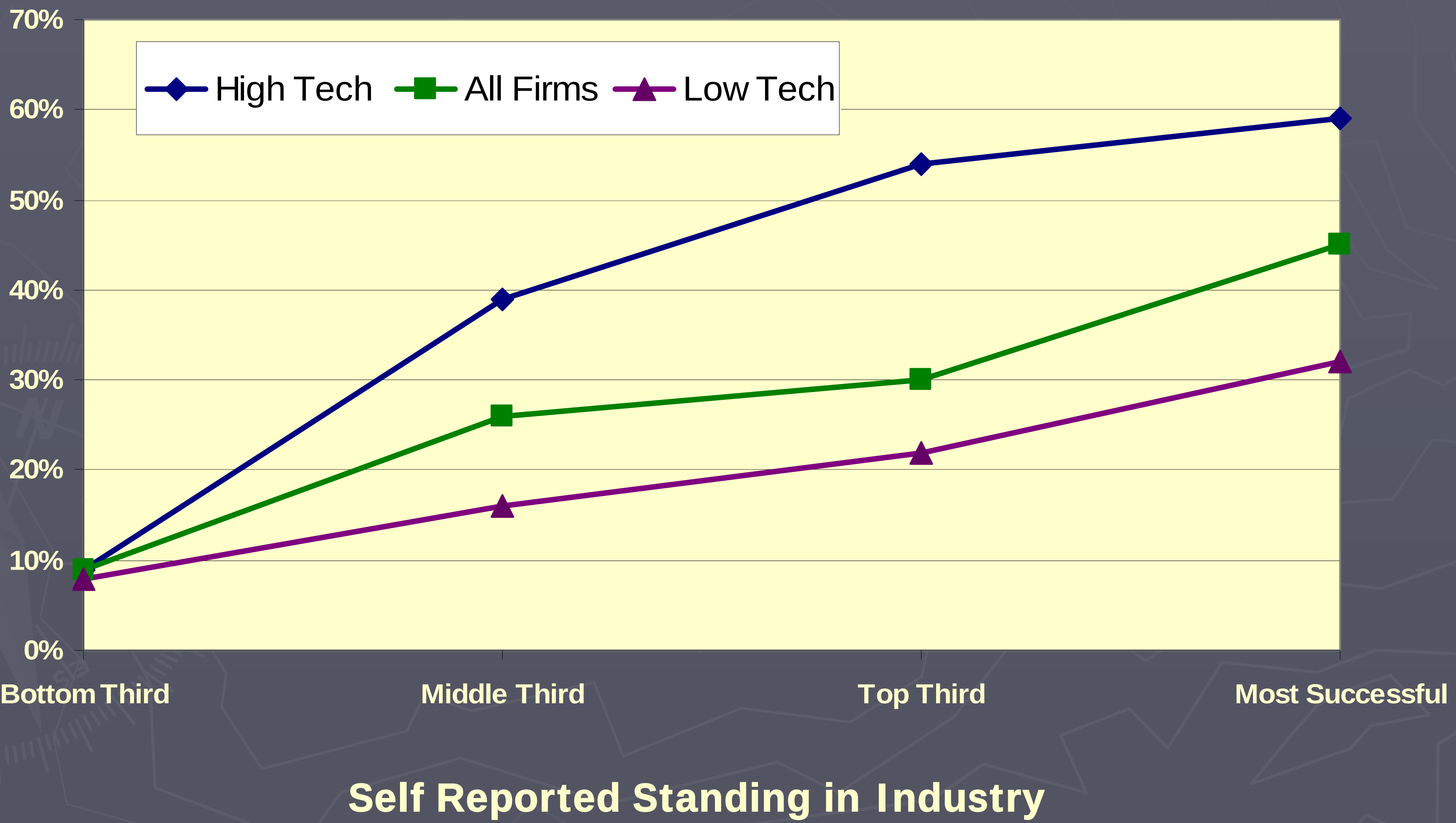
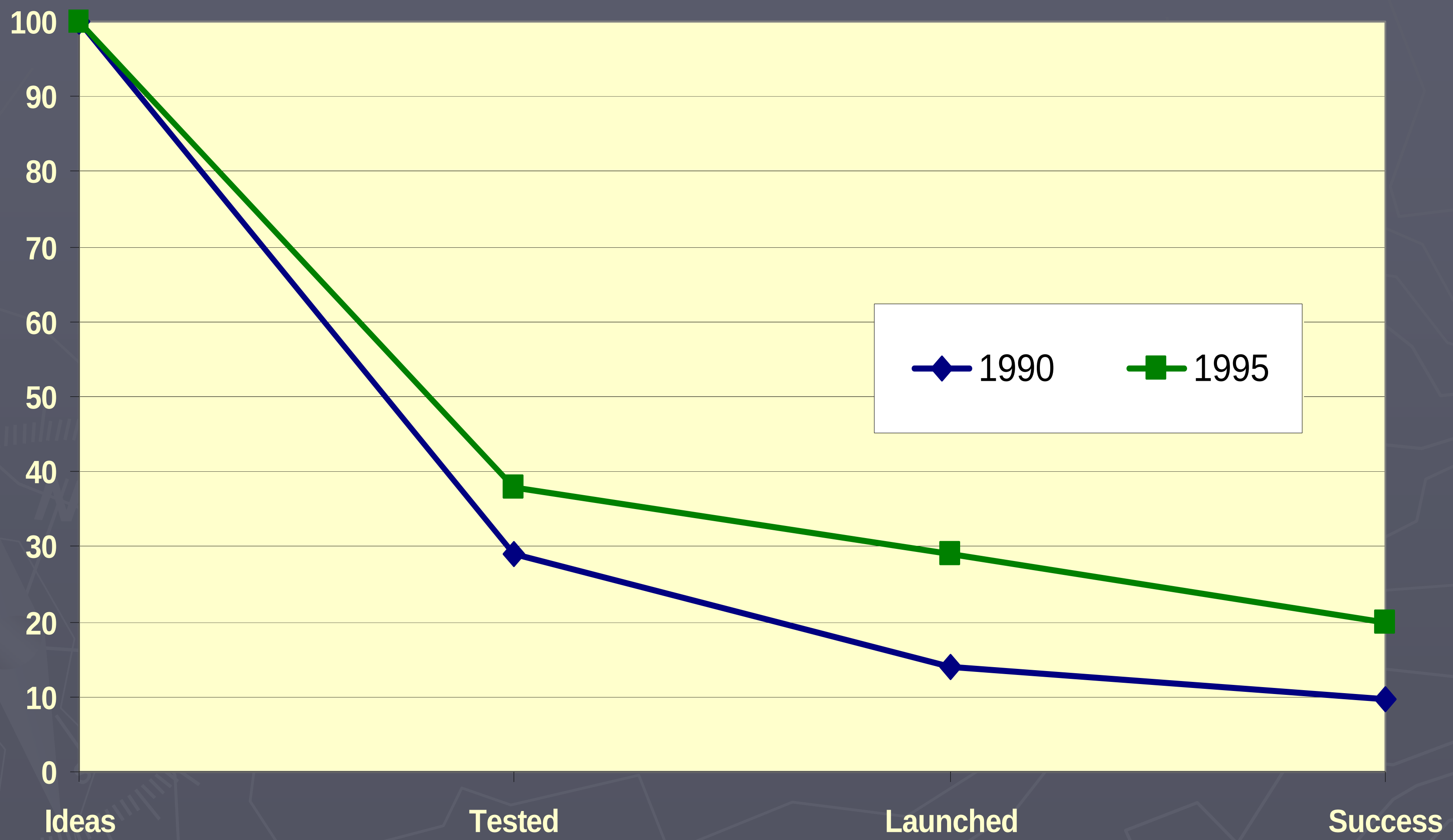
Tools & Trends in Product Development

Percent of Current Sales Contributed by New Products

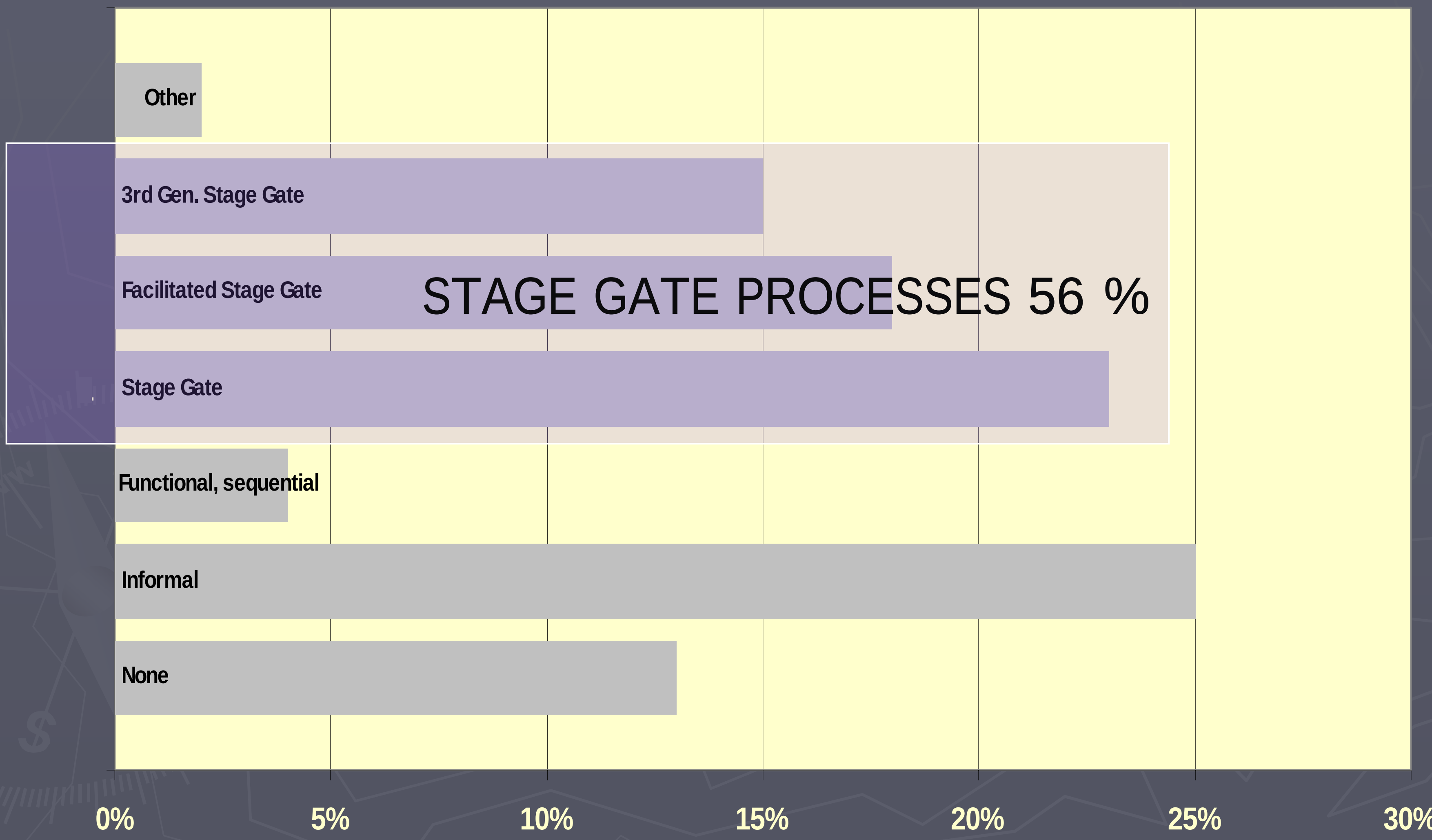


Decay Curve


100
90
80
70
60
50
40
30
20
10
0
1990
1995
Ideas
Tested
Launched
Success

Design Processes

NPD Processes in Use in the US



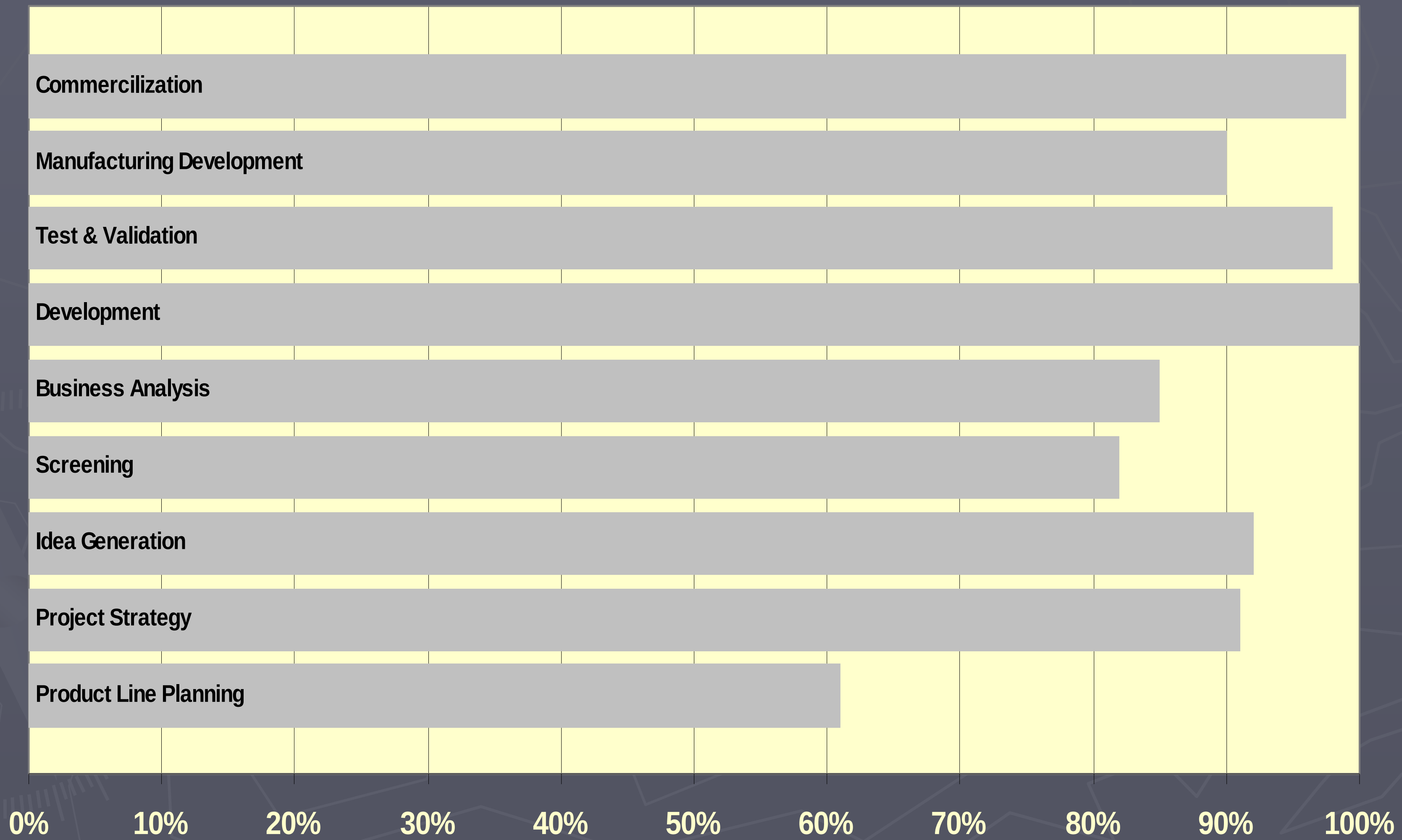
Process Tasks ...

- Product Line Planning
  - Portfolio, Competition
- Strategy Development
  - Target Market, Needs, Attractiveness
- Idea/Concept Generation
  - Opportunities and Solutions
- Idea Screening
  - Sort, Rank, Eliminate

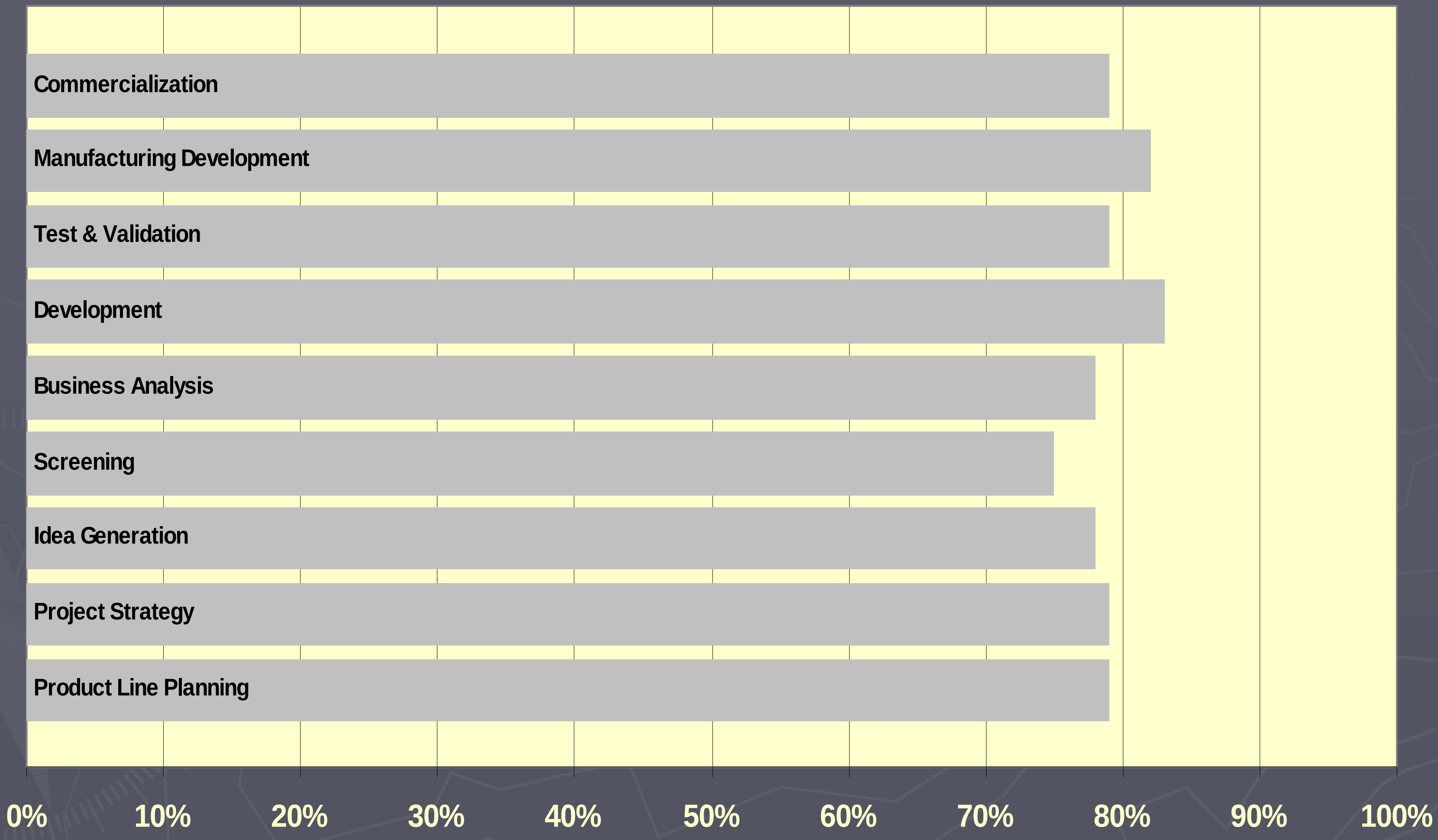
... Process Tasks

- Business Analysis
  - Business Case, Development Contract
- Development
  - Convert Concept into Working Product
- Test & Validation
  - Product Use, Market
- Manufacturing Development
  - Developing and Piloting Manufacturing Process
- Commercialization
  - Launch of Full-Scale Production and Sales

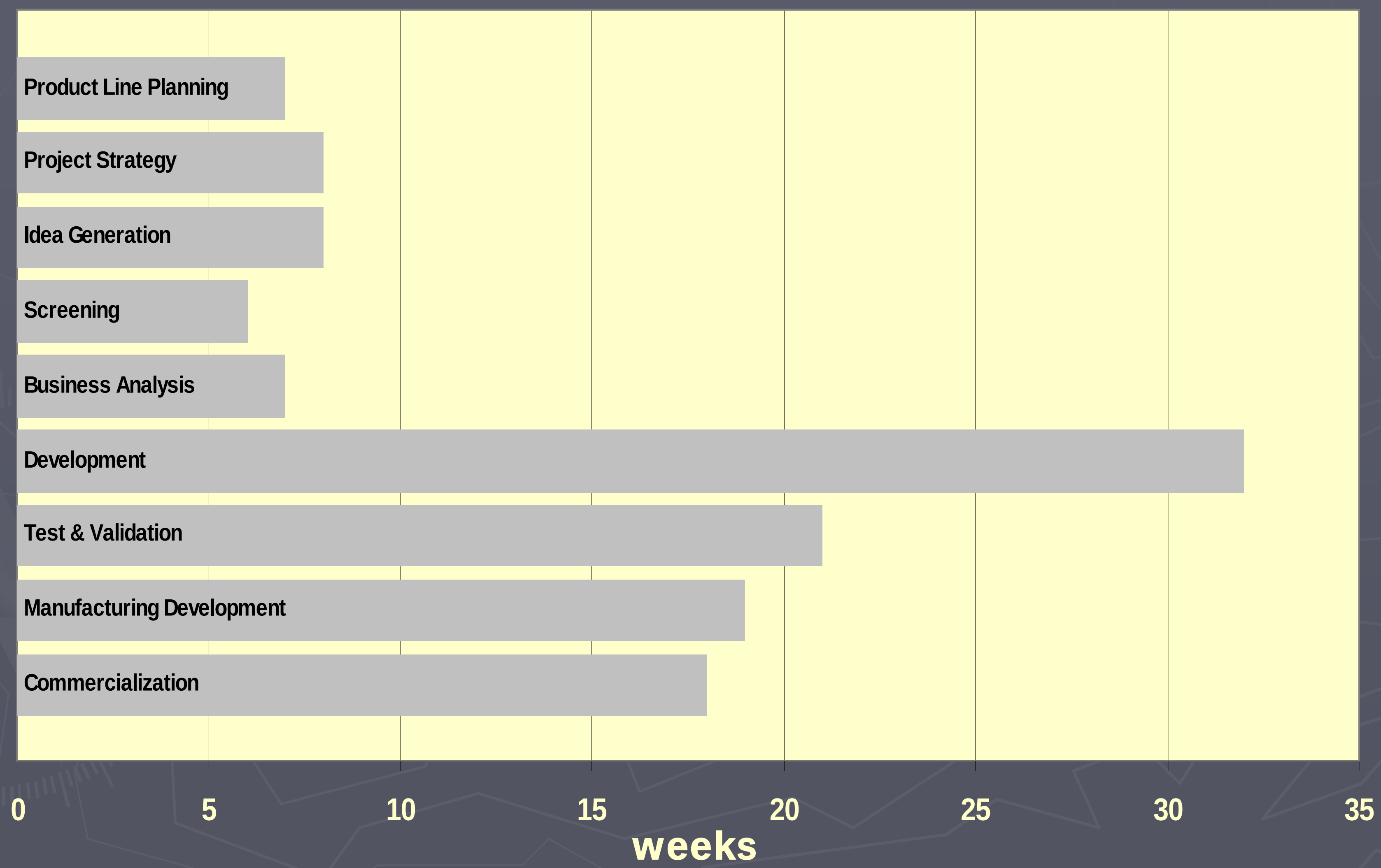
Tasks Included in Processes



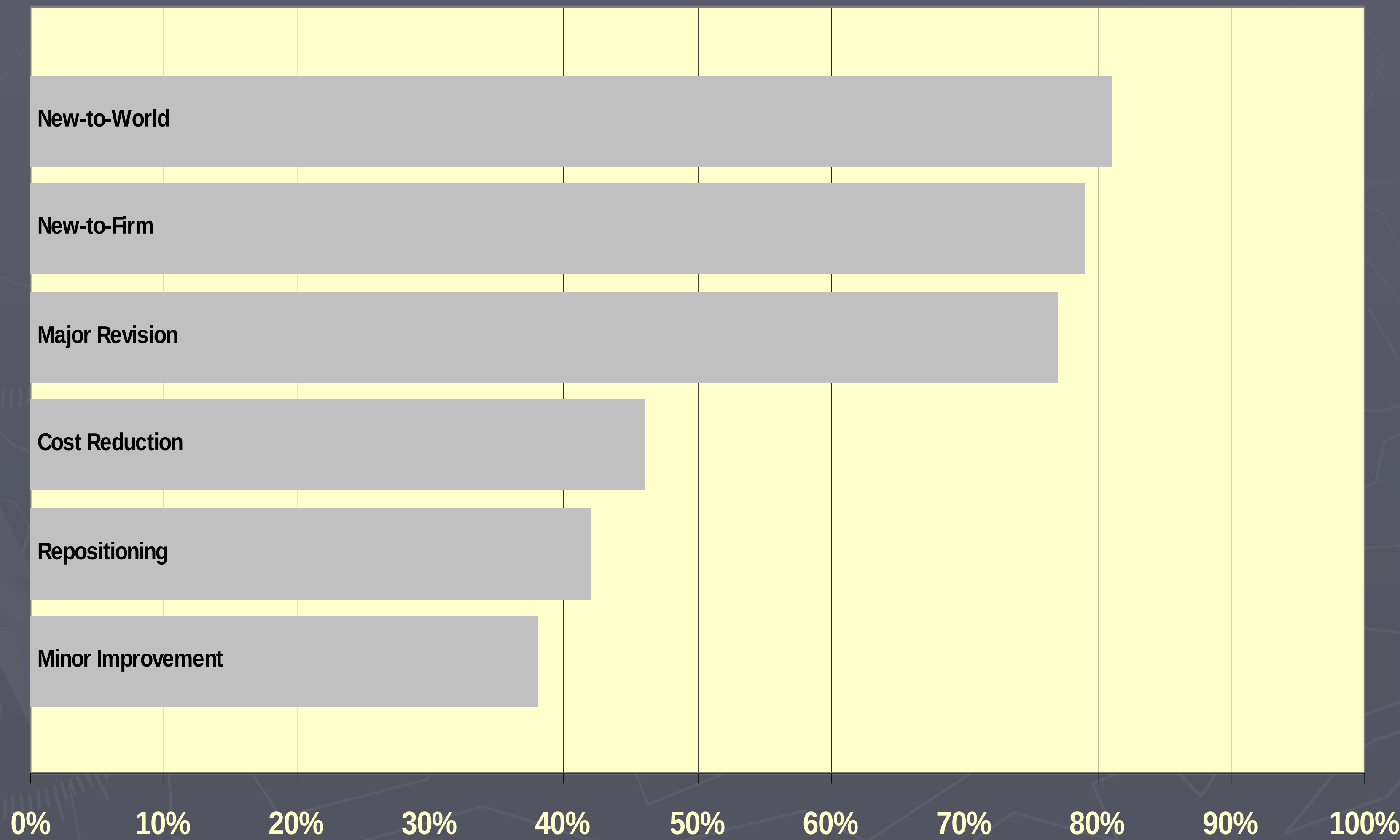
Projects Completing Tasks



Average Time Spent on Tasks

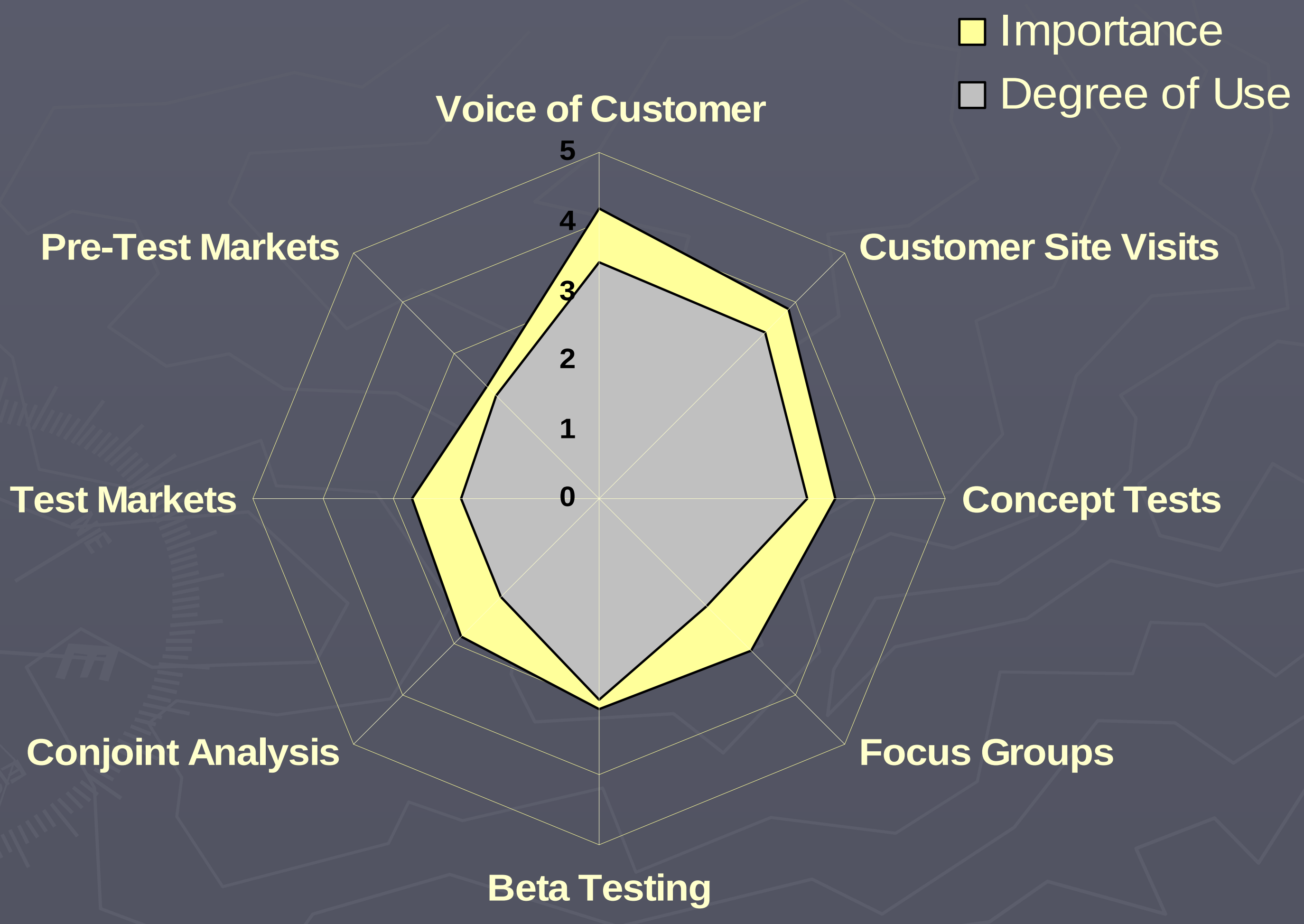


Percentage of Projects Using Multifunctional Teams

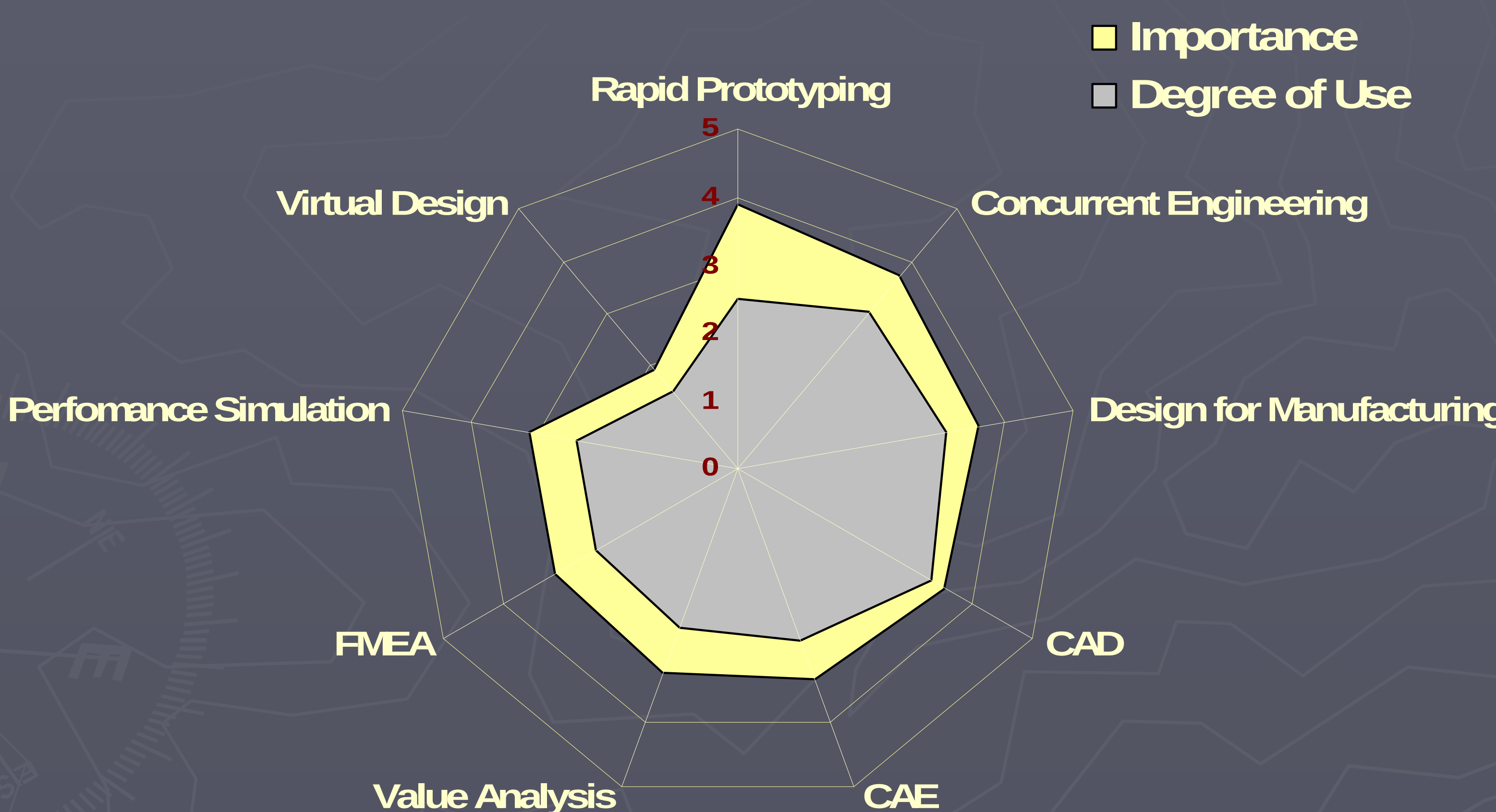


Tools

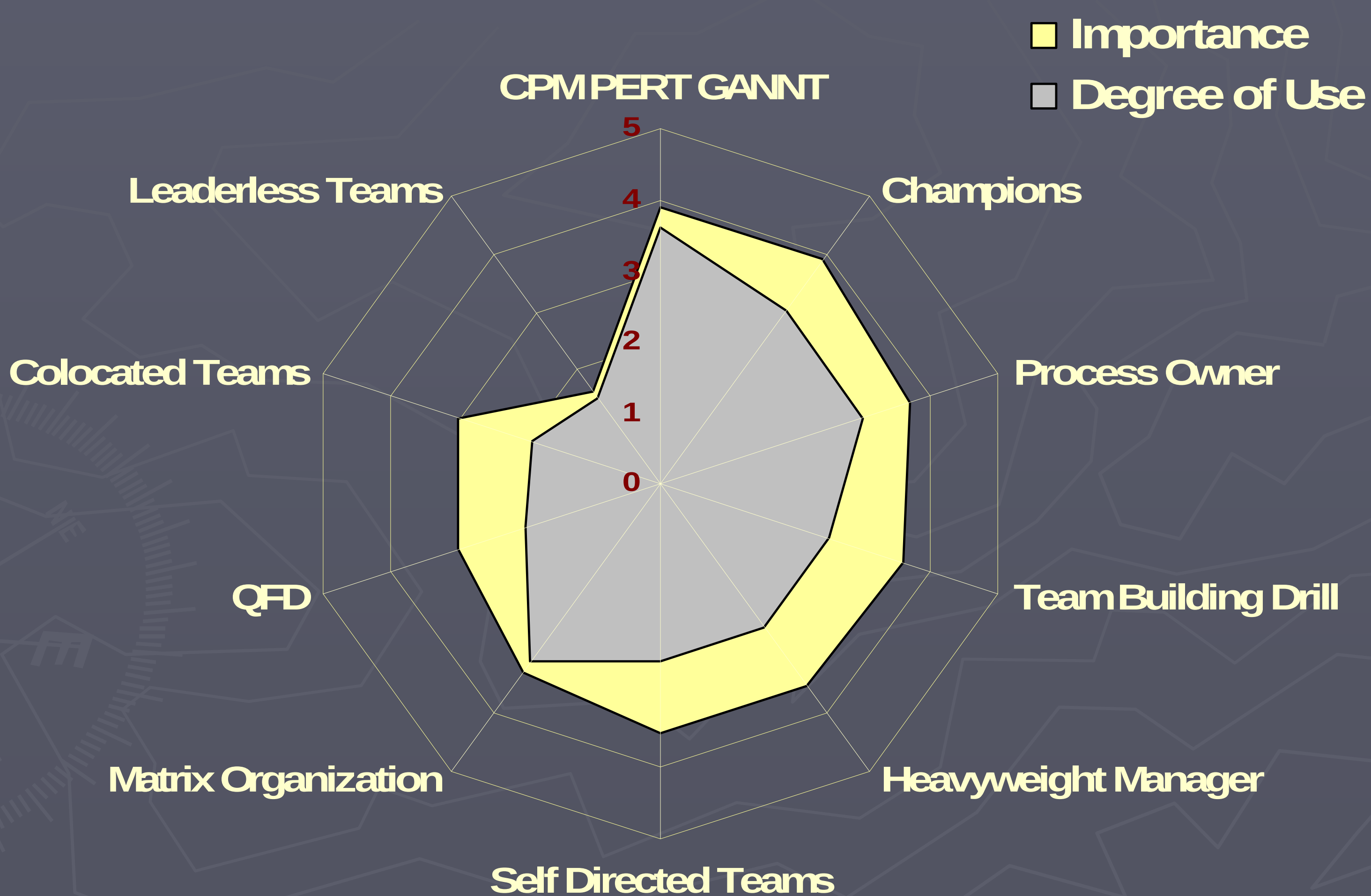
Perceived Importance and Use of Marketing Research Tools



Perceived Importance and Use of Engineering Tools



Perceived Importance and Use of Organization Tools



Perceived Importance: Top 5

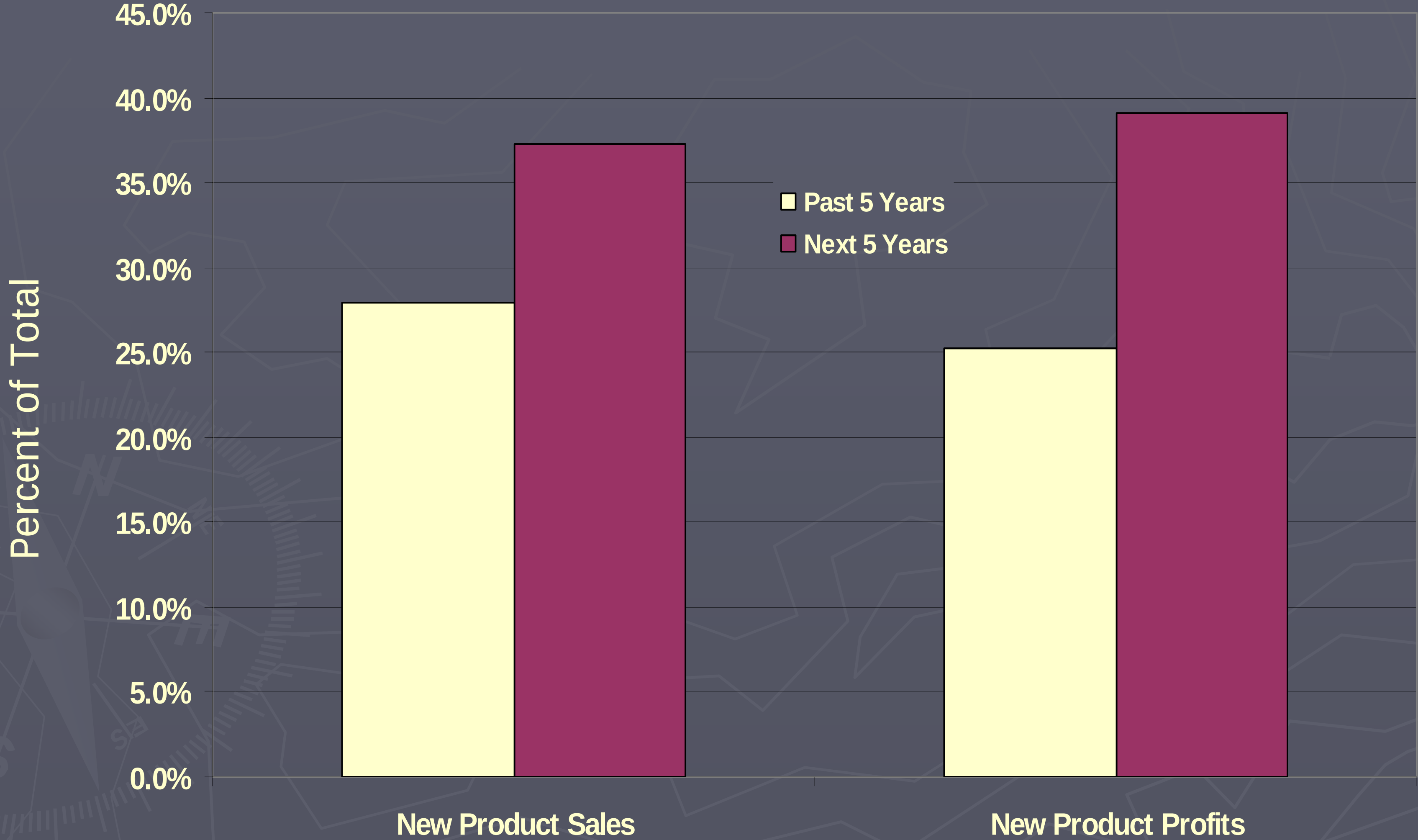
- Voice of the Customer (4.2)
- Customer Site Visits (3.9)
- Rapid Prototyping (3.9)
- Project Scheduling Tools (3.9)
- Product Champions (3.9)

Frequency of Use: Top 5

- Project Scheduling Tools (3.7)
- Voice of Customer (3.6)
- Customer Site Visits (3.5)
- Computer-Aided Design (3.4)
- Matrix Organizations (3.2)

Performance

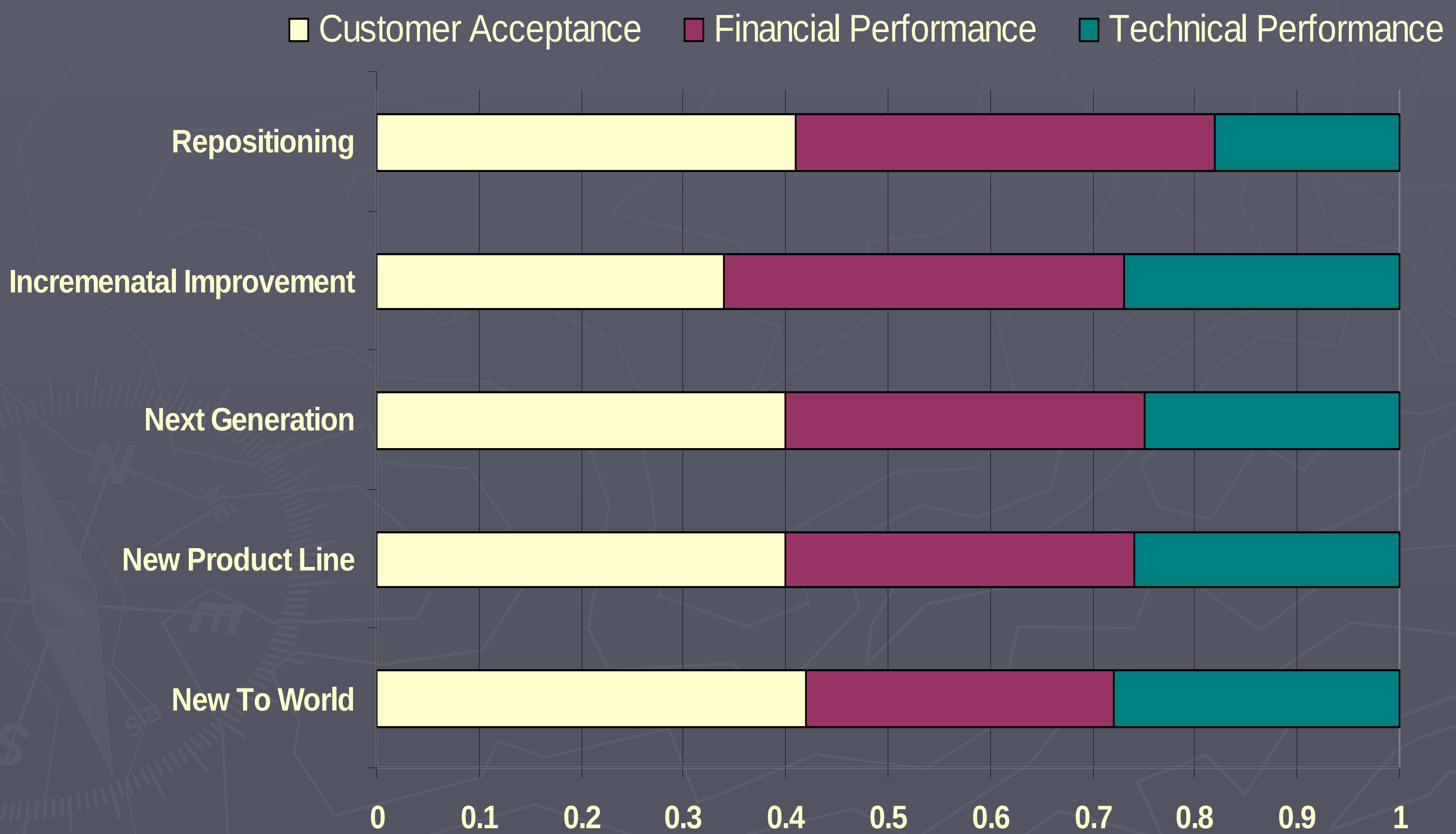
Past and Future Impact of New Products



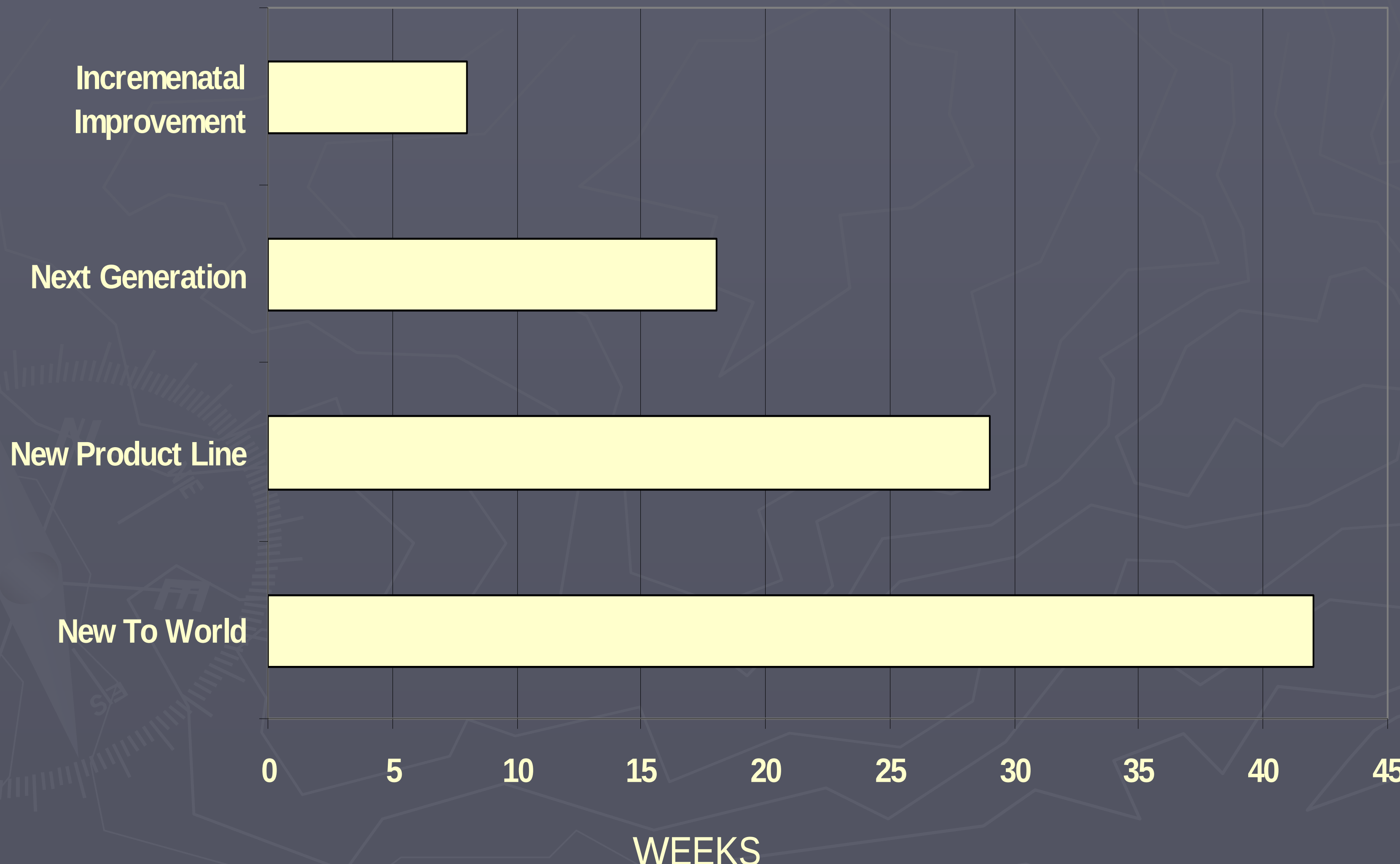
Product Success

► Successful Products (subjective)	55.9 %
► Profitable	51.7 %
► Still on market after 5 years	74.1 %

Performance Criteria



Average Length of Development Projects



Further Reading

- Rosenau et al. “The PDMA Handbook of New Product Development”
  - Data Source for preceding slides

- Cooper, Robert G. “Winning at New Products”
  - Stage-Gate Processes

Tools For Innovation: The Design Structure Matrix

Thomas A. Roemer

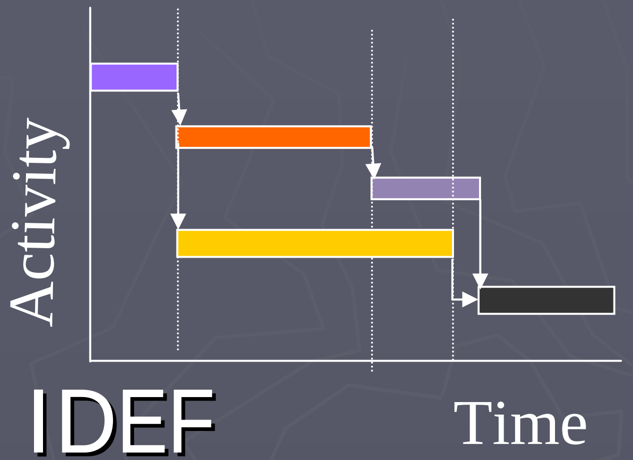
Spring 06, PD&D

Outline

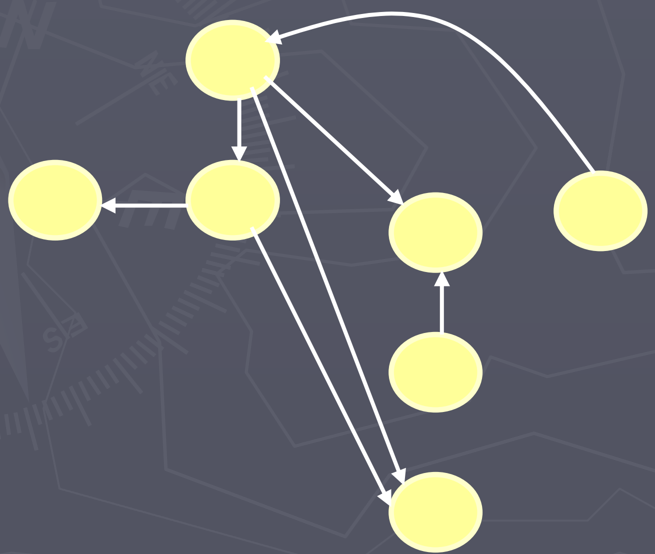
- Overview
  - Traditional Project Management Tools and Product Development
- Design Structure Matrix (DSM) Basics
  - How to create
  - Classification
- The Iteration Problem:
  - Increasing Development Speed
  - Sequencing, Partitioning and Simulation
- The Integration Problem:
  - DSM Clustering
  - Organizational Structures & Product Architectures

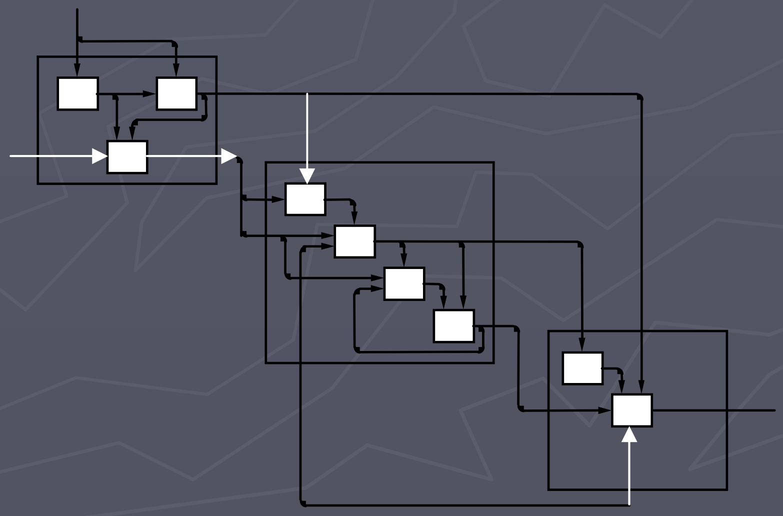
Classical Project Management Tools

- ►Gantt Charts



- ►Graph-based: PERT, CPM, IDEF





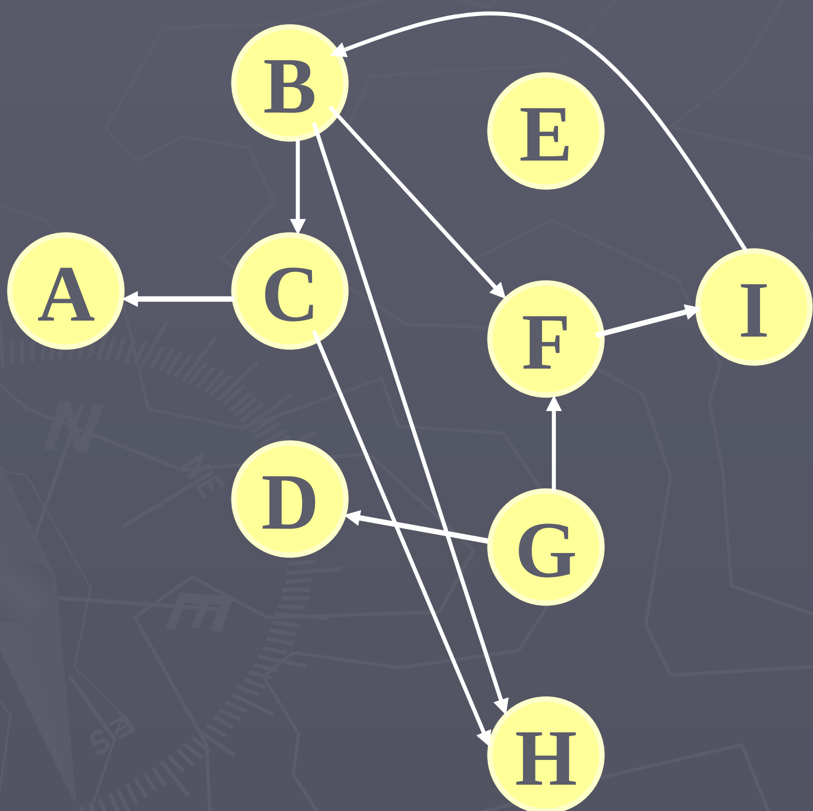
Characteristics

- Complex Depiction
- Focus on Work Flows
  - DSM focuses on Information Flows
- Ignore Iterations & Rework
  - Test results, Planned design reviews, Design mistakes, Coupled nature of the process
- Decomposition & Integration
  - Assume optimal Decomposition & Structure
  - Integration of Tasks not addressed

Design Iteration

- Iteration: The repetition of tasks due to new information.
  - Changes in input information (upstream)
  - Update of shared assumptions (concurrent)
  - Discovery of errors (downstream)
- Fundamental in Product development
  - Often times hidden
- Understanding Iterations requires
  - Visibility of information flows

A Graph and its DSM



	A	B	C	D	E	F	G	H	I
A	A		X						
B		B							X
C		X	C						
D				D			X		
E					E				
F		X				F	X		
G							G		
H		X	X					H	
I						X			I

Creating a DSM

- Design manuals
- Process sheets
- Structured expert interviews
  - Interview engineers and managers
  - Determine list of tasks or parameters
  - Ask about inputs, outputs, strengths of interaction, etc
  - Enter marks in matrix
  - Check with engineers and managers
- Questionnaires

Four Types of DSMs

Activity based DSM
Parameter based DSM

→

Iteration

Sequencing
Partitioning
Simulation

Team based DSM
Product Architecture DSM

→

Integration

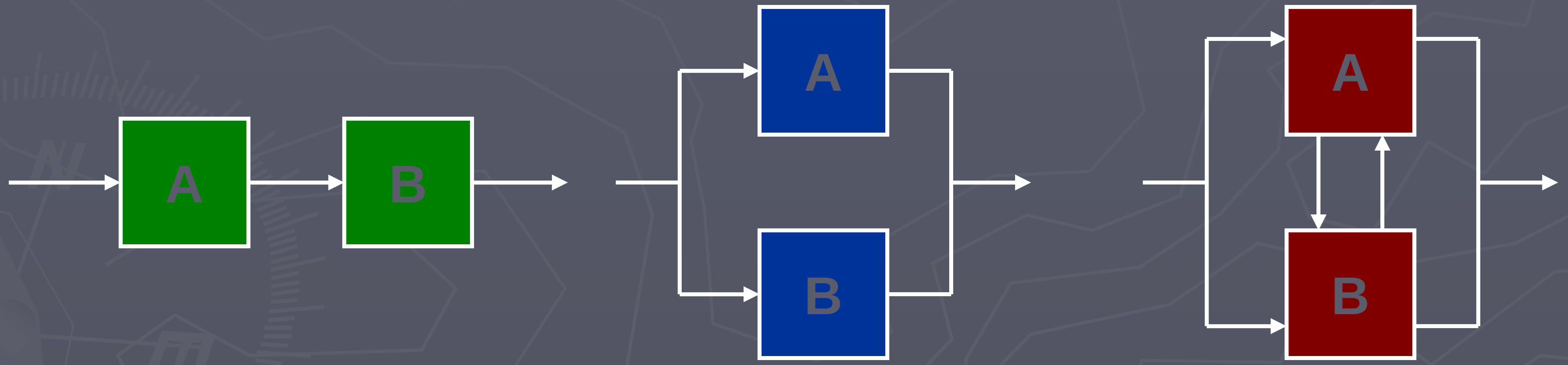
Clustering

Iteration Focused Tools

Concepts, Examples, Solution Approaches

Sequencing Tasks in Projects

Possible Relationships between Tasks



Dependent (Series)

Independent (Parallel)

Interdependent (Coupled)

DSM: Information Exchange Model

	A	B	C	D	E	F	G	H	I	J	K	L
A	•		X									
B		•										
C		X	•									
D				•	X	X						X
E					•	X		X			X	
F		X				•						X
G		X					•				X	
H	X			X			X	•			X	
I			X			X			•	X		
J		X	X							•	X	X
K		X	X				X				•	
L	X								X	X	X	•

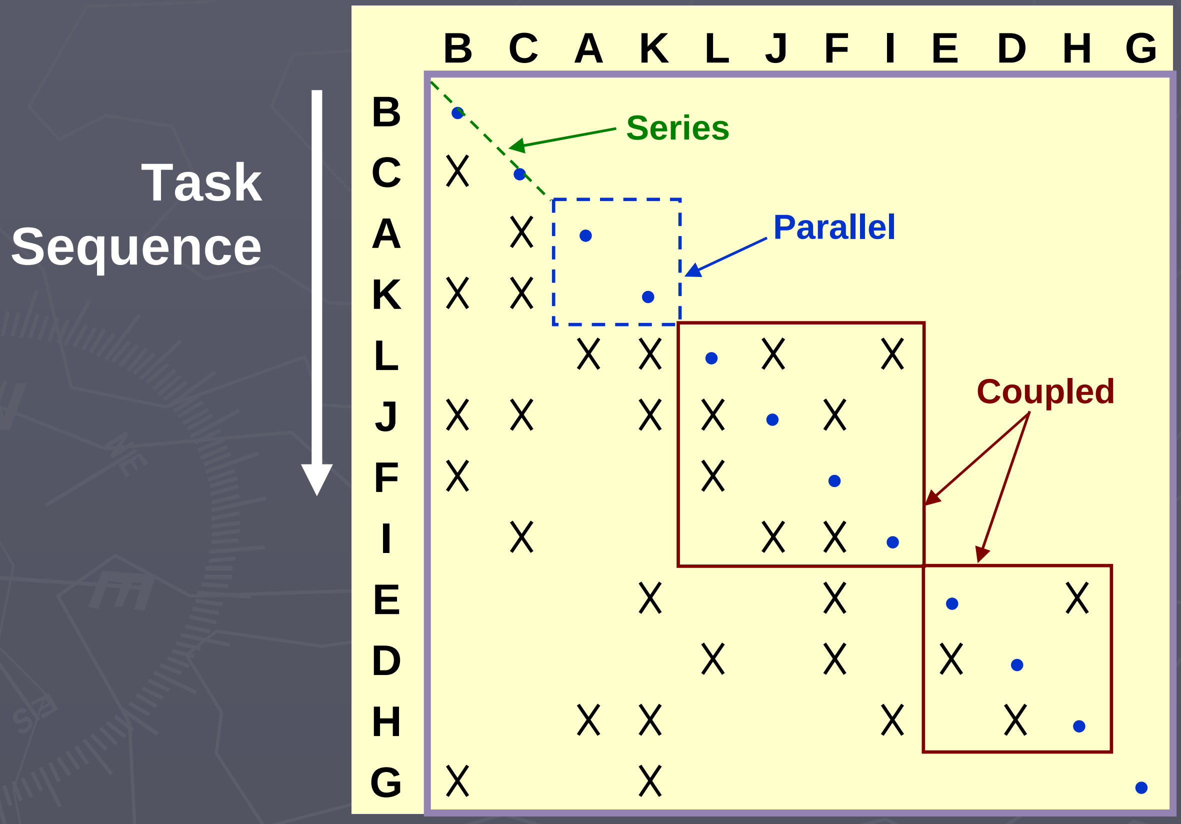
Interpretation:

- Rows: Required Information
  - D needs input from E, F & L.
- Columns: Provided Information
  - B transfers info to C,F,G,J & K.

Note:

- Information flows are easier to capture than work flows.
- Inputs are easier to capture than outputs.

DSM: Partitioned or Sequenced



Sequencing Algorithm

- Step 1: Schedule tasks with empty rows first
- Step 2: Delete the row and column for that task
- Step 3: Repeat (Go to step 1)
- Step 4: Schedule tasks with empty columns last
- Step 5: Delete the row and column for that task
- Step 6: Repeat (Go to step 4)
- Step 7: All the tasks that are left unscheduled are coupled. Group them into blocks around the diagonal

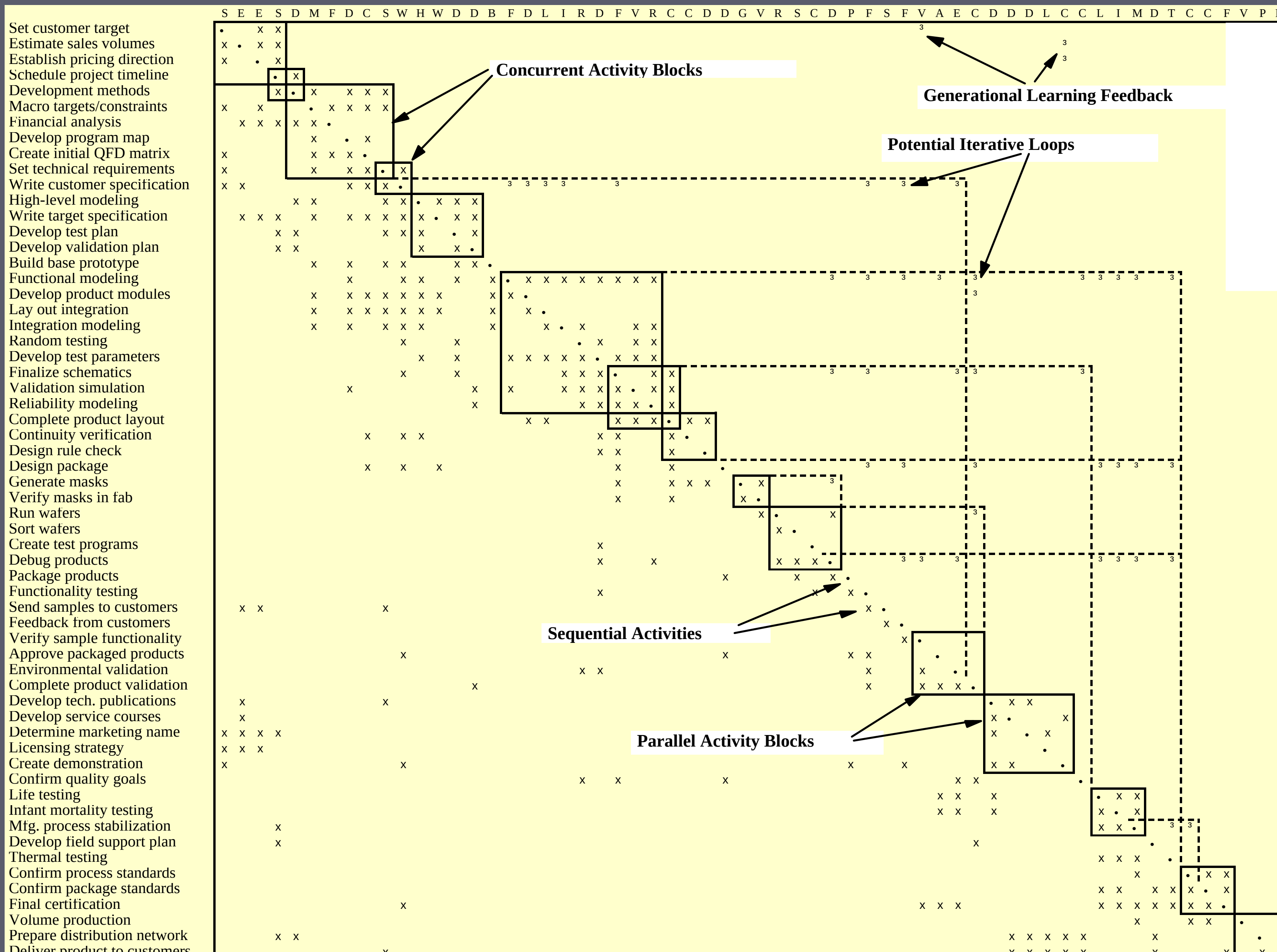
Example: Brake System Design

		1	2	3	4	5	6	7	8	9	10	11	12	13
Customer_Requirements	1	1												
Wheel Torque	2		2		X									
Pedal Mech. Advantage	3	X		3	X	X			X		X			X
System_Level_Parameters	4	X			4									
Rotor Diameter	5	X	X	X	X	5		X	X		X	X		X
ABS Modular Display	6		X				6			X				
Front_Lining_Coef._of_Friction	7			X	X	X		7	X		X			X
Piston-Rear Size	8		X		X				8		X			
Caliper Compliance	9			X	X					9	X			X
Piston- Front Size	10		X		X				X		10			
Rear Lining Coef of Friction	11			X	X	X			X		X	11		X
Booster - Max. Stroke	12												12	X
Booster Reaction Ratio	13		X	X	X	X		X	X	X	X	X	X	13

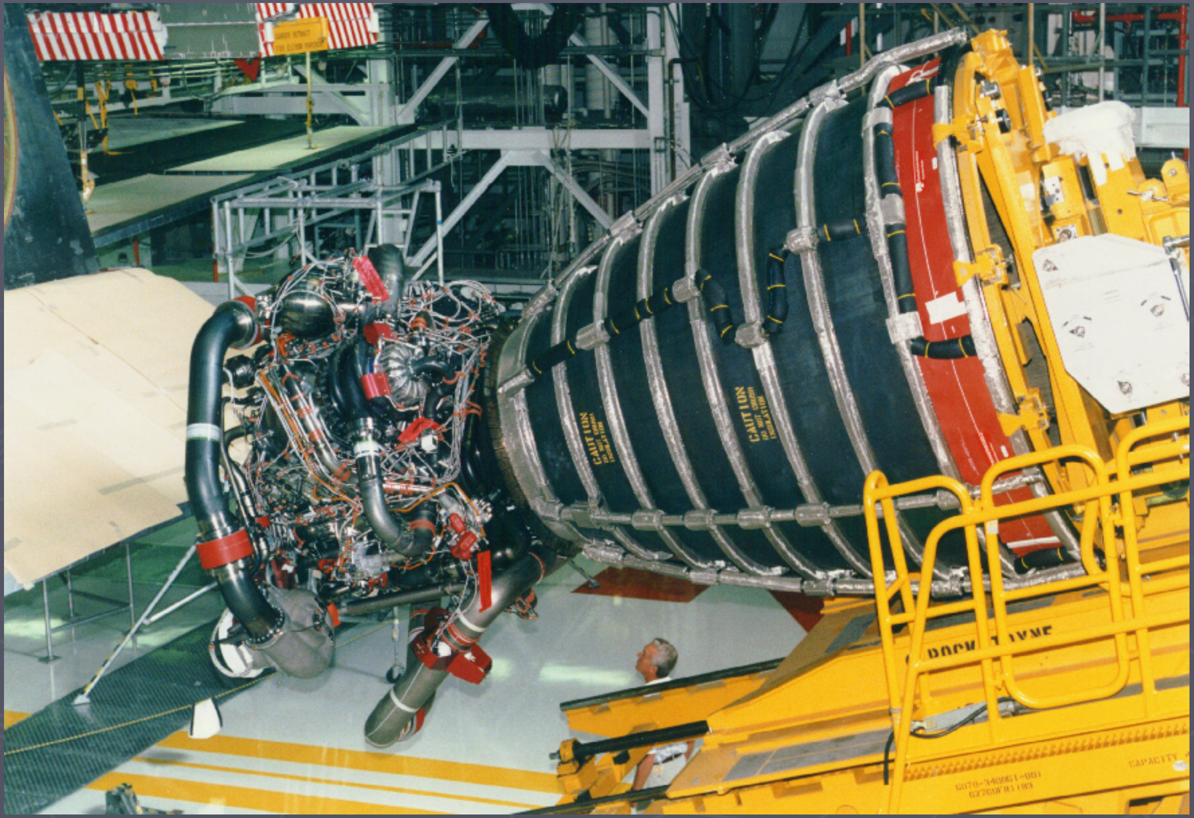
Partitioned DSM: Brake Design

		1	4	2	10	8	3	11	7	13	5	12	9	6
Customer_Requirements	1	1												
System_Level_Parameters	4	X	4											
Wheel Torque	2		X	2										
Piston- Front Size	10		X	X	10	X								
Piston-Rear Size	8		X	X	X	8								
Pedal Mech. Advantage	3	X	X		X	X	3			X	X			
Rear Lining Coef of Friction	11		X		X	X	X	11		X	X			
Front_Lining_Coef._of_Friction	7		X		X	X	X		7	X	X			
Booster Reaction Ratio	13		X	X	X	X	X	X	X	13	X			
Rotor Diameter	5	X	X	X	X	X	X	X	X	X	5			
Booster - Max. Stroke	12									X		12		
Caliper Compliance	9		X		X		X			X			9	
ABS Modular Display	6												X	6

Semiconductor Design Example

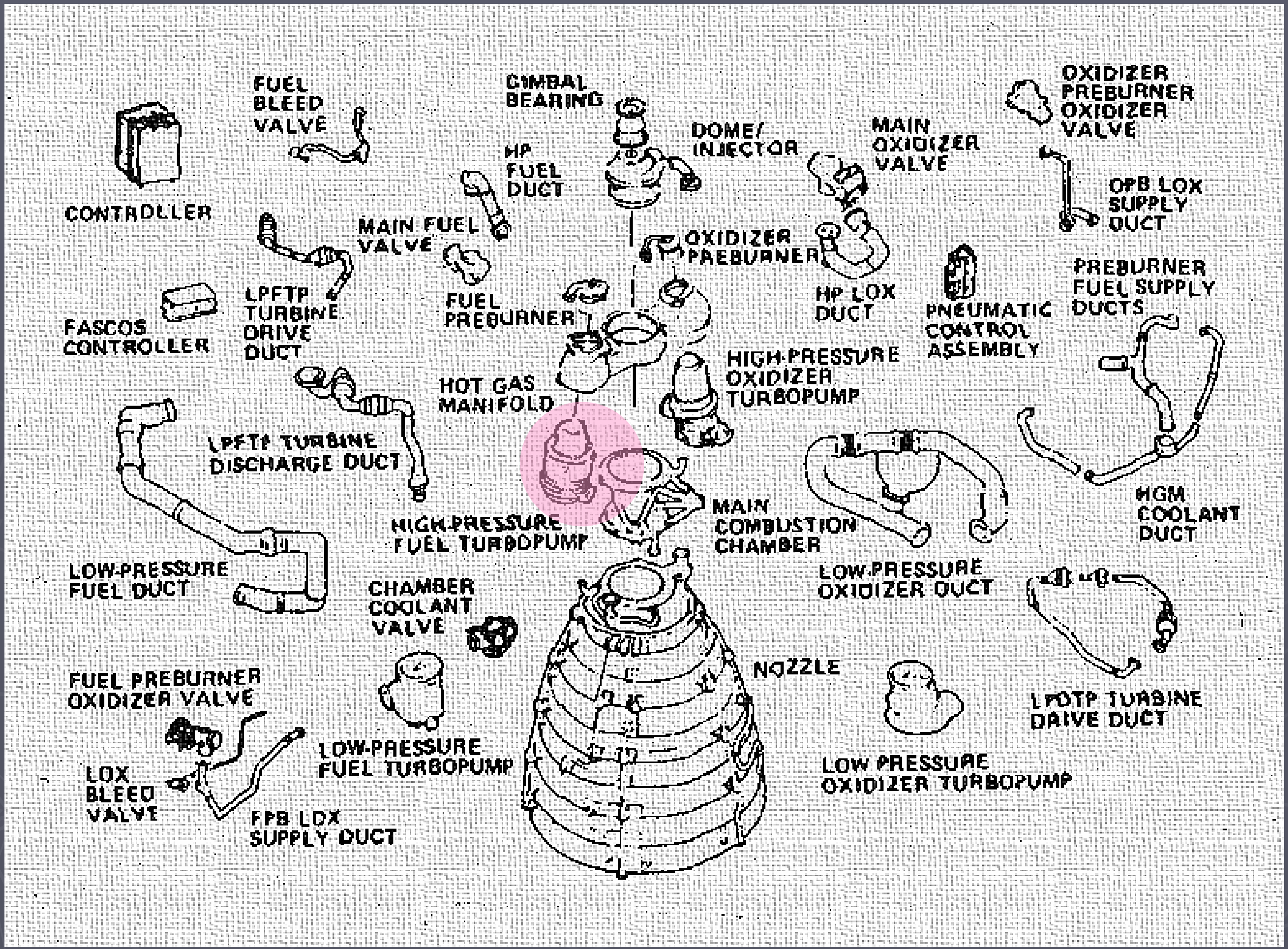


Task Sequencing Example



Space Shuttle Main Engine

Engine Components



Dependency Relations in Conceptual Design Block

ACTIVITIES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
SSP Engine Balance	1	4	0.15					0.1			0.1																	
CMT Make Preliminary Material Selections	2		1	0.1			0.1		0.1	0.1			0.1															
CST Assess Pump Housing	3			8	1																							
Design Pump Housing	4		0.5	0.2	4						1			1					0.1	1			0.1					
CST Assess Turbine Housing	5					4																						1
CST Compare Design Annulus Area...	6						1	1																				
CAX Determine Optimum Turbine Staging	7	1	0.1				0.1	6	0.1		1							0.2										0.1
CST Compare Design Pitchline Velocities...	8								1																			
CST Compare Design Impeller Tip Speed...	9									1	1																	
CHX Determine Pumping Components	10	1	0.1					0.2		0.1	6	0.2																
CDE Design Pumping Elements	11		0.5								1	8	0.3		0.1													
CST Evaluate Rotor Sizing	12											1	1					1										
CDE Incorporate Bearing Dimensions	13													2		1												
CDE Design Rotor	14		0.2									1		1	2			1	0.1	1			0.2			0.1		
CBR Determine Bearing Geometry	15				0.1								1		0.2	4	1									0.1		0.1
CDE Position Bearings and Selection	16		0.2					1			1			0.2			2											
CDE Design Turbine	17		0.2					1					0.3		0.1			4										
CDE Integrate Rotor and Structure Layout	18				1										1				8								0.1	1
CDE Incorporate Seal Dimensions	19																			1		1						
CSL Define Seal System	20		0.2		0.1			1			1									0.3	4							
CSL Define Individual Sealing Elements	21											0.1			0.2						1	2	0.1					0.1
CDE Develop Thrust Balance	22										0.2								1				6					
CRD Build Finite Element Model	23		0.1			0.3									1									1				
CRD Define Linear Rotordynamic Behavior	24							1			1					1						1		1	2			
CRD Evaluate Design	25																								1	1		
CDE Analyze Weight	26																		1							0.2	4	
Design Turbine Housing	27		0.5			0.1		1						1					0.2	1			0.1					4

Block Decomposition

$$\min \sum_{ij \in A} a_{ij} n_{ij} y_{ij}$$

s.t.

$$\sum_{m=1}^{M} x_{im} = 1, \quad \forall\, i$$

$$\sum_{i=1}^{N} x_{im} \le C, \quad \forall\, m$$

$$x_{im} - \sum_{h=m+1}^{M} x_{jh} - y_{ij} \le 0, \quad \forall\, i, j, m$$

$$x_{im}, y_{ij} \in \{0,1\}, \quad \forall\, i, j, m$$

i,j = index for activities, $i,j = 1,2,\ldots,N$;

m = index for stages, $m = 1,2,\ldots,M$;

A = the set of directed arcs in the design graph;

a_{ij} = the level of dependency of activity i on j

$$x_{im} = \begin{cases} 1 & \text{if activity } i \text{ is assigned to stage } m \\ 0 & \text{otherwise} \end{cases}$$

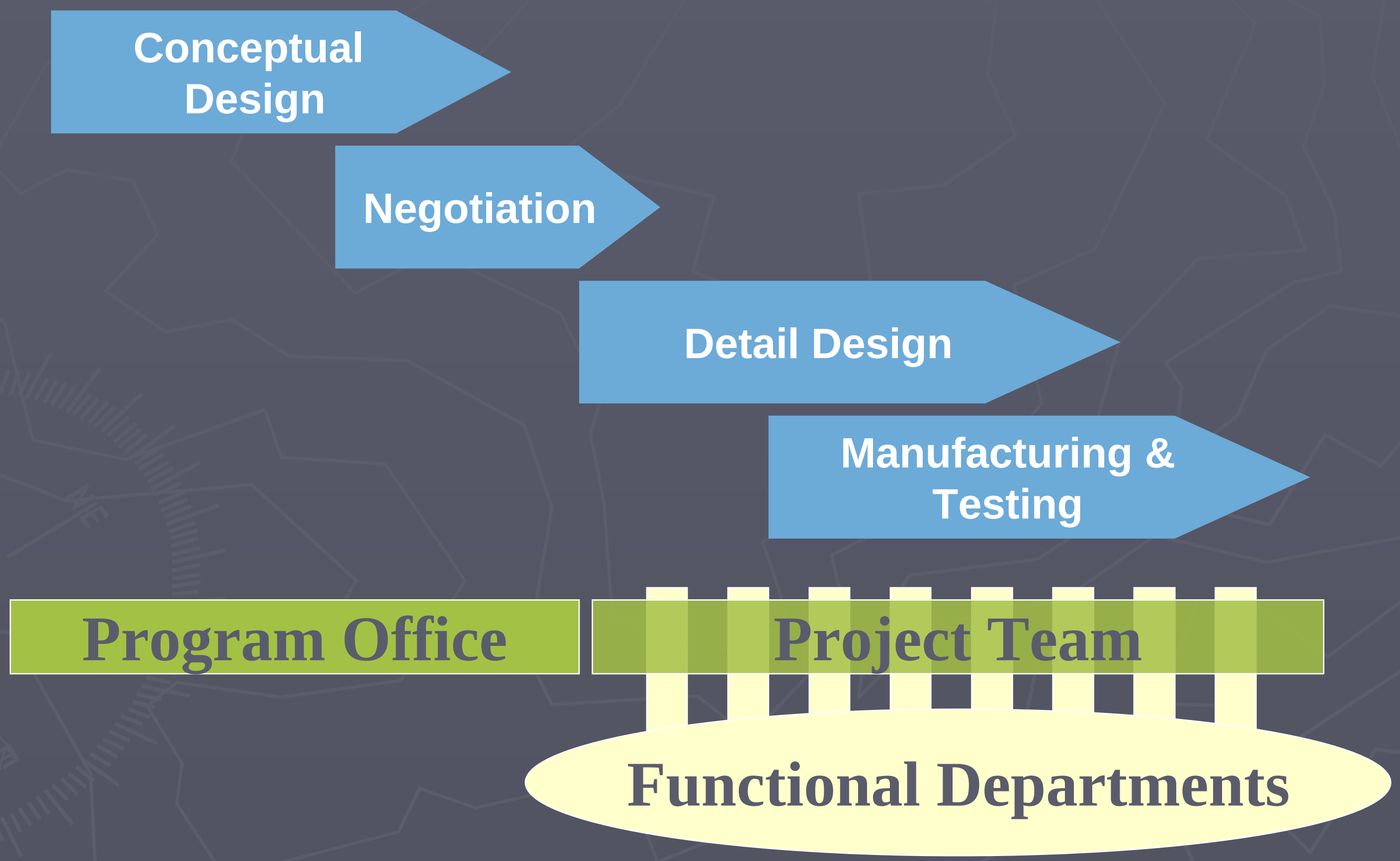
$$y_{ij} = \begin{cases} 0 & \text{if arc } ij \text{ is a feed back between stages} \\ 1 & \text{otherwise} \end{cases}$$

$$n_{ij} = \begin{cases} W & \text{(a large number) if } a_{ij} = 1 \\ 1 & \text{otherwise} \end{cases}$$

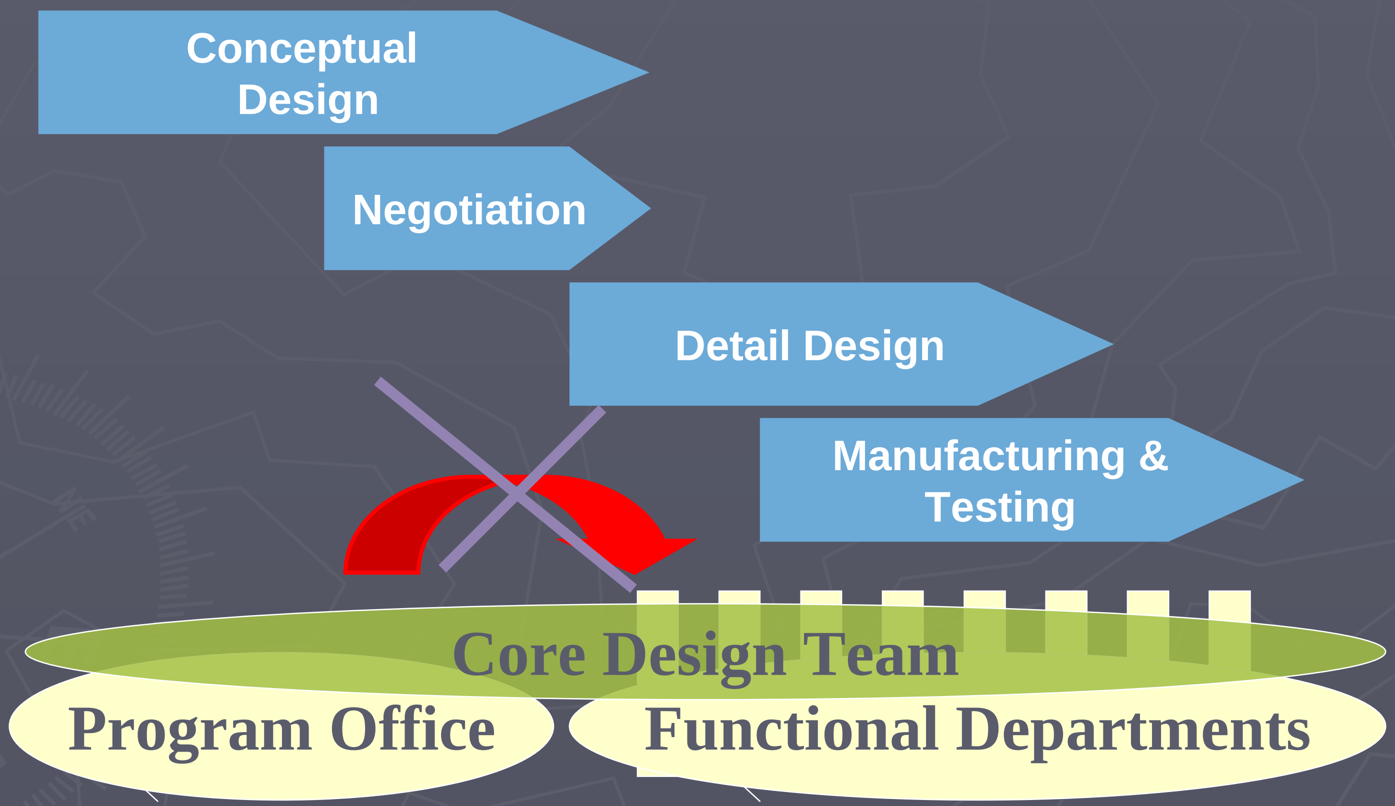
Resulting Structure for Conceptual Design Block

ACTIVITIES		1	10	9	2	7	8	17	11	12	6	16	20	21	19	15	13	4	3	27	14	18	22	5	23	24	25	26
SSP Engine Balance	1	4	0.1		0.15	0.1																						
CHX Determine Pumping Components	10	1	6	0.1	0.1	0.2			0.2																			
CST Compare Design Impeller Tip Speed…	9		1	1																								
IT Make Preliminary Material Selections	2			0.1	1		0.1			0.1	0.1								0.1									
CAX Determine Optimum Turbine Staging	7	1	1		0.1	6	0.1	0.2			0.1									0.1								
ST Compare Design Pitchline Velocities…	8						1																					
CDE Design Turbine	17				0.2	1		4		0.3											0.1							
CDE Design Pumping Elements	11		1		0.5				8	0.3											0.1							
CST Evaluate Rotor Sizing	12							1	1	1																		
CST Compare Design Annulus Area…	6					1					1																	
CDE Position Bearings and Selection	16		1		0.2	1						2					0.2											
CSL Define Seal System	20		1		0.2	1							4		0.3			0.1										
CSL Define Individual Sealing Elements	21								0.1				1	2						0.1	0.2		0.1					
CDE Incorporate Seal Dimensions	19													1	1													
CBR Determine Bearing Geometry	15									1		1				4		0.1		0.1	0.2						0.1	
CDE Incorporate Bearing Dimensions	13															1	2											
Design Pump Housing	4		1		0.5										1		1	4	0.2			0.1	0.1					
CST Assess Pump Housing	3																	1	8									
Design Turbine Housing	27				0.5	1									1		1			4		0.2	0.1	0.1				
CDE Design Rotor	14				0.2			1	1						1		1				2	0.1	0.2				0.1	
DE Integrate Rotor and Structure Layout	18																	1		1	1	8						0.1
CDE Develop Thrust Balance	22		0.2																			1	6					
CST Assess Turbine Housing	5																			1				4				
CRD Build Finite Element Model	23				0.1																1			0.3	1			
RD Define Linear Rotordynamic Behavior	24		1			1								1		1									1	2		
CRD Evaluate Design	25																									1	1	
CDE Analyze Weight	26																					1					0.2	4

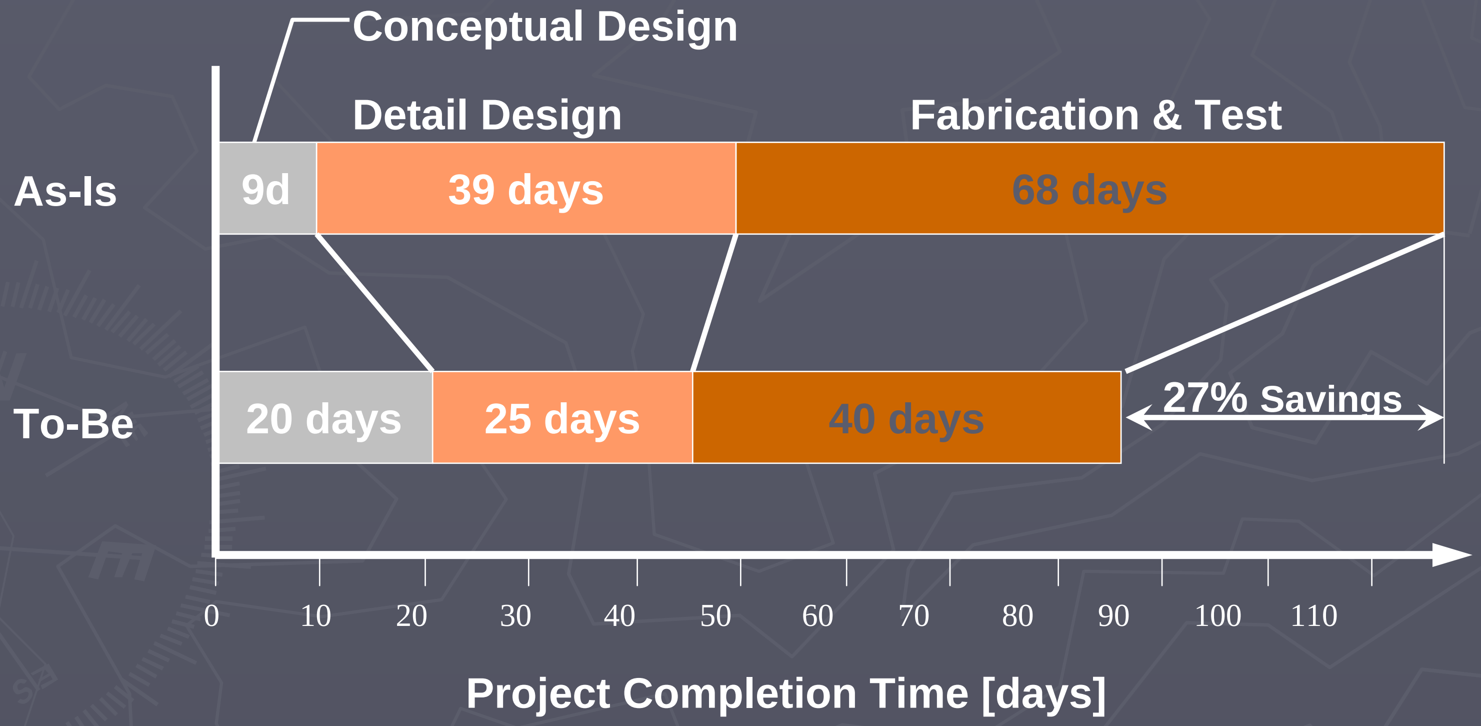
STC's Existing Process



Proposed Process



Pilot Project Performance



DSM Simulation

Task A			X
Task B	X		
Task C		X	

- Task A requires input from task C
- Perform A by assuming a value for C’s output
- Deliver A’s output to B
- Deliver B’s output to C
- Feed C’s output back to A
  - Check initial assumption (made by A)
- Update assumption and repeat task A.

Simulating Rework

Task A			**R**
Task B	**X**		
Task C		**X**	

R is the probability that Task A will be repeated once task C has finished its work.

R = 0.0 : There is 0 chance that A will be repeated based on results of task C.
R = 1.0 : There is 100% probability that A will be repeated based on results of task C.

Simulating 2^{nd} Order Rework

Task A			X
Task B	R2		
Task C		X	

Second Order rework is the rework associated with forward information flows that is triggered by feedback marks.

First order rework: Output of task C causes task A to do some rework
2^{nd} order rework: Consequently there is a chance tasks depending on A (e.g. task B) will also be repeated.

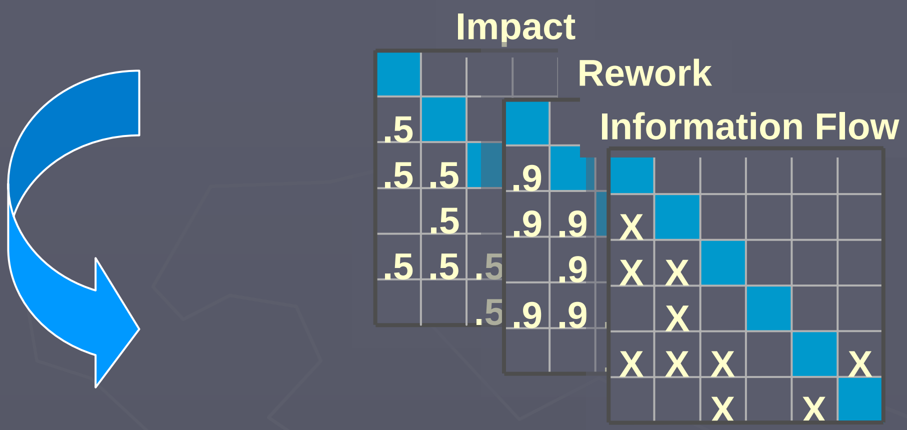
Simulating Rework Impact

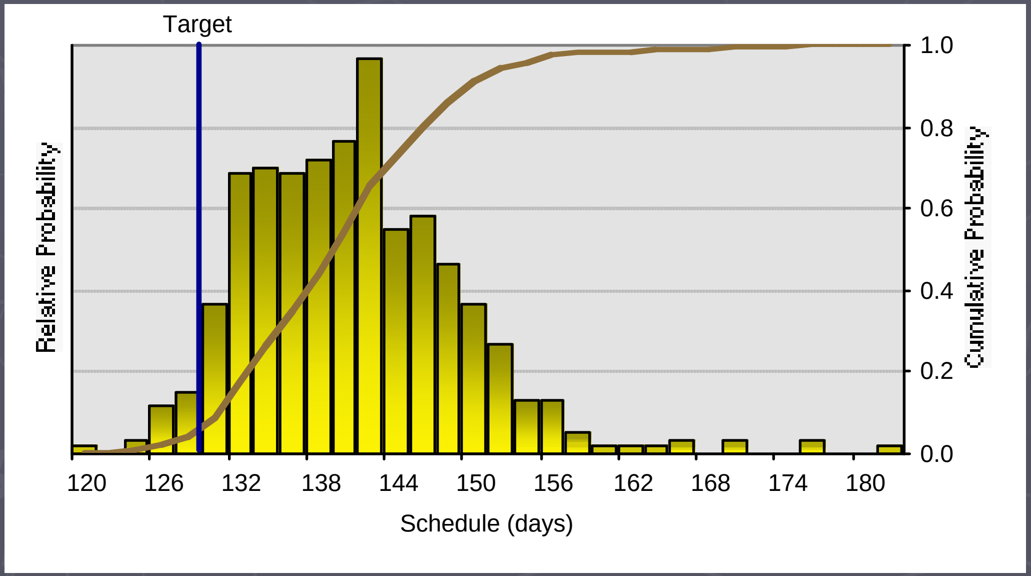
Task A			**I**
Task B	**X**		
Task C		**X**	

I = 0.0 : If task A is reworked due to task C results, then 0% of task A's initial duration will be repeated

I = 1.0 : If task A is reworked due to task C results, then 100% of task A's initial duration will be repeated

Simulation Results

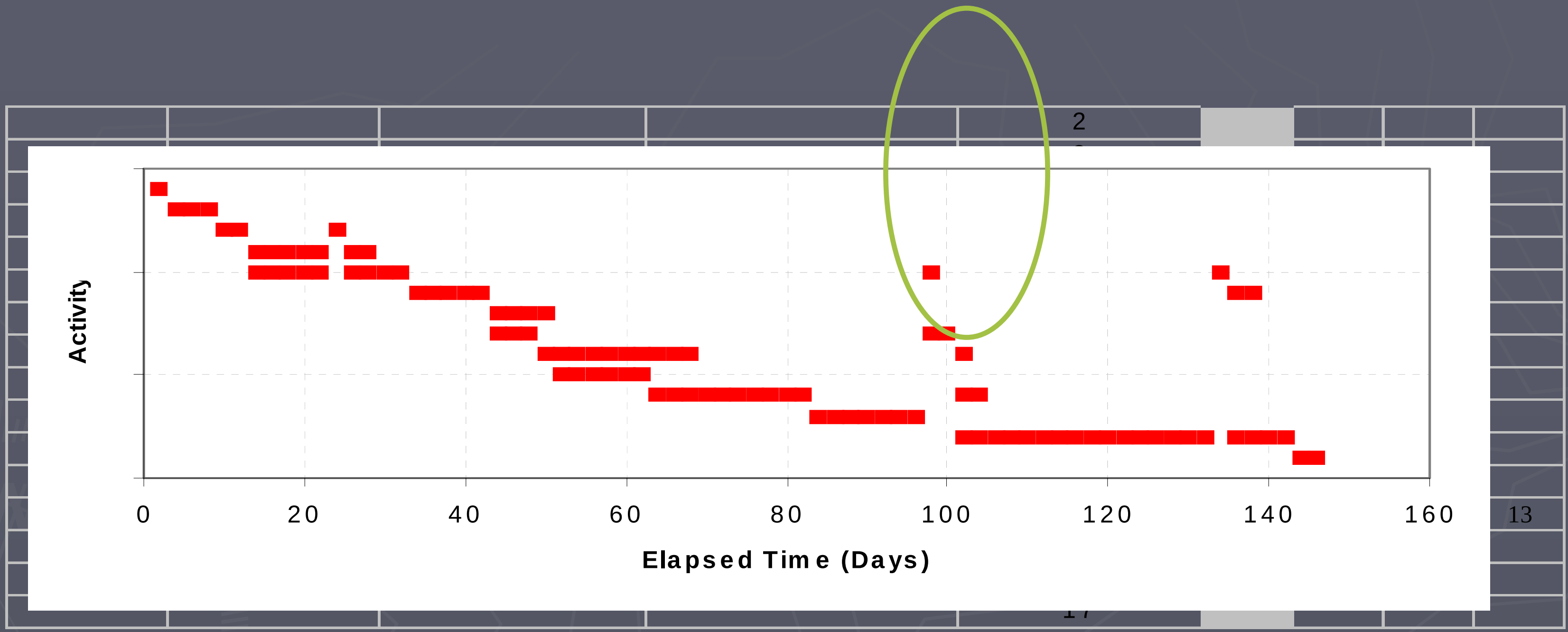




- DSM contains rework probabilities and impacts
- Cost and time add up
- Many runs produce a distribution of total time and cost
- Different task sequences can be tried

Source: "Modeling and Analyzing Complex System Development Cost, Schedule, and Performance" Tyson R. Browning PhD Thesis, MIT A&A Dept., Dec 99

Gantt Chart with Iteration



- Typical Gantt chart shows monotone progress
- Actual project behavior includes tasks stopping, restarting, repeating and impacting other tasks

Source: "Modeling and Analyzing Complex System Development Cost, Schedule, and Performance" Tyson R. Browning PhD Thesis, MIT A&A Dept., Dec 99

Lessons Learned: Iteration

- Development is inherently iterative
- Understanding of coupling is essential
- Iterations improve quality but consumes time
- Iteration can be accelerated through
  - Information technology (faster iterations)
  - Coordination techniques (faster iterations)
  - Decreased coupling (fewer iterations)
- Two Types of Iteration
  - Planned Iterations (getting it right the first time)
  - Unplanned iterations (fixing it when it's not right)

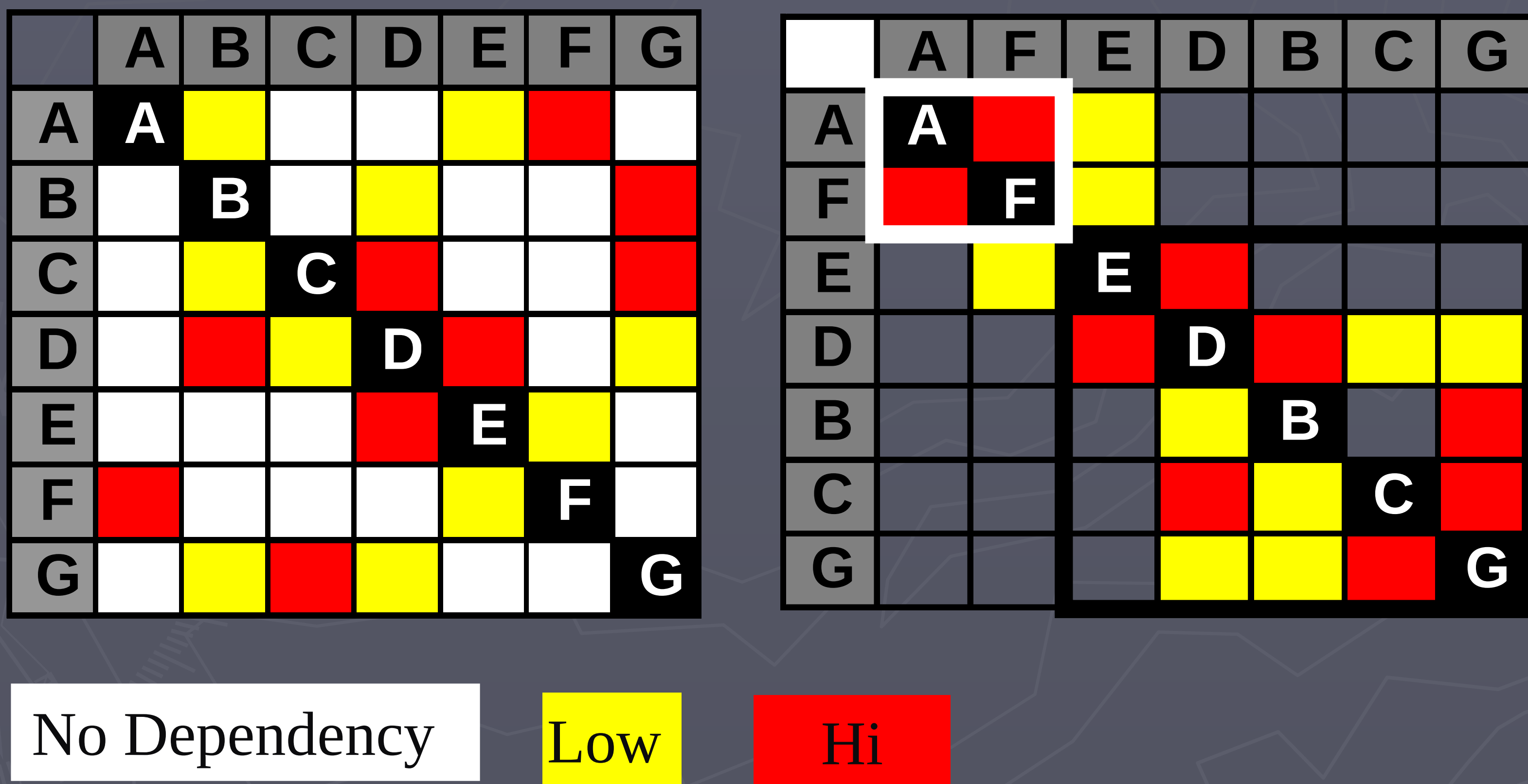
Integration Focused Tools

Concepts, Examples, Solution Approaches

Team Selection

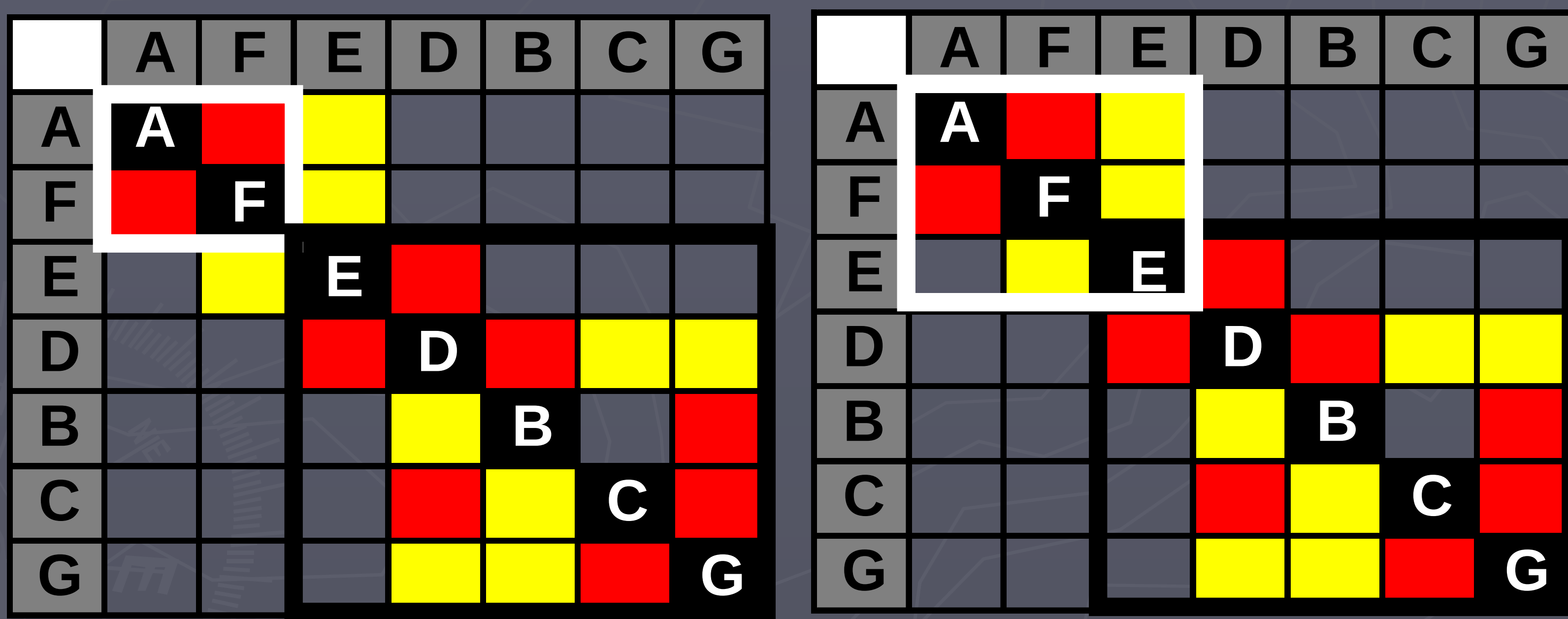
- Team assignment is often opportunistic
  - "We just grab whoever is available."
- Not easy to tell who should be on a team
- Tradition groups people by function
- Info flow suggests different groupings
- Info gathered by asking people to record their interaction frequency with others

Clustering a DSM



Alternative Arrangement

Overlapped Teams



No Dependency

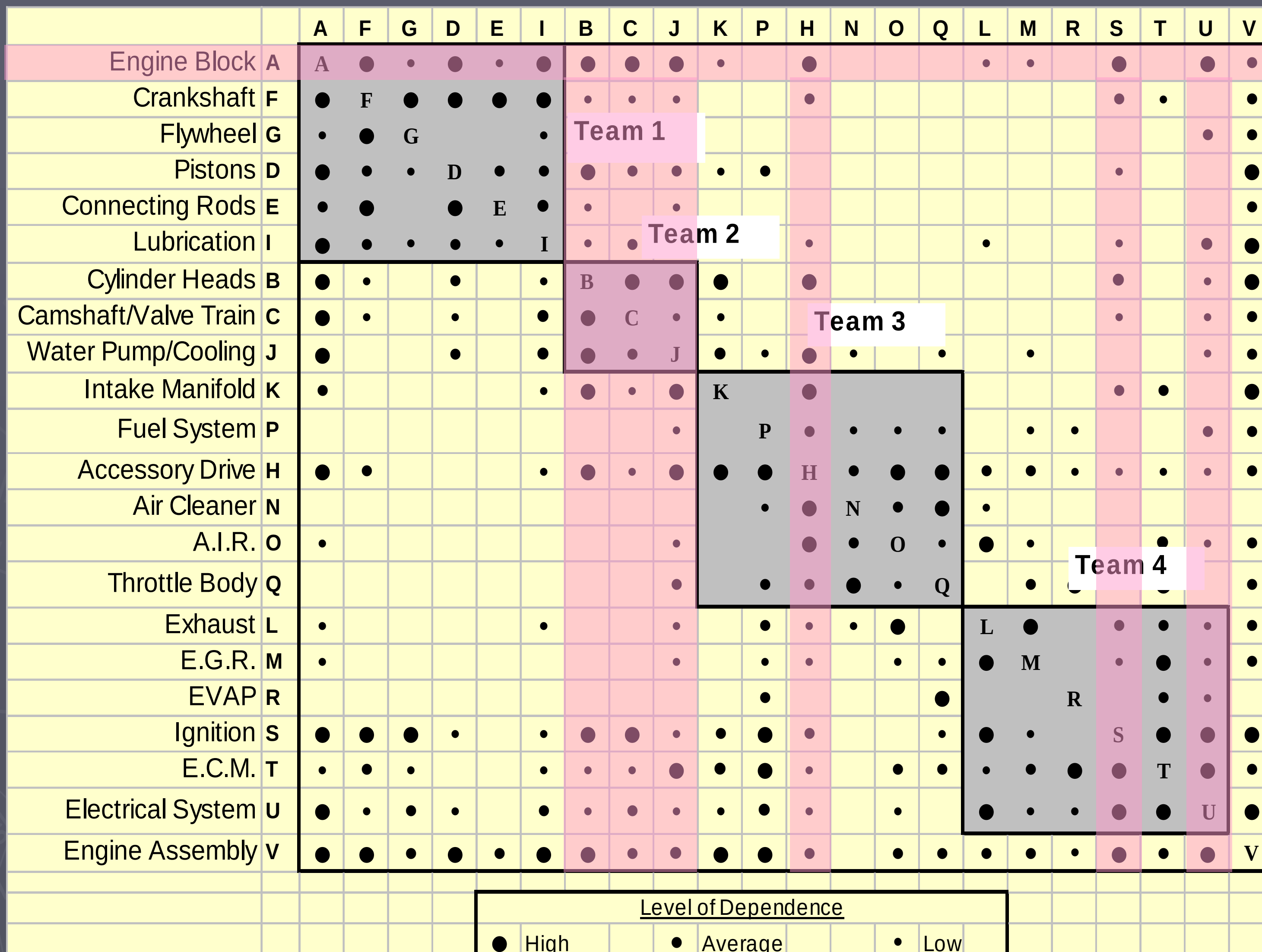
Low

Hi

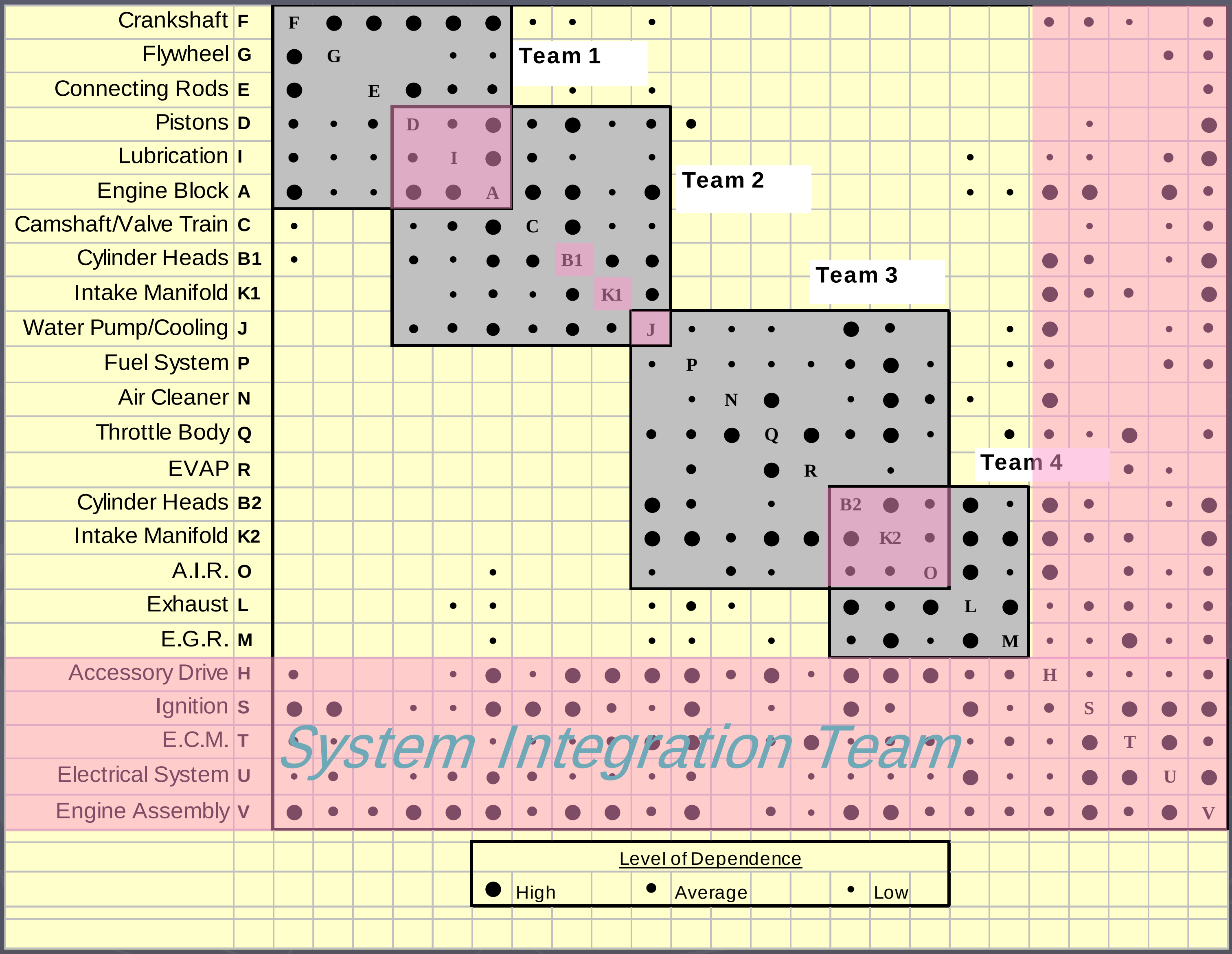
GM's Powertrain Division

- 22 Development Teams into four System Teams
  - Short block: block, crankshaft, pistons, conn. rods, flywheel, lubrication
  - Valve train: cylinder head, camshaft and valve mechanism, water pump and cooling
  - Induction: intake manifold, accessory drive, air cleaner, throttle body, fuel system
  - Emissions & electrical: Exhaust, EGR, EVAP, electrical system, electronics, ignition

Existing PD System Teams



Proposed PD System Teams



Lessons Learned: Integration

- Large development efforts require multiple activities to be performed in parallel.
- The many subsystems must be integrated to achieve an overall system solution.
- Mapping the information dependence reveals an underlying structure for system engineering.
- Organizations and architectures can be designed based upon this structure.

Conclusions

- The DSM supports a major need in product development:
  - documenting information that is exchanged
- It provides visually powerful means for designing, upgrading, and communicating product development activities
- It has been used in industry successfully

Additional Material

- Eppinger, S.D., "Innovation at the Speed of Information," Harvard Business Review, January, 3-11, 2001.