2.810 manufacturing processes and systems

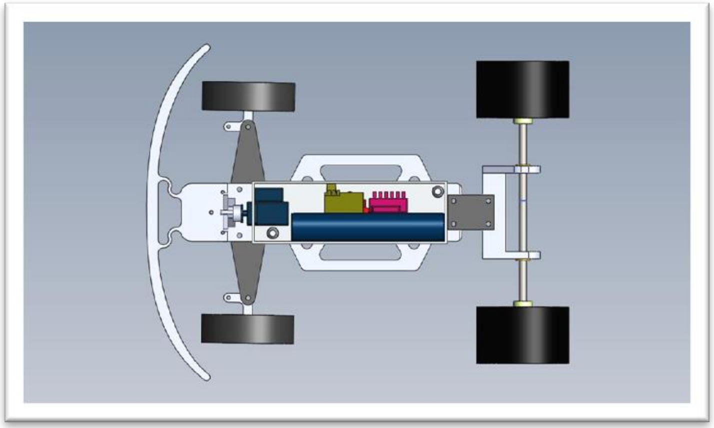
Prof. Tim Gutowski, gutowski@mit.edu

September 4, 2013

Prereq: 2.001, 2.006, 2.008

Hands-on Experience

Processes to Systems



Today’s Agenda

- Business
  - You
  - Us
  - Class/Project
- Concepts
  - Manufacturing Enterprise
  - Processes
  - Communication Tools

Please fill out information form

- Basic information
- Experience in shop
- Experience in mfg

52 students Pre-registered for 2.810

1. Artiles,Jessica A.
2. Bhadauria,Anubha-Sin
3. Chandar,Arjun Subram
4. Chang,Woolim
5. Charpentier,Erik Leo
6. Chawla,Yugank
7. Chiang,Jerry Kao
8. Churchill,Hugh Edwar
9. Colucci,Lina Avancin
10. Garcia,Jose Manuel
11. Georgiadis,Vasilis
12. Ghosh,Sourobh
13. Graves,Carmen M
14. Guan,Dong
15. Jain,Sonam
16. Jamerson,Holly M.
17. Jiang,Sheng
18. Kimball,Peter Evan
19. Knodel,Philip Clinto
20. Kuan,Jiun-Yih
21. Larson,Richard W
22. Llorens - Bonilla,Ba
23. Lopez,Saul
24. Mangan,Esther Hu
25. Mantzavinou,Aikateri
26. McMullin,Nathan Keit

1. Modak,Ashin Pramod
2. Modi,Vrajesh Y
3. Morris,Taylor J.
4. Olle,Chase R.
5. Pak,Nikita
6. Pan,Yichao
7. Penalver-Aguila,Llui
8. Pharr,Vanea Ryann
9. Pombrol,Christopher
10. Puszko,Gregory D.
11. Ramos,Joshua D
12. Ranjan,Aditya
13. Reed,Christian R.
14. Rodrigo,Michael
15. Secundo,Rafael Garci
16. Sedore,Blake William
17. Shah,Adhvait M.
18. Solomon,Brian Richmo
19. Sondej,Nicholas Matt
20. Sun,Xu
21. Swamy,Tushar
22. Taylor,David Donald
23. Thomas,Dale Arlingto
24. Wu,Faye Y
25. Xu,Ruize
26. deGuzman,Jeremy Erne

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

____

____

____

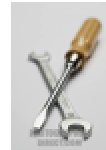
____

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

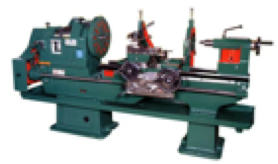


Are you familiar with these tools? Can you use them? ☐ Y ☐ N

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? ____________________

____



Have you ever used - an engine lathe? ☐ ☐

- band saw? ☐ ☐

- drill press? ☐ ☐
Y N

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

Can you program CNC machine tools? ☐ Y ☐ N

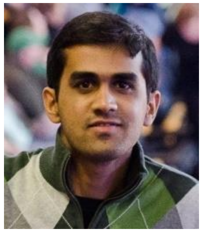
Please list any CAD/CAM software you already have experience with:

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

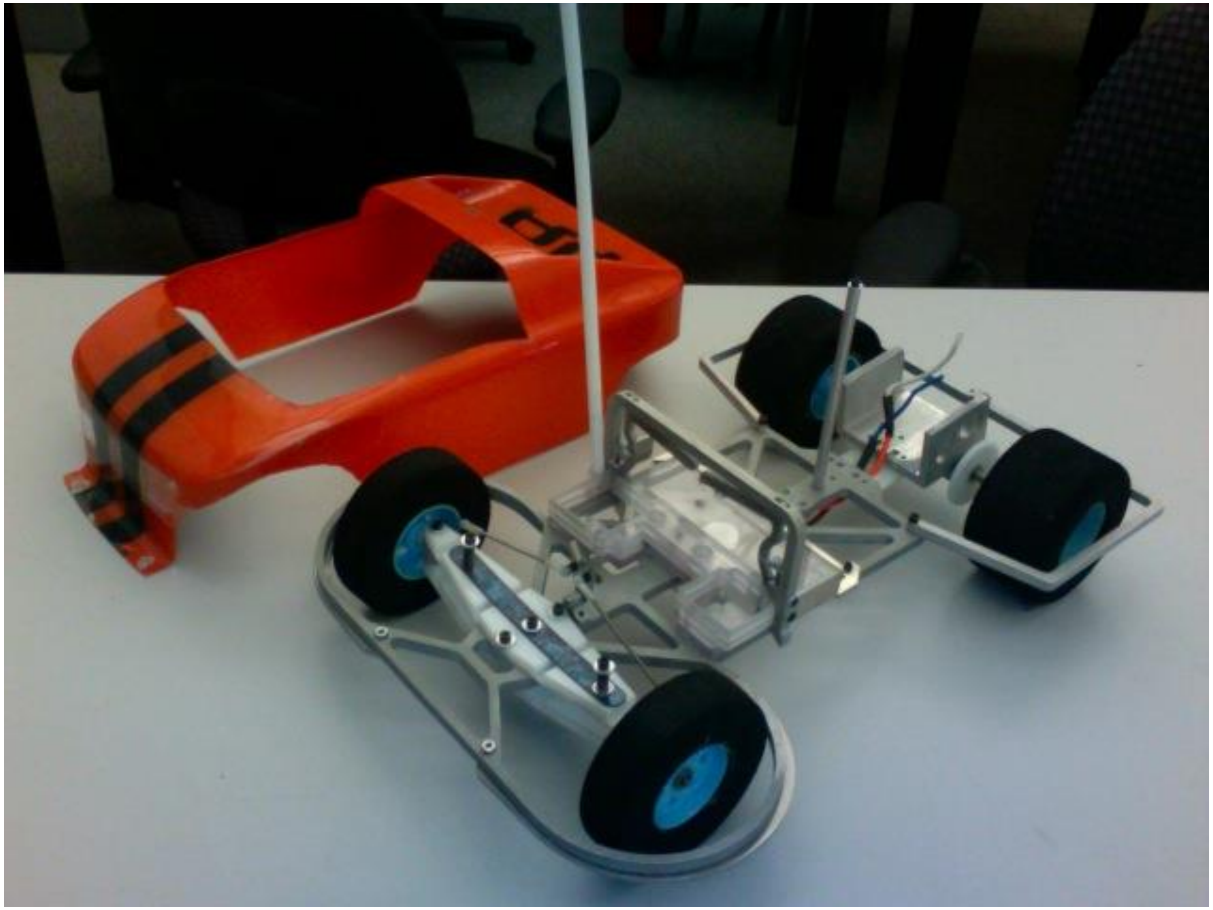
Bill Buckley

bbuckley@mit.edu

Basic info can be found on the 2.810 webpage

web page:	*http://web.mit.edu/2.810/www*	
Instructor:	*Prof. T. G. Gutowski* *gutowski@mit.edu*	*Rm. 35-234*
T.A.: 	*Sumant Raykar* *sraykar@MIT.EDU*	*Rm 35-005*
Tech Inst:	*Mr. William Buckley* *bbuckley@mit.edu*	*Rm. 35-110*
Text:	***Manufacturing Engineering and Technology, 7th Ed.*** *Kalpakjian and Schmid, 2014. Prentice Hall.*	

2.810 team project



Key dates for project

Sept 23	-	Teams finalized
October 7	-	Pattern Design Discussion/ Kits assembled
Week of Oct 7	-	Preliminary design concept review (schedule a time for group to meet with Bill)
October 23-	CAD chassis Drawings due (waterjet file and dimensioned drawing)	
Week of Oct 28	-	Production chassis' cut on waterjet
November 13	-	Oral Progress Reports
December 9	-	Contest
December 11	-	Evaluation & Clean up

Available at 2.810 Website

2.810 Labs

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

Week of September 12	Safety, Shop Orientation, Car Review
Week of September 19	**Machining**
Week of September 26	**Machining**
Week of October 3	**Machining**
Week of October 10	**Waterjet / Sheetmetal**
Week of October 17	No Lab (QUIZ Week)
Week of October 24	Team Project (this continues through term)

2.810 Schedule

Mondays	**2:30 - 4:00**	**Wednesdays**	**2:30 - 4:00**
Sept.		4	Introduction
9	How is this part made?	11	Intro to Processes
16	Process Performance	18	Machining
23	Machining (teams finalized)*	25	Injection Molding
30	Thermoforming		
Oct.		2	Sheet Forming
7	Casting (kits assembled)*	9	Car/Quiz Review
14	(Holiday)	16	QUIZ I
21	Intro to Mfg. Systems	23	Assembly (Dan Whitney)
28	Mfg Time and Rate	30	Process Control (Dave Hardt)
Nov.			
4	Toyota Production System	6	Supply Chains (Steve Graves)
11	(Holiday)	13	Progress Reports
18	Systems Summary	20	QUIZ II
25.	Sustainable Manufacturing	27	Work on Projects
Dec.			
2	Additive Mfg (John Hart)	4	Preparation for Contest
9	**Contest**	11	**Clean up & evaluation**

The Mfg Enterprise

- History
  - England, U.S., Japan, China…
- Trends
  - Developing Countries, Outsourcing, Globalization, Lean…
- Shadow Side
  - Labor practices, Environment, Externalities, Sustainability…

Basic Concepts

1. Manufacturing Processes
   - Flows
   - Performance Attributes
   - Classification Schemes

2. Manufacturing Communication Tools
   - Engineering Drawings
   - Process Plans
   - System Designs

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

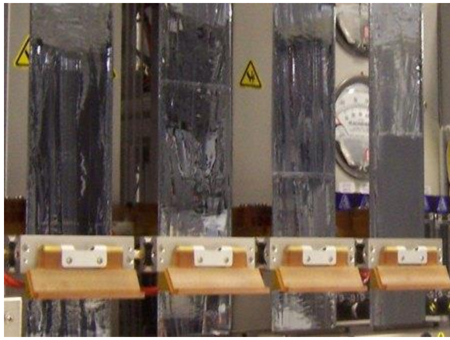
LIQUID STATE WELDING
- RESISTANCE WELDING
- ARC WELDING
- THERMAL WELDING

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, …



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

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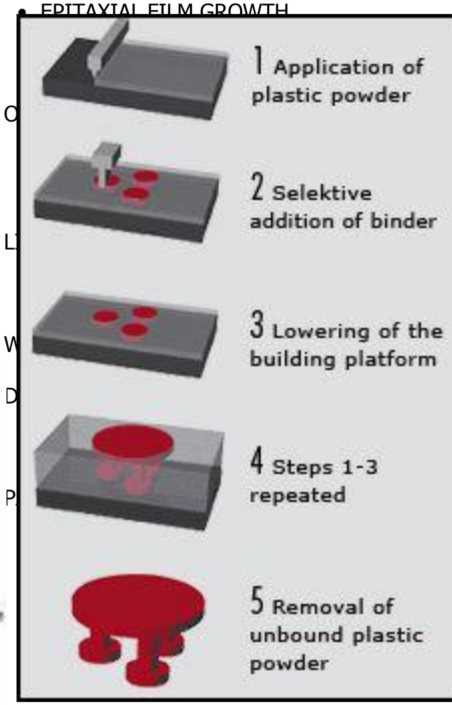
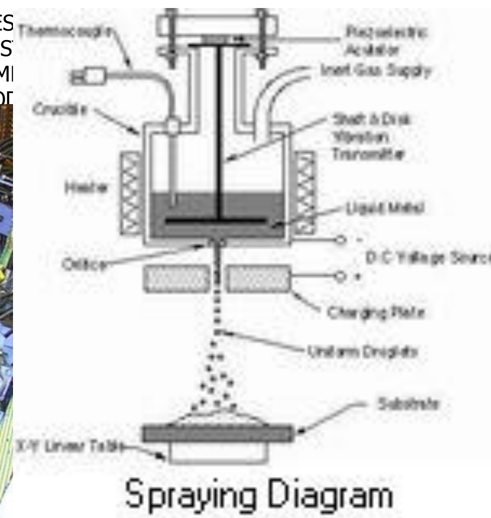
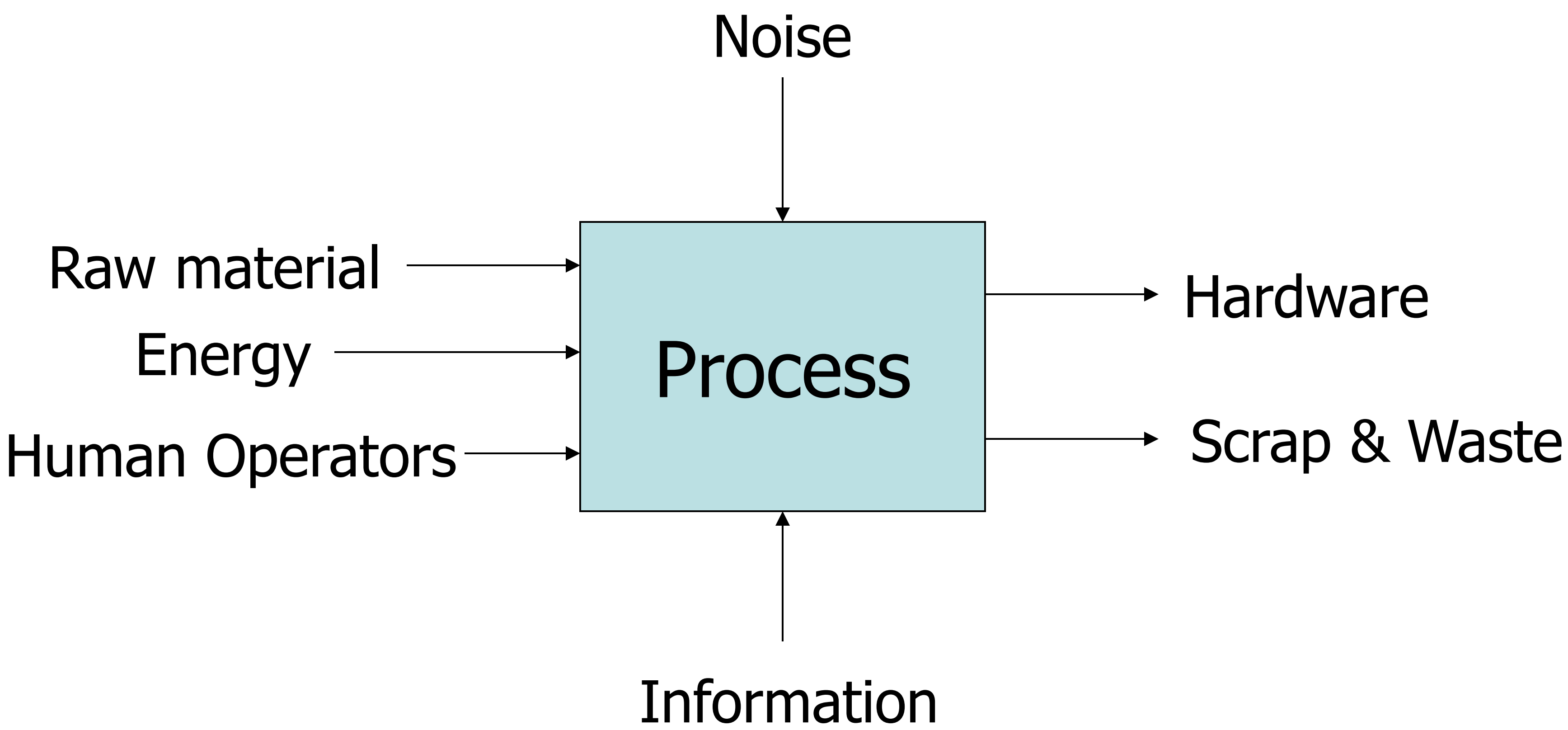




172 processes + rapid prototyping + etc, etc

Abstraction of a Mfg Processes



Resource Flows & Transformations

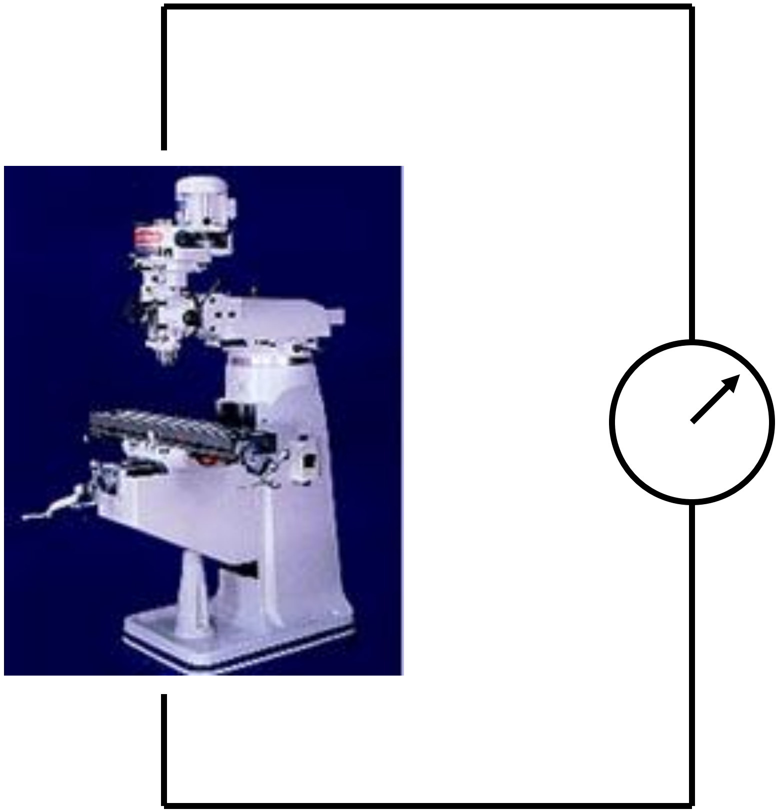
- *Materials* -> hardware, waste
- Energy -> useful work, heat
- Information ->shape, properties, in presence of noise

Efficiencies (resources)

$$\eta = \frac{\text{useful output}}{\text{total input}}$$

- materials
- energy (exergy)
- time…

Performance measures

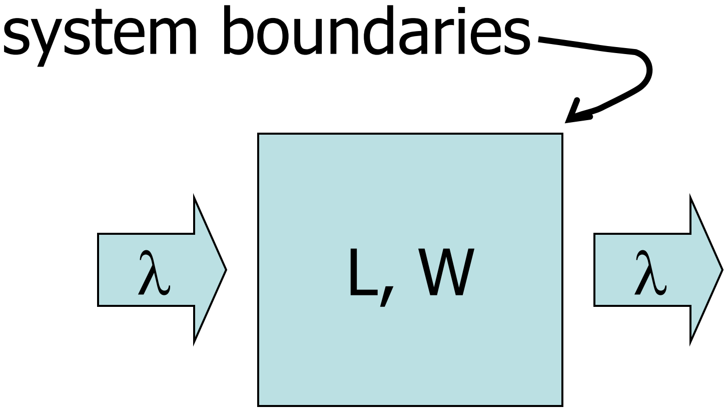


- Rate
- Time
- Cost
- Quality
- Flexibility
- Environment

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

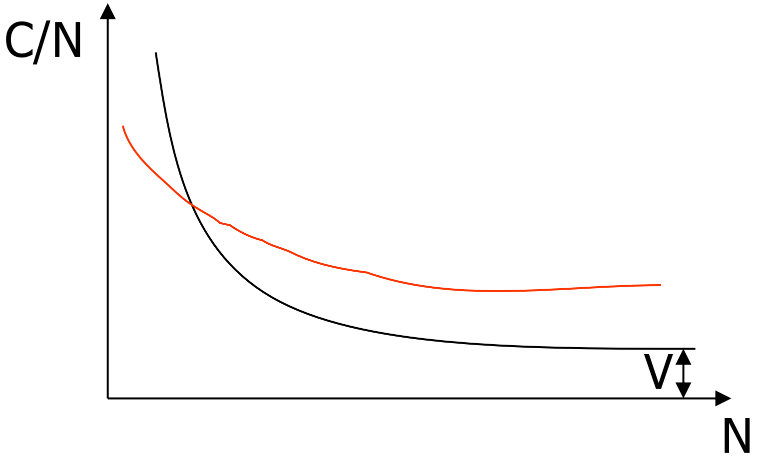
Rate and Time



- Little's law: $L = \lambda W$
  - L = units in system (inventory)
  - λ = rate of material flow through the system
  - W = time in system
- Takt Time = available time/units required
  - Time between products to meet demand

Cost

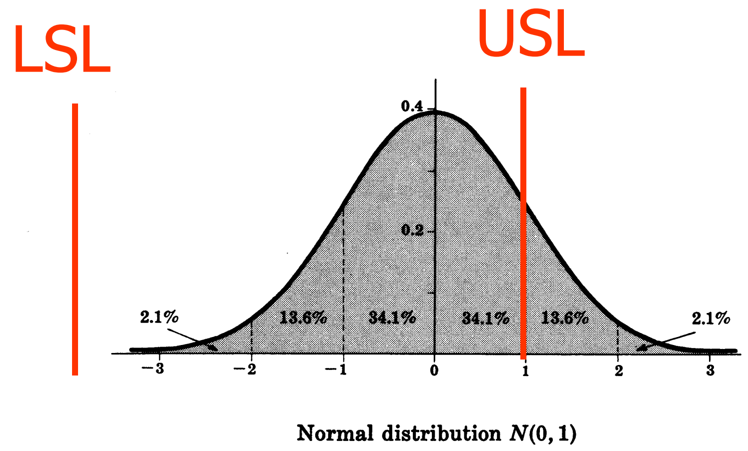
– Profit = Income - Expenses
– Manufacturing Cost = Material + Labor + Tooling + Equipment
– Economies of scale
  - C = F + V X N
    – C = Total cost
    – F = Fixed cost
    – V = Variable cost
    – N = number of units



Quality

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

Quality



Process Capability Index, C_p

- C_p = (USL-LSL) / 6σ
  - 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

- Material efficiency
- Energy efficiency
- Consumption and Releases to the environment
- Toxic and/or harmful effects
- Carbon

Process Classification

- Materials
- Machines
- Applications

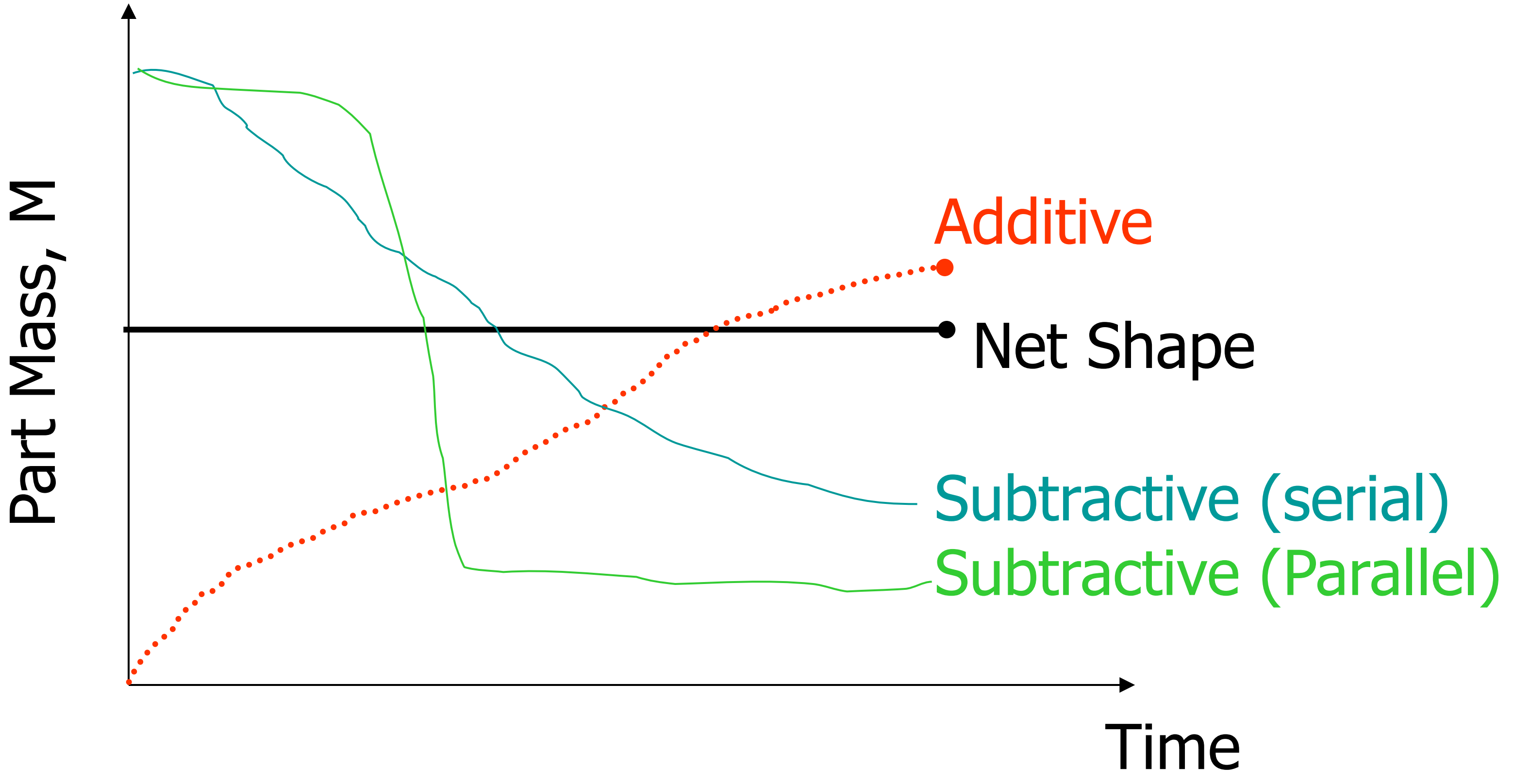
vs

- Geometry
- Time
- Energy

Process Classification

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

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				

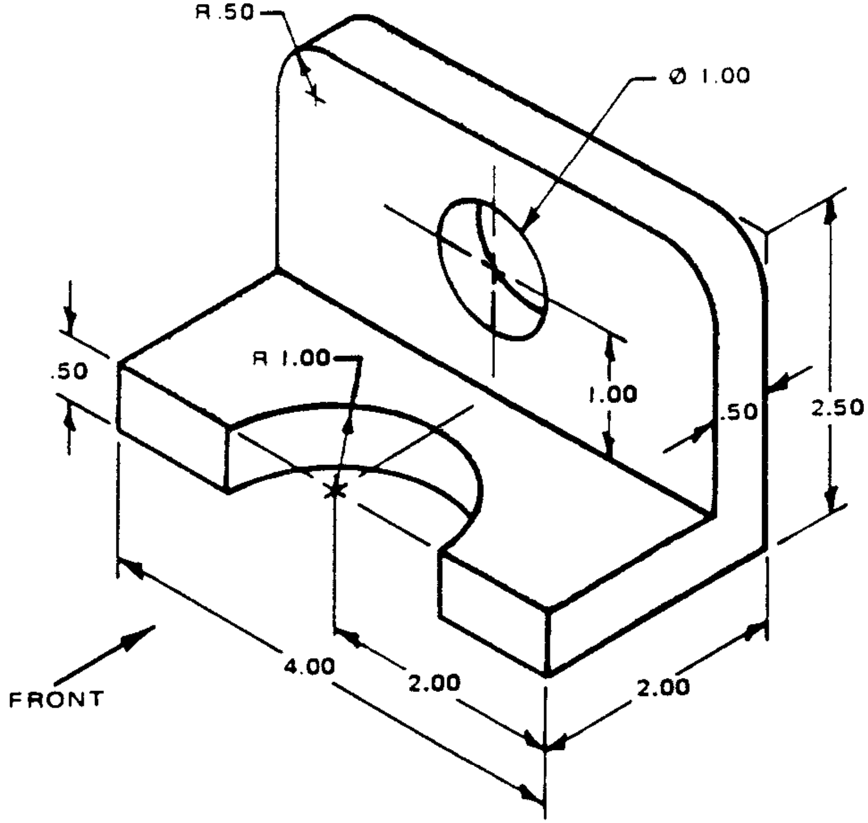
Transformation	DEFORMATION PROCESSES							
Mode	SERIAL				PARALLEL			
Energy Source	Mechanical	Thermal	Chemical	Electrical	Mechanical	Thermal	Chemical	Electrical
	Bending	*Line heating*			*Drawing*			
	Forging (open)				*Forging (die)*			
	Rolling							

* Taken from “Manufacturing Processes and Process Control,” David E. Hardt, 1994.

Mfg Communication tools

Design	Process	System
Physical Representation Materials Tolerances	Equipment Tools Set points and parameters	Equipment arrangement Flows Skill Levels
Engineering Drawing	Process Plan	System Design

Engineering Drawing; Rod Support

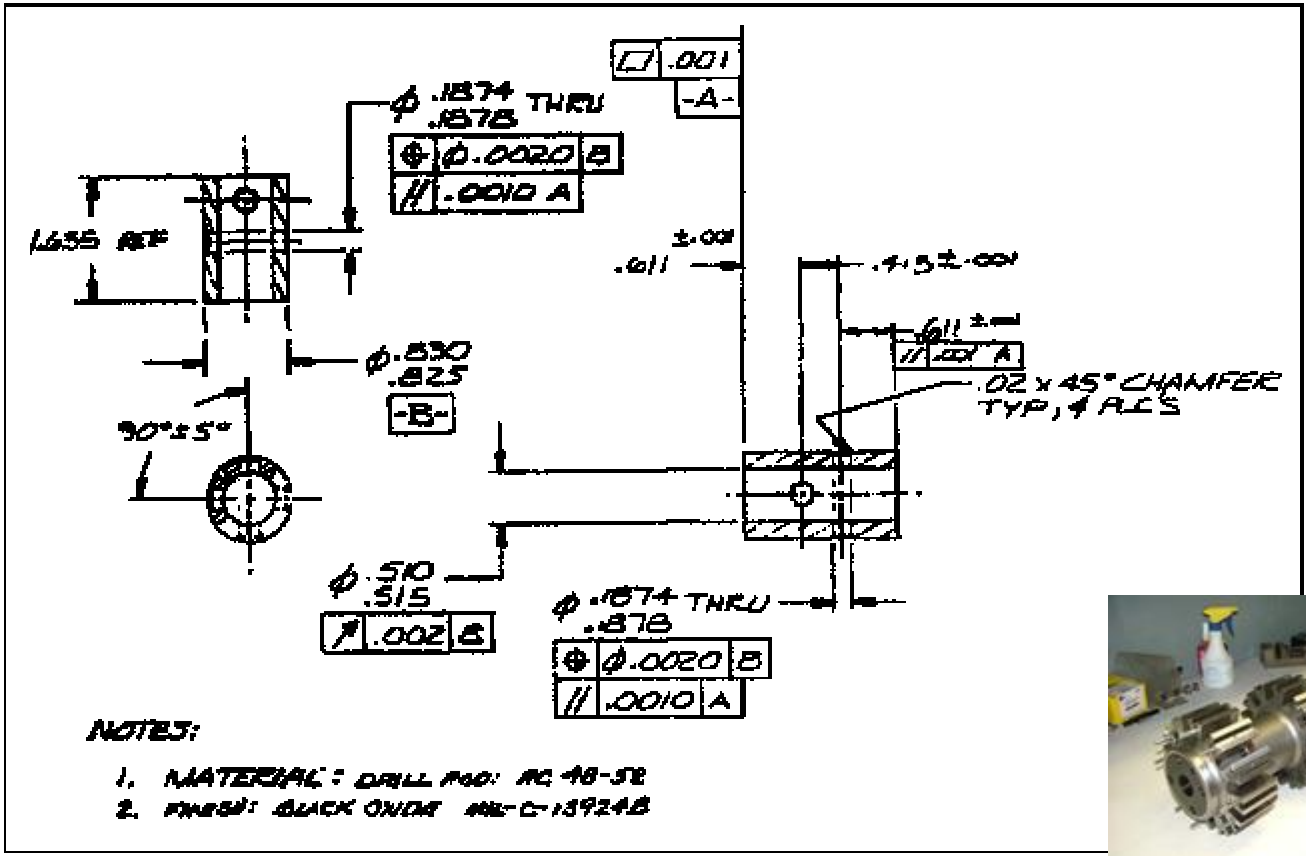


Process Plan

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
40	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
50	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
60	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
70	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

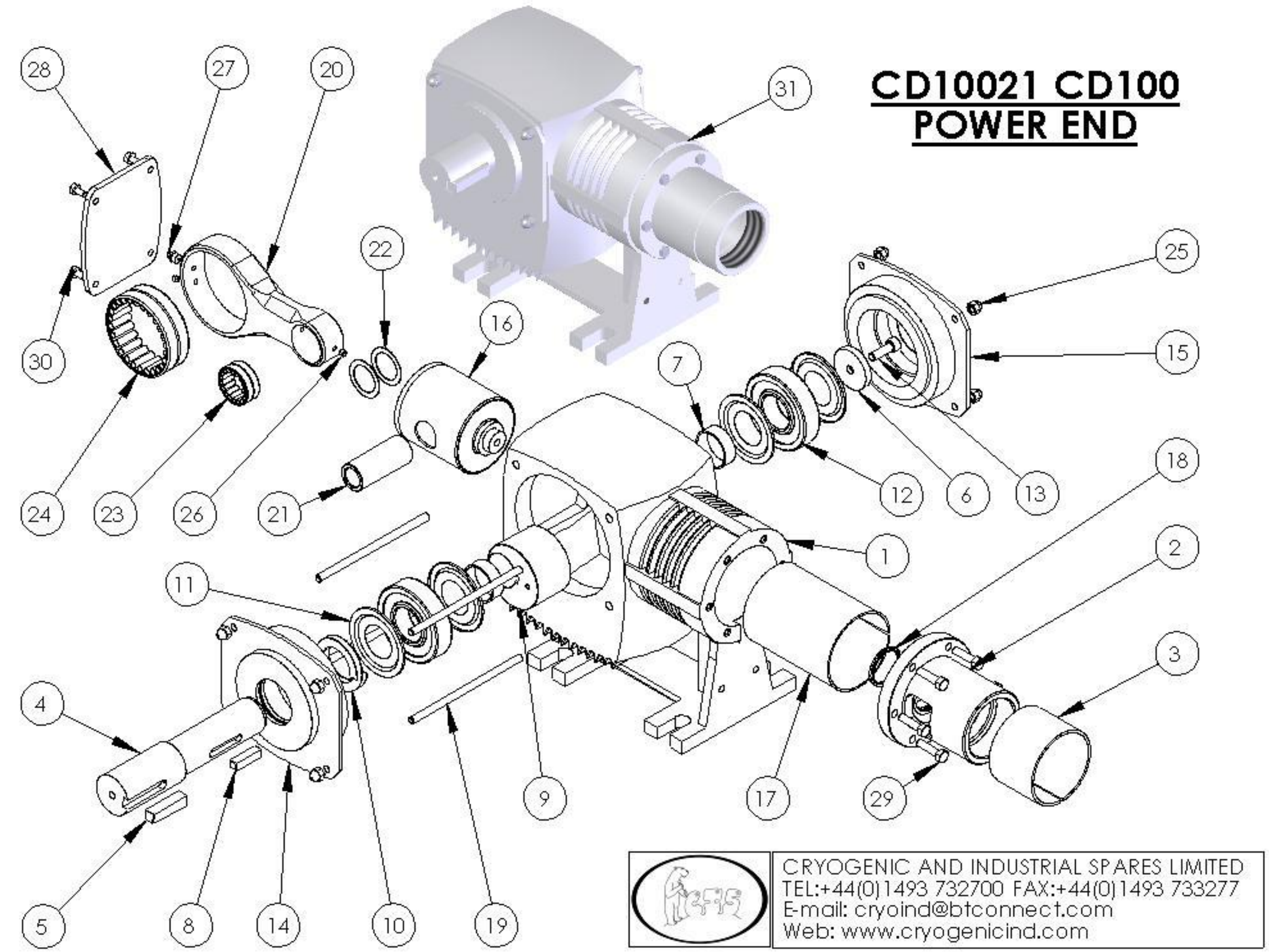


Process Plan

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

Assembly Drawing



From 2.810 report

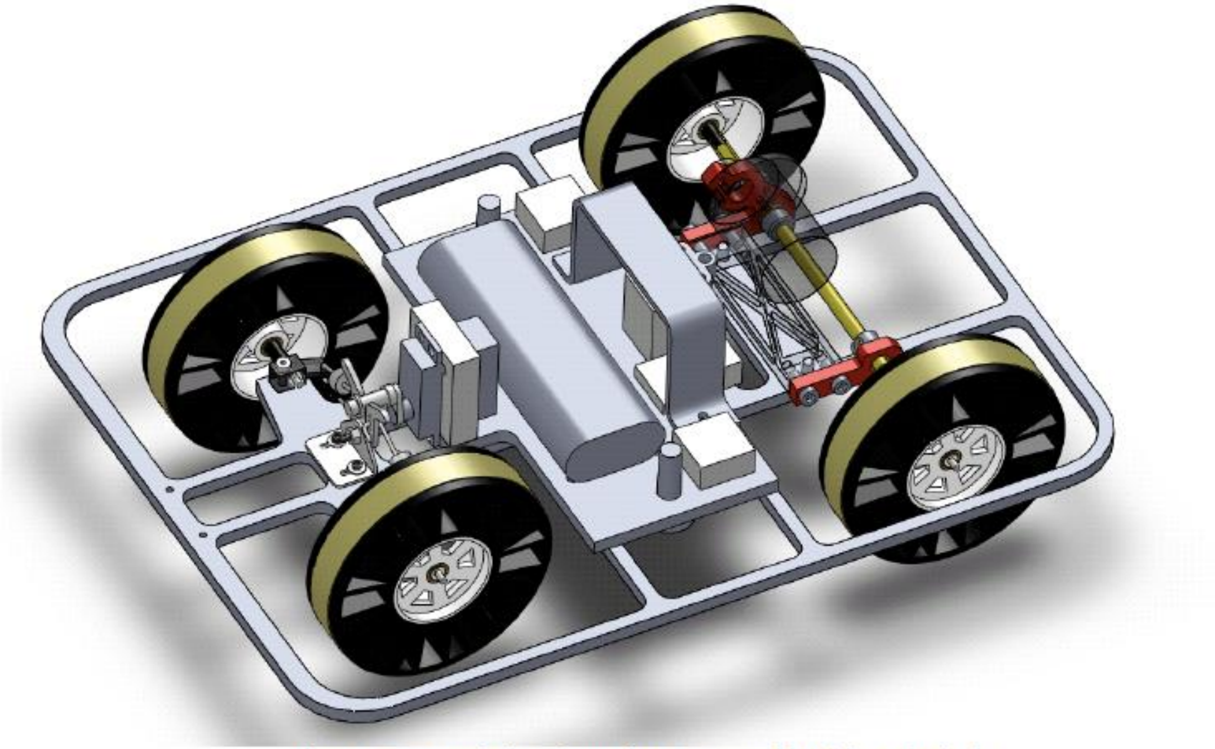
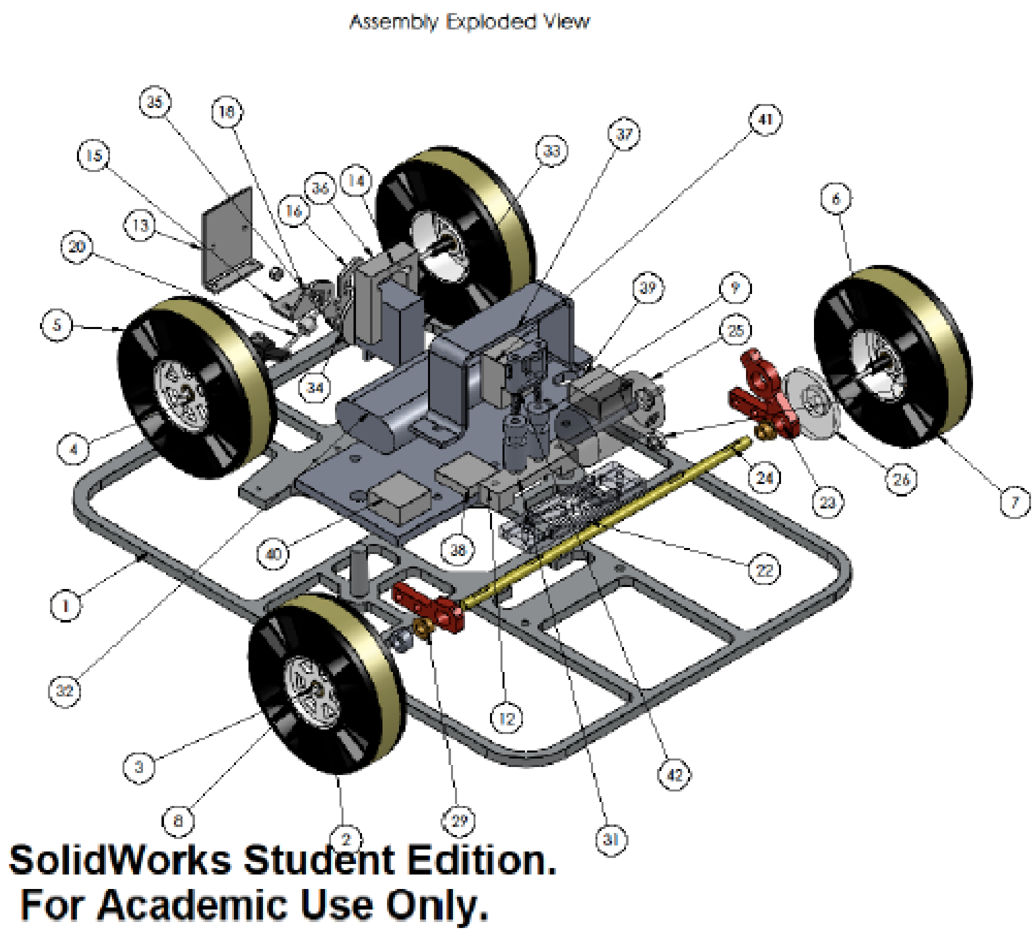


Figure 7- CAD rendering of complete car assembly without the body.

Detailed Prints

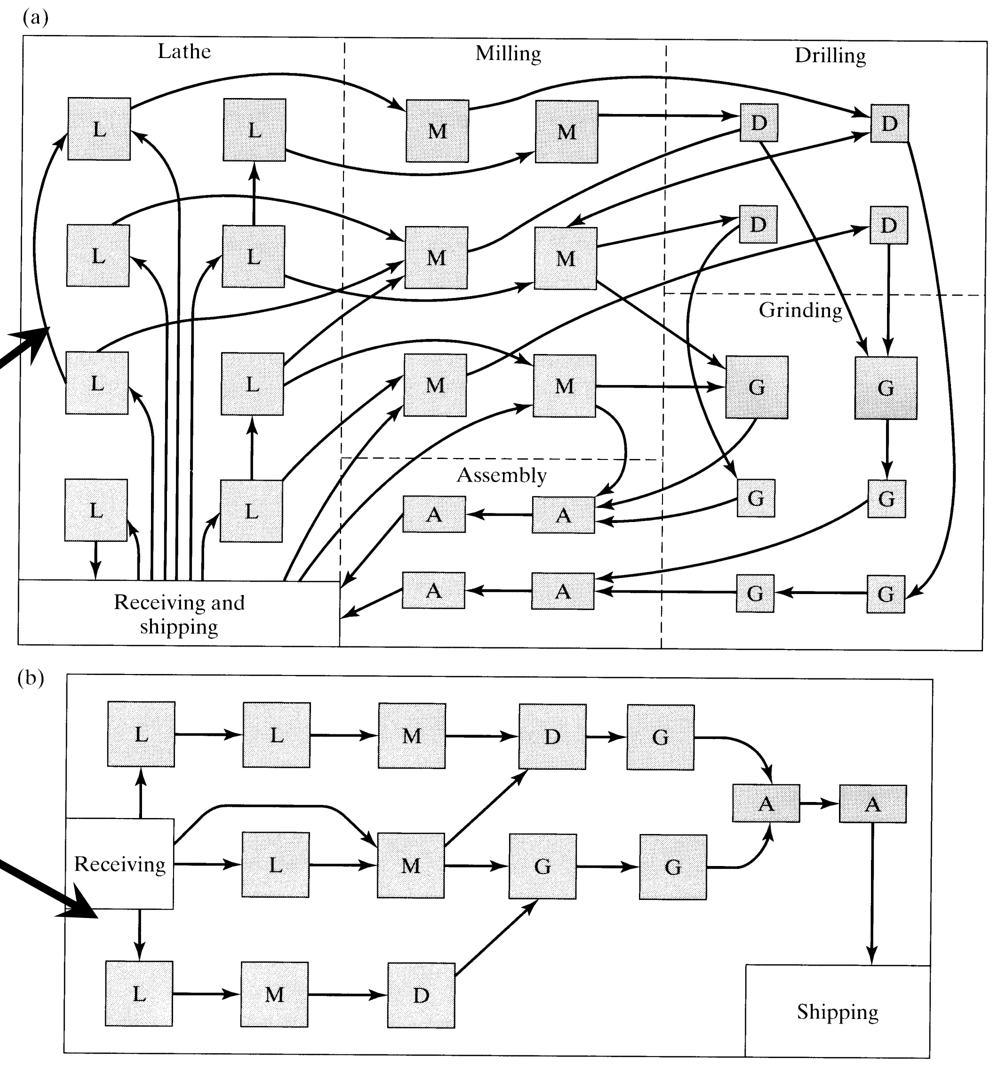
Exploded Assembly with BOM



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	BP1282091(DualBanana)	1

Figure 8- Exploded Assembly with BOM

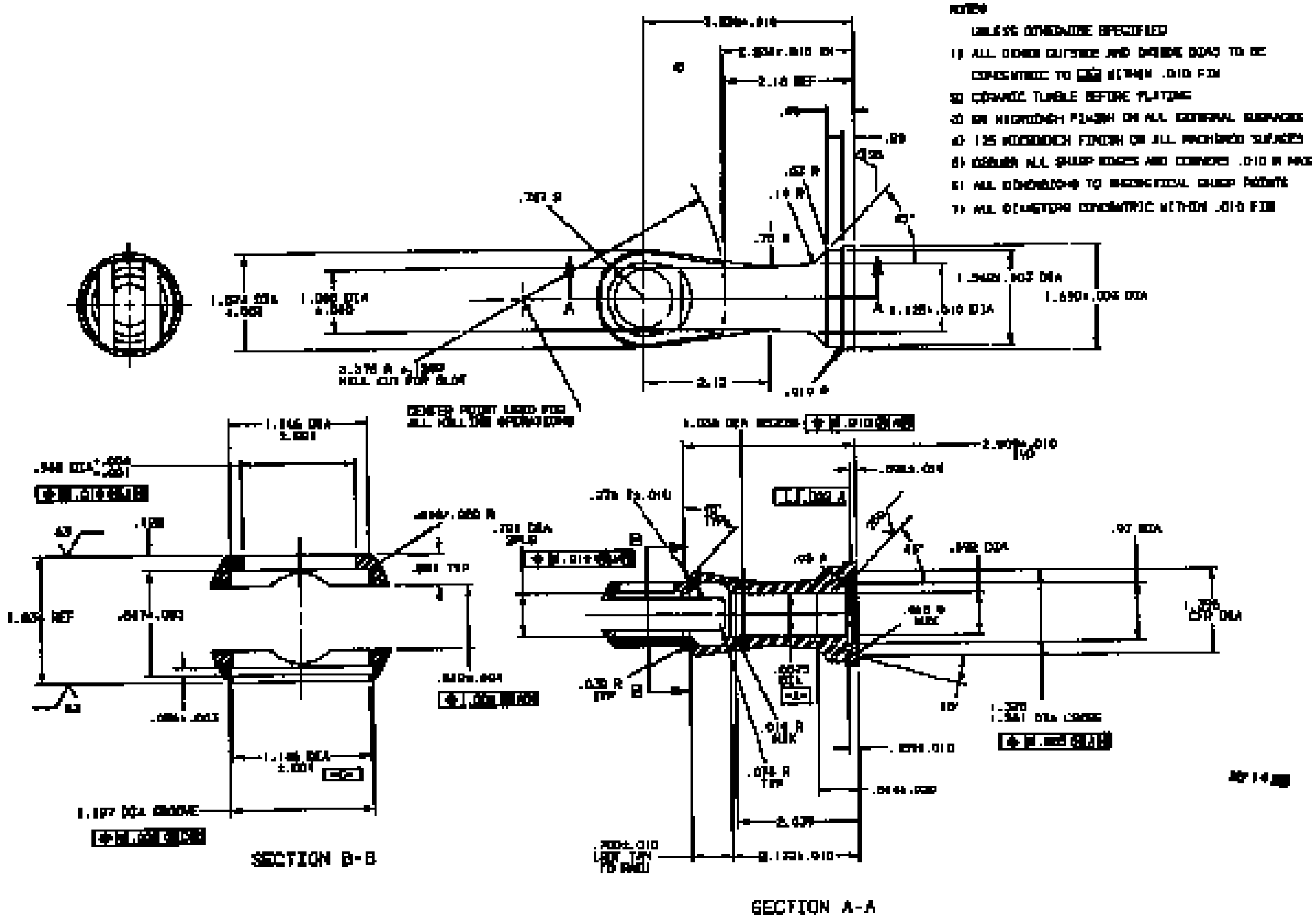
Mfg. System Designs; (a) job shop (b) flow shop



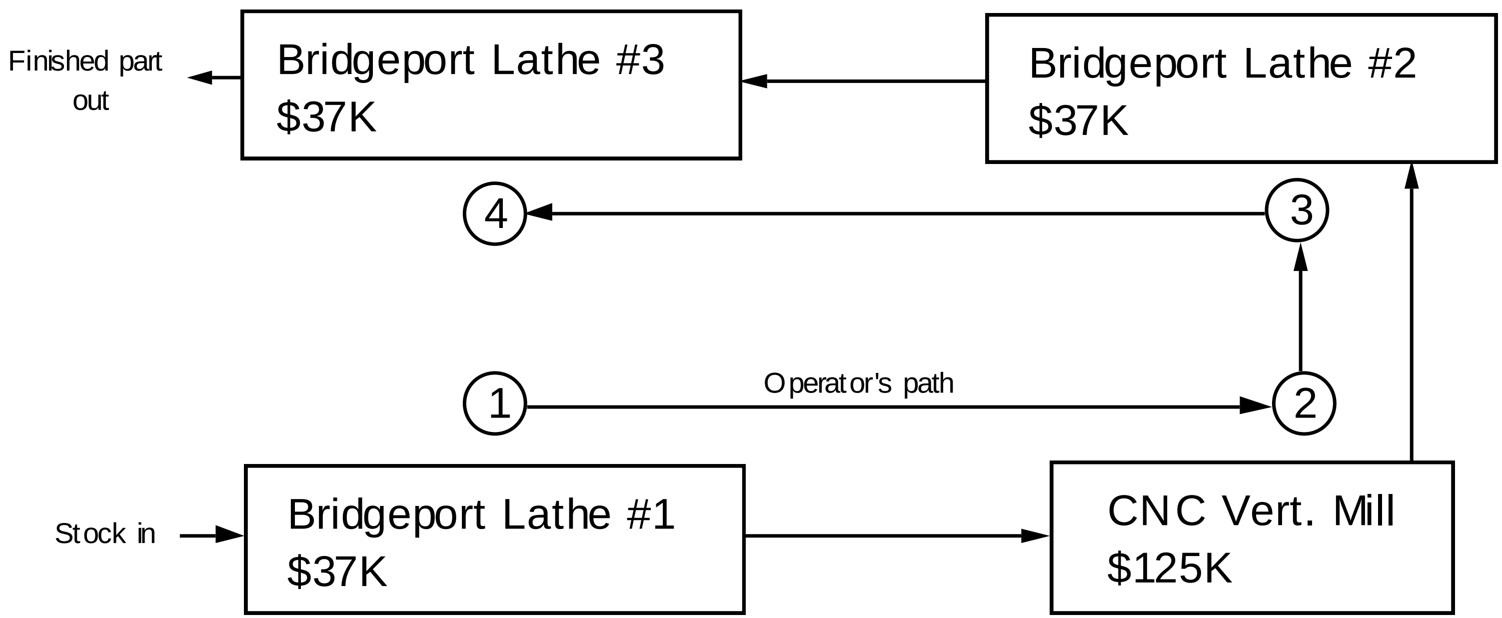
Manufacturing Systems

- job shop
- flowline
- transfer line
- “flexible” manufacturing line
- Toyota cell

Engineering Drawing; Ratchet Housing



System Design: Cell for manufacturing ratchet housing



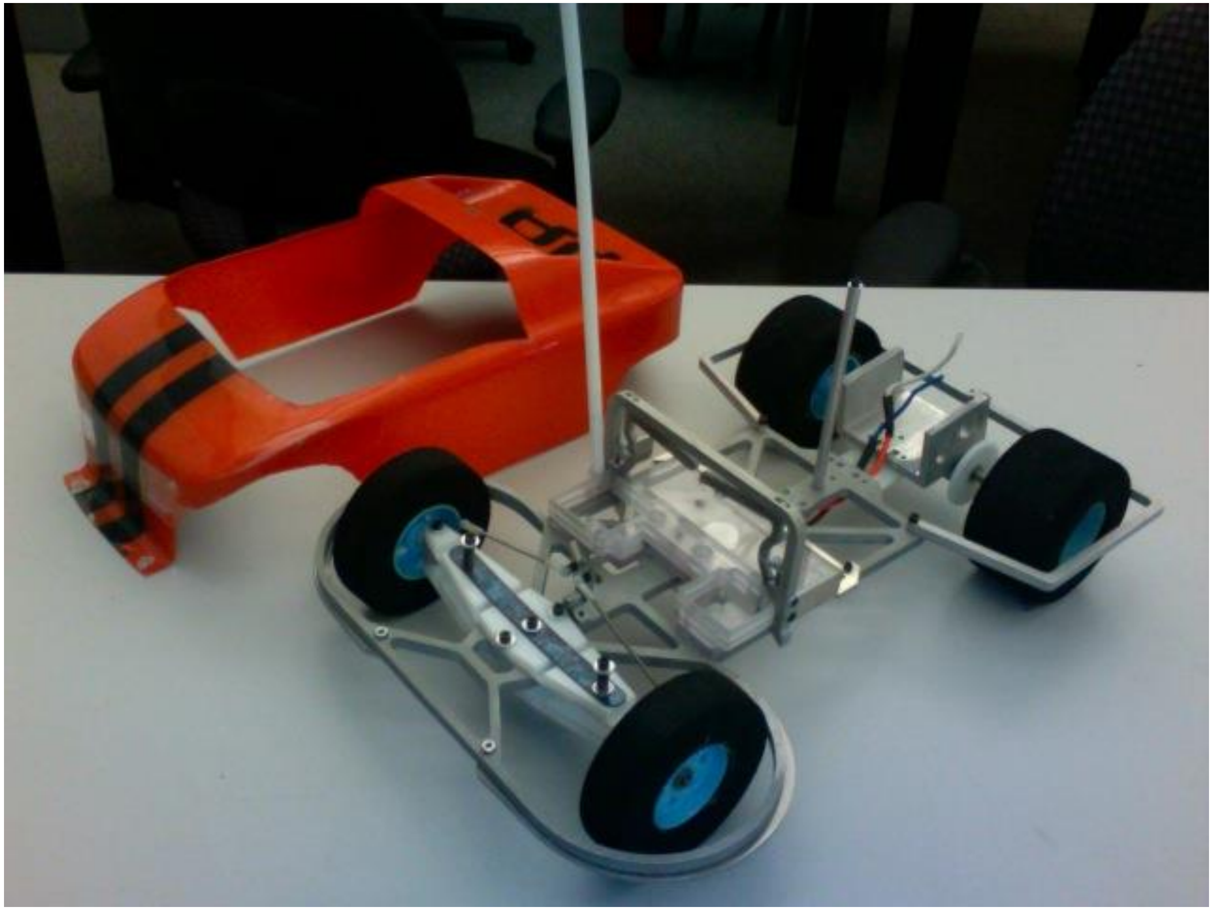
Check List

- Hand in information sheets
- 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