2.810 manufacturing processes and systems

Prof. Tim Gutowski, gutowski@mit.edu

September 5, 2018

Prereq: 2.001, 2.006, 2.008

(translation: solid & fluid mech, heat transfer, mfg)

Today's Agenda

- Business
  - Administrative stuff
  - Your background
- Concepts
  - Manufacturing Enterprise – Big Picture
  - Processes
  - Systems

Basic info can be found on the 2.810 webpage

web page: *http://web.mit.edu/2.810/www*

Instructor: *Prof. T. G. Gutowski* *Rm. 35-234*
gutowski@mit.edu

T.A.: *John Lewandowski* *Rm 35- 135*
dowski@MIT.EDU

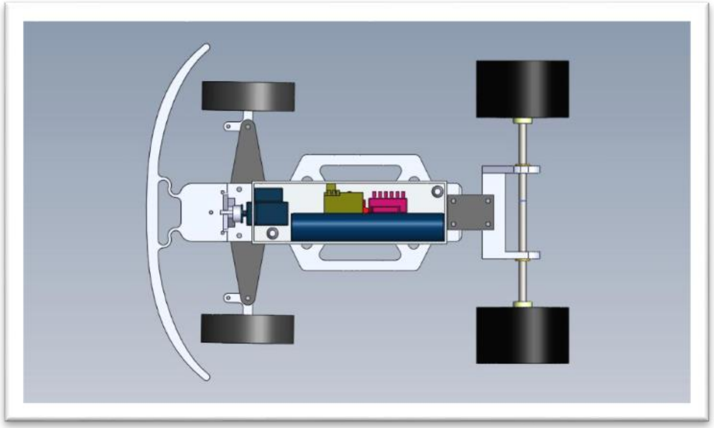
Tech Inst: *Mr. Paul Carson* *Rm. 35-112*
pcarson@mit.edu

Text: ***Manufacturing Engineering and Technology, 7th Ed.***
Kalpakjian and Schmid, 2014. Prentice Hall.

Paul Carson & the Bldg 35 Shop

pcarson@mit.edu

Hands-on Experience



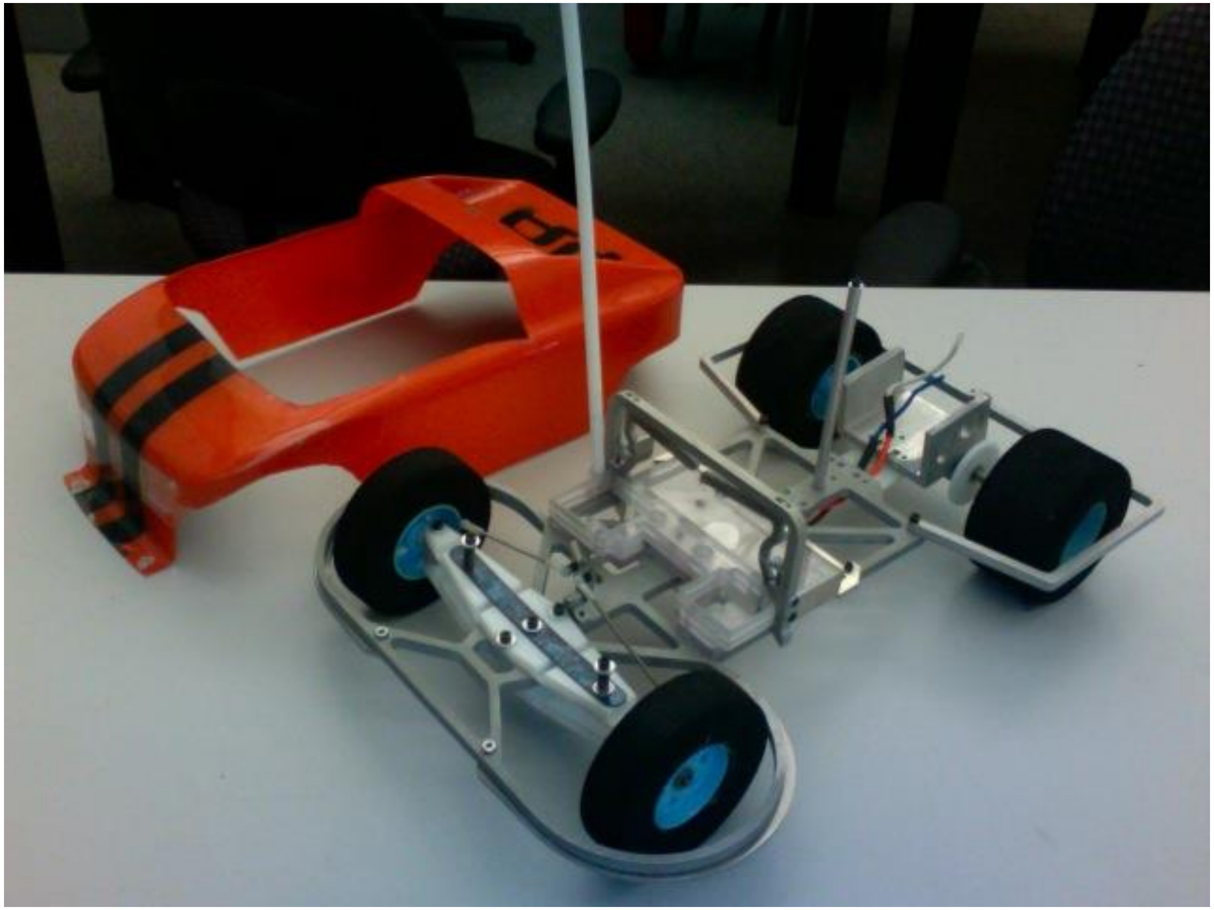
Processes to Systems

2.810 Schedule

	Mondays 2:30 - 4:00		Wednesdays 2:30 - 4:00	
Sept.			5	Introduction
	10	How is this part made? (3-370)	12	Intro to Processes
	17	Process Performance	19	Machining
	24	Injection Molding	26	Polymer Processing
Oct.				
	1	Additive Mfg. (John Hart video*)	3	Process Control (Dave Hardt)
	8	**No Class (Columbus Day)**	10	Car/Quiz Review**
	15	Additive Mfg. (John Hart)	17	QUIZ I
	22	Intro to Mfg. Systems	24	TPS & Current Practices (J. Pacheco)
	29	Processes/Assembly	31	Time & Variability (Gershwin)
Nov.				
	5	System Tools	7	Progress Reports
	12	**No Class (Veterans Day)**	14	QUIZ II
	19	Supply chains (Steve Graves)	21	Work on Projects
	26	AM start up (Austin Schmidt)	28	Sustainable Mfg.
Dec.				
	3	Digital Mfg. (Brian Anthony)	5	Work on Project
	10	**Contest (Lobby 13)**	12	**Clean up & evaluations**

* https://www.youtube.com/watch?v=ICjQ0UzE2Ao

2.810 team project



2.810 Labs

Labs 9-12 M, T, R, F; Building 35 shop

Week of September 10	Safety, Shop Orientation, Car Review
Week of September 17	**Machining /Flashlight Project**
Week of September 24	**Machining /Flashlight Project**
Week of October 1	**Machining /Flashlight Project**
Week of October 8	CAD/CAM (extra flashlight if needed)
Week of October 15	Finish up Lab (QUIZ Week)
Week of October 22	Car Project (this continues through term)

Lab Maximum 16 people

Teams and Labs are Different

- Labs occur at the beginning of the term:

  basic skills some CNC

- Teams are to build cars: you select your team members, usually 4 to 6 per team

Key dates for project

Sept 17	-	Teams finalized
October 1	-	Kits assembled
Week of Oct 1	-	Preliminary design concept review
		(schedule a time for group to meet with Paul)
Week of Oct 15	-	Injection mold wheels
October 22	-	Chassis drawings due
		(waterjet file and dimensioned drawing)
Week of Oct 29	-	Production chassis cut on waterjet
November 7	-	Oral Progress Reports
December 10	-	Contest
December12	-	Evaluation & Clean up

Available at 2.810 Website

Please fill out information form; background, interests, skills

- Basic information
- Experience in shop
- Experience in mfg

2.810 Manufacturing Processes and Systems

Name: ____

Year: ____________________ **Course:** ____________________

Email: ___________________

Prerequisites (Please check off it taken):

2.001 or equivalent	☐
2.006	☐
2.008	☐

Previous experience in industry/research/manufacturing, please describe

____

____

____

____

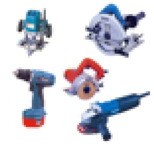
If you have had significant manufacturing experience, would you be interested in giving a short "show & tell" (about 5-10 min) to the class if we can schedule it?

_______ **Y** _______ **N**

List the Topic: ____

2.810 Hands-on Experience Questionnaire

Are you familiar with these tools? Can you use them? ☐ **Y** ☐ **N**



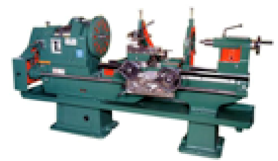
Are you comfortable using power tools? ☐ **Y** ☐ **N**

Have you ever built or repaired something? ☐ ☐

Ex: Built a boat, repaired a lawn mower etc. Y N

What specifically did you do? ____________________

____



	Y	N
Have you ever used - an engine lathe?	☐	☐
- band saw?	☐	☐
- drill press?	☐	☐

Are you comfortable in a machine shop and can operate machine tools without supervision? ☐ **Y** ☐ **N**

Can you program CNC machine tools? ☐ **Y** ☐ **N**

Please list any CAD/CAM software you already have experience with:

1. **2.** **3.**

Lab Sign-up

- See Google Doc: web & email
- State your availability & preference
- See schedule (don’t miss first 5 weeks)

Labs & Copies (9 per sheet Y_ or N_?)

Which Lab sessions are you available to attend?

- [ ] M 9-Noon
- [ ] W 9-Noon
- [ ] Tr 9- Noon
- [ ] F 9 - Noon

Among the sections you can attend, which is your FIRST preference? Please check only one.

- [ ] M 9-Noon
- [ ] W 9-Noon
- [ ] Tr 9- Noon
- [ ] F 9 - Noon

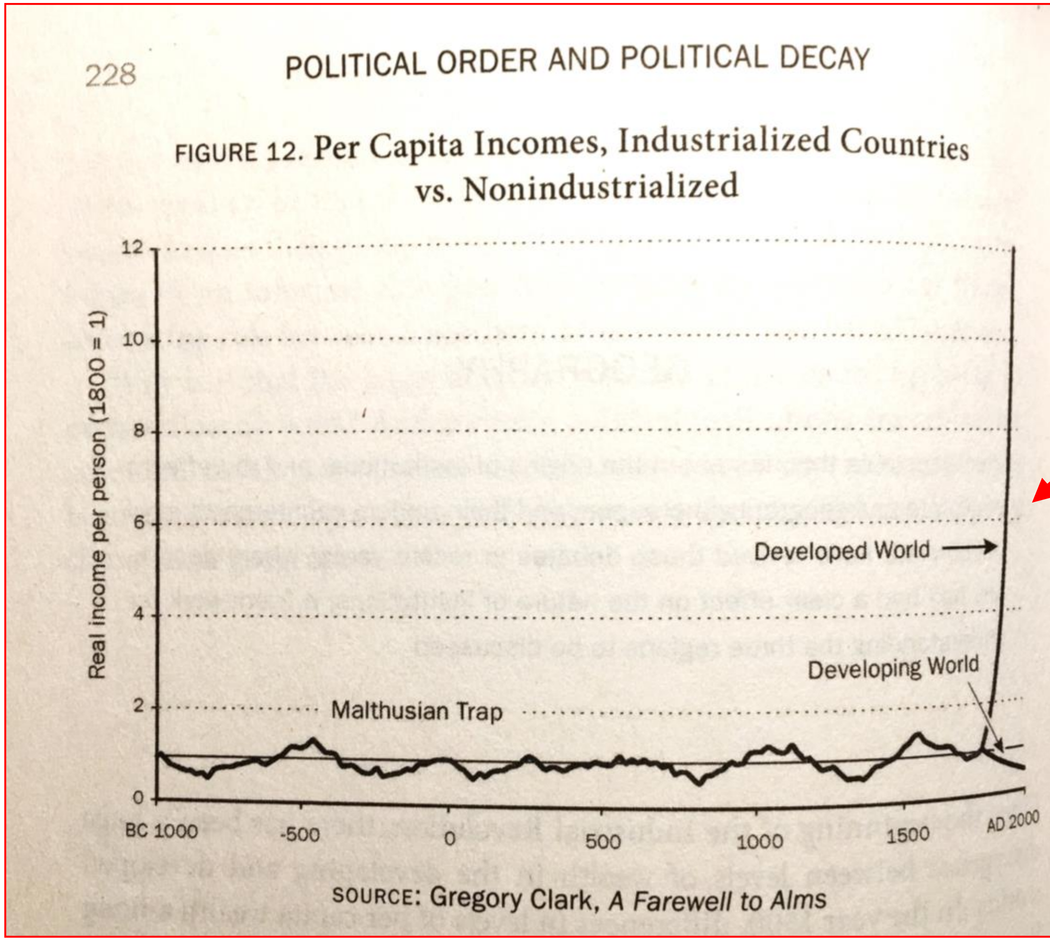
Fall Term 2018-2019 Pre-registration Class List 2.810 31-AUG-18
2.810 Mfg Processes and Systems (entire class list)

MIT ID	Student Name	Course	Year	Subj Reg	REC	LEC	LAB	DES	E-MAIL ADDRESS
913538744	Addy,Robert	2 M	G						radd@MIT.EDU
910995801	Amarasinghe,Sal	EM ID	G						saluka@MIT.EDU
923887657	Amlani,Ankur	15 L	G						amlania@MIT.EDU
917351984	Booker,Dextina Alana	EM ID	G						dextina@MIT.EDU
910190878	Boyle,Casey Alex	15 L	G						caboyle@MIT.EDU
926483305	Burd,Joshua Thomas J	IDS TPP	G						jburd@MIT.EDU
917632643	Butala,Caitlin M.	15 L	G						cbutala@MIT.EDU
922001344	Cheng,Karen	EM ID	G						kacheng@MIT.EDU
924004927	Chiu,Brendon W.	15 L	G						bchiu@MIT.EDU
913658635	Chu,Jeffrey Bowen	15 L	G						jeffbchu@MIT.EDU
950158198	Coates,Donald Mateo	15 L	G						donmateo@MIT.EDU
917546947	Coleman,Ellen Marie	15 L	G						coleman4@MIT.EDU
910807663	Dachiardi Pascualy,D	2 M	G						davidhdp@MIT.EDU
921042338	Daigle,Lea A.	15 L	G						ladaigle@MIT.EDU
925377108	Danner,Kyle Ricardo	15 L	G						krd@MIT.EDU
914575436	Defrance de Tersant,	EM ID	G						gtersant@MIT.EDU
912971299	Du,Lucy Wei	2 D	G						lucydu@MIT.EDU
911239030	Fan,Yiling	2 M	G						yilingf@MIT.EDU
928873193	Fernandes,Diarny Oli	2 P	G						diarny@MIT.EDU
916219013	Gaudio,Brian Gabriel	15 L	G						bgaudio@MIT.EDU
915010955	Ghersin,Noa	15 L	G						ghersinn@MIT.EDU
924072691	Goh,Nigel Min Feng	2 M	G						ngoh@MIT.EDU
915857508	Grant,Fiona R.	2 M	G						fionag@MIT.EDU
922177065	He,Denton Xiang	2 M	G						dentonhe@MIT.EDU
993591648	Hsu,Emily	EM ID	G						emilyhsu@MIT.EDU
913217284	Krause,Christopher A	2 A	4						cakrause@MIT.EDU
925823457	Landis,Jordan R.	15 L	G						jlandis@MIT.EDU
917066744	Murphy,Lorcan Andrew	2 M	G						murphyl@MIT.EDU
928873018	Muthui,Marian Mwikal	MAS M	G						muthui@MIT.EDU
926382729	Nowak,Hans Antoon	15 L	G						nowak@MIT.EDU
920677417	Park,Tae Joong	2 M	G						tjpark@MIT.EDU
924545066	Qiao,Kuan	2 D	G						kqiao@MIT.EDU
918300099	Robinson,Taylor Kirs	15 L	G						tayrob@MIT.EDU
926966361	Ross,Michael Columbu	15 L	G						mcross@MIT.EDU
929847022	Ryu,Seungchan	2 D	G						scryu@MIT.EDU
922904867	Sun,Zhumei	2 D	G						zhumeis@MIT.EDU
922945369	Tessmer,Lavender	4 ACM	G						ltessmer@MIT.EDU
928320861	Turner,Adriane Ann	15 L	G						adrianet@MIT.EDU
916570013	Varela,Claudia Elena	HST ED	G						cvarela@MIT.EDU
914281445	Wanyiri,Juliet Wanji	EM ID	G						jwanyiri@MIT.EDU
912128272	Woodruff,David Travi	2 M	G						dtkw@MIT.EDU
918425608	Yadama,Sagar Pandey	15 L	G						syadama@MIT.EDU
923266865	Yan,Tongxi	2 M	G						tyan@MIT.EDU
920587599	Yeung,Steven Yip Fun	2 M	G						yyeung@MIT.EDU
927551048	Zhang,Xiaotong	2 M	G						kevxt@MIT.EDU

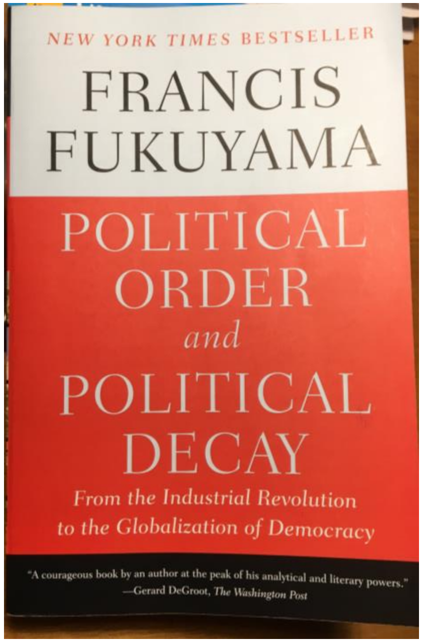
SUMMARY: Yr 1: 0 Yr 2: 0 Yr 3: 0 Yr 4: 1 Yr G: 44 TOTAL: 45
0% 0% 0% 2% 98%

The Mfg Enterprise – Big Picture

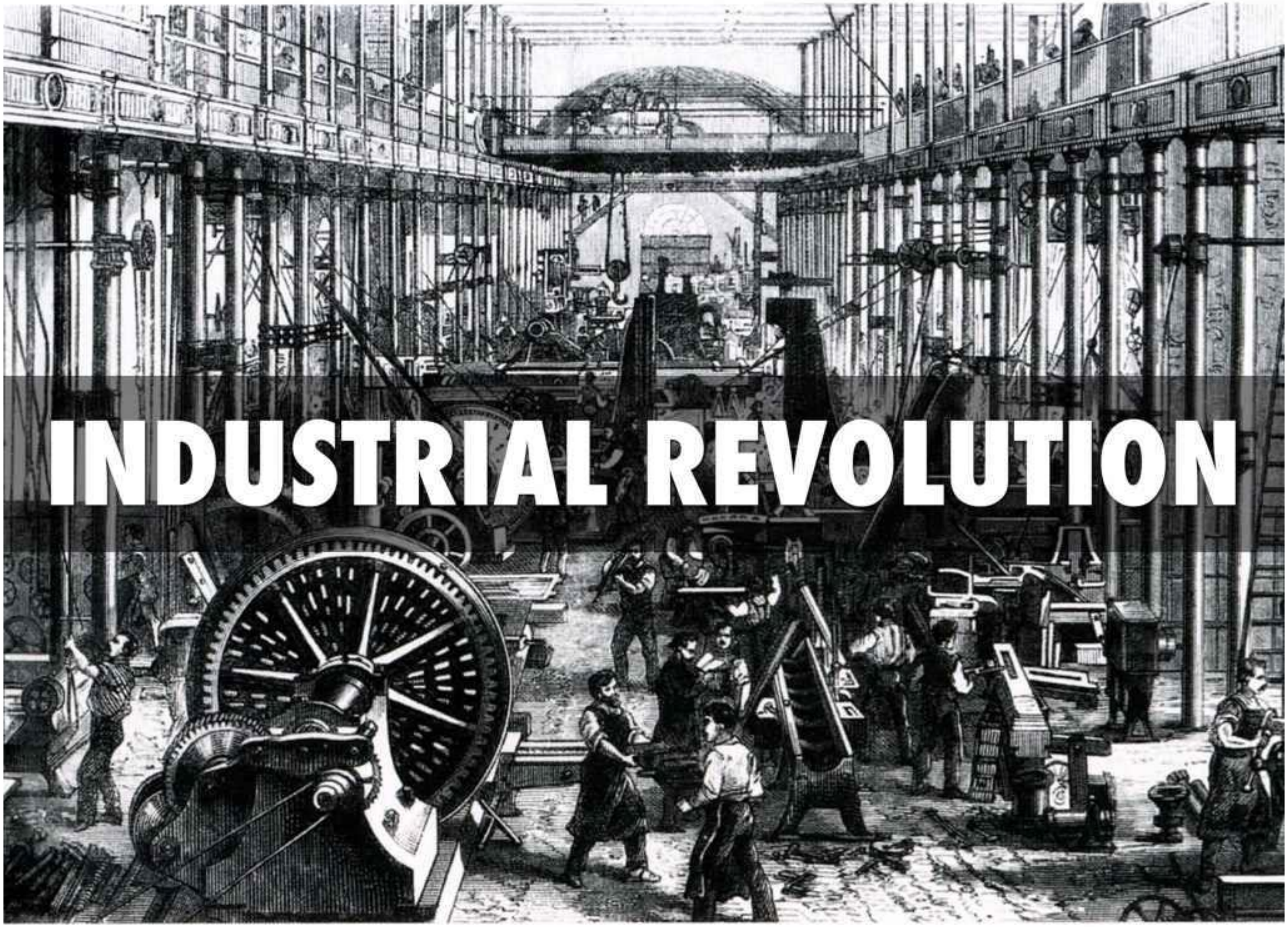
- Industrialization and Economic Growth
- Big Push Industrialization
- Divergence
- Democracy and Political Development
- The Future: Growth? Employment? Environment?



What caused this surge in per capita income around 1800 AD?



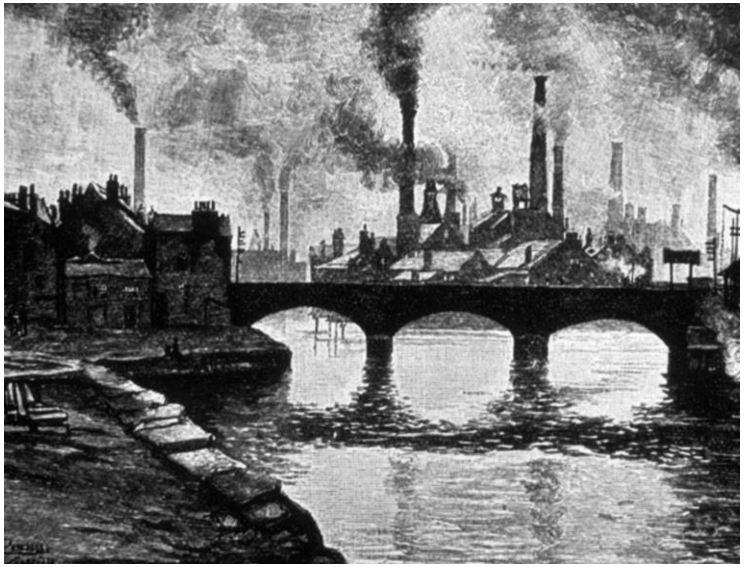
Ref. p 228



http://www.historydiscussion.net/history/industrial-revolution/history-of-the-industrial-revolution/1784

The Industrial Revolution

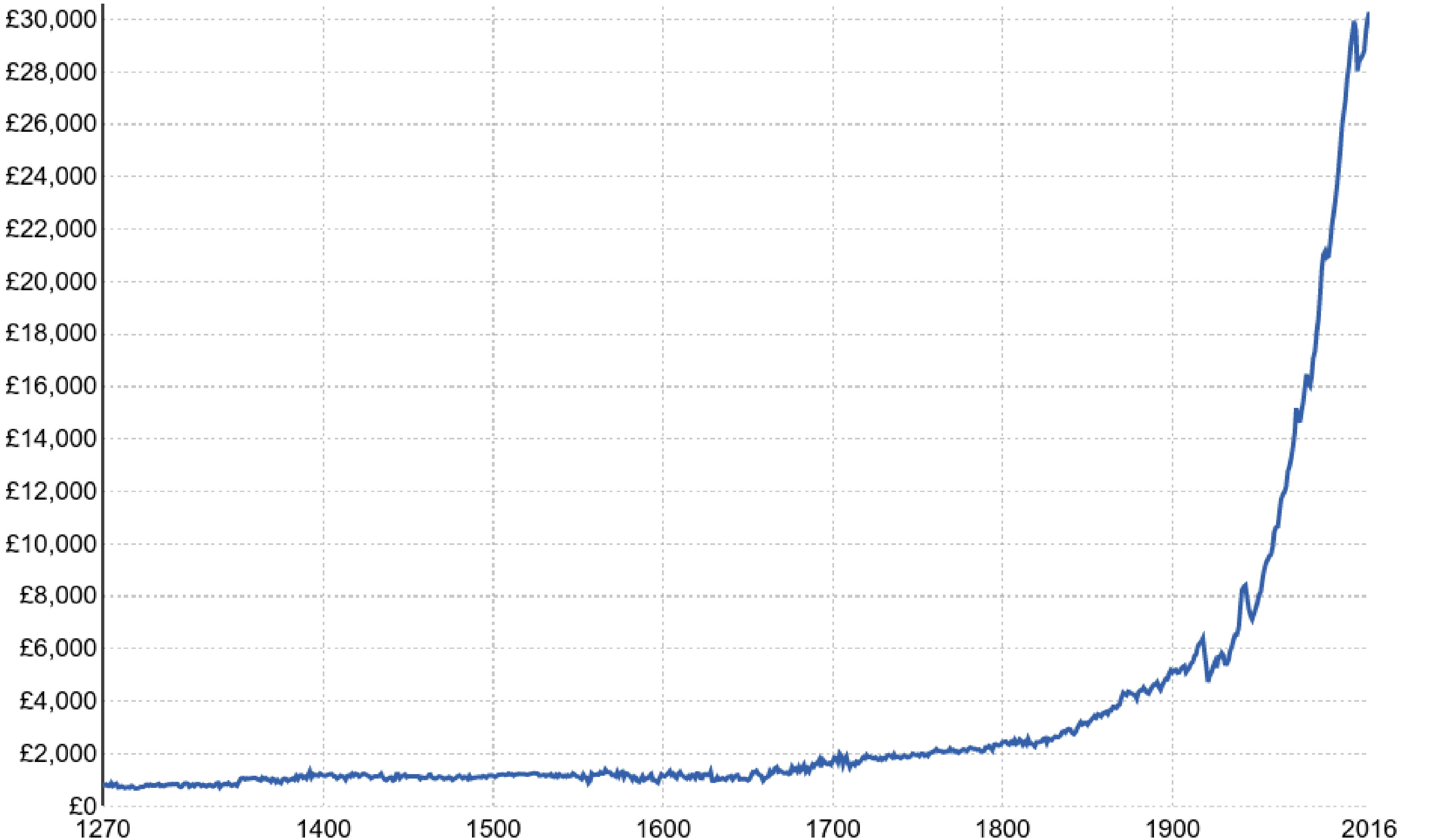
- England 1760 – 1830s
- Coal
- Steam power
- Textile mills
- Steel
- Railroads



https://sites.google.com/a/online.sd71.bc.ca/human-rights-morgan-rachel-rylee/the-industrial-revolution

GDP per capita in England since 1270

Adjusted for inflation and measured in British Pounds in 2013 prices



Source: GDP in England (using BoE, 2017)

Note: Data refers to England until 1700 and the UK from then onwards.

The importance of Manufacturing to economic growth

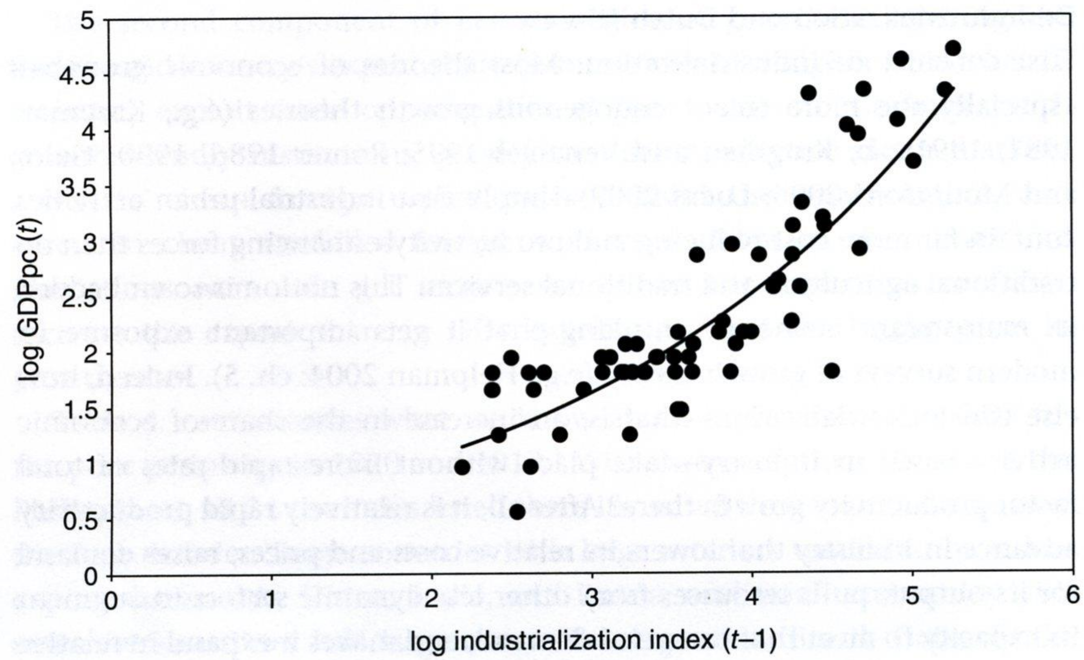
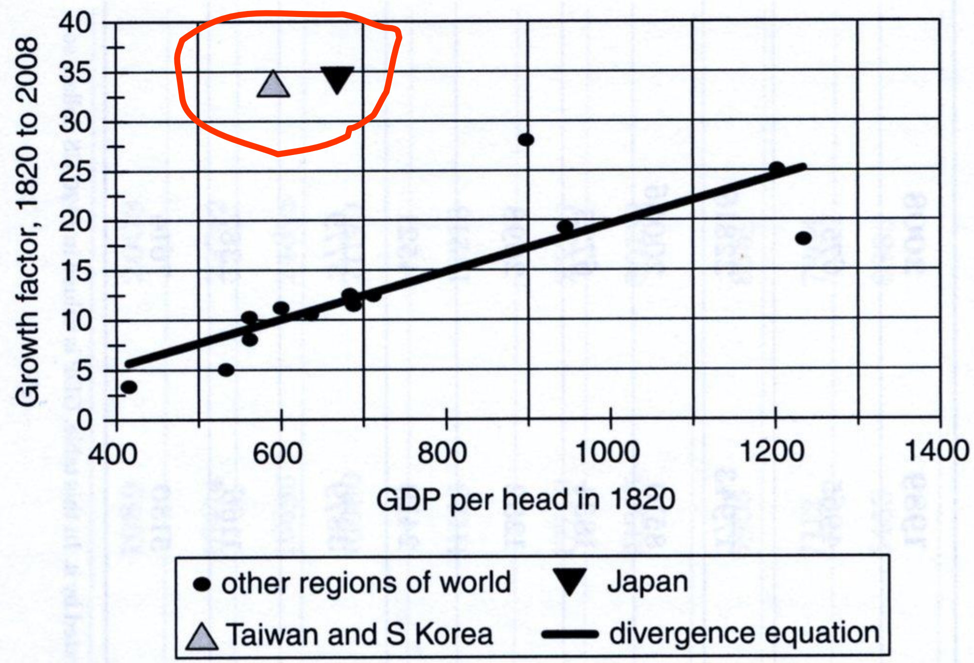


Figure 4.1
Do industrial countries get richer?
Source: Data from Bairoch (1982: table 4, p. 281) and Maddison (2001: tables A1–A3, pp. 185, 195, 215)

The plot shows the correlation, both in logs, of current GDP per capita (1820 -1950: Maddison), and past levels of industrialization per capita (50 or 70 years earlier: Bairoch).

Reference; Jeffrey G. Williamson, " Trade and Poverty" MIT Press, 2011, p 50

The Great Divergence

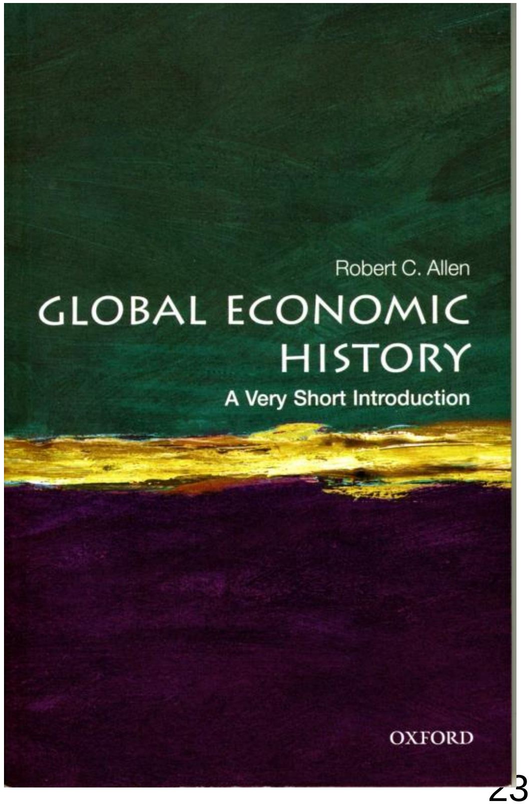


1. The great divergence

R.C. Allen 2011

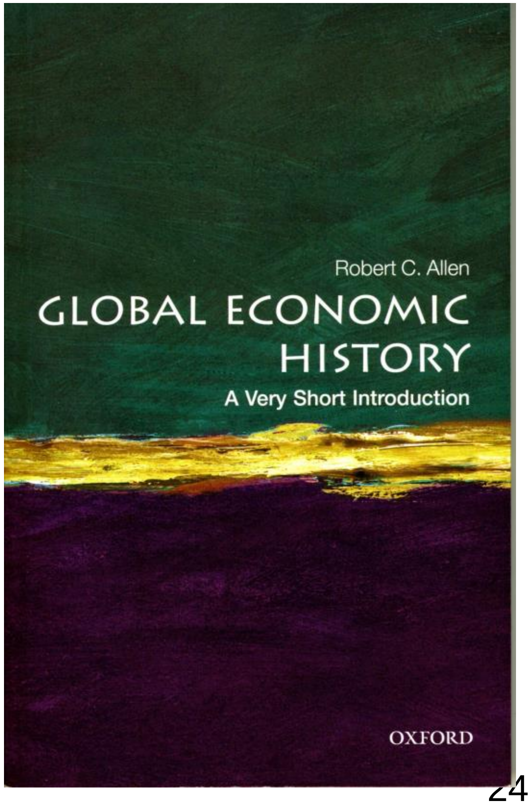
How do you join the developed?

- “Big Push Industrialization”
  - Do everything at once
  - Trust
  - Planning Authority
  - Then Transition…
- Required GDP growth
  - ~6% over 60years



How do you join the developed?

- “Big Push Industrialization”
  - Japan
  - South Korea
  - Taiwan
- Less successful
  - Russia
  - South America

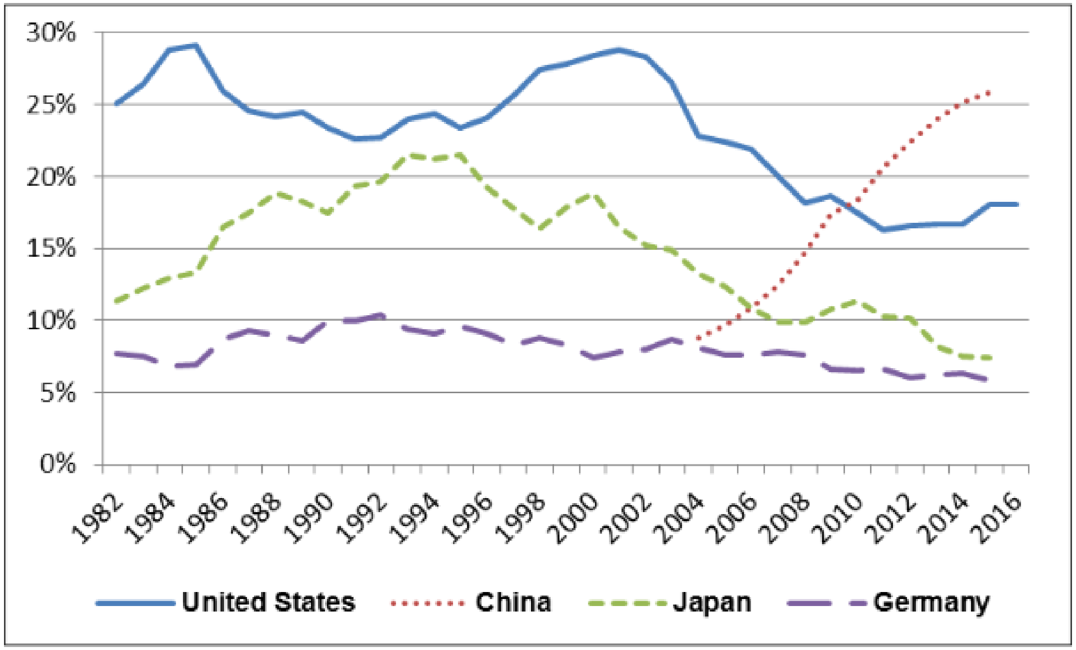


The Importance of Manufacturing for Economic Development

- The rise of China and Manufacturing

Figure 2. Selected Countries' Shares of Global Manufacturing Value Added

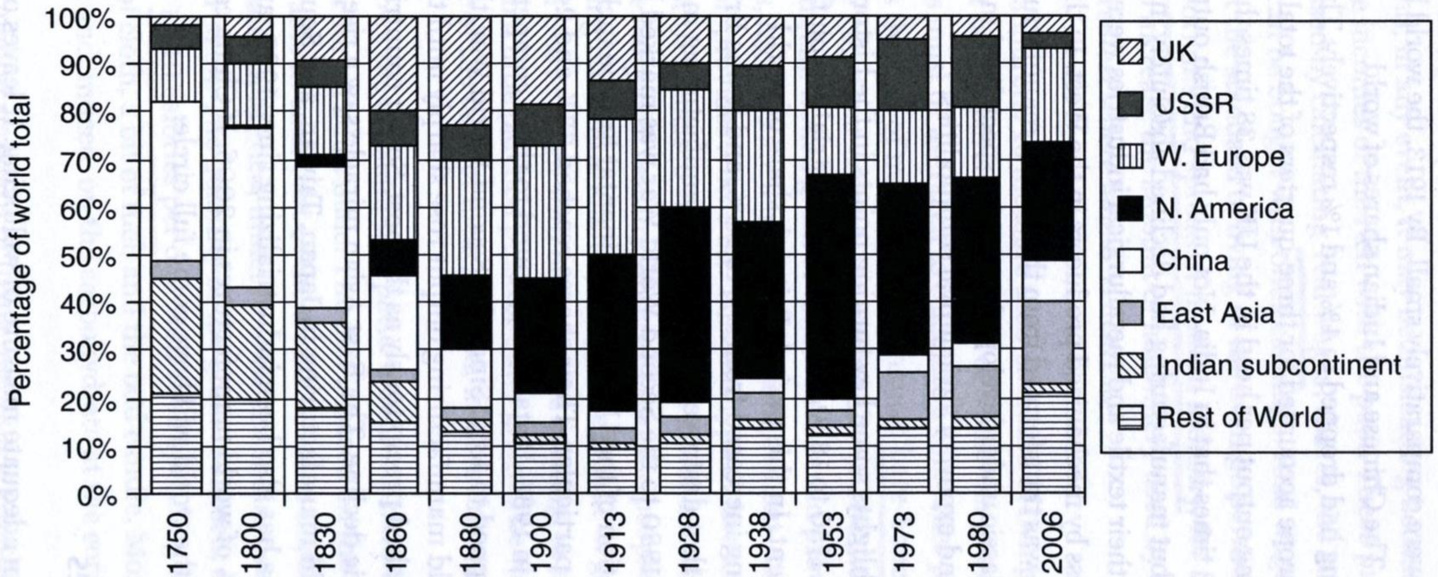
Calculated in current U.S. dollars



Source: U.N. National Accounts Main Aggregates Database, value added by economic activity, at current prices—U.S. dollars.

Marc Levinson, Cong. Res. Ser. 2018

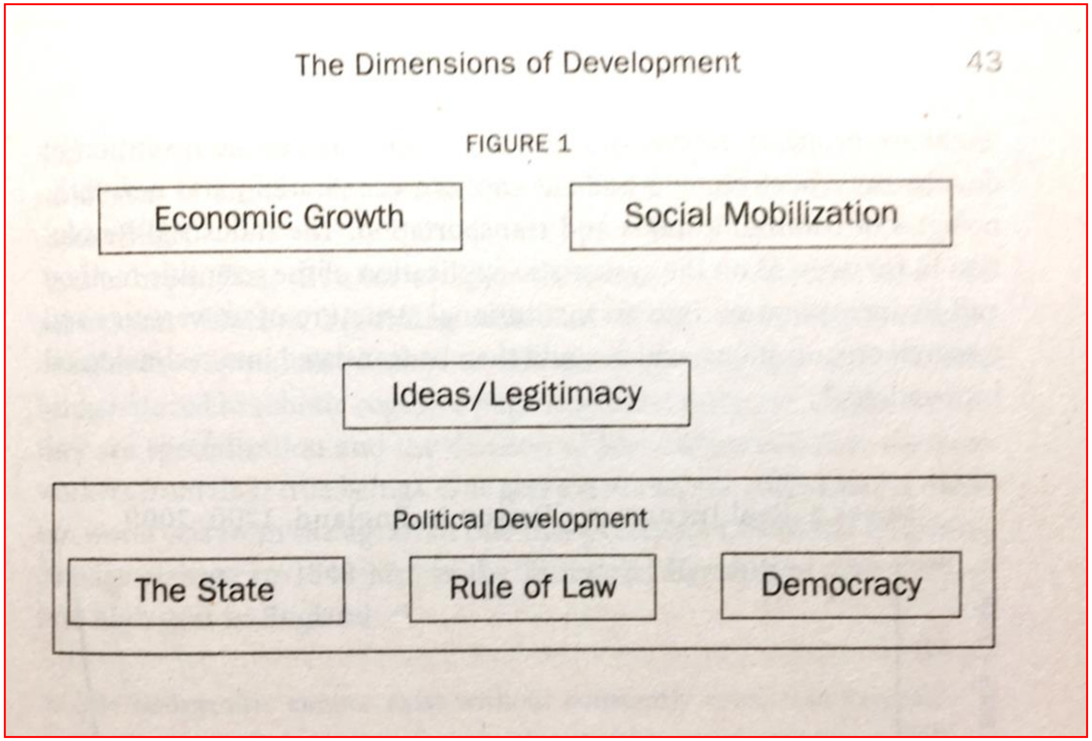
Global Mfg Shares 1750-2006



2. Distribution of world manufacturing

R.C. Allen 2011

The Role of Economic Growth in Political Development



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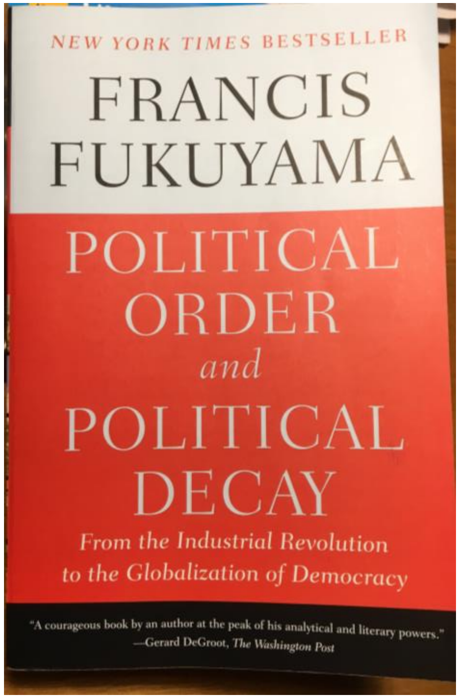
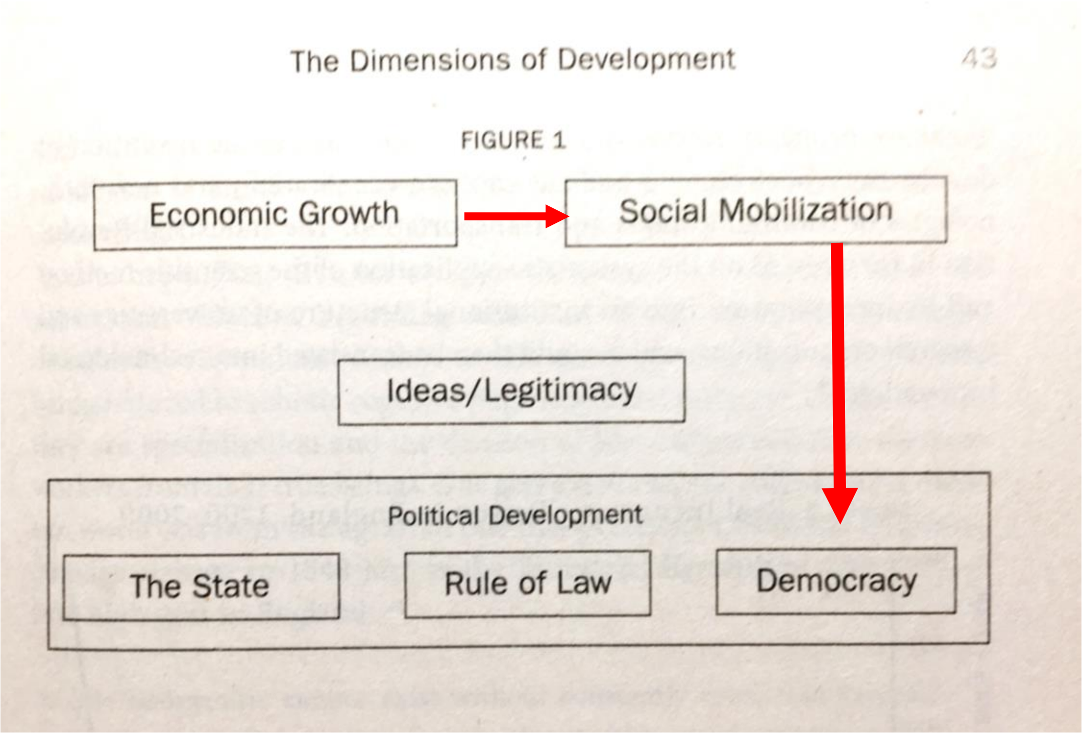


How Democracy might develop…



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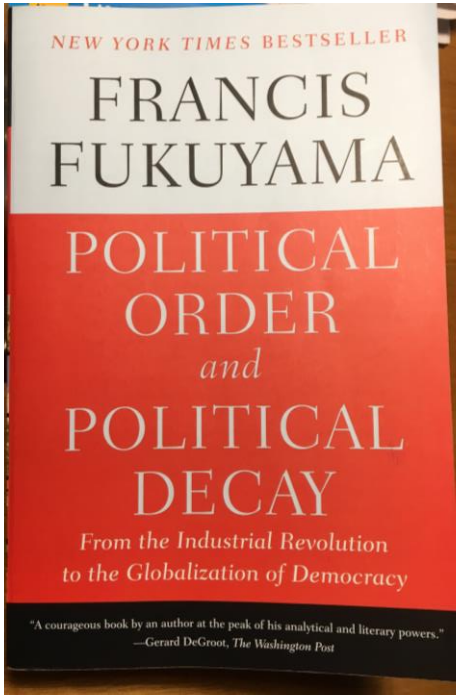
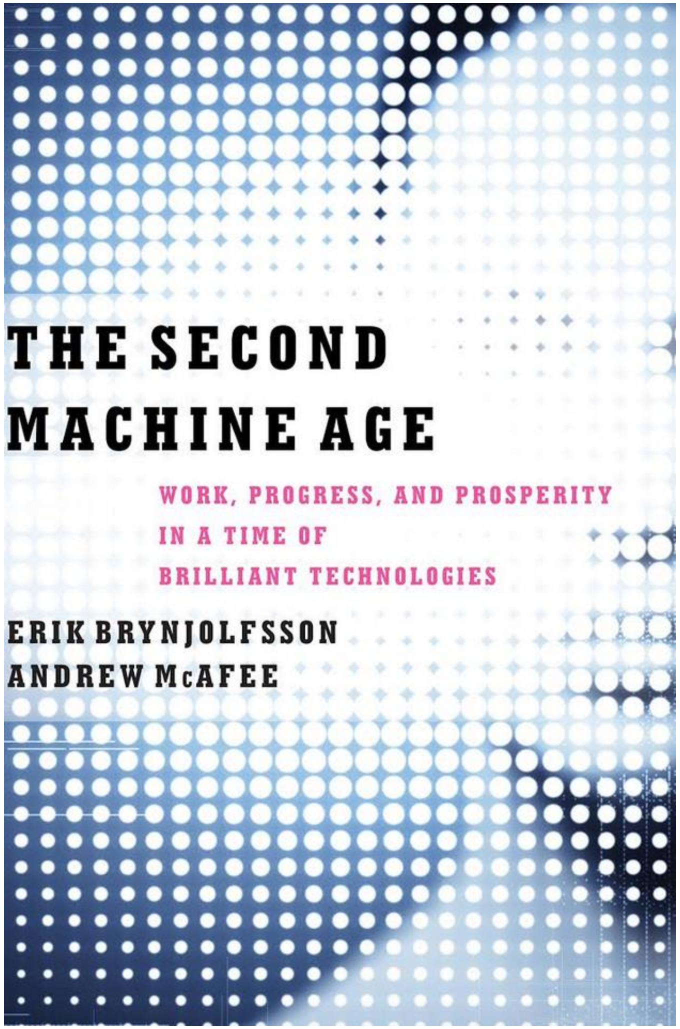
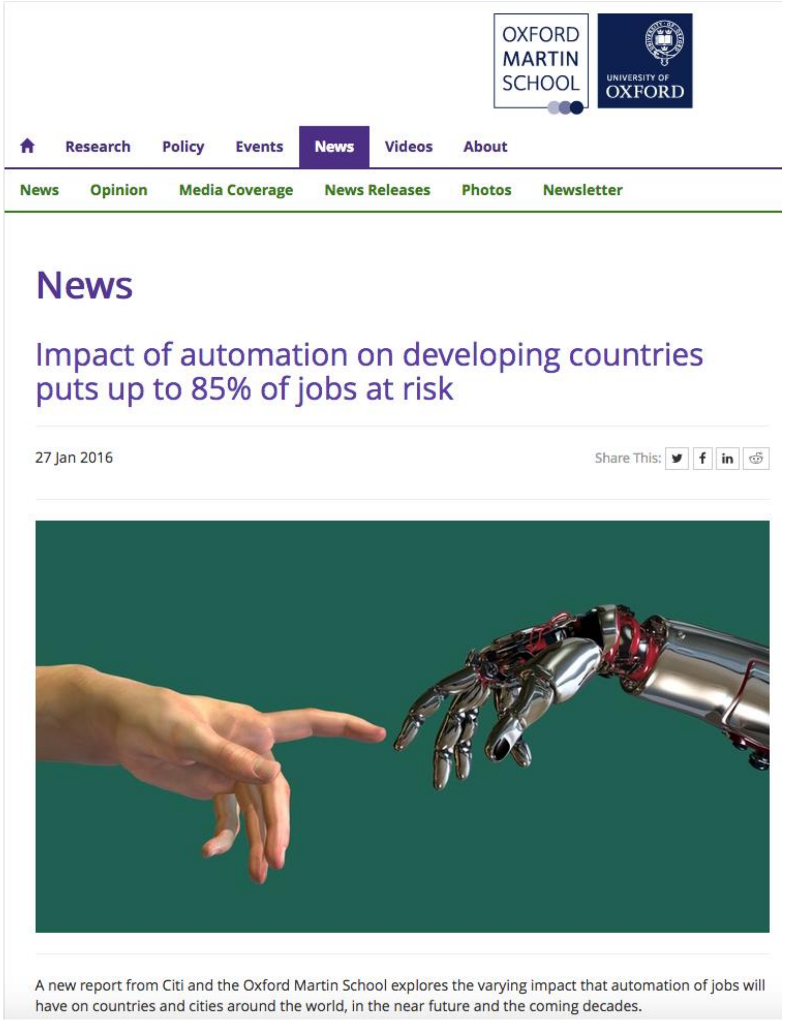


Future trends: "the bounty & the spread"
Inequality, Control & Environment





SIMON SIMARD

The Human Cost of Technology

Problem-solving technologies sometimes cause new problems. Let's fix that.

To stand in Killian Court on a June morning and look out on the faces of 2,800 new MIT graduates is a powerful experience of hope and wonder. These students came to us with brilliant capabilities of their own. And if we have done our job as educators, they leave us equipped with a rare set of skills and steeped in this community's deepest values: A commitment to excellence. Integrity. Meritocracy. Boldness. Humility. An open spirit of collaboration. A strong desire to make a positive impact. And a sense of responsibility to make the world a better place.

We can be sure that the creativity of this group of graduates will be the source of remarkable new discoveries, methods, products, designs, organizations—and perhaps even whole new industries. And as the past decade has shown, we should not be surprised if some of those new concepts are deeply disruptive.

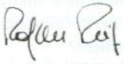
Disrupting old systems and assumptions can be a very good idea. But it can also have a great human cost. And I believe that as members of an "institute of technology," we need to see this human question as very much our concern.

At MIT, our mission guides us to advance knowledge, to educate students, and to bring knowledge to bear on the world's great challenges. As a result, we are driven and motivated to work on big problems. And we like to solve them, in part, by developing new technologies. Yet one of today's great challenges is figuring out how to help society navigate the unintended impact of technology itself.

This is not something we can leave for "other people" to figure out. Getting this right will require the expertise, insight, and imagination of those in a position to truly understand the technologies in play. As our new graduates prepared to leave us, I challenged them—as they work to conjure new ideas, invent new products, design new ways to manufacture them, and devise new ways to use them in the world—to consider the impact on all of society, right from the start.

I know that many members of our community, from faculty and students to our alumni around the world, are already hard at work on these questions—and I encourage you to share your ideas and initiatives with your fellow alumni in these pages.

By making such societal considerations not an afterthought, but a first concern, we will contribute to solving one of the deepest and most difficult challenges of our time.



L. RAFAEL REIF

Basic Concepts for 2.810

1. Manufacturing Processes
   – Abstraction
   – Performance Attributes
   – Classification Schemes

2. Manufacturing Systems
   – Physical part
   – Required machines
   – Process steps
   – Equipment arrangements

MACHINING PROCESSES

SINGLE POINT MACHINING
- TURNING
- BORING
- FACING
- FORMING
- SHAPING,PLANNING

MULTIPOINT MACHINING
- DRILLING
- MILLING
- SAWING, FILING
- BROACHING, THREAD CUTTING

GRINDING
- SURFACE GRINDING
- CYLINDRICAL GRINDING
- CENTERLESS GRINDING
- INTERNAL GRINDING
- FORM GRINDING

ABRASIVE WIRE CUTTING
HONING
LAPPING
ULTRASONIC MACHINING
BUFFING, POLISHING
URNISHING
TUMBLING
GRIT BLASTING

CHEMICAL MACHINING
- ENGRAVING
- CHEMICAL MILLING
- CHEMICAL BLANKING

ELECTROCHEMICAL MACHINING
ELECTRICAL DISCHARGE MACHINING
LASTER MACHINING
ELECTRON BEAM MACHINING
PLASMA-ARC CUTTING
FLAME CUTTING, WATER JET CUTTING

DEFORMATION PROCESSES

OPEN-DIE FORGING
IMPRESSION-DIE FORGING
CLOSED-DIE FORGING
- PRECISION OR FLASHLESS FORGING
- COINING
- HEADING, PIERCING, HUBBING, COGGING, FULLERING, EDGING, ROLL FORGING, SKEW ROLLING

ROLLING
- FLAT, RING, THREAD, GEAR, PIERCING

EXTRUSION
- DIRECT, INDIRECT HYDROSTATIC, IMPACT, BACKWARD

DRAWING
- ROD & WIRE, FLAT STRIP, TUBES

SWAGING

SHEARING
BENDING
- PRESS-BRAKE FORMING, ROLL FORMING TUBE FORMING

BEADING, FLANGING, HEMMING, SEAMING
STRECH FORMING
BULGING
DEEP DRAWING
PRESS FORMING
RUBBER FORMING
SPINNING
EXPLOSIVE FORMING
ELECTROHYDRAULIC FORMING
MAGNETIC-PULSE FORMING
SUPERPLASTIC FORMING

METAL CASTING AND POWDER PROCESSES

CASTING
CASTING OF INGOTS
CONTINUOUS CASTING

SAND CASTING
SHELL MOLDING
SLURRY MOLDING
INVESTMENT CASTING (LOW-WAX PROCESS)
EVAPORATIVE CASTING
DIE CASTING
(GRAVITY-FEED, PRESSURIZED…)
CENTRIFUGAL CASTING
SQUEEZE CASTING
RHEOCASTING

CRYSTAL GROWING
- CRYSTAL-PULLING
- ZONE MELTING

Electro forming
Plasma Spraying

POWDER METALLURGY
PRESSING
ISOSTATIC PRESSING
SINTERING

JOINING PROCESSES

MECHANICAL JOINING
- BOLTS, SCREWS, RIVETS

SOLID-STATE WELDING
- DIFFUSION, FORGING, FRICTION, DEFORMATION

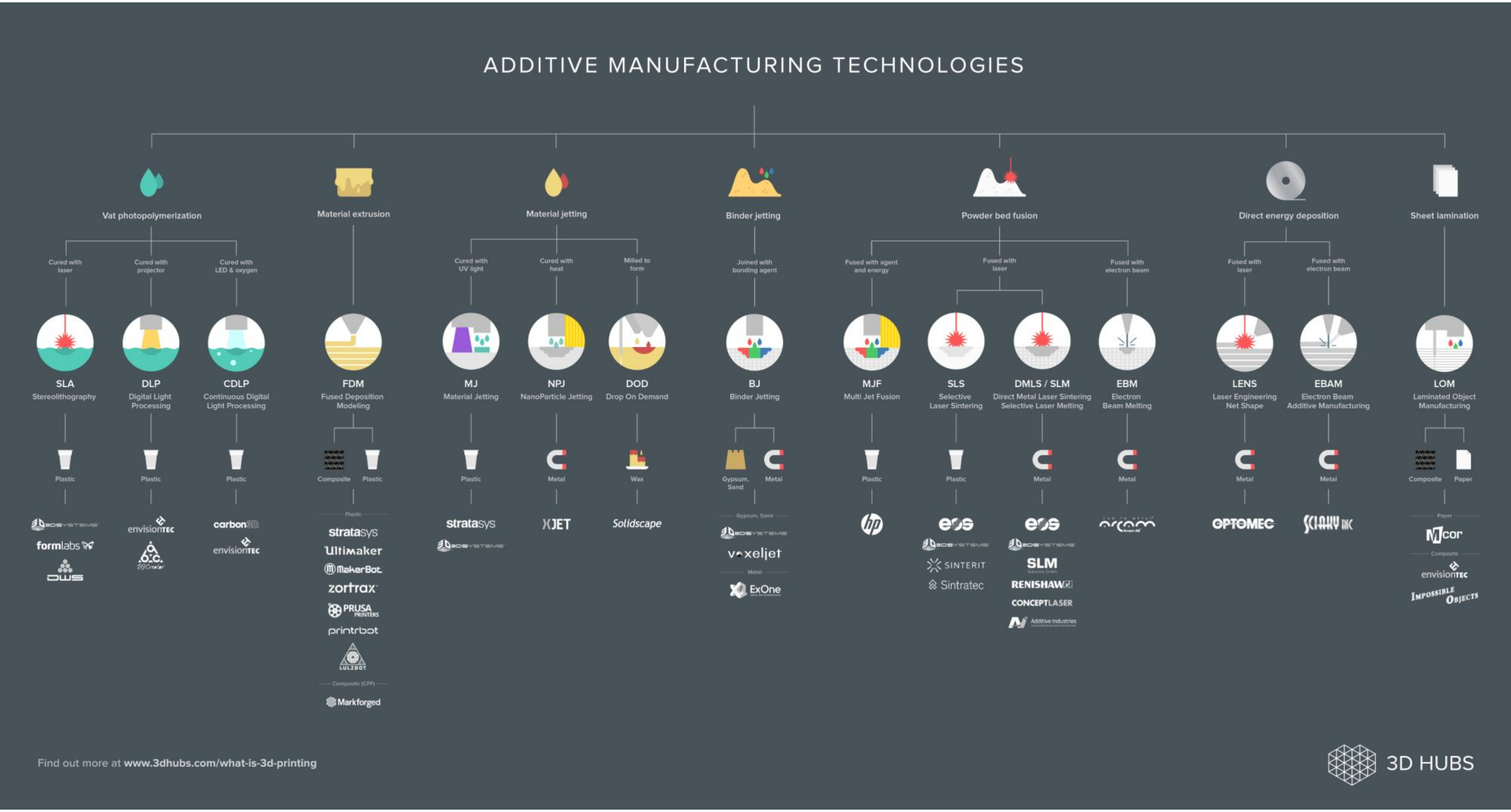
LIQUID STATE WELDING
- RESISTANCE WELDING
- ARC WELDING
- THERMAL WELDING

HIGH-ENERGY BEAM WELDING
- ELECTRONIC BEAM, LASER

LIQUID-SOLID STATE BONDING
- BRAZING
- SOLDERING

ADHESIVE BONDING
- PLASTICS AND COMPOSITES JOINING (MECHANICAL, HEATING, SOLVENTS, ULTRASONICS…)

Manufacturing processes, …


ADDITIVE MANUFACTURING TECHNOLOGIES
Vat photopolymerization
Material extrusion
Material jetting
Binder jetting
Powder bed fusion
Direct energy deposition
Sheet lamination
SLA
Stereolithography
DLP
Digital Light Processing
CDLP
Continuous Digital Light Processing
FDM
Fused Deposition Modeling
MJ
Material Jetting
NPJ
NanoParticle Jetting
DOD
Drop On Demand
BJ
Binder Jetting
MJF
Multi Jet Fusion
SLS
Selective Laser Sintering
DMLS / SLM
Direct Metal Laser Sintering
Selective Laser Melting
EBM
Electron Beam Melting
LENS
Laser Engineering Net Shape
EBAM
Electron Beam Additive Manufacturing
LOM
Laminated Object Manufacturing
Find out more at www.3dhubs.com/what-is-3d-printing
3D HUBS

TATIC,

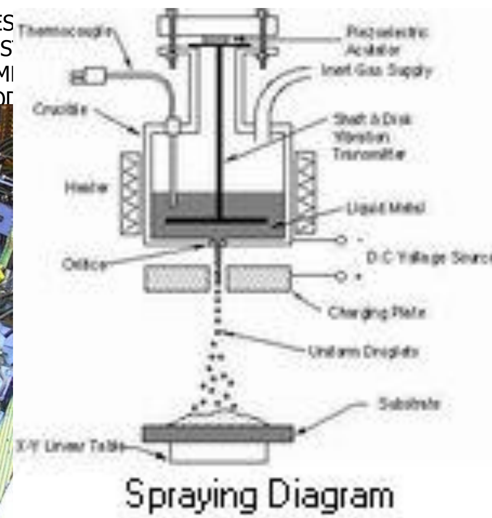
COMPRESSION MOLDING
TRANSFER MOLDING
CASTING
THERMOFORMING
ROTATIONAL MOLDING
SOLID STATE FORMING

MACHINING
ETCHING SOLVENT PROCESSING
FOAMING
BONDING
IMPREGNATING
PAINTING

DIAPHGRAM FORMING
INJECTION MOLDING
(FILLED THERMOPLASTICS, BMC…)
REINFORCED REACTION INJECTION MOLDING
(RRIM)

(METAL MATRIX COMPOSITES)

HOT PRES
HOT ISOS
LIQUID MI
ELECTROD



MICROELECTRONICS PROCESSING

CRYSTAL GROWTH
- CZOCHRALSKI CRYSTAL GROWTH
- FLOAT-ZONE CRYSTAL GROWTH

WAFER PROCESSING
- SLICING, ETCHING, POLISHINNG

SURFACE PROCESSES
- CHEMICAL VAPOR DEPOSITION (CVD)
- EPITAXIAL FILM GROWTH

O
LI
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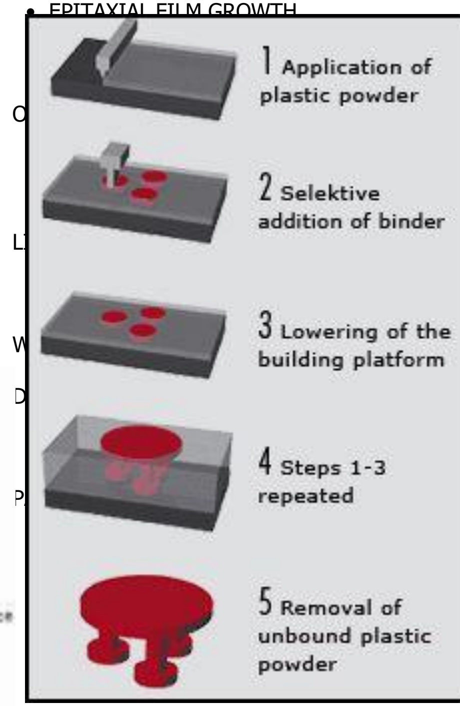
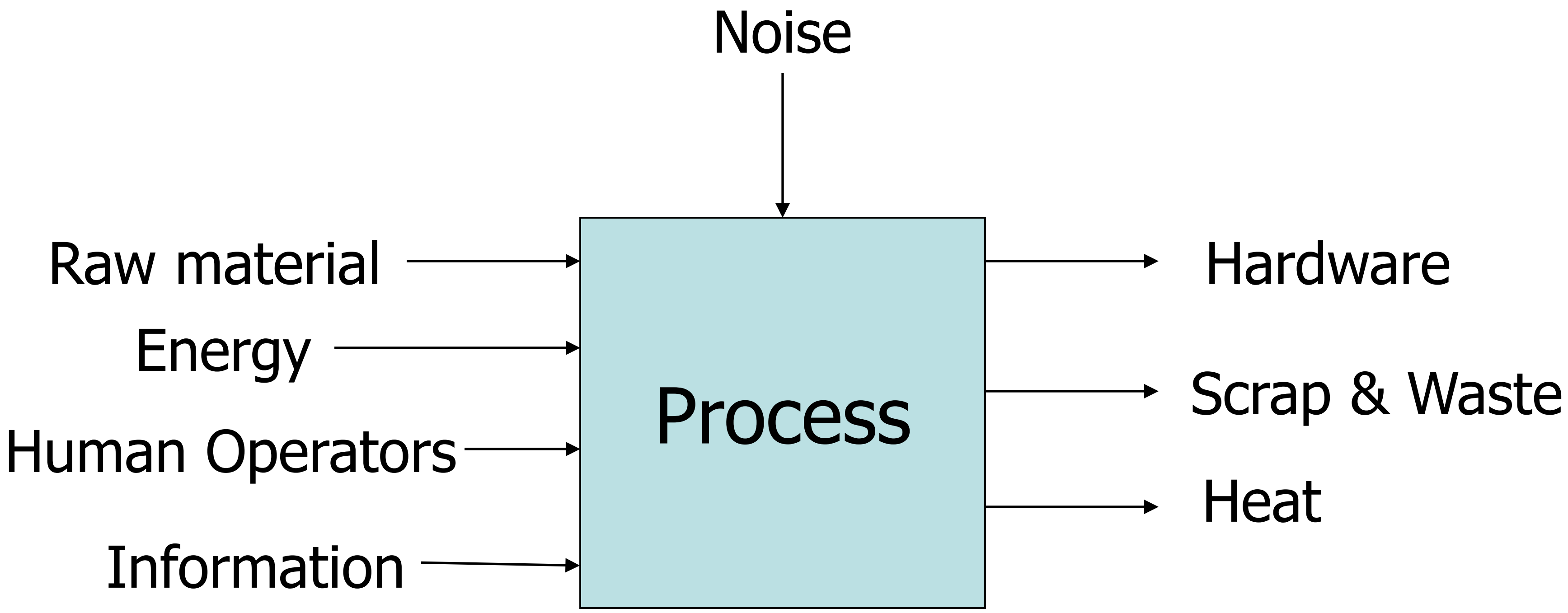


172 processes + rapid prototyping + etc, etc

Abstraction of a Mfg Processes



Process Classification

- Materials
- Machines
- Applications

vs

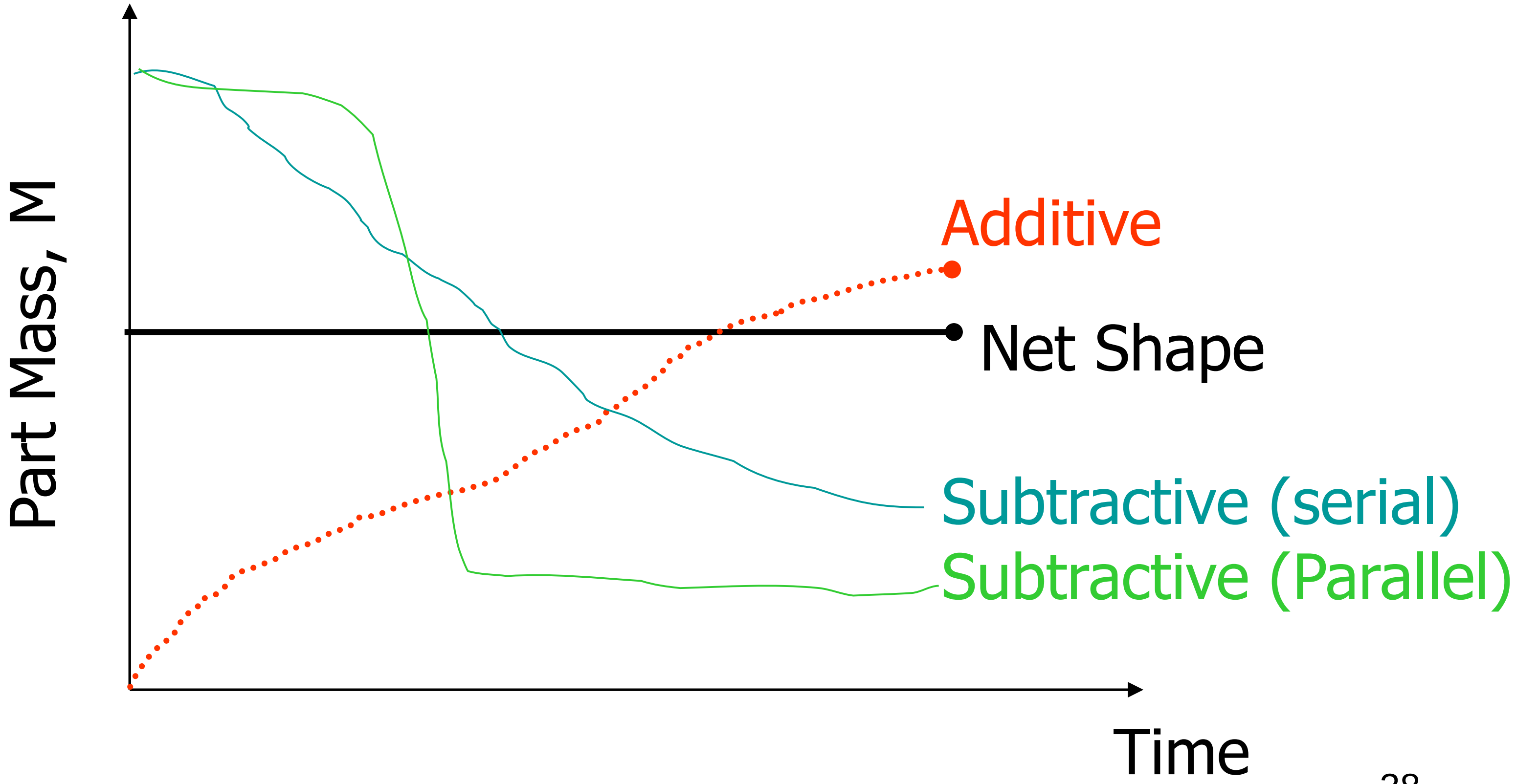
- Geometry
- Time
- Energy

Process Classification

- Geometrical transformation
  - Subtractive / Additive / Net
- Time sequence
  - Serial / Parallel
- Energy domain
  - Mechanical / Thermal / Chemical / Electrical

See "Manufacturing Processes and Process Control," David E. Hardt

Geometrical classification



Transformation	REMOVAL PROCESSES							
Mode	SERIAL				PARALLEL			
Energy Source	Mechanical	Thermal	Chemical	Electrical	Mechanical	Thermal	Chemical	Electrical
	Cutting	*Laser cutting*		*EDM*	*Die stamping*		*ECM*	*EDM*
	Grinding	*Flame cutting*					*Photolithography*	
	Broaching	*Plasma cutting*						
	Polishing							
	Water jet							

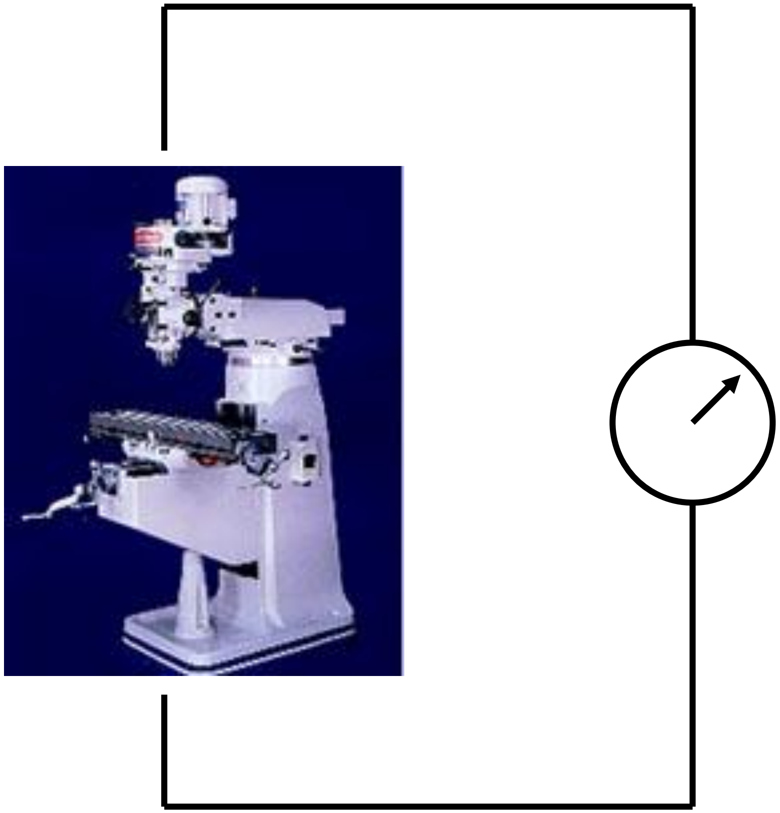
Transformation	ADDITION PROCESSES							
Mode	SERIAL				PARALLEL			
Energy Source	Mechanical	Thermal	Chemical	Electrical	Mechanical	Thermal	Chemical	Electrical
	3D printing	*Laser sintering*	*Stereolithography*		*HIP*	*Sintering*	*LPCVD*	
							Plating	

Transformation	SOLIDIFICATION PROCESSES							
Mode	SERIAL				PARALLEL			
Energy Source	Mechanical	Thermal	Chemical	Electrical	Mechanical	Thermal	Chemical	Electrical
	Ultrasonic Welding	*Plasma spray*		*E-beam Welding*	*Inertia bonding*	*Casting*	*Diffusion bonding*	
				Arc welding		*Molding*		
				Resistance welding				

Transformation	DEFORMATION PROCESSES							
Mode	SERIAL				PARALLEL			
Energy Source	Mechanical	Thermal	Chemical	Electrical	Mechanical	Thermal	Chemical	Electrical
	Bending	*Line heating*			*Drawing*			
	Forging (open)				*Forging (die)*			
	Rolling							

* Taken from "Manufacturing Processes and Process Control," David E. Hardt

Performance measures



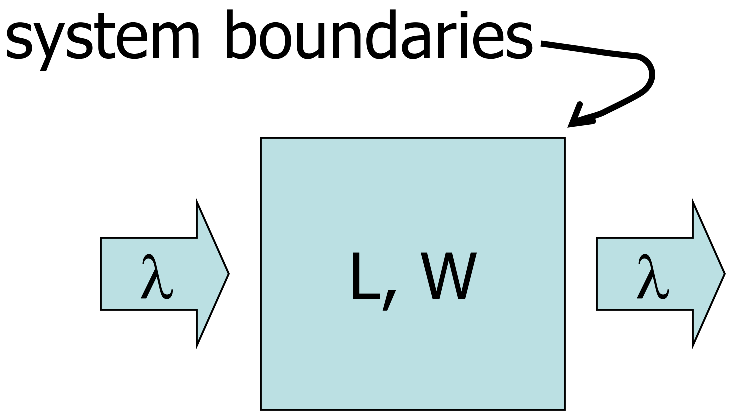
- Rate
- Time
- Cost
- Quality
- Flexibility
- Environment

See "Competitive Attributes…" T. Gutowski

Time – must be defined

- Time at the machine
  - set-up, process, cycle time?
- Customer lead time (order to receipt)
  - Release to shop floor
  - Queuing, waiting, inspection
  - Processing
  - Storage, transport

Rate and Time



– Little's law: L = λ W (all average values)
  - L = units in system (inventory)
  - λ = rate of material arrival
  - W = time in system

– Takt Time = available time/units required
  - Time between products to meet demand

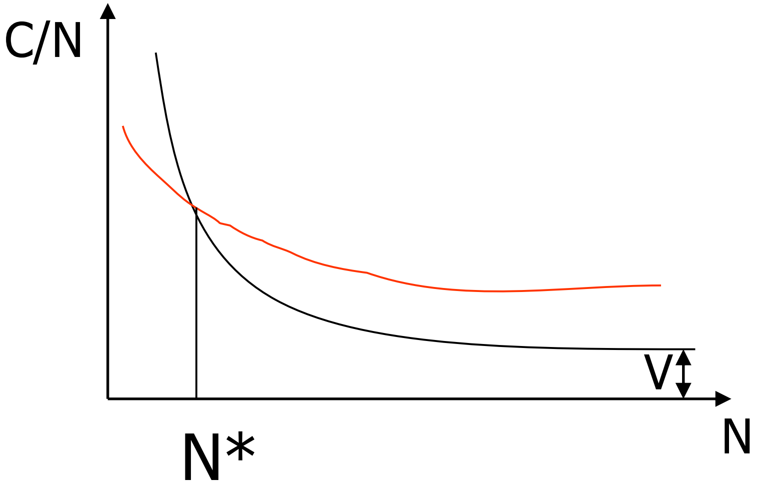
Direct Cost

Profit = Income - Expenses

Manufacturing Cost = Material + Labor + Tooling + Equipment

Economies of scale

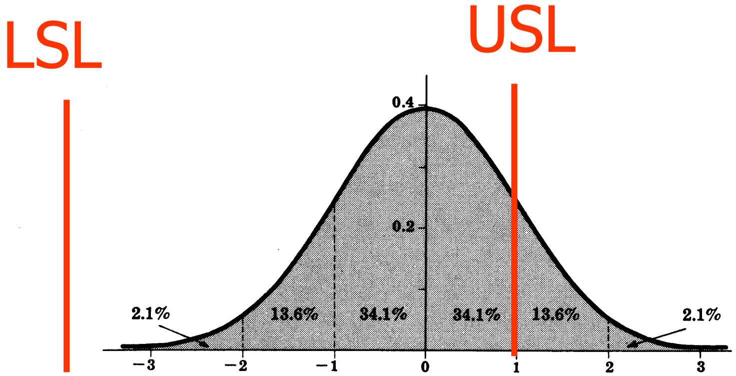
- $C = F + V \times N$
  - C = Total cost
  - F = Fixed cost
  - V = Variable cost
  - N = number of units



Quality

- Satisfied Customer (systems level)
- Deviation from target (process level)
    - material properties
    - geometry
    - appearance, etc

Quality



Normal distribution $N(0, 1)$

Process Capability Index, C_p

- $C_p = (USL - LSL) / 6\sigma$
  - USL = Upper Specification Limit
  - LSL = Lower Specification Limit
  - σ = standard deviation of the process output
- USL and LSL are something specified by design
- The standard deviation is due to variation in the process

Flexibility

- Ability to accommodate different geometries, materials, production volumes
- Measured as Δ cost, Δ time, etc,

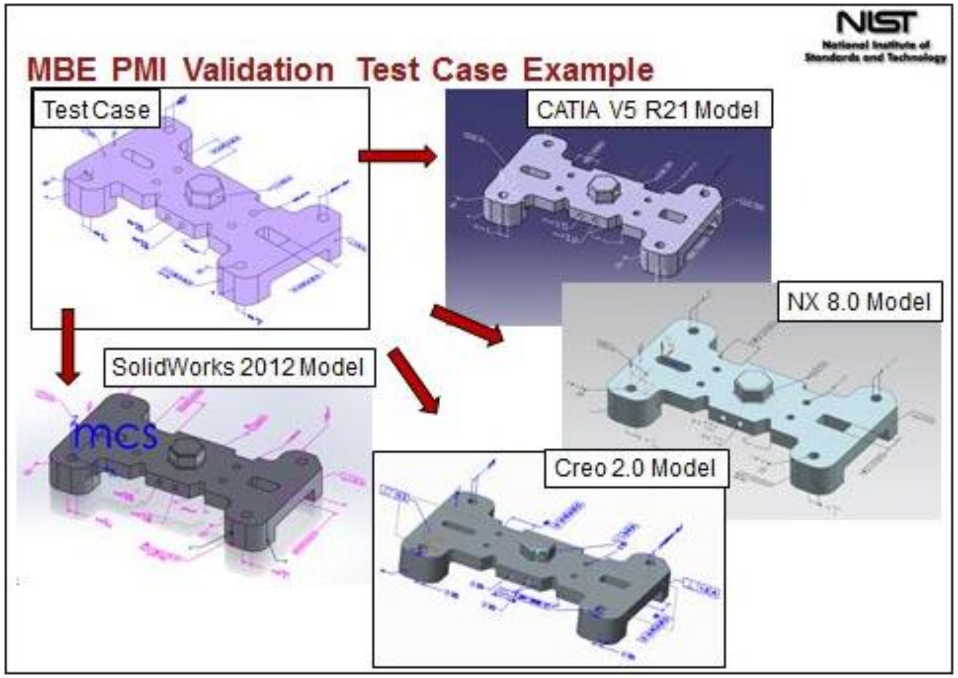
Environmental performance

- LCA Process and Product
- Enterprise Level
- Global Level

From part to system

Physical Part	Process Steps	System Design
Shape, Materials, Tolerances	Equipment, Tools, Procedures	Equipment arrangement, Flows Skill Levels, other Resources
Representation	Process Plan -	Cell or system-

digital representation of parts



Downstream activities: processing, assembly, product performance, maintenance, end of life, supply chain, factory control,

http://www.nist.gov/el/msid/infotest/mbe-pmi-validation.cfm

CADCAM and CNC

MIT IST Information Systems and Technology

GET STARTED WITH IT
connect, configure, & go

OUR SERVICES
find resources fa

SolidWorks

Mastercam

AUTODESK

FUSION 360

OMAX MACHINES

OMAX ABRASIVE WATERJETS

OMAX Instruction-
1st team meeting
Needs DXF file
OMAX app available

AUTODESK HSM

From 2.810 report

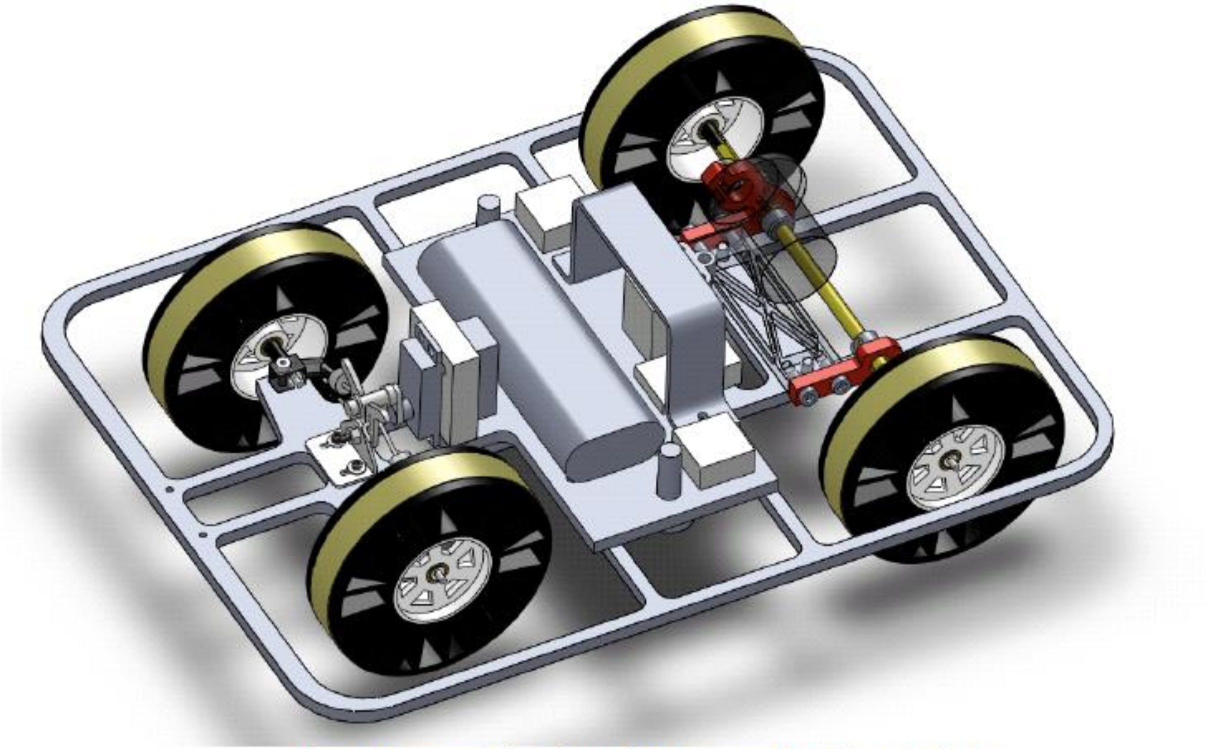
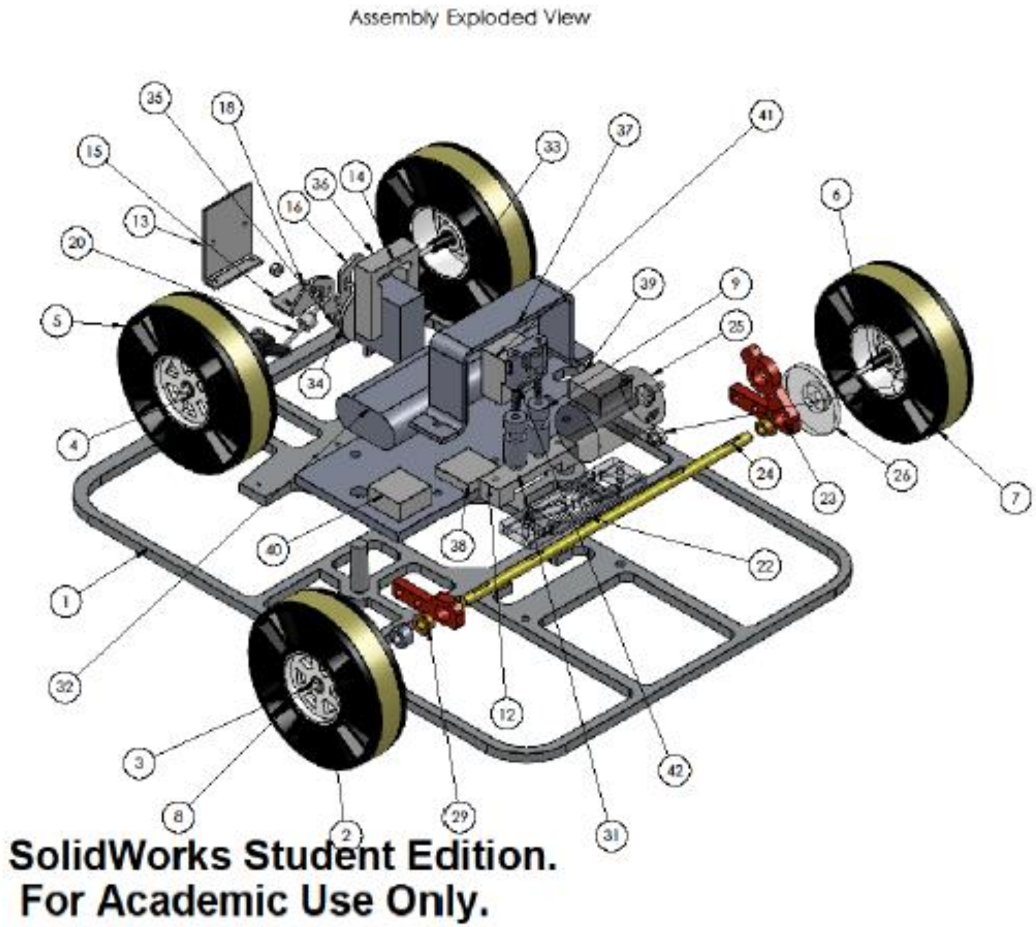


Figure 7- CAD rendering of complete car assembly without the body.

Detailed Prints

Exploded Assembly with BOM



ITEM NO.	PART NUMBER	QTY.
1	chassis	1
2	wheel	4
3	frontaxle	4
4	bearing	8
5	front tire	4
6	SPACER	4
7	rubber band	4
8	nylon washer_small	4
9	Banana Jack	2
10	Maglock Catch	1
11	Maglock Strike	1
12	clip holder plate	1
13	Body Mount Bracket	1
14	steering block	2
15	steering mount	1
16	V bar	1
17	shoulder screw	2
18	screw 0_5	1
19	nut 4_40	1
20	tie rod	1
21	tie rod 2	1
22	DRIVETRAIN CONNECTOR BLOCK	1
23	MOUNT R	1
24	REAR SHAFT	1
25	MOTOR	1
26	LARGE GEAR	1
27	SMALL GEAR	1
28	STOPPER_RING	1
29	REAR_BUSHING	2
30	MOUNT R	1
31	Control Box Body	1
32	battery	1
33	servo	1
34	servo connector	1
35	servo drive connector	1
36	servo holder	1
37	handle	1
38	transponder	1
39	motor controller	1
40	tranciever	1
41	plug adapter	1
42	BP1252091(DualBanana)	1

Figure 8- Exploded Assembly with BOM

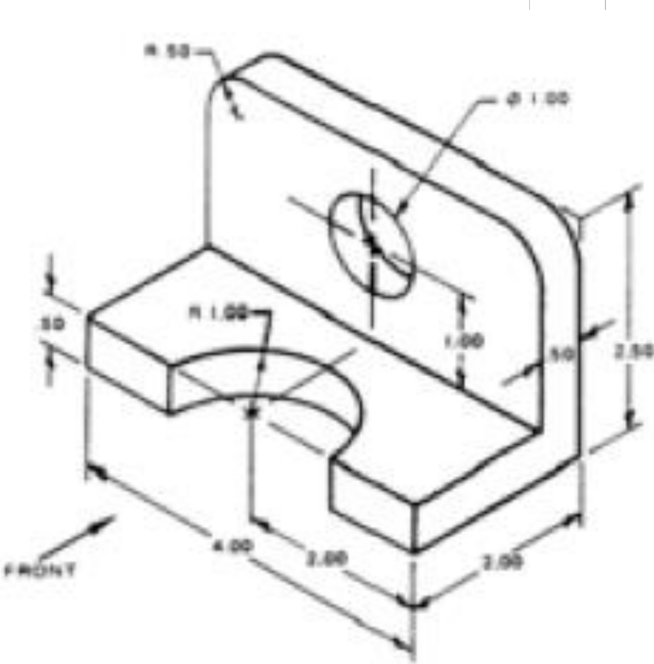
Process Planning

- Identify machines
- Tools
- Settings
- Steps required to produce a geometry to tolerance
- Time estimation

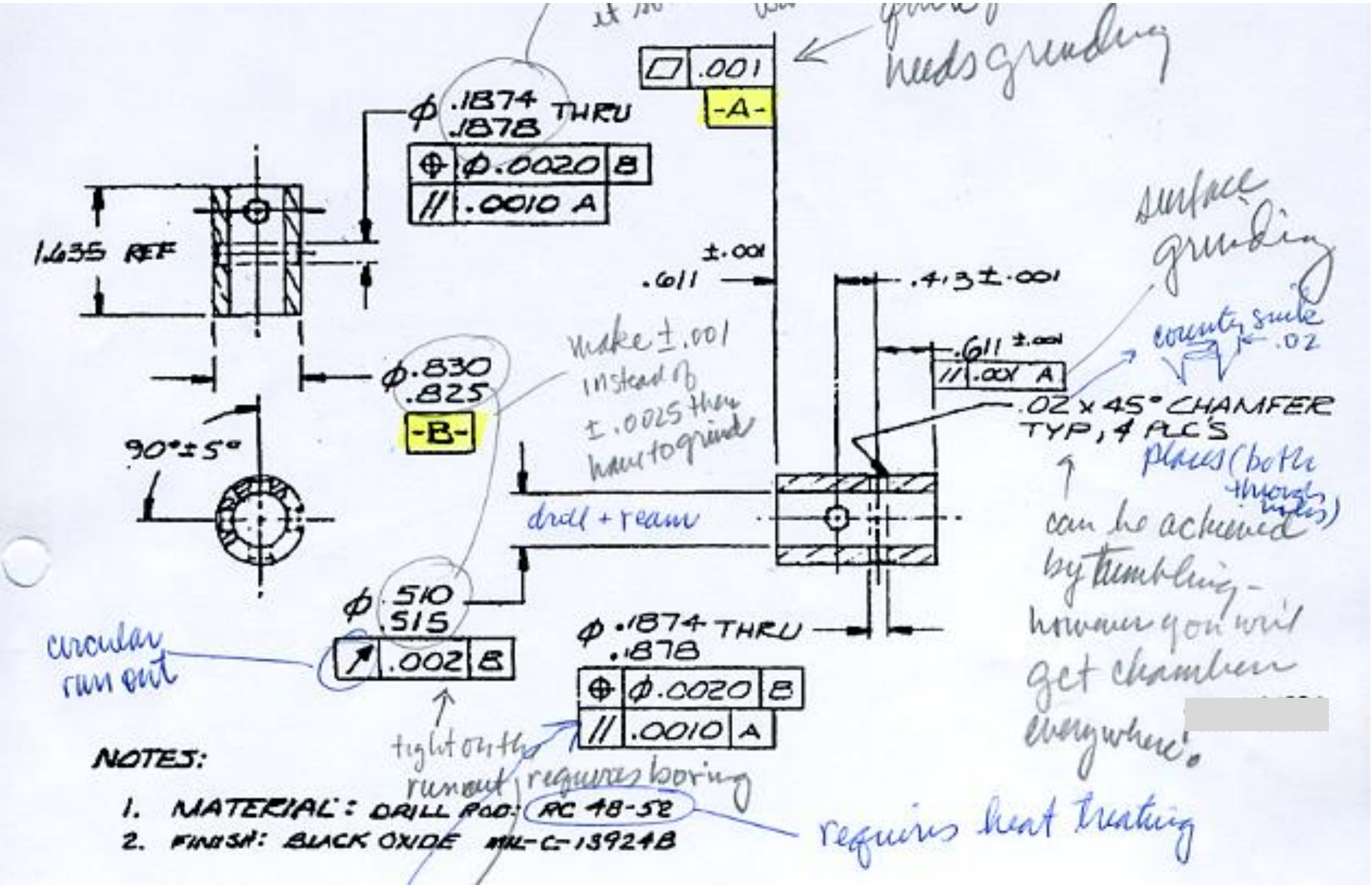
Process Plan Time Estimation

Rod Support

#	Machine	Operation (V = Volume A = Area P = Perimeter)	Fixture	Tool Change	Run (R = Rough F = Finish)	Deburr Inspect Measure
10	1	Saw stock to ~ 4.125” A = 5.625 in2 P = 9 in	0.23	–	2.02	0.30D 0.05I
20	2	Mill two ends to length 4” V = 0.703 in3 A = 11.25 in2 P = 19 in	0.20 0.20	2	0.13R 0.75F	0.63D 0.05I 0.13M
30	2	Mill width to 2” V = 2.5 in3 A = 10 in2 P = 13 in	0.20	–	0.46R 0.67F	0.43D 0.05I 0.13M
	2	Mill out 2”x1.5”x4” V = 12 in3 A = 14 in2 P = 15 in	–	–	2.19R 0.93F	0.50D 0.05I 0.13M 0.13M
	2	Drill hole 1” diameter -Center drill -Pilot drill 1/2” -Pilot drill 63/64” -Ream	0.20	2 2 2 2	0.03 0.05 0.04 0.01	0.21D 0.05I 0.17M
	2	Bore 1” radius V = 0.79 in3 A = 1.57 in2 P = 7.28 in	0.20	2	0.96R 0.10F	0.24D 0.05I 0.06M
	3	Sand 0.5” radii V = 0.05 in3 A = 0.79 in2 P = 3.14 in	0.08	–	0.20R 0.21F	0.10D 0.05I 0.06M 0.06M
		Totals:	1.31	12.00	8.75	3.63



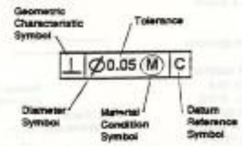
Engineering Drawing; Connecting Link



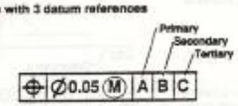
Geometric Tolerancing Explanations

(See also Kalpakjian pages 1057-1063)

FEATURE CONTROL FRAME



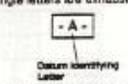
Control frame with 3 datum references



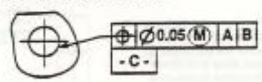
DATUMS

A Datum is a theoretically exact point, axis or plane derived from the true geometric counterpart of a specified datum feature. A datum is the origin from which the location or geometric characteristics of features of a part are established.

A Datum Feature is an actual feature of a part (for example a surface, hole, or slot) that is used to establish a datum. Each datum requiring identification is assigned a different letter (except I, O, or Q). Double letters (AA, AB, etc.) may be used when single letters are exhausted.



When a feature controlled by a geometric tolerance also serves as a datum, the control frame and datum are combined.

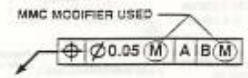


FLATNESS

Flatness is the condition of a surface having all points in one plane. A flatness tolerance specifies a zone defined by 2 parallel planes. In the example shown the surface must lie between 2 parallel planes 0.18mm apart and the surface must be within the specified size limits.

Ⓜ **Maximum Material Condition (MMC)**

The condition in which a feature of size contains the maximum amount of material within the stated size limits (for example, minimum hole diameter or maximum shaft diameter). A feature identified as MMC is permitted greater positional or form tolerance as its size departs from MMC.



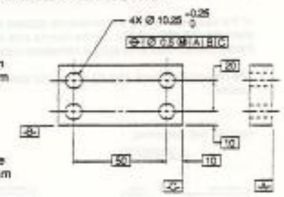
POSITION

If position tolerances are to be modified as features depart from maximum material condition, the MMC modifier must be specified on the drawing.

A positional tolerance defines a zone within which the center, axis or center plane of a feature of size is permitted to vary from the true (exact) position. Basic dimensions establish the true position.

In the example shown, the centers of the holes must lie within circles of 0.5mm diameter when the holes are at 10.25mm diameter.

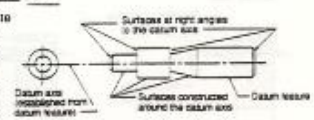
As the diameters of the holes increase to 10.5mm diameter, the tolerance zones increase proportionately to 0.75mm diameter.



The tolerances, in this example, apply to the center distance between holes as well as the location of these features as a group from the datum planes (A-B-C).

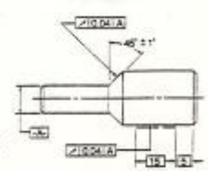
CIRCULAR RUNOUT

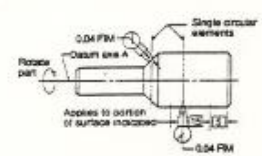
Runout is a composite tolerance used to control the relationship of one or more features to a datum axis. The illustration shows the types of features that can be controlled by runout tolerances.



Circular runout provides control of circular elements of a surface. It can be used to control the cumulative variations of circularity (roundness) and coaxiality.

In the example shown, each circular element of the surfaces toleranced must fall within 0.04mm (Full Indicator Movement) when the part is rotated 360° about the datum axis.





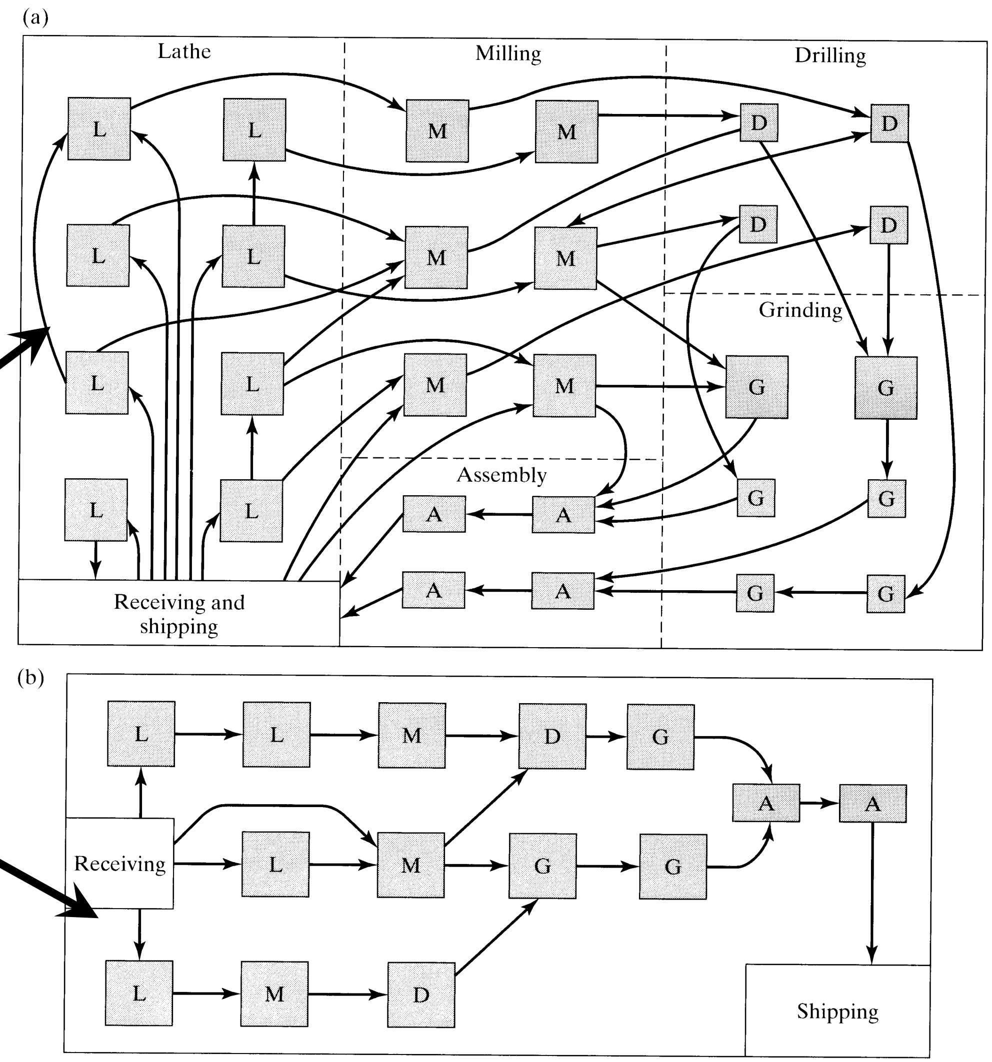
See Tolerance hand-out

Process Plan Time Estimate

Connecting Link

#	Machine	Operation (V = Volume A = Area P = Perimeter)	# Dims.	Fixture	Tool Change	Run (R = Rough F = Finish)
10	1	Face end Assume V = 0.075 in3	–	0.17	0.1	0.08
20		Turn diameter to 0.827" V = 0.105 in3	–	–	–	0.11
30		Turn diameter finish pass A = 23 in2	1	–	–	1.35
40		Center drill 0.512" dia.	–	–	0.1	0.05
50		Drill with 0.4688" drill	–	–	0.1	0.28
60		Bore to 0.512" V = 0.033 in3	1		0.1	0.05
70	2	Grind to exact length of 1.635" Assume V = 0.075 in3 A = 0.331 in2	1	0.04	–	0.11R 0.01F
80	3	Fixture in collet on indexer to drill holes V = 1.65 in3	–	0.17	–	–
90		Center drill 0.1875" hole	–	–	0.5	0.05
100		Drill to 11/64"	–	–	0.5	0.17
110		Ream to 0.1875"	2	–	0.5	0.06
120		Index part	–	0.1	–	–
130		Center drill 0.1875" hole	–	–	0.5	0.05
140		Drill to 11/64"	–	–	0.5	0.17
150		Ream to 0.1875"	4	–	0.5	0.06
160		Deburr all edges P = 10.77 in	–	–	–	0.72
		Totals:	9	0.48	3.40	3.32

Mfg. System Designs; (a) job shop (b) flow shop



Manufacturing Systems

- Configurations
- Analysis tools (time performance)
- Historical development
- Current practice
- Future trends

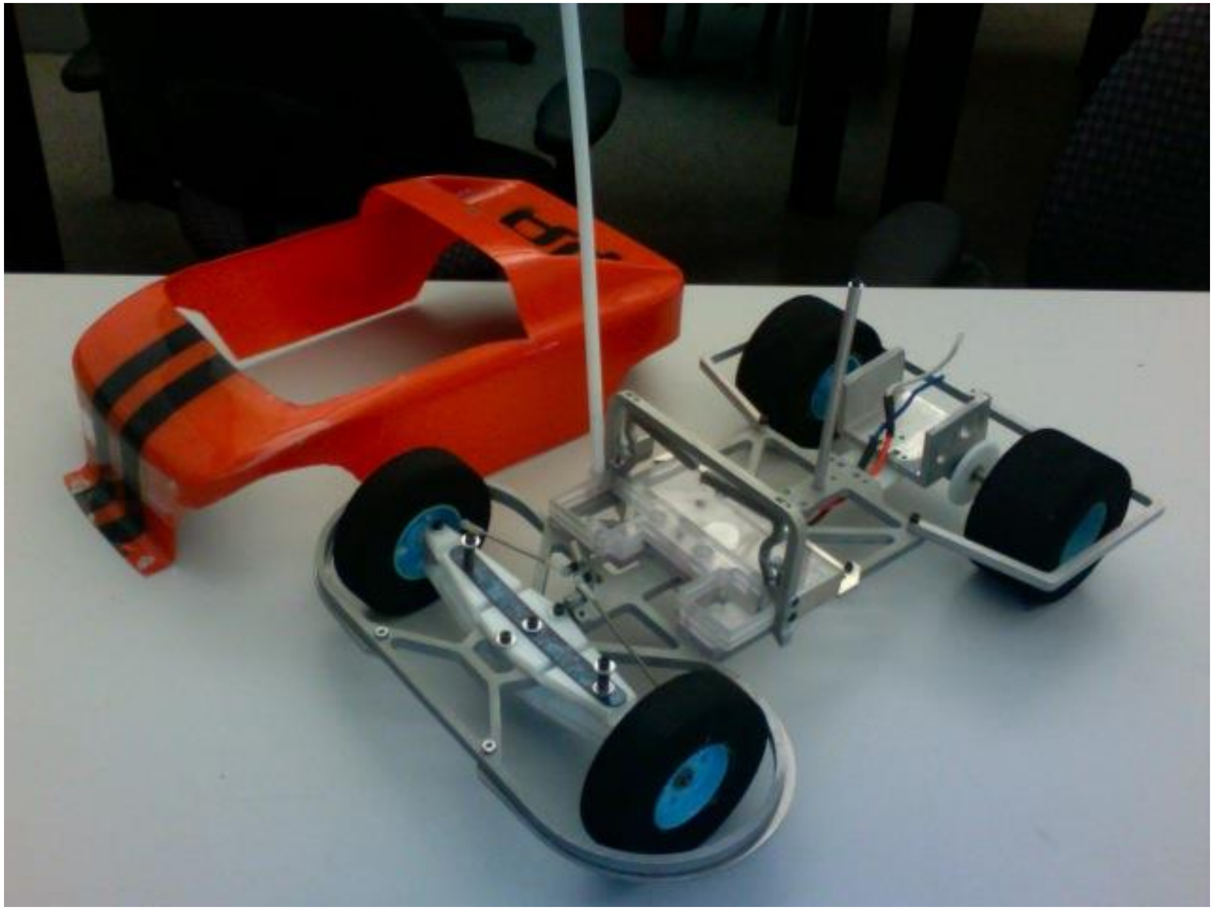
Check List

- Hand in information sheets
- Fill in Google doc for labs ASAP
- Attend Lab next week
- Read:

1. "Competitive Attributes…"
2. "Mfg Processes and Control"
3. "Geometric Tolerancing"
4. skim Kalpakjian Ch 1-9.

- Homework #1

2.810 team project



http://www.youtube.com/watch?v=BcnwGV4tNNY