Reduction and Simplification of Material Flows in a Factory: The Essential Foundation for JobshopLean

What is "Flow"?

Flow is "the progressive movement of product/s through a facility from the receiving of raw material/s to the shipping of the finished product/s without stoppages at any point in time due to backflows, machine breakdowns, scrap, or ***other*** production delays"

Source: Suzaki, K. (1987). *The new manufacturing challenge: Techniques for continuous improvement*. New York, NY: Free Press.

Role of Flow at Toyota[+]

- (Page 11) "…I was manager of the machine shop at the Koromo plant. As an experiment, I arranged the various machines in the sequence of machining processes …"
- (Page 33) "…We realized that the (kanban) system would not work unless we set up a production flow that could handle the kanban system going back process by process …"
- (Page 39)"…It is undeniable that leveling becomes more difficult as diversification develops …"

[+] Ohno, T. 1988. *Toyota Production System: Beyond Large-Scale Production.* Portland, OR: Productivity, Inc. ISBN 0-915299-14-3.

Role of Flow at Toyota[+]

- (Page 54) "…Toyota's main plant provides an example of a smooth production flow accomplished by rearranging the conventional machines after a thorough study of the work sequence …"
- (Page 54) "…It is crucial for the production plant to design a layout in which worker activities harmonize with rather than impede the production flow …"
- (Page 100)"…By setting up a flow connecting not only the final assembly line but all the processes, one reduces production lead time …"

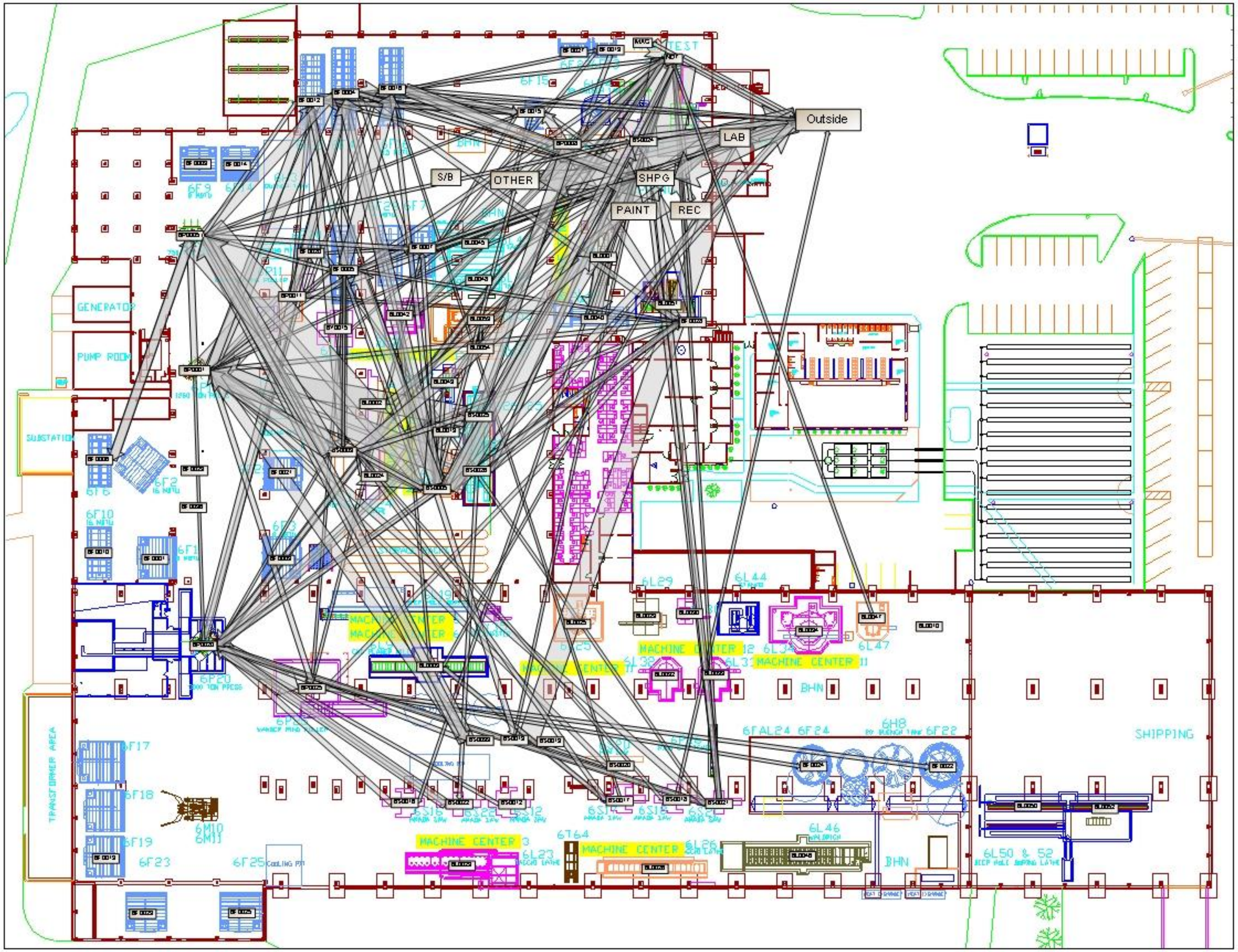
[+] Ohno, T. 1988. *Toyota Production System: Beyond Large-Scale Production.* Portland, OR: Productivity, Inc. ISBN 0-915299-14-3.

Role of Flow at Toyota+

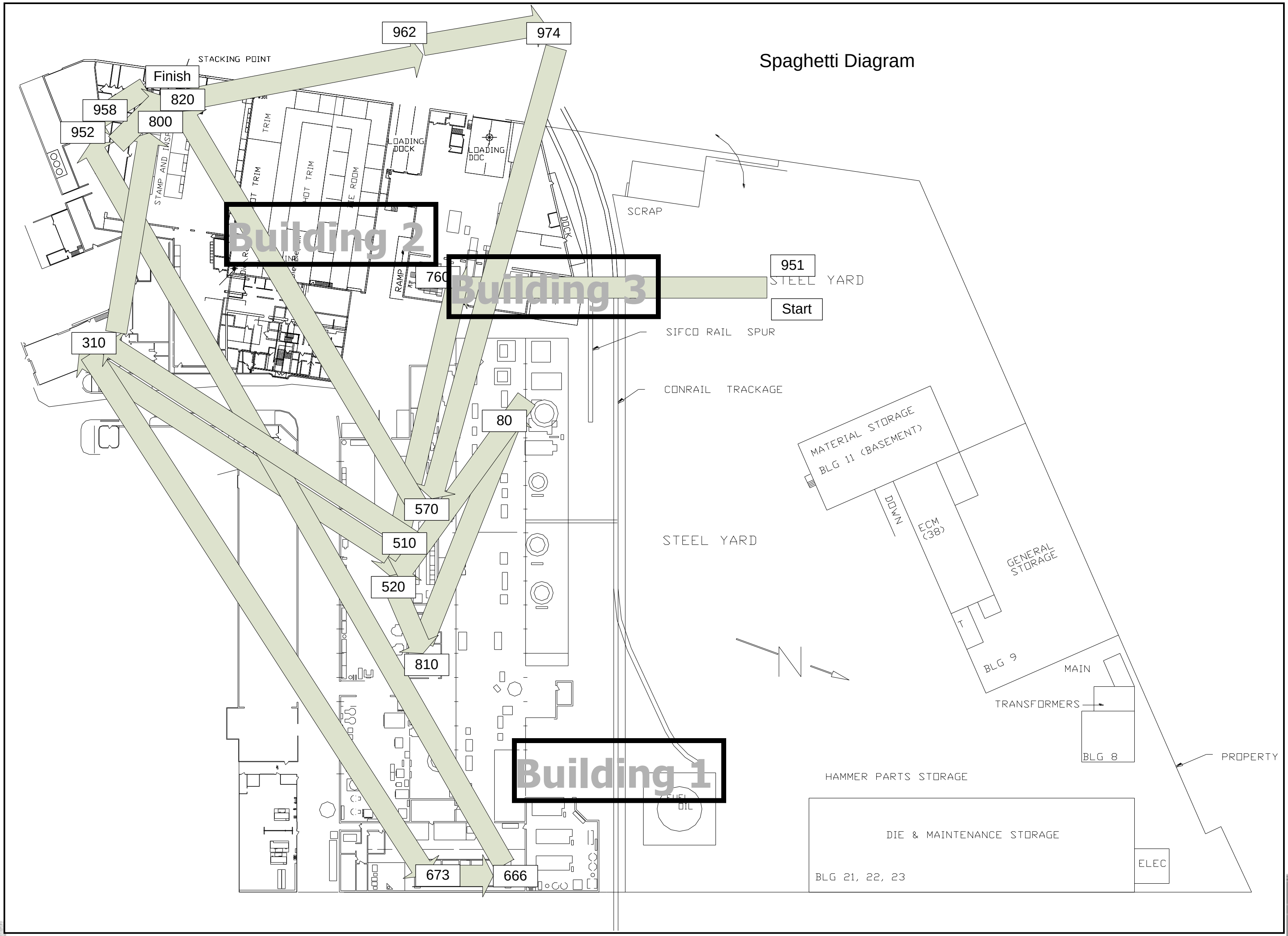
- (Page 123) "…When work flow is properly laid out, small isolated islands do not form …"
- (Page 125) "…For the worker on the production line, this means shifting from being *single-skilled* to becoming *multi-skilled* …"
- (Page 128)"…The first aspect of the TPS…means putting a flow into the manufacturing process…Now, we place a lathe, a mill and a drill in the actual sequence of the manufacturing processing …"

+ Ohno, T. 1988. *Toyota Production System: Beyond Large-Scale Production.* Portland, OR: Productivity, Inc. ISBN 0-915299-14-3.

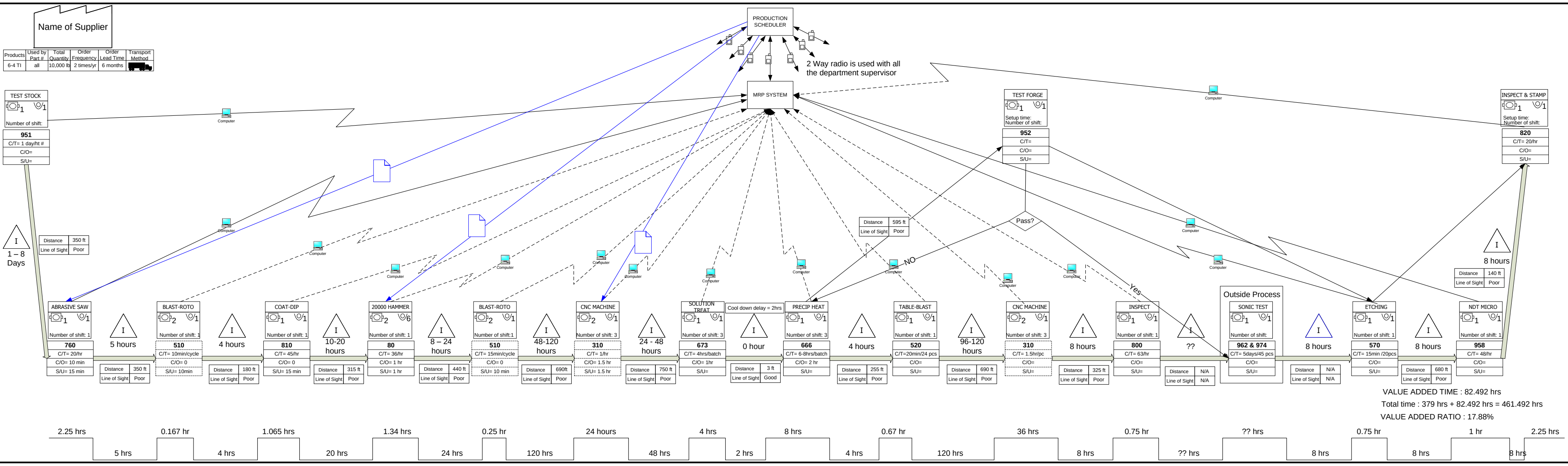
Are these ≈<u>*500*</u> Forgings "Flow"ing?



Is this *One* Forging "Flow"ing?



Value Stream Analysis for the Forging



Value Added Ratio = Value-Added Time/Flow Time

= 17.88%

Focus on Flow ***not*** Waste Elimination

Flow is “the progressive movement of product/s through a facility from the receiving of raw material/s to the shipping of the finished product/s without stoppages at any point in time due to backflows, machine breakdowns, scrap, or ***other*** production delays”

Source: Suzaki, K. (1987). *The new manufacturing challenge: Techniques for continuous improvement*. New York, NY: Free Press.

Performance Metric (KPI) for Flow

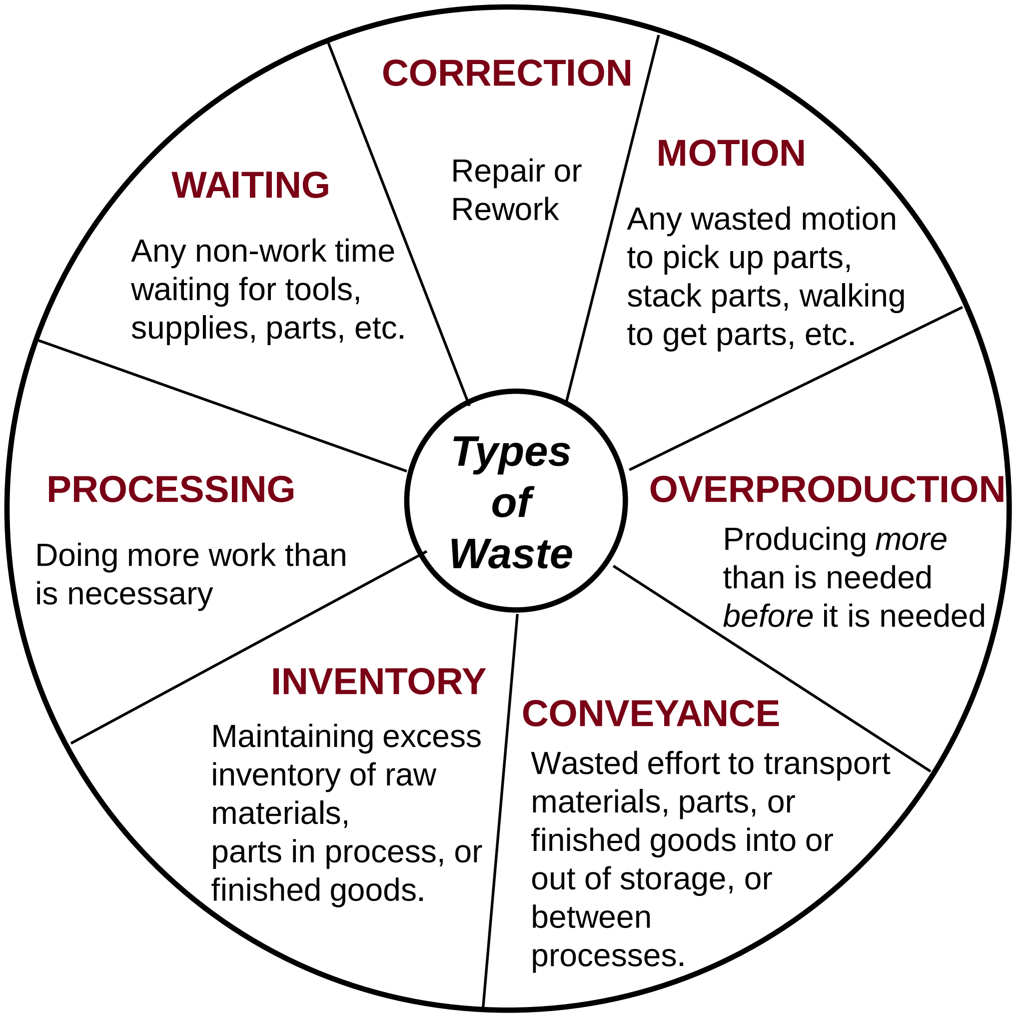
Flow Time (days) = WIP ($)/Throughput ($/day) [+]

Therefore, a common sense strategy to eliminate waste, lower costs and increase order fulfillment on a daily basis should be to:

Reduce average flow time per order

[+] Little, J.D.C. 1961. A Proof for the Queuing Formula: L=λW. *Operations Research*, 9, 383-387.

Waste ↑ NVA Delays ↑ Flow Time

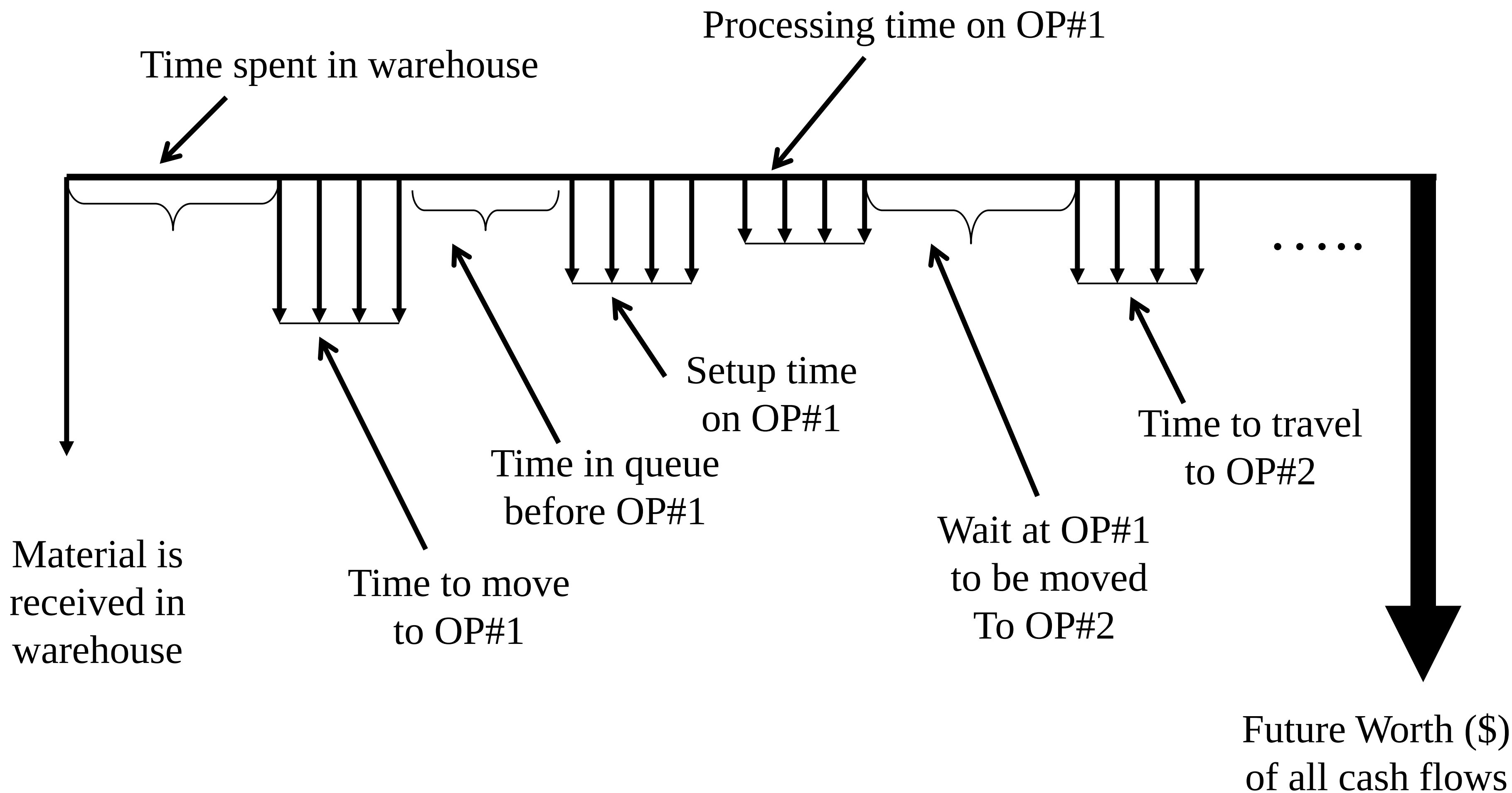


Example: Cost of Inventory[1]

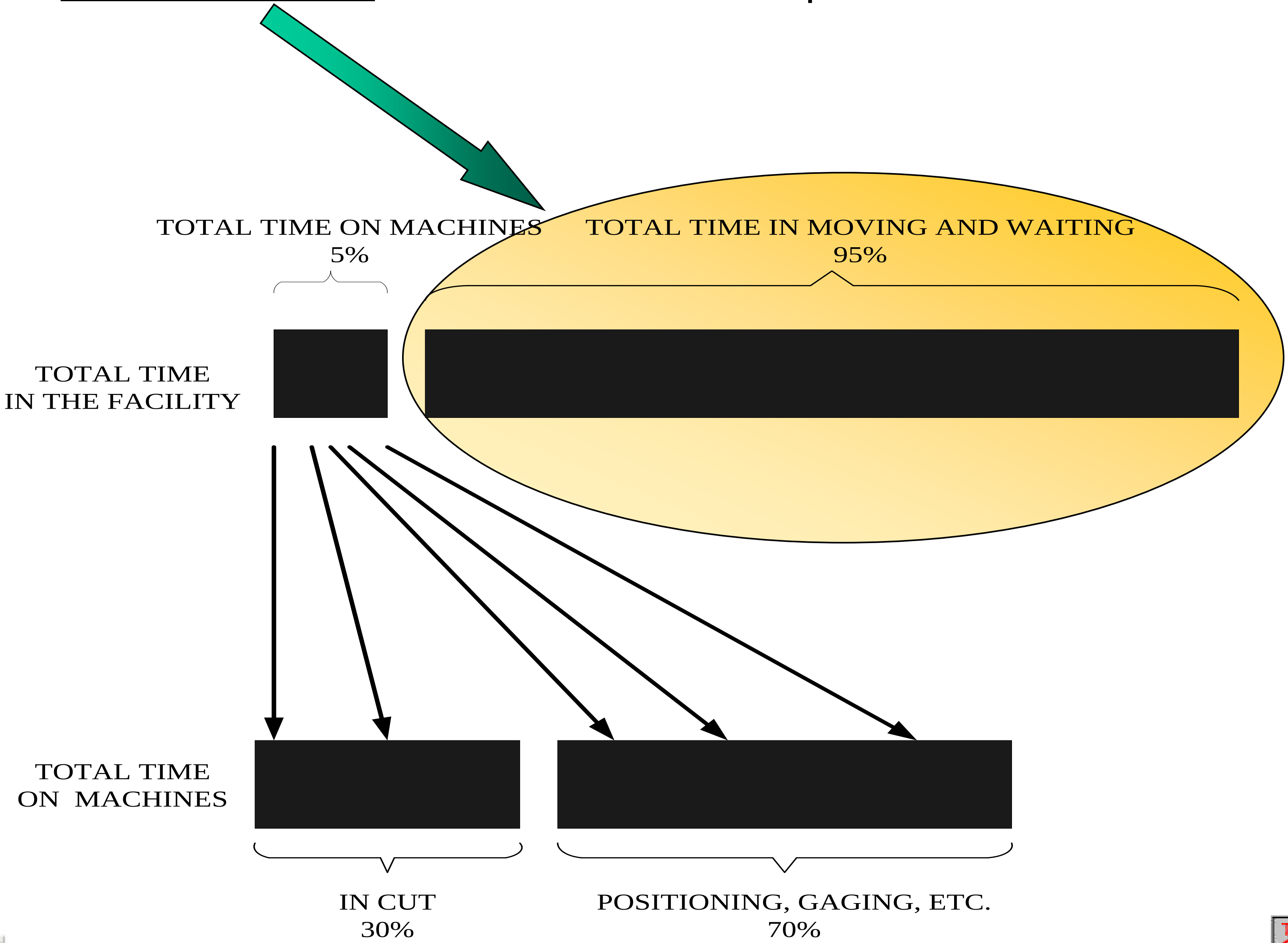
Say that the annual inventory costs of a company are $10,000,000. If we assume that work-in-process and raw materials make up 25% of this inventory, then the company has locked up $2,500,000 on its shopfloor. Next, if we assume that the inventory carrying cost is 10%, then the company is paying an additional $250,000 for warehouse space, security, electricity, etc. Hence, the penalty being paid by the company for not moving materials rapidly through its facility is $2,750,000!

[1] Courtesy of E.J. Phillips (President, The Sims Consulting Group)

How The NVA Delays Increase Part Cost



Dominant Wastes that ↑ Flow Time



Relating Facility Layout & Flow Time

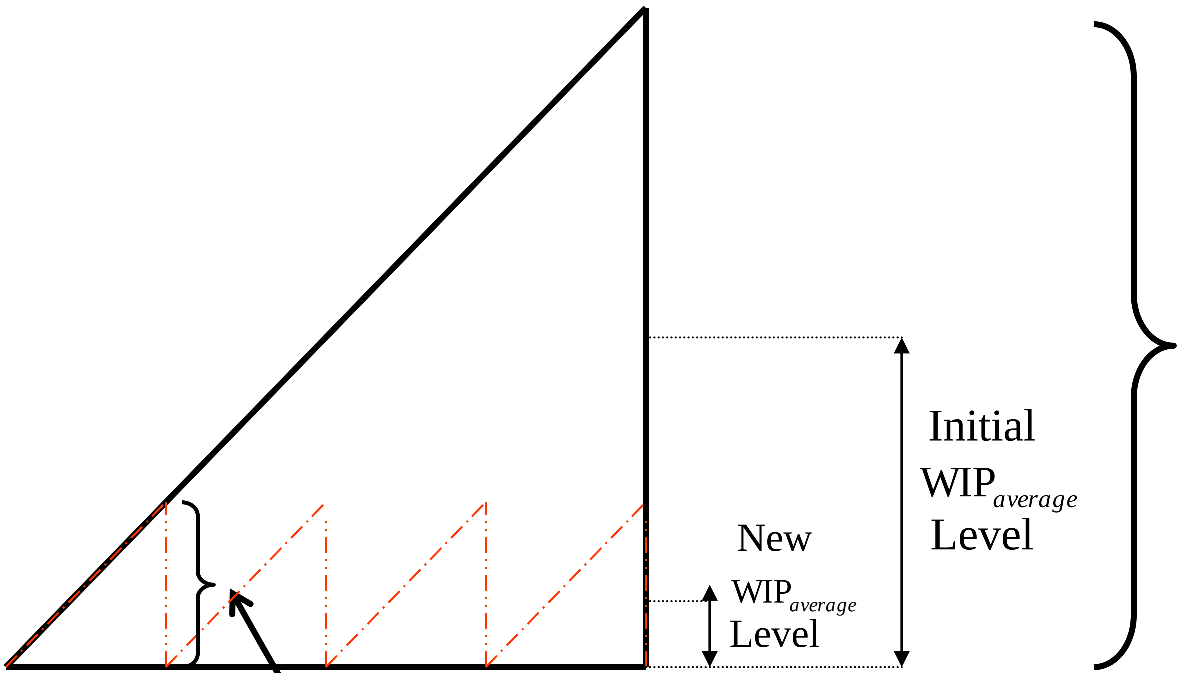
In a poorly-designed facility layout, the Average Travel Distance per Order ↑ **therefore** Transportation Waste ↑ **therefore** WIP Waste ↑ **therefore** Waiting Waste ↑ **therefore** Flow Time ↑, Throughput ↓ and Operating Cost ↑

Relating Facility Layout & WIP[2]

"If successive processes are immediately adjacent, a single unit is moved at a time, as in an assembly line. If the next process is across the aisle, the handling lot size is a unit load. If the next process is across the plant, the handling lot size is, at least, an hour's supply of product, because more frequent collection is impractical. If the next process is in another plant, the handling lot size is at least one day's production ….. (since) the WIP between processes will be, at least, one half the handling lot size, (there are) potential orders-of-magnitude differences in WIP levels based on the layout"

[2] Harmon, R.L. & Peterson, L.D. (1990). *Reinventing the Factory*. New York, NY: The Free Press.

Relating WIP & Moving Costs



Transfer Batch Quantity when travel distance between two machines is large

Transfer Batch Quantity when travel distance between two machines is reduced by a layout change

How to reduce the ***Dominant*** Wastes

Design For Flow (DFF)

Minimize Flows

- Eliminate operations
- Combine operations
- Minimize multiple flows

Maximize Directed Flow Paths

- Eliminate backtracking
- Eliminate crossflows and intersections among paths

Minimize Cost of Flows

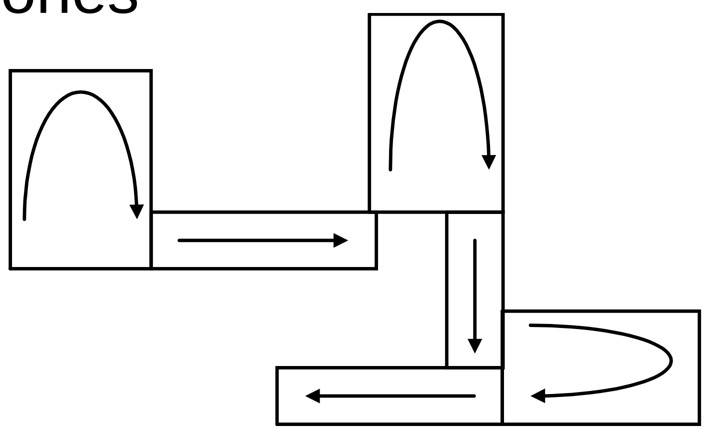
- Eliminate handling
- Minimize handling costs

- Minimize queuing delays
- Minimize Pick-Up/Drop-Off delays
- Minimize in-process storage
- Minimize transport delays

Adapted from: Tompkins, J.A., et al. (1996). *Facilities planning*. New York, NY: John Wiley.

Strategies to Minimize Flow

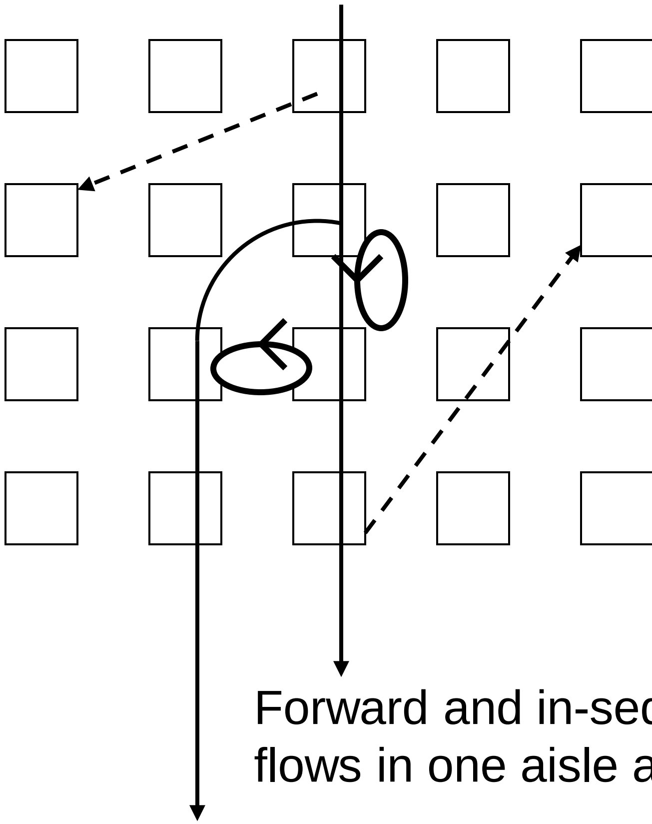
- Modify product designs to eliminate non-functional features
- Adopt new multi-function manufacturing technology to replace conventional machines
- Deliver materials to points of use which will minimize warehouse storage space
- Modularize the facility into flowlines, cells and focused factories



Strategies to Minimize Flow

- Process parts or subassemblies in parallel
- Combine several transfer batches into unit loads
- Select process plans with minimum number of operations
- Eliminate “outlier” routings by rationalization of the product mix
- Prevent proliferation of new routings - Use variant process planning to generate new routings

Types of Directed Flow Paths



Cross flows across a single aisle are okay

Backtrack flows to an immediately previous machine are okay

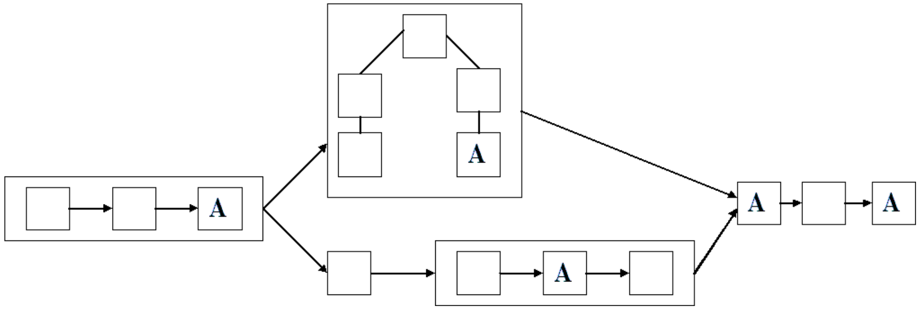
Cross flows across multiple aisles are NOT okay

Forward and in-sequence flows in one aisle are best

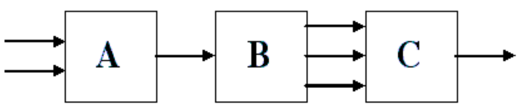
Forward flows between parallel and adjacent lines of machines separated by a single aisle are okay

How to Maximize Directed Flow Paths

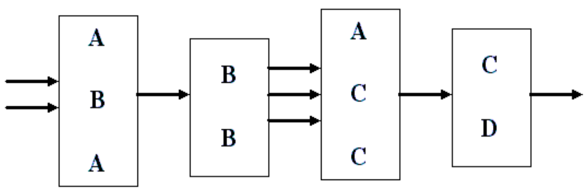
- Duplicate machines of the same type at multiple locations



- Use hybrid flowshop layouts

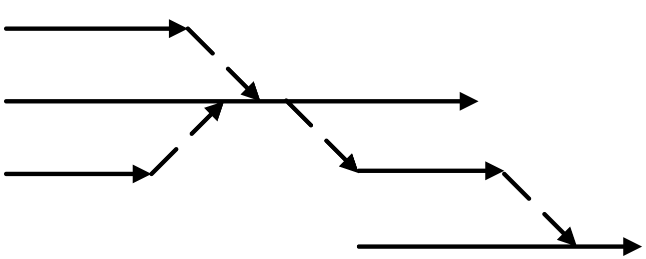


Flowshop



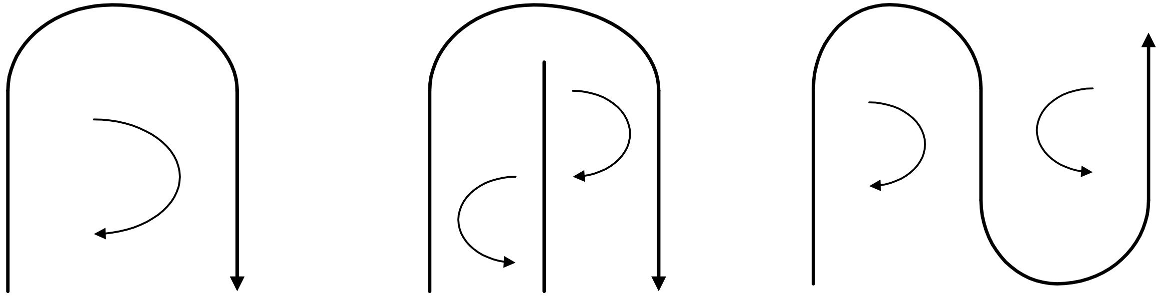
Hybrid Flowshop

- Cascade flowlines in parallel



How to Maximize Directed Flow Paths

- Bend flowlines into U,W or S shapes



- Develop the layout based on the complete assembly operations process (flow) chart

How to Minimize Cost of Flows

- Design all material flow paths using ↑, L, U, S or Z (linear) contours
- Design layouts to minimize travel distances for heavy/large unit loads
- Utilize relevant principles of material handling
  - Unit load
  - Utilization of cubic space
  - Standardization of equipment and methods
  - Mechanization of processes (if possible, automation of processes)
  - Flexibility of equipment and methods
  - Simplification of methods and equipment
  - Integration of material, people and information flows
  - Computerization of material, people and information flows
  - Utilize gravity to move materials

How to Minimize Cost of Flows

- Minimize all buffer/storage spaces at machines
- Balance consecutive operations - Use buffers (safety stock) strategically
- Maximize use of small transfer batches - Use “roving” forklifts to serve “zones” on the shopfloor on a First Come First Served (FCFS) basis
- Release materials in controlled quantities - Rely on kanbans (visual scheduling), production rate of bottleneck machines only, firm orders not production forecasts, etc.

Guidelines for Design For Flow

1. Optimum material flow
2. Continuous flow from receiving to shipping
3. Straight-line flow (as practicable)
4. Minimum flow between related activities
5. Proper consideration of process vs. product vs. group vs. alternative layouts
6. Minimum material handling distances between operations and activities
7. Heavy material to move least distance
8. Optimum flow of personnel –
   a. Number of persons
   b. Frequency of travel
   c. Space required
9. Minimum backtracking
10. Line production (as practicable)
11. Operations combined to eliminate or minimize handling between them
12. Minimum re-handling of materials
13. Processing combined with handling
14. Minimum of material in work area
15. Material delivered to point of use
16. Material disposed by one operator in convenient location for next operator to pick up
17. Minimum walking distances between operators
18. Compatible with building (present or proposed)
    a. Configuration (shape)
    b. Restrictions (strength, dimensions, column location and spacing, etc.)
19. Potential aisles
    a. Straight
    b. From receiving towards shipping
    c. Minimum number
    d. Optimum width
20. Related activities in proper proximity to each other

Source: Apple, J. M. (1977). *Plant layout and material handling*. New York, NY: John Wiley.

Guidelines for Design For Flow

21. Provisions for expected
    a. In-process material storage
    b. Scrap storage and transport
22. Flexibility in regard to
    a. Increased or decreased production
    b. New products
    c. New processes
    d. Added departments
23. Amenable to expansion in pre-planned directions
24. Proper relationship to site
    a. Orientation
    b. Topography
    c. Expansion (plant, parking, auxiliary structures, etc.)
25. Receiving and shipping in proper relation to
    a. Internal flow
    b. External transportation facilities (existing and proposed)
26. Activities with specific location requirements situated in proper spots
    a. Production operations
    b. Production services
    c. Personnel services
    d. Administration services
27. Supervisory requirements given proper consideration
    a. Size of departments
    b. Shape
    c. Location
28. Production control goals easily attainable
29. Quality control goals easily attainable
30. Consideration given to multi-floor possibilities (existing and proposed)
31. No apparent violations of health or safety requirements

Source: Apple, J. M. (1977). *Plant layout and material handling*. New York, NY: John Wiley.

Strategies from DFMA Practices

- "Inside-Out": In high mix environments, keep standard modules and components on the inside and "bolt on" the special features and options on the outside; *keep the product variation as far to the end of the line as possible*
- "Monument Avoidance": Avoid component designs that require a new and unique process that has to serve multiple product lines
- "Batch Early": If processes that necessitate batching (plating, painting, heat treat, ovens, drying/aging) are absolutely necessary, try to design products where these "batch" processes can be used as early as possible (Nothing is worse than requiring an oven/drying cycle in the middle of the Final Assembly Process)
- "Standardize Modules,not necessarily Products": Offering a broad product mix is a competitive advantage, so reducing product SKU's may not be a good idea. However, reducing module and component SKU's should be a core strategy

– Courtesy of Ray Keefe, VP-Manufacturing, Emerson Electric Co.

Strategies from DFMA Practices

- “Don’t Hide Quality Risks”: Design the product so that the potential quality risks remain “hidden” during the sub-assembly and assembly process until they are visually checked ex. a design that needs to “trap” a ball and spring with a cover before the ball and spring are checked for accurate orientation is not good
- “Design for Poke-Yoke”: Not only avoid symmetry but design parts and assemblies with Poke-Yoke in mind
- “Challenge every tolerance”: Nothing is worse than holding tolerances that are not necessary - Tolerances should be analyzed and accepted based on conventional standards
- “Touch 100 times”: Think material handling and orientation while designing. If the product is heavy, are there quick and secure grab points? Can one orientation be used through all processes? Do we need to have special carriers? Remember, the product is designed ONCE, but each unit produced might be touched a 100 times!

– Courtesy of Ray Keefe, VP-Manufacturing, Emerson Electric Co.

Production Flow Analysis

What is Production Flow Analysis?

Production Flow Analysis (PFA) is a technique for machine grouping, part family formation, cell layout and overall factory layout that was developed by J. L. Burbidge. When used for factory design, PFA consists of four stages, each stage progressively achieving ***Flow*** in a smaller portion of the factory.

Stages in PFA Methodology

Factory Flow Analysis (FFA): Develops a unidirectional flow system joining the various departments in a factory; each department completes all the parts it makes.

Group Analysis (GA): Studies the flows in each of the shops identified by FFA; the operation sequences of parts are analyzed to design manufacturing cells.

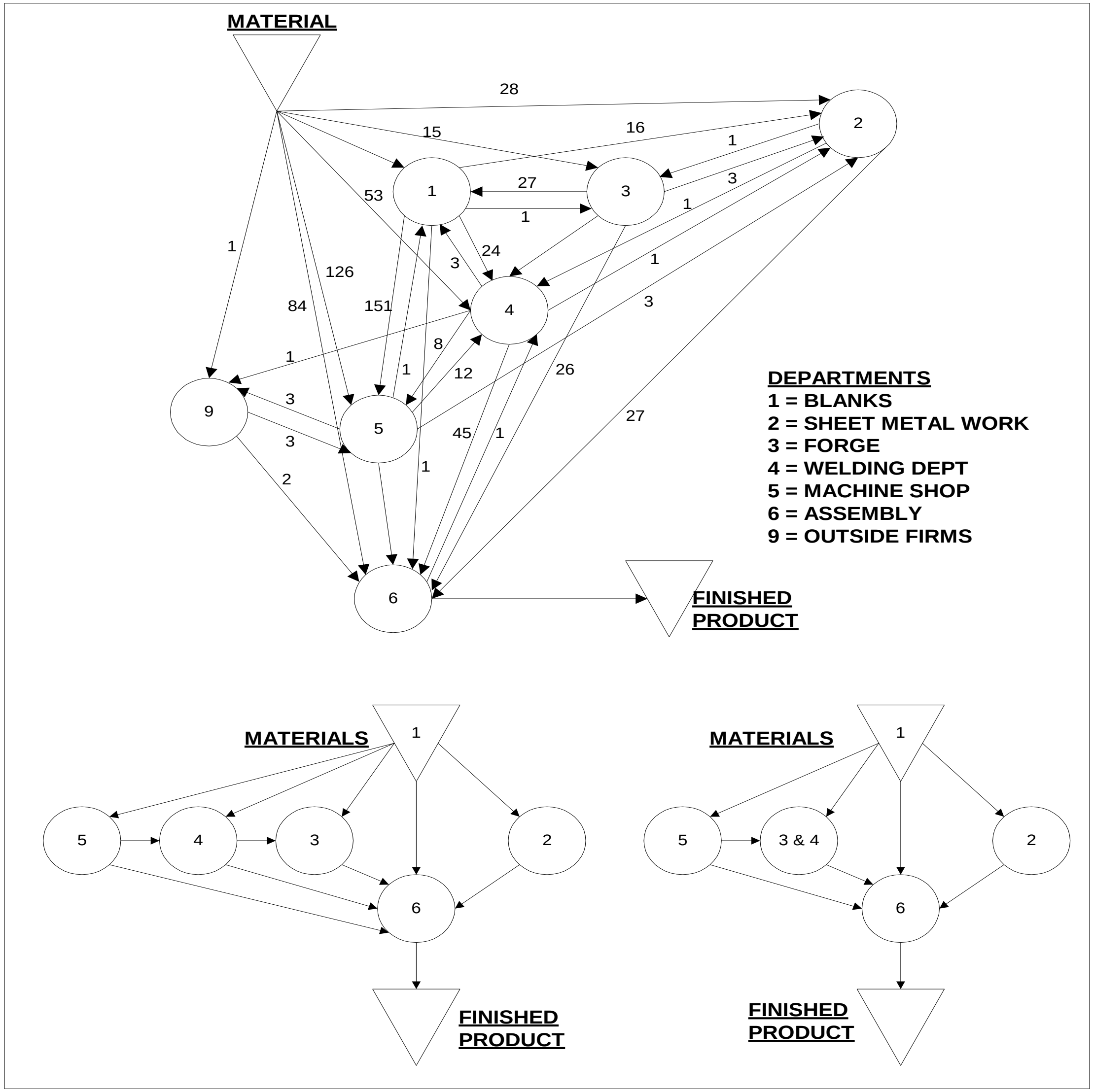
Line Analysis (LA): Analyzes the flows corresponding to the operation frequencies and sequences of parts in each of the cells formed by GA; develops a cell configuration that ensures efficient transport inside the cell.

Tooling Analysis (TA): Studies the bottleneck machine in a cell in order to find “tooling families” of parts; families of parts are sequenced consecutively on the machine to minimize lost capacity due to setup changes.

Additional Stage

Shop Layout Analysis (SLA): Develops a shop layout that will minimize intercell flow delays when multiple interdependent cells share “monuments” and common expensive resources.

Factory Flow Analysis



Shop Flow Analysis

Before PFAST Analysis

MACHINE/WORKSTATION	K48251A	L48388	L48267B	M44276E	M47693F	L48388M	M48195C	M44276D	E41795	E48596	E34267	E12204	E12288	K47697	E47782	E48586	K34596	E33494	M48265D	K44276C	M45691D	M45691B	M48386H	K34098A	E7392	E46364	E33295	K45199	K43590	M61592	E18694
DMT(3)		X									X			X	X	X								X		X		X	X		X
DM(3)			X	X				X				X		X			X	X	X					X			X	X	X	X	
PG			X			X											X	X	X	X											
DXY(3)	X	X	X														X							X				X	X	X	
P&GR					X																										
PGR													X													X					
PGH																															
PGG																					X	X					X				
P&G							X	X	X	X	X	X											X	X			X	X	X	X	X
RP																									X						
PGB				X										X	X						X	X					X				
W&P	X						X																	X				X	X		
WG3												X																			

COMPONENT - MACHINE CHART. INITIAL RECORD. FORGE.

After PFAST Analysis

PART/PRODUCT

MACHINE/WORKSTATION	L48267B	K34596	M48265D	E33494	K44276C	L48388M	E7392	K34098A	K45199	K43590	M61592	M48195C	M44276D	E34267	E12204	E18694	E41795	E48596	M48386H	K48251A	L48388	M45691D	M45691B	M44276E	K47697	E47782	E46364	E12288	E33295	E48586	M47693F
PG	X	X	X	X	X	X																									
DM 3/1	X	X	X	X																											
DXY 3/1	X	X																													
RP							X																								
P&G								X	X	X	X	X	X	X	X	X	X	X	X										X		
DMT 3/2								X	X	X				X		X					X										
DM 3/2								X	X	X	X		X		X																
DXY 3/2								X	X	X	X									X	X										
W&P								X	X	X		X								X											
WG3															X																
PGG																						X	X						X		
PGB																						X	X	X	X	X			X		
PGR																											X	X			
DMT 3/3																									X	X	X			X	
DM 3/3																								X	X				X		
P&GR																															X

GROUP 1 — FAMILY - 1

GROUP 2 — FAMILY - 2

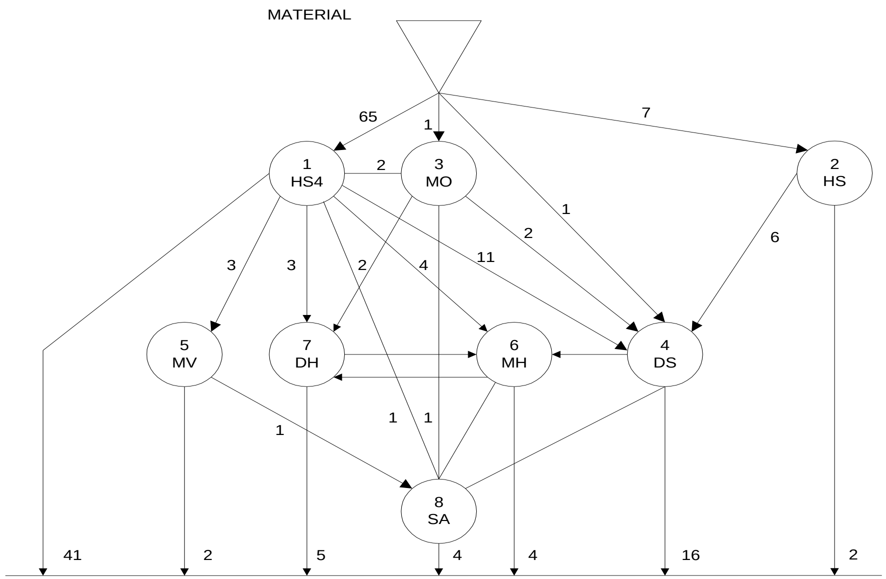
FAMILY -3

ONE "EXCEPTION" X

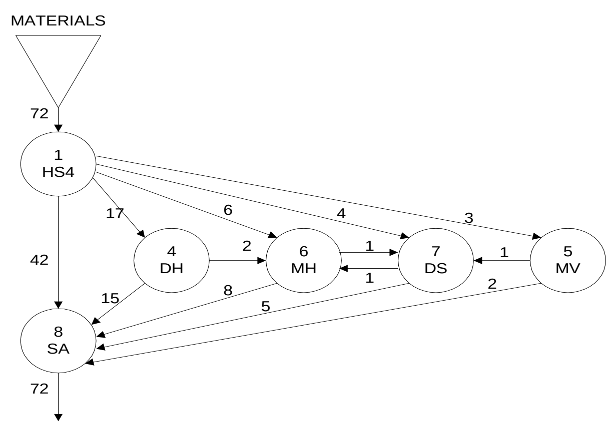
COMPONENT - MACHINE CHART. AFTER FINDING FAMILIES AND GROUPS

Potential Cells in this Machine Shop

Cell Flow Analysis

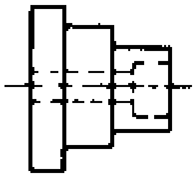


GROUP FLOW NETWORK DIAGRAM - GROUP 2



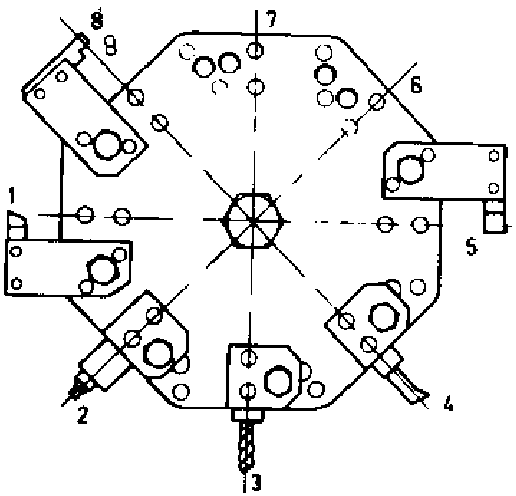
SIMPLIFIED GROUP FLOW NETWORK - GROUP 2

Tool Flow Analysis – Type I



Turret Pos.	Tool Description
1	Face and Rgt. Turn (use as stop)
2	Center
3	Drill
4	Boring
5	Finish Turn
6	Free
7	Free
8	Part Off

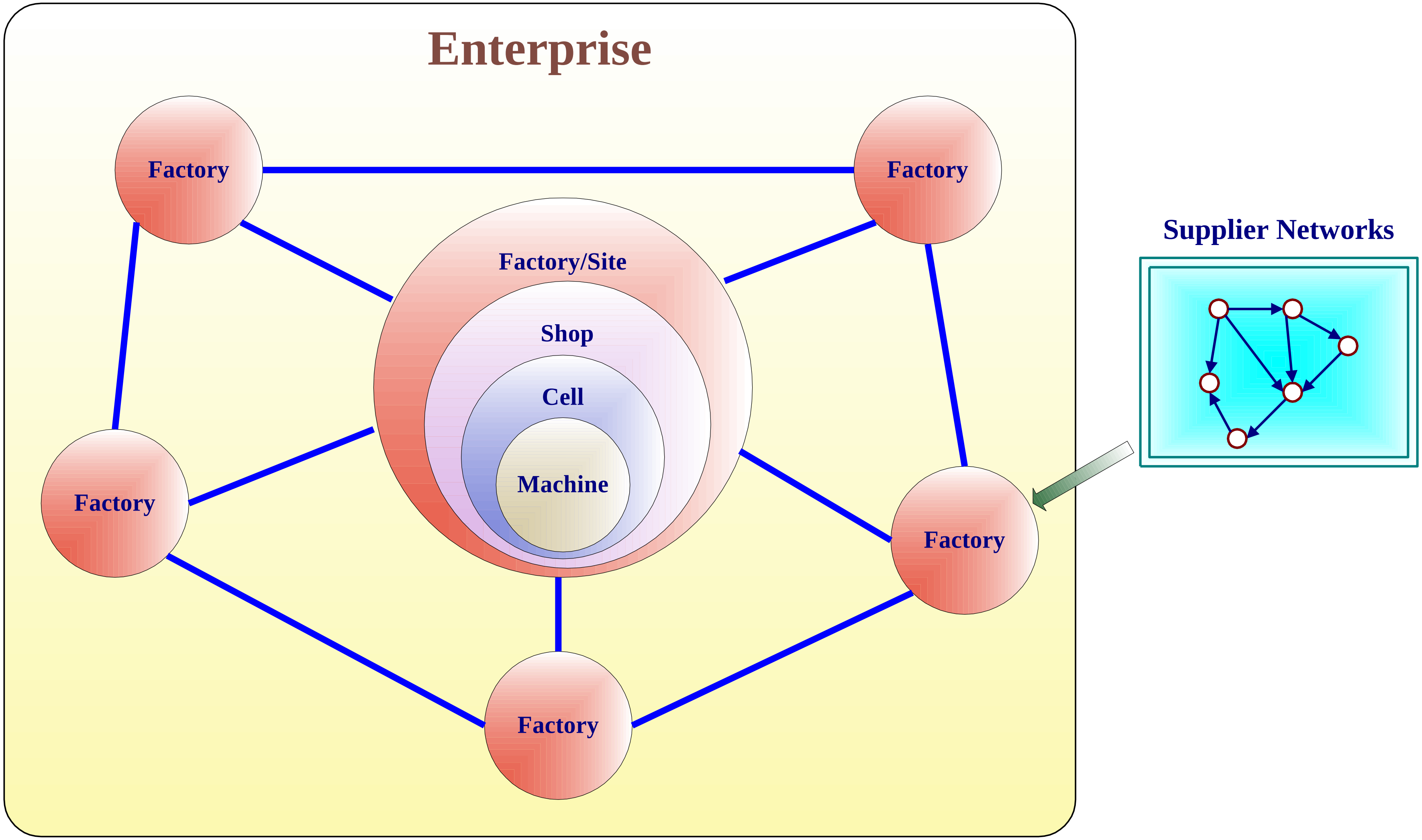
Notes – Additional tools should be placed in a free position where possible thus preserving the basic settings



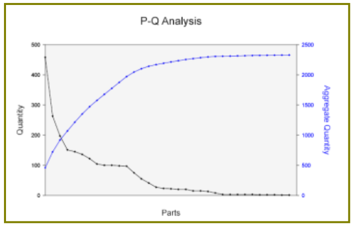
Tool Flow Analysis – Type II

	Digit 1	Digit 2			Digit 3	Digit 4	Digit 5	Digit 6	Digit 7	Digit 8	
	Method of holding	Dimension				Matching with			Material	Surface accuracy	
		3 Jaw chuck									
		Bore dia. ϕ	Over all	D_w	L	Special attachments	Boring tool carrier	Quadruple single point tool holder			
0	3 Jaw chuck outer			< 40	$L/D_w<0.1$	w/o	w/o	w/o	GG-formed	rough turned ∇	0
1	3 Jaw chuck inner	42 ϕ	160	41…… 100	$L/D_w<0.5$	Axial copying	Boring, counter-sinking, reaming, tapping.	Uniform cutting, w/o accuracy.	ST-formed	fine turned $\nabla\nabla$	1
2	4 Jaw chuck	60 ϕ	250	101… 200	L/D_w up to limit of chuck	Face copying	Only outer turning.	Uniform cut, or staggered cut, with accuracy, simple boring up to 48 ϕ.	NE-formed	outer fit	2
3	Spring collet	80 ϕ	315	301… 400	Shafts<500	2 Axis copying	1 with 2	Outer shaping, chamfering, inserting with form tool, not copying.	GG-cut off	inner fit (+ outer)	3
4	Mandrel or arbor	80 ϕ	400	401… 500	Shafts 500…1000	Conical Surface tapering$\pm 12°$	Shaping, etc. with form tool; with 3; not copying.	3 with 4	ST-cut off	positional accuracy	4
5	Jig or fixture	125 ϕ	500	501… 1000	Shafts 1m…2m	Steep cone	Inner shaping inserting chamfering; with 3; copying.	Shaping, inserting chamfering with form tool; copying.	NE-cut off	polishing	5
6	Between centers			> 1000	Shafts 2m…5m	Short thread milling	Inner & outer at the same time	5 with 2 & 1 or 3	GG-bar	knurling, etc.	6
7	Chuck-center				Shafts > 5m	Threading with lead screw		6 with back tool holder	ST-bar		7
8	Steadies					Thread with copying			NE-bar		8
9	Eccentric (face plate)					Unround copying		Automatic cycle with 4th & 5th digits	non-metal		9

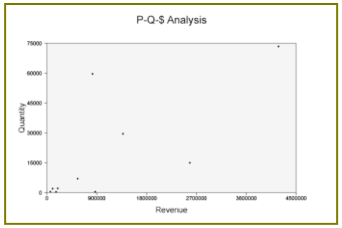
Role of PFA in the Lean Enterprise



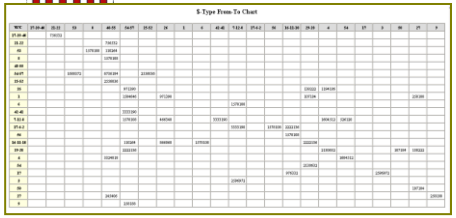
Production Flow Analysis and Simplification Toolkit



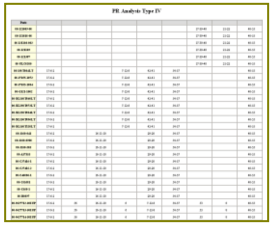
P-Q Analysis



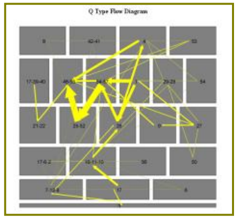
P-Q-$ Analysis



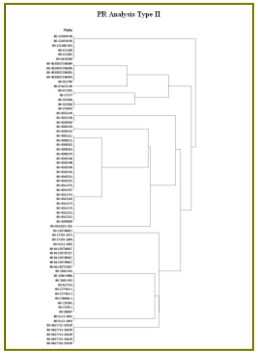
From-To Chart



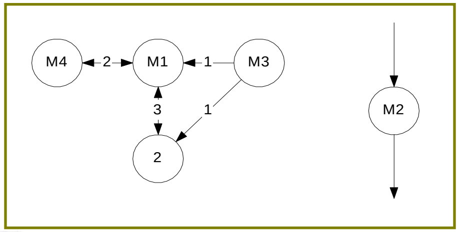
P-R Analysis Type IV



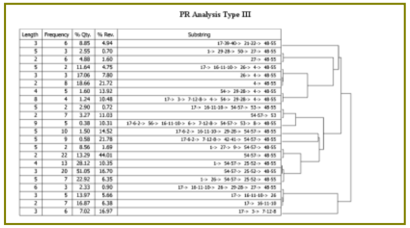
Flow Diagram



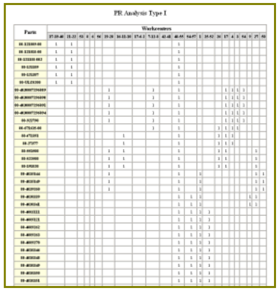
P-R Analysis Type II



Inter-Module Flow Diagram



P-R Analysis Type III



P-R Analysis Type I

Lean Advisory Tools using PFAST

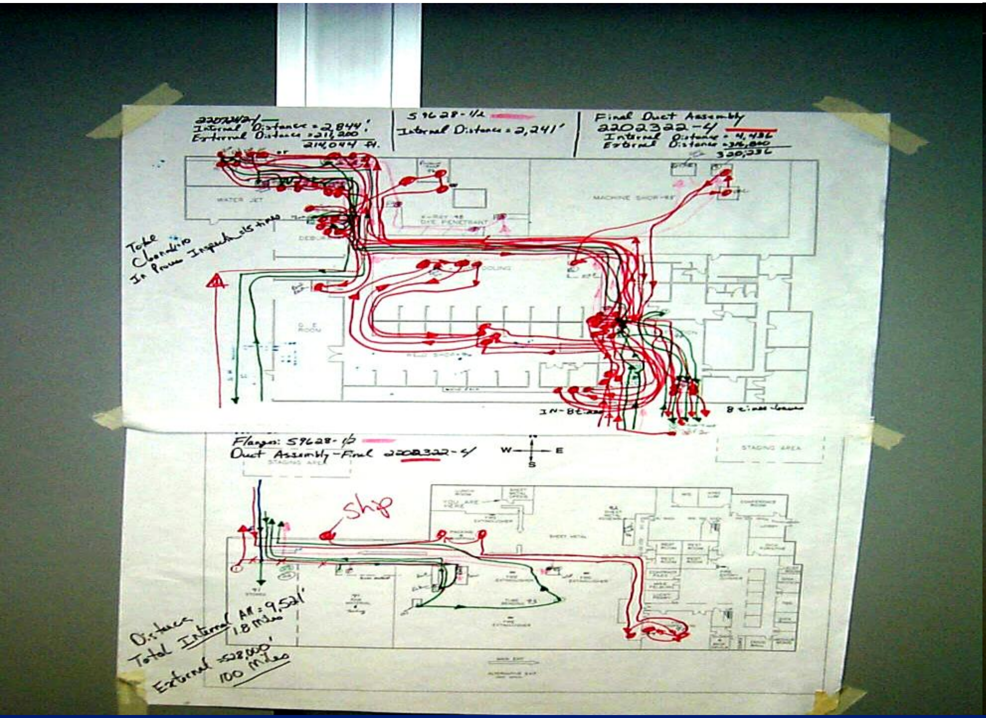
Initial Menu of Lean Advisory Tools powered by PFAST

- Waste Assessment in the Current State
- Product Mix Segmentation
- Feasibility Analysis for Cellular Manufacturing
- Cell Layout
- Design of Hybrid Cellular Layouts
- Product Mix Rationalization
- Revision of Manufacturing Routings
- Evaluation of Current and Proposed Layouts
- Value Network Mapping

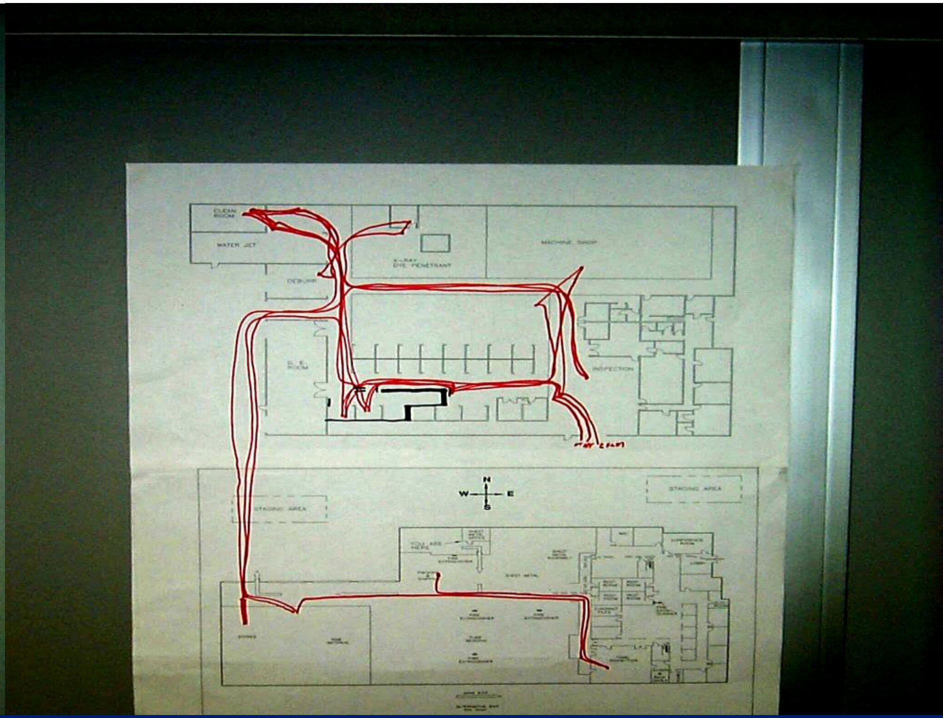
Success Stories

Factory Flow Analysis

Before

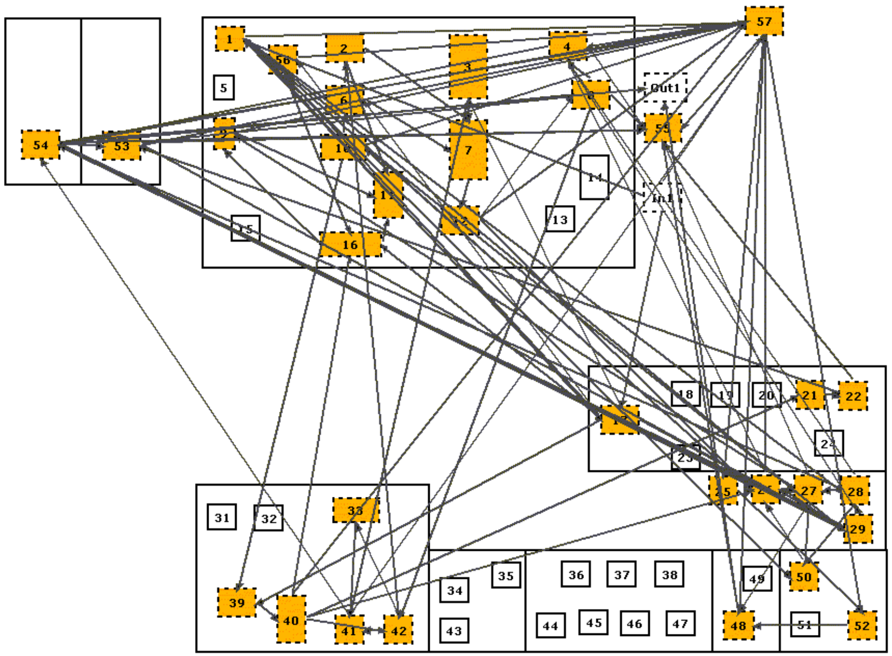


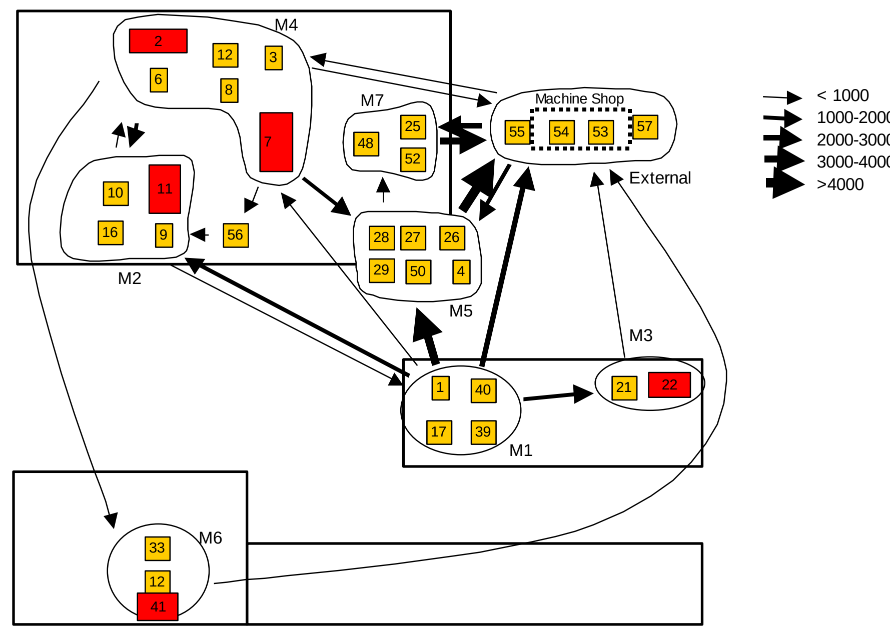
After



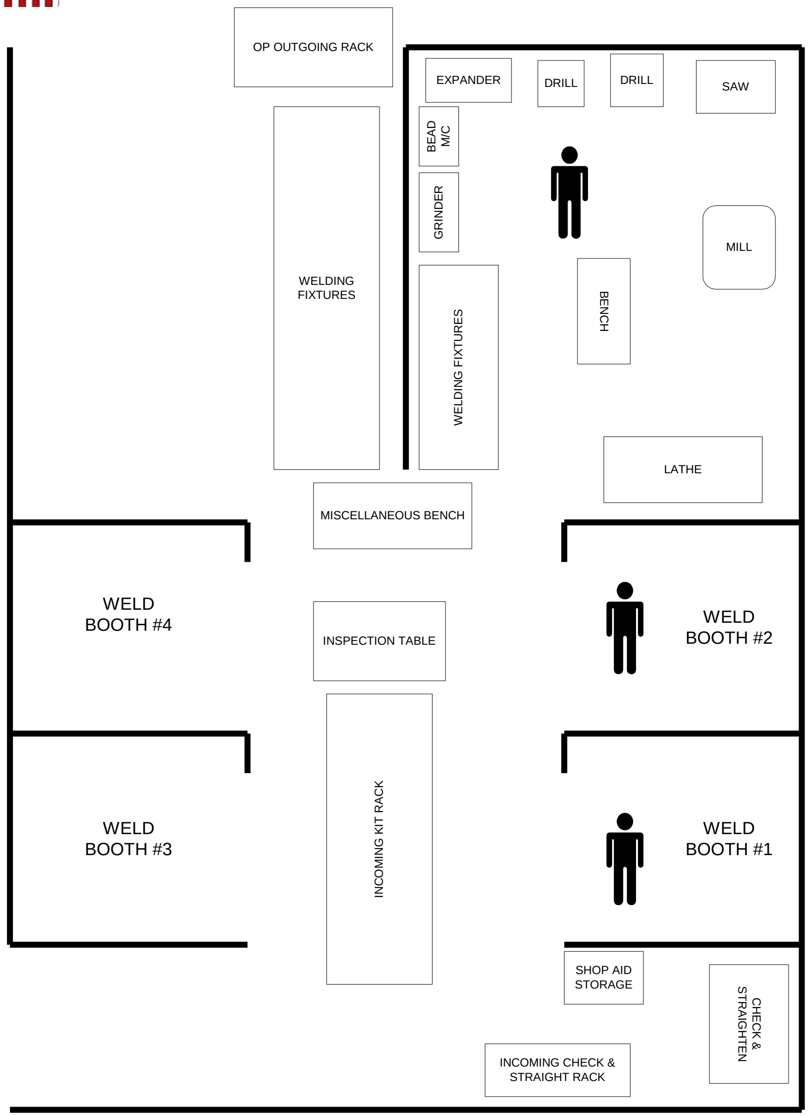
	Before	After	% Reduction
Lead Time	7 weeks	3 1/2 weeks	50 %
Cycle Time	8 hours	6 hours	25 %
Part Travel (ft.)	2,450 ft	1,578 ft	36%
Walking (ft.)	3,150 ft	1,578 ft	50%
WIP	360 pcs.	200 pcs.	44%

Forge Shop




M4
M7
Machine Shop
External
M2
M5
M3
M1
M6
< 1000
1000-2000
2000-3000
3000-4000
>4000

Welding Cell



Co-located machines, equipment, tooling and processes to minimize part transportation and waiting

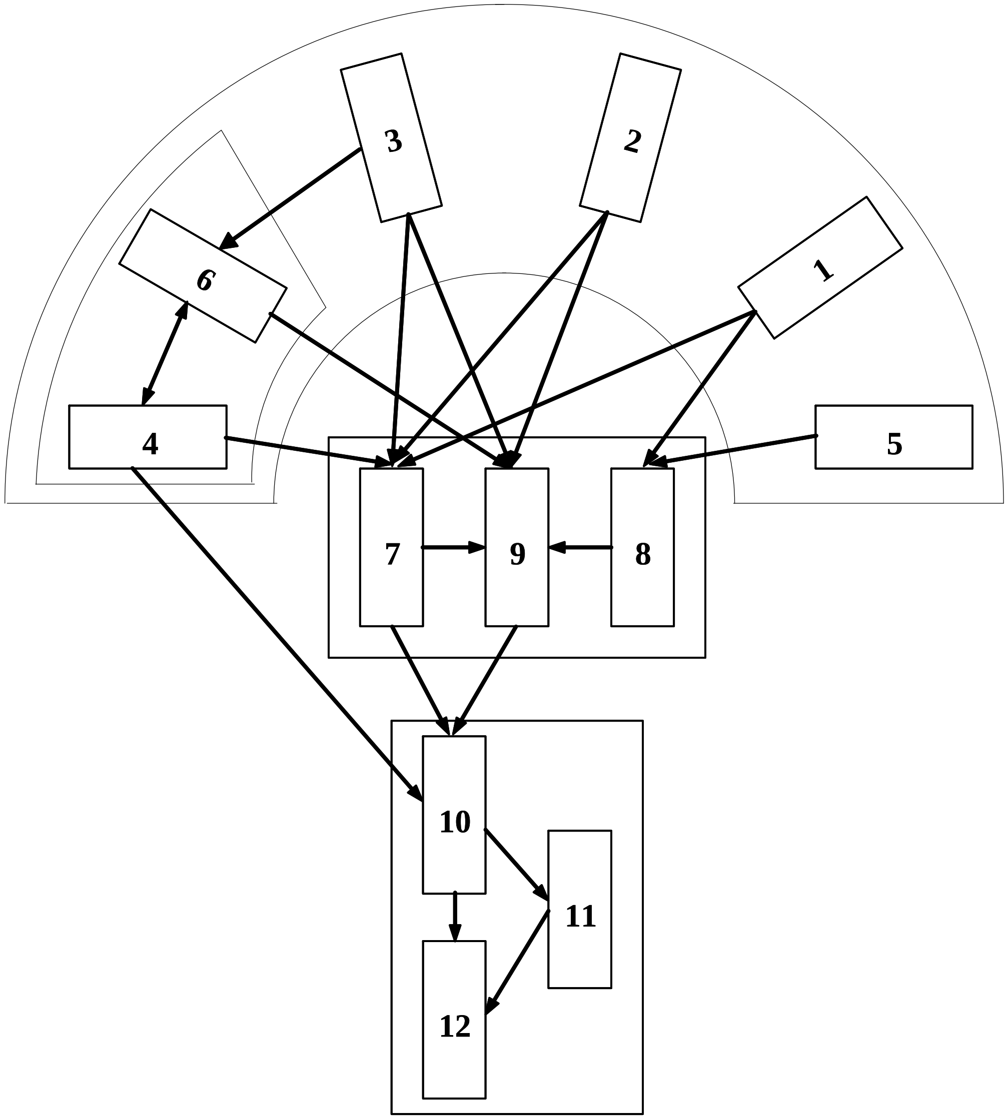
Emphasis placed on Flow

Eliminate wasteful steps that impede the speed at which the parts can flow through the assembly process

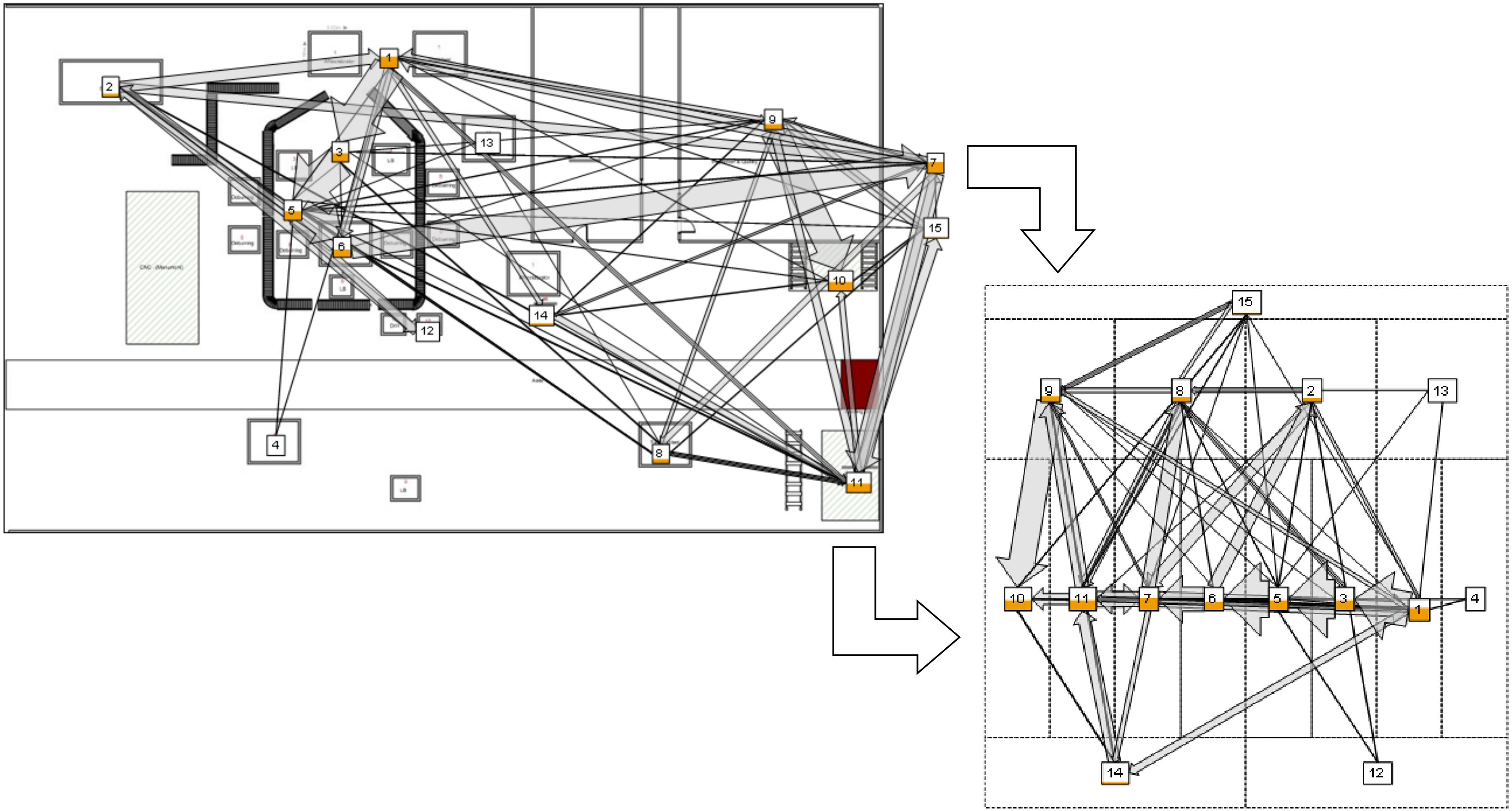
Create a visual workplace that is self-explaining, self-regulating and self-improving.

Waste Has No Place to Hide

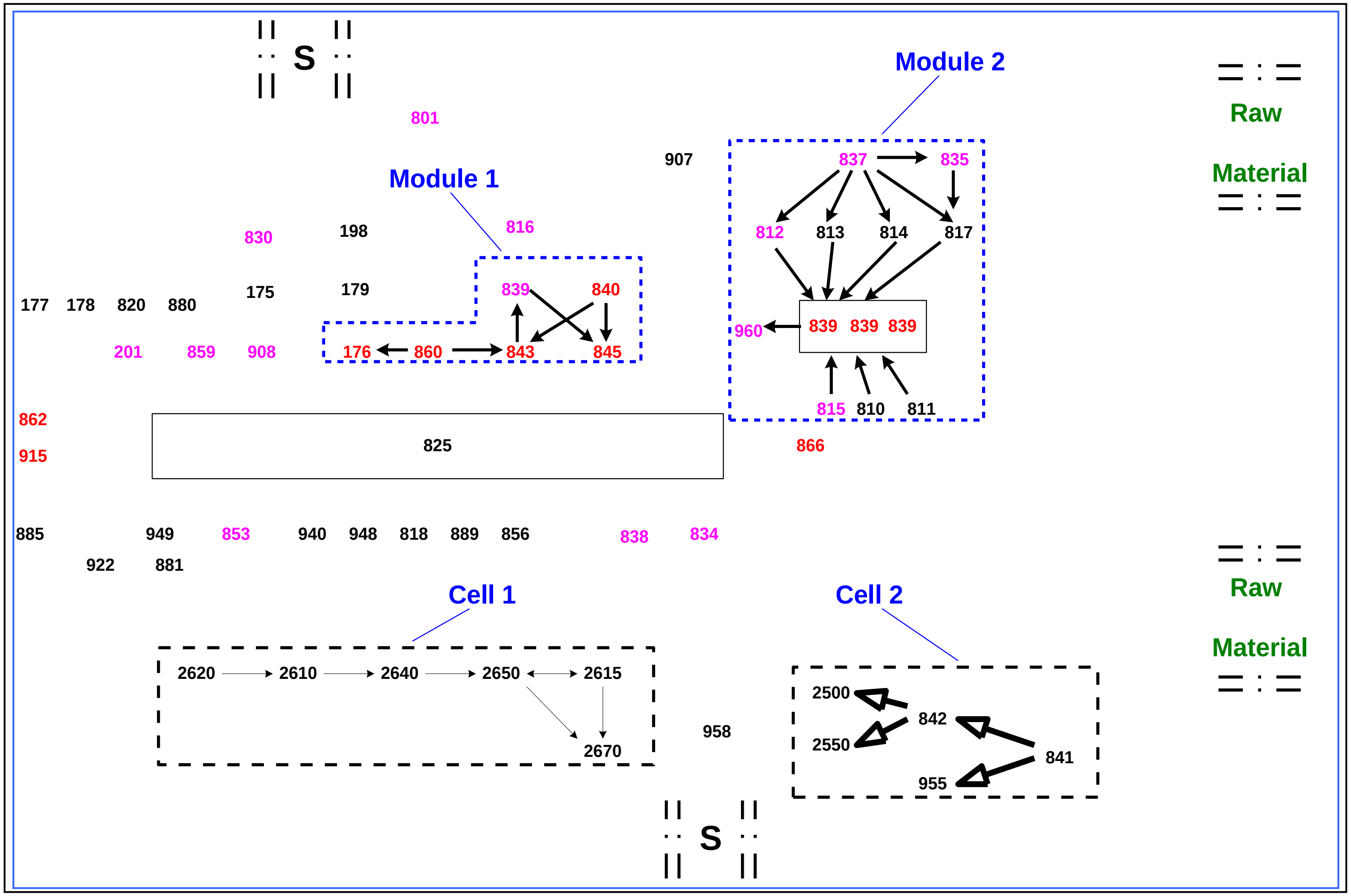
Flexible Machining Cell



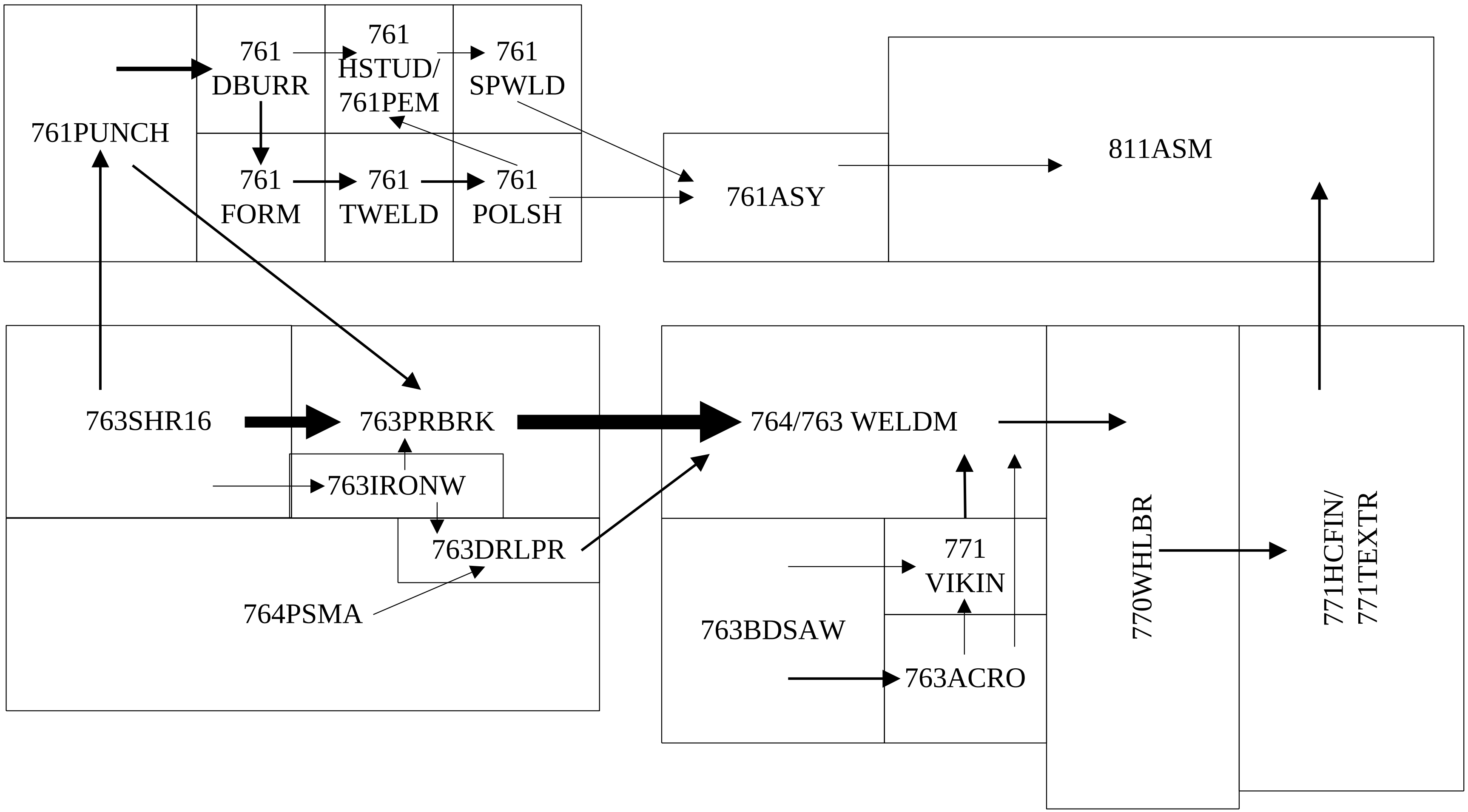
Finish Machining of Castings



Pipe Fabrication Jobshop



Assembly of Industrial Scales



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