Why Factory Physics Analytics?

- Projects are like factories
  - Have deliverables with deadlines to meet a demand
  - Have capacity limitations in the productive processes
  - Can perform some production ahead of demand
  - Have variability in both “production” and demand

- Factory Physics addresses
  - Demand
  - Production
  - On time delivery
  - Variability
  - And how they interact
Factory Physics Inc

Core Competence:
- Wrote ‘the book’ on operations performance
- IIE Book of the Year
- Application of scientific principles to improving operations performance

Clients
- European, North and South American manufacturers

Global Operations Based in U.S.A
- Established in 2001 based on 22 years of research

A consulting company with software.

What makes this approach different?

- It is scientific—science relentlessly tested in industry
- It has software to standardize analysis and learning
  - Rapid modeling, data obtained from existing systems
  - Efficient frontier curves to quickly identify opportunities
  - Where do you want to operate? Where can you operate?

<table>
<thead>
<tr>
<th>Ability Matrix</th>
<th>Current State Analysis</th>
<th>Future State Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>Speed</td>
<td>Detail</td>
</tr>
<tr>
<td>Factory Physics Analytics</td>
<td>2 weeks</td>
<td>Moderate</td>
</tr>
<tr>
<td>Six Sigma</td>
<td>3+ months</td>
<td>NA</td>
</tr>
<tr>
<td>Lean</td>
<td>1 week</td>
<td>Low</td>
</tr>
<tr>
<td>Monte Carlo Simulation</td>
<td>3 months+</td>
<td>High</td>
</tr>
</tbody>
</table>

How to Profit from Science?

- What to make?
- When to make it?
- How much to make?
- How many people and machines do I need?
- How much inventory should I have?

**Value Chain Excellence:** High On-time delivery, low cost, low inventory

To drive profits, there are many levers a supply-chain executive must control

- **Capacity**
  Ours or outside?

- **Customer Delivery**
  What is the wait?

- **Inventory**
  How much, where?

- **Classes of product**
  - Standard “quick-ship”?
  - Custom?

The Project Production Manager

- **Capacity**
  Ours or outside?

- **Customer Delivery**
  What is the wait?

- **Pre-fab**
  What, where?

- **Classes of project**
  - Standard?
  - Custom?
The goal of supply chain management

Many managers bounce back and forth and call it continuous improvement.
Project Production—no variability: demand = capacity, no waiting
Project Production—with variability: capacity > maximum demand

Start early but no waiting
Project Production—with variability:
max dmd > capacity > mean dmd

Start early and still late
Project Production—with variability: little extra capacity

Start early and very late
The Fundamental Factory Physics® Framework

Two *essential* components
- Demand
- Transformation

Two *structural* elements
- Stocks
- Flows

Buffers develop when *variability* is present.

Only three buffers:
1. Inventory
2. Time
3. Capacity

How it Works

\[
\begin{align*}
\frac{dp}{dt} &= (\{p, H\} - \eta p) dt + \beta dW \\
\frac{dq}{dt} &= \{q, H\} dt \\
p(0) &= p_0 \\
q(0) &= q_0
\end{align*}
\]

There’s physics behind Factory Physics science.
Demand—Stock—Production

Production

Target

Net Inv = 0

Avg Dmd = 5/day

Production = 5 – Net Inv

Stock

Demand

More variability in production—Less variability in net inventory
Low variability in production—High variability in net-inventory
Buffers in Project Production

- **Inventory**—pre-fabrication
  - Prefab units
  - Prepare materials (e.g., rebar, etc.) before hand

- **Time**—quoting lead times
  - Lead time depends on current queue.
  - Average lead time will be less then using a constant lead time for same on-time delivery

- **Capacity**—mitigate variability
  - Recourse capacity (e.g., extra shift, weekend, overtime)
  - No recourse = delays
Application of Factory Physics Analytics
Some Basic Factory Physics Principles

- **Little’s Law**
  - Relates basic plant performance measures
  
  $WIP = (Cycle\ Time)(Throughput)$

- **VUT Equation**
  - Quantifies queueing effects
  - Relates variability, capacity, and time buffers

  $CT_q \approx V \times U \times t$
  
  $\approx \left( \frac{c_a^2 + c_e^2}{2} \right) \left( \frac{u}{1-u} \right) t_e$

- **Variance of Replenishment Time Demand**
  - Drives inventory and service
  - Accounts for variability in demand AND supply

  $\sigma^2 = t \sigma_D^2 + d^2 \sigma_T^2$

Appropriate use provides predictive control and optimal performance.

Law: Cycle time increases sharply as utilization goes to 100%

You will not schedule at 100% utilization over the long term.

Performance Graph for Throughput, WIP and Cycle Time

Best combination of Revenue, Working Capital, and Response Time
Efficient Frontiers for Stock

- Average On Hand Inventory vs. Fill Rate
- Current - 40 orders/3 months
- Optimal Policies
- 40, 80, 160

Set optimal RM, Kanban, and/or FG for desired customer service.
Best Possible Performance Goals

Flows
• Maximum throughput with minimum cycle time

Stocks
• Highest service level at minimum cost

The final measure is cash flow.
The Factory Physics approach provides complete, predictive control.
Managing Working Capital

An overview of what is possible.
Case I: *Learning to See*
by Rother and Shook

- **Two Parts**
  - Left Bracket $10.00
  - Right Bracket $1.00

- **Time in system**
  - Raw material 5 days
  - Work in process 14 days
  - Finished goods 12 days

- **Working capital for two parts**
  - Finished goods $83.5 K
  - Work in process $91.3 K

- **On time delivery** 88%

- ~ 1 hour per day
Current State Map

Source: Lean Enterprise Institute

Current State

Absolute Benchmarking

Flow Benchmarking Brackets

Overview of the Process

1. **Determine the efficient frontier** (i.e., min inventory investment for given service level)

2. **Move to the frontier** by optimizing policies

3. **Move the frontier** with improvements to the operation

4. **Move to the new frontier** by re-optimizing the policies and continue

The Process

- Reduce Inventories
  - Little’s Law
  - Optimize lot sizes, safety stocks
  - Optimize Inventory

- Reduce WIP
  - Reduce variability and waste

- Repeat
Step 1

- Reduce Inventories
  - Optimize Inventory

- Reduce WIP
  - Little’s Law
  - Optimize lot sizes, safety stocks

- Repeat
  - Reduce variability and waste
- Optimize inventory controls
- No change to environment (yet!)

**Results**

- Reduce inventory from $83.5K to $76.4K
- Increase fill rate from 88% to 89%
Step 2

- Reduce Inventories
  - Optimize Inventory
  - Little’s Law
  - Optimize lot sizes, safety stocks

- Reduce WIP
  - Reduce variability and waste

Repeat
Control WIP with Little’s Law

CONWIP Control

Start next job whenever WIP falls below maximum level
WIP remains mostly “constant”

CONWIP is a general pull strategy
that can be used in a high-mix environment
Control WIP—Check Throughput

- Optimal Lot Sizes
- Virtual Queue (throughput check)
- Active WIP
- Planned Lead Time
- Optimal CONWIP Level
- Optimal Inventory Policy
- Stock
  - For make-to-stock
  - Early completions

When Virtual Queue exceeds limit …
Use “recourse” capacity or push out due dates

Before and after reducing WIP

**Cycle time** = 14.0 days  
**WIP** = 91.3 K$

**Cycle time** = 11.9 days  
**WIP** = 77.9 K$

Step 2—continued

- Optimize Inventory
- Little’s Law
  - Optimize lot sizes, safety stocks
- Reduce variability and waste

Reduce Inventories
Reduce WIP
Repeat

Before and after optimizing lot sizes

<table>
<thead>
<tr>
<th>Metric</th>
<th>Before Optimization</th>
<th>After Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle time</td>
<td>11.9 days</td>
<td>2.7 days</td>
</tr>
<tr>
<td>WIP</td>
<td>77.9 K$</td>
<td>16.9 K$</td>
</tr>
</tbody>
</table>
Repeat Step 1 for improved environment

- Reduce Inventories
  - Re-optimize Inventory

- Reduce WIP
  - Little’s Law
  - Optimize lot sizes, safety stocks

- Repeat
  - Reduce variability and waste
Before and after re-optimization

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill Rate</td>
<td>89%</td>
<td>95%</td>
</tr>
<tr>
<td>FG</td>
<td>76.4 K$</td>
<td>24.6 K$</td>
</tr>
</tbody>
</table>

Step 3: Reduce variability and waste
Re-optimize

- Optimize inventory
- Little’s Law
- Optimize lot sizes, safety stocks
- Reduce variability and waste

Repeat
Reduce variability and waste

- Better balance of line.
- Employ standardized processes in the work place using 5S
- Reduce down time with FMEA and SMED.
- Re-optimize after improving environment
Before and after reducing variability and waste

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill Rate</td>
<td>= 95.0%</td>
<td>= 98%</td>
</tr>
<tr>
<td>FG</td>
<td>= 24.6 K$</td>
<td>= 5.55 M$</td>
</tr>
<tr>
<td>WIP</td>
<td>= 16.9 K$</td>
<td>= 3.70 M$</td>
</tr>
<tr>
<td>Cycle time</td>
<td>= 2.7 days</td>
<td>= 0.60 days</td>
</tr>
</tbody>
</table>

Initial and Final States

<table>
<thead>
<tr>
<th>Initial State</th>
<th>Final State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill Rate</td>
<td>88%</td>
</tr>
<tr>
<td>FG</td>
<td>83.5 K$</td>
</tr>
<tr>
<td>WIP</td>
<td>91.3 K$</td>
</tr>
<tr>
<td>Cycle time</td>
<td>14 days</td>
</tr>
</tbody>
</table>

Eliminated all overtime.

Conclusions

- The improvements were dramatic

- The improvements were the result of changing both
  - The policies (larger improvements) and
  - The environment (smaller improvements)

- Lean and Six Sigma focus on the environment

- Factory Physics methods can optimize policies and identify improvement opportunities in the environment