"Lean Engineers make things cheaper, better, faster, in a green, flexible way"
# HISTORY OF FACTORY DESIGNS

<table>
<thead>
<tr>
<th>1700-1850</th>
<th>NO FACTORIES CRAFT/COTTAGE</th>
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<tbody>
<tr>
<td>1840-1910</td>
<td>FIRST FACTORY DESIGNS</td>
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<tr>
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<td>JOB SHOP AMER.</td>
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<td>AROMORY</td>
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<td>POWERED MACHINES</td>
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<td>INTERCHANGEABLE PARTS</td>
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<td>1910 -1970</td>
<td>MASS PRODUCTION</td>
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<td>MOVING ASSEMBLY LINE</td>
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<td>FLOW SHOP- AUTOMATION</td>
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<td>STANDARDIZATION</td>
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<td>1970 - NOW</td>
<td>LEAN PRODUCTION – TPS</td>
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<td>LINKED-CELL MFG SYSTEM</td>
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<td></td>
<td>DESIGN</td>
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MASS PRODUCTION SYSTEM

FINAL ASSEMBLY

SUB-ASSEMBLY
FLOW LINES

CONVEYOR
TRANSFER LINES

FUNCTIONAL DESIGN
LARGE Batches

CONVEYOR LINES
Flow Lines
Transfer Lines

LINE BALANCING
MRP DIVISION OF LABOR

LINE BALANCING
CONVEYOR TRANSFER LINES

JOB SHOP

Lathes
Mills
Drills
Saws
Shipping receiving
Final inspection
Grind
In the Linked-cell manufacturing system, the cells are linked with controllable inventory buffers call kanban links or loops.
Figure 1. The mass production system on the left is compared to the lean production system on the right. Subassembly and manufacturing cells are linked by kanban to final assembly, creating a linked-cell manufacturing system.
Lean Engineering

The Lean Engineer (LE), has an IE foundation, enhanced with lean tools, six sigma capability and a lean to green outlook. Non-value adding work is waste. To remove waste from the system, the lean charged with:

- The design of a mixed model final assembly line to level demand on the supply chain.
- The design of subassembly cells using rabbit chase, sub-cells or TSS to eliminate conveyer lines and line balancing.
- The design of manufacturing cells using existing equipment to eliminate the job shop with its functional design.
- The design of quick change work holders and cutting tool holders for the manufacturing cells.
- The integration of quality tools and defect prevention devices, in-line inspection devices, including poka-yokes and decouplers.
Lean Engineering Contd..

- The integration of safety devices, walk away switches, automatic unload mechanisms and ergonomic improvements.
- The development of one piece flow processes for operations like painting and heat treatment and inspection.
- The development of machine tools for true lean manufacturing cells, designed and built for the manufacturing cells.
- The last step requires lots of creativity and innovation to design and build and implement machine tools for the cells with narrow footprints, rapid tool and work holder exchanges, in-process inspection, rapid unload and load for one-piece flow, good ergo and safety features and one-piece flow operation built around standard work.
LEAN ENGINEERING

- Mixed Model Final Assembly (Flexibility and Leveling)
- Self – Balancing Sub Assembly Cells (Flexibility)
- Cellular Mfg. / Standard Work
- Setup Reduction / SMED
- Integrated Quality / 7 tools and Six Sigma
- Integrated PM / TPM
- Value Stream Mapping
- Kanban (Inventory and Production Control)
- Continuous Improvement (KAIZEN)
- Elimination of Waste / 5S
- Lean to Green Factory Design
FIVE DESIGN RULES FOR LEAN PRODUCTION

TAKT TIME RULE

SELF-BALANCING SUB-ASSEMBLY RULE

CELL DESIGN RULE

SMED RULES

KANBAN RULES
IN THE L-CMS UNDERSTANDING THESE DESIGN RULES IS TO UNDERSTAND HOW THE SYSTEM IS DESIGNED AND WORKS

- **RULE 1** $TT = \text{HR's Available in a Day}/\text{DD}$, where $\text{DD} = (\text{No. of Cars/Month})/(\text{No. of Days in Month})$
  
  Note: $\text{PR} = \text{Production Rate} = 1/TT$

- **RULE 2** MO-CO-MOO (OPF with defect prevention) using SBSA cells

- **RULE 3** $MT_{ij} < \text{NCT}$ where $\text{NCT} \equiv TT (1 - \text{allowance})$
  
  $\text{NCT} = \text{Necessary Cycle Time for Cells}$

- **RULE 4** SMED Rules and Methodology

- **RULE 5** $K = \frac{(DD \times L + SS)}{a}$ (Little's Law - Operational Version)
LITTLE’S LAW \[ \text{WIP} = \text{TPT} \times \text{PR} \]

THE WIP (WORK-IN-PROCESS) IS RELATED TO THE THROUGHPUT TIME (TPT) AND OUTPUT RATE (PR) BY

\[ \text{TAKT TIME} = \frac{1}{\text{PR}} \]
RULE 1 TAKT TIME RULE

Level & Balance the manufacturing system – make final assembly mixed model – cells produce the daily demand. Sequence and Synchronize.

The lean production system depends upon smoothing the manufacturing system (Toyota's terminology). In order to eliminate variation or fluctuation in quantities in the supply chain, it is necessary to eliminate fluctuation in the final assembly by MMFA.

\[
DD = \text{average daily demand for parts} = \frac{\text{Monthly demand (forecast plus customer orders)}}{\text{Number of days in each month}}
\]

\[
PR = \frac{\text{Average daily demand (parts)/shift}}{\text{Available hours/shift}} = \frac{DD}{\text{Hrs/day}} = \frac{\text{parts}}{\text{minute}}
\]

\[
TT = 1/\text{production rate for final assembly (FA)} = 1/PR
\]

\[
TT = \frac{\text{Available hours/shift}}{\text{Available DD/shift}} = \text{TAKT TIME for final assembly}
\]
RULE 2 SBSA RULE

Redesign the subassembly lines into U-shaped Self-Balancing-Subassembly cells that operate flexibly with OPF to match final Assembly needs.

MO-CO-MOO = Make One – Check One – Move One On with output a linear function of the Number of Operators in a cell.

![Graph showing output per hour vs. number of workers.](image-url)
**Before:** Layout with conveyor—Subassembly with two conveyors

**After:** U-Shape layout—Conveyors removed

### Measurable Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Units/Sh</td>
<td>700</td>
<td>1056</td>
</tr>
<tr>
<td>WIP/SOH</td>
<td>750</td>
<td>8</td>
</tr>
<tr>
<td>Operators</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Output/person per day</td>
<td>70</td>
<td>132</td>
</tr>
<tr>
<td>Cycle Time (Min)</td>
<td>0.6</td>
<td>0.43</td>
</tr>
</tbody>
</table>
Allocation of six workers to the frame area

Cycle time
165 sec/unit

Allocation of eight workers to the frame area

Cycle time
120 sec/unit

W = walking worker
RULE 3 LEAN SHOP RULE

\[ MT_{ij} < CT \]

Where \( CT = \) Cycle Time for Cell

Cell Cycle Time is based on Takt Time

where \( CT = TT \times (1 - \text{allowance}) \)

and \( MT_{ij} = \text{machining time} \)

\( i = \text{no. of products in family} \)

\( j = \text{no. of SCA’s in cell} \)

THE MACHINE TOOLS ARE SINGLE CYCLE AUTOMATICS (SCA’S)
CELL DESIGN

THE JOB SHOP IS
RESTRUCTURED
INTO
MANUFACTURING
CELLS
The machines in the interim cell are modified to process a family of parts, reducing setup.

BEFORE

A
B
C
D

Table

Handwhee

Feed

Drill

A
B
C
D

Turn-table holds four fixtures

AFTER

Drill

Counter weight to maintain vertical alignment of turret

Table at correct ergonomic height

Typically, a machine that has four jobs, with four different fixtures or jigs, would need four different setups, each consisting of changing fixtures or jigs and alignment.

After redesign, the four fixtures are mounted on a turntable and are permanently aligned to the spindle when locked in position. Turret replaces single spindle. Automatic feed can replace handwheels.
MANNED INTERIM MANUFACTURING CELL WITH TWO WORKERS

Key:
S = Saw
L = Lathe
HM = Horizontal milling machine
VM = Vertical milling machine
G = Grinder

= Worker positions

Paths of workers moving within cell
Material movement paths within cell

Decoupler
RULE 4 SMED (SHINGO)

1. Determine what is happening now – video the setup
2. Separate the internal from external elements
3. Shift internal to external
4. Eliminate Adjustments

REDUCE SETUP / CHANGE OVER TIME TO MINUTES (BELOW CT)
FIGURE 43-7 How setup flows through the cell.
RULE 5 KANBAN RULE

\[
K = \frac{(DD \times L + SS)}{a}
\]

K = No. of carts; a = cart size, L = Lead time, SS = Safety stock
DD = Daily Demand = Cars/day
Ka = DD \times L + SS = inventory in a link

**Little's Law** = WIP = TPT \times PR (for any manufacturing system)

Where, TPT = Throughput time and PR = Production Rate of output

WIP = TPT \times PR (units in the system)

= TPT/TT (units in inventory)

For A Link

Ka = L \times DD = WIP = TPT \times PR

For A System

So Σ L for a series of LINKS = TPT for system

Note: DD = Cars/Day = PR = Cars/Day
LEAN MANUFACTURING CELLS

- Flexibility:
  - Mixed Model Final Assembly
  - Rapid tooling changeover in cells
  - Rapid modification for new products
  - LTFC Design to scale up or down
  - MO – CO – MOO operation in Sub Assembly

- Design Manufacturing Cells for One – Piece Flow, Maintainability, Reliability, Durability

- Quick Tooling Exchange

- Single Cycle Automatics

- Integrated Quality – 7 Tools, Poka – yokes and Decouplers

- Design Machine for Lean Cells
THE NEW INDUSTRIAL ENGINEER

When the Toyota Motor Company and Taiichi Ohno invented the Toyota Production System, they also redefined the profession of industrial engineering which grew up and flourished with the mass production system. This new engineer, a lean engineer, must be able to design a mixed model final assembly lines for zero defects, design of manufacturing and subassembly cells for one-piece flow, design of tooling (work holding and cutting tools) for rapid changeovers, and implement (pull) production/inventory control system called Kanban), all part of the design of the lean manufacturing system.
This is a good example of the design of the modern job shop with machine tools collected in areas. The induction hardening (I.H.) furnaces for quench and temper operations and the drawing (tempering) furnaces work on large batches. After heat-treating, the bars are straightened (s), then sent out for crack detection, then returned to the plant for grinding.
Figure: Standard work sheet for Rack manufacturing cell as operated by two workers.

The NCT is 1 minute. The right end is a transfer line.
FIGURE 43-19 The broach as designed for the job shop is not a good machine tool for a lean manufacturing cell.
FIGURE 43-20  A broaching machine tool designed for a lean manufacturing cell.
The Lean Management formula for success is to treat the external customers like guests and the internal customers with respect.

JT. Black
Lean in Healthcare Panel Discussion

Victoria Jordan, PhD, MS, MBA
Director, Quality Measurement and Engineering,
University of Texas MD Anderson Cancer Center
UT Chancellor’s Health Fellow for Systems Engineering
MD Anderson: Quick Look

• **Created:** 1941
• **First patient:** 1944 (more than 900,000 patients treated overall)
• **Ranking:** No. 1 in cancer care, America’s Best Hospitals, U.S. News and World Report (top-ranked 10 of past 12 years)
• **Employees:** 19,655
• **Faculty:** 1,671
• **Volunteers:** 1,200
• **Trainees:** 6,474
• **Average number of operating beds:** 656
• **Research grants:** No. 1 in grants awarded and total grant dollars by the National Cancer Institute
• **Active clinical research protocols:** 1,065 (about 7,600 patient registrants)
What is special about hospital systems and the role of Lean Engineering?

- The challenge of Systems Thinking
- Difficulty of strategic planning in an academic medical center
- Costs are not typically measured
- Improvements help people
  - “Why do you make me wait... as I have so little time”
- Efficiency is critical to reducing the cost of healthcare
“I know that, among the important dimensions of quality – safety, effectiveness, patient-centered care, timeliness, efficiency, and equity – I am not sure any of us would have chosen “efficiency” – the reduction of waste – as our favorite. It’s not my favorite. Nonetheless, it is the quality dimension of our time.”

“I would go so far as to say that, for the next three to five years at least, the credibility and leverage of the quality movement will rise or fall on its success in reducing the cost of health care – and, harder, returning that money to other uses – while improving patient experience.”
Why can Lean and 6-sigma “never be separated”?

• “Lean-Six Sigma”
• Lack of continuous metrics
• Biggest opportunity is reduction of waste
Lean Improvements at MD Anderson

Courses (> 600 employees trained)
• 1-day course for team member
• 2-day course for team leaders
• 2-day additional course for trainers
• System-wide “train-the-trainer” class developed in 2013

Examples of lean improvements:
• 80% reduction in interdepartmental transfers and 48% reduction of on hand inventory of consumable supplies in Perioperative Enterprise resulted in annual labor savings of $47,376, and the material restocking lead time went from 33.1 to 8.3 hours
Lean Efforts at MD Anderson (continued)

- Reduced patient wait time **Leukemia Center** and reduced walking distance for the patient by 90% from 680 feet to 70 feet.

- **Pharmacy** – 22 projects completed (136 employees and 15 managers trained.) Projects resulted in improvements (with no additional investment) that include a 67.5% reduction in chemotherapy waste, generating annual savings of $578,640, and a 40% reduction in process time for telephone prescription, resulting in time savings that translate to an estimated $25,000 per year; Reducing TAT of dispensing meds in EC Pharmacy by 84%, reducing total number of inventory items in G14 chemotherapy satellite by 56%, decreasing TAT for patients to obtain high-dollar prescription by 83%, and reducing the average time for dose preparation by 36% are some of the example of the results. Total savings > $1 million (2nd place, 2013 IIE Lean Best Practice Award)
# Quality Improvement Gains for Pathology & Laboratory Medicine

<table>
<thead>
<tr>
<th>83 Projects: FY2004 – FY2013</th>
<th>Annualized</th>
<th>Cumulative</th>
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<tbody>
<tr>
<td>Revenue Enhancement</td>
<td>$6.8M</td>
<td>$29.3M</td>
</tr>
<tr>
<td>Direct $ Savings</td>
<td>$1.1M</td>
<td>$5.3M</td>
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<tr>
<td>Cost Avoidance</td>
<td>$4.8M</td>
<td>$7.1M</td>
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<table>
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<tr>
<th>% Improvement</th>
<th>Average</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>Turnaround Time Reduction</td>
<td>40%</td>
<td>11% - 82%</td>
</tr>
<tr>
<td>Error Reduction</td>
<td>55%</td>
<td>12% - 88%</td>
</tr>
<tr>
<td>Personnel Time Saved</td>
<td>60%</td>
<td>30% - 89%</td>
</tr>
</tbody>
</table>

Lab Wait Time Saved per week 33,000 hours

Internal / UT System Recognition: 40 Projects

2012 IIE Lean Best Practice Award
Why is the Lean Engineer needed as a new discipline?

- Healthcare is over 18% of GDP

- Lean is important to improving efficiency and reducing cost in healthcare

- Coordinated, professional guidance is necessary

- Lean Engineers as a subset of Industrial and Systems Engineers
"Lean Engineering", Graduate Education and Research Issues

F. Frank Chen, Ph.D.

Lutcher Brown Distinguished Chair

The University of Texas at San Antonio
Principles of Lean

• Let customers identify **Value**
  – Companies provide what customers really want
  – A product/service is not just an object, but a whole experience

• **Identify the Value Stream**
  – Value Stream: Sequence of all activities and resources required to bring a product/service to customers

• **Make the value stream Flow**
  – Create smooth and uninterrupted flow for products/processes

• **Pull from downstream**
  – Operations are performed when needed, not before

• **Always pursue Perfection**
  – Continuous improvement is a way of life

(Womack & Jones, 1996)
Six Sigma Improvement for Both Manufacturing and Non-Manufacturing Processes

Same Lean and 6 Sigma tools applicable to input-process-output systems at manufacturing or non-manufacturing organizations
An Exemplary Model in Use by University of Alabama-Huntsville

Lean Engineering Graduate Programs/Research – Enterprise Problem Orientation with “Systems” Perspective

- **Depth** in a chosen area (e.g., Manufacturing Systems, Operations Research, Human Factors/Ergonomics, Management Systems, etc.)
- **Breadth** with enterprise systems and global business perspectives (e.g., modeling and optimization at the supply chain level using systems approach).
- “**Future Professoriate Program (FPP)**” : prepare students for professorial careers in higher education (e.g., Virginia Tech model)
Lean Engineering Graduate Programs/Research-with Center/Institute facilitated projects

• Industry-government-university cooperative research centers/institutes often provide best project opportunities for graduate students

• Graduate students working in center/institute projects are more inspired and more likely to complete their research requirements in a timely manner.

• Graduate students will become better researchers and are better prepared for future employers
Lean Engineering Research Opportunities (I)

• Concurrent development of People, Processes and Technologies/Tools to enable successful Lean Implementation at enterprise-wide level.
  – New Technologies and tools are useful only if they enable people to conduct more efficient and effective processes.
  – People/Human Resources are the key to determine if new processes are even needed, and if new tools/technologies are even needed to conduct process improvement.
Lean Engineering Research Opportunities (II)

• **From Lean to Green**: Exploring Green Value Stream Thinking
  – New performance metrics
  – Revised Lean tools and concepts
Lean Engineering Research Opportunities (III)

• Creating a Lean and Green Business System
  – Lean and Green **Business Process** management
  – Lean and Green Business **Leadership**
  – Lean and Green **Strategy Deployment**
  – Lean and Green **Supply Chain Collaboration**
Lean Engineering Research: Summary

• Tools and Methodologies are developed only if they contribute to improved processes or systems.
• Standardization of Lean tools and their implementation methodologies is a must (to make Lean Engineering as a new branch of applied science).
• Research in applying Lean Engineering approach to non-manufacturing functions and processes is a must.
Launching a New Engineering Discipline

*The Lean Engineer*

Dr. Don T. Phillips, Ph.D, PE

Dr. JT. Black, Ph.D, PE
What is an Industrial Engineer?

*Industrial Engineering* is concerned with the design, installation, operation and continuous improvement of integrated systems of men, materials and machinery; drawing upon specialized knowledge and skills in the mathematical, physical and social sciences, together with the principles and methods of engineering analysis and design, to specify, predict and evaluate the results to be obtained from those systems.
Six Sigma Engineer is any engineer who strives to achieve defect-free manufacturing performance. The six sigma engineer is basically concerned with variance reduction; and uses a wide variety of statistical analysis tools to achieve that goal. Root Cause Analysis, data analysis, design centering and Statistical Experimental Design methodologies are core tools. Six Sigma Engineering also involves a management structure and organizational commitment to relentlessly pursue Continuous Productivity Improvement.
What is a Lean Engineer?

**Lean Engineering** is concerned with the design, installation, operation and continuous improvement of integrated systems of men, materials and machinery. Lean Engineering draws upon the fundamental principles of Industrial and Systems Engineering, Six-Sigma and Lean Thinking to reduce waste, improve System performance measures, promote Quality Assurance and increase customer satisfaction; drawing upon the specialized skills of ergonomics, human factors, statistics and systems analysis to design, evaluate, implement and improve operational systems.
Pedagogical Foundation

**LEAN ENGINEERING**

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<th>Industrial Engineering</th>
<th>Lean Thinking</th>
<th>Lean System Design</th>
<th>6-Sigma Engineering</th>
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<tr>
<td>Waste Reduction</td>
<td>Variance Reduction</td>
<td>RAM Technologies</td>
<td>Continuous Improvement</td>
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<td>Zero Defects</td>
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<td>Lean Production Cells</td>
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<td>WIP Reduction</td>
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<tr>
<td>Lean supply Chain</td>
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Industrial Engineering

- Ergonomics
- Human factors
- Methods Analysis
- Standards
- Workstation Design
- Production Planning & Control
- Operations Research
- Management and Control
- Systems Simulation
- Materials Handling
- Warehousing & distribution
- Supply Chain Management
Lean Thinking

- Banish Waste
- Improve System Performance Measures
- Reduce Variance
- Reduce WIP
- Empower Workers
- Cross Train Workforce
- Quality is Everyone’s Responsibility
24th International Conference on Flexible Automation & Intelligent Manufacturing (FAIM)
Theme: Capturing Competitive Advantage via Advanced Manufacturing and Enterprise Transformation

- Pull vs Push...Push-Pull Interfaces
- Lean Work cells
- Poka-Yoke
- SMED
- Unit Flow
- Linked Cell Manufacturing System (LC-MS)
- Mixed-Model Final Assembly (MM-FA)
- Balance-Level-Synchronize (BLS)
- Just-in-Time and Supply Chain Integration
- Versatile and Flexible Systems Design
Lean Six-Sigma

- Variance Reduction – DOE / ANOVA / RSA
- Statistical analysis
- Data Mining / Data Integration
- Quality Function Deployment
- Process Capability Analysis
- Predictive Statistical Control Charts
- FMEA
- DMAIC
- Failure Mode Analysis
Summary and Conclusions

- Lean and 6-Sigma are here to stay
- Industry wants a Lean Six-Sigma Engineer
- Who will give Lean Engineering a home?
- Industrial Engineering is the best choice

_This is not a “fad’ but a revolution_

"Build a better mousetrap and the world will beat a path to your door."

_Ralph Waldo Emerson_