Factory Physics Principles

Law (Little's Law):

$$\text{WIP} = \text{TH} \times \text{CT}$$

Law (Best Case Performance): *The minimum cycle time for a given WIP level, w, is given by*

$$CT_{best} = \begin{cases} T_0, & \text{if } w \leq W_0 \\ w/r_b, & \text{otherwise.} \end{cases}$$

The maximum throughput for a given WIP level, w is given by,

$$TH_{best} = \begin{cases} w/T_0, & \text{if } w \leq W_0 \\ r_b, & \text{otherwise.} \end{cases}$$

Law (Worst Case Performance): *The worst case cycle time for a given WIP level, w, is given by,*

$$CT_{worst} = wT_0$$

The worst case throughput for a given WIP level, w, is given by,

$$TH_{worst} = 1/T_0$$

Definition (Practical Worst Case Performance): *The practical worst case (PWC) cycle time for a given WIP level, w, is given by,*

$$CT_{\text{PWC}} = T_0 + \frac{(w-1)}{r_b}$$

The PWC throughput for a given WIP level, w, is given by,

$$TH_{\text{PWC}} = \frac{w}{W_0 + w - 1} r_b$$

Law (Labor Capacity): *The maximum capacity of a line staffed by n cross-trained operators with identical work rates is*

$$TH_{\max} = \frac{n}{T_0}$$

Law (CONWIP with Flexible Labor): *In a CONWIP line with n identical workers and w jobs, where $w \geq n$, any policy that never idles workers when unblocked jobs are available will achieve a throughput level $TH(w)$ bounded by*

$$TH_{\mathrm{CW}}(n) \leq TH(w) \leq TH_{\mathrm{CW}}(w)$$

where $TH_{\mathrm{CW}}(x)$ represents the throughput of a CONWIP line with all machines staffed by workers and x jobs in the system.

Law (Variability): *Increasing variability always degrades performance of a production system.*

Corollary (Variability Placement): *In a line with where releases are independent of completions, variability early in a routing increases cycle time more than equivalent variability later in the routing.*

Law (Variability Buffering): *Variability in a production system will be buffered by some combination of:*

1. *inventory,*
2. *capacity,*
3. *time.*

Corollary (Buffer Flexibility): *Flexibility reduces the amount of variability buffering required in a production system.*

Law (Conservation of Material): *In a stable system, over the long run, the rate out of a system will equal the rate in, less any yield loss, plus any parts production within the system.*

Law (Capacity): *In steady state, all plants will release work at an average rate that is strictly less than the average capacity.*

Law (Utilization): *If a station increases utilization without making any other changes, average cycle time will increase in a highly nonlinear fashion.*

Law (Process Batching): *In stations with batch operations or with significant changeover times:*

1. *The minimum process batch size that yields a stable system may be greater than one.*
2. *As process batch size becomes large, cycle time grows proportionally with batch size.*
3. *Cycle time at the station will be minimized for some process batch size, which may be greater than one.*

Law (Move Batching): *Cycle times over a segment of a routing are roughly proportional to the transfer batch sizes used over that segment, provided there is no waiting for the conveyance device.*

Law (Assembly Operations): *The performance of an assembly station is degraded by increasing any of the following:*

1. *number of components being assembled,*
2. *variability of component arrivals,*
3. *lack of coordination between component arrivals.*

Definition (Station Cycle Time): *The average cycle time at a station is made up of the following components:*

$$\begin{aligned} \textit{cycle time} \;=\; & \textit{move time} + \textit{queue time} + \textit{setup time} + \textit{process time} + \\ & \textit{wait-to-batch time} + \textit{wait-in-batch time} + \\ & \textit{wait-to-match time} \end{aligned}$$

Definition (Line Cycle Time): *The average cycle time in a line is equal to the sum of the cycle times at the individual stations less any time that overlaps two or more stations.*

Law (Rework): *For a given throughput level, rework increases both the mean and standard deviation of the cycle time of a process.*

Law (Lead Time): *The manufacturing lead time for a routing that yields a given service level is an increasing function of both the mean and standard deviation of the cycle time of the routing.*

Law (CONWIP Efficiency): *For a given level of throughput, a push system will have more WIP on average than an equivalent CONWIP system.*

Law (CONWIP Robustness): *A CONWIP system is more robust to errors in WIP level than a pure push system is to errors in release rate.*

Law (Self-Interest): *People, not organizations, are self-optimizing.*

Law (Individuality): *People are different.*

Law (Advocacy): *For any program, there exists a champion who can make it work, . . . at least for a while.*

Law (Burn-out): *People get burned out.*

Law (Responsibility): *Responsibility without commensurate authority is demoralizing and counterproductive.*