Design for Assembly Line Performance: The Link Between DFA Metrics and Assembly Line Performance Metrics

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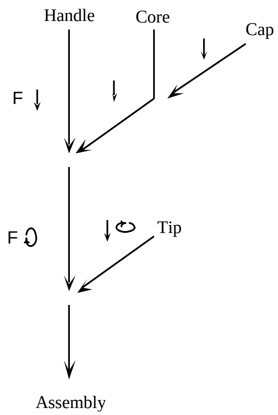
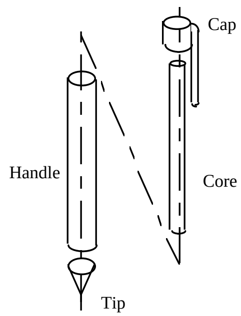
Motivation





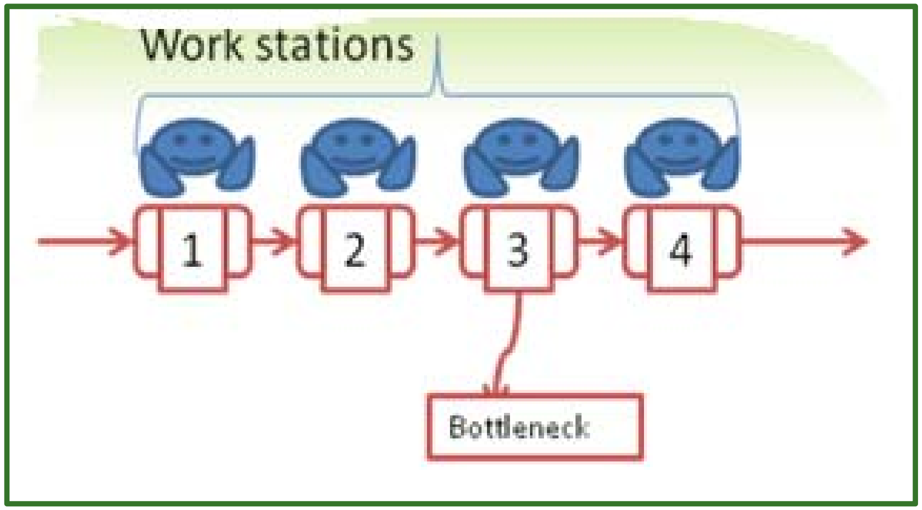
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Part/Operation Description	hand. cond.	size	thick.	insert. align.	end to end align.	inset. direc.	insert. cond.	insert. clear.	fastn.	fastn. proc	time/ oper. (T op)	no. of reps. (Nrep)	repet. time K * L	insert part? 0 = no,	eliminate part? 1 = yes
1	handle		0.1		0.25	1	0.6	2.25				4.2	1	4.2	1	0
2	Core		0.4		0.25	1	0.6		0.25		1	3.5	1	3.5	1	0
3	Cap		0.4		0.25	1	0.6		0.9		1	4.15	1	4.15	1	0
4	Flip sub-assy							2.25				2.25	1	2.25	0	0
5	Tip		0.1		0.25	1	0.6		0.25		4	6.2	1	6.2	1	0
6																
7																
8																
9																
##																
													5	20.3	4	
													TOP	TAT	NUP	

Summary Statistics

NUP	4	= number of unique parts
TOP	5	= total no. of operations
TAT	20.3	= total assembly time
NP	4	= no. of parts = sumprod.(L,N)
Tavg	4.06	= avg time/operation = TAT/(sumRep)
Pmin	4.0	=min # parts = NP - sumprod.(L,N,O)
AR	0.463	= Assembly rating = 2.35 * NP /TAT
PE	1	= Part Effciency = Pmin/NP

- Fewer Parts
- Easier Assembly
- Shorter Assembly Time
  - Major Cost Savings
  - Reduced Defects
  - Improved Quality & Reliability

Motivation



- Cycle Time
- Work in Process
- Line Balancing

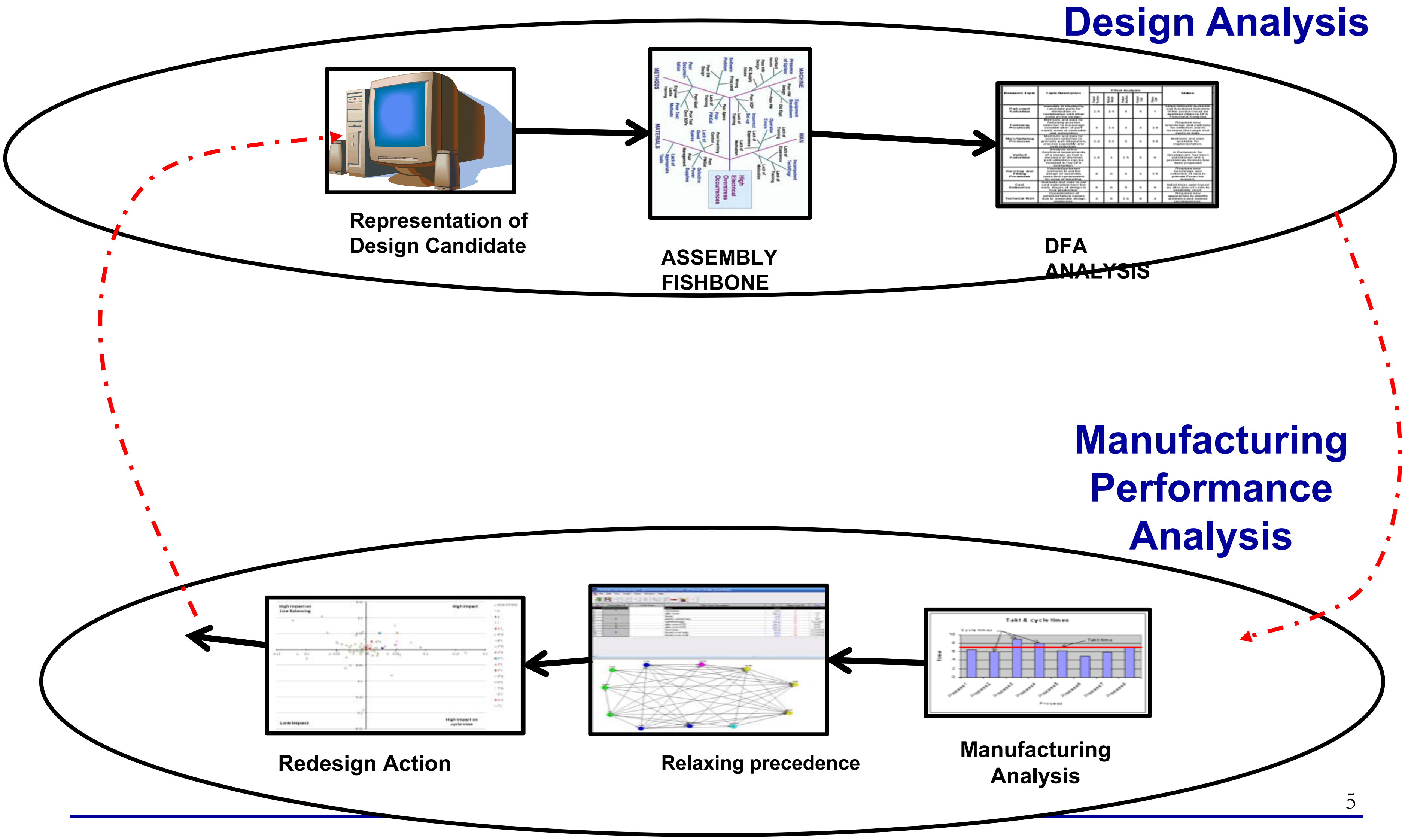
Typically Performed After Design Has Been Completed

Can these metrics be linked to the design stage, so that improvements to manufacturing line performance can be made through design changes?

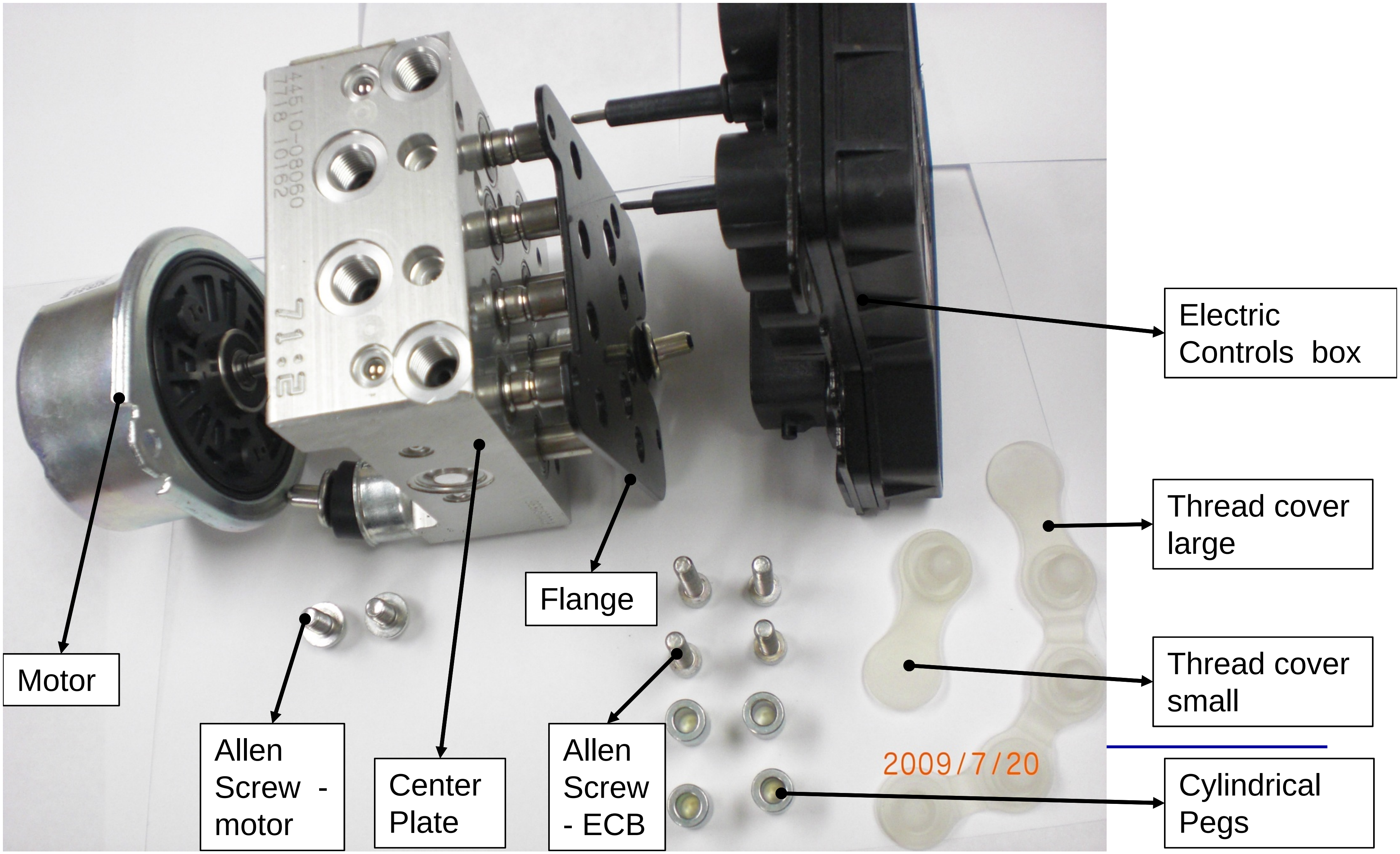
Original Research Questions

- Can an explicit link between DFA and assembly line performance be made?
- If so, can this link be leveraged to provide a method to aid product development practioners during product development?
- What type of design actions can be taken to improve manufacturing line performance given an initial design candidate?

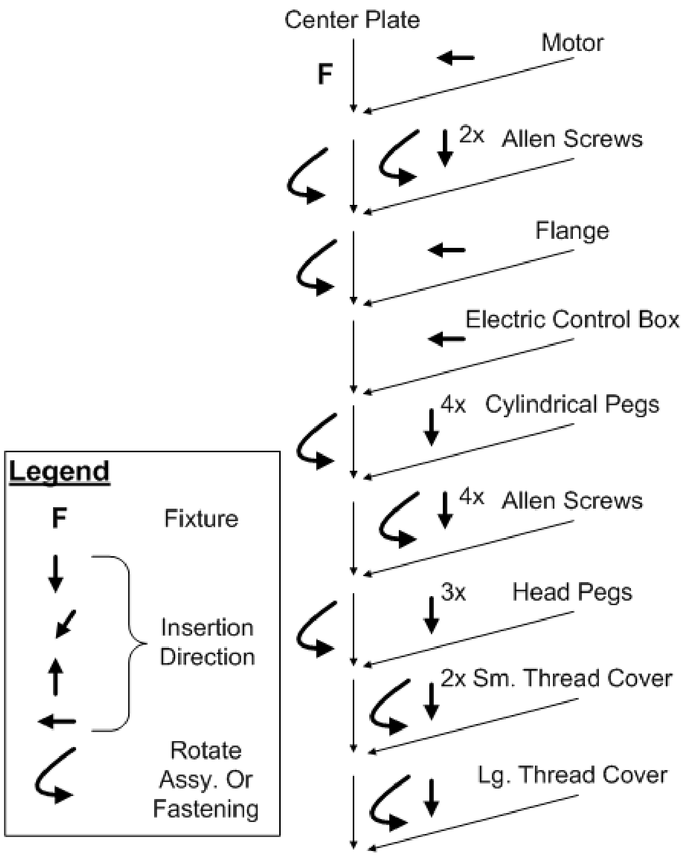
Methodology



Design Analysis: Select Design Candidate



Design Analysis: DFA



		Time Factors (seconds)														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
No.	Part/Operation Description	End-to-End Orientation	Rotational Alignment	Part Size	Part Thickness	Insertion Clearance	Insertion Direction	Insertion Condition	Fastening	Fastening Process	Handling Condition	Time/Each Operation (T^{op})	Number of Repetitions (N^{rep})	Repetition Time (K*L) (T^{rep})	Insert Part (1 = Yes; 0 = No)	Eliminate Part (1=yes; 0 = No)
1	Motor	0.8	1.5	0.0	0.0	1.6	1.4	1.3	0.0	0.0	0.0	6.6	1	6.6	1	
2	Center Plate	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1	0.5	1	
3	Flange	2.3	1.0	0.0	0.2	0.0	1.4	0.0	0.0	0.0	0.0	4.9	1	4.9		
4	Electric controls box	0.8	1.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	3.2	1	3.2	1	
5	head pegs	0.8	0.5	0,1	0.0	0.9	0.6	0.0	1.0	1.0	0.0	4.8	3	14.4		
6	allen screw	1.8	0.0	0.1	0.0	0.3	0.6	1.3	4.0	4.0	0.0	12.1	4	48.4		
7	allen screw motor	1.8	0.0	0.1	0.0	0.3	0.6	1.3	4.0	4.0	0.0	12.1	2	24.2		
8	thread cover small	1	1	0	0	0	1	0	1	1	0	4.6	2	9.2		
9	cylindrical pegs	1	0	0	0	0	1	1	0	0	0	3.6	4	14.4		
10	thread cover large	1	0	0	0	0	1	0	1	4	0	6.6	1	6.6		
													20	132.4	3	
													TOP	TAT	NUP	

Step 1: Draw the Assembly Sequence Diagram
Step 2: List Parts & operations in order (left column)
Step 3: Enter times from Estimated DFA Time Chart
Step 4: Sum time per part/oper. in column K
Enter no. of repetitions for each operation in col. L
Enter K*L in col. M
Step 5: Enter a 1 in col. N if a part was inserted during opera
Enter a 1 in col. O if part or operation can be elimina
Step 6: Calculate Summary Statistics

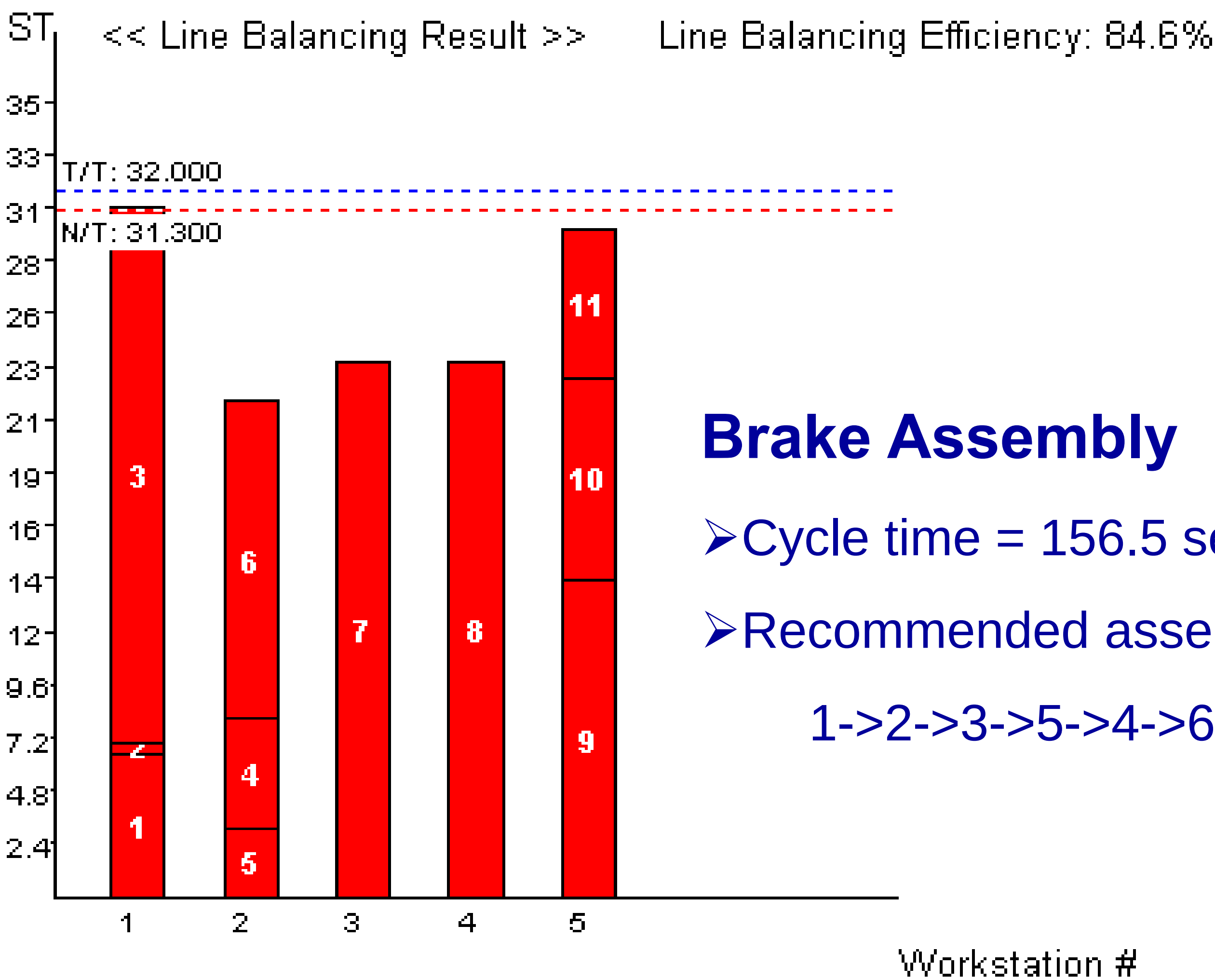
Summary Statistics

NUP	3	= number of unique parts (Sum of Column N)
TOP	20	= total number of operations (sum of Column L)
TAT	132.4	= total assembly time (sum of Column M)
NP	3	= number of parts = sumproduct(L,N)
T_{avg}	6.6	= avg time/operation = TAT/TOP
P_{min}	3.0	= min # parts = NP - sumproduct(L,N,O)
AR	0.05	= Assembly rating = 2.35 * NP /TAT
PE	1.00	= Part Effciency = Pmin/NP
C	84.40	= Assembly complexity = TAT - (2.4*TOP)
OR	2.76	= Operation difficulty rating = TAT/(2.4*TOP)

Manufacturing Performance Analysis

- Determine Baseline
  - Inputs
    - Candidate design precedence relationships, TAKT Time
  - COMSOAL Algorithm selected
    - Ease of implementation
  - Relevant Outputs
    - Number of Workstations, Cycle Time, Recommended Assembly Sequence
- Identify Components Most Likely to Improve Manufacturing Line Performance
  - Systematically (& Artificially) Relax Precedence Constraints
  - Select Components with Biggest Performance Indices Change
- Redesign Actions

Determine Baseline



Brake Assembly

- Cycle time = 156.5 sec
- Recommended assembly sequence:

  1->2->3->5->4->6->7->8->9->10->11

Performance Improvement Indices

- Cycle Time Index

$$CTI = (1 - (\frac{CT_p}{CT_{Baseli}}))$$

where,

CTI = Cycle Time In

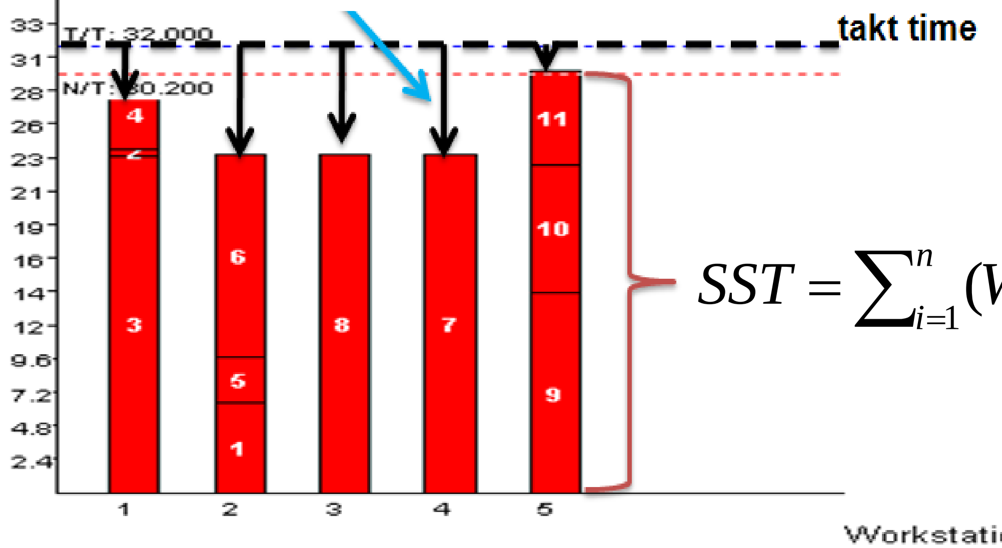
CT_p = Cycle time of a Permutation

$CT_{Baseline}$ = Cycle time of a line considering all com the original desi

- Line Balancing Index

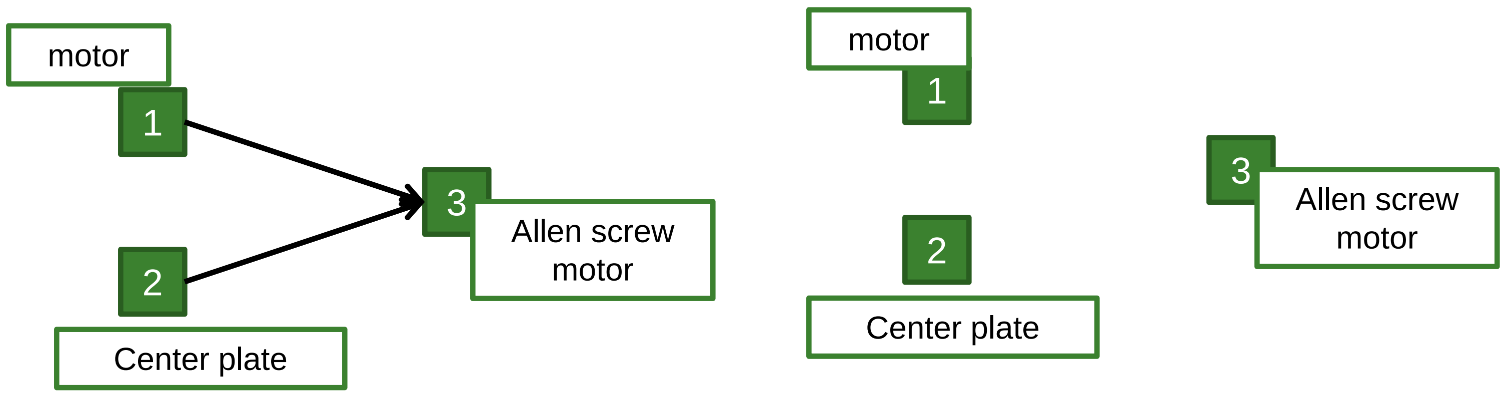
$$LBI = 1 - \frac{SSTKE}{SST}$$

$$SSTKE = \sum_{i=1}^{n} (TT - Wkstn_i)^2$$



$$SST = \sum_{i=1}^{n} (Wkstn_i)^2$$

Relaxing Precedence Relationships

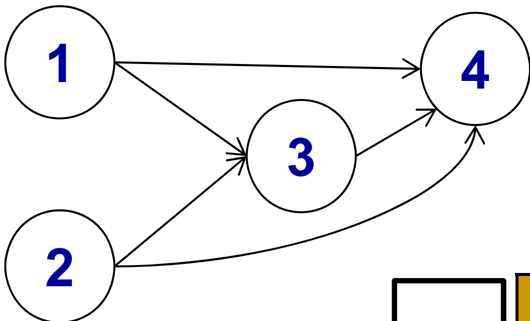


Allen screw with precedence constraints

Allen screw without precedence constraints

- The feasible assembly sequences with precedence:
  - **1->2->3 or 2->1->3**
- The feasible assembly sequences ***without*** precedence:
  - **1->2->3 or 1->3->2 or 2->1->3 or 2->3->1 or 3->2->1 or 3->1->2**

Systematically Relaxing Precedence Relationships



SUPPLYING

RECEIVING

COMPONENT	1	2	3	4
1				
2				
3				
4				

Column Permutation

Row Permutation

Systematically Relaxing Precedence Relationships

Minitab - ROW PERMUTATIONS.MPJ - [Worksheet 1 ***]

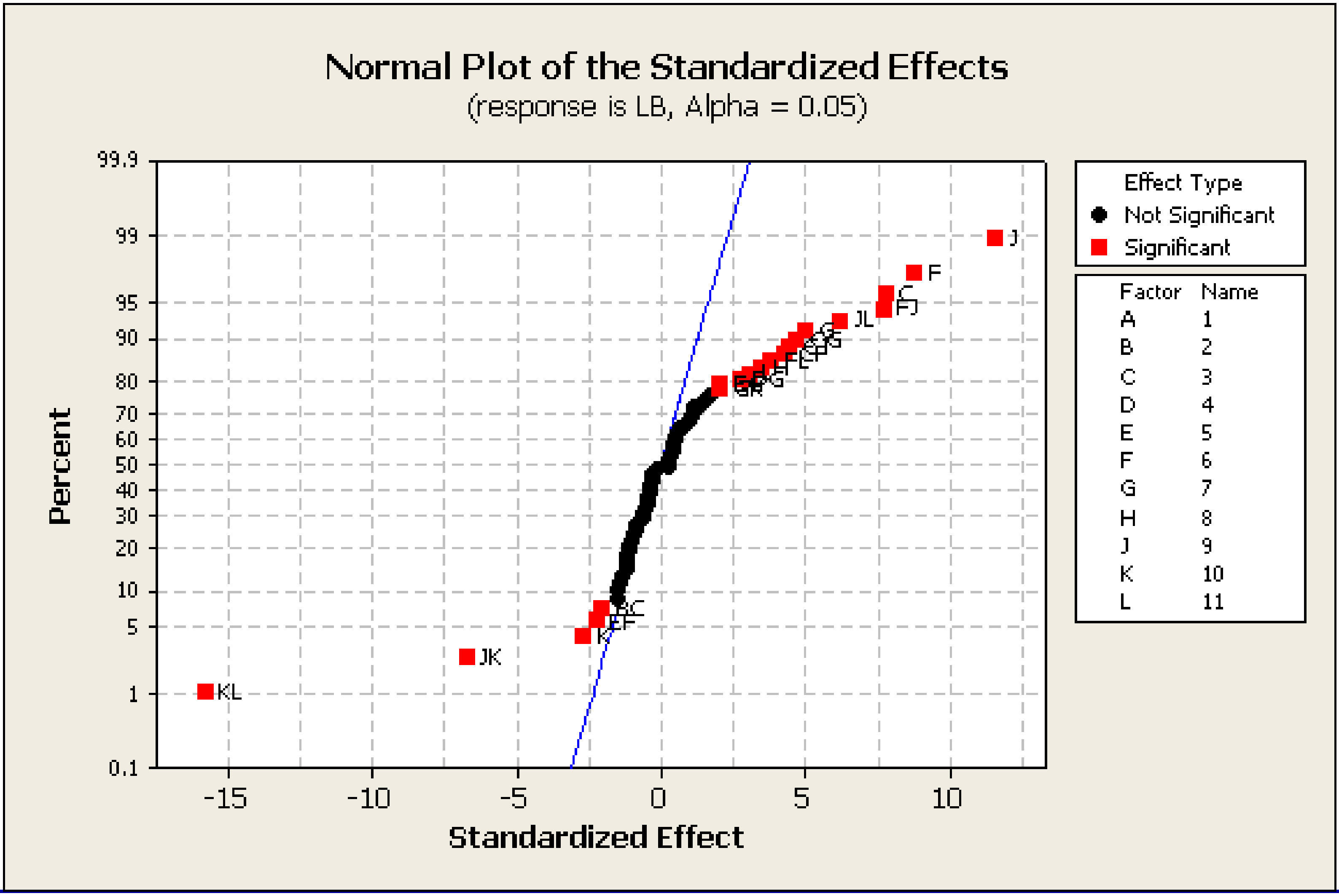
File Edit Data Calc Stat Graph Editor Tools Window Help

CTI & LBI Calculated for Each Configuration

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
	1	2	3	4	5	6	7	8	9	10	11	CTI	LBI
1	0	0	0	0	0	0	0	0	0	0	0	0.35144	0.162071
2	1	0	0	0	0	0	0	0	0	0	0	0.79872	0.145403
3	0	1	0	0	0	0	0	0	0	0	0	0.79872	0.145403
4	1	1	0	0	0	0	0	0	0	0	0	0.79872	0.145403
5	0	0	1	0	0	0	0	0	0	0	0	0.35144	0.162071
6	1	0	1	0	0	0	0	0	0	0	0	0.35144	0.162071
7	0	1	1	0	0	0	0	0	0	0	0	0.35144	0.162071
8	1	1	1	0	0	0	0	0	0	0	0	0.35144	0.162071
9	0	0	0	1	0	0	0	0	0	0	0	0.79872	0.145403
10	1	0	0	1	0	0	0	0	0	0	0	0.79872	0.145403
11	0	1	0	1	0	0	0	0	0	0	0	0.19169	0.162951

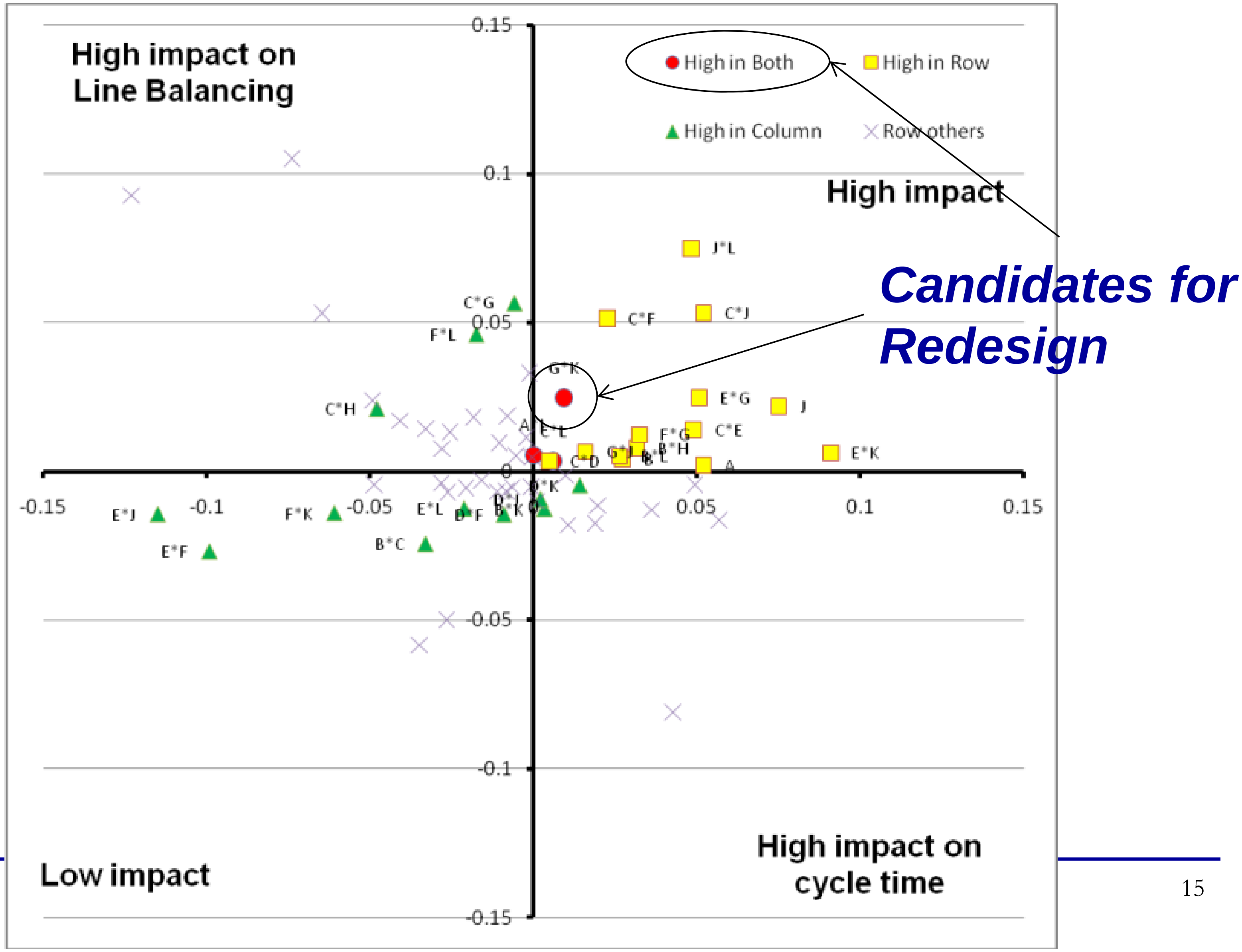
2^{11} Possible Combination of Relaxed Constraint Configurations

Filtering the Data



Brake Assembly: Significant effects plot (Row Permutation)

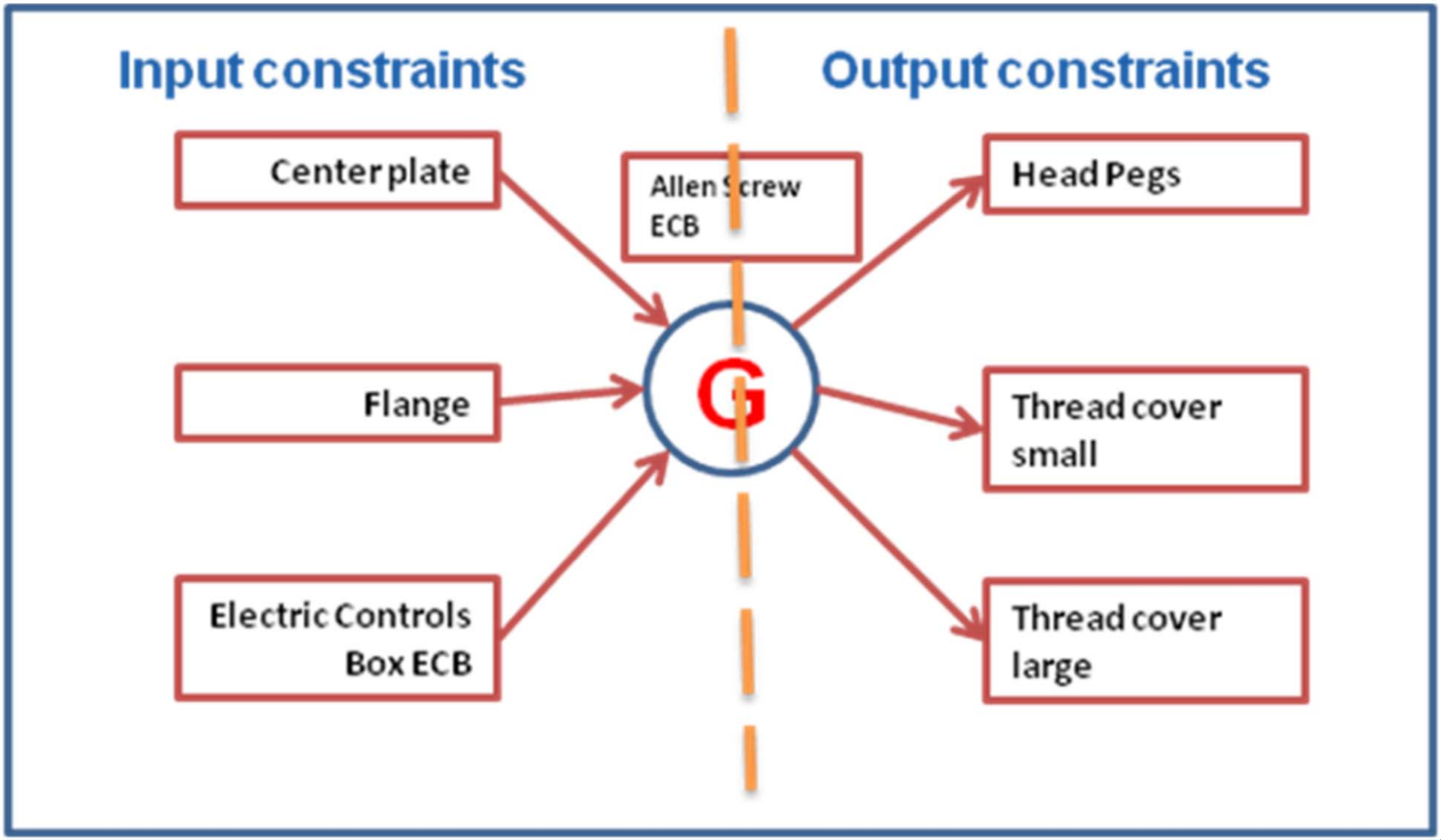
Identifying Components for Redesign



Redesign Actions (Adapted from Whitney, 2004)

Symbol	Constraint	Interpretation	Analysis	Recommendations
U	Under-constrained	Degree of freedom has no value and it is required or necessary	Motion Analysis	Redesign or combine components for making the assembly properly constrained
O	Over-constrained	Degree of freedom has more than one value creating locked in stress	Constraint analysis	Redesign or eliminate the component for making the assembly properly constrained
P	Properly Constrained	The part is neither over constrained nor under constrained	not required	If all constraints are properly constrained then analyze the assembly of the part and the mating parts as a whole for opportunities of redesign
M	Mistake	Non functional over constraint or under constraint	not required	Eliminate

Redesign Actions



Conclusions

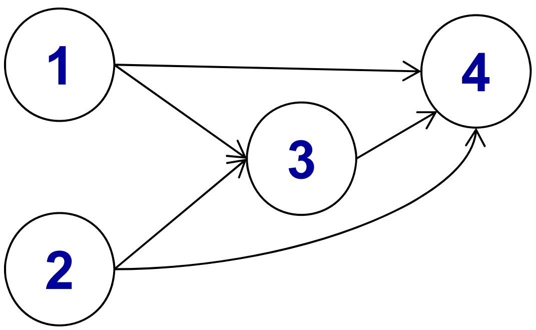
- Link between DFA and assembly line performance established
- Analysis procedure developed to systematically identify redesign components
  - line balance and cycle time performance could be improved during the design stage
- Potential utility of the approach demonstrated through a case study

Opportunities to Explore

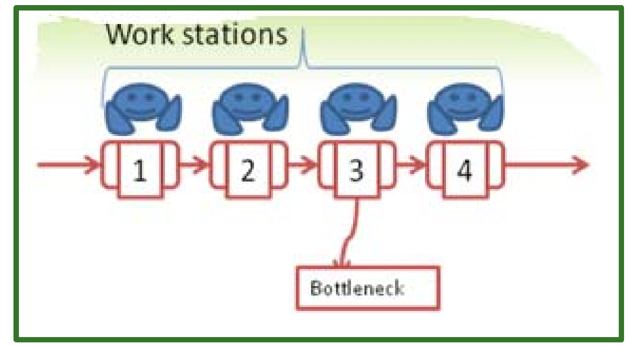
- The use of a more efficient and effective line balancing algorithm
- A more efficient and effective search process to identify redesign candidates
- More systematic guidance on redesign actions based on the analysis results
- The validation of the methodology on more realistic case studies.

Line Balancing

Thangavelu and Shetty, 1971



Set of Tasks
i={1,2,3..n}



Set of Workstations
j={1,2,3..n}

$nC_j \leq C_{j+1}$

$$Min\_Z = \sum_{i=1}^{n} \sum_{j=1}^{n} C_j X_{ij}$$

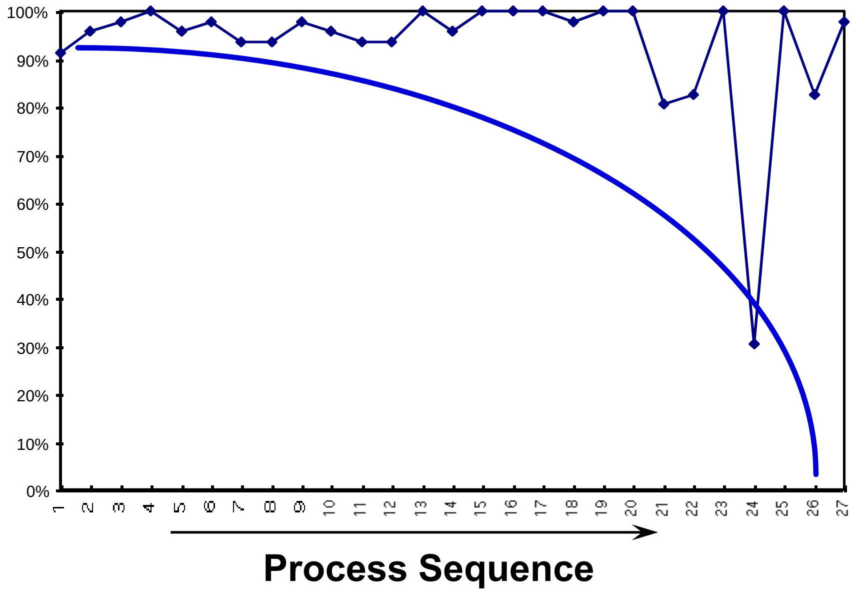
X_{ij}: **1, if task i assigned to station j**
0, otherwise

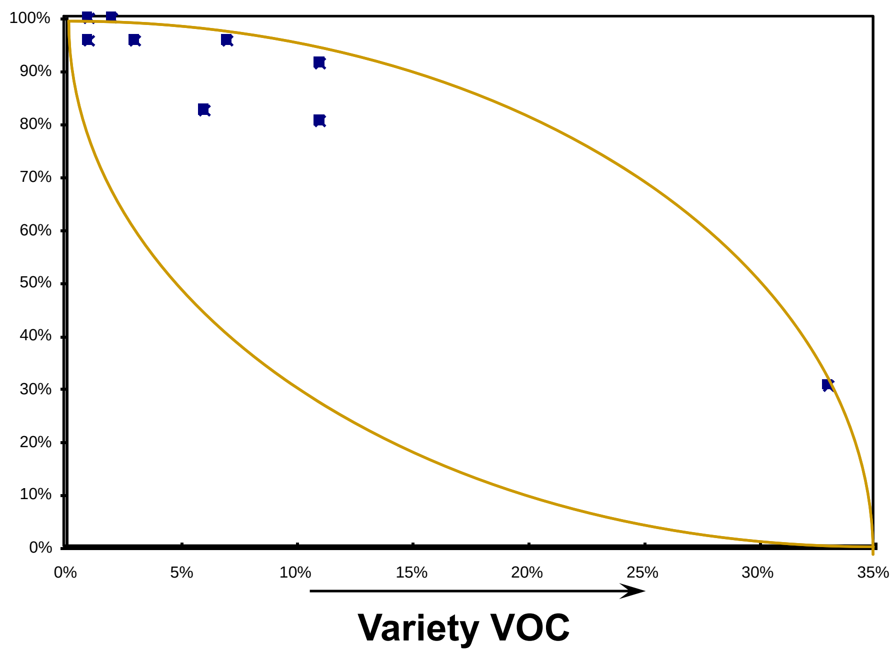
- **Each task is assigned to only one station**
- **Time for processing all tasks assigned to each station does not exceed the takt time**
- **Precedence constraints are preserved**
- **Any task is assigned to a station only if all its predecessors have been already assigned to a previously opened station, or to the same station**

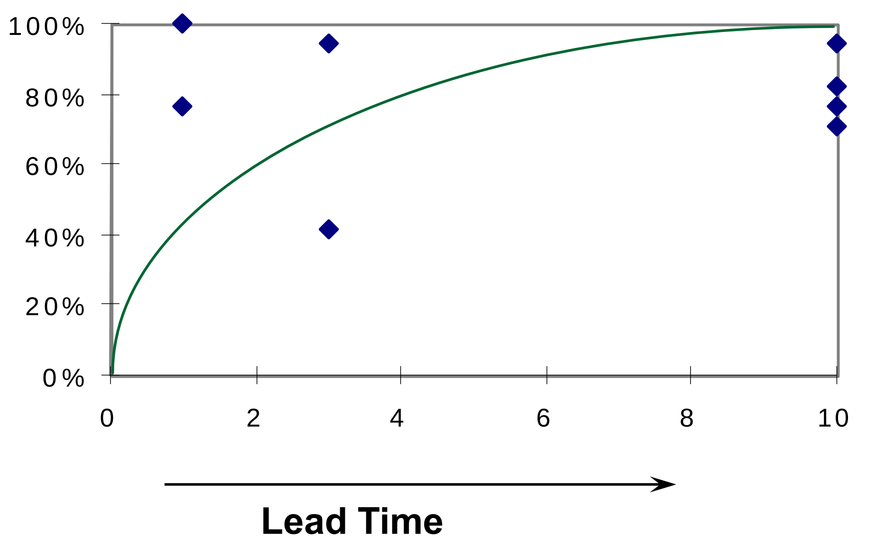
Design Candidate Search

- How do we efficiently and effectively identify the precedence constraints that should be explored for elimination (by taking a redesign action)?
- How do we efficiently and effectively identify assembly tasks that should be split-up (also through redesign action)?

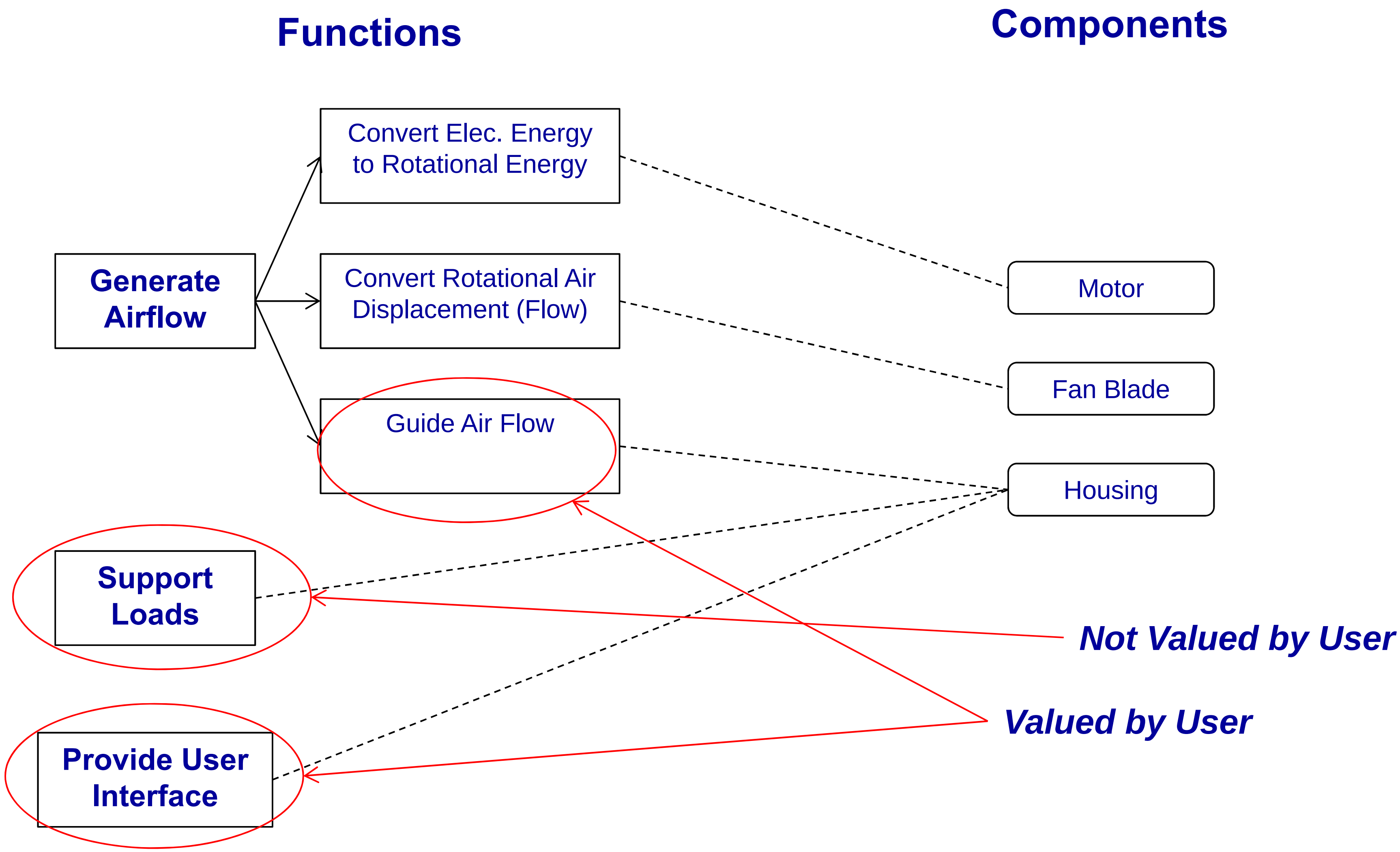
Design for Variety







Component Division



Next Steps

- Develop Metrics as Discussed Above
- Integrate into an optimization problem formulation
  - May result in non-linear formulations
  - Linearization or other techniques may be necessary to solve
- Identify Industry Partner to develop realistic case study
  - Essential to elicit implementation issues & to demonstrate utility

Questions