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?)

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Basic CONWIP

**Rationale:**
- Simple starting point
- Effective in some environments

**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 – $\text{WIP} = \text{CT} \times r_p$ 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

CONWIP Cards

Production Line

Inbound Stock

Outbound Stock

Card Deficits

Jobs without Cards

Jobs with Cards

Bottleneck Process

Failed Machine
**Tandem CONWIP Lines**

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

**Bottleneck Treatment:**
- Non-bottleneck 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)
Coupled and Uncoupled CONWIP Loops

- CONWIP Loop
- Buffer
- Job
- CONWIP Card
- Material Flow
- Card Flow

Splitting Loops at Shared Resource

- Routing A
- Routing B
- CONWIP Loop
- Buffer
- Card Flow
- Material Flow


http://factory-physics.com
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 Controller

![Diagram of CONWIP Controller](http://factory-physics.com)
**CONWIP Assembly**

Processing Times for Line A

Processing Times for Line B

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**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
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

Backlog

http://factory-physics.com
Implementing PFB

Notation:

\[ b_i = \text{The time required on the bottleneck by job } j \text{ on the backlog.} \]
\[ \ell_i = \text{The average time after release required for job } i \text{ to reach the bottleneck.} \]
\[ L = \text{The specified time for jobs to wait in the buffer in front of the bottleneck.} \]

Work at Bottleneck: total hours of work ahead of job \( j \) is
\[ \sum_{i=1}^{k} b_i \]

Job Release Mechanism: Release job \( j \) whenever
\[ \ell_j + L \leq \sum_{i=1}^{k} b_i \]

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
- \( N_t \): production in \([0,t]\)
- \( Y_n \): time to make quota in \(n^{th}\) regular time period
- \( \mu_E \): mean time to make quota, \(E[Y_n]\)
- \( \sigma_E \): std dev of time to make quota, \(\sqrt{Var(Y_n)}\)

STC Mechanics

**Assumption:** \( N_t \) is normally distributed with mean \( \mu t/R \) and variance \( \sigma^2 t/R \).

**Implications:**
- \( N_{\text{var}} - Qt/R \) is normally distributed with mean \((\mu - Q) t/R\) and variance \(\sigma^2 t/R\).
- \( N_{\text{var}} \) is normally distributed with mean \(\mu (R - t)/R\) and variance \(\sigma^2 (R - t)/R\).
- If \( N_t = n_t \), where \( n_t - Qt/R = x \), then we will miss quota only if \( N_{\text{var}} < Q - n_t \).

**Formula:** The probability of missing quota by time \( R \) given an overage of \( x \) is

\[
P( N_{\text{var}} \leq Q - n_t ) = P( N_{\text{var}} \leq Q - x - Qt/R )
= P( N_{\text{var}} \leq Q(R - t)/R - x )
= \Phi \left( \frac{(Q - \mu)(R - t)/R - x}{\sigma \sqrt{(R - t)/R}} \right)
\]
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 $\alpha$:

$$\Phi \left( \frac{(Q - \mu)(R - t)/R - x}{\sigma \sqrt{R(t - t)/R}} \right) = \alpha$$

• which yields

$$x = -(\mu - Q)(R - t)/R - z_\alpha \sigma \sqrt{(R - t)/R}$$

• where $z_\alpha$ is chosen such that $\Phi(z_\alpha) = \alpha$. 

STC Chart (Q=\mu)

Probability of Missing Quota by End of Regular Time

![STC Chart](http://factory-physics.com)
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 he have $\mu_s$ and $\sigma_s$, then we can smooth these (as shown later) and then convert to $\mu$ and $\sigma$ by using

$$\mu = \frac{RQ}{\mu_s}$$
$$\sigma^2 = \frac{\sigma^2_s RQ^2}{\mu_s}$$
Smoothing Capacity Parameters

Mean Production:

\[ \hat{\mu}(n) = \alpha Y_n + (1 - \alpha)(\hat{\mu}(n-1) + \hat{T}_{n-1}) \]
\[ \hat{T}(n) = \beta (\hat{\mu}(n) - \hat{\mu}(n-1)) + (1 - \beta)\hat{T}(n-1) \]

* where \( \alpha \) and \( \beta \) are smoothing constants.

Production Variance:

\[ \sigma^2(n) = \gamma(Y_n - \hat{\mu}(n))^2 + (1 - \gamma)\sigma^2(n-1) \]

* where \( \gamma \) is a smoothing constant.

LR Tracking - Mean Production
Smoothed Trend in Mean Production

LR Tracking - Std Dev of Production
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