.

Kanban
Single-Card Kanban



- The upstream machine does an operation when its previous operation or downtime is completed, there is a kanban in the kanban buffer, and a part is available.
- After the operation, the kanban is attached to the part and they move to the WIP buffer together.
- The upstream cycle repeats.

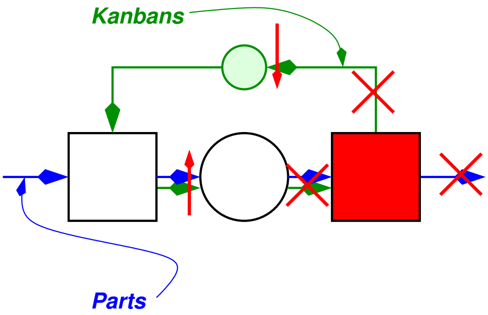
Kanban
Single-Card Kanban



- When the previous operation or downtime of the downstream machine is completed and it is not blocked, the downstream machine takes a part from the WIP buffer.
- It removes the kanban and puts it into the kanban buffer.
- It does the operation on the part and the part is sent to its next production step.
- The downstream cycle repeats.

Kanban

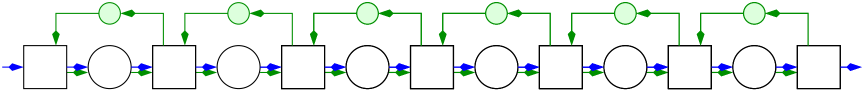
Single-Card Kanban



- If the downstream machine goes down, it does not take any parts from the WIP buffer and it does not add any kanbans to the kanban buffer.
- If the first machine remains operational, it can continue to work. It removes cards from the kanban buffer and adds parts (with kanbans attached) to the WIP buffer.
- The upstream machine can keep operating until there are no more kanbans in the kanban buffer.

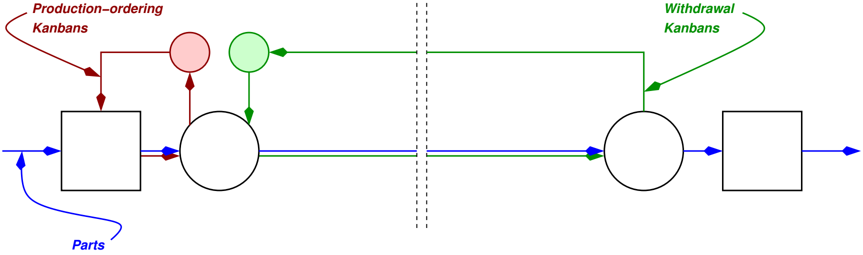
Kanban

Single-Card Kanban



- If the last machine stops for a long enough time, it can prevent the next to last from working.
- If the stoppage lasts long enough, the machine upstream of that can be prevented from working.
- Et cetera.

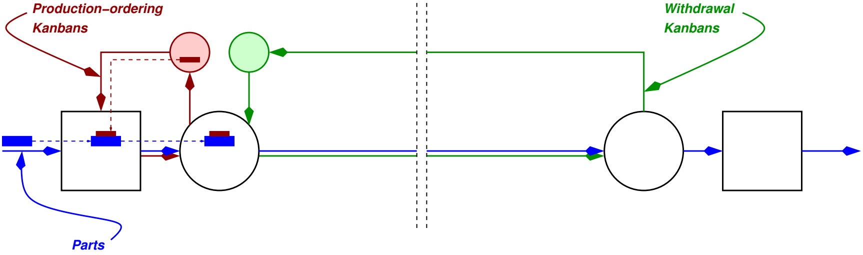
Kanban
Two-Card Kanban



- In a two-card kanban system, there are *production-ordering* kanbans and *withdrawal* kanbans.
- It is often used when there is a long distance between operations or work cells...
- ... or when parts are delivered to the machines in different-sized batches.

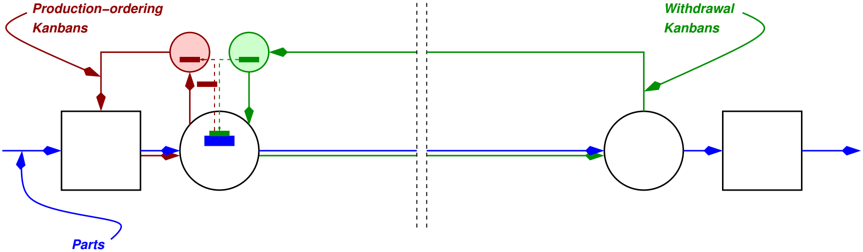
Kanban

Two-Card Kanban



- The upstream machine does an operation when its previous operation or downtime is completed, there is a production-ordering kanban in the production-ordering kanban buffer, and a part is available.
- After the operation, the kanban is attached to the part and they move to the output WIP buffer of the upstream machine together.
- The upstream cycle repeats.

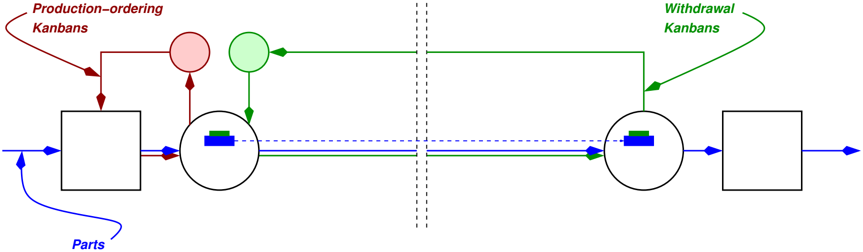
Kanban
Two-Card Kanban



- If the withdrawal kanban buffer is not empty, the production-ordering kanban is removed from a part in the output WIP buffer of the upstream machine and moved to the production-ordering kanban buffer.
- A withdrawal kanban is attached to that part.
- The part is made ready for transportation. Transportation occurs according to some specific protocol: there may be a transportation batch size or there may be a transportation schedule.

Kanban

Two-Card Kanban



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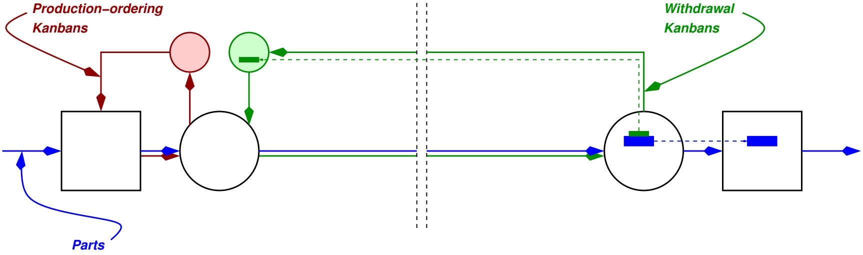
Kanban

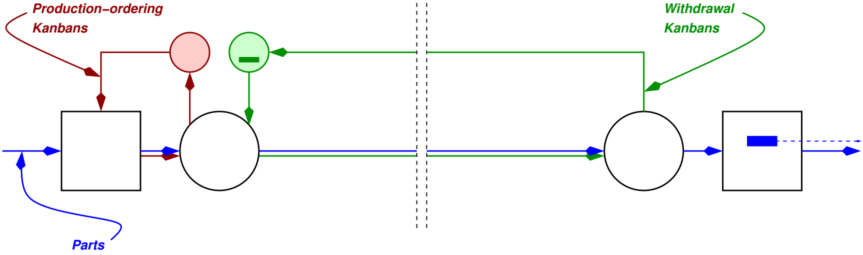
Two-Card Kanban



- When the previous operation or downtime of the downstream machine is completed and it is not blocked, the downstream machine takes a part from its input WIP buffer.
- The withdrawal kanban is removed from the part. The withdrawal kanbans are transported to the withdrawal kanban buffer according to a transportation protocol.

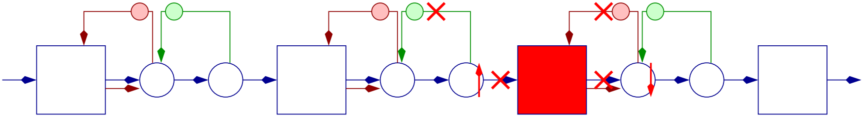
Kanban

Two-Card Kanban



- The downstream machine does an operation on the part and the part is sent to its next step.
- The downstream cycle repeats.

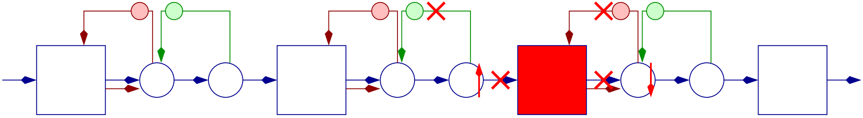
Kanban
Two-Card Kanban



- Effects of a machine failure.
- Withdrawal kanbans are not added to the upstream withdrawal kanban buffer. The ones already there are removed from the buffer and attached to parts as the upstream machine does operations.
- A part in the output WIP buffer of the upstream machine gains a withdrawal kanban and is transported to the input buffer of the failed machine.
- This continues until the upstream withdrawal kanban buffer is empty.

Kanban

Two-Card Kanban



- No parts are added to the output buffer of the failed machine.
- The parts that remain in the output buffer of the failed machine have their production-ordering kanbans replaced by withdrawal kanbans and the parts are moved to the input WIP buffer of the downstream machine.
- This continues until the output buffer of the failed machine is empty.

Kanban
Other kanbans

- *Supplier kanban:* same as withdrawal, except for external supplier
- *Signal kanban:* same as production kanban, but sent to production station when inventory goes down to a reorder point.
- *Material requisition kanban:* same as production kanban, but sent to a material storage area when local inventory goes down to a reorder point.
- ... and more.

Kanban

Rules

1. Each process withdraws the *necessary* products from the previous in *necessary* quantities at the *necessary* time.

   - ⋆ To enforce this, workers must first be won over.
   - ⋆ Kanbans must be attached to the product.

2. Each process produces only what is withdrawn by subsequent process.

3. Defective products are never moved to next process.

4. The number of kanbans should be minimized.

5. The kanban system should be used to adapt to small fluctuations in demand.

Production smoothing

- The purpose of production smoothing is to diminish or control quantity variation in a production line.
- It includes
  - ⋆ smoothing of total production quantity, and
  - ⋆ smoothing of each model's production quantity
- However, production must respond to variable demand.

Production smoothing

Adaptation to varying demand

- Just-in-time (JIT) in sales: supplying products in salable quantities only.
  - ⋆ That means that production must adapt promptly to demand changes.
  - ⋆ This eliminates excess inventories of finished goods.

Production smoothing
Adaptation to varying demand

- If demand increases, hire temporary workers; add shifts, etc.
- If demand decreases,
  - ⋆ dismiss temporary workers,
  - ⋆ transfer workers to lines with increased demand,
  - ⋆ decrease overtime,
  - ⋆ fill up workers' time with quality control meetings, set-up practice, maintenance, etc.

Production smoothing

Waste Reduction

- A system has a maximum production rate, its capacity. When demand is less than that maximum, capacity is wasted.
- Smoothing production can reduce the required maximum.
- However, when demand is greater than capacity, there will have to be inventory or lost sales.

Production smoothing
Total production

- Goal: minimize the variance of total output in a period.
  - ⋆ Produce the same amount every day, if demand is constant.
- Amount produced in a day is the total for a planning period (eg, one month) divided by the number of days in the period.
  - ⋆ The planning period should be as short as possible.

Production smoothing
Example

- Consider an engine line that normally produces 100 engines per day.
- An assembly plant requests lots of 5 with withdrawal kanbans.
- Withdrawals normally occur 20 times per day.

Production smoothing
Example

- If demand is reduced to 90 per day, withdrawals occur 18 times per day.
  - ⋆ The process is stopped after 90 are produced.
- If demand is increased to 110 per day, withdrawals occur 22 times per day.
  - ⋆ The additional engines are produced in overtime.
- If the engine plant did not alter their work hours, they would either build inventory or starve the assembly plant.

Production smoothing
Mixing models

Mix models to:

- minimize inventory
- maximize utilization.
- minimize variability.

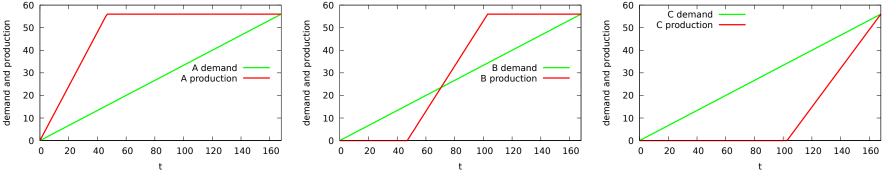
Production smoothing

Mixing models

Example:

- Over a period of 168 working hours (8 hours/day for 21 days), there is a constant demand for 56 A items, 56 B items, 56 C items.
- A items have a 50-minute operation time; B items require 60 minutes; C items require 70 minutes.
- If they are produced $AAAA...BBBB...CCCC...$, the production rate of the line changes over time:
  - ⋆ 46 hours, 40 minutes for A items at a rate of 1.2 items/hour
  - ⋆ 56 hours for B items at a rate of 1 item/hour
  - ⋆ 65 hours, 20 minutes for C items at a rate of .86 items/hour

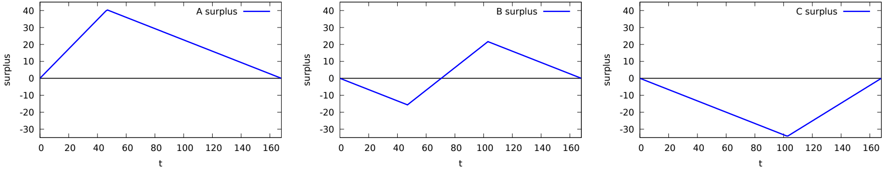
Production smoothing
Mixing models



Cumulative production and demand if parts are produced

$$AAAA...BBBB...CCCC...$$

Production smoothing
Mixing models

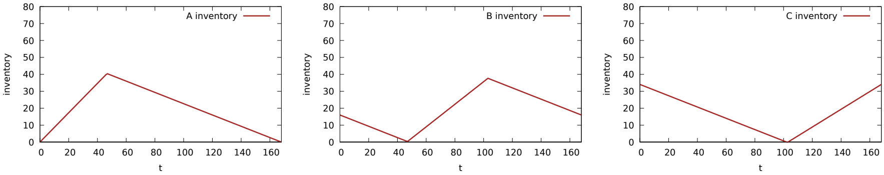


Surpluses *and backlogs* if parts are produced

$$AAAA...BBBB...CCCC...$$

Production smoothing

Mixing models



Inventories if parts are produced

$$AAAA...BBBB...CCCC...$$

Production smoothing
Mixing models

- If the items are are produced $ABCABCABCABC$... and demand is constant,
  - ⋆ the production rates are constant
    - ▸ $(3/(50+60+70)) = 3/180 = 1/60$),
  - ⋆ the surpluses and inventories are all small.
- This is possible only if the machines and the people in this factory are flexible.

Production smoothing
Example

- A plant produces 10,000 Toyota Coronas in a month.
  - ⋆ 5,000 sedans, 2,500 hardtops, 2,500 wagons
- 1 month = 20 eight-hour shifts
- Production is divided equally. Every shift:
  - ⋆ 250 sedans, 125 hardtops, 125 wagons (500 cars).
- eight-hour shift = 480 minutes. Therefore *unit cycle time* $= 480/500 = .96$ minute $= 57.5$ seconds.

Production smoothing

Example

- One sedan must be generated every 1 min, 55 sec.
- One hardtop must be generated every 3 min, 50 sec.
- One wagon must be generated every 3 min, 50 sec.
- Possible sequence: sedan, wagon, sedan, hardtop, sedan, wagon, sedan, hardtop, ...
- As long as there is no setup cost, a sequence like this is desirable because it minimizes inventory.
- Machines and people must be flexible for this.

Setup changes

- All people and many machines can perform more than one task.
- In many cases, an activity is required to change the task that a machine is performing.
- An activity may also be required for the machine to perform the same task but on a different part.
- This activity is called a *setup change.*

Setup changes

- Setup changes can be time-consuming, and sometimes expensive for other reasons.
- They reduce the time that a machine can be used for productive work.
- If they are done infrequently (to reduce the loss of productive time), they cause inventory to be stored.
- Machines that have very short setup times are said to be *flexible* .

Setup changes

- Toyota has had a major emphasis on reduction of setup time.
- Pressing department setup times:
  - ⋆ 2-3 hours, 1945-1954.
  - ⋆ 15 min., 1955-1964.
  - ⋆ 3 min. after 1970.
- *Internal* setup: can only be done while machine is stopped.
- *External* setup: setup work that can be done while operation is taking place.
- Often, a setup change involves both kinds of activities.
- One element of the setup time reduction strategy is to convert some of the internal setup change activity to external.

Standard Operations

Goals

- Minimize the number of workers for production.
    - ⋆ Maximize efficiency and eliminate wasteful motions.
    - ⋆ The standardized order of actions performed for each task are posted as *standard operations routine sheets* to be visible to all workers.
- Minimize WIP.
    - ⋆ There is a *standard quantity of work-in-process.*

Standard Operations
Goals

- Balance lines.
  - ⋆ The *cycle time of an operation* is the time it takes to complete the operation.
  - ⋆ The *cycle time of a line* is the maximum cycle time of any operation in the line.
  - ⋆ Ideally, operations on the same line should take the same length of time.

Standard Operations
Techniques

- Standard operations are determined by foreman, not IE staff.
- *Takt time* is the time in which one copy of an item must be produced. It is given by

$$\text{takt time} = \frac{\text{effective daily operating time}}{\text{required daily quantity}}$$

- *Necessary condition for a line to meet demand:*

$$\text{cycle time} \le \text{takt time}$$

Standard Operations

Techniques

- Late in the month, the central planning office tells each production department the volume required for the next month — in effect, the next month's takt time .
- Lines are rebalanced so that cycle time is less than the takt time.
- If the take time is shorter than before, some workstations may have to be added.
- Process managers determine how many workers are needed.

Process Design

- Previous layout: machines organized by type (lathe, mill, etc.), and one worker per machine.

- TPS layout:

  - ⋆ Machines are organized to smooth material flow.
  - ⋆ Each worker handles three different machines.
  - ⋆ Worker deals with one piece at a time *(one-piece flow)* .

Process Design

- Benefits
  - ⋆ inventory reduced
  - ⋆ fewer workers needed
  - ⋆ workers feel better about their jobs
  - ⋆ workers have increased knowledge of the production process

Improvement and Quality Strategies
Waste

Muda = waste.

- production of defects
- manpower inefficiency
- excess inventories
- missed delivery deadlines
- waste of manpower, outputs, money, space, time, information, etc.

Improvement and Quality Strategies
Reduction of waste

Goals: reduction of

- Unnecessary setup time
  - including time wasted looking for things
- Defective materials and products
- Clutter
- Late deliveries of materials and supplies
  - to work areas, not only to customers
- Unsafe conditions

Improvement and Quality Strategies
5S

- *Seiri:* throw out what you don't need.
- *Seiton:* lay out things neatly.
- *Seiso:* clean up
- *Seiketsu:* standardize the above activities.
- *Shitsuke:* inspire workers, and have them make conforming to rules a habit.

Improvement and Quality Strategies
Visual control

- Seiri: Systematic labeling of items to be discarded
- Seiton: Selecting where things should go and labeling them permanently
- See *andon* below.

Improvement and Quality Strategies
Autonomation

Jidoka = Autonomation

- Not only automation
- "The autonomous check of the abnormal in a process."
- Mechanism to detect defects
- Mechanism to stop the line when defects are detected

Improvement and Quality Strategies
Autonomation

- If a machine produces a defect, it stops the whole line.
- For manual operations, workers can stop the entire line.
- *Poka-yoke:* "mistake-proofing;" a system for checking to prevent defects.

Improvement and Quality Strategies
Visible control system

- An automated device to delay or stop a line.
- Workers have the power and responsibility to delay or stop a line.
- *Andon:* electric light board.
- Board is large and high and therefore visible from all points in factory.
- Color coding:
  - ⋆ When a worker delays a job, he turns on a yellow light.
  - ⋆ When a worker stops a job, he turns on a red light.
  - ⋆ There can be colored lights for other conditions.

Improvement and Quality Strategies
Quality Control Circles

- Improvement suggestions are obtained from workers via *Quality Control (QC) circles.*
- Workers know things that managers do not. They can provide good ideas.
- This shows respect for workers, and improves their morale.

Improvement and Quality Strategies
Quality Control Circles

Kinds of suggestions:

- refinement of manual operations
- introduction of new machinery, or improvements in existing equipment
- ways to economize on material and supplies

Improvement and Quality Strategies

Quality Control Circles

- Formally structured.
- Participation by all workers and recognized by management.
- Meetings regularly scheduled.
- Prizes and commendations awarded.

Toyota Production System

- The Toyota Production System is a system for continuous improvement.
- There is much more detail, and many more areas, in the Toyota Production System.
- The major emphasis is to deal with variation: to reduce it if possible; to respond to it appropriately if not.
- The elements of the system are inter-related.
  - ⋆ For example, it is only possible to mix models if setup change times are short.
- Respect for people is an integral part of the system.

Toyota Production System.

- This has been a *very* brief overview.
- TPS Toyota Production System has been extremely successful.
- The Toyota Production System has been extremely influential.