2.810

- The Toyota Production System & Implementation in a highly automated (4.0) Assembly / Manufacturing Plant

- Jose J. Pacheco

23 October 2019

Today in 2.810

- A bit of history
- Principles
- Design Rules
- Real World Examples
- Application in Mercedes-Benz Truck Plant in Brazil

History

Three Major Mfg Systems from 1800 to 2000

Machine tools, specialized machine tools, Taylorism, SPC, CNC, CAD/CAM

1800 1900 2000

Interchangeable Parts at U.S. Armories

Mass Production at Ford

Toyota Production System

Three Major Mfg Systems from 1800 to 2000

Future

Machine tools, specialized machine tools, Taylorism, SPC, CNC, CAD/CAM

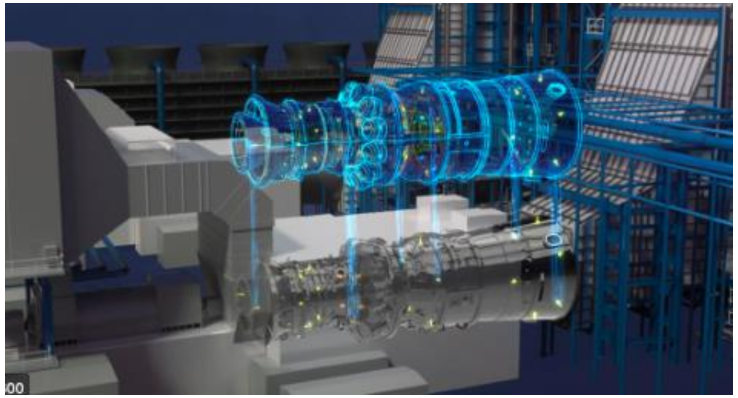
1800 | 1900 | 2000 | 2010

Interchangeable Parts at U.S. Armories

Mass Production at Ford

Toyota Production System

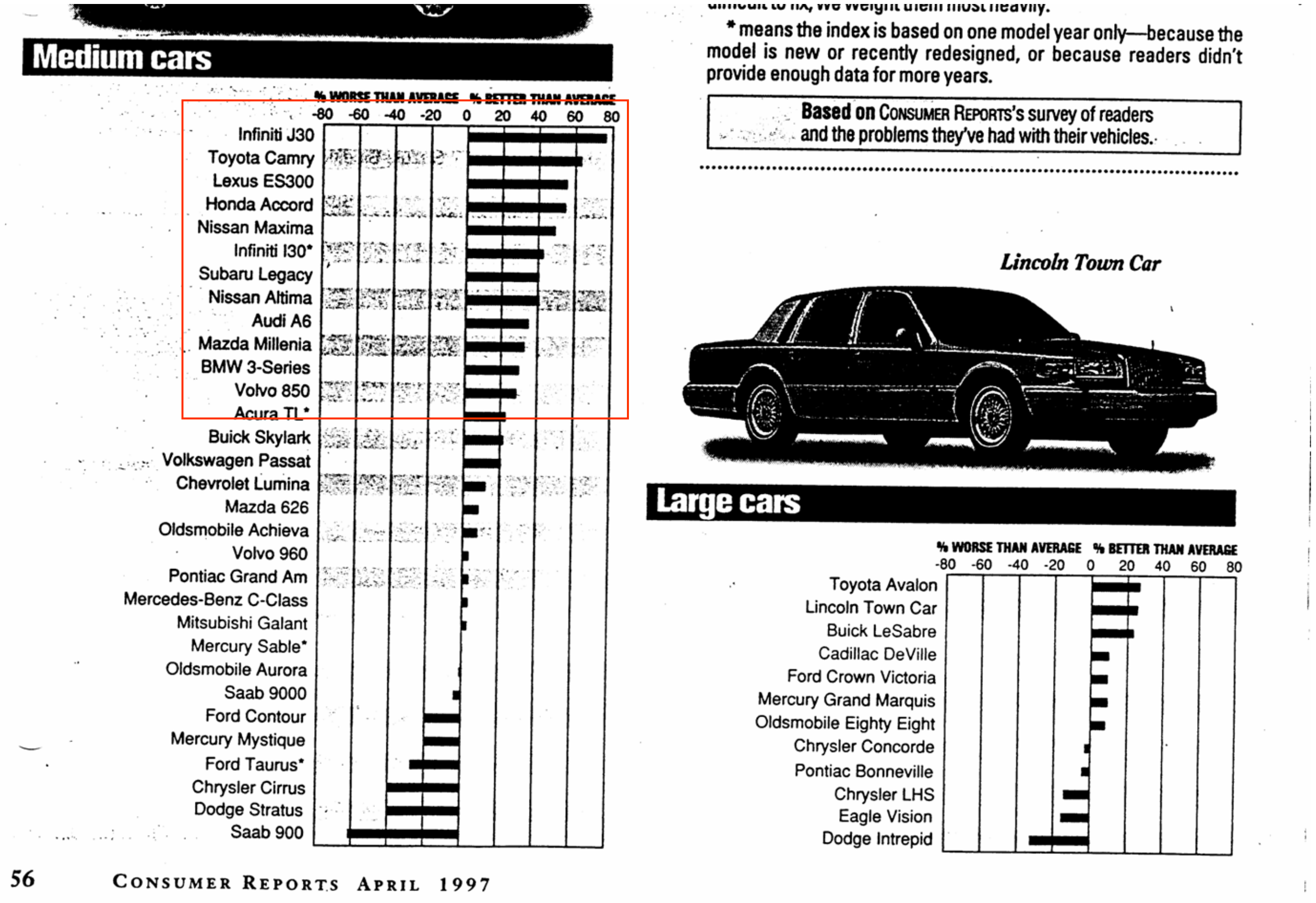
Digitization, Automation "4.0" , Smart Mfgr



How we got here

1980’s OPEC oil embargo drives up fuel prices, Japan imports small cars with increased fuel mileage

Consumer Reports



Medium cars

% WORSE THAN AVERAGE % BETTER THAN AVERAGE
-80 -60 -40 -20 0 20 40 60 80

Infiniti J30
Toyota Camry
Lexus ES300
Honda Accord
Nissan Maxima
Infiniti I30*
Subaru Legacy
Nissan Altima
Audi A6
Mazda Millenia
BMW 3-Series
Volvo 850
Acura TL*
Buick Skylark
Volkswagen Passat
Chevrolet Lumina
Mazda 626
Oldsmobile Achieva
Volvo 960
Pontiac Grand Am
Mercedes-Benz C-Class
Mitsubishi Galant
Mercury Sable*
Oldsmobile Aurora
Saab 9000
Ford Contour
Mercury Mystique
Ford Taurus*
Chrysler Cirrus
Dodge Stratus
Saab 900

* means the index is based on one model year only—because the model is new or recently redesigned, or because readers didn't provide enough data for more years.

Based on CONSUMER REPORTS's survey of readers and the problems they've had with their vehicles.

Lincoln Town Car

Large cars

% WORSE THAN AVERAGE % BETTER THAN AVERAGE
-80 -60 -40 -20 0 20 40 60 80

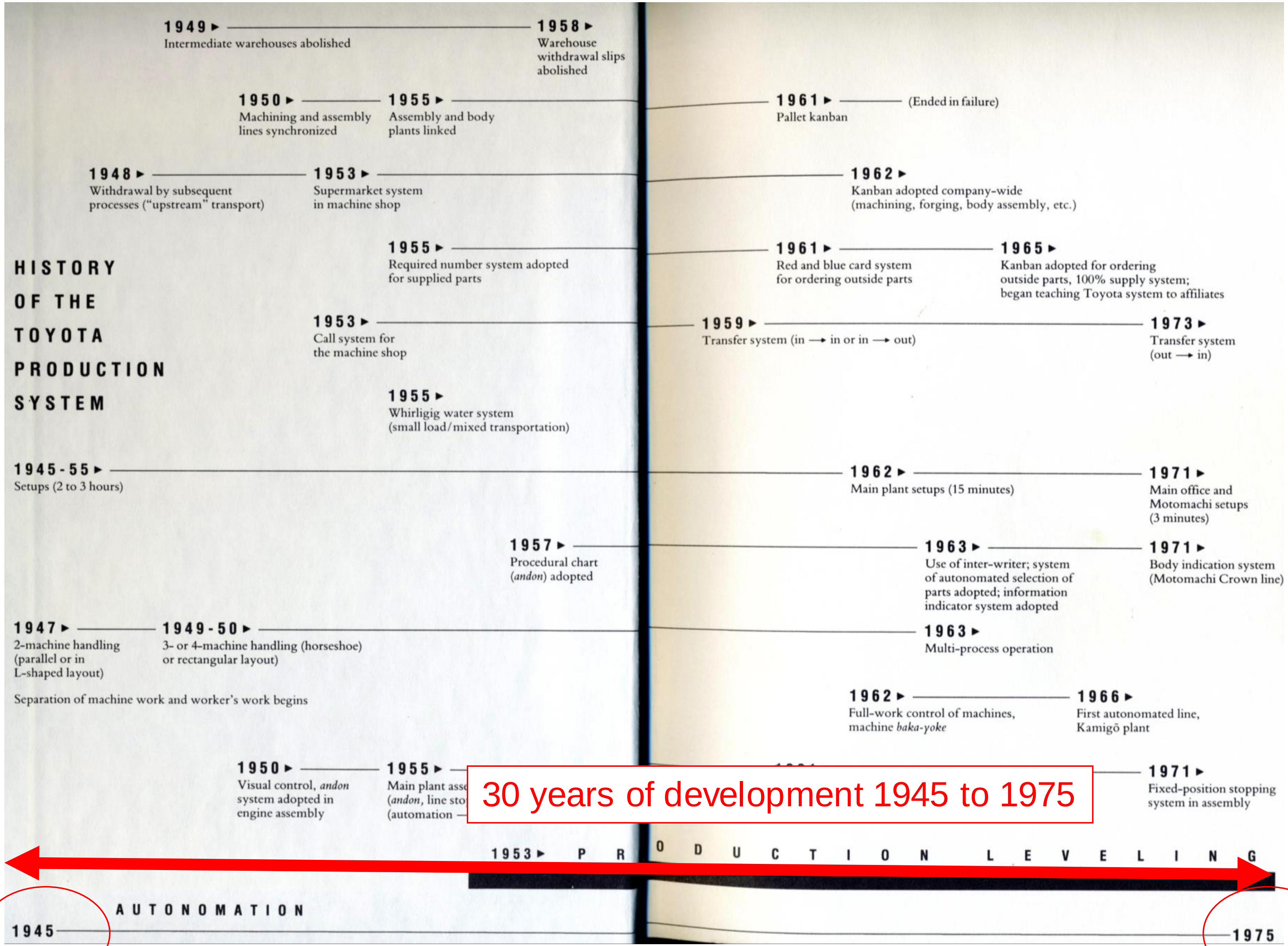
Toyota Avalon
Lincoln Town Car
Buick LeSabre
Cadillac DeVille
Ford Crown Victoria
Mercury Grand Marquis
Oldsmobile Eighty Eight
Chrysler Concorde
Pontiac Bonneville
Chrysler LHS
Eagle Vision
Dodge Intrepid

56 CONSUMER REPORTS APRIL 1997

How we learned about TPS

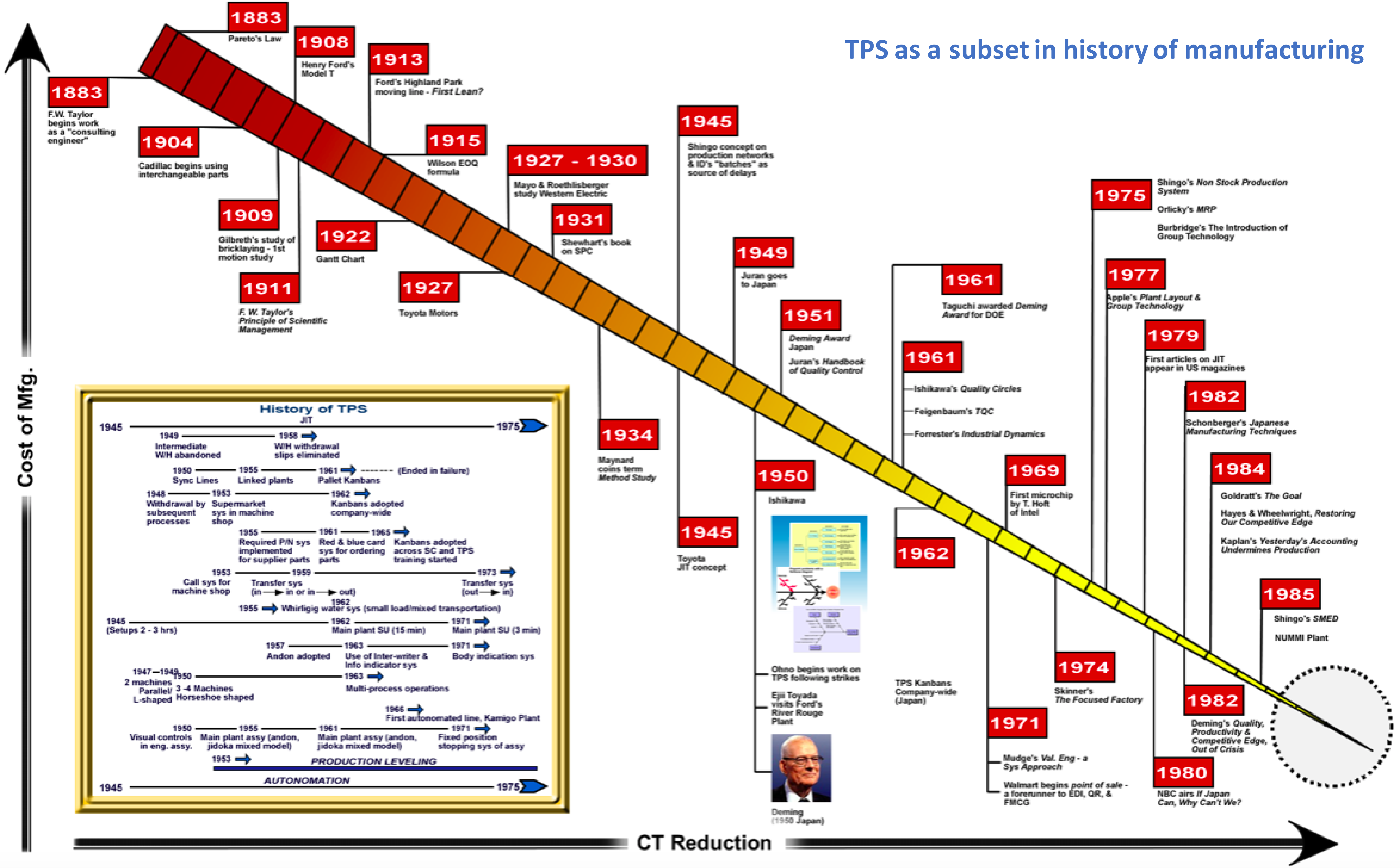
- Quality of cars - but not right away
- Pilgrimages - Hayes, Wheelwright, Clark
- Joint ventures - Nummi-Geo…
- Japanese NA operations-Georgetown, KY
- Japanese sages- Ohno, Shingo, Monden
- American translation- "Lean", J T. Black..
- Consulting firms-…Shingjutsu,…

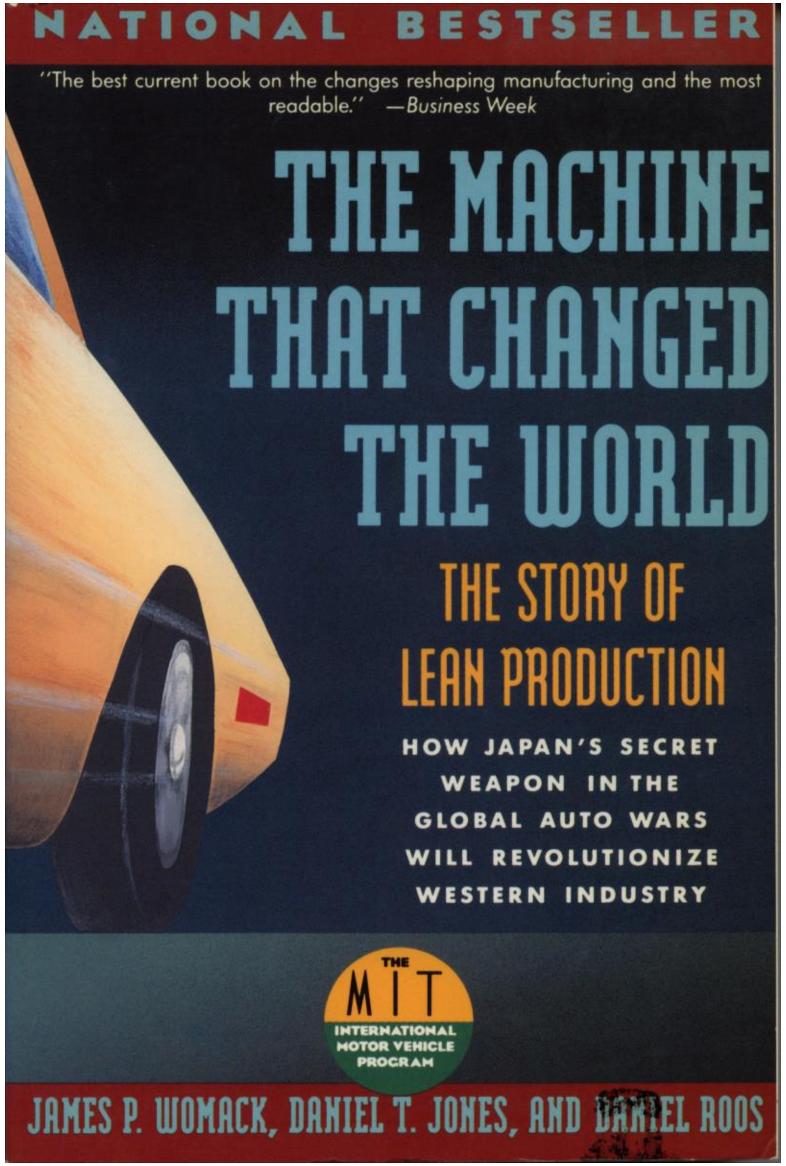
Toyota Production System Development History - Taiichi Ohno



30 years of development 1945 to 1975

TPS as a subset in history of manufacturing





1990

REFERENCES ON THE TOYOTA PRODUCTION SYSTEM;

Taiichi Ohno, "The Toyota Production System" Productivity Press 1988

Shigeo Shingo, "A Study of the Toyota Production System" Productivity Press 1989

Yasuhiro Monden, "Toyota Production System", 2nd Ed 1983

Hayes, Wheelwright and Clark, "Dynamic Manufacturing" Free Press 1988

Womack and Jones, "Lean Thinking" Simon and Schuster, 1996

Spear & Bowen, "The DNA of the TPS' HBR 1999

JT Black, "Design Rules for Implementing the Toyota Production System" IJPR 2007

E. Lander & J. K. Liker (2007) The Toyota Production System and art: making highly customized and creative products the Toyota way" IJPR 2007

Performance Observations

- Early observations of reliability, after some initial start-up problems
- IMVP got actual factory level data 1980’s
  - defect counts
  - direct labor hours for assembly
  - level of automation

Summary of Assembly Plant Characteristics,
Volume Producers, 1989
(Average for Plants in Each Region)

	Japanese in Japan	Japanese in North America	American in North America	All Europe
Performance:				
Producvitity (hours/Veh.)	16.8	21.2	25.1	36.2
Quality (assembly defects/100 vehicles)	60	65	82.3	97
Layout:				
Space (sq.ft./vehicle/yr)	5.7	9.1	7.8	7.8
Size of Repair Area (as % of assembly space)	4.1	4.9	12.9	14.4
Inventories(days for 8 sample parts)	0.2	1.6	2.9	2
Work Force:				
% of Work Force in Teams	69.3	71.3	17.3	0.6
Job Rotation (0 = none, 4 = frequent)	3	2.7	0.9	1.9
Suggestions/Employee	61.6	1.4	0.4	0.4
Number of Job Classes	11.9	8.7	67.1	14.8
Training of New Production Workers (hours)	380.3	370	46.4	173.3
Absenteeism	5	4.8	11.7	12.1
Automation:				
Welding (% of direct steps)	86.2	85	76.2	76.6
Painting(% of direct steps)	54.6	40.7	33.6	38.2
Assembly(% of direct steps)	1.7	1.1	1.2	3.1

Source: IMVP World Assembly Plant Survey, 1989, and J. D. Power Initial Quality Survery, 1989

THE IMVP WORLD ASSEMBLY PLANT SURVEY IN SUMMARY

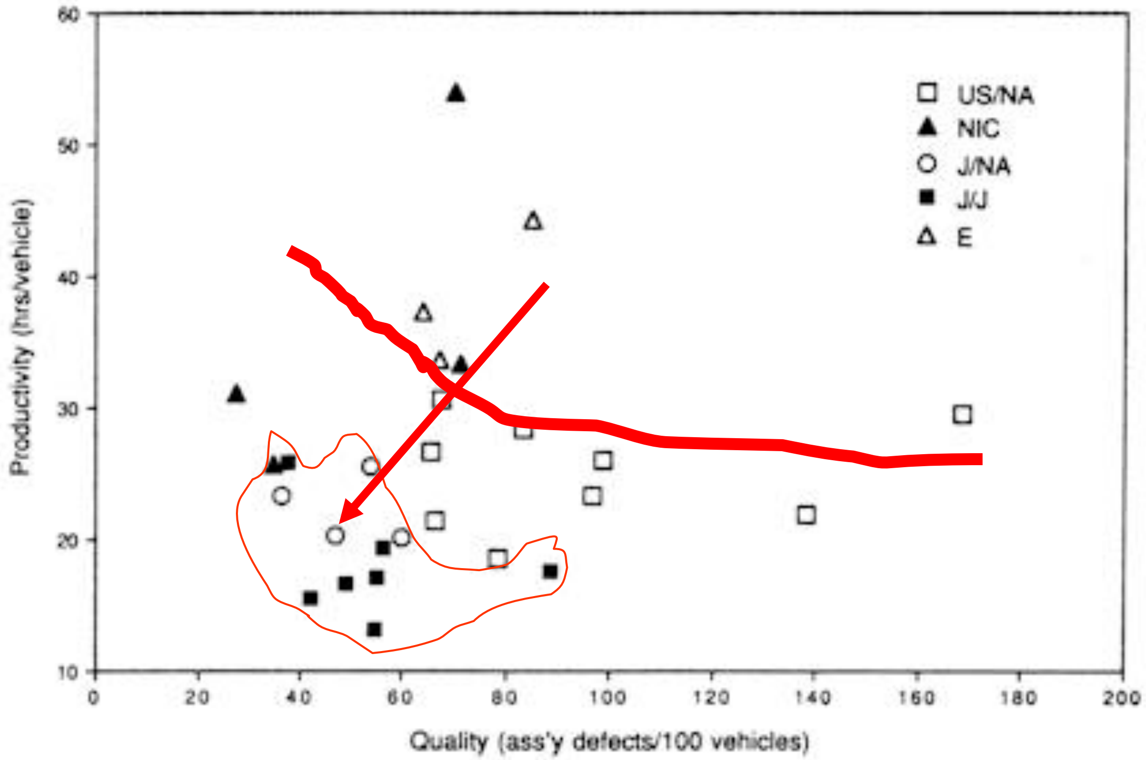
Figure 4.7 summarizes a number of dimensions of current worldwide performance of the volume producers at the assembly-plant level in addition to productivity and quality. In particular, it is striking to note the difference between average Japanese performance and the average in North America and Europe in terms of the size of repair area needed, the fraction of workers organized into teams, the number of suggestions received (and the lack so far of suggestion systems in the Japanese transplants), and the amount of training given new assembly workers.

Cost Vs Defects

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

FIGURE 4.8

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



Source: IMVP World Assembly Plant Survey, 1989

One additional and very important finding of the survey bears note: the relation between productivity and quality. When we first began the survey and correlated productivity with quality in all plants, we found almost no relationship. What's more, this did not change over time. In Figure 4.8, showing the relationship across the world at the end of 1989, the correlation between productivity and quality is .15.

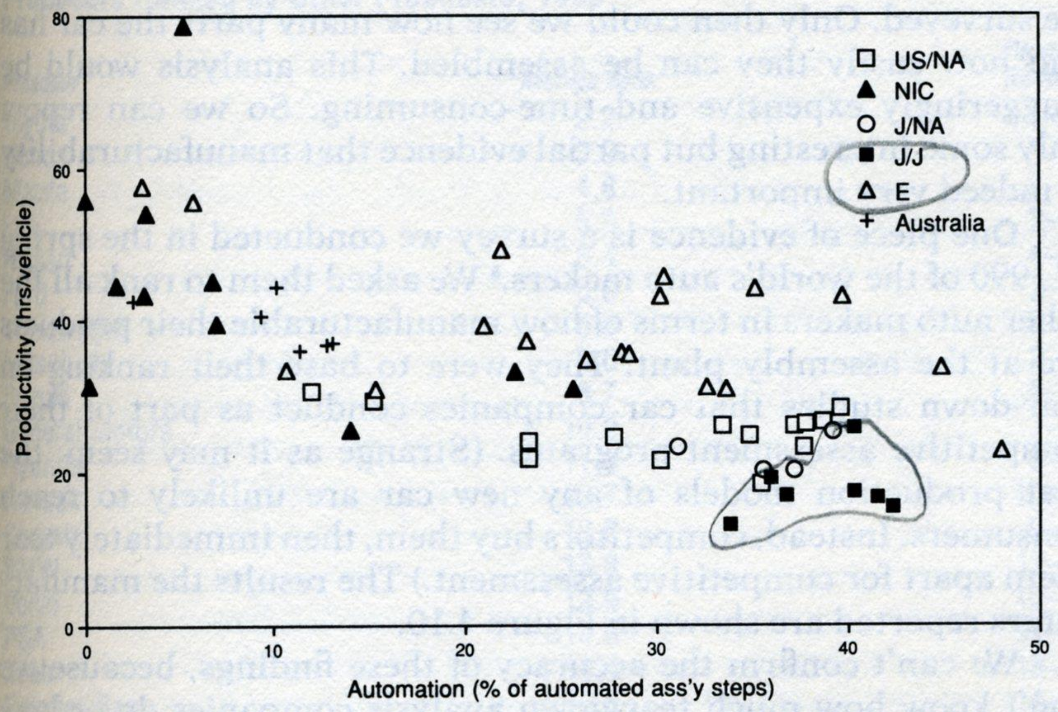
This seemed puzzling. We thought it should either be negatively correlated—plants with high quality should require more effort to achieve this, as Western factory managers had long thought—or it should be positively correlated—quality should be "free," as many writers on Japanese manufacturing had suggested. The answer to the puzzle, as a moment's examination of Figure 4.8 will show, is that both trends are in evidence and they cancel each other out. The Japanese domestic and transplant facilities are all concentrated in the lower left corner of the figure. For these lean plants, quality really is free. Removing these plants leaves a pattern in which plants tend to have high quality or high productivity but not both. For these mass-producers, quality is expensive when it can be achieved at all.

Cost Vs Automation

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

FIGURE 4.9

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.

Source: IMVP World Assembly Plant Survey, 1989

First, they ask whether automation is the secret. Our answer is that it is and it isn't. Figure 4.9 shows the relation between the fraction of assembly steps that are automated—either by robotics or more traditional "hard" automation—and the productivity of plants. There is clearly a downward slope to the right—more automation means less effort. (Stated another way, higher levels of automation show a strong negative correlation (−.67) with higher levels of effort.) We estimate that on average automation accounts for about one-third of the total difference in productivity between plants.

However, what is truly striking about Figure 4.9 is that at any level of automation the difference between the most and least efficient plant is enormous. For example, the least automated Japanese domestic plant in the sample (with 34 percent of all steps accomplished automatically), which is also the most efficient plant in the world, needs half the human effort of one comparably automated European plant and a third the effort of another. Looking farther to the right in Figure 4.9, we can see that the European plant that is the most automated in the world (with 48 percent of all assembly steps done by automation) requires 70 percent more effort to perform our standard set of assembly tasks on our standard car than is needed by the most efficient plant with only 34 percent automation.

The obvious question is, how can this be? From our survey findings and plant tours, we've concluded that high-tech plants that are improperly organized end up adding about as many indirect technical and service workers as they remove unskilled direct workers from manual assembly tasks.

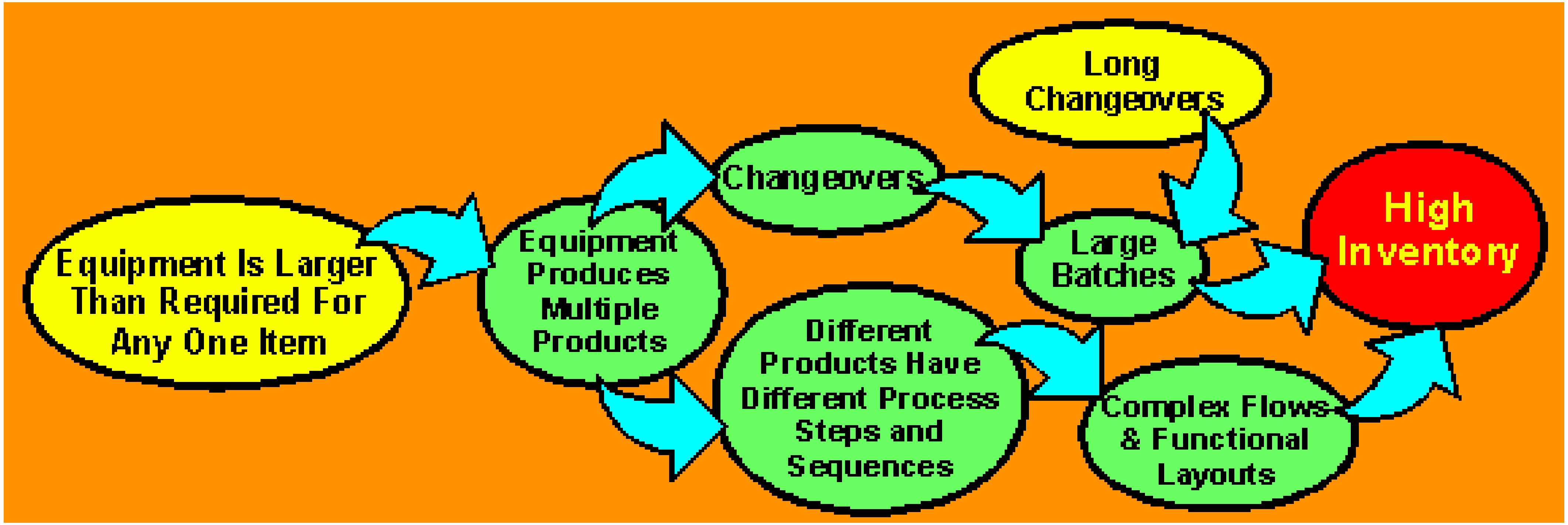
What's more, they have a hard time maintaining high yield, because breakdowns in the complex machinery reduce the fraction of the total operating time that a plant is actually producing vehicles. From observing advanced robotics technology in many plants, we've devised the simple axiom that lean organization must come before high-tech process automation if a company is to gain the full benefit.[7]

More than tools

Fundamental Differences in Manufacturing Technology + Mental Model

- Mental model is **what a person believes** about the system at hand.
- Note
  - A mental model is based on **belief, not facts**:
  - Individual users each have their own mental model.

An example



Long Changeovers
Changeovers
Equipment Is Larger Than Required For Any One Item
Equipment Produces Multiple Products
Large Batches
High Inventory
Different Products Have Different Process Steps and Sequences
Complex Flows & Functional Layouts

Design Rules

History of the Development of the Toyota Production System

ref; Taiichi Ohno

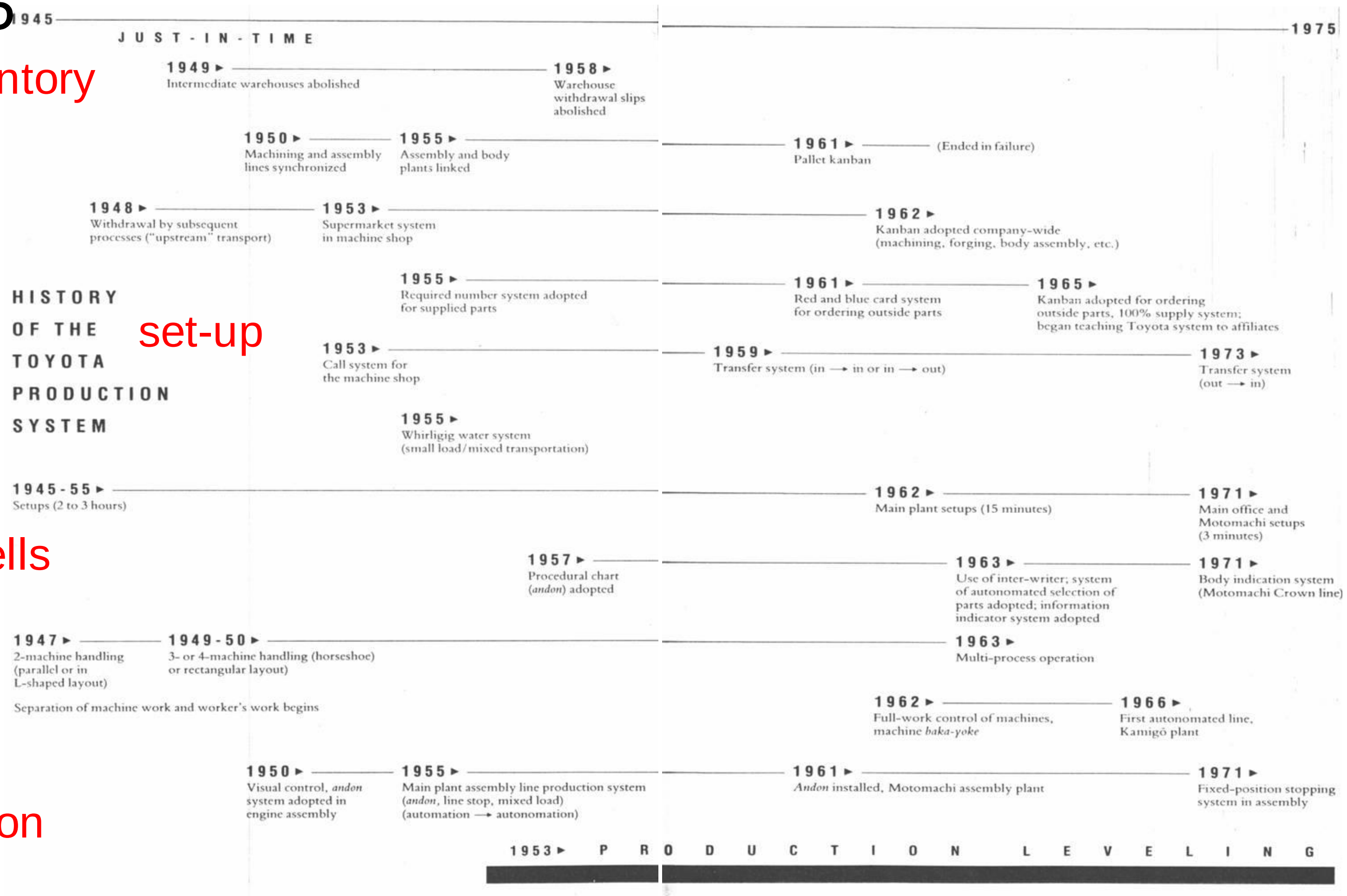
1945 1975

inventory

set-up

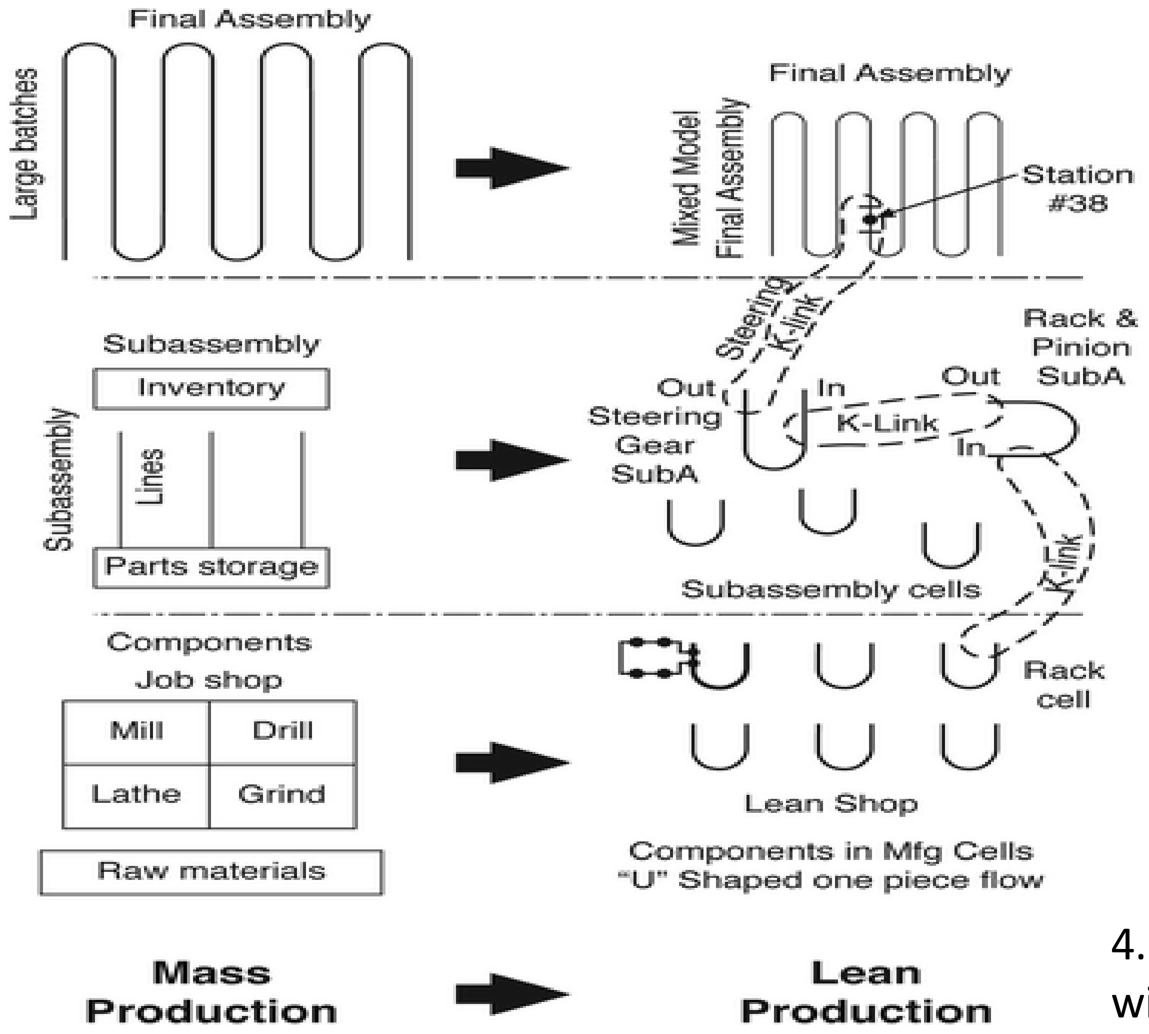
cells

Andon



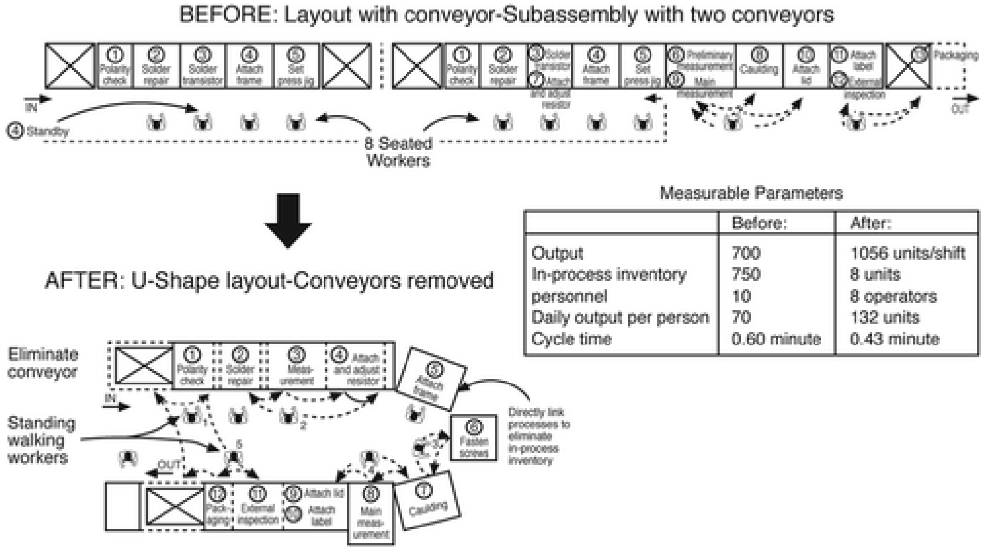
JT Black’s Design Rules

1: Final assembly (FA) line which has a takt time (TT) that is based on the daily demand for the goods being made in the factory.



2. All the goods producing aspects of the system operate on a MO-CO-MOO basis, like final assembly.

3. The subassembly manufacturing factories must be redesigned into parallel lines or U-shaped assembly cells to achieve one-piece flow



4. The manufacturing components are connected to final assembly with Kanban links, a pull system which withdraw material from the subassembly and component suppliers cells as needed by final assembly and give production orders to all the suppliers automatically

Evolution of Principles

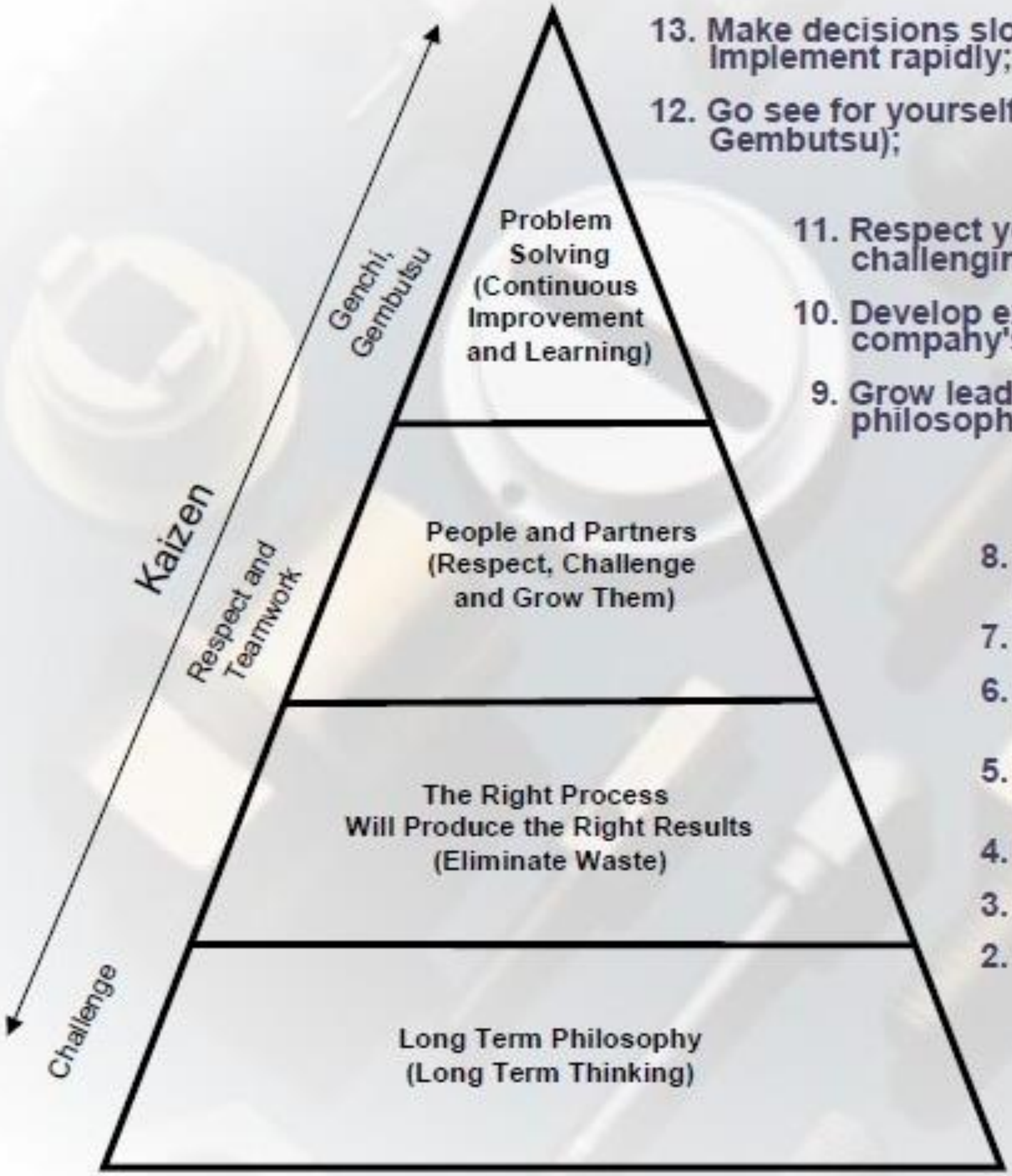
Chapter 4

The 14 Principles of the Toyota Way: An Executive Summary of the Culture Behind TPS

Since Toyota's founding we have adhered to the core principle of contributing to society through the practice of manufacturing high-quality products and services. Our business practices and activities based on this core principle created values, beliefs and business methods that over the years have become a source of competitive advantage. These are the managerial values and business methods that are known collectively as the Toyota Way.

—Fujio Cho, President Toyota
(from the Toyota Way document, 2001)

... than Tools and



- Source: Toyota Way, Liker

14. Become a learning organization through relentless reflection (hansei) and Kaizen.
13. Make decisions slowly by consensus, thoroughly considering all options. Implement rapidly;
12. Go see for yourself to thoroughly understand the situation (Genchi Gembutsu);
11. Respect your extended network of partners and suppliers by challenging them and helping them improve;
10. Develop exceptional people and teams who follow your company's philosophy;
9. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others;
8. Use only reliable, thoroughly tested technology that serves your people and processes.
7. Use visual control, so no problems are hidden;
6. Standardized tasks are the foundation for continuous improvement and employee empowerment;
5. Build a culture of stopping to fix problems to get quality right the 1st time (jidoka);
4. Level out the workload (heijunka);
3. Use Pull Systems to avoid overproduction;
2. Create Process Flow to surface problems;
1. Base management decisions on a long-term philosophy, even at the expense of short term financial goals;

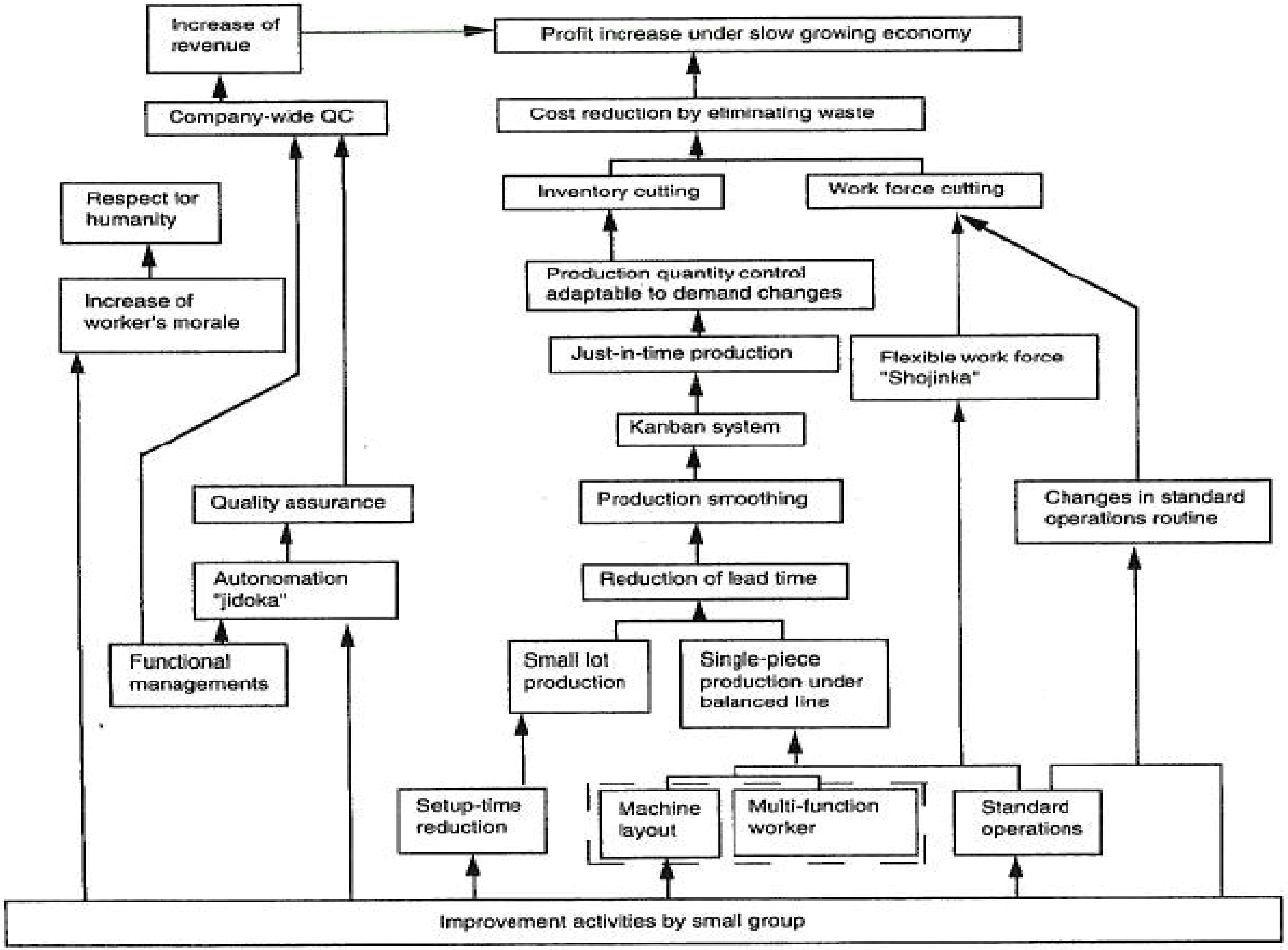
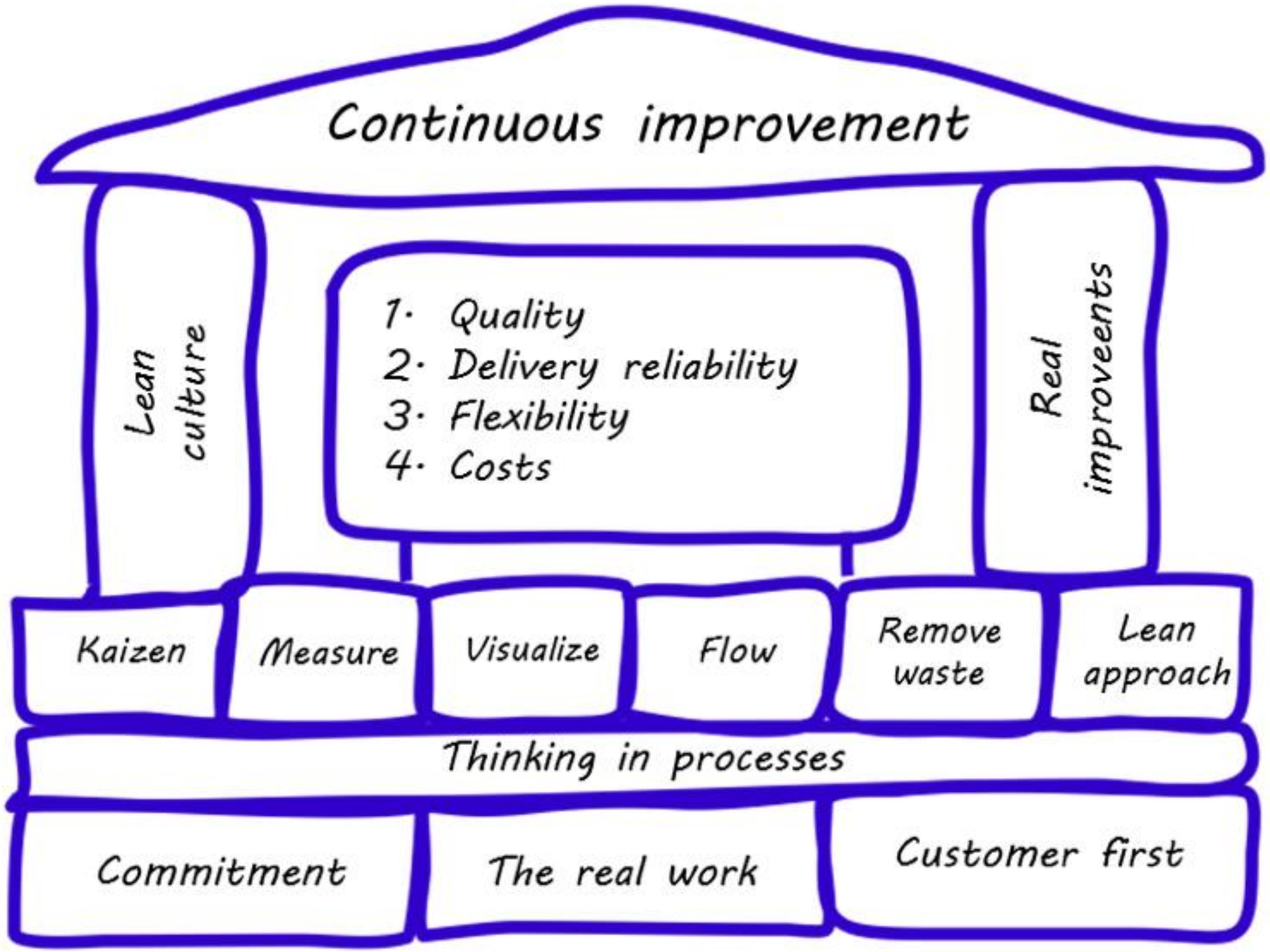


Figure 1.2. How costs, quantity, quality, and humanity are improved by the Toyota production system.

Ref Yasuhiro Monden

A more recent view



JT Black's Implementation

Table 3 of 4
Table 3. Lean production methodology for implementation.

1	*Level and balance the manufacturing system, smoothing the material flow* (Monden 1983):Leveling involves the development of mixed model final assembly. Level or smooth the demand on the cells or the suppliers. Balancing is getting the output from the cells to match the needs of final assembly.	• Establish the daily demand
• Develop mixed model final assembly; takt time		
• Balance the output from the suppliers		
• Develop single-piece flow in subassemblies		
• Sequence subassemblies with order of assembly		
• Design Rule 1		
2	*Design or reconfigure the manufacturing system:*Design and implement manufacturing and assembly cells. The design of the manufacturing system must consider the design of the product and the need of the internal and external customers while meeting the FRs for system stability. FRs functional requirements.	• Standard work for operators in cells
• Design/implement manufacturing cells (Black 1991)		
• Design Rule 2		

JT Black's Implementation (Cont)

3	*Setup reduction, changing methods and designs to reduce setup time* (Shingo 1985):Setup time is delay time. Affects lot size. Optimum lot size is one. Use SMED because it involves everyone on the factory floor (SMED = single minute exchange of dies). Permits small lots and creates flexibility.	• Teach everyone SMED
• Develop one touch setups in the cells		
• Operators perform changeovers		
4	*Integrate quality control into the manufacturing system* (Shingo 1986):Does the manufacturing process satisfy the design specifications every time? Inspection to prevent the defect from occurring (pokayokes).	• Inspect to prevent defects (Sekine 1990)
• Use the seven (7) tools for quality control and line stop		
• Teach everyone quality		
• Zero defects via Design Rule 3		
5	*Integrate preventive maintenance* (Nakajima 1988):Do the machines and people behave reliably? Design equipment to be reliable. Design methods to check people and methods for people to check machines, identify and solve problems. System will breakdown if machines and support equipment fail.	• Machines designed for reliability using TPM (Nakajima 1990)
• Operators solve problems		
• Operators perform daily maintenance		
6	*Integrate production control, link the cells, pull material to final assembly*:Control the where, when, and how much material. The design of the manufacturing system defines flow and the kanban operates within the structure. This is integrated production control or kanban (Black 1991).	• Link the cells
• Pull material to final assembly		
• Kanban drives the production		
• Design Rule 4		

JT Black's Implementation (Cont)

7	*Integrated inventory control*:Reduce the WIP in the links that connect the cells. This is control of the quantity of material in the links. Minimized and optimized and controlled by the internal customers, the users of the materials (Black 1991).	• Gradually remove inventory from links
• Expose problems		
• Solve problem, improve system TPT		
8	*Integrate the suppliers: make them JIT manufacturers just like you*:Suppliers become remote cells. Suppliers become partners. Relationship built on trust. This is how real technology transfer takes place.	• Suppliers are sole source
• Teach suppliers steps 1 to 7		
9	*Autonomation: autonomous control of quality and quantity within the manufacturing system*:Automate the integrated pull manufacturing system.	• Design/implement lean manufacturing cells
• Apply computers, robots, automation		
10	*Design the lean enterprise around the L-CMS.*	• Design new products concurrently with customers in mind.
• Design/implement lean manufacturing with lean machine tools.		

J T. Black's 10 Steps

Ref; JT. Black "Factory with a Future" 1991

1. Form cells
2. Reduce setup
3. Integrate quality control
4. Integrate preventive maintenance
5. Level and balance
6. Link cells – KANBAN
7. Reduce WIP
8. Build vendor programs
9. Automate
10. Computerize

J T. Black –1, 2

1. Form Cells

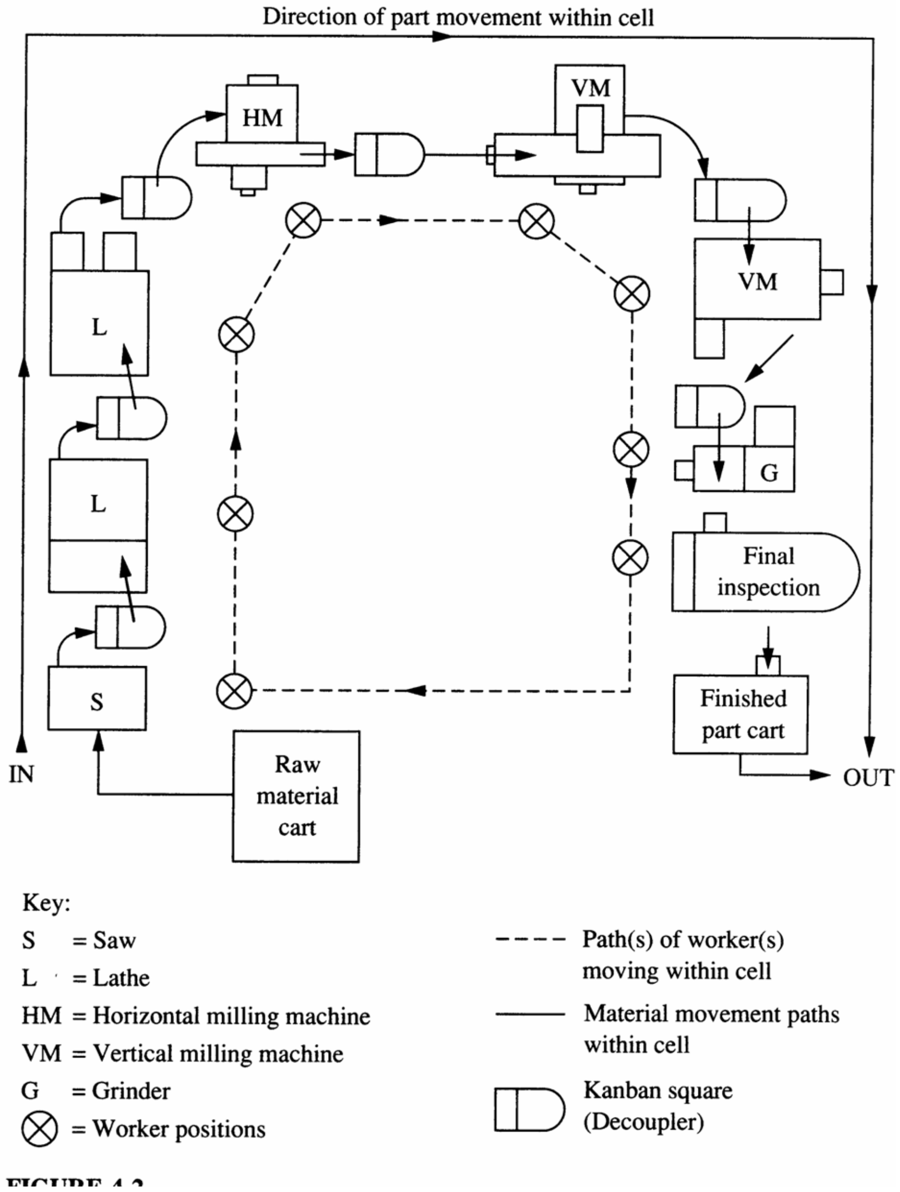
   Sequential operations, decouple operator from machine, parts in families, single piece flow within cell

2. Reduce Setup

   Externalize setup to reduce down-time during changeover, standardize set-up

TPS Cell

Toyota Cell, one part is produced for every trip around the cell



J T. Black

J T. Black – 3, 4

3. Integrate quality control

   Check part quality at cell, poke-yoke, stop production when parts are bad, make problems visible, Andon - info about work being done…

4. Integrate preventive maintenance

   worker maintains machine , runs slower, operator owns production of part

J T. Black – 5, 6

5. Level and balance

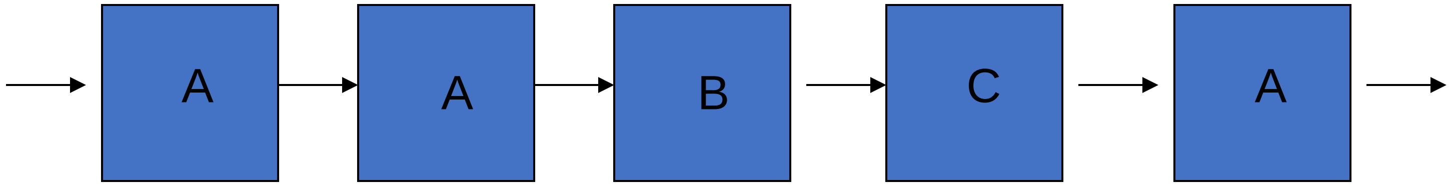
   Produce to Takt time, reduce batch sizes, smooth production flow, produce in mix to match demand

6. Link cells- Kanban

   Create “pull” system – “Supermarket” System that indicates the status of the system

Balancing and Leveling

- Balanced line: adjust process time for smooth flow “Takt time”
- Leveled Line: each product is produced in the needed distribution.



Pull System at the Supermarket

Comparison of Toyota Production System and Lean

Method	Toyota Production System	Lean (1988)	Lean (1996→)
Designer	Industrial Engineers	Mechanical Engineer*	Social Scientists**
Goal	Cost Reduction Productivity Improvement	Quality Productivity	Maximize Customer Value
Principles	Continuous Improvement Respect for People	Continuous Improvement	Specify Value Identify the Value Stream Flow Pull Perfection
Normal Condition	Flow	Flow	Perfect Processes
Focus of Improvement	Human	Technical	Technical
Primary Teaching Method	Genba Kaizen	Team Leader	Classroom
Object of Interest	Waste, Unevenness, Unreasonableness	Inventories	Value Creating Activities
Desired Outcome	Customer Satisfaction Survival	High Plant Performance	Perfect Value

Four Rules…

- Rule 1: All work shall be highly specified as to content, sequence, timing and outcome.

- Rule 2: Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.

- Rule 3: The pathway for every product and service must be simple and direct.

- Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

Spear and Bowen

Real World Examples

Real World Examples

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Real World Examples

Optimizing the Economic Efficiency by Micro-drill Life Improvement during Deep-hole Drilling in the 212-Valve Manufacturing Process

By

Yan Zhuang

Submitted to the Department of Mechanical Engineering

On 15th August, 2013 in partial fulfillment of the

Requirements for the Degree of Master of Engineering in Manufacturing

Abstract

This thesis addresses the value of optimizing lot sizing to meet part demand within the limits of machine capacity, focusing on a method for improving productivity within the CNC turning and CNC milling departments at the Waters Corporation Machining Center in Milford, Massachusetts. A detailed study of the machining center revealed problems with low machine utilization in turning and milling, low on-time delivery performance and a need for day-to-day adjustments to the production schedule. These problems were attributed to inefficient data collection and use of data, poor production scheduling, and lot sizing that the system's capacity could not handle, causing frequent occurrence of redundant part setups and enabling delays in turning and milling which cascaded to downstream processes. This thesis addresses the latter problem by implementing optimized lot sizing for ten selected part types going through the turning and milling departments; the system design called for increases to the lot sizes of five of these part types. In order to prevent increased lot sizes from causing unforeseen problems in downstream processes, the project further implemented a supermarket for these selected parts at the end of milling operations, in order to decouple turning and milling from other processes.

The lot sizing methodology focused on parts going through a turning operation followed by a milling one, with selected part types being machined on one of two machines in each department. In order to limit increases to work-in-progress inventory caused by increased lot sizes, the supermarket was designed to be managed by a Kanban-based pull system using a modified (Q, R) inventory policy with an expected weekly service level of 95%. Over the course of the implementation period, the lot sizing methodology saved an estimated 36.75 hours of setup time for parts made in 407.25 productive hours of run time. Moreover, a simulation over a year-long period estimates that with the new lot sizes, the machines in question will achieve an aggregated increase in productive hours of nearly 10%.

Real World Examples

System Improvements in Valve Manufacturing Cell at Waters Corporation

by

Snegdha Gupta
Bachelor of Engineering in Manufacturing Engineering,
College of Engineering Guindy, Anna University-Chennai, 2012

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

Real World Examples

ABSTRACT

This thesis addresses the challenge of improving on-time delivery performance of stators in the high mix valve manufacturing cell at the Milford facility of Waters Corporation with a focus on efficient line design without exceeding the average WIP levels observed in the current system. A detailed study of the current process was done and it was concluded that the poor on-time delivery performance of stators to the assembly department could be attributed to the unacceptably long fabrication lead times—due to the long waiting induced by the fabrication of a high mix of 28 different types of stators— and the lack of an efficient inventory management policy that makes the system susceptible to extreme situations of either stock-outs or inventory explosion. Therefore, a pull-type production system with a responsive fabrication line establishing WIP control and an end of line standardized finished goods inventory management was designed and implemented.

An efficient line design was developed by dedicating lines for high volume and high mix parts and by placing in-process buffers to implement a Kanban based pull-type production process that in turn limits the amount of WIP as well. An overall lead time reduction from 21 days to 3 days was achieved through the implementation of this line design and a 40% reduction in WIP levels was observed simultaneously. For standardizing the finished goods inventory management in order to maintain high service levels while eliminating the possibility of WIP explosion, a mixed inventory review policy or the (s,S) policy—that uses a re-order point to trigger production at appropriate times and a base stock level that maintains an upper control limit on the inventory levels— is suggested for implementation. With this policy, a calculated service level of at least 96% is expected even for high demand periods alongside a 50% reduction in average finished goods inventory levels.

Real World Examples

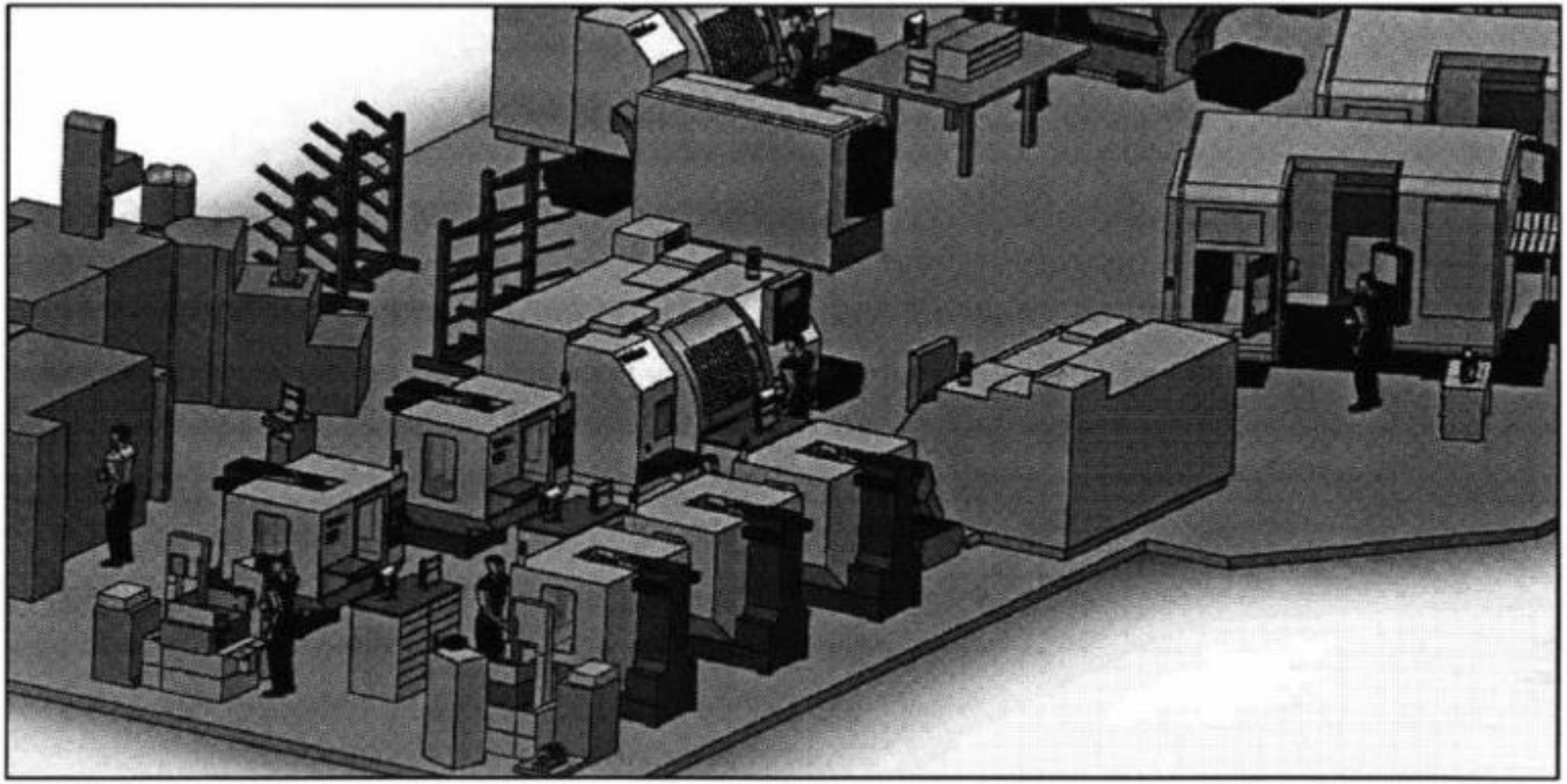


Fig. 1 Valve cell layout

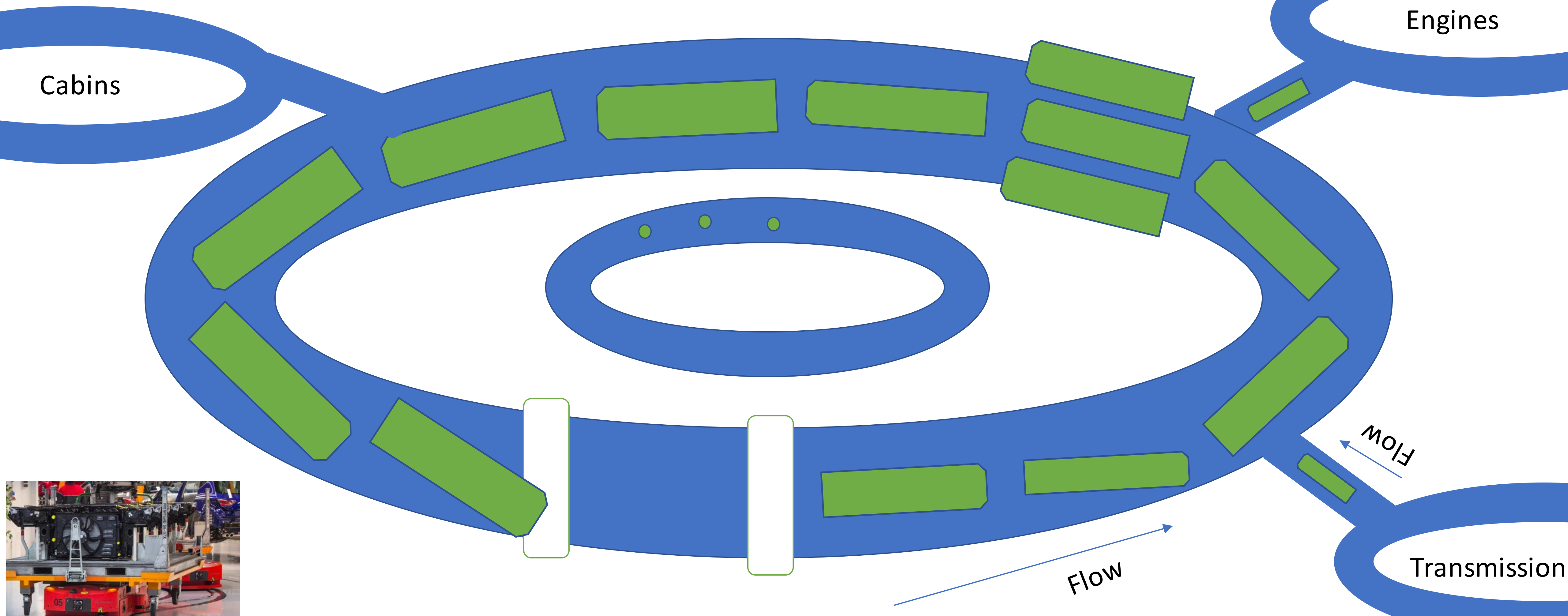
A cell - Machining valves

Mercedes Benz - São Bernardo do Campo 2019

Mercedes Benz- São Bernardo do Campo 2019

Layout of Mercedes Benz Truck Plant

4th design rule: The manufacturing components are connected to final assembly with Kanban links which withdraw material from the subassembly and component suppliers cells as needed by final assembly and give production orders to all the suppliers automatically.



Design Rules

- 4th design rule: The manufacturing components are connected to final assembly with Kanban links which withdraw material from the subassembly and component suppliers cells as needed by final assembly and give production orders to all the suppliers automatically.

https://images.app.goo.gl/8cAXadxZkRuUCD1W8

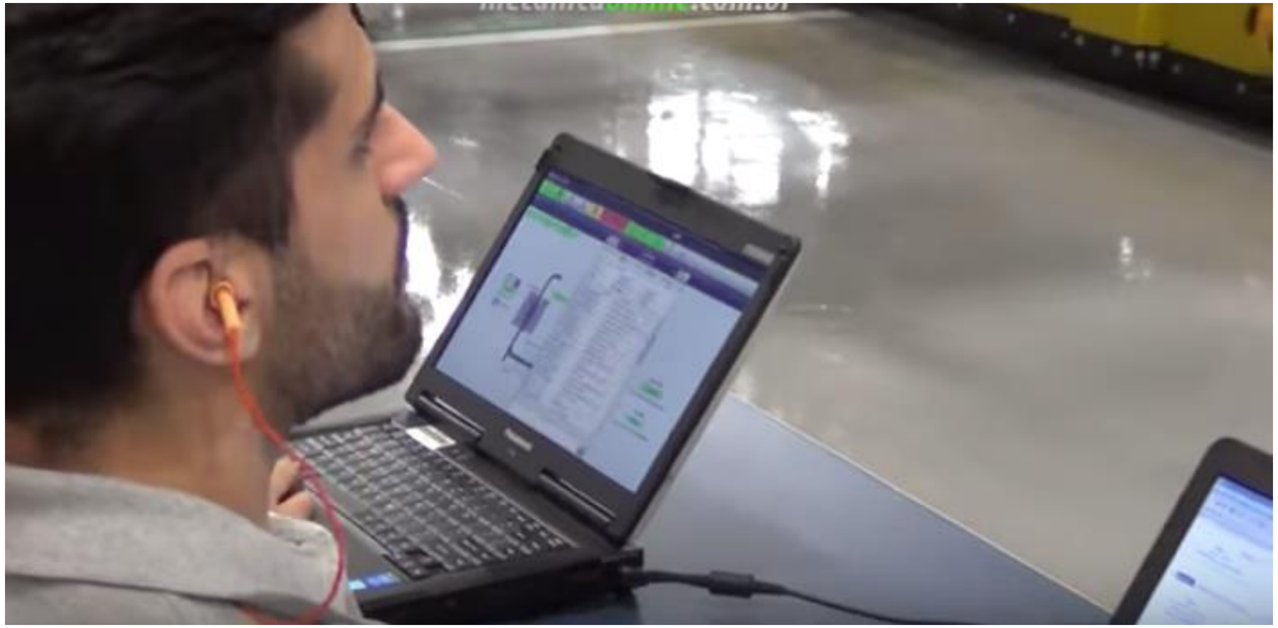
Design Rules

- The 2nd design rule is that all the goods producing aspects of the system operate on a MO-CO-MOO basis, like final assembly. One-piece flow or single-piece flow).

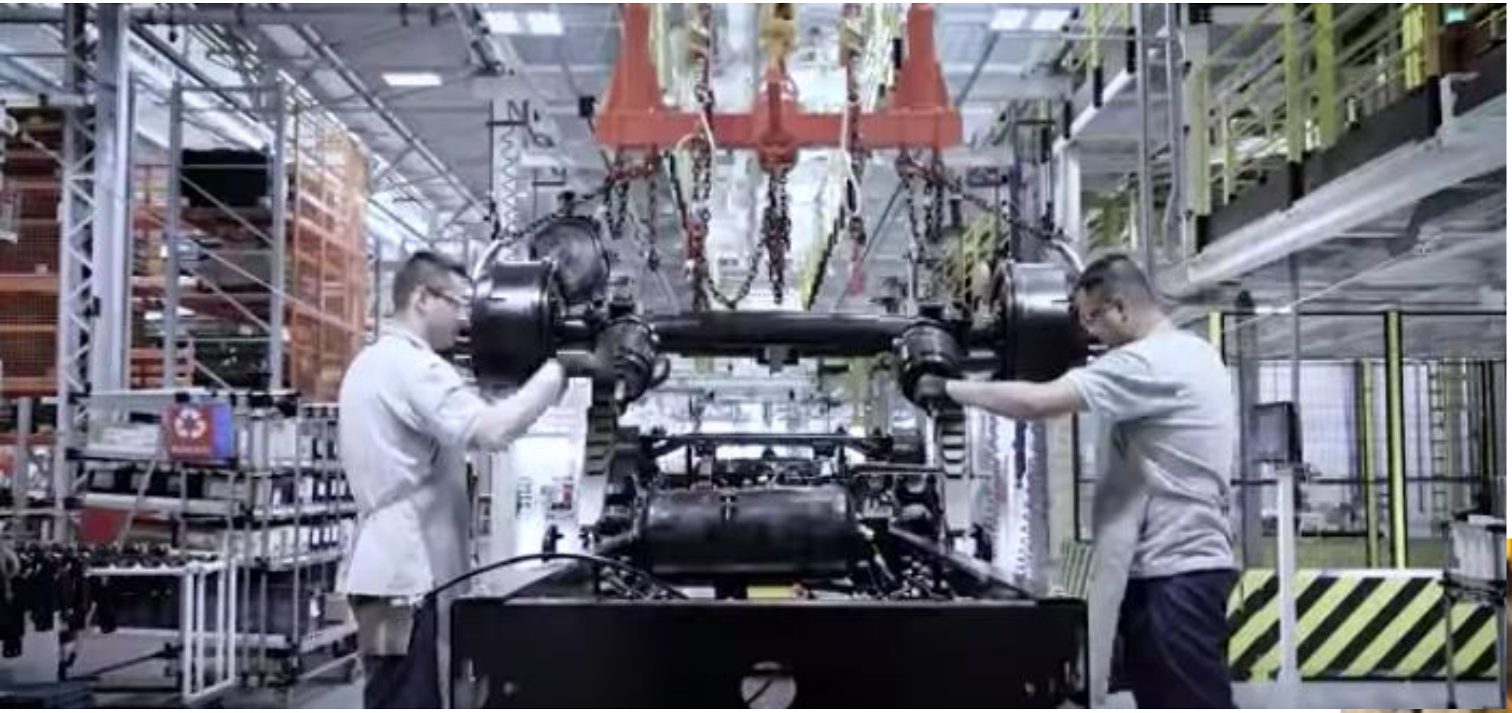
https://images.app.goo.gl/kfqHXoTYoLMM8YgA9

Design Rules

- The final assembly (FA) line which has a takt time (TT) that is based on the daily demand for the goods being made in the factory.

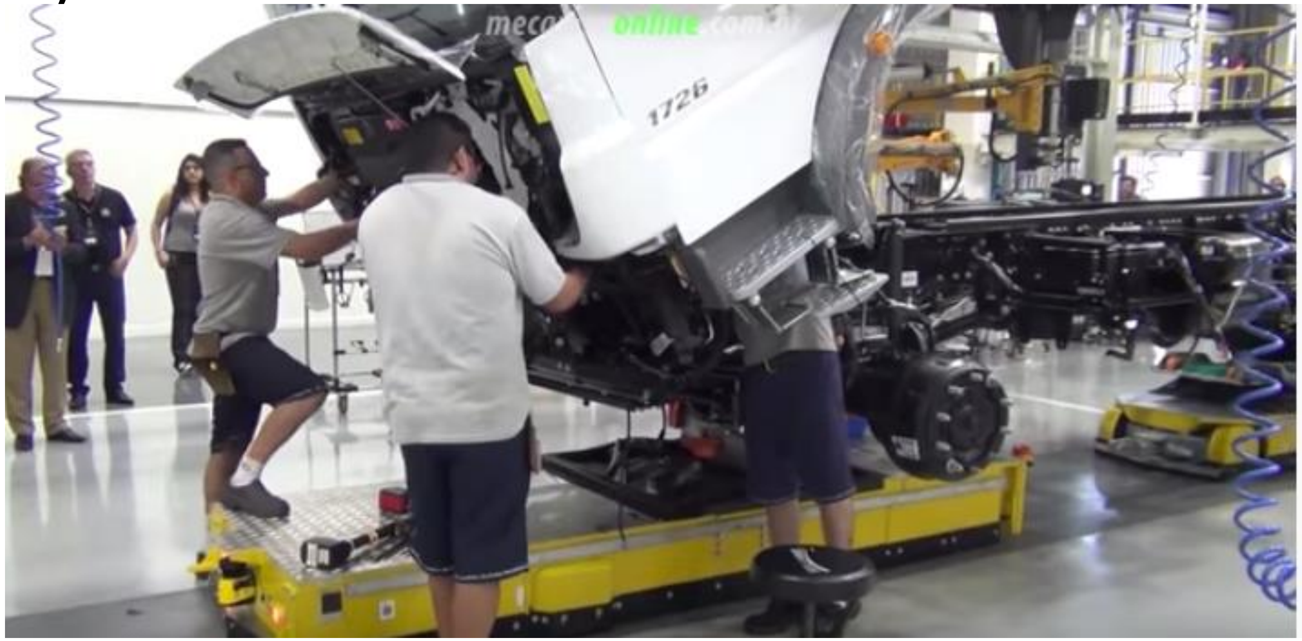


A cell?



Design Rules

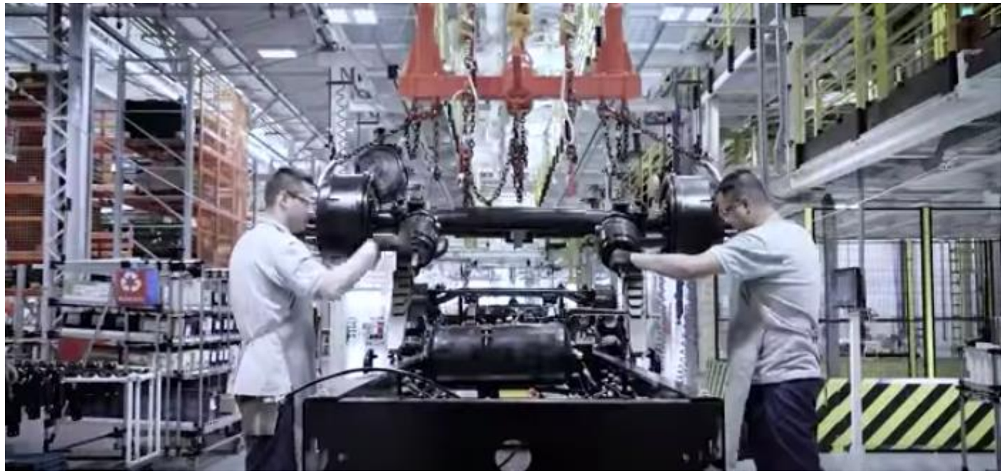
- The 2nd design rule is that all the goods producing aspects of the system operate on a MO-CO-MOO basis, like final assembly. One-piece flow or single-piece flow).



https://www.youtube.com/watch?v=zhqYqKiwTVQ

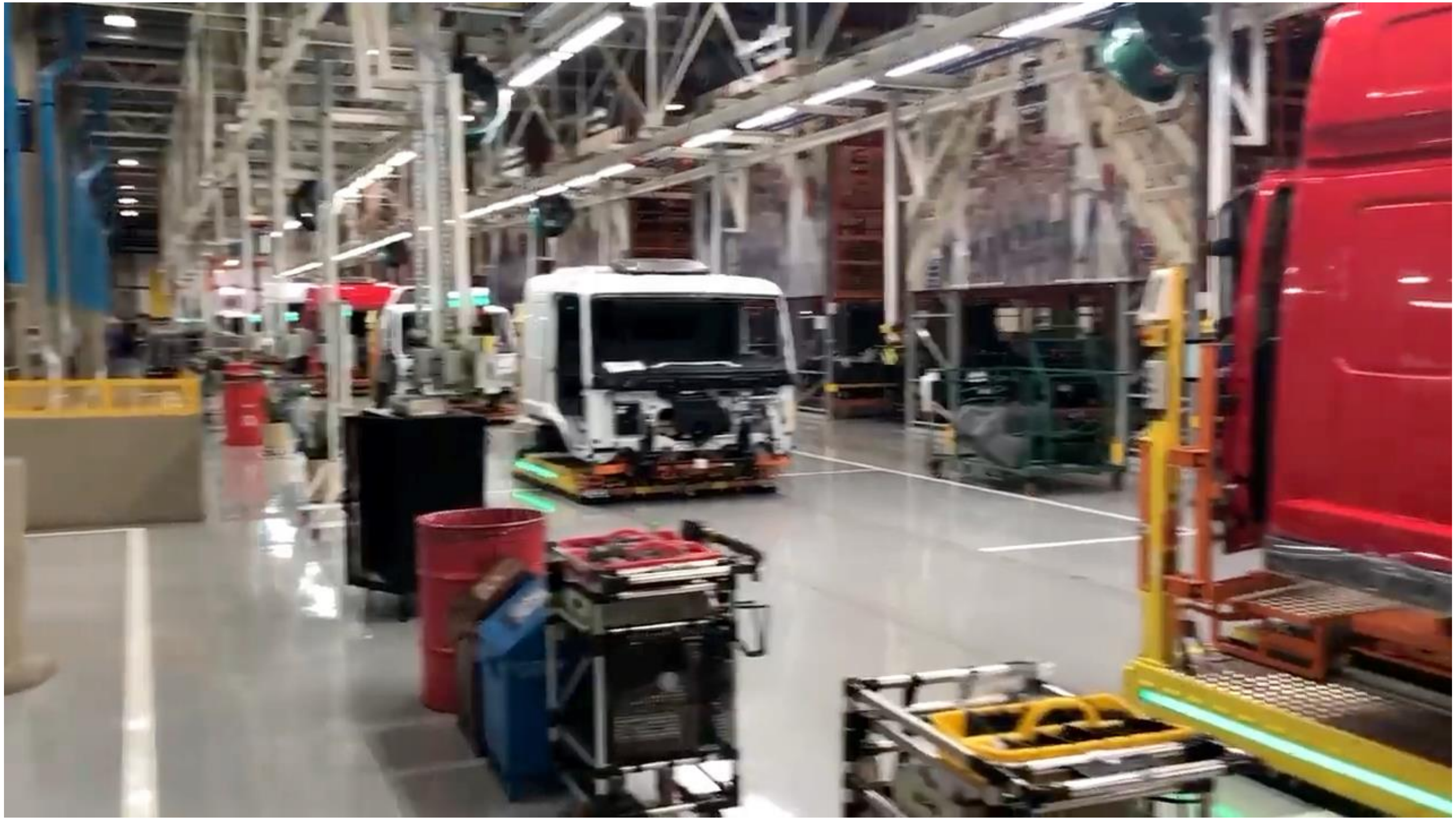
Numerical Problem

Example Operations



Machine tool	Operation or process	Machining times (MT) (min)	Operator‡ manual time (min)	Operator‡ walk time (min)

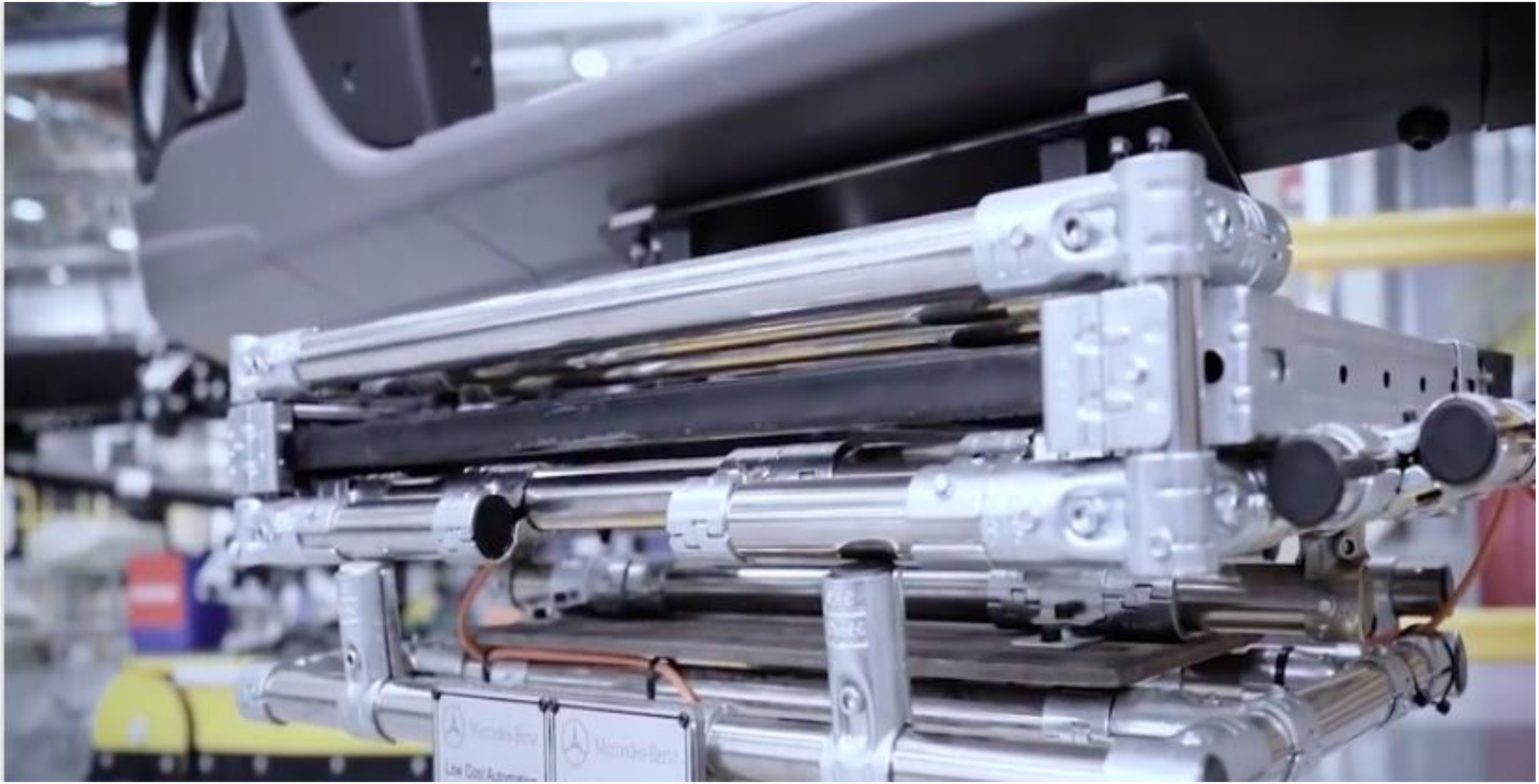
Cabins



Cabins - Cont

Final Assembly - Start

Moving Assembly line – Moving Workers – Moving Information



Kanban

Kanban (Cont)

Information Flows

Ergonomics

2.810

- The Toyota Production System & Implementation in a highly automated (4.0) Assembly / Manufacturing Plant

- Jose J. Pacheco

23 October 2019

Questions?