ESD.33 -- Systems Engineering

Session #3
Lean Thinking
Set-Based Design

Dan Frey

Many slides adapted from Tim Gutowski

Announcement

- I had a discussion with the SDM directors
- Pointed out that 12 units => 17 hours /wk due to summer compression
- They agreed I can run the class as a 9 unit subject (roughly 12 hours / week)
- I will cut time by leaning out each homework (not cutting the number of homeworks)
- If it works, the 9 unit designation will become official

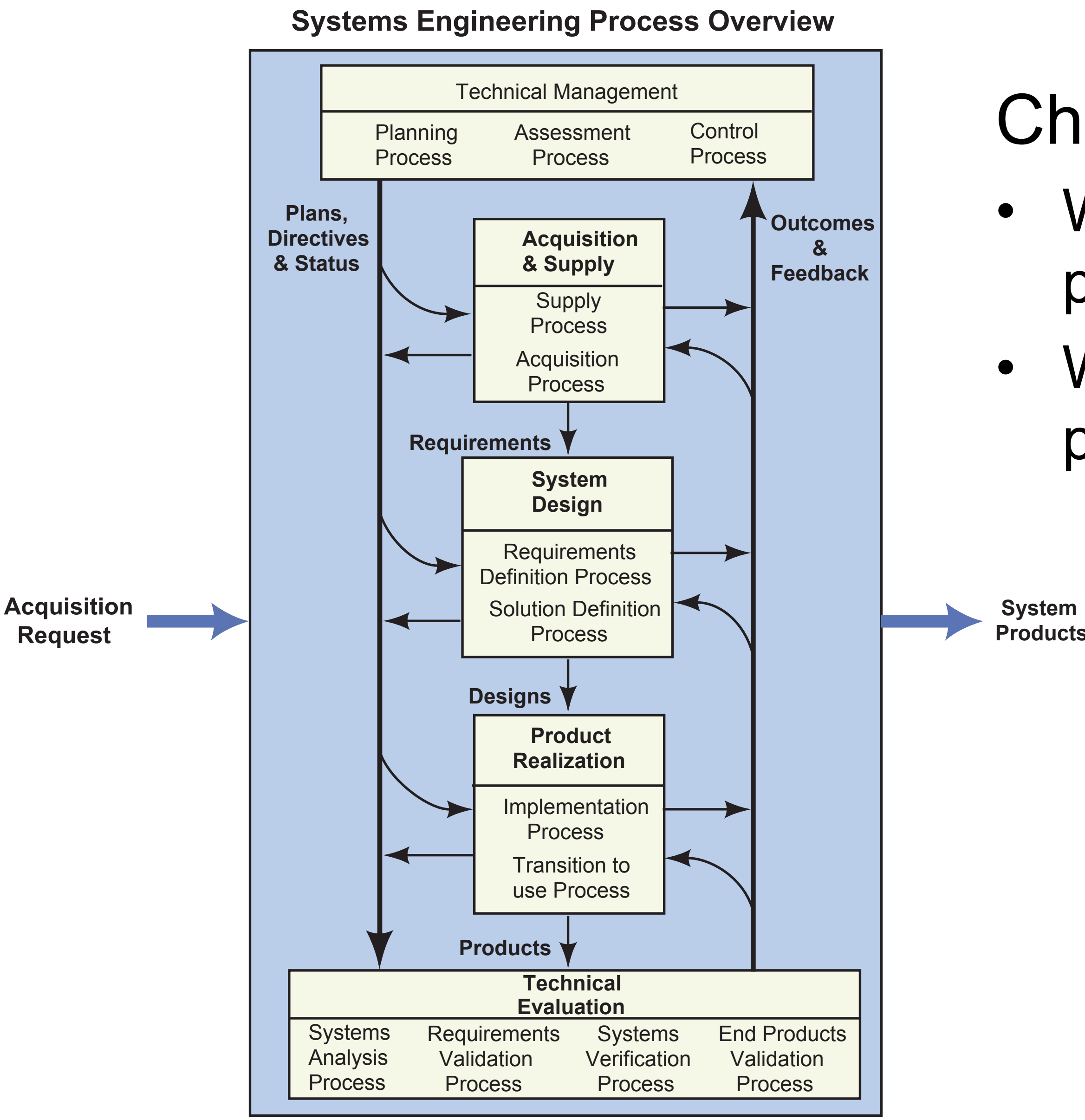
Plan For the Session

- Follow-up from session #2
- Feedback on HW#1
- The Toyota Production System
- Lean thinking
- Set-based design
- Summary & Next steps

Virginia Lentz

Program Manager at Otis, past President of INCOSE

- We liked it! (I asked the Otis folks as well)- Great cognitive thinking slide.
- Regarding System Engineering vs. Engineering Systems, there is more history than MIT coining the term …the INCOSE & Navy community has been arguing about the order of the words for some time and we almost changed the name of the organization …
- There is an INCOSE handbook rev 3 in process …



Ch 4 Questions

- Who participates in each process?
- What emerges from each process?

Virginia Lentz

Program Manager at Otis, past President of INCOSE

- The diagram is actually from ISO 15288 - that is a system life cycle model and not an SyE Process. Acquisition was meant to be either the Govt acq for the contractor acq - or even acquisition by a sub tier supplier - Yes INCOSE is confused. Only a few members have worked both sides but everyone has an opinion.

- It was good to hear the emphasis on a few top level requirements and layers of requirements.

- One addition might show how the traditional SyE processes are used to support RCI - they are needed in addition to the QFD etc... SyE is methods which are supported by tools - the TQM / HOQ tools are one way of doing things - and the mil aero community tried those as well.

HW#1 -- Learning

- I am generally very happy with the quality
- Glad to see students challenging the readings
- Many students emphasized need for examples and case studies
- Based on some student comments I am going to start cold calling

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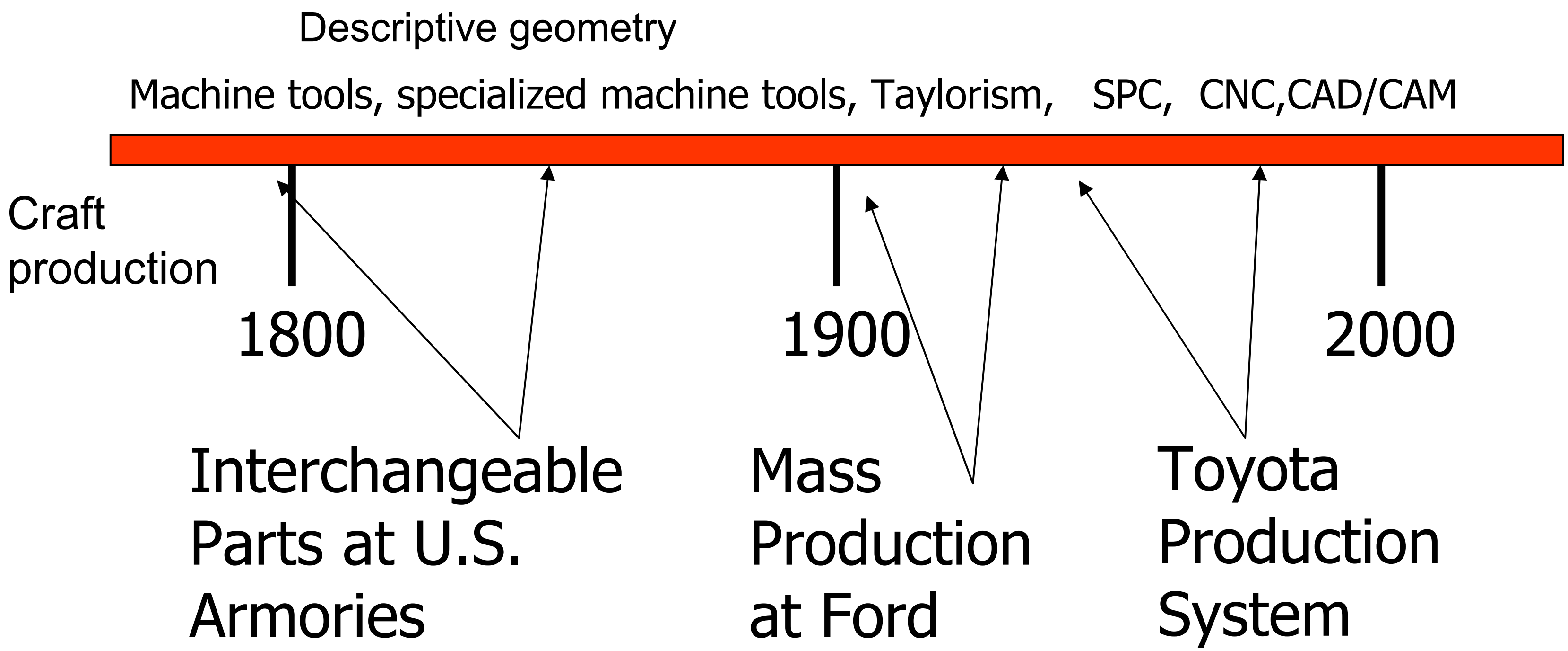
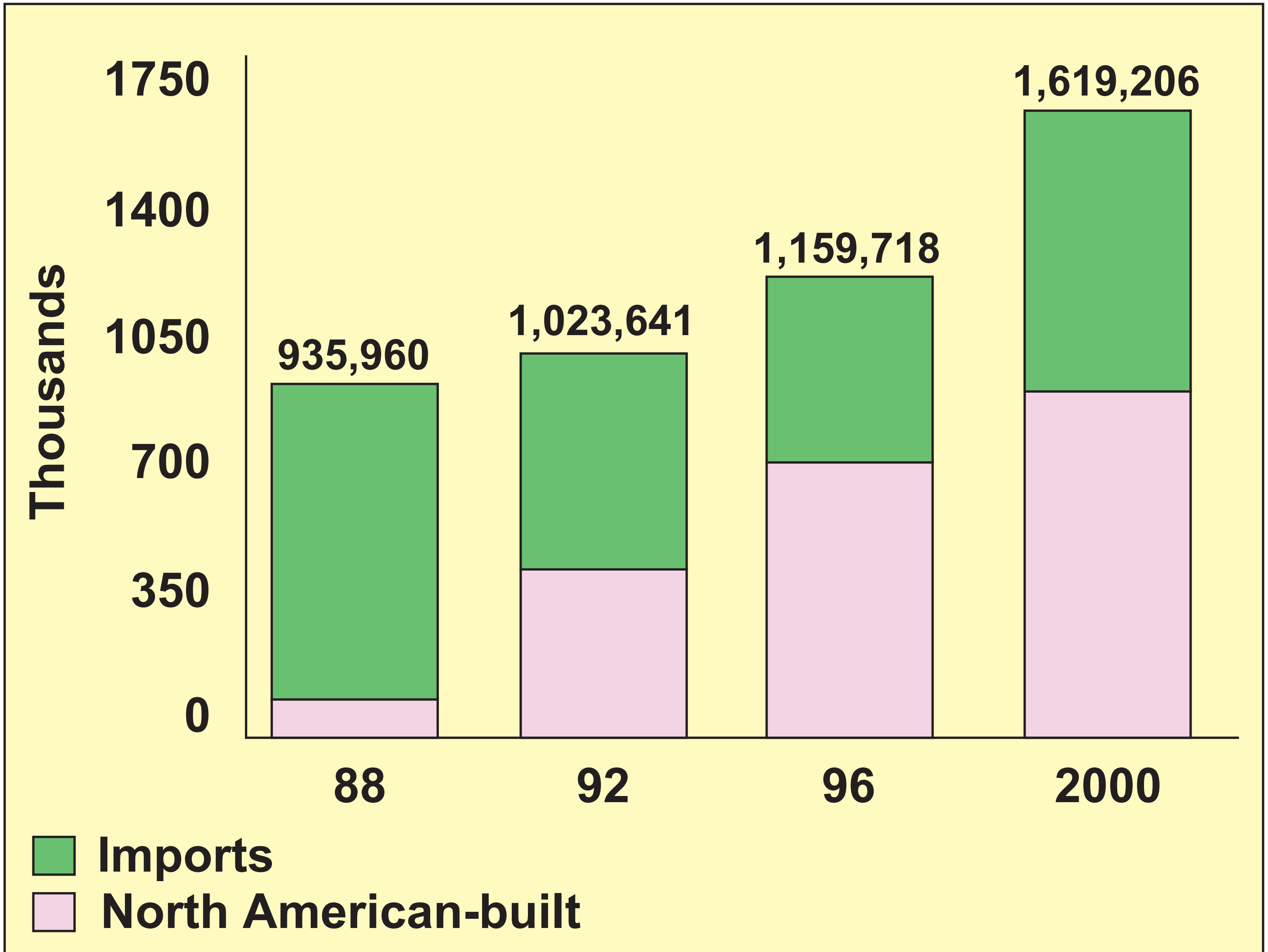
Major Manufacturing Systems from 1800 to 2000

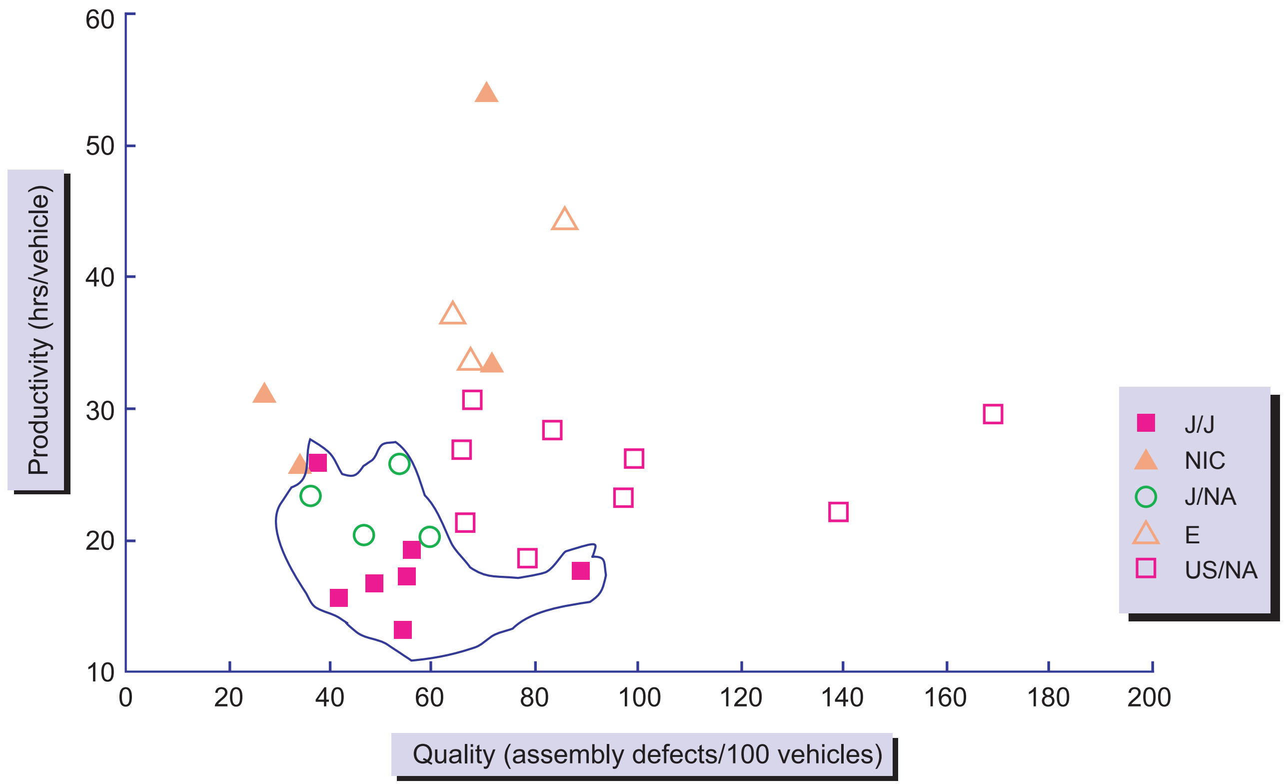


Toyota Vehicle Sales



Cost Vs Defects

Ref. "Machine that Changed the World" Womack, Jones and Roos



Productivity versus Quality in the Assembly Plant, Volume Producers, 1989

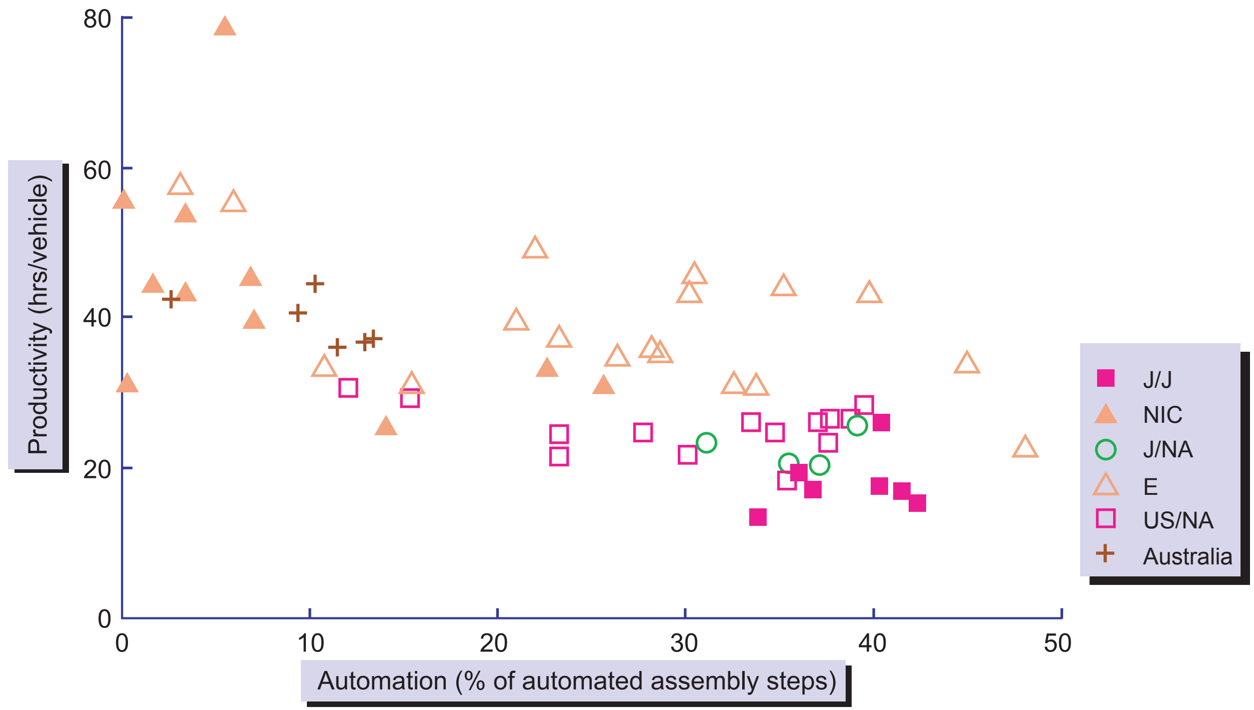
Toyota Production System

Taiichi Ohno

- Yes automation, but …
- Value (mapping the value chain)
- Flow (Takt time, below economic run qty)
- Pull (we will see a video)
- Perfection (workers empowered to solve problems)

Cost Vs Automation

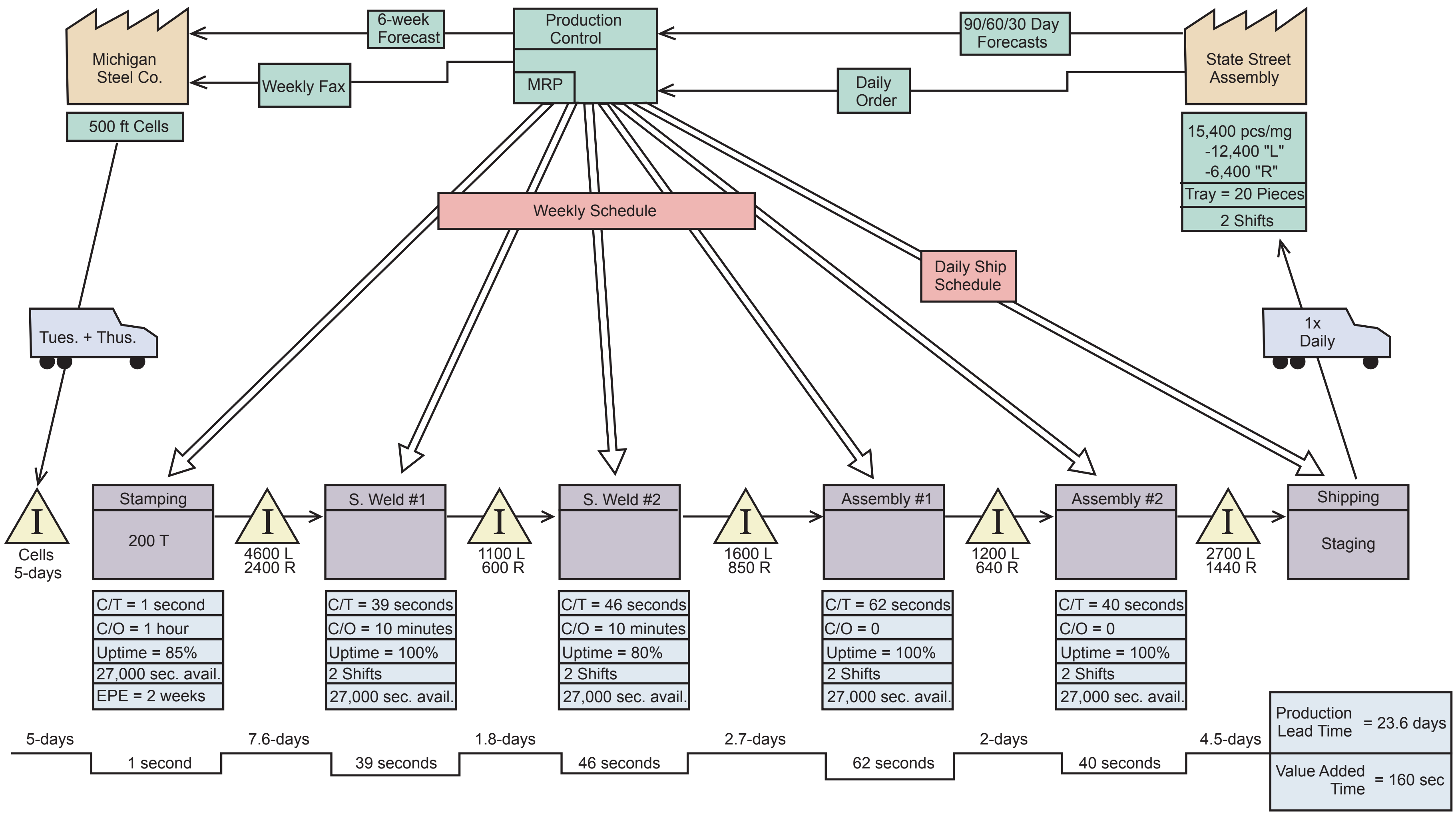
Ref. "Machine that Changed the World" Womack, Jones and Roos



Automation versus Productivity, Volume Producers, 1989

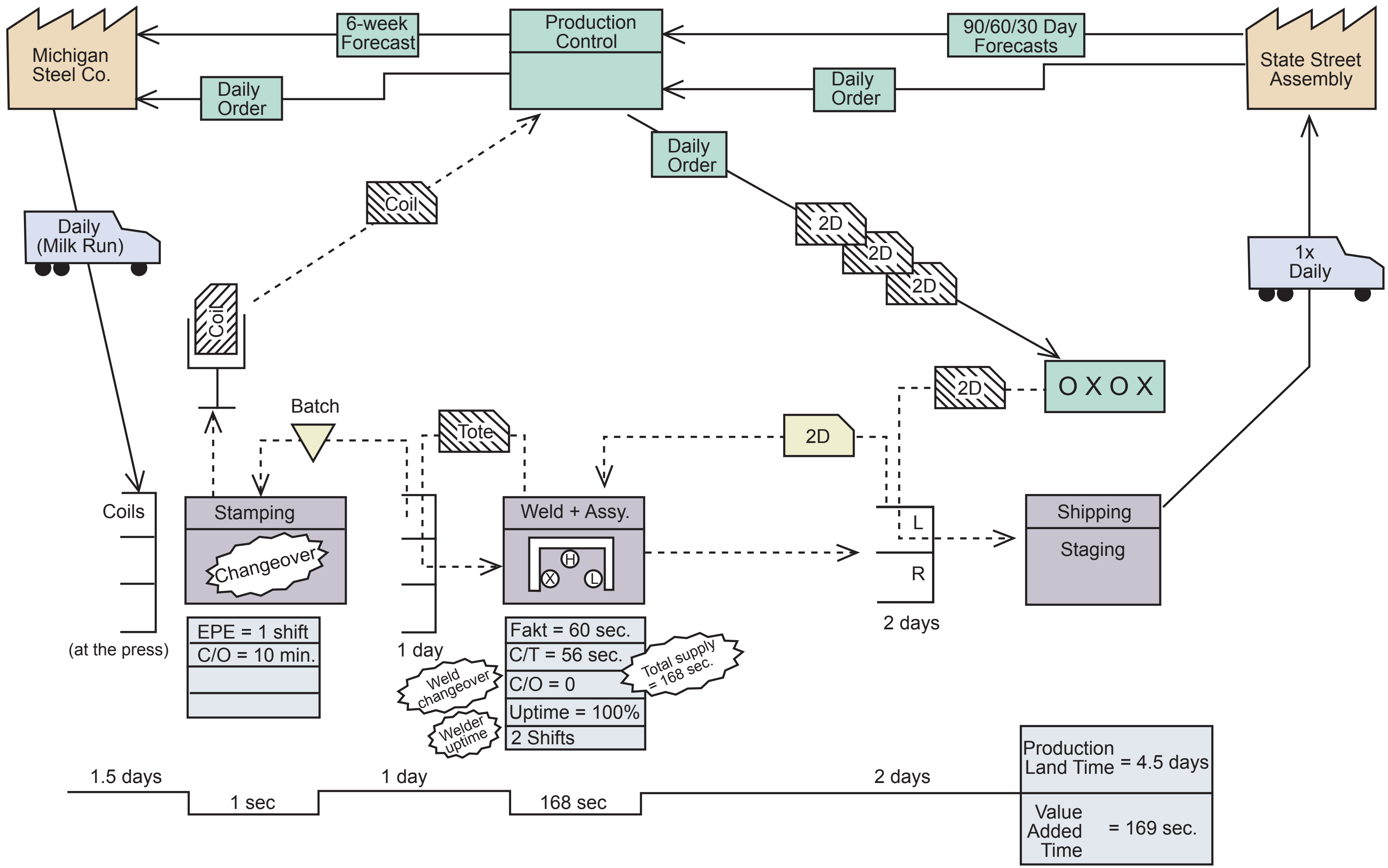
Note: "Automation" equals the percent of assembly tasks that have been automated. Automation includes both fixed automation such as multi-welders and flexible automation using robots. Automation of materials handling is not included.

Current Value Stream Map



Adapted from Womak.

Future Value Stream Map



Adapted from Womak.

Standardized Fixtures

Takt Time – to pace production

$$\text{Takt Time} = \frac{\text{Available Time}}{\text{Product Demand}}$$

Calculate Takt Time per month, day, year etc. Available time includes all shifts, and excludes all non-productive time (e.g. lunch, clean-up etc). Product demand includes over-production for low yields etc.

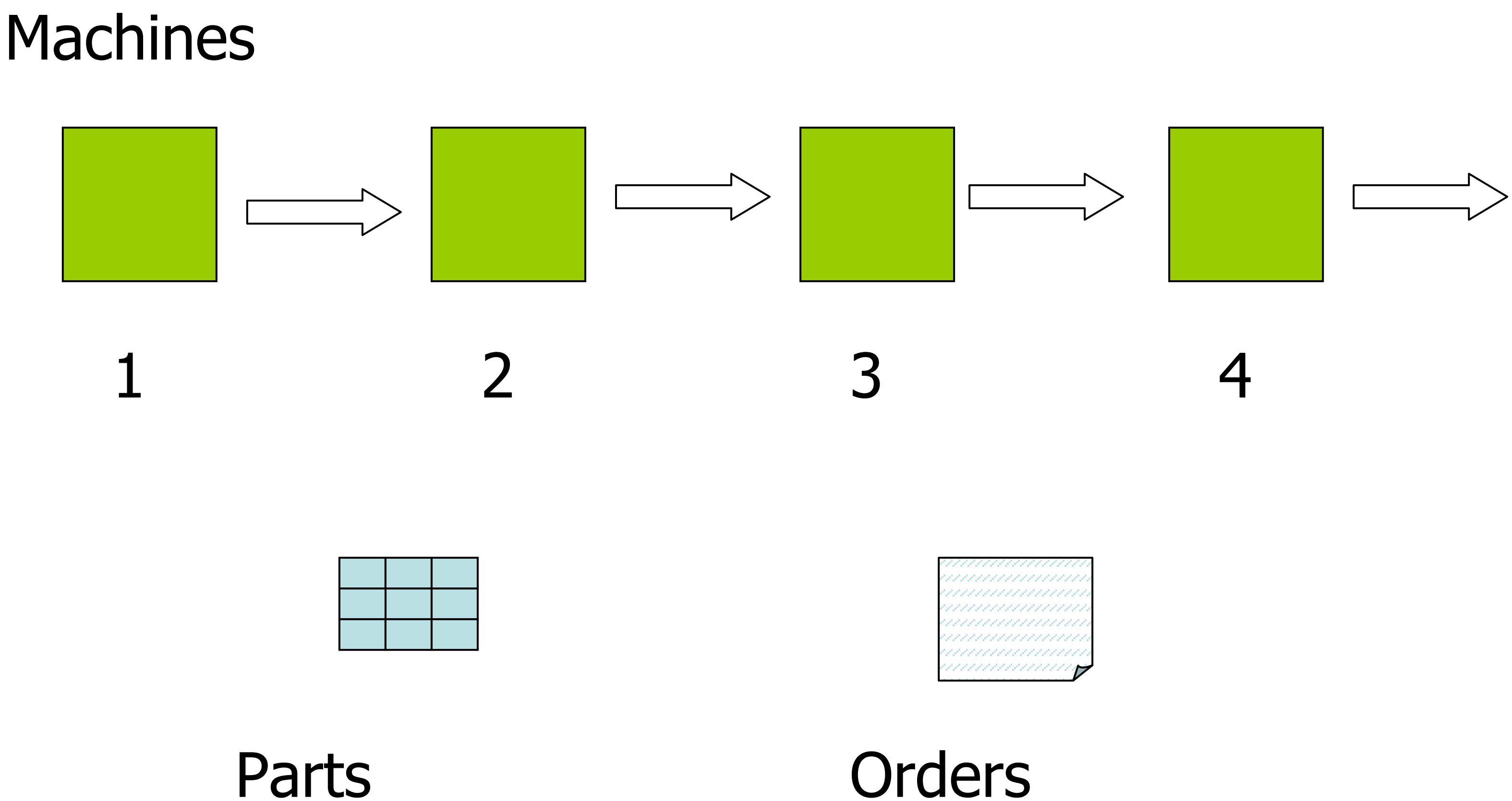
Takt Time

Automobile Assembly Line; Available time = 7.5 hr X 3 shifts = 22.5 hrs or 1350 minutes per day. Demand = 1600 cars per day. Takt Time = 51 sec

Aircraft Engine Assembly Line; 500 engines per year. 2 shifts X 7 hrs => 14 hrs/day X 250 day/year = 3500hrs.

Takt time = 7 hrs.

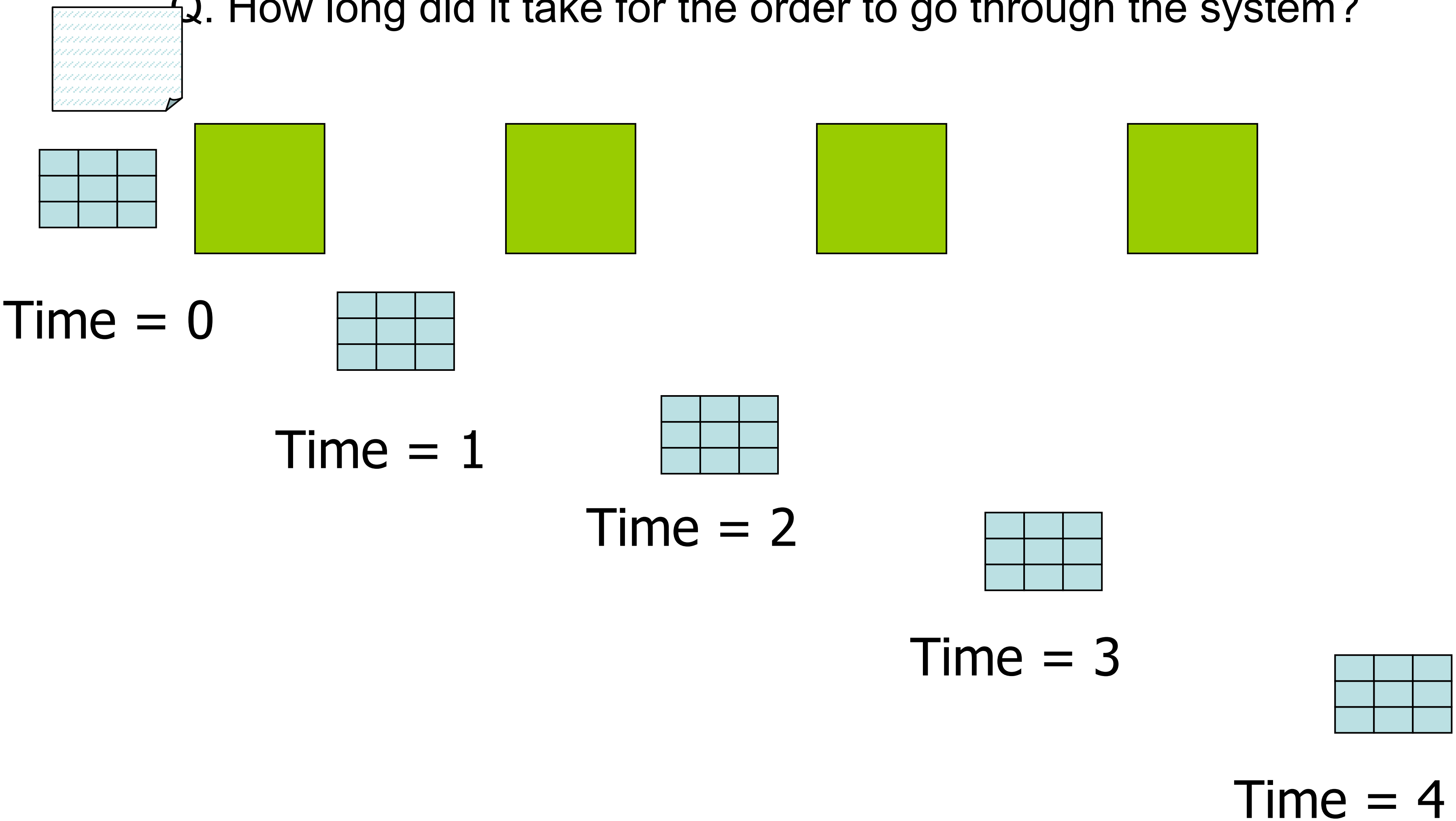
Push and Pull Systems



Push Systems –

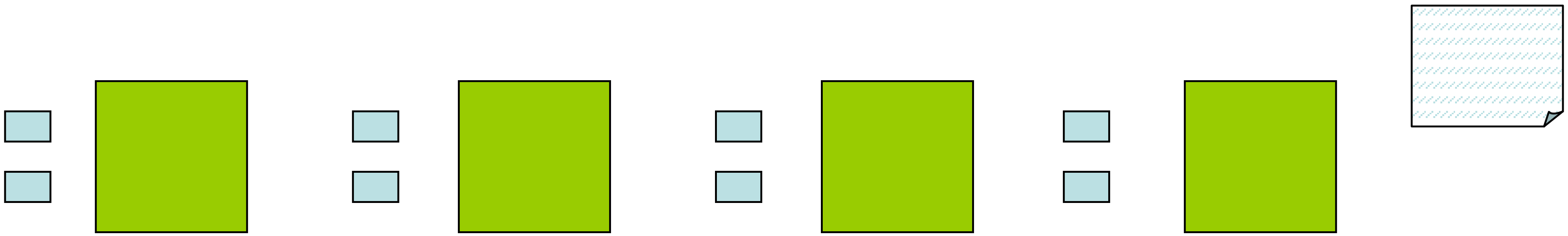
Order arrives at the front of the system and is produced in the economical order quantity.

Q. How long did it take for the order to go through the system?



Pull Systems-

The order arrives at the end of the line and is “pulled” out of the system.
WIP between the machines allows quick completion.



Pros and Cons;

Pull can fill small orders quickly, but must keep inventory for all part types. Design can help here but not in all cases.

HP Video Results

	Push system (6)	**Pull (3)**	**Pull (1)**
Space	2 Tables	2 Tables	1 Table
WIP = **L**	30	12	4
Cycle time = **W**	3:17	1:40	0:19
Rework Units ≈ **WIP**	26	10	3
Quality Problem	Hidden	Visible	Visible
Production Rate λ = **L / W**	0.15	0.12	0.21

Can TPS be Transferred?

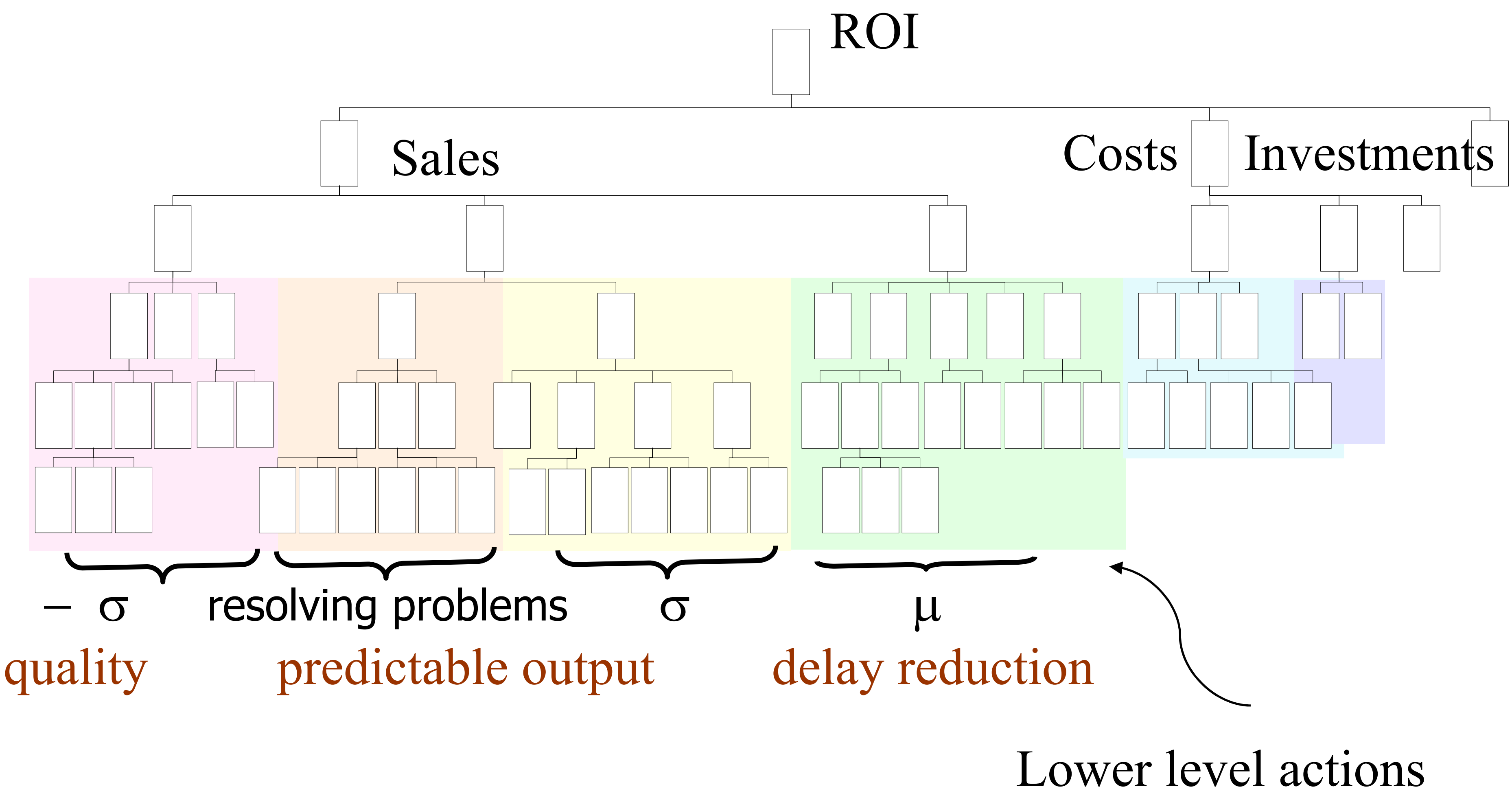
- Failed TPS attempts;
  - GM Linden NJ
  - GM-Suzuki, Ontario Canada
- Successes
  - GM NUMMI
  - Saturn

C. Ichniowski, T. Kochan et al "What Works at Work: Overview and Assessment", Industrial Relations Vol 35 No.3 (July 1996)

Barriers to Implementation

- Early abandonment
- Costs
- History of conflict and distrust
- Resistance of supervisors
- Lack of supportive infrastructure

Manufacturing System Design Decomposition (MSDD)



Plan For the Session

- Follow-up from session #2
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- ➡ Lean thinking
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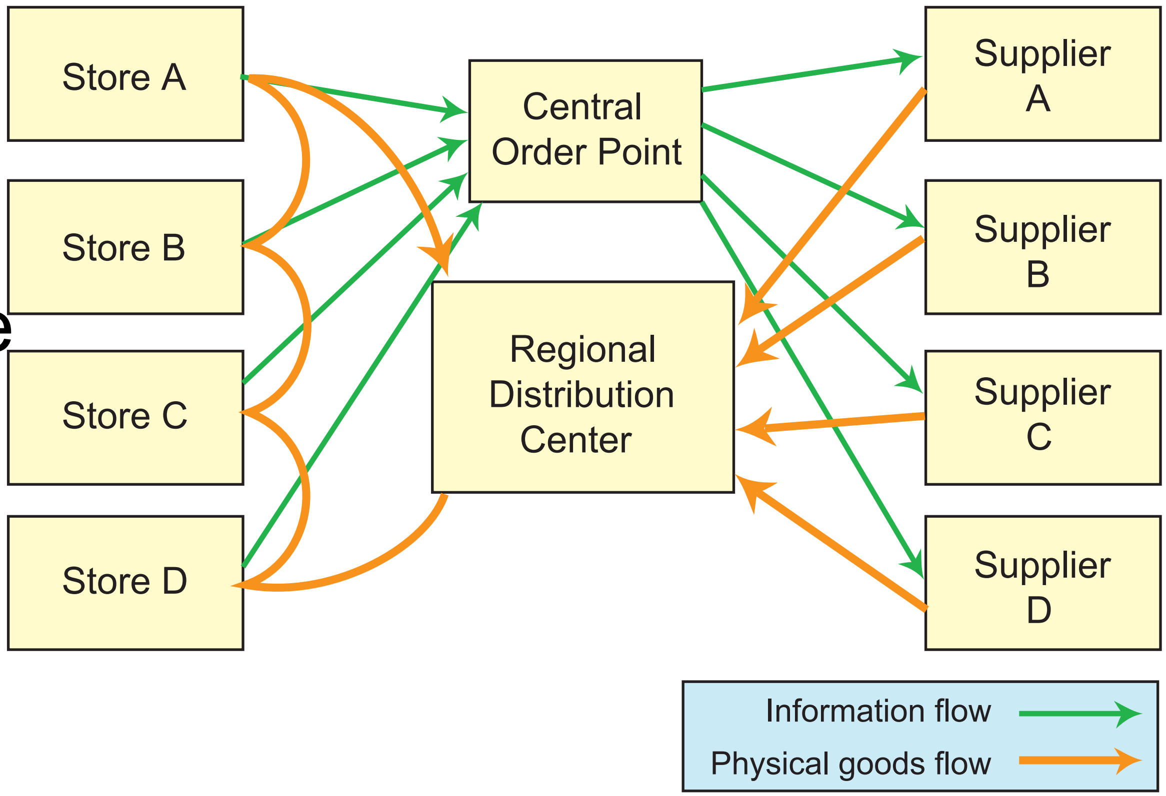
Womak's "Lean Thinking"

- Focus on identifying and reducing *muda*
  - Mistakes
  - Inventory
  - Un-needed processing
  - Movement without purpose
  - Waiting
  - Goods and services that don't meet customer needs

Womak's "Lean Thinking"

1. Specify Value (<u>customer</u> perspective)
2. Identify the Value Stream
3. Flow
4. Pull
5. Perfection



Tesco Reorder System. Adapted from Womak.

Next two slides borrowed from:

LEAN PRODUCT DEVELOPMENT FLOW

Lean Aerospace Initiative
Massachusetts Institute of Technology

April 14, 2004

Bohdan W. Oppenheim

Loyola Marymount University, Los Angeles, Mechanical Engineering

Seven Categories of Waste in PD [LAI]

1. **Over-production** (creating unnecessary information, work not needed)
2. **Inventory** (keeping more information than needed, piles of paper in IN/OUT boxes)
3. **Transportation** (lack of coordination, inefficient transmittal, wrong format)
4. **Unnecessary movement** (people chasing data)
5. **Waiting** (for information, data, inputs, tests, approvals, releases, etc.)
6. **Defects** (insufficient quality of information, the killer "re's": Rework…)
7. **Over-processing** (working more than necessary to produce the outcome, poor).

Waste in PD = 60-90% or more of charged time [Cool, McManus,…]

LEAN PRINCIPLE 3: FLOW PER TAKT TIME

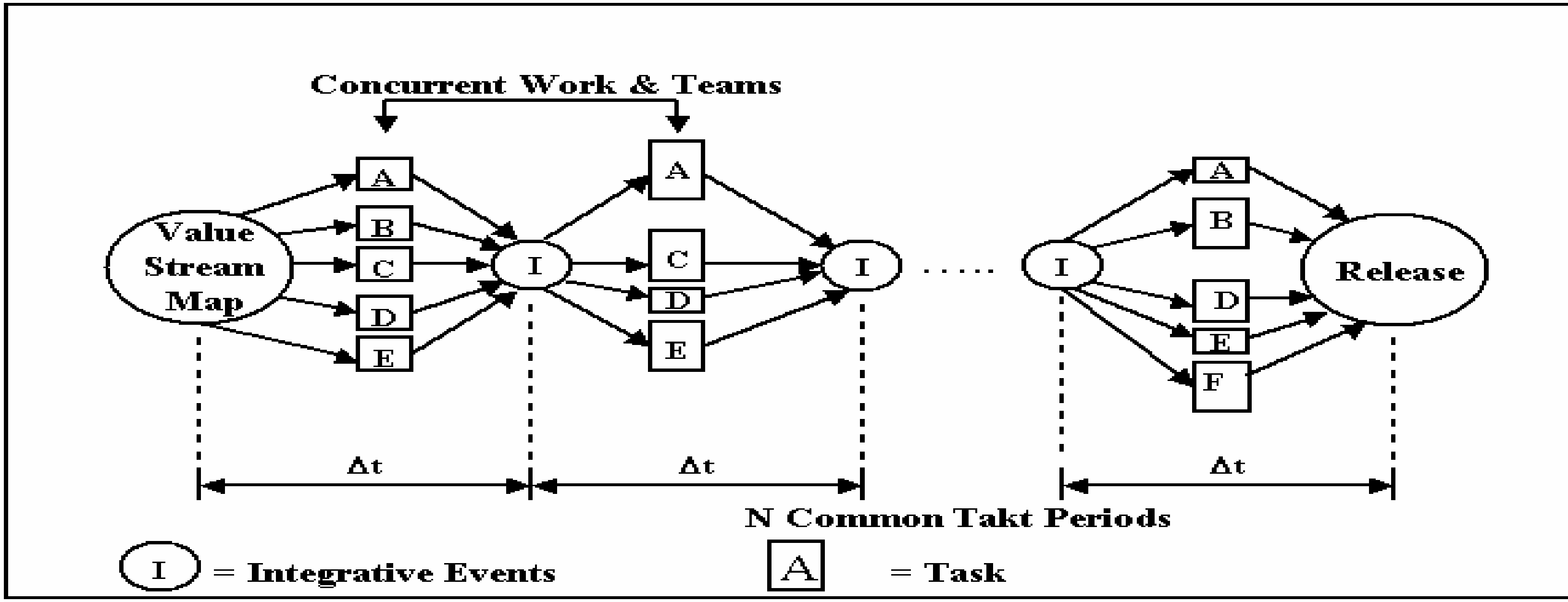


Fig.1 Schematics of Lean Product Development Flow

The flow begins with a value definition and detailed optimized value stream map

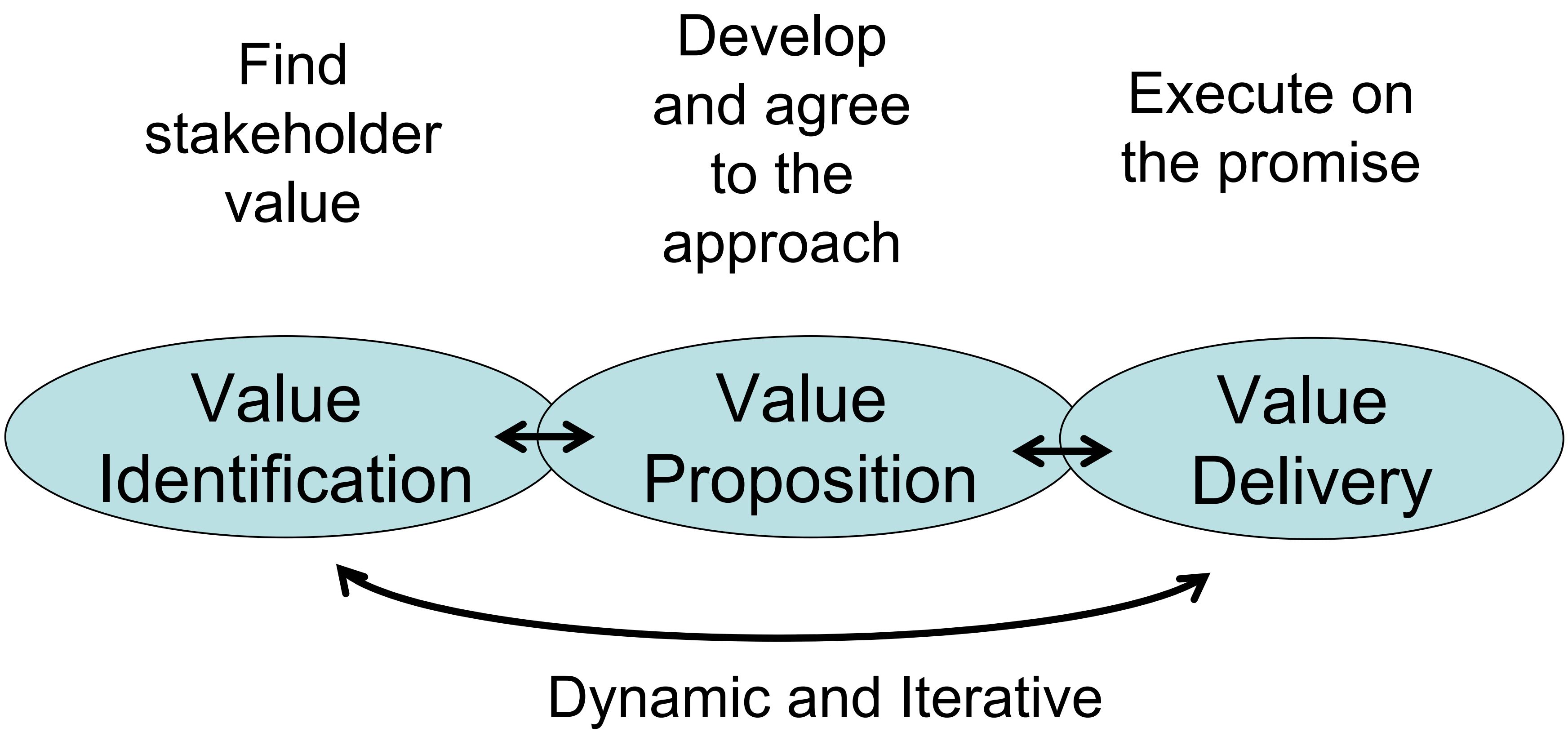
The flow ends with release of deliverables

The flow = **alternating** short "Takt Periods of Work" and Integrative Events

The Chief and Core Team coordinate dynamically allocated sub-teams, departments and individuals

People trained to communicate within Periods.

Best Lifecycle Value



Stanke and Murman, 2002, “A Framework for Achieving Lifecycle Value in Aerospace Product Development”, ICAS 2002 Congress.

Value Identification CMM

	Level 1	Level 2	Level 3	Level 4	Level 5
	Focus: *What is the desired system capability? How is it defined?*				
Holistic Perspective	Desired system capability is unknown and not all stakeholder contributions are identified.	Desired system capability is identified in terms of form only; some stakeholder contributions are identified	Desired system capability is identified mostly in terms of form with some consideration of function. Core enterprise stakeholder contributions are clearly communicated.	Desired system capability is identified mostly in terms of function with specification of form. All enterprise stakeholder contributions are clearly communicated.	Desired system capability is identified in terms of function only. All enterprise stakeholder contributions are clearly communicated.
	Focus: *Who are the system stakeholders? What role do they each play in a discussion focused on system value?*				
Organizational Factors	Few stakeholders are represented, and system value is not considered as the focal point for any discussion or decisions.	Some enterprise stakeholders are represented. Value is considered as part of the discussion regarding a system.	Representatives of core enterprise stakeholders contribute to value focused decisions.	Representatives for all enterprise stakeholders contribute to the value discussion.	Representatives for all enterprise stakeholders contribute to the value discussion. They have the authority to make value decisions for their organization.
	Focus: *Are stakeholder expectations clearly communicated?*				
Requirements and Metrics	Stakeholders do not share their expectations.	Stakeholder expectations are expressed inconsistently.	Core enterprise stakeholder expectations are clearly communicated.	All enterprise stakeholder expectations are communicated, but level of consistency may vary between stakeholders.	All enterprise stakeholder expectations are clearly communicated.

Desired system capability is identified in terms of function only

All enterprise stakeholders expectations clearly communicated

Value Proposition CMM

Requirements and Metrics	***Focus:*** *Are both technical and programmatic requirements defined to reflect stakeholder expectations and contributions regarding the system? Do these requirements have established target values and measurable metrics?*				
	Requirements and metrics are understood but may or may not be concretely established, including little or no consideration of lifecycle issues.	Requirements and metrics are established and may or may not include lifecycle considerations.	Requirements and metrics are well established with target values. They include lifecycle considerations and are communicated throughout the enterprise.	Requirements and metrics are well established with target values. They include lifecycle considerations and are articulated and communicated unambiguously.	Requirements and metrics are well established with target values. They include lifecycle considerations and are articulated and communicated unambiguously, resulting from close interaction amongst enterprise stakeholders focused on lifecycle value.
Tools and Methods	***Focus:*** *Is a structured holistic approach used to decide and understand the implications of system trade-offs?*				
	System and program trade-offs are made with little or no consideration of lifecycle issues.	System and program trade-offs are made considering some lifecycle issues.	System and program trade-offs are made considering most lifecycle value attributes. The need to follow a structured method is identified.	System and program trade-offs are made considering all lifecycle value attributes. A systems engineering approach is established.	System and program trade-offs are made considering all lifecycle value attributes with equal credibility. A fully integrated systems engineering approach is implemented.

Requirements and metrics are established with target values

Trade-offs are made considering all life cycle value attributes with equal credibility …

Value Delivery CMM

	Level 1	Level 2	Level 3	Level 4	Level 5
	***Focus:** What visibility exists for the system, its interfaces, and its lifecycle?*				
Holistic Perspective	There is awareness of several levels of the system with little or no consideration of its lifecycle.	There is awareness of entire system with little or no consideration of its lifecycle.	There is good awareness of the entire system with some lifecycle considerations.	There is good awareness of the entire system and its entire lifecycle.	There is exceptional awareness of entire system and full implementation of lifecycle issues.
	***Focus:** Are effective product based teams aligned with a relevant system decomposition?*				
Organizational Factors	There are functionally specialized working groups, with little cross-functional interaction.	There are informal cross-functional working relationships.	There is a formal cross-functional structure in effective product Integrated Product Teams (IPTs).	Effective product IPTs are aligned with product decomposition and empowered by management support.	Effective product IPTs are aligned with product decomposition and empowered by management support. Balance between functional and product responsibilities is created through shared business processes.

Effective IPTs are aligned with product decomposition …
Balance between functional and product responsibilities …

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The Toyota Paradoxes

The First Paradox

- Production lots far below "minimum economical order quantity"
- Don't have experts on quality control do your quality control
- Mix tasks at a single workstation

The Second Paradox

- Delay decisions
- Communicate ambiguously
- Pursue an very large number of prototypes

Another paradox? -- Toyota itself does not apply "lean thinking" to its product development process

Design a Weekend Get-Away

Timing — I don't have any meetings on Monday 28 June, let's get away for a three day weekend!

Activities — I really feel like golf.

Location — Let's go to the best place there is – Pebble Beach

Transportation — Let's buy some airline tickets now and be sure to get the 10 day advance price.

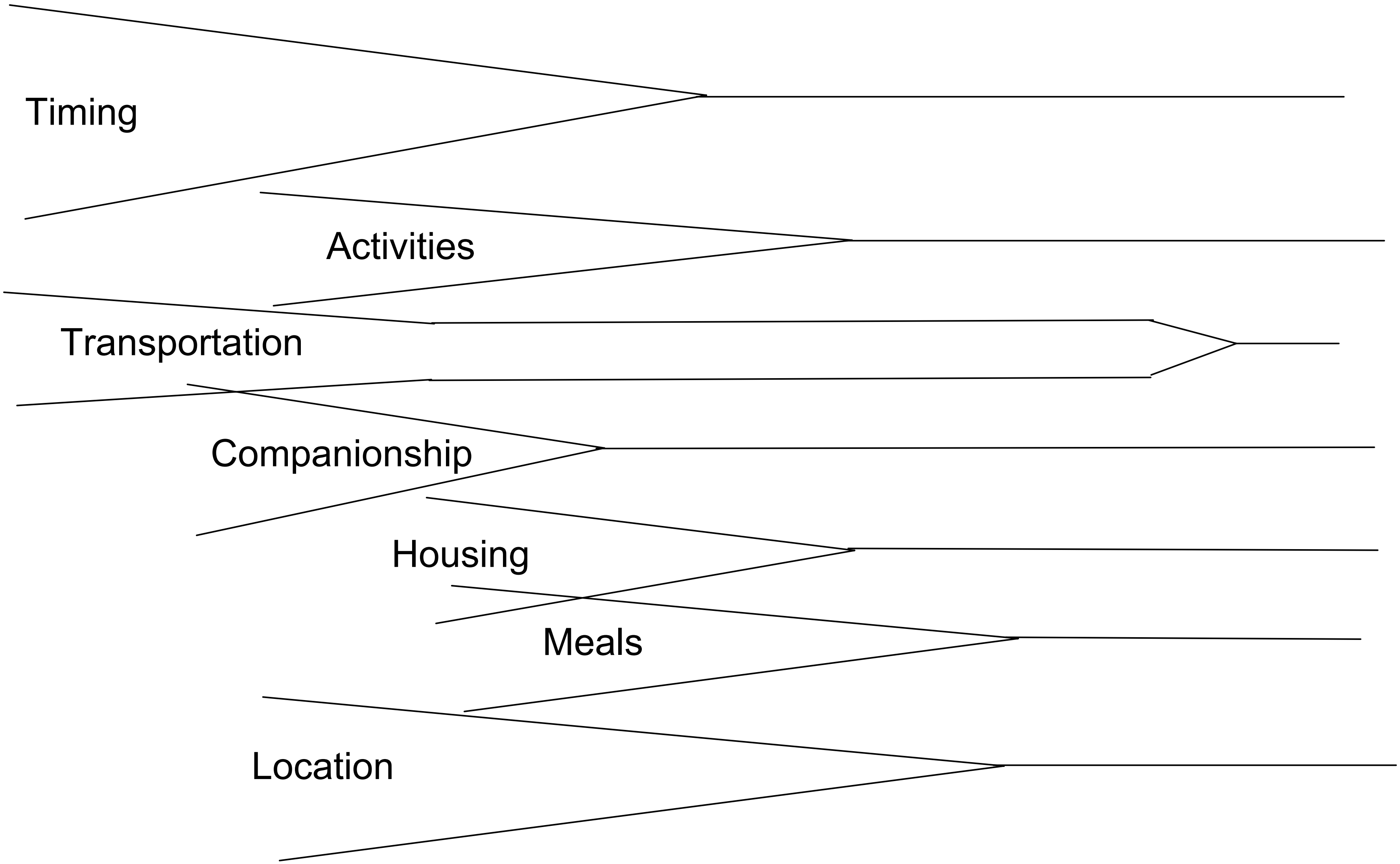
Companionship — Well, the only people we know who like golf are the Jones' and the Smiths and the Jones' can't make it.

Housing — There's a place right on the course, let's stay there. It's a bit expensive but we'll max out our golf time.

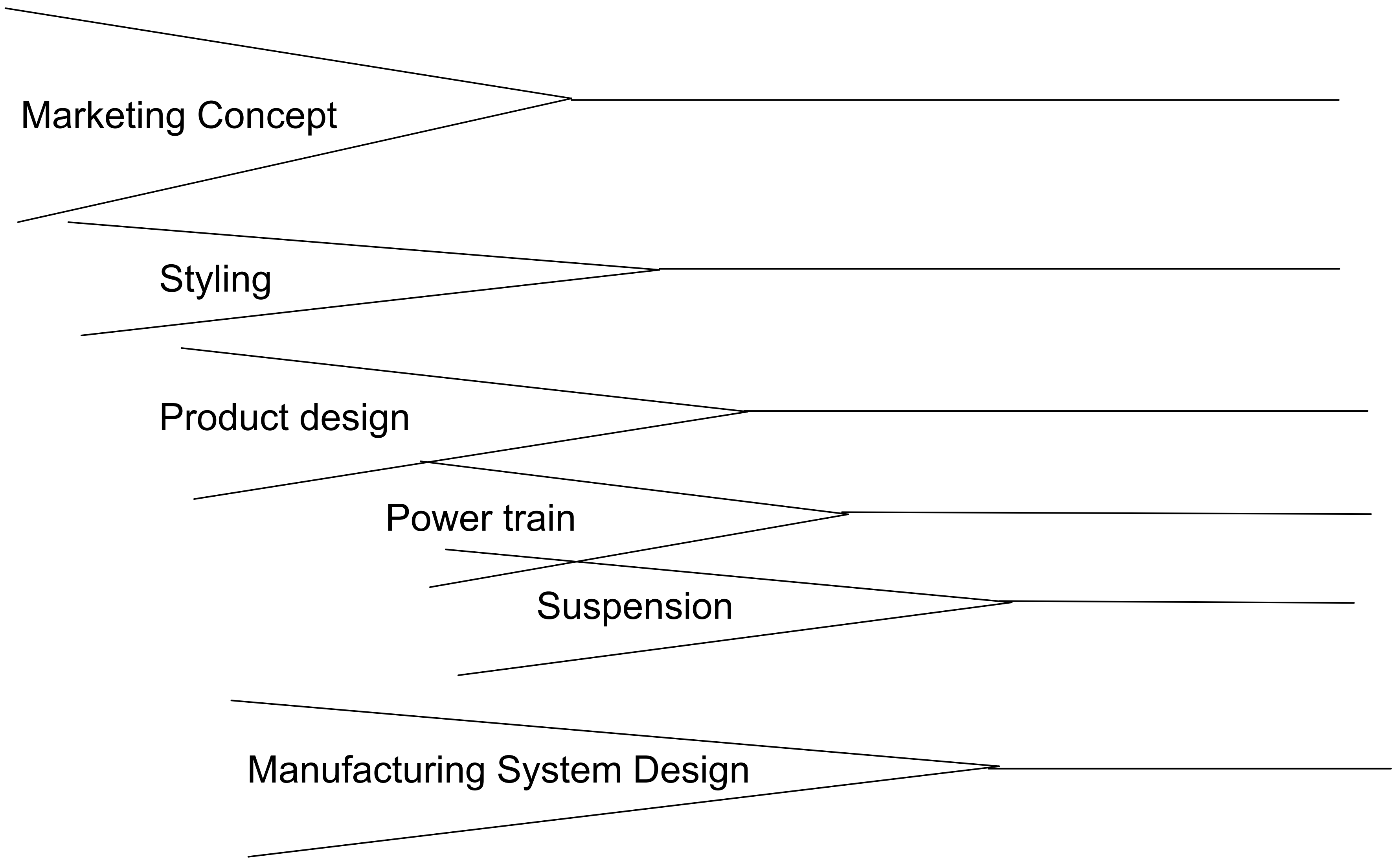
Meals — The Smiths love seafood. I'll make a reservation.

Set-Based Design

of a Weekend Get-Away



Set-Based Design
of an Automobile



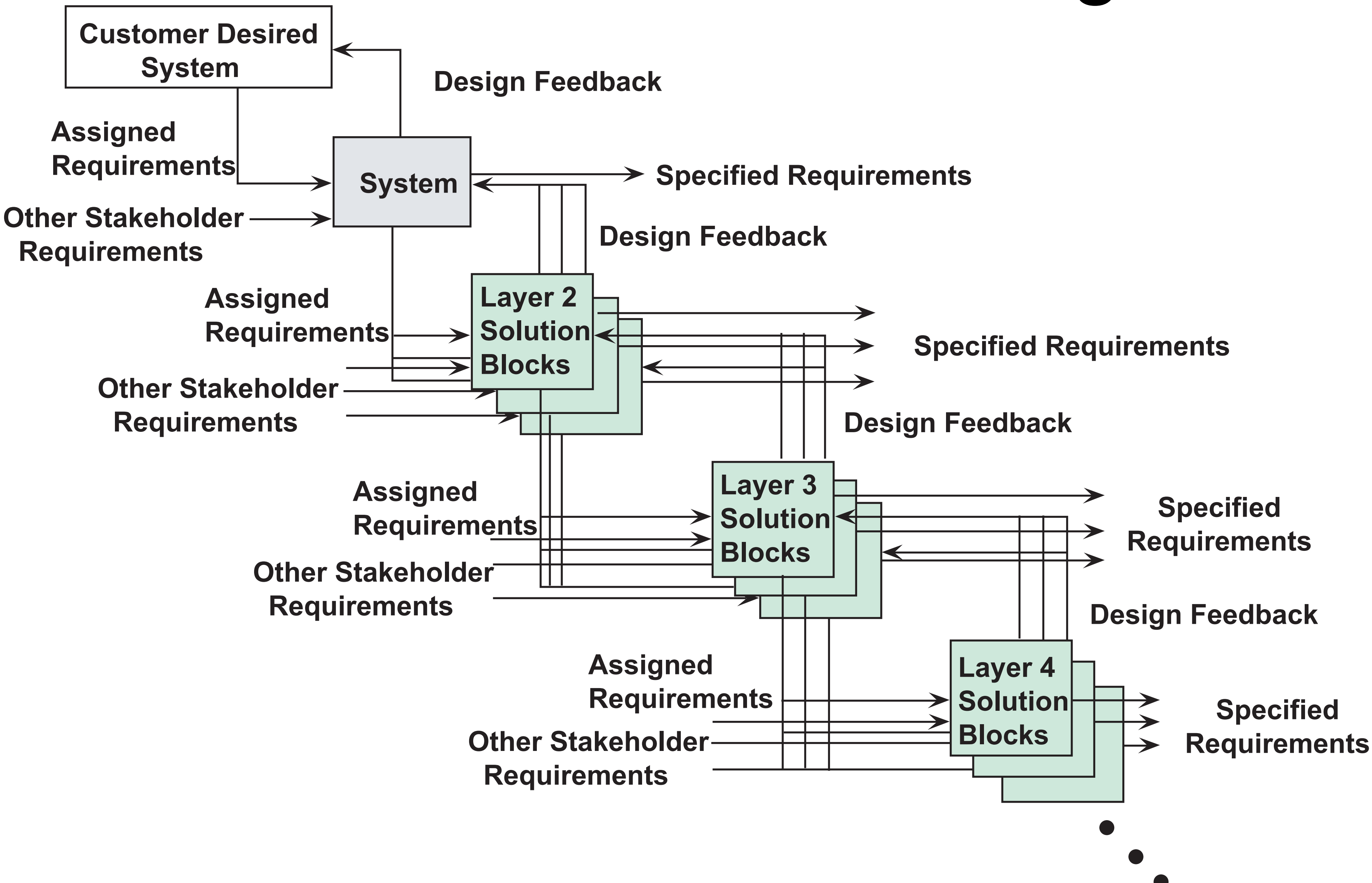
Evidence of Set-Based Design

Area	**Non-Toyota**	**Toyota**
Clay models	3 to 5	5 to 20
Body hardpoints	Fix before full sized clay	Up to 2 cm band
Exhaust systems prototyped	1	10 to 50
Cooling fan spec	Hard spec at full sized clay	30% at first prototype 5% and 2nd
# of fans	2 or 3	4 or 5
Design tolerance is % flexibility remaining in the design about a ref point		

Advantages of a Set-Based Approach

- Enables more efficient communication
- Allows for more parallelism in the design process
- Bases the most critical decisions on data
- Promotes institutional learning
- Allows for more extensive search and a more globally optimal design

Is this Point-Based Design?



System Design Hierarchy

Next Steps

- Do the reading assignments for session #4
  - Suh_Axiomatic Design Theory for Systems.pdf
  - Frey_Cognition and Complexity.pdf
  - Hazelrigg_Axiomatic Engineering Design.pdf
  - Gigerenzer_Bounding Rationality to the World.pdf
- Finish Assignment #2
- Come to session #4
  - 8:30AM Thursday 17 June