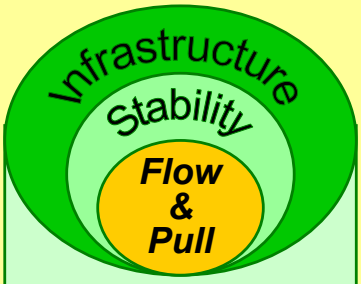
Appendix: Instructor's Comments and Class Discussion 7.4

- There are tradeoffs in structure of maintenance groups
  - Structuring by trade v. structuring by area of plant (depth or breadth?)
  - Separating maintenance and production groups v. integrated v. hybrid
  - Root cause problem solving v. reactive maintenance
- Educating management and maintenance teams is very important
- How should group leaders be found?

A Core Framework – Parts III, IV and V



Physical Systems & Social Systems

Look for:
- Material Flow
- Knowledge/Information Flow
- Hybrid "pull" Systems
- Transition States

Part I: Foundations – Infrastructure	
1.0	Lean Thinking
2.0	Six Sigma Principles Systems Change Principles
3.0	"Pre-Stability" Considerations
Part II: Stability	
4.0	Team-Based, Knowledge-Driven
5.0	Stakeholder Alignment
6.0	In-Process Station Control
7.0	Total Productive Maintenance
Parts III, IV and V: Flow & Pull	
8.0	Value Streams
9.0	Material Flow
10.0	Knowledge and Information Flow
11.0	Customer "Pull"
12.0	Industry Context
13.1	Transitions, Enterprise and Integration

Takt Time
Module 8.1

Colin Ducharme, LFM '06
Todd Ruddick, LFM '06

Mark Graban, Internal Lean Consultant for Honeywell (LFM '99)

Presentation for:
ESD.60 – Lean/Six Sigma Systems
MIT Leaders for Manufacturing Program (LFM)
Summer 2004

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Short History

***Takt*: German word for "baton"**

Refers to beat, timing, and regulation of speed

1930's: Germany, Japan collaborated within the Axis Powers

After WWII, Japan uses concept to organize its Just In Time system

Takt Time: Defined

GENERAL DEFINITION: *Takt Time* is the desired time that it takes to make one unit of production output.**

***CUSTOMER DRIVEN: Available Operating Time / Customer Demand**

e.g.-- 8 hours of Daily Operating Time / 4 units of daily demand = Takt Time of 2 Hours

***OPERATION DRIVEN: Available Operating Time / "Forecasted" Demand**

e.g.– 8 hours of Daily Operating Time / 5.7 units of forecasted demand = Takt Time of 1.4 Hours

Nominally this is an initial design variable that dictates the architecture of the entire manufacturing operation

***Takt Time* differs from *Cycle Time*, which is the actual time it takes to make one unit of production output.**

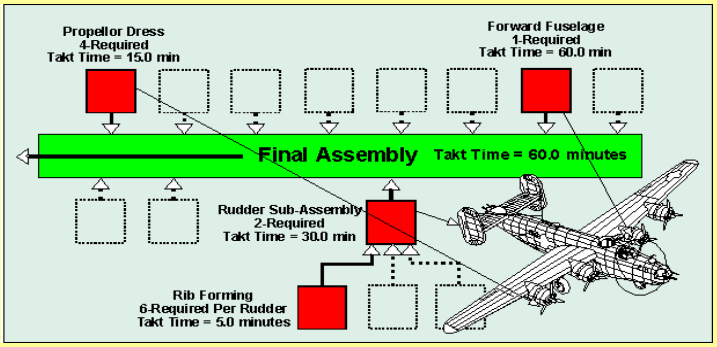
Real World Example: WWII B-24's

~1940: Charles Sorensen builds plant to output "a bomber an hour"

Stabilized operation by preventing inventory buildups, consequential stops and starts

A balance to the assembly process that ensures that all pieces arrive when they are needed

RESULT: Syncopated system with all pieces working in concert and a balance a balanced assembly line



Takt Time Disconnects

- **Technical Factors**
  - Need to be able to properly set the takt time for each operation
  - Once the operational takt time is set it can be very difficult to change (example: speeding up or slowing down an assembly line)
  - Hard to control customer demand fluctuations (order stability)
  - Difficult to ensure processes remain in control
- **Social Factors**
  - Workforce can be resistive to being told what speed to work at
  - A company controlled by finance may throw the system out of whack by forcing products to be made in order to meet/exceed a quarter point
  - Lack of trust in management's commitment to employees (Why should we work to improve a process if management will just lay us off?)

There are numerous reasons plants have trouble implementing takt time

Appendix: Instructor's Comments and Class Discussion for 8.1

- Takt time is at the heart of a value stream map
- Operations on the critical path work to the takt time, regulated by the constraint in the process
  - Feeder operations need not work to the takt time, but as waste is eliminated, interdependency increases and the takt time becomes more relevant
- Say more about the dynamics in assembly operations as compared to machining, continuous production, etc.

Machining Operations- *Cycle Time*

Module 8.2

Tamboura Gaskins, LFM '06
Sean Holly, LFM '06

Mentor: Professor Tim Gutowski
Professor and Associate Head of Mechanical Engineering, MIT
Brian Bowers, LFM '03

Presentation for:
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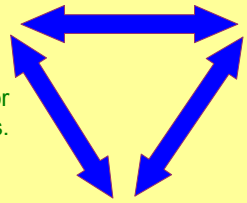
Cycle Time as Process *Cash Flow*

Just as cash flow is a direct measure of company financial performance, cycle time is a direct measure of process and equipment performance.

Cycle Time

The time to complete a task or collection of tasks.



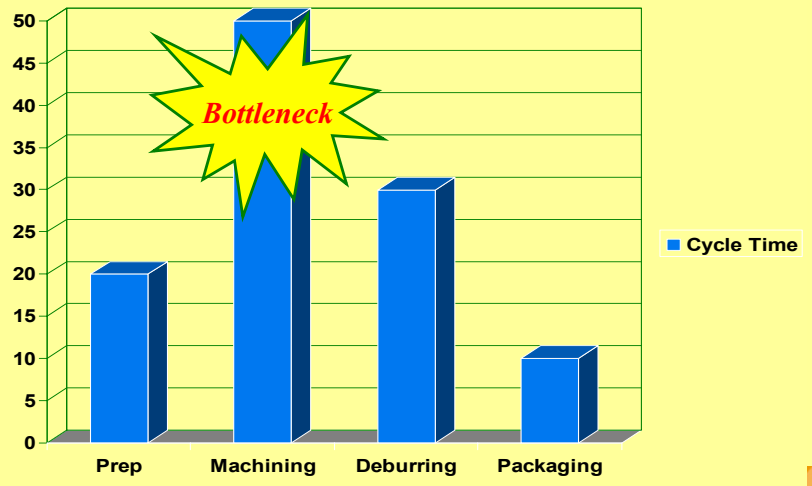
Throughput

The desired process throughput is inverse takt time.

Yield

The amount of product during a processing cycle

The Cycle Time Metric



Cycle Time at Work

Product Demand

500 units

Available Work Time

1 shift/day = 8.5 hrs – 0.5 hr (lunch) – 0.5 hr (breaks)=

450 mins.

Takt Time

450 mins./500 units =

54 secs./unit

The average time to make one unit of product. Inverted, it is the average throughput for the process.

The time to complete a task or collection of tasks from beginning to end.

Process Cycle Time

Σ(cycle times of each unit operation in the process) =

130 secs.

Work Balance

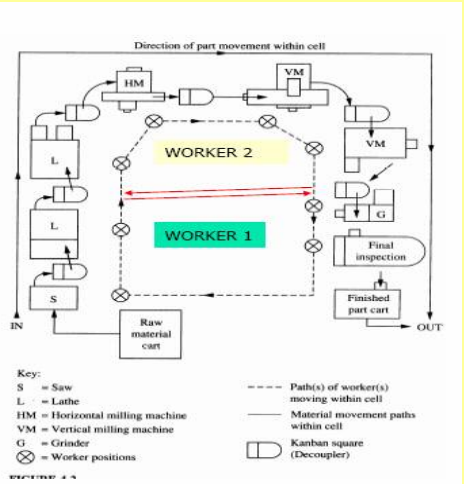
Work Cells (or operators) =

Process Cycle Time/Takt Time =

2.4 cells (operators)

Step 2: Balance the Load

	Manual (Sec)	Walk (Sec)	Machine (Sec)
Raw		3	
Saw	15	3	60
L1	10	3+3	70
L2	12	3	50
HM	12	3	120 → 80
VM1	20	3	70 → 80
VM2	20	3+3	60 → 90
G	15	3	60
F.I.	19	3 + 3	
Totals	**M+W**	**= 159**	**490**
Work 1		**80**	
Work 2		**79**	



Adapted from T. Gutowsky, Course 2.810

Connecting Cycle Time to Lean

- In a mass production setting, cycle time improvements are driven by management with the goal of maximizing machine productivity.
  - Cycle time improvements, such as that shown in step one, are easy for management to drive because machines are idle.
- In the Lean Model, cycle time improvements are driven by workers, based on their knowledge of the work and equipment, with the goal of increasing value added work and minimizing non-value added work.
  - Cycle time improvements, such as that shown in step two, require an intimate familiarity of both product and process that workers possess.

Disconnects

- *Technical Factors*
  - Relating cycle time to other performance metrics, such as yield and first-pass throughput
  - Prioritizing cycle time improvements to minimize production interruptions
  - Knowing when cycle time improvement is not the answer to productivity problems, e.g. when poor yield is a quality issue not a throughput issue
- *Social Factors*
  - Better communication in scheduling product orders to minimize set-up time and maximize production time
  - The knowledge possessed by the workers signifies the strongest leveraging point in an organization to drive continuous improvement.

Appendix: Instructor's Comments and Class Discussion on 8.2

- Cycle time is linked to other aspects of lean/ six sigma
  - Continuous improvement leads to stepped improvement in cycle once takt times come down for all steps
  - Standardized work is key to making cycle time work on the floor
- This module is particularly focused on machining operations, where cycle time is machine paced (in contrast to assembly operations)

Continuous Flow Operations
Module 8.3

Bret Awbrey & Jacob Silber

Chris Musso, MIT ESD

Presentation for:
ESD.60 – Lean/Six Sigma Systems
MIT Leaders for Manufacturing Program (LFM)
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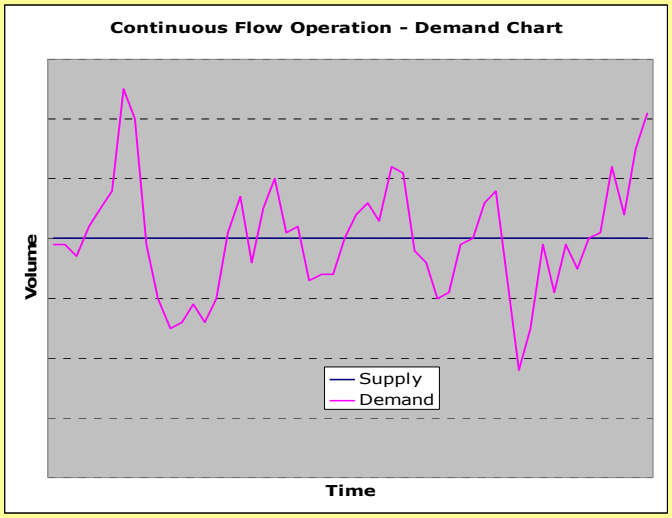
Continuous Flow – Defining Factors[2,3]

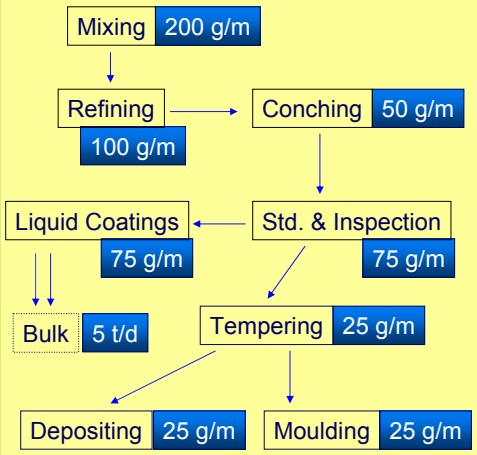
- High product volume
- Special purpose equipment (low flexibility)
- Uninterrupted product flow
- Few schedule changes
- Low number of standardized products
- Low variable cost (up to capacity level)
- Low labor skill (operators) during regular operations

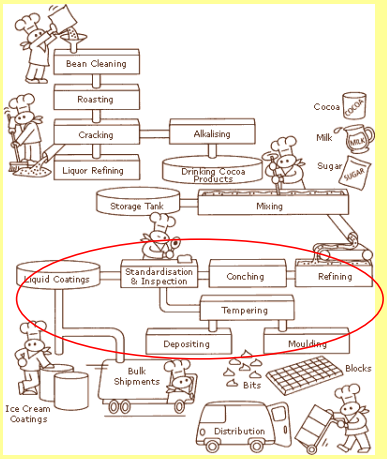
Typical Continuous Flow Supply vs. Demand



Variability of demand is the challenge in continuous flow operations

Chocolate Production Flow





Overall Equipment Effectiveness

- OEE = Availability x Performance Rate x Quality Rate
- Δ between capability and real output

- Options:
  - Inspect equipment for flaws, repair
  - Test equipment
  - Check original design document (original specifications)
  - Add inline tempering/conching unit (additional capacity)

Availability *(operating time/net available time) X*
Performance *((ideal cycle time x total parts run)/operating time) X*
Quality *((total parts run - total defects)/total parts run)*

Disconnects

- **Technical Factors**
  - Supply is typically constant, hard to change in a Brownfield operation
  - Initial design might not account for later improvements
  - Maintenance more difficult (downtimes may not exist)
  - High cost of production step-function
- **Social Factors**
  - Demand is typically variable
  - Operators typically have little input (chemical reactors, generators), so harder to get continuous improvement
  - High competition for lowest cost, commodity game

Appendix: Instructor's Comments and Class Discussion

- Key issue in continuous flow industries: balancing supply and demand
  - Economies of scale lead to continuous, large scale production—often more than market demands
  - Apparent economies become disabilities
  - Process industries often use financial instruments to make up for inability to scale to demand
- Socio-tech teams are often used instead of lean teams, since there is more meeting time and global focus on plant is required
- Scope of OEE is important: it can be for an individual machine, the bottleneck operation, an production operation or line, or an entire plant

Engineering Design Operations Cycle Time

Module 8.4

Mindy Hsu & Matt Hasik
6/28/04

Chip McDaniel
Ford Motor Company

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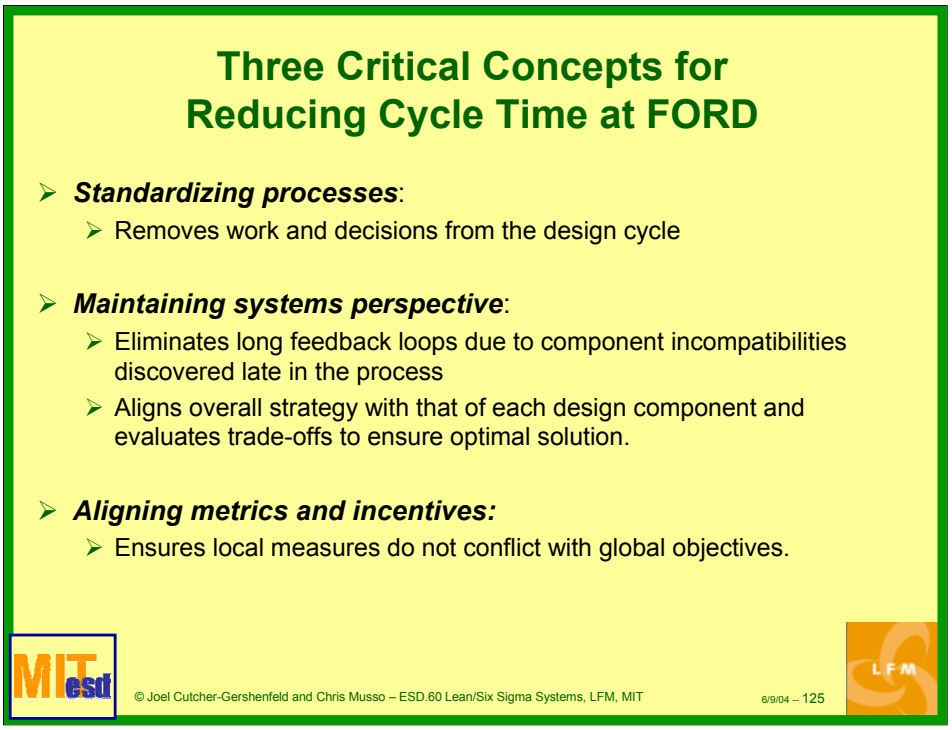


The lean designer/producer standardizes his work to maximize value-added

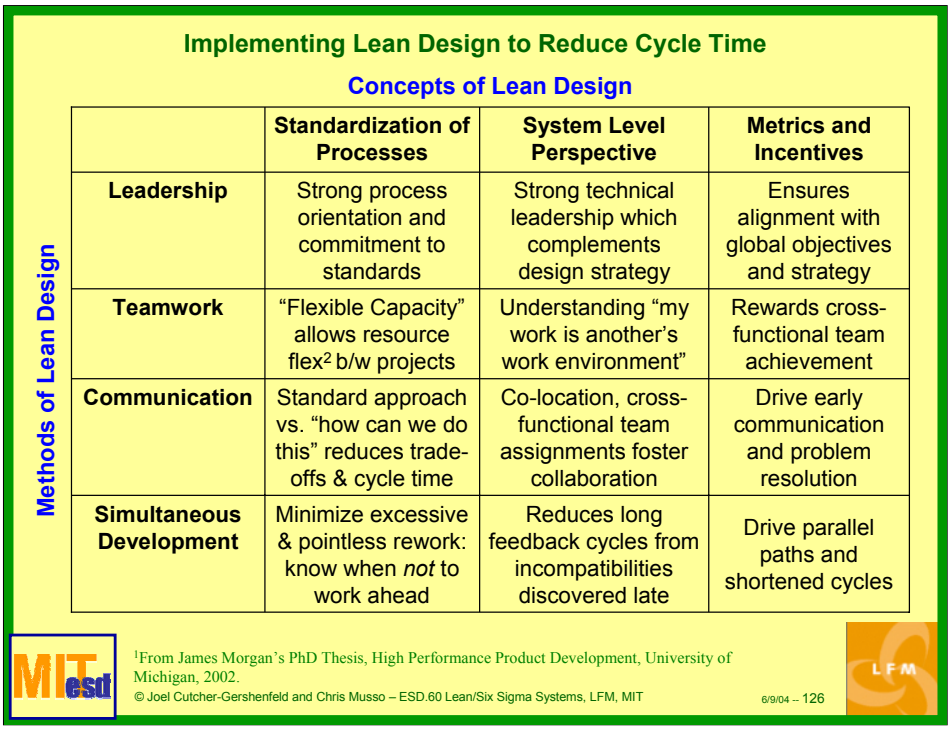
- Developing new methods of door welding will not be a priority for the new product program manager; instead, he relies on proven company practices
- Improvement to these practices are made, but not only for the one model, and not necessarily implemented during new model roll-out

Other designers/producers attempts to develop new/innovative methods on each new model designed, and to roll them out on the new model production.

- This work does not always add value
- Incentive system may be driving program manager to attempt to develop new methods for “his” product/launch
- Optimal incentives and metrics drive program managers to develop improved methods across multiple products
- To speed conflict resolution and reduce development time

Lean producer maintains system-level view of design process

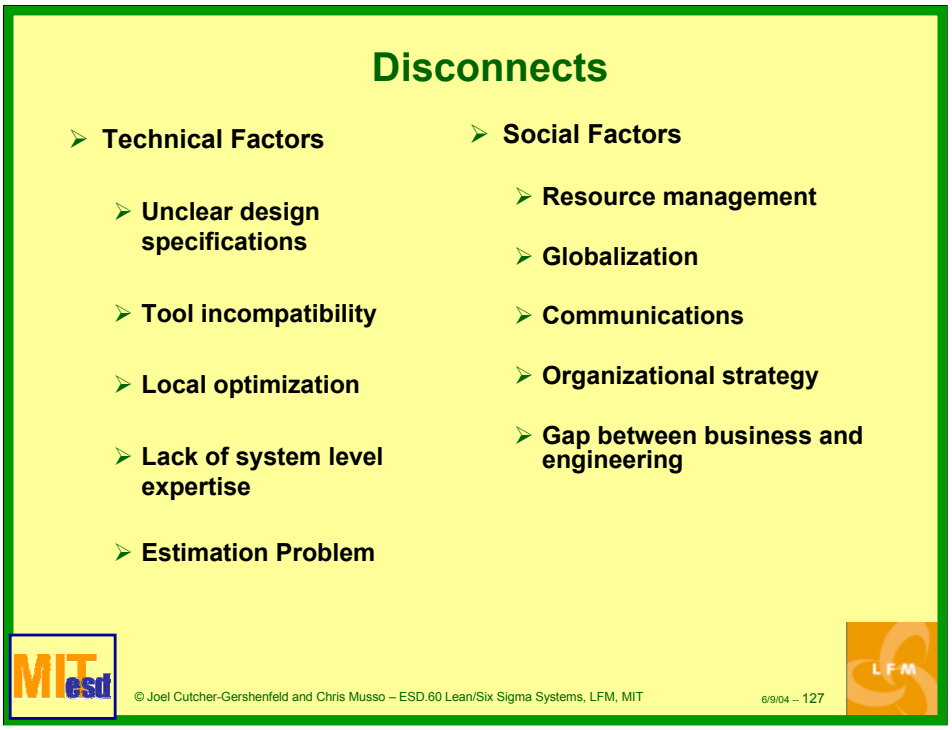
- Motorola example



•**Teamwork**--concept of "flexible capacity" in development resources (engineering personnel). Individuals can be flexed between products/projects due to standardized design approaches and corresponding standardized personal skill sets.

•**Communications**--there are simply fewer early trade-offs decisions to be made due to strong standards orientation (start from a standard approach versus start from "how can we do this").

•**Concurrent engineering-**-working ahead also has serious potential pitfalls leading to excessive and pointless rework. Must know two things: 1) how to work to appropriate "resolution" or detail for the design stage and 2) must know when NOT to work, e.g. working ahead is counterproductive--design equivalent of idle time on a non-constraint resource in a manufacturing facility. The extra work does not lead to additional throughput, it just piles up WIP.



Tech fac.

1) lack of design standards

2) between design phases, project completed globally. Compatible tools ensure smooth hand offs/ transitions

3) push off issues/problems somewhere else in the system

4) missing overall view. System doesn't work after combing all components

5) knowing the state of development in other organizations

Social Fac.

1) resource allocation. Enough? Geographic Locations?

2) language, time zone, culture, working habit

3) address issues/problems immediately. Communicate and confirm, especially "interfaces"

4) Incentives/culture that encourage collaboration?

5) must tie engineering into key market-driven activities in the company.

Engineering Design Performance by Regional Auto Industries, mid-1980s

	Japanese Producers	American Producers	European Producers
Average Development Time (months)	46.2	60.4	57.3
# of Employees on Project Team	485	903	904
Ratio of Delayed Products	1 in 6	1 in 2	1 in 3
Die Development Time (months)	13.8	25.0	28.0
Return to Normal Quality after New Model (months)	1.4	11	12

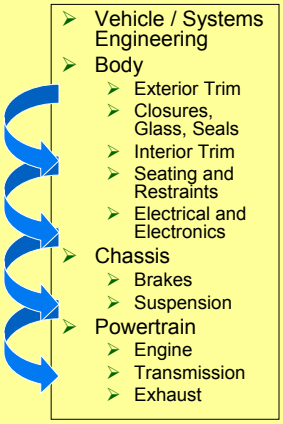
From *The Machine That Changed the World (Womack, Jones, Roos; 1990)*

Appendix: Instructor's Comments and Class Discussion

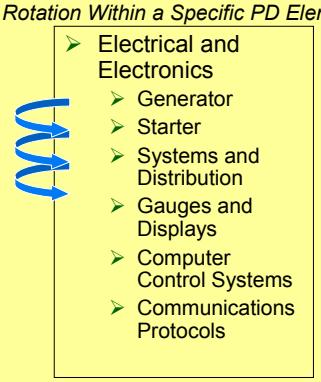
- The application of lean principles to engineering design is still being debated relative to process re-engineering, systems engineering, integrated product and process design teams, and other candidates
- Engineering process mapping and process improvement can have a huge impact on engineering cycle time
  - Co-location is important (Chrysler Development Center, BMW design center)
  - Many sources of waste exist in PD and can be targeted – adapting the 5Ss and the 7 Ws
- Upstream integration of manufacturing and downstream engagement of design (after launch) have high leverage
  - Making changes early sounds nice, and works well if *all* contingencies can be identified, or it can be extraordinarily expensive if contingencies are not identified and early changes have to be changed again later
- Consider the concept of "set based design" documented at Toyota
- See attached slides on career development in Product Development

Career Paths in Product Development

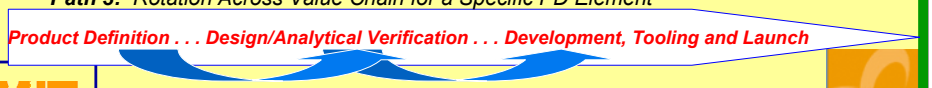
Path 1: *Rotation Across PD Elements*



Path 2: *Rotation Within a Specific PD Element*



Path 3: *Rotation Across Value Chain for a Specific PD Element*



Source: WorkMatters, LLC and Ford Motor Company

Sustainability
Module 8.5

Neil Bar – LFM '06
Todd Robinson – LFM '06
Kerry Person – LFM '06

Michael Miller
Six Sigma MBB – Operational Excellence
Amazon

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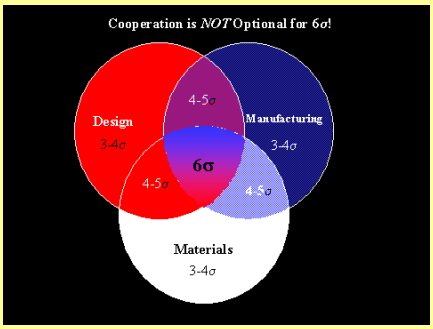
Three Perspectives on Sustainability

- Sustainability of a lean implementation initiative
- Sustainability of a product/business
- Sustainability of the environment

All have common "lifecycle" perspective

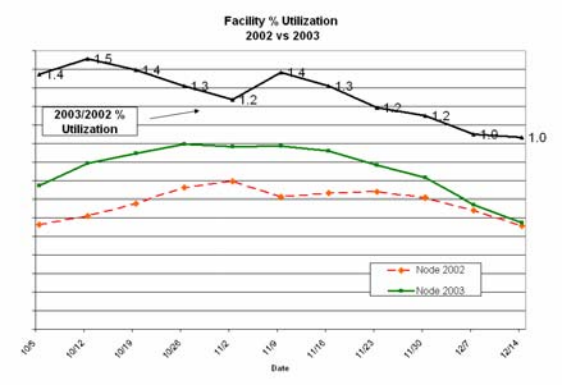
How Does Lean/Six Sigma Sustain the Business?

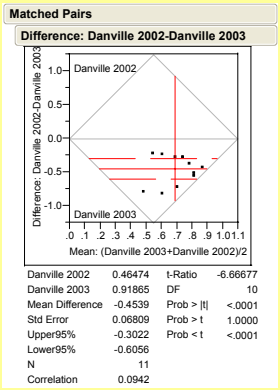
- Product Development
  - Helps to develop more capable processes.
  - Feeds high quality and manufacturable products into the factory.
  - Shortens product development time.
  - Defines product line in terms of customer value.
  - Allows quicker response to changing market demands and customers tastes



- Logistics
  - Reduces inventory requirements.
  - More adaptable to market changes.

Amazon Example: Space Utilization in Offsite Storage, cont.





Danville 2002	0.46474	t-Ratio	-6.66677
Danville 2003	0.91865	DF	10
Mean Difference	-0.4539	Prob > |t|	<.0001
Std Error	0.06809	Prob > t	1.0000
Upper95%	-0.3022	Prob < t	<.0001
Lower95%	-0.6056		
N	11		
Correlation	0.0942		

Statistics show that there is greater than 95% certainty that the 2003 trend was a result of the project implementation, and not an outcome of random chance.

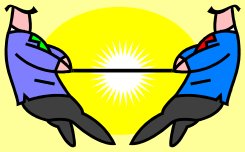
Data courtesy of Michael Miller, Amazon.com.

Examples from the Real World

- An attempt at 5S was attempted at a plant in a large consumer products company. It failed because:
  - No background was ever given as the reason it was being implemented. Why? Because we said so.
  - Leadership support consisted of random audits (of cubicles—not shops or control room) which were promptly round-filed by the recipient of the audit.
  - No one in the plant was consulted before the program was started—and no results were shared. So there was no incentive to support the program.

Common Disconnects

- **Technical Factors**
  - **Scenario:**
    6σ Black Belt – Systems Refrigeration
    GE Consumer & Industrial
  - **Problem:**
    * Objective – Minimize shipping damage in distribution network
    * Projects distributed by management
    * No knowledge-driven activities among employees in prioritizing customer Y
    * An alternative project may have yielded better results with fewer resources
- **Social Factors**
  - **Role Distinction & Awareness:**
    * Performance metrics & responsibilities
    * Black Belts vs. Green Belts
  - **Employee Buy-in:**
    * Old vs. Young generation
    * Entrenched attitude/mindset
    * Existing culture & ways of thought



Appendix: Instructor's Comments and Class Discussion on 8.5

- Long-term sustainability is very broad including:
  - Sustainability of a lean implementation, with issues of leadership turnover, follow-through in improvement suggestions, mitigation against destabilizing events, etc.
  - Sustainability of a product/service, attending to issues of end-of-life use, recycling, etc.
  - Sustainability of the environment, with issues of prevention, packaging, etc.
- Lean principles can be applied in each situation
- Metrics should be carefully considered
- Sustainability is a mindset, not a list of things to do – just like lean

Kanban/Supply Chain Sequencing Module 9.1

Michal Hovav, LFM 06
Sandeep Khattar, LFM 06

James Katzen, LFM'03, Pratt & Whitney

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Kanban - Defined

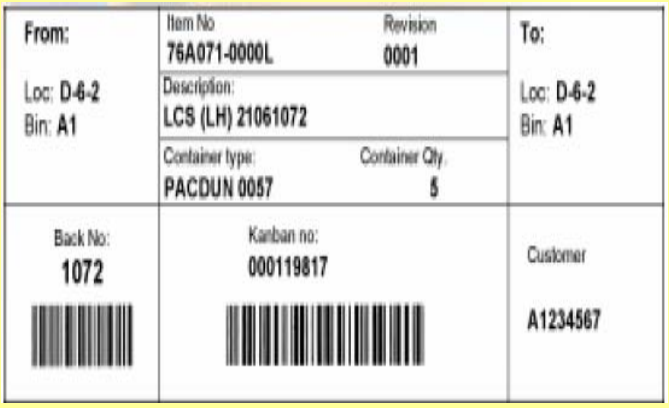
Kanban (Japanese):

Kan – card, ban – signal

- A visual tool used to achieve Just In Time production[1]
  - -Signals a cycle of replenishment for production and materials
  - -Maintains an orderly and efficient flow of materials throughout entire manufacturing process
  - -Authorizes production or withdrawal of parts/components
  - -Optimizes inventory levels to the minimum desired

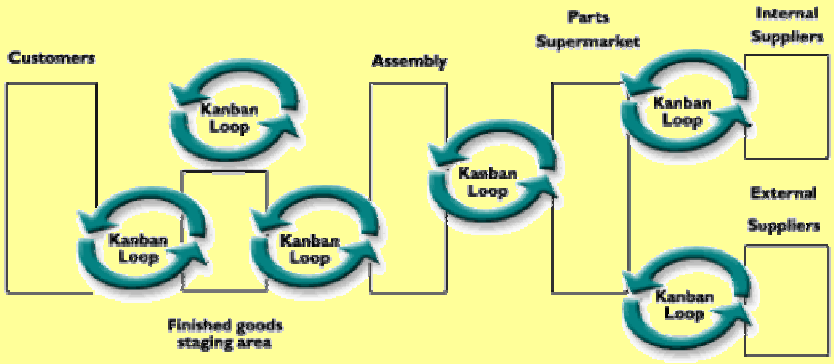
Sources: MIT LFM thesis by Sean Hilbert, and 'Lean Production Simplified' by Pascal Dennis

Kanban Card Example



Kanban – The Big Picture

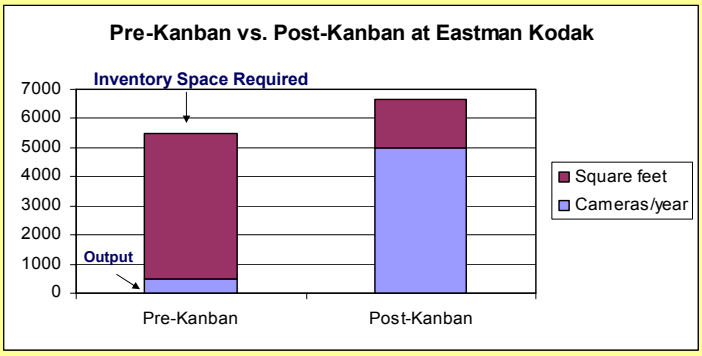
Kanban loops link demand to operations and to supply bases



Implementing Kanban will ensure that no over-inventory or over production occurs in each Kanban loop

http://www.blhumber.co.uk/site/operations/leanmanufacturing/kanban.asp

Eastman Kodak – Before and After Kanban Results



•**Went from 500 cameras/year using 5000 sq. feet to 5000 cameras/year using 1667 sq. feet**

Kanban - Common Disconnects

- **Technical Factors**
  - Sub-optimal quantity of kanbans in the system (need to calculate exactly how many are needed)
  - Improper infrastructure to support Kanban implementation
  - Payroll/Union contract regarding utilized/idle time will need to adjust
  - Insufficient value stream mapping (lack of knowledge)
- **Social Factors**
  - Automotive example: abuse of kanban system by workers tampering with the cards to get more breaks
  - Paradigm shift (from large to small inventories, 24-7 to idle time)
  - Lack of trust in the system (or in the down-stream customer) decisions

Appendix: Instructor's Comments and Class Discussion on 9.1

- The key issue in Kanban centers on the lot size triggered by the kanban card
  - Continuous improvement allows for operations with ever smaller lot sizes – approaching the limit of a lot size of "1"
  - This process is central to how the term "lean" emerged
- A parts marketplace allows for the use of Kanban with this temporary "buffer" that can be shrunk as suppliers become more capable
- Time delay in Kanban can be very challenging—the kanban should trigger pull that meshes with the cadence (takt) of the system.
- People can manipulate kanban
  - Automotive example: people would hide kanban cards when they wanted a 10 minute smoking break
  - Very important to get everyone on board
- Formulas can be found in lean books for optimal kanban size (similar to EOQ) and other dimensions

Parts Marketplaces and Parts Presentation
Module 9.2

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Alumni / Mentor / Coach: Lynn Delisle, LFM '01

Presentation for:
ESD.60 – Lean/Six Sigma Systems
MIT Leaders for Manufacturing Program (LFM)
Summer 2004

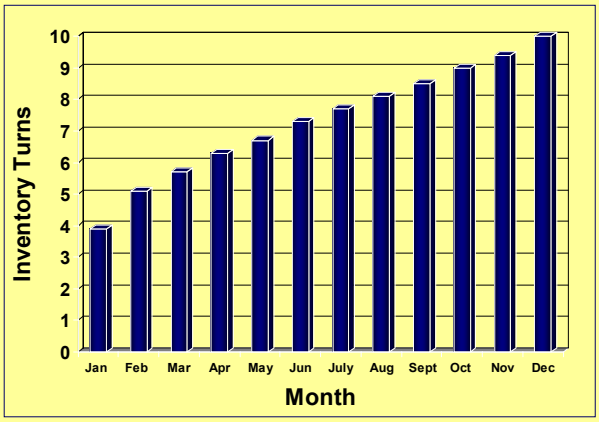
These materials were developed as part of MIT's ESD.60 course on "Lean/Six Sigma Systems." In some cases, the materials were produced by the lead instructor, Joel Cutcher-Gershenfeld, and in some cases by student teams working with LFM alumni/ae. Where the materials were developed by student teams, additional inputs from the faculty and from the technical instructor, Chris Musso, are reflected in some of the text or in an appendix

Parts Marketplace in Action

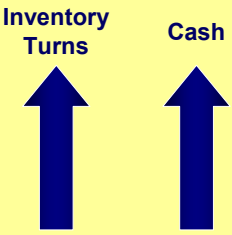
- **High** volume of parts per storage unit
- **Stationary** Storage - Mechanized movement required for delivery to production line

- **Low** volume of parts per storage unit requiring frequent replenishment
- **Movable Storage** – Wheeled parts bins enables transport to line and multiple pick-points

Financial Impact of Parts Marketplaces



$$\text{Inventory Turns} = \frac{\text{COGS}}{\text{Avg. Inventory}}$$



An Iterative Approach: Days of On-Hand Inventory Decrease over Time…Improving Cash Position

Key Concepts: Parts Presentation

- What is the concept of parts presentation?
  - Organization of production material in a manner that facilitates value-added manufacturing
- What are some of the key components of parts presentation?
  - Organization / orientation of incoming material
  - Kitting of material

Benefits of Enhanced Parts Presentation Process

- **Increased** ability to manage visually…identification of parts shortages
- **Reduced** production cycles
- **Improved** organization of work area
- **Increased** worker safety / ergonomics
- **Promotes** standardized work environment
- **Enhanced** ability to detect defects and quality issues with parts

Disconnects of Parts Marketplaces / Parts Presentation

➢ **Technical Factors**

- Marketplace incorporation with 'push' legacy MRP systems
- Failure to adequately engage with supply base to maximize marketplace / presentation effectiveness
- Increased challenge of marketplace and presentation implementation for larger parts…yet increased benefit

➢ **Social Factors**

- Training and discipline associated with parts marketplaces
- Resistance to role / responsibility changes with parts marketplaces…potential for elimination of warehouse positions
- Outsourcing of parts kitting in organized labor environment