Agenda

Web Resources

Schedule

Factory Physics

(New Assignment

Chapter 13: Problem 1

Chapter 14: Problems 1, 2)

Web Resources

http://sdmines.sdsmt.edu/sdsmt/directory/courses/2009fa/tm663M021-099

I have your exams graded.

Have entered results in D2L.
A Pull Planning Framework

We think in generalities, we live in detail.

—Alfred North Whitehead

Purpose of Production Control

Objective: Meet customer expectations with on-time delivery of correct quantities of desired specification without excessive lead times or large inventory levels.

Two Basic Approaches:

**Push Systems**: Material Requirements Planning
- General.
- Provides a planning hierarchy.
- Underlying model often inappropriate.

**Pull Systems**: Kanban, CONWIP
- Reduces congestion.
- Improves production environment.
- Suitable only for repetitive manufacturing.
Advantages of Pull

Advantages:

- **Observability**: We can see WIP but not capacity.
- **Efficiency**: Pull systems require less average WIP to attain same throughput as equivalent push system.
- **Robustness**: Pull systems are less sensitive to errors in WIP level than push systems are to errors in release rate.
- **Quality**: Pull systems require and promote improved quality.

**Magic of Pull: WIP Cap**

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A Dilemma

**Question**: If pull is so great, why do people still buy ERP systems?

**Answer**: Manufacturing involves planning as well as execution.

<table>
<thead>
<tr>
<th></th>
<th>Planning</th>
<th>Execution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Push</td>
<td>good</td>
<td>bad</td>
</tr>
<tr>
<td>Pull</td>
<td>bad</td>
<td>good</td>
</tr>
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MRP II Planning Hierarchy
Hierarchical Pull Planning Framework

Goals:
- To attain the benefits of a pull environment.
- To gain the generality of hierarchical production planning systems.

The Environment:
- CONWIP production lines.
- Daily/Weekly production quota.

The Hierarchy:
- Based on CONWIP for predictability and generality.
- Consistency between levels.
- Accommodate different implementations of modules for different environments.
- Use feedback.

Hierarchical Planning in a Pull System

CONWIP as the Foundation

Pull:
- jobs into the line whenever parts are used.
- jobs with the same routing.
- jobs for different part numbers.

Push:
- jobs between stations on line.
- jobs into buffer storage between lines.

A CONWIP Line:
- represents a level in a bill of material.
- is between stock points.
- maintains a constant amount of work in process.
Benefits of CONWIP

CONWIP vs. Push:
- Easier and more robust control.
- Less congestion.
- Greater predictability.

CONWIP vs. Kanban:
- Can accommodate a changing product mix.
- Can be used with setups.
- Suitable for short runs of small lots.
- More predictable.

Conveyor Model of CONWIP

Predicting Completion Times:
- Practical production rate: $r_f$ parts per hour
- Minimum practical lead time: $T_P$ hours
- $X_i$ is number of parts in job $i$ on the backlog.
- Then the expected completion time of the $n^{th}$ job, $c_n$, will be:

$$c_n = \sum_{i=1}^{n} X_i T_P + \frac{T_P}{r_f}$$

Quoting Due Dates: need to add a “fudge factor” (which should consider cycle time variability) to ensure a reasonable service level.

Aggregating Planning by Time Horizon

<table>
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<tr>
<th>Time Horizon</th>
<th>Length</th>
<th>Representative Decisions</th>
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<tr>
<td>Intermediate-Term</td>
<td>week – year</td>
<td>Work Scheduling, Scheduling Assignments, Marketing Scheduling, Sales Promotion, Purchasing Decisions</td>
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<tr>
<td>Short-Term (Operational)</td>
<td>hour – week</td>
<td>Material Flow Control, Worker Assignments, Machine Setup Decisions, Process Control, Quality Compliance Decisions, Inventory Management, Reports</td>
</tr>
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</table>
### Other Levels of Aggregation

**Processes:** Treat several workstations as one. Leave out unimportant (never bottleneck) workstations.

**Products:** Group different part numbers into product families, which have
- have roughly the same routing
- have roughly the same price
- share setups

**Personnel:** Categorize people according to
- management vs. labor
- shift
- workstation
- craft
- permanent vs. temporary

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### Forecasting

**Basic Problem:** predict demand for planning purposes.

**Laws of Forecasting:**
1. Forecasts are always wrong!
2. Forecasts always change!
3. The further into the future, the less reliable the forecast will be!

**Forecasting Tools:**
- Qualitative:
  - Delphi
  - Analogies
  - Many others
- Quantitative:
  - Causal models (e.g., regression models)
  - Time series models

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### Capacity/Facility Planning

**Basic Problem:** how much and what kind of physical equipment is needed to support production goals?

**Issues:**
- Basic Capacity Calculations: stand-alone capacities and congestion effects (e.g., blocking)
- Capacity Strategy: lead or follow demand
- Make-or-Buy: vending, long-term identity
- Flexibility: with regard to product, volume, mix
- Speed: scalability, learning curves
Workforce Planning

**Basic Problem:** how much and what kind of labor is needed to support production goals?

**Issues:**
- **Basic Staffing Calculations:** standard labor hours adjusted for worker availability.
- **Working Environment:** stability, morale, learning.
- **Flexibility/Agility:** ability of workforce to support plant’s ability to respond to short and long term shifts.
- **Quality:** procedures are only as good as the people who carry them out.

Aggregate Planning

**Basic Problem:** generate a long-term production plan that establishes a rough product mix, anticipates bottlenecks, and is consistent with capacity and workforce plans.

**Issues:**
- **Aggregation:** product families and time periods must be set appropriately for the environment.
- **Coordination:** AP is the link between the high level functions of forecasting/capacity planning and intermediate level functions of quota setting and scheduling.
- **Anticipating Execution:** AP is virtually always done deterministically, while production is carried out in a stochastic environment.
- **Linear Programming:** is a powerful tool well-suited to AP and other optimization problems.

Quota Setting

**Basic Problem:** set target production quota for pull system

**Issues:** Larger quotas yield

**Benefits:**
- Increased throughput.
- Increased utilization.
- Lower unit labor hour.
- Lower allocation of overhead.

**Costs:**
- More overtime.
- Higher WIP levels.
- More expediting.
- Increased difficulties in quality control.
Planned Catch-Up Times

<table>
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<tr>
<td>0</td>
<td>R</td>
<td>T</td>
<td>T + R</td>
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Economic Production Quota Notation

\[ p = \text{unit profit} \]
\[ C_{ot} = \text{fixed overtime cost} \]
\[ T = \text{regular time production (random variable)} \]
\[ \mu = \text{mean regular time production (mean (T))} \]
\[ \sigma = \text{std dev of regular time production (std (T))} \]
\[ M = \text{maximum overtime production} \]
\[ Q = \text{regular time production quota (decision variable)} \]

Simple “Sell-All-You-Can-Make” Model

Objective Function: Average weekly profit

\[ \max_0 Z = pQ - C_{ot} \Pr[Y \leq Q] \]

Reasonability Test: We want the probability of not being able to catch up on overtime to be small (i.e., \( \alpha \)):

\[ \Pr(Q^* - Y > M) \leq \alpha \]

If this is not true, another (lost sales) model should be used.
Simple “Sell-All-You-Can-Make” Model (cont.)

Normal Approximation: Express $Q = \mu - k\sigma$, so the objective and reasonability test can be written:

$$\max Z = \rho(\mu - k\sigma) - C_{in}(1 - \Phi(k))$$
$$\Phi(k + M/\sigma) < 1 - \alpha$$

Solution: The objective function is maximized by:

$$k^* = \left[\frac{2\ln \left(\frac{C_{in}}{\rho}\right)}{\sigma^2}\right]^{1/2}$$

$$Q^* = \mu + k^*$$

Intuition from Model

- Optimal production quota depends on both mean and variance of regular time production ($Q^*\) increases with $\mu$ and decreases with $\sigma$).
- Increasing capacity increases profit, since
  $$\frac{\partial Q^*}{\partial p} > 0$$
- Decreasing variance increases profit, since
  $$\frac{\partial Q^*}{\partial \sigma} < 0$$
- Model is valid (i.e., has a solution $0 < k^* < \infty$) only if
  $$p \leq \frac{C_{in}}{\sqrt{2\pi}\sigma}$$

since otherwise the term in the $\sqrt{}$ becomes negative. If this occurs, then OT cost does not exceed revenue lost to make-up period and a different model is required.

Other Quota Setting Models

Model 2: Lost Sales
- Run continuously
- Choose periodic production quota $Q$
- Demand above $Q$ is lost (or vendored) at a cost.
- Solution looks like that to the Newsboy problem

Model 3: Fixed plus Variable Cost of Overtime
- Same as Model 1, except that cost of overtime has a fixed component, $C_{ot}$, and a component proportional to the amount of the shortage
- Solution looks like that to Model 1 except term under $\sqrt{}$ is more complex
Other Quota Setting Models (cont.)

**Model 4: Backlogging**
- Fixed plus variable cost of overtime.
- Decision maker can choose to carry shortage to next period at a cost.
- Dependence between periods requires more sophisticated solution techniques (e.g., dynamic programming).
- Solution consists of $Q^*$, optimal quota, plus $S^*$, an "overtime trigger" such that we use overtime only if the shortage is at least $S^*$.

Quota Setting Implementation

- Iteration between quota setting and aggregate planning may be necessary for consistency.
- Motivation (setting the "bar") vs. Prediction (quoting due dates).
- MPS smoothing - necessary to keep steady quota.
- Gross capacity control through shift addition/deletion, rather than production slow-down.

Setting WIP Levels

**Basic Problem:** establish WIP levels (card counts) in pull system.

**Issues:**
- Mean regular time production increases with WIP level.
- Variance of regular time production also affected by WIP level.
- WIP levels should be set to facilitate desired throughput.
- Adjustment may be necessary as system evolves (feedback).
- Easy method:
  1. Specify feasible cycle time, CT, and identify practical production rate, $r_p$.
  2. Set WIP from $WIP = r_p \times CT$.
Demand Management

**Basic Problem:** establish an interface between the customer and the plant floor, that supports both competitive customer service and workable production schedules.

**Issues:**
- **Customer Lead Times:** shorter is more competitive.
- **Customer Service:** on-time delivery.
- **Batching:** grouping like product families can reduce lost capacity due to setups.
- **Interface with Scheduling:** customer due dates are an enormously important control in the overall scheduling process.

Sequencing and Scheduling

**Basic Problem:** develop a plan to guide the release of work into the system and coordination with needed resources (e.g., machines, staffing, materials).

**Methods:**
- **Sequencing:**
  - Gives order of releases but not times.
  - Adequate for simple CONWIP lines where FISFO is maintained.
  - The "CONWIP backlog."
- **Scheduling:**
  - Gives detailed release times.
  - Attractive where complex routings make simple sequence impractical.
  - MRP-C.

Sequencing CONWIP Lines

**Objectives:**
- Maximize profit.
- No late jobs.
- All firm jobs selected.

**Job Sequencing System:**
- Sequences bottleneck line.
- Uses Quota to explicitly consider capacity.
- Tries to group like families of jobs to reduce setups.
- Identifies the "offensive" jobs in an infeasible schedule.
- Suggests where more work could start in a lightly loaded schedule.
- Provides sequence for other lines.
Real-Time Simulation

**Basic Problem:** anticipate problems in schedule execution and provide vehicle for exploring solutions.

**Approaches:**
- **Deterministic Simulation:**
  - Given release schedule and dispatching rules, predict output times.
  - Commercial packages (e.g., FACTOR).
- **Conveyor Model:**
  - Allow hot jobs to pass in buffers, not in the lines.
  - Use simplified simulation based on conveyor model to predict output times.

Shop Floor Control

**Basic Problem:** control flow of work through plant and coordinate with other activities (e.g., quality control, preventive maintenance, etc.)

**Issues:**
- **Customization:** SFC is often the most highly customized activity in a plant.
- **Information Collection:** SFC represents the interface with the actual production processes and is therefore a good place to collect data.
- **Simplicity:** departures from simple mechanisms must be carefully justified.

Tracking and Feedback

**Basic Problems:**
- Signal quota shortfall.
- Update capacity data.
- Quote delivery dates.

**Functions:**

**Statistical Throughput Control:**
- Monitored at critical tools.
- Like SPC, only measuring throughput.
- Problems are apparent with time to act.
- Workers aware of situation.

**Feedback:**
- Collect capacity data.
- Measure continual improvement.
Conclusions

Pull Environment Provides:
• Less WIP and thereby earlier detection of quality problems.
• Shorter lead times allowing increased customer response and less reliance on forecasts.
• Less buffer stock and therefore less exposure to schedule and engineering changes.

CONWIP Provides: a pull environment that
• Has greater throughput for equivalent WIP than kanban.
• Can accommodate a changing product mix.
• Can be used with setups.
• Is suitable for short runs of small lots.
• Is predictable.

Conclusions (cont.)

Planning Hierarchy Provides:
• Consistent framework for planning.
• Links between levels.
• Feedback.

Forecasting

The future is made of the same stuff as the present.

– Simone Weil
Forecasting “Laws”
1) Forecasts are always wrong!
2) Forecasts always change!
3) The further into the future, the less reliable the forecast!

Quantitative Forecasting

Goals:
• Predict future from past
• Smooth out “noise”
• Standardize forecasting procedure

Methodologies:
• Causal Forecasting:
  – regression analysis
  – other approaches
• Time Series Forecasting:
  – moving average
  – exponential smoothing
  – regression analysis
  – seasonal models
  – many others

Time Series Forecasting

\[ A(i), i = 1, \ldots, T \]  \rightarrow \text{Time series model} \rightarrow \text{Forecast} \]

\[ f(t+1), i = 1, 2, \ldots \]
Time Series Approach

Notation:

\[ A(t) = \text{observation in period } t, \quad t = 1, \ldots, T \]
\[ F(t) = \text{forecast for period } t + \tau \]
\[ F(t) = \text{smoothed estimate as of period } t \]
\[ T(t) = \text{smoothed trend as of period } t \]

Time Series Approach (cont.)

Procedure:
1. Select model that computes \( f(t+\tau) \) from \( A(i), i = 1, \ldots, T \)
2. Forecast existing data and evaluate quality of fit by using:
   * MAD = \( \frac{1}{n} \sum_{t=1}^{n} |f(t) - A(t)| \)
   * MSD = \( \frac{1}{n} \sum_{t=1}^{n} (f(t) - A(t))^2 \)
   * BIAS = \( \frac{1}{n} \sum_{t=1}^{n} \frac{(f(t) - A(t))}{n} \)
3. Stop if fit is acceptable. Otherwise, adjust model constants and go to (2) or reject model and go to (1).

Moving Average

Assumptions:
* No trend
* Equal weight to last \( m \) observations

Model:

\[ F(t) = \frac{1}{m} \sum_{i=1}^{m} A(t) \]
\[ f(t+\tau) = F(t), \quad \tau = 1, 2, \ldots \]
### Moving Average (cont.)

**Example:** Moving Average with \( m = 3 \) and \( m = 5 \).

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand</th>
<th>Forecast (( m = 3 ))</th>
<th>Forecast (( m = 5 ))</th>
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<td>-</td>
</tr>
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<td>-</td>
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</tbody>
</table>

**Note:** bigger \( m \) makes forecast more stable, but less responsive.

### Moving Average: \( m = 3, 5 \)

![Graph showing moving average with \( m = 3, 5 \)]

### Exponential Smoothing

**Assumptions:**
- No trend
- Exponentially declining weight given to past observations

**Model:**

\[
\begin{align*}
F(t) &= \alpha A(t) + (1-\alpha) F(t-1) \\
f(t + \tau) &= F(t), \quad \tau = 1, 2, \ldots
\end{align*}
\]
Exponential Smoothing, $\alpha=0.2$

![Exponential Smoothing Graph](Image)

Frank Matejcik  SD School of Mines & Technology

Exponential Smoothing with a Trend

Assumptions:
- Linear trend
- Exponentially declining weights to past observations/trends

Model:

\[ F(t) = \alpha A(t) + (1-\alpha)(F(t-1) + T(t-1)) \]
\[ T(t) = \beta[F(t) - F(t-1)] + (1-\beta)T(t-1) \]
\[ f(t+\tau) = F(t) + \tau T(t) \]

Note: these calculations are easy, but there is some "art" in choosing $F(0)$ and $T(0)$ to start the time series.

Exponential Smoothing with a Trend (cont.)

Example: Exponential Smoothing with Trend, $\alpha = 0.2$, $\beta = 0.5$.

<table>
<thead>
<tr>
<th>Month</th>
<th>$A(t)$</th>
<th>$F(t-1)$</th>
<th>Trend of $A(t)$</th>
<th>Trend of $T(t)$</th>
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Note: we start with trend equal to zero.
Exponential Smoothing with Trend, $\alpha=0.2$, $\beta=0.5$

Effects of Altering Smoothing Constants

Exponential Smoothing with Trend: various values of $\alpha$ and $\beta$

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<th>$\beta$</th>
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<th>MSD</th>
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Note: these assume we start with trend equal to zero.
Effects of Altering Smoothing Constants (cont.)

Observations: assuming we start with zero trend
- $\alpha = 0.3$, $\beta = 0.5$ work well for MAD and MSD
- $\alpha = 0.6$, $\beta = 0.6$ work better for BIAS
- Our original choice of $\alpha = 0.2$, $\beta = 0.5$ had MAD = 3.73, MSD = 22.32, BIAS = -2.02, which is pretty good, although $\alpha = 0.3$, $\beta = 0.5$, with MAD = 3.65, MSD=21.78, BIAS = -1.32 is better.

Winters Method for Seasonal Series

Seasonal series: a series that has a pattern that repeats every $N$ periods for some value of $N$ (which is at least 3).

Seasonal factors: a set of multipliers $c_t$, representing the average amount that the demand in the $t$th period of the season is above or below the overall average.

Winter's Method:
- The series: $F(t) = \alpha(A(t)/A(t-N)) + (1-\alpha)(F(t-1) + T(t-1))$
- The trend: $T(t) = \beta(F(t)-F(t-1)) + (1-\beta)T(t-1)$
- The seasonal factors: $c(t) = \gamma(A(t)/F(t)) + (1-\gamma)c(t-N)$
- The forecast: $F(t+\tau) = (F(t)+\tau)c(t)+T(t)\tau-N)$, $t+\tau = N+1, 2N$

Winters Method - Sample Calculations

Initially we set:
- smoothing estimate = first season average
- smoothed trend = zero ($T(N)=T(12) = 0$)
- seasonality factor = ratio of actual to average demand

From period 13 on we can use initial values and standard formulas...

$$F(12) = \frac{A(12)}{12} = \frac{4+2+4+4}{12} = 0.33$$
$$c(t) = \frac{A(t)}{F(t)} = \frac{3}{13}$$

$$F(13) = \alpha(A(13)/A(3-12)) + (1-\alpha)(F(12) + T(12)) = \alpha(0.33/0.48) + (1-\alpha)(0.33 + 0.33) = 0.34$$
$$T(13) = \beta(F(13)-F(12)) + (1-\beta)T(12) = 0.34 - 0.33 + (1-0.33) = 0.30$$
$$c(13) = \gamma(A(13)/F(13)) + (1-\gamma)c(12) = 0.33(0.33 + 0.33) = 0.41$$
### Winters Method Example

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<th>Actual</th>
<th>Base</th>
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**1998**

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**Conclusions**

- **Sensitivity:** Lower values of \( m \) or higher values of \( \alpha \) will make moving average and exponential smoothing models (without trend) more sensitive to data changes (and hence less stable).
- **Trends:** Models without a trend will underestimate observations in time series with an increasing trend and overestimate observations in time series with a decreasing trend.
- **Smoothing Constants:** Choosing smoothing constants is an art; the best we can do is choose constants that fit past data reasonably well.
- **Seasonality:** Methods exist for fitting time series with seasonal behavior (e.g., Winters method), but require more past data to fit than the simpler models.
- **Judgement:** No time series model can anticipate structural changes not signaled by past observations; these require judicious overriding of the model by the user.
Shop Floor Control

Even a journey of one thousand li begins with a single step.

– Lao Tze

It is a melancholy thing to see how zeal for a good thing abates when the novelty is over, and when there is no pecuniary reward attending the service.

– Earl of Egmont

What is Shop Floor Control?

Definition: Shop Floor Control (SFC) is the process by which decisions directly affecting the flow of material through the factory are made.

Functions:
- WIP Tracking
- Throughput Tracking
- Status Monitoring
- Work Forecasting
- Capacity Feedback
- Quality Control
- Material Flow Control

Planning for SFC

Gross Capacity Control: Match line to demand via:
- Varying staffing (no. shifts or no. workers/shift)
- Varying length of work week (or work day)
- Using outside vendors to augment capacity

Bottleneck Planning:
- Bottlenecks can be designed
- Cost of capacity is key
- Stable bottlenecks are easier to manage

Span of Control:
- Physically or logically decompose system
- Span of labor management (10 subordinates)
- Span of process management (related technology?)
Basic CONWIP

Rationale:
• Simple starting point
• Can be effective

Requirements:
• Constant routings
• Similar processing times (stable bottleneck)
• No significant setups
• No assemblies

Design Issues:
• Work backlog – how to maintain and display
  • Line discipline – FIFO, limited passing
• Card counts – WIP = CT \times r_i initially, then conservative adjustments
• Card deficits – violate WIP-cap in special circumstances
• Work ahead – how far ahead relative to due date?

CONWIP Line Using Cards

Card Deficits
Tandem CONWIP Lines

Links to Kanban: when “loops” become single process centers

Bottleneck Treatment:
- Nonbottleneck loops coupled to buffer inventories (cards are released on departure from buffer)
- Bottleneck loops uncoupled from buffer inventories (cards are released on entry into buffer)

Shared Resources:
- Sequencing policy is needed
- Upstream buffer facilitates sequencing (and batching if necessary)
Modifications of Basic CONWIP

Multiple Product Families:
- Capacity-adjusted WIP
- CONWIP Controller

Assembly Systems:
- CONWIP achieves synchronization naturally (unless passing is allowed)
- WIP levels must be sensitive to “length” of fabrication lines
### CONWIP Assembly

#### Processing Times for Line A

1. 2. 3. 4.

#### Processing Times for Line B

3. 3. 2.

---

### Kanban

**Advantages:**
- Improved communication
- Control of shared resources

**Disadvantages:**
- Complexity – setting WIP levels
- Tighter pacing – pressure on workers, less opportunity for work ahead
- Part-specific cards – can’t accommodate many active part numbers
- Inflexible to product mix changes
- Handles small, infrequent orders poorly

---

### Kanban with Work Backlog

- Standard Container
- Card
Pull From the Bottleneck

Problems with CONWIP/Kanban:
- Bottleneck starvation due to downstream failures
- Premature releases due to CONWIP requirements

PFB Remedies:
- PFB ignores WIP downstream of bottleneck
- PFB launches orders when bottleneck can accommodate them

PFB Problem:
- Floating bottlenecks

Simple Pull From the Bottleneck

Material Flow

Card Flow

Routings in a Jobshop
Implementing PFB

Notation:
- $b_i$: The time required on the bottleneck by job $i$ on the backlog.
- $r_i$: The average time after release required for jobs to reach the bottleneck.
- $L$: The specified time for jobs to wait in the buffer in front of the bottleneck.

Work at Bottleneck: total hours of work ahead of job $j$ is
$$\sum b_i$$

Job Release Mechanism: Release job $j$ whenever
$$\sum b_i \leq r_i + L$$

Enhancement: establish due date window, before which jobs are not released.

Production Tracking

Short Term:
- Statistical Throughput Control (STC)
- Progress toward quota
- Overtime decisions

Long Term:
- Long range tracking
- Capacity feedback
- Synchronize planning models to reality

STC Notation

$R$: length of regular time
$\mu$: mean production during regular time
$\sigma$: standard deviation of regular time production
$Q$: production quota
$N$: production in $[0,1]$ $\quad \sum b_i \leq r_i + L$
$T$: time to make quota in $n^\sigma$ regular time period

$\mu_r$: mean time to make quota, $E[T]\nand \sigma_r$: std dev of time to make quota, $\sqrt{\text{Var}(T)}$

Note: we might have these instead of $\mu$ and $\sigma$ if we stop when quota is made.
Assumption: $N_t$ is normally distributed with mean $\mu_t/R$ and variance $\sigma^2_t/R$.

Implications:
- $N_t - Q/R$ is normally distributed with mean $(\mu_t - Q)/R$ and variance $\sigma^2_t/R$.
- If $N_t = n_t$, where $n_t - Q/R = x$, we will miss quota only if $N_t < Q - n_t$.

Formula: The probability of missing quota by time $R$ given an overage of $x$ is

$$P(N_t \leq Q - n_t - x/R) = P(N_t - Q/R \leq x/R)$$

$$= \Phi \left( \frac{Q - \mu_t - Q/R - x/R}{\sigma_t \sqrt{R - 1/R}} \right)$$

STC Charts

Motivation: information "at a glance"

Computations: Pre-compute the overage levels that cause the probability of missing quota to be a specified level $\alpha$:

$$\frac{Q - \mu_t - Q/R - x/R}{\sigma_t \sqrt{R - 1/R}} = \alpha$$

which yields

$$x = (\mu - Q/R - x/R - \sigma_t \sqrt{R - 1/R})$$

where $\Phi(\alpha)$ is chosen such that $\Phi(\alpha) = \alpha$. 
Long-Range Tracking

Statistics of Interest:
- $\mu$: mean production during regular time
- $\sigma^2$: variance of regular time production

Observable Statistics: if we stop when quota is achieved, then instead of $\mu$ and $\sigma$ we observe
- $\mu_S$: mean time to make quota
- $\sigma^2_S$: variance of time to make quota

Conversion Formulas: If we have $\mu_S$ and $\sigma^2_S$, then we can smooth these (as shown later) and then convert to $\mu$ and $\sigma$ by using

$$
\mu = \frac{RQ}{\mu_S}, \quad \sigma^2 = \frac{\sigma^2_S (RQ)}{\mu_S^2}
$$

Smoothing Capacity Parameters

Mean Production:
$$
\hat{\mu}(n) = a\hat{\mu}_{n-1} + (1-a)(\hat{\mu}(n-1) + \bar{T}_{n-1})
$$
$$
\hat{T}(n) = \beta(\hat{\mu}(n) - \hat{\mu}(n-1)) + (1-\beta)\hat{T}(n-1)
$$
where $\alpha$ and $\beta$ are smoothing constants.

Production Variance:
$$
\hat{\sigma}^2(n) = \gamma(Y_{n-1} - \hat{\mu}(n))^2 + (1-\gamma)\hat{\sigma}^2(n-1)
$$
where $\gamma$ is a smoothing constant.
Shop Floor Control Takeaways

General:
- SFC is more than material flow control (WIP tracking, QC, status monitoring, …)
- good SFC requires planning (workforce policies, bottlenecks, management, …)

CONWIP:
- simple starting point
- reduces variability due to WIP fluctuations
- many modifications possible (kanban, pull-from-bottleneck)

Shop Floor Control Takeaways (cont.)

Statistical Throughput Control (STC):
- tool for OT planning/prediction
- intuitive graphical display

Long Range Tracking:
- feedback for other planning/control modules
- exponential smoothing approach