Week 1 | Lecture 2

ED6008: (still) An Introduction

Instructor
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www.athulan.com

January – May, 2023

Administrivia

- Instructor: Athulan Vijayaraghavan (athulan@gmail.com)
- Office Hours: TBD + By Appointment
- Text: Assigned in the Lectures
- Lecture Timings: Thursday from 2-5pm (starting from Feb).

Course Structure

- Lectures (and guest lectures)
- Homework assignments / Pop quizzes
- Literature Review / Project [presentation, report]
- ~~Final Exam~~

- Notes:
  - Exceptional Class Participation bonus points
  - Grading rubric will be shared soon.

Conduct

- Professional
- Punctual
- Ethical

What this class is about

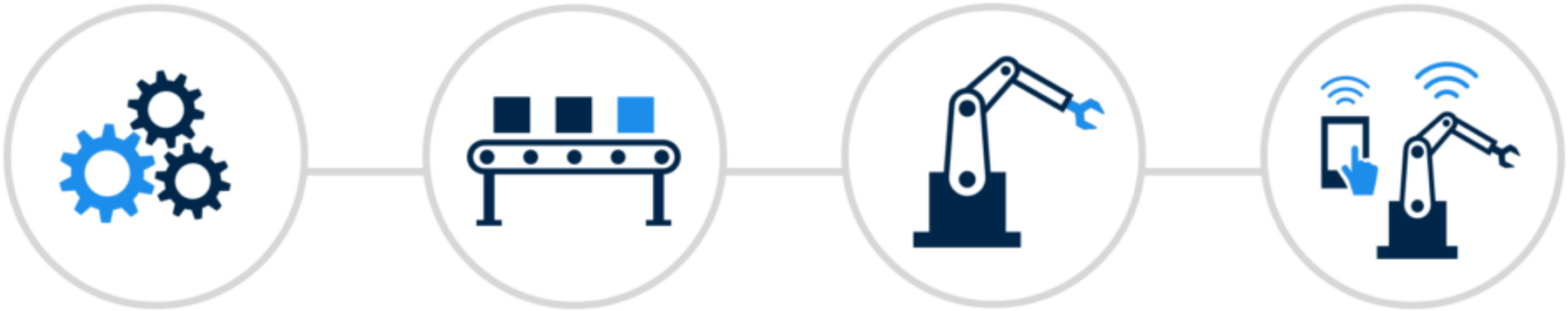
What is Industry 4.0 / Smart Manufacturing and what makes it so great?

What are the fundamentals of Manufacturing?

How do you make it Smart?

How can we learn from the mistakes (and successes) of others?

Section 1: Transformations, an Introduction



Industry 1.0

Mechanization and the introduction of steam and water power

Industry 2.0

Mass production assembly lines using electrical power

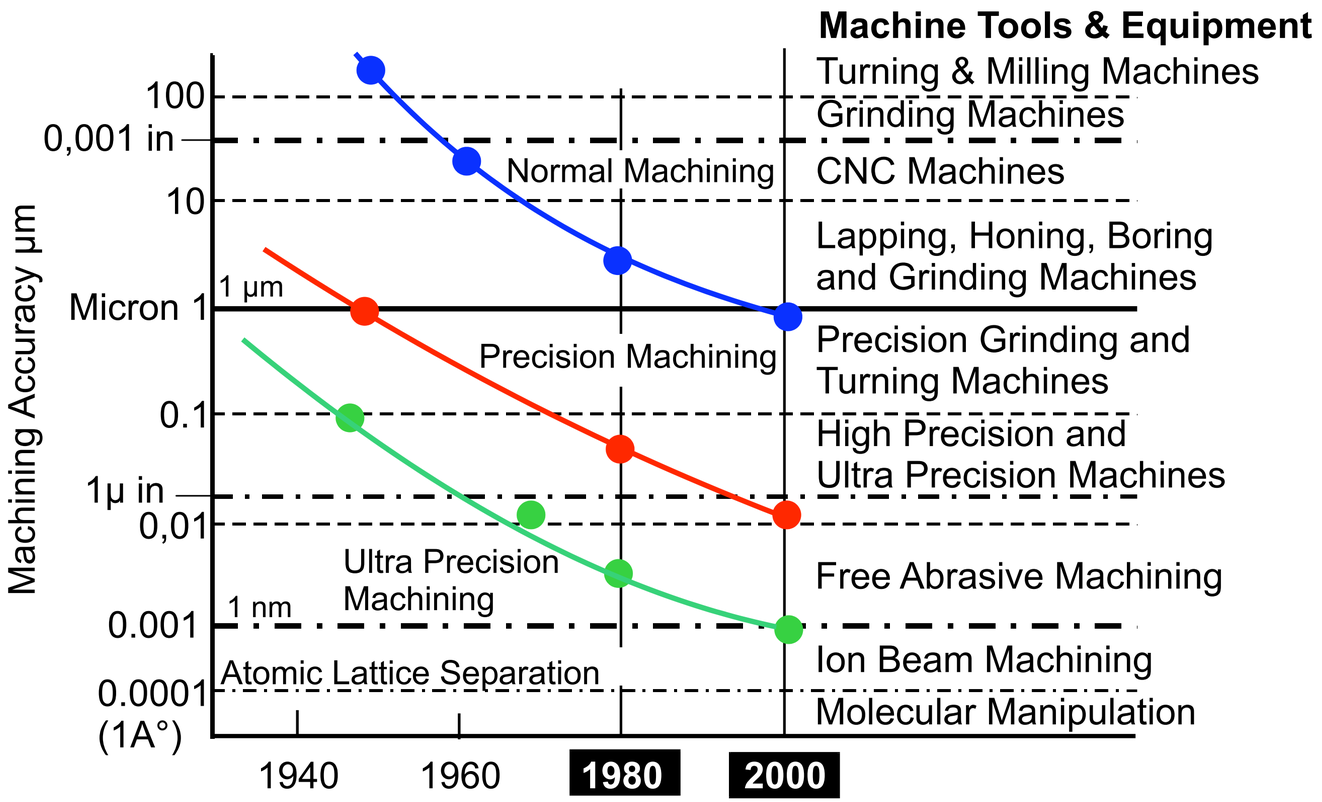
Industry 3.0

Automated production, computers, IT-systems and robotics

Industry 4.0

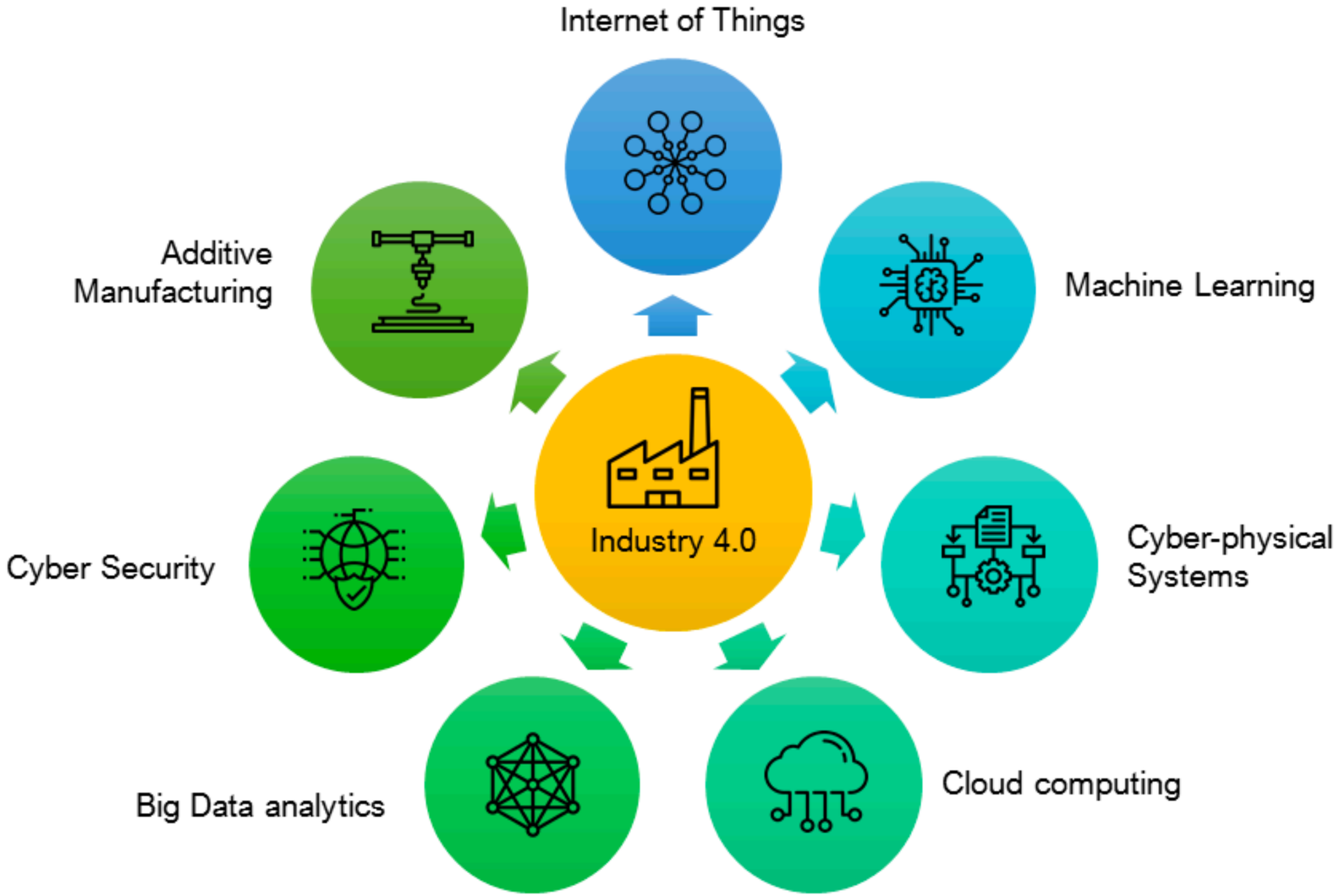
The Smart Factory. Autonomous systems, IoT, machine learning

Section 2: Fundamentals



source: McKeown after Taniguchi

Section 3: Enablers



https://www.mistralsolutions.com/blog/industry-4-0-implications-process-industry/

Section 4: Case Studies

TESLA

DMG MORI

Course Outline

Introduction
Course Introduction
Industrial Transformations

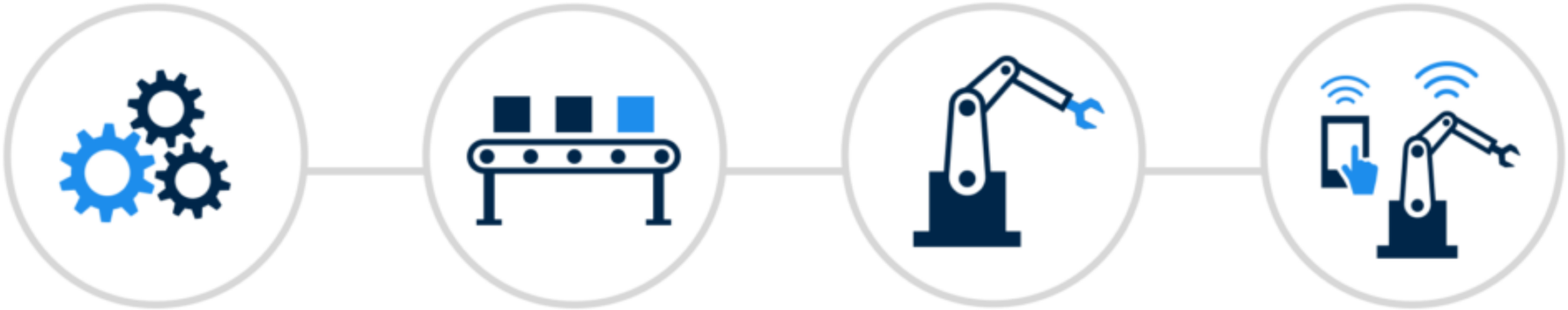
Fundamentals
Manufacturing Processes
Measurement
Machine Design
Metrology
Manufacturing Systems
Factory Dynamics

Enablers
Connectivity / Interoperability
Additive
Automation + Robotics
Sensors + Data Collection
Industrial IoT
ML/AI
Design
LCA / Energy / Environment

Case Studies
Smart Factory
Connected Vehicles
Predictive Maintenance
Predictive Quality
…

What do you want to learn more?

Section 1: Overview of Transformations



But first: 0.0

Chola Bronze – Lost Wax Casting

TABLE 1.1
HISTORICAL DEVELOPMENT OF MATERIALS AND MANUFACTURING PROCESSES (DATES ARE APPROXIMATE). (After J. A. Schey, C. S. Smith, R. F. Tylecote, T. K. Derry, T. I. Williams and S. Kalpakjian

	PERIOD	METALS AND CASTING	FORMING PROCESSES
Egypt: ~3100 BC to ~300 BC; Greece: ~1100 BC to ~146 BC; Roman empire: ~500 BC to AD 476; Middle ages: ~476 to 1492; Renaissance: 14th to 16th centuries	Before 4000 BC	Gold, copper, meteoritic iron	Hammering
	4000–3000 BC	Copper casting, stone and metal molds, lost wax process, silver, lead, tin, bronze	Stamping, jewelry
	3000–2000 BC	Bronze casting	Wire by cutting sheet and drawing; gold leaf
	2000–1000 BC	Wrought iron, brass	
	1000–1 BC	Cast iron, cast steel	Stamping of coins
	AD 1–1000	Zinc, steel	Armor, coining, forging, steel swords
	1000–1500	Blast furnace, type metals, casting of bells, pewter	Wire drawing, gold and silver smith work
	1500–1600	Cast iron cannon, tinplate	Water power for metalworking, rolling mill for coinage strips
Industrial revolution: ~1750 to 1850	1600–1700	Permanent mold casting, brass from copper and metallic zinc	Rolling (lead, gold, silver), shape rolling (lead)
	1700–1800	Malleable cast iron, crucible steel	Extrusion (lead pipe), deep drawing, rolling (iron bars and rods)
	1800–1900	Centrifugal casting, Bessemer process, electrolytic aluminum, nickel steels, babbitt, galvanized steel, powder metallurgy, tungsten steel, open-hearth steel	Steam hammer, steel rolling, seamless tube piercing, steel rail rolling, continuous rolling, electroplating
WWI	1900–1920		Tube rolling, hot extrusion
WWII	1920–1940	Die casting	Tungsten wire from powder
	1940–1950	Lost wax for engineering parts	Extrusion (steel), swaging, powder metals for engineering parts
	1950–1960	Ceramic mold, nodular iron, semiconductors, continuous casting	Cold extrusion (steel), explosive forming, thermomechanical treatment
Space age	1960–1970	Squeeze casting, single crystal turbine blades	Hydrostatic extrusion
	1970–1980s	Compacted graphite, vacuum casting, organically bonded sand, automation of molding and pouring, large aluminum castings for aircraf: structures, rapid solidification technology	Precision forging, isothermal forging, superplastic forming, die design by analytical methods

Art

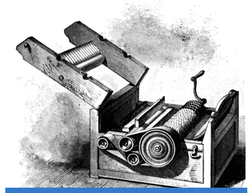
Science

Technology

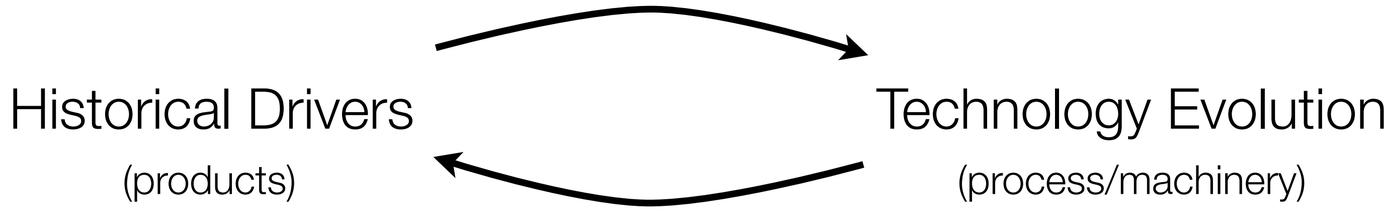
drivers?

Systemic Trends

a.k.a. *The Ages of Manufacturing*

Enabler of Shift		Standardize parts	Automate processes	CAD/CAM/ Planning/Control	This Class
					
Industry ___	0.0	1.0	2.0	3.0	4.0
Lot Size	small	large	very large	large	small
Product Mix	high	low	low	medium	high
Lead Time	huge	large	medium	low	very low
Inventory	almost none	large	huge	medium	almost none

Manufacturing Change



How does history affect technology?

How does technology affect history?

What changes?

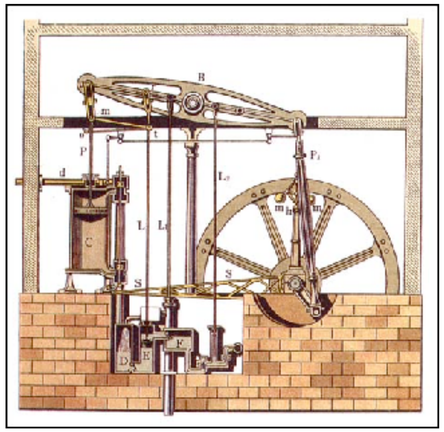
What does this say about design?

Historical Drivers

What are the basic drivers for manufacturing processes?

"(S)he who has the most energy generally wins"

water pumps
↓
mining
↓
coal
↓
steam boilers
↓
drive machines

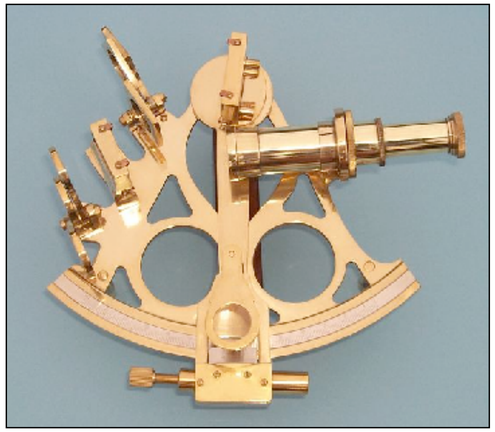


"(S)he who shoots furthest generally wins"

machinery
↓
cylinders
↓
cannons
↓
shoot projectiles
↓
hit enemy

"(S)he who sells the most generally wins"

time pieces
↓
navigate
↓
sail for trade
↓
trade to sell-buy
↓
make money



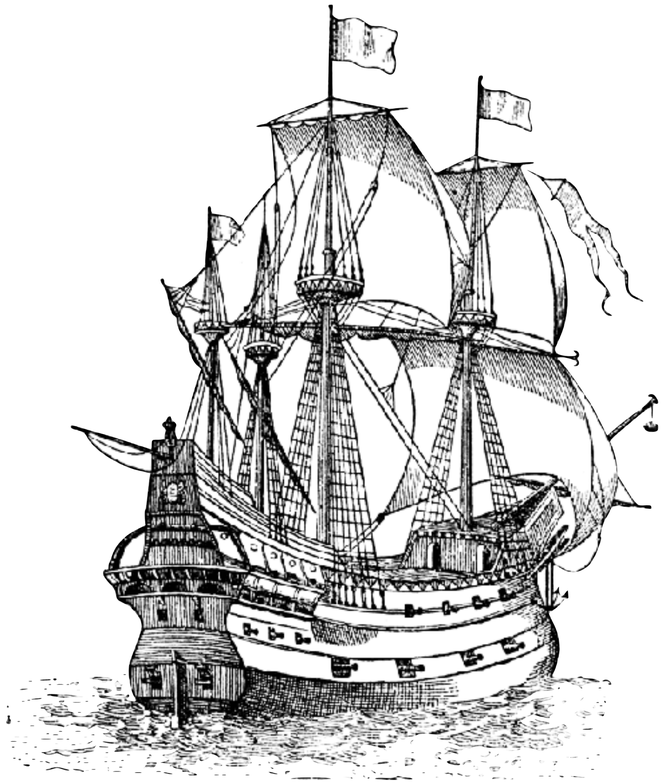
Example

"The ship was the plane of past centuries"

"(S)he who has the most energy generally wins"	"(S)he who shoots furthest generally wins"	"(S)he who sells the most generally wins"

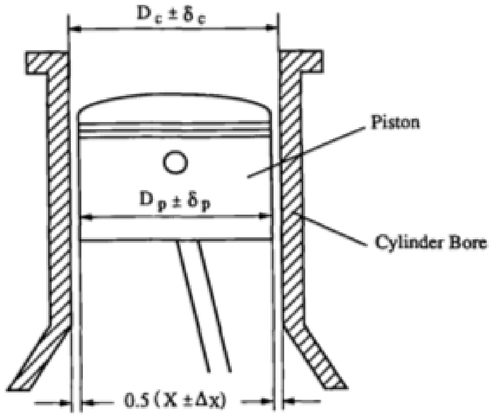
better steam engines helps increase speed
better guns helps combat enemies
better navigation helps reduce delays

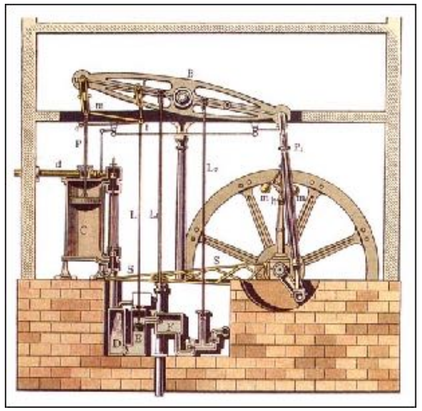
competitive advantage: speed, lethality, navigability



Engine Tolerances

piston/cylinder clearance one of primary "bottlenecks"





Watt's steam engine (1769): "thickness of a shilling" - about 0.08" (2000 microns!)

www.spartacus.schoolnet.co.uk/TEXrotary.htm

Porsche 912 (1960s): about 0.002" (~50 microns)

http://www.hillmanimages.com/912/index.html

Modern Japanese motorcycle (1990s): about 0.0001" (2.54 microns)

http://www.buykawasaki.com

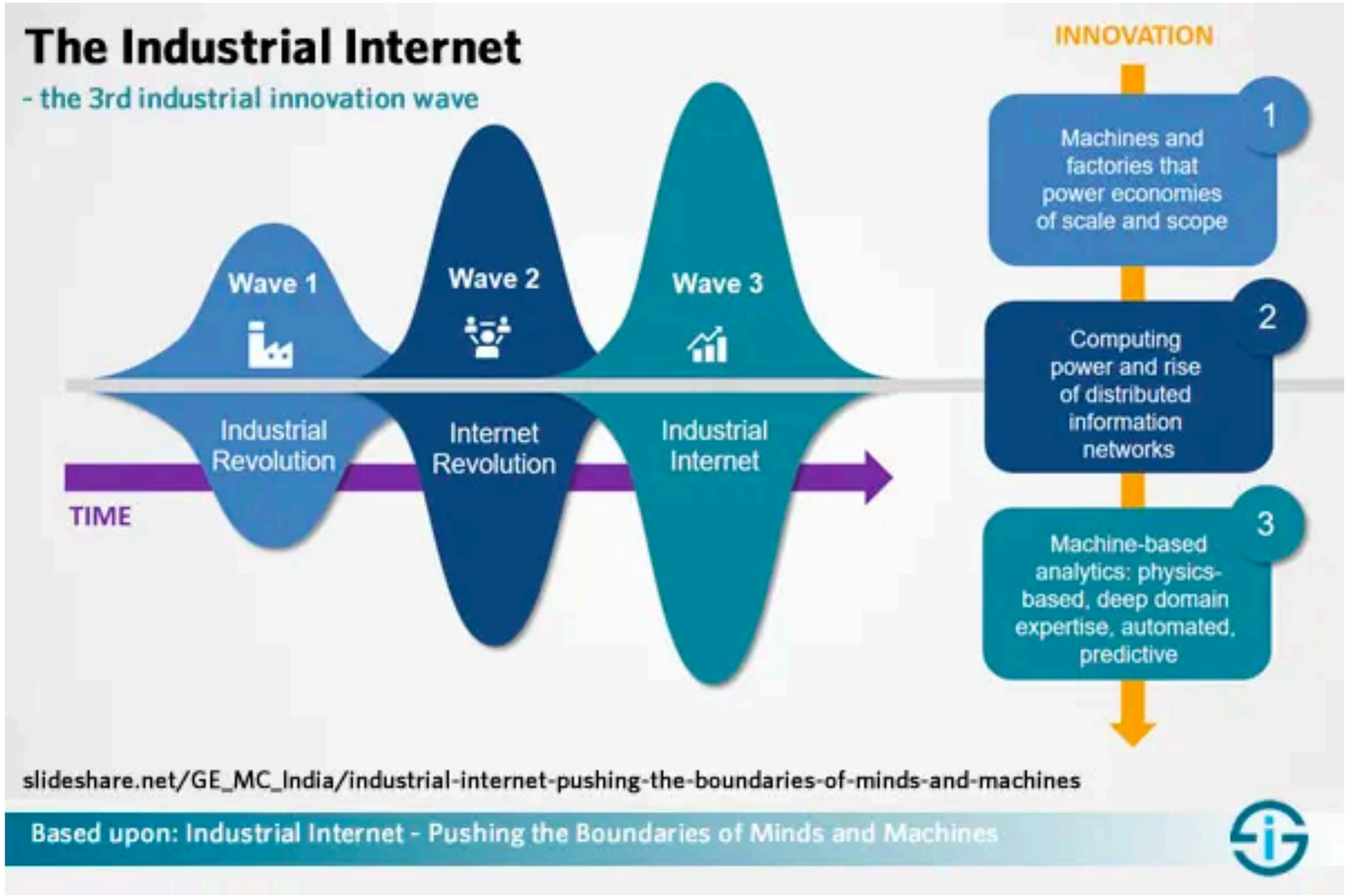
Origins: Industrie 4.0

- 2006: German government presented “High-Tech Strategy” – *‘Die Neue Hightech-Strategie Innovationen für Deutschland’*
- 2011: Advisory board presented first articulation of “Industrie 4.0”
- 2013: Advisory board presented to German Chancellor Angela Merkel

Credit: https://www.i-scoop.eu/industry-4-0/

> The factory of the future combines unprecedented flexibility with optimal resource utilisation. Industrie 4.0 offers Germany the chance to further strengthen its position as a manufacturing location, manufacturing equipment supplier and IT business solutions supplier. It is encouraging to see that all the stakeholders in Germany are now working closely together through the Plattform Industrie 4.0 in order to move ahead with implementation.
>
> **Henning Kagermann, Chairman of the acatech Board of Trustees and Co-Chair of the Industrie 4.0 Working Group**

Industry meet Internet



Credit: https://www.i-scoop.eu/industry-4-0/

2016: Industry Perception

The vast majority of respondents see Industry 4.0 as an opportunity to improve productivity, not a burning platform

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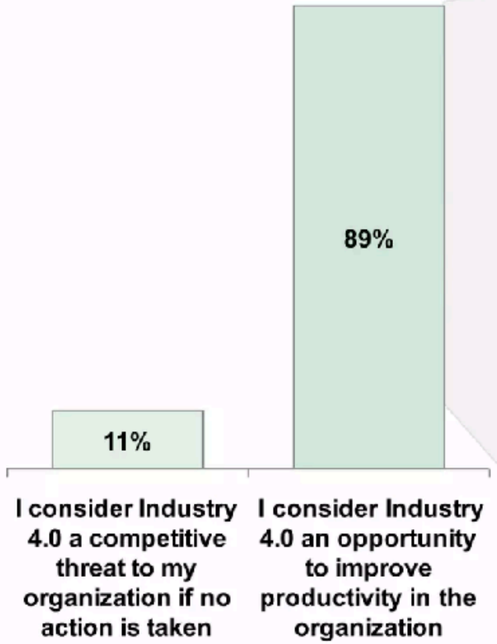
Do you consider Industry 4.0 as an opportunity to improve productivity or rather a competitive threat if no action is taken?



"It is a novel approach to automation and data exchange that should help the organization be more productive *and efficient, impacting operating cost and supply chain."*

"Industry 4.0 aids in the streamlining of processes and business improvements. It sets our company apart from our competitors *and aids in business development and marketing enhancements."*

"Computer integration and robotics can greatly increase production *and quality of our products."*

"Having up to the minute information can make or break a project."

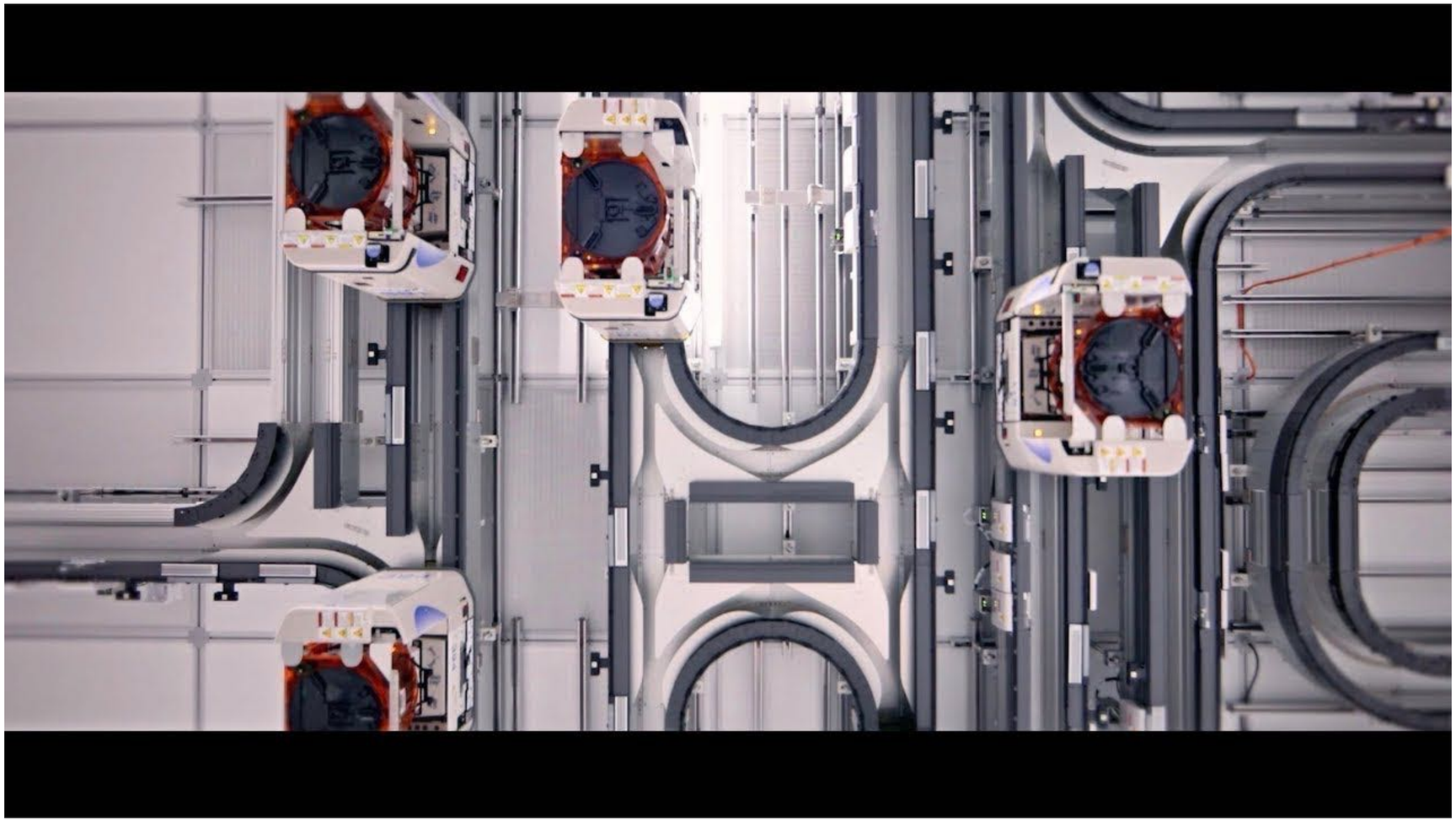
"In design engineering, ***3D modeling and use of augmented reality applications*** *combined with existing data measurement systems is* ***saving large amount of time and cost while improving design speed and accuracy."***

THE BOSTON CONSULTING GROUP

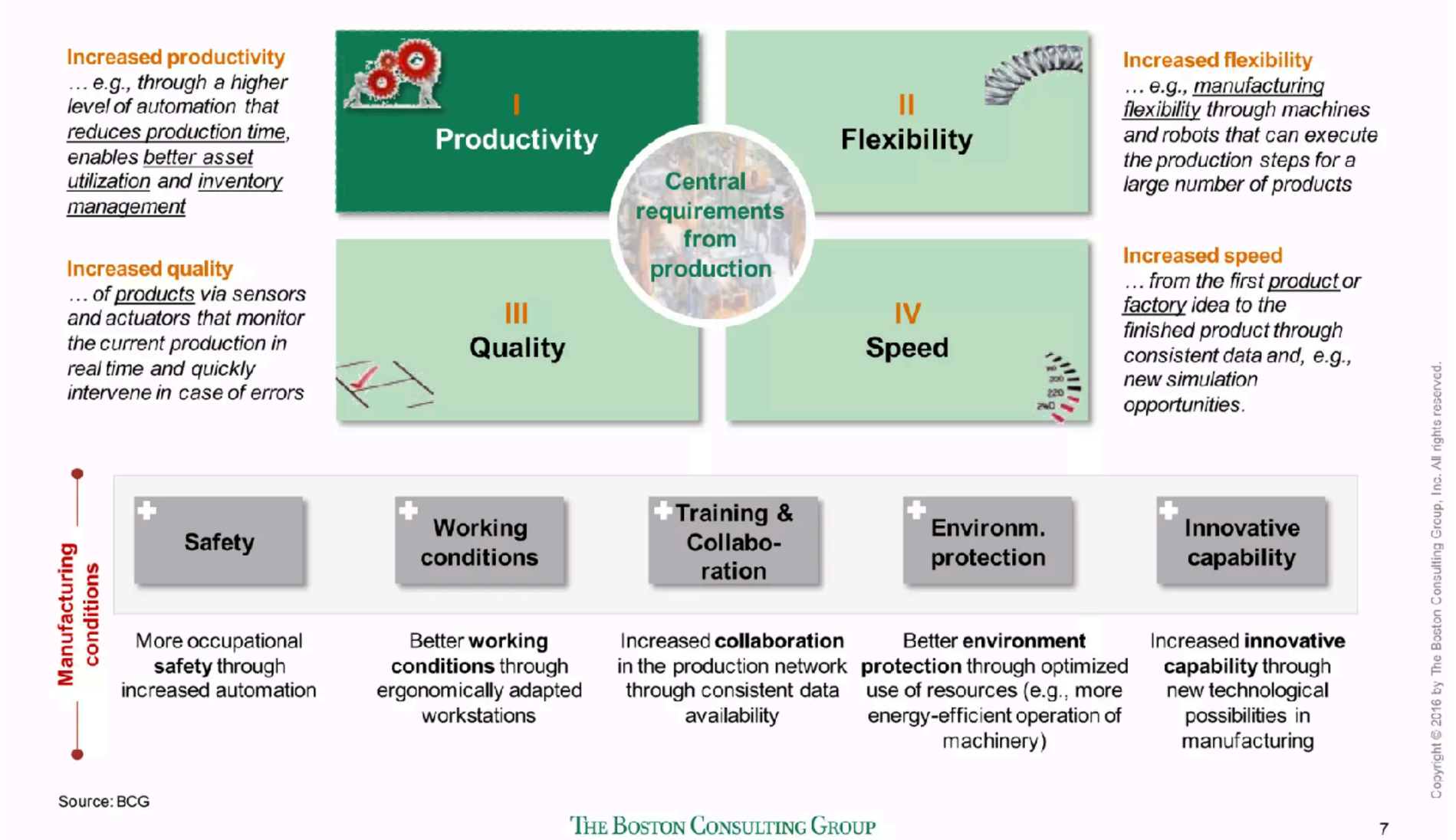
5

Credit: The Boston Consulting Group, https://www.slideshare.net/TheBostonConsultingGroup/sprinting-to-value-in-industry-40

Today: Companies are actively trying ...

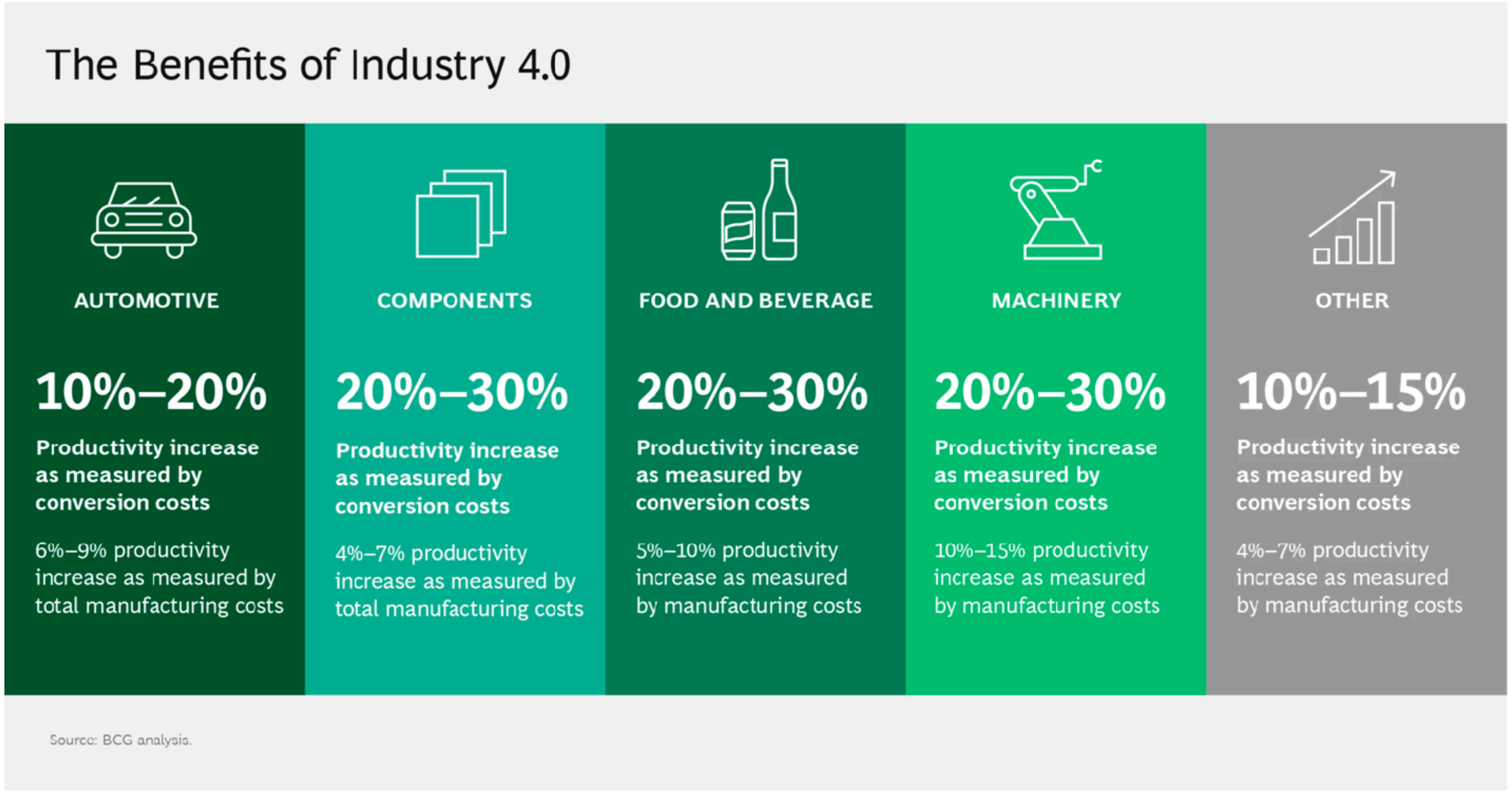


… to realize Value …



Credit: The Boston Consulting Group

… with measurable Impact

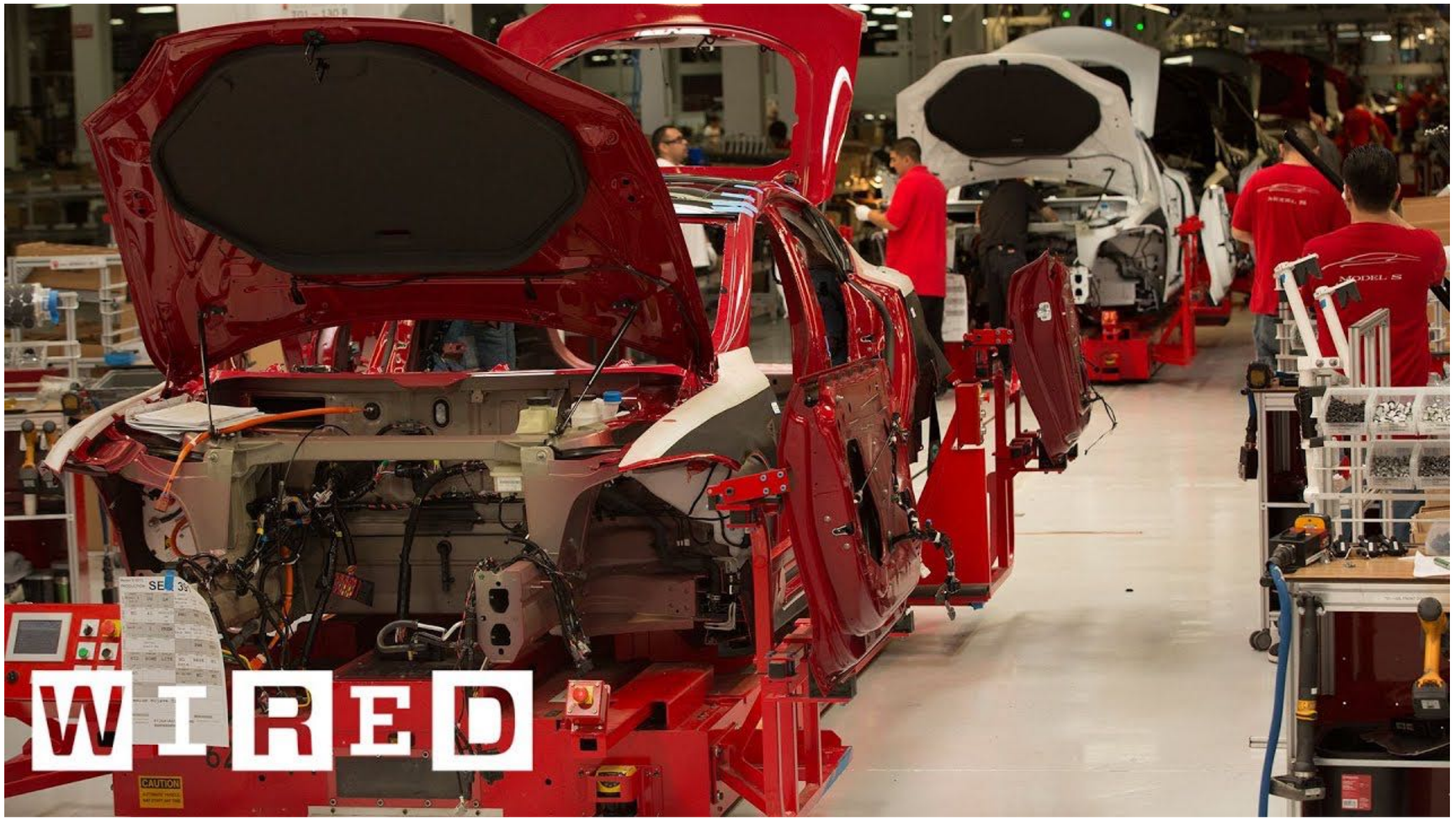


Credit: The Boston Consulting Group

But … challenges and risks!

- Where do we want to go – Organisation strategy
- How do we get there – Internal processes, decision making, cultural changes
- Can we afford it – Business case and investment
- Do we have the right people for it – Talent and hiring.

Example: Tesla (circa 2013)



Assignment 01

- What has evolved in Tesla's use of Industry 4.0 technology from 2014 to today? Why do you think they have evolved (what was the motivation for the evolution)? Please cite your sources.
- Due: Jan 28, Friday

Next Time: What is Manufacturing?

The art/science/technology of converting raw materials into products

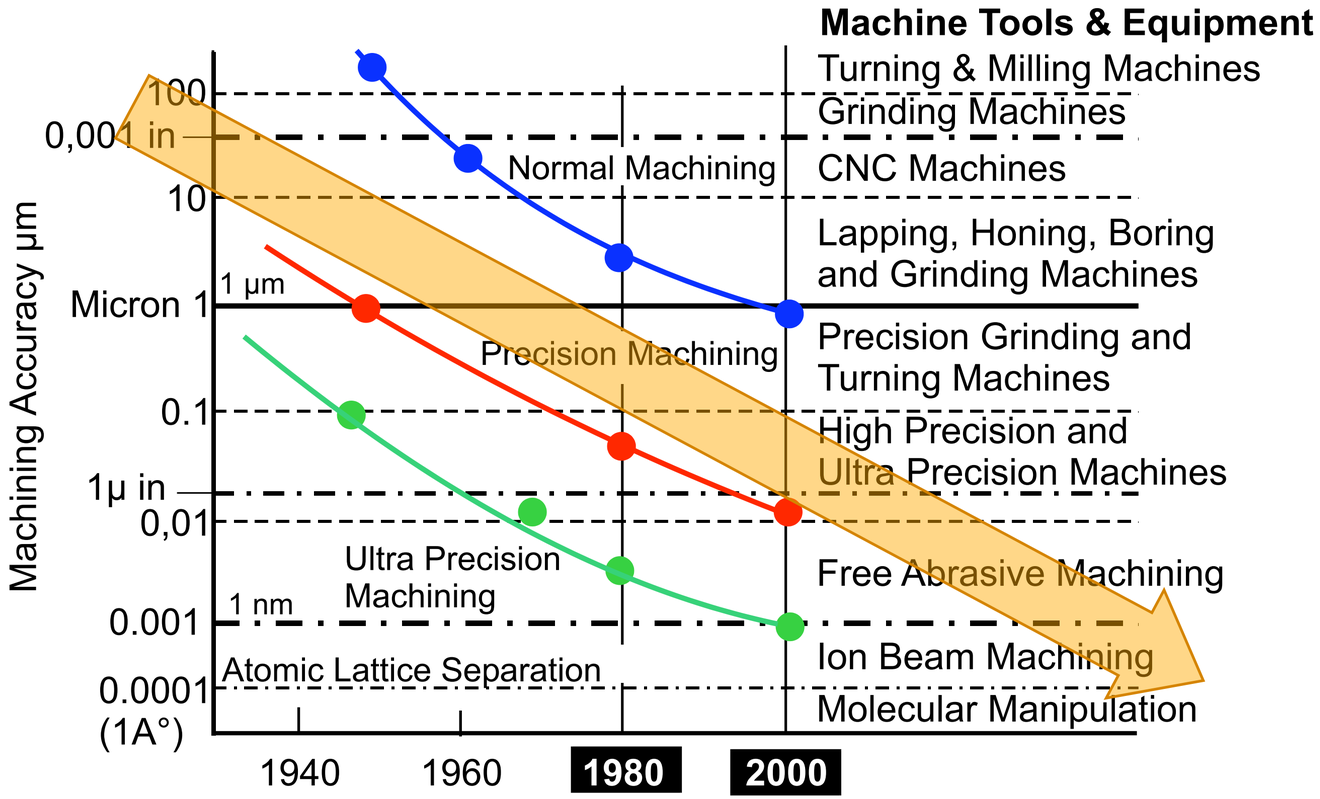
S. Kalpakjian

Additive	Subtractive	Conservative
Lithography	Bulk machining	Imprinting
Rapid prototyping	Grinding and polishing	Rolling
Chemical vapor deposition	Turning, drilling, milling	Forging/forming
	Chemical etching	

(this is not a comprehensive list)

What motivates this trend?

And ... what else changes with this?
Rather ... are some fundamentals preserved?



source: McKeown after Taniguchi

Ref. Byrne, G., Dornfeld, D., and Denkena, B., "Advancing Cutting Technology," STC "C" Keynote, CIRP Annals, 52, 2, pp. 483-507, 2003.

What is Precision?

- *noun.*
  1. The state or quality of being precise; exactness.
  2. The ability of a measurement to be consistently reproduced.
  3. The number of significant digits to which a value has been reliably measured.

- *adjective.*
  1. Used or intended for accurate or exact measurement: *a precision tool*.
  2. Made so as to vary minimally from a set standard: *precision components*.
  3. Of or characterized by accurate action: *precision bombing*.

What is Precision?

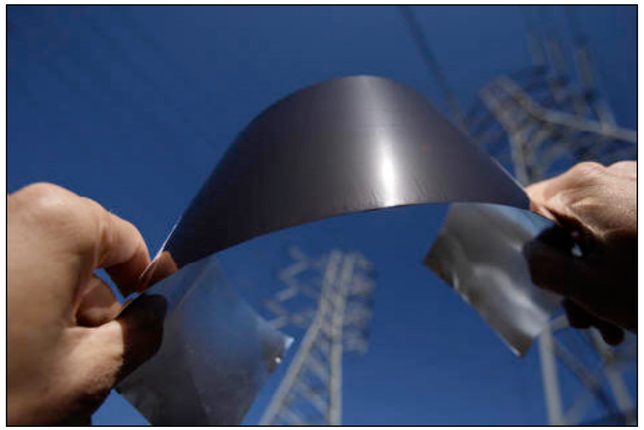
- "The difference between the instrument's reported values during repeated measurements of the same quantity." (for metrology)
- Corollary: "The difference between physical features generated in the 'same' fashion." (for manufacturing)
- Same as accuracy? repeatability? reproducibility? resolution? tolerances?
- A measure of engineering "discipline"...

Doing what has to be done,
when it has to be done,
as well as it can be done,
and doing it that way all the time.

What is Precision Manufacturing?

The concept of making things in a *repeatable* and *precise* fashion

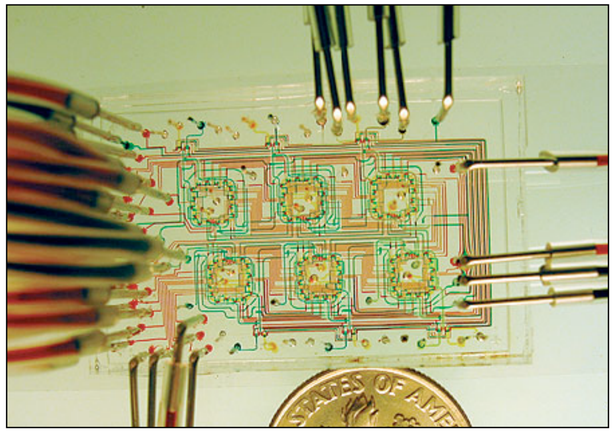
This includes making large and small parts ...



Nanosolar Panel

Keck Telescope Mirror

Laptop Enclosure

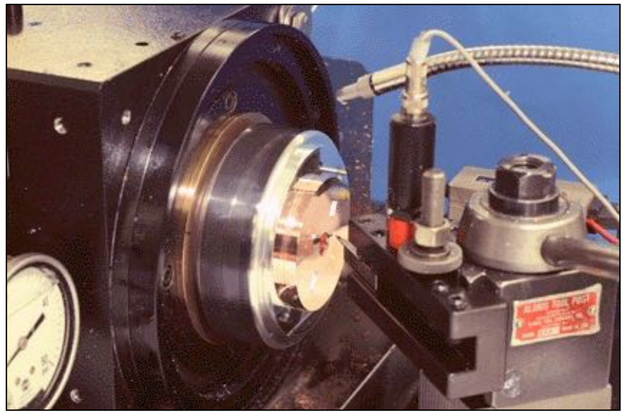


Microfluidic Device

Aspherical Telescope Lens

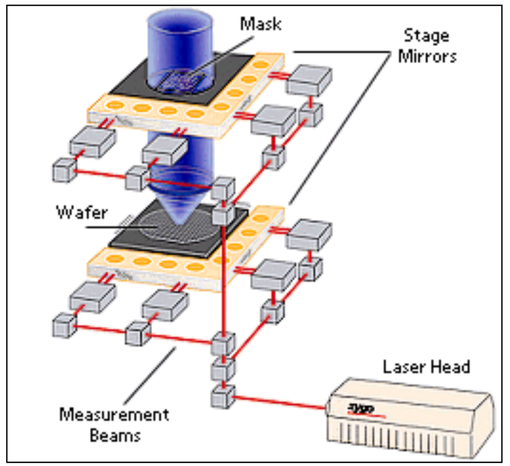
What is Precision Manufacturing?

The concept of making things in a *repeatable* and *precise* fashion

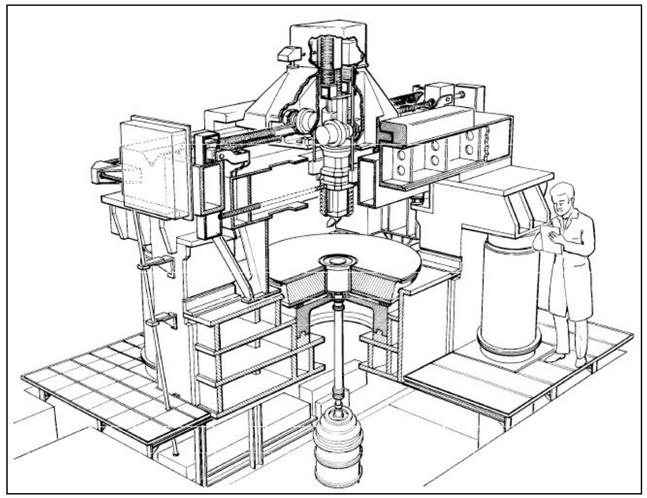


Diamond Turning

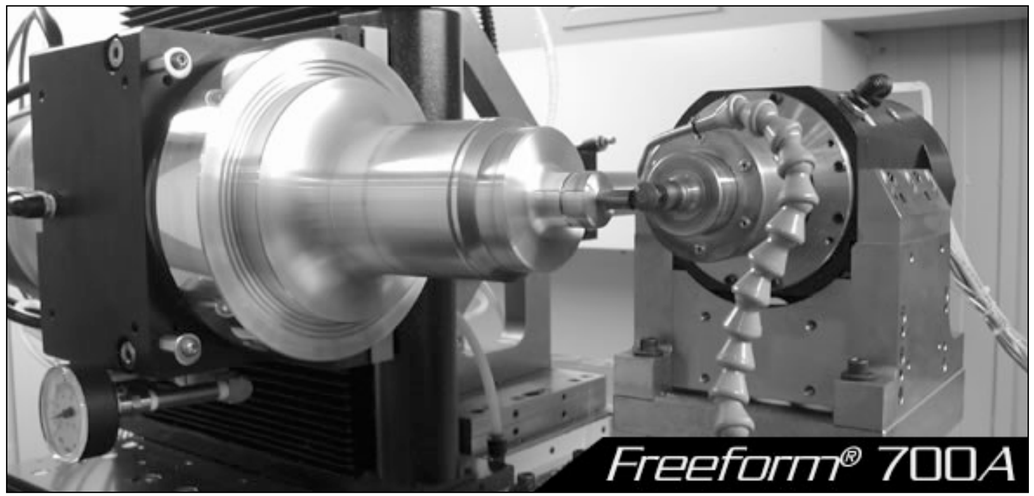
... using the right tools and systems ...



UV Stepper



LODTM

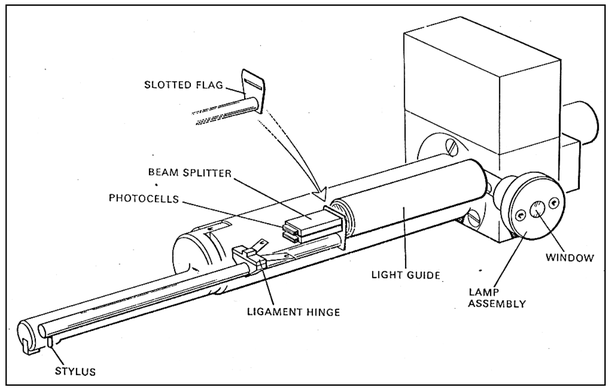


5-Axis Machining

What is Precision Manufacturing?

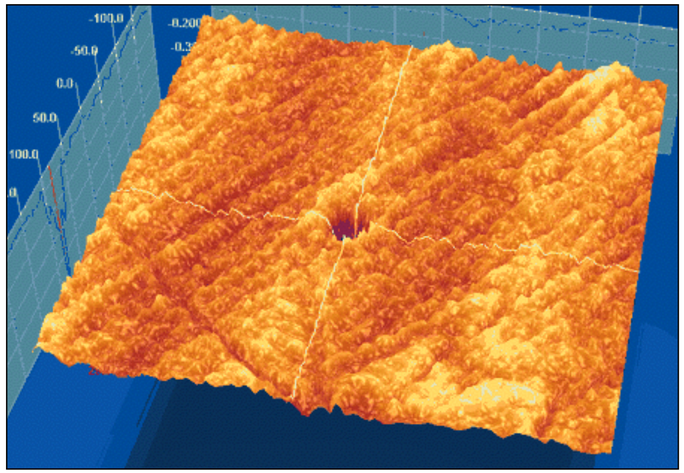
The concept of making things in a *repeatable* and *precise* fashion

Laser Interferometry

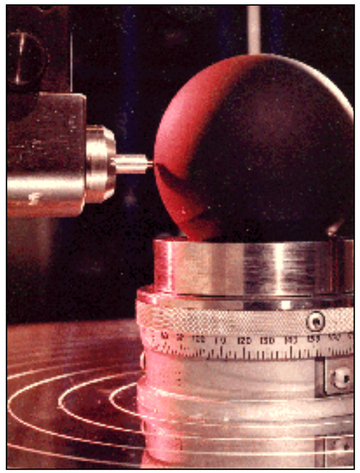


Stylus Profilometer

... and measuring them with the right metrology.



Atomic Force Microscopy



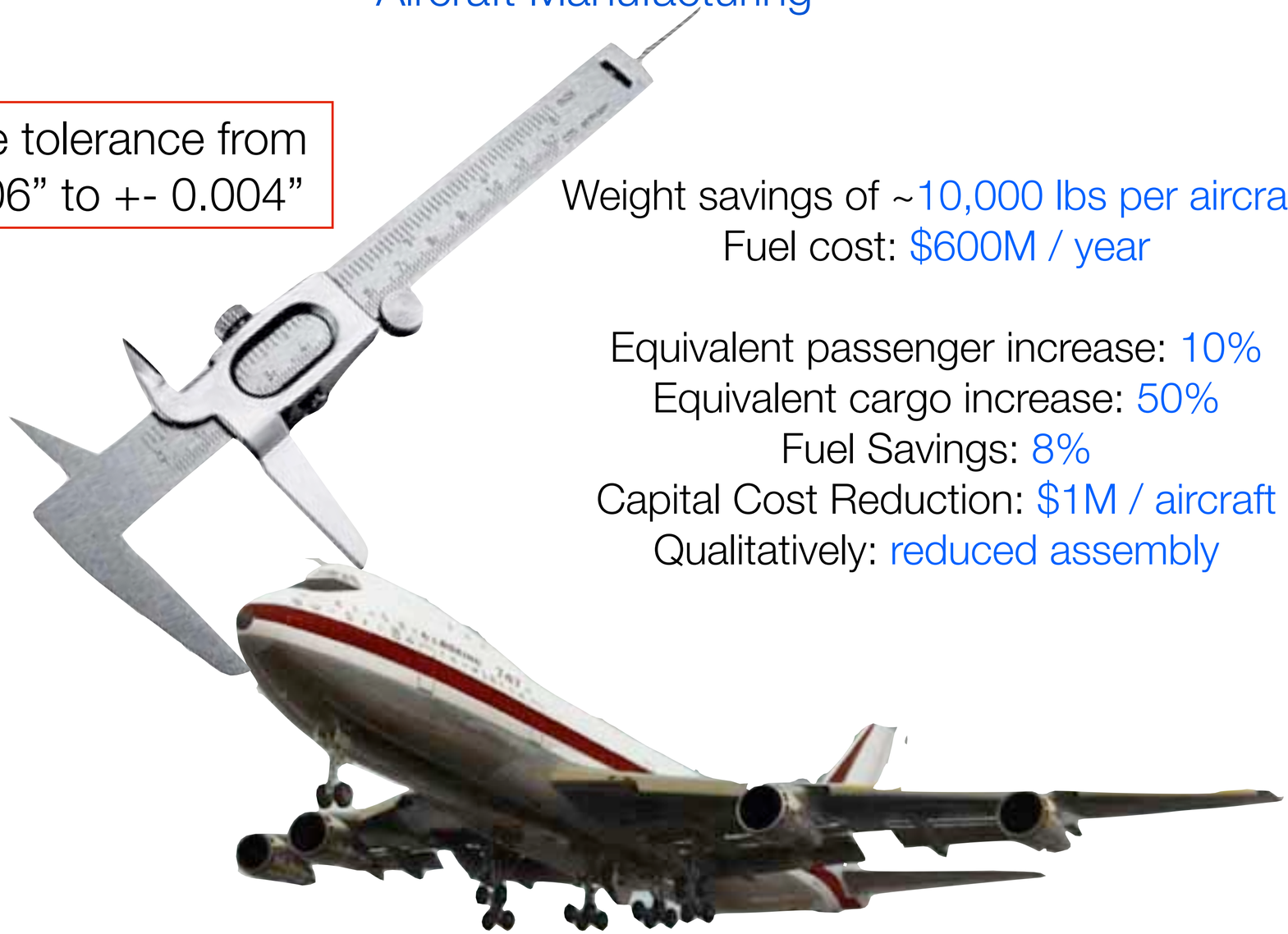
Roundness Tester

Micrometer

Why Precision is Important

Aircraft Manufacturing

Reduce tolerance from
+- 0.006” to +- 0.004”



Weight savings of ~10,000 lbs per aircraft
Fuel cost: $600M / year

Equivalent passenger increase: 10%
Equivalent cargo increase: 50%
Fuel Savings: 8%
Capital Cost Reduction: $1M / aircraft
Qualitatively: reduced assembly