Design for Manufacturing

Teaching materials to accompany:

Product Design and Development
Chapter 11

Karl T. Ulrich and Steven D. Eppinger
2nd Edition, Irwin McGraw-Hill, 2000.

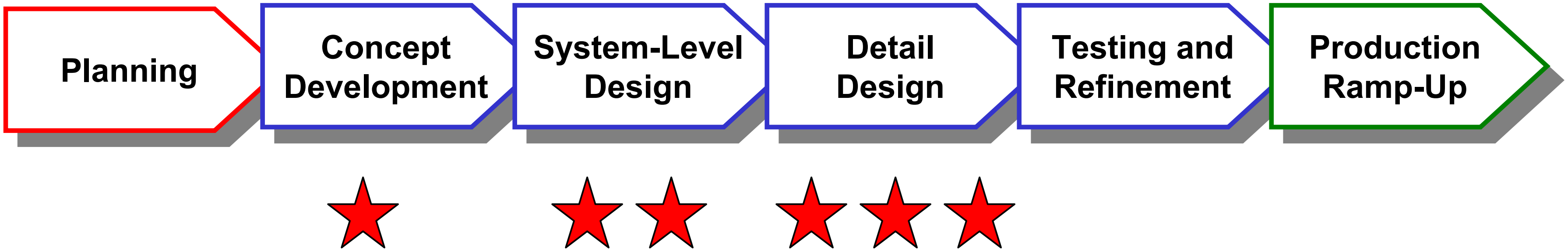
Product Design and Development

Karl T. Ulrich and Steven D. Eppinger

2nd edition, Irwin McGraw-Hill, 2000.

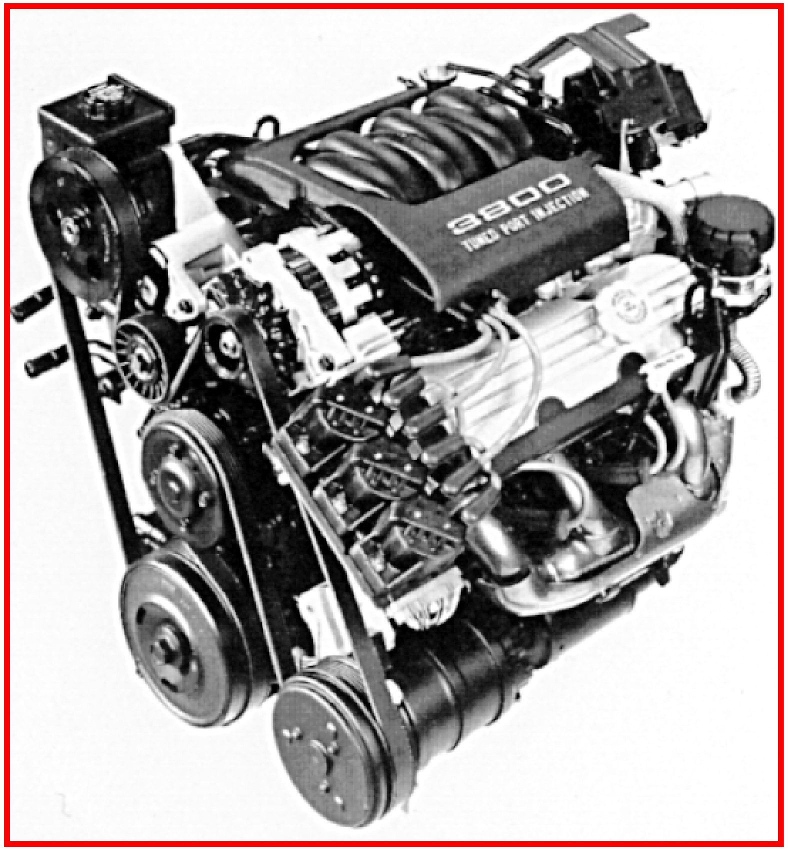
Chapter Table of Contents

Product Development Process

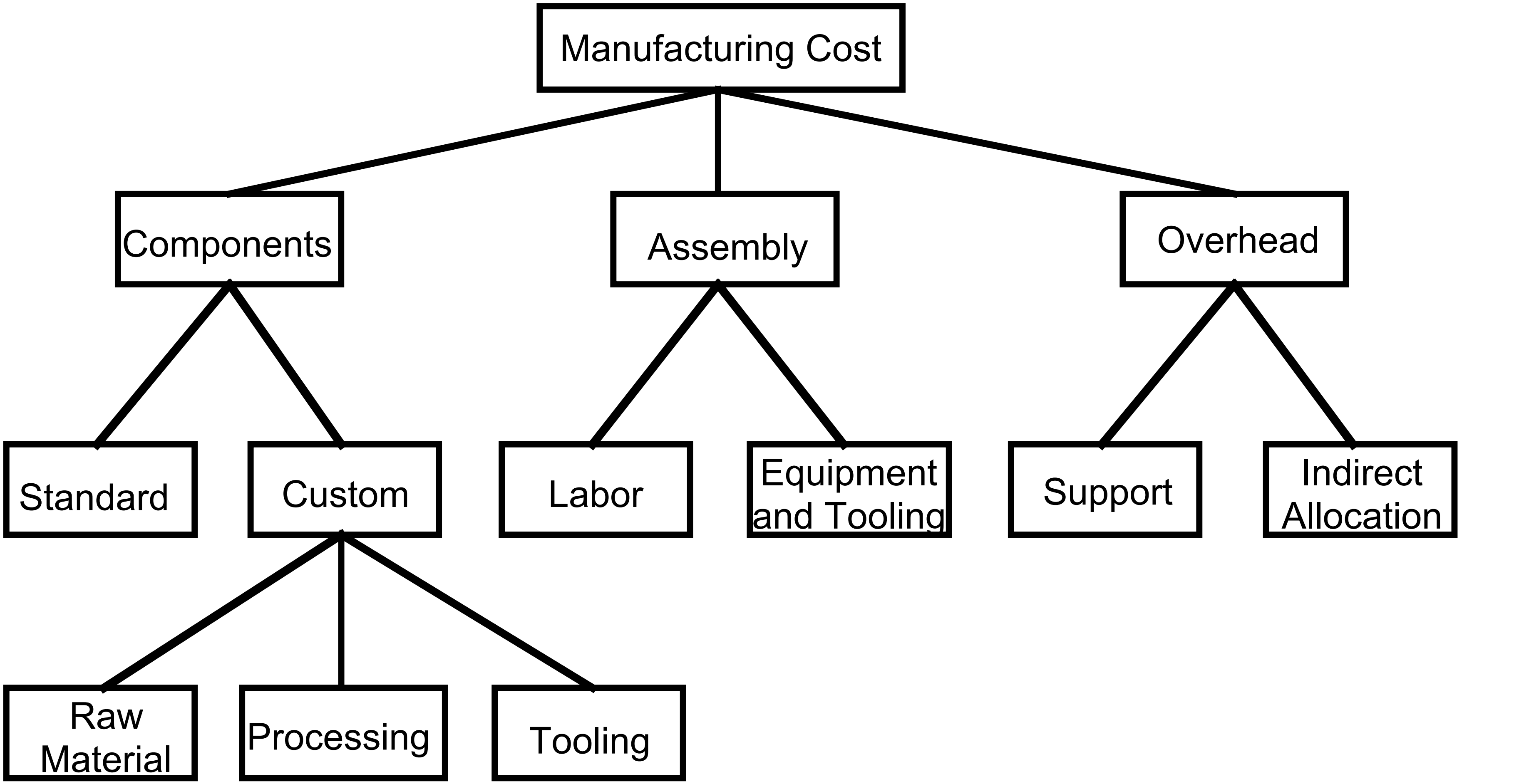


How can we emphasize manufacturing issues throughout the development process?

Design for Manufacturing Example: GM 3.8-liter V6 Engine



Understanding Manufacturing Costs



Definition

- **Design for manufacturing (DFM) is a development practice emphasizing manufacturing issues throughout the product development process.**
- **Successful DFM results in lower production cost without sacrificing product quality.**

Three Methods to Implement DFM

1. Organization: Cross-Functional Teams

2. Design Rules: Specialized by Firm

3. CAD Tools: Boothroyd-Dewhurst Software

Design for Assembly Rules

Example set of DFA guidelines from a computer manufacturer.

1. Minimize parts count.
2. Encourage modular assembly.
3. Stack assemblies.
4. Eliminate adjustments.
5. Eliminate cables.
6. Use self-fastening parts.
7. Use self-locating parts.
8. Eliminate reorientation.
9. Facilitate parts handling.
10. Specify standard parts.

Design for Assembly

- Key ideas of DFA:
  - Minimize parts count
  - Maximize the ease of handling parts
  - Maximize the ease of inserting parts
- Benefits of DFA
  - Lower labor costs
  - Other indirect benefits
- Popular software developed by Boothroyd and Dewhurst.
  - http://www.dfma.com

To Compute Assembly Time

Handling Time

+ Insertion Time

Assembly Time

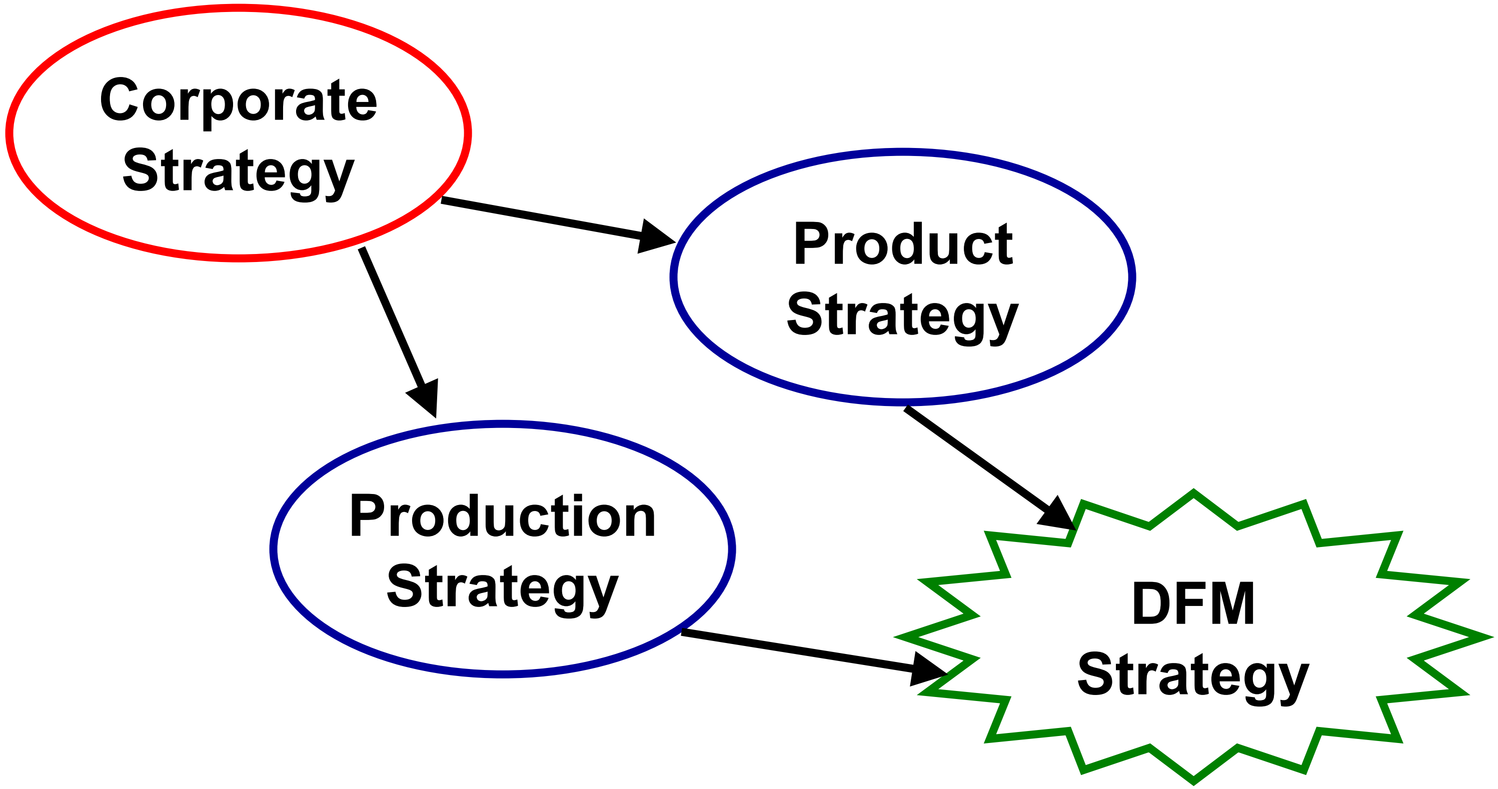
Method for Part Integration

- Ask of each part in a candidate design:
  1. Does the part need to move relative to the rest of the device?
  2. Does it need to be of a different material because of fundamental physical properties?
  3. Does it need to be separated from the rest of the device to allow for assembly, access, or repair?
- If not, combine the part with another part in the device.

Videocassette DFM Exercise

- 2 billion worldwide annual volume
- 7 major producers of 1/2” cassette shells
- JVC licenses the VHS standard
  - dimensions, interfaces, light path, etc
- VHS cassette shells cost ~$0.25 each
- What is a $0.01 cost reduction worth?

DFM Strategy is Contingent



Concept Generation

Teaching materials to accompany:

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Chapter 6

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Product Design and Development

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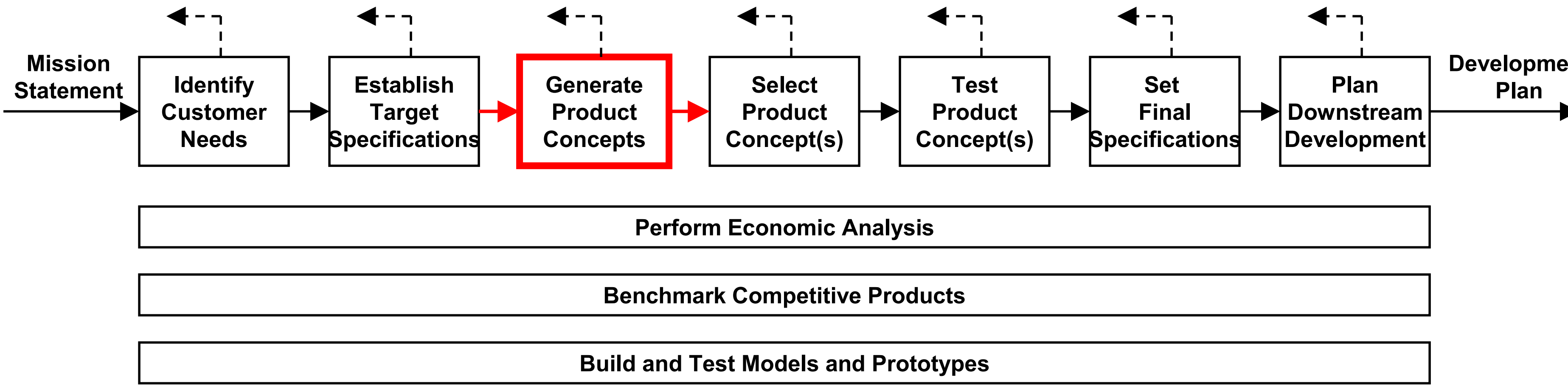
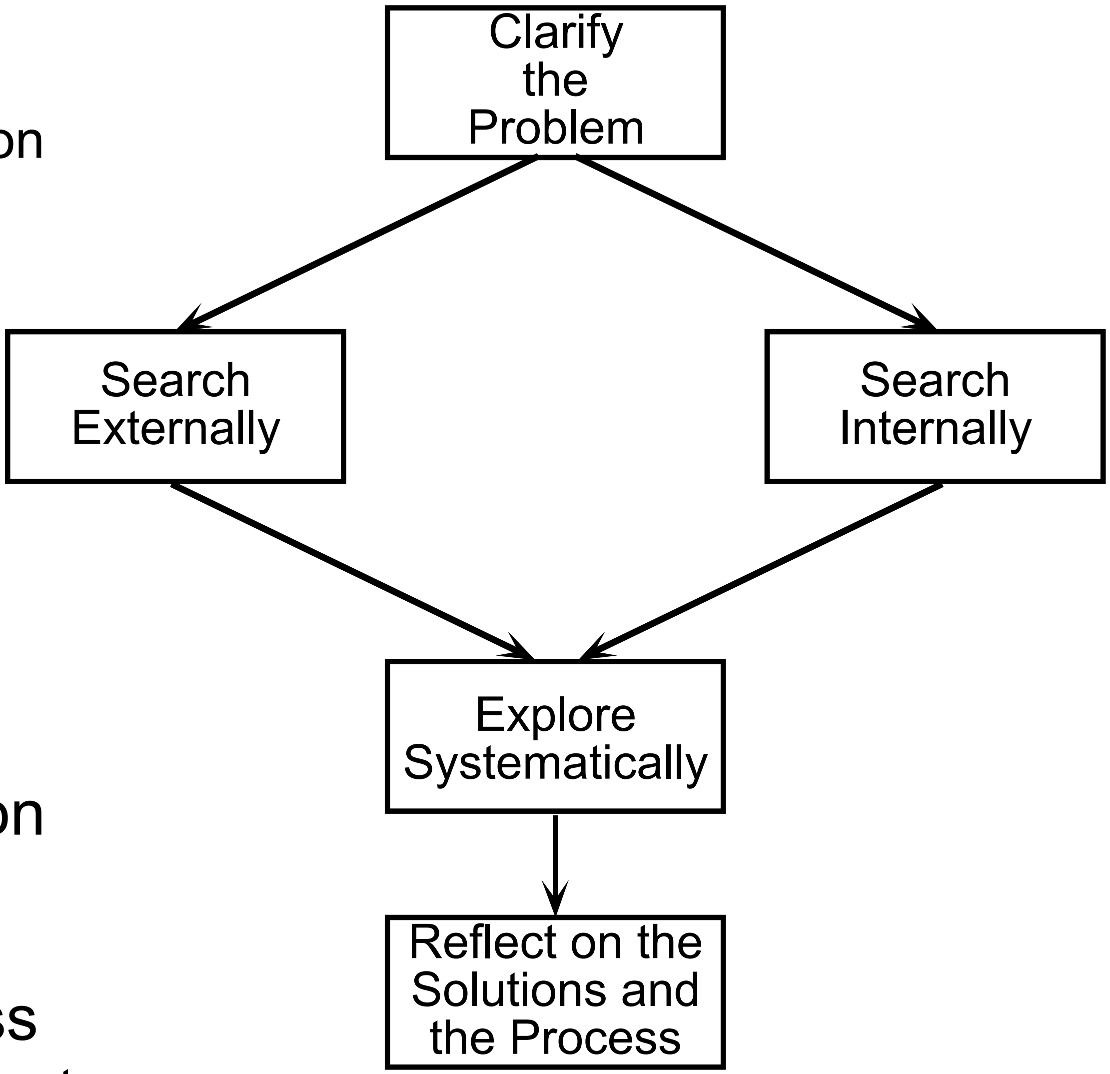
Concept Development Process



Concept Generation Example: Power Nailer

Concept Generation Process

- Clarify the Problem
  - Problem Decomposition
- External Search
  - Lead Users
  - Experts
  - Patents
  - Literature
  - Benchmarking
- Internal Search
  - Individual Methods
  - Group Methods
- Systematic Exploration
  - Classification Tree
  - Combination Table
- Reflect on the Process
  - Continuous Improvement



Concept Generation Exercise: Vegetable Peelers

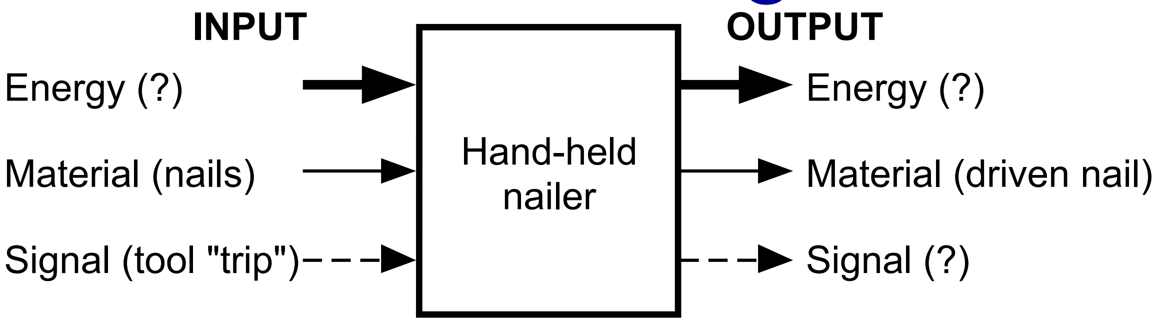
Vegetable Peeler Exercise: Voice of the Customer

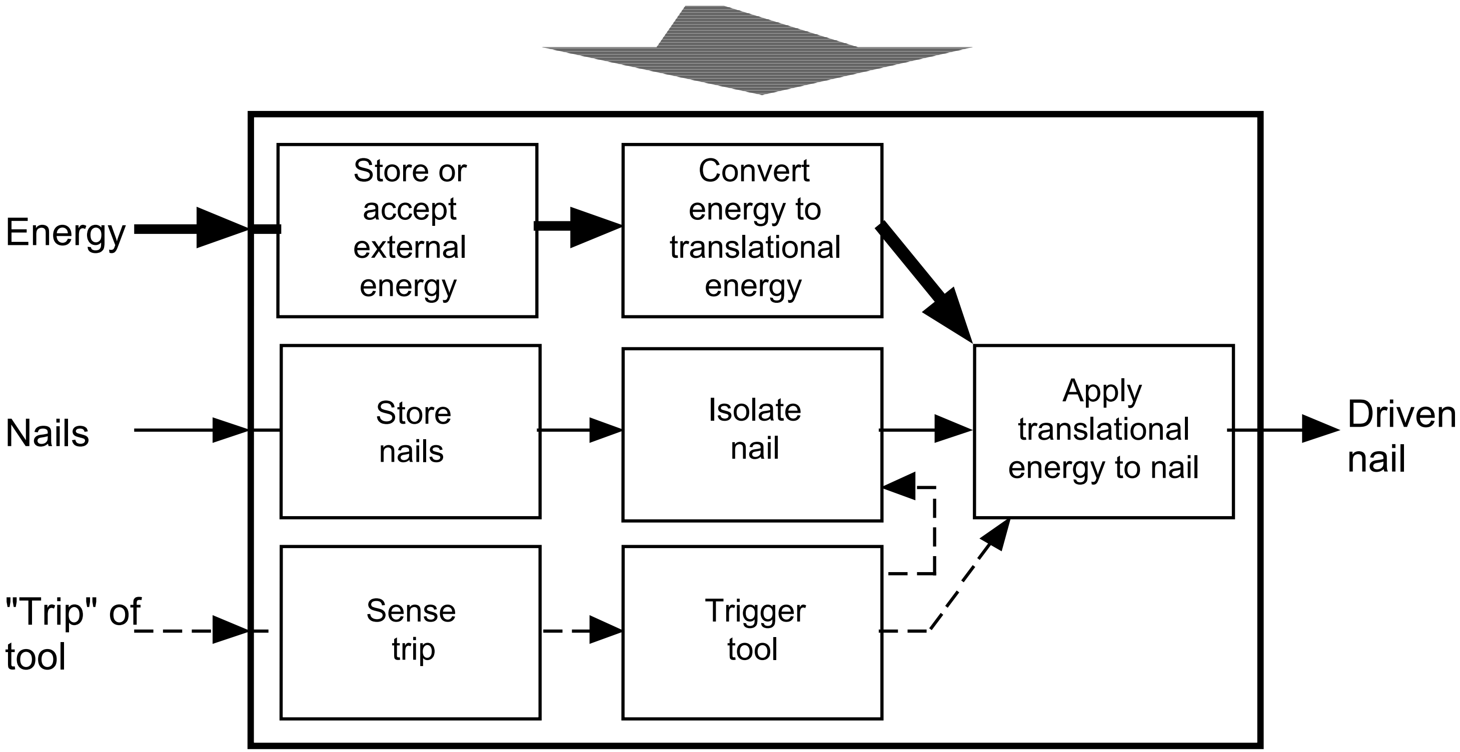
- "Carrots and potatoes are very different."
- "I cut myself with this one."
- "I just leave the skin on."
- "I'm left-handed. I use a knife."
- "This one is fast, but it takes a lot off."
- "How do you peel a squash?"
- "Here's a rusty one."
- "This looked OK in the store."

Vegetable Peeler Exercise: Key Customer Needs

1. The peeler peels a variety of produce.
2. The peeler can be used ambidextrously.
3. The peeler creates minimal waste.
4. The peeler saves time.
5. The peeler is durable.
6. The peeler is easy to clean.
7. The peeler is safe to use and store.
8. The peeler is comfortable to use.
9. The peeler stays sharp or can be easily sharpened.

Problem Decomposition: Function Diagram

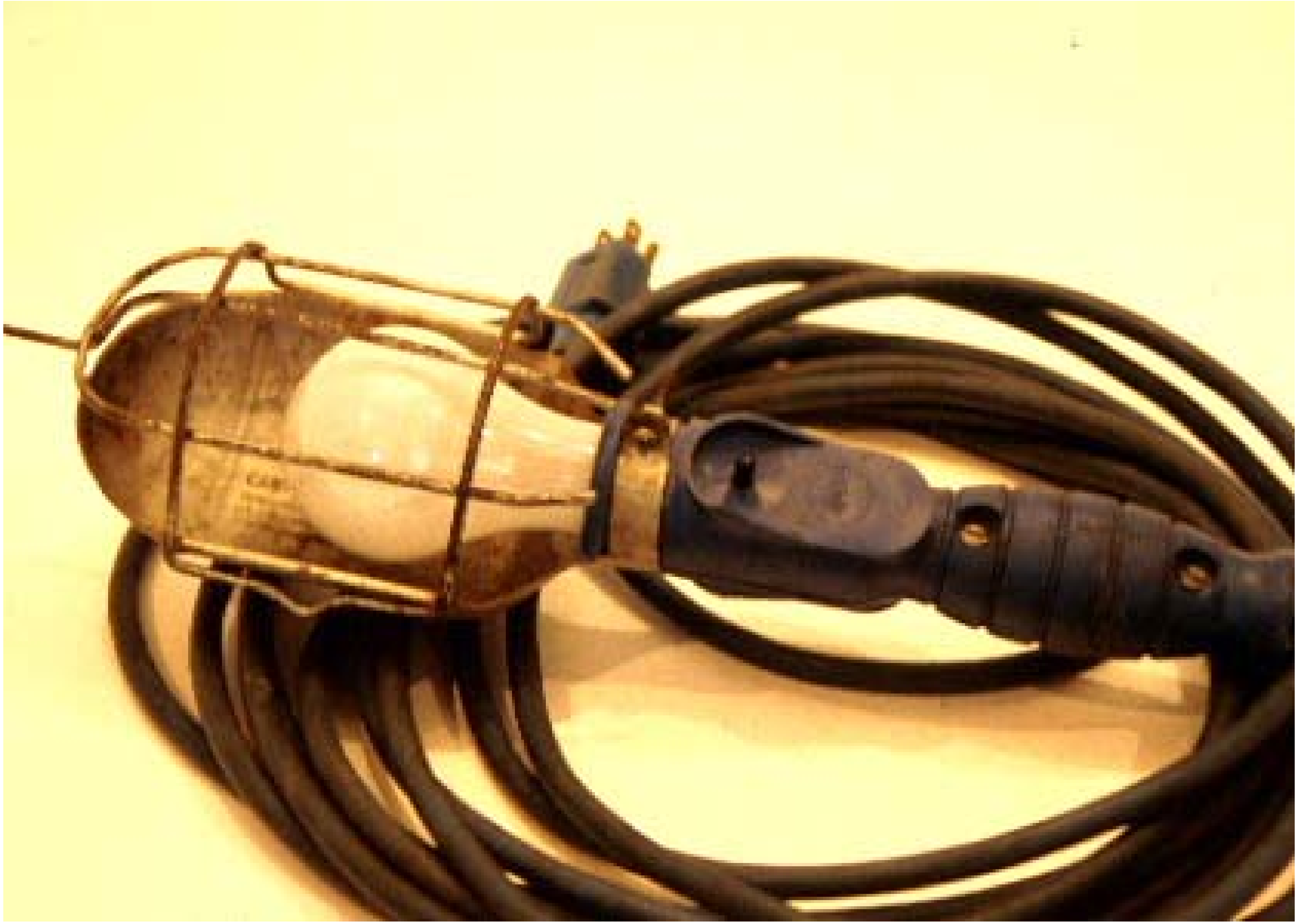




External Search:
Hints for Finding Related Solutions

- Lead Users
  - benefit from improvement
  - innovation source
- Benchmarking
  - competitive products
- Experts
  - technical experts
  - experienced customers
- Patents
  - search related inventions
- Literature
  - technical journals
  - trade literature

Capture Innovation from Lead Users: Utility Light Example

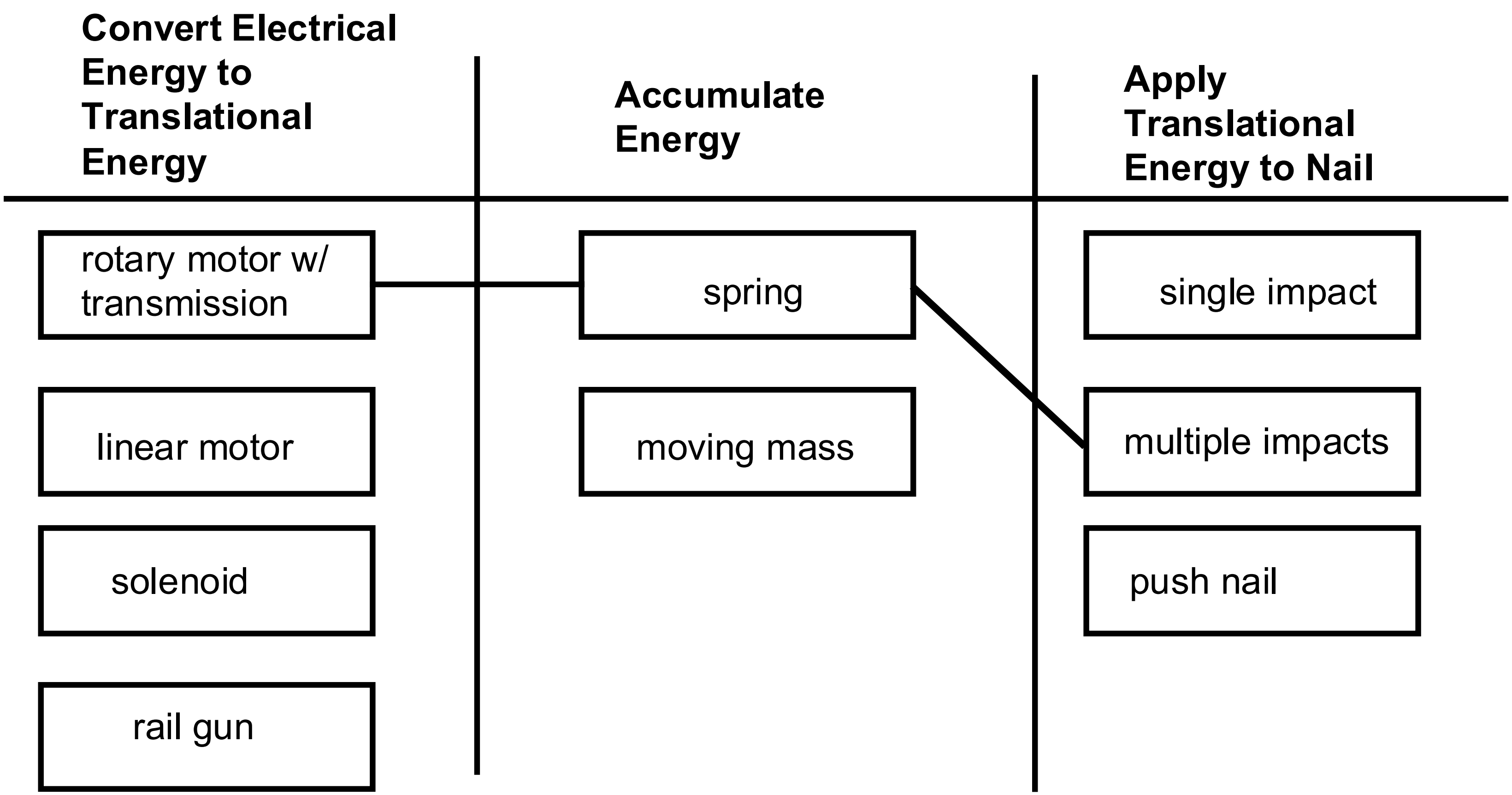


Capture Innovation from Lead Users: Utility Light Example

Internal Search:
Hints for Generating Many Concepts

- Suspend judgment
- Generate a lot of ideas
- Infeasible ideas are welcome
- Use graphical and physical media
- Make analogies
- Wish and wonder
- Solve the conflict
- Use related stimuli
- Use unrelated stimuli
- Set quantitative goals
- Use the gallery method
- Trade ideas in a group

Systematic Exploration:
Concept Combination Table



Concept Testing

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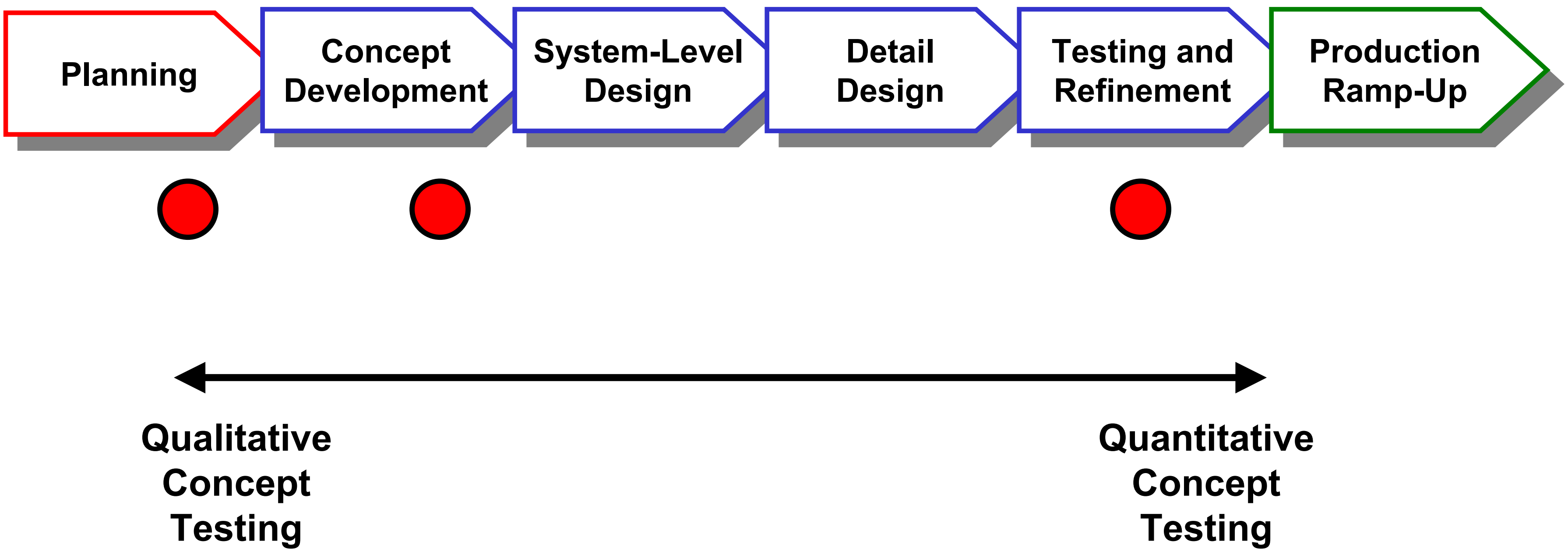
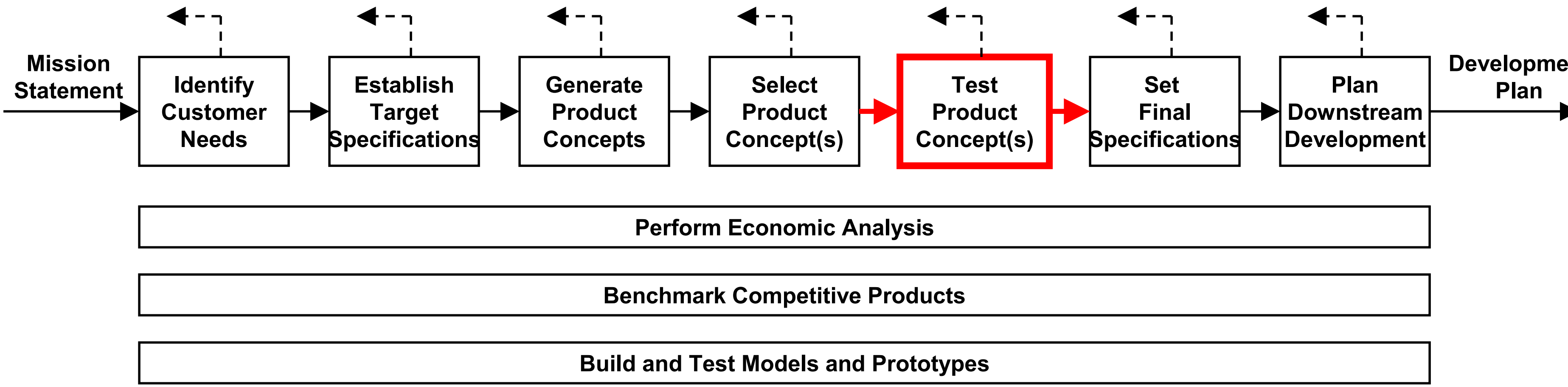


Concept Development Process



Concept Testing is Used for Several Purposes

- Go/no-go decisions
- What market to be in?
- Selecting among alternative concepts
- Confirming concept selection decision
- Benchmarking
- Soliciting improvement ideas
- Forecasting demand
- Ready to launch?

Concept Testing Process

- Define the purpose of the test
- Choose a survey population
- Choose a survey format
- Communicate the concept
- Measure customer response
- Interpret the results
- Reflect on the results and the process

Concept Testing Example: emPower Electric Scooter

Scooter Example

- Purpose of concept test:
  - What market to be in?
- Sample population:
  - College students who live 1-3 miles from campus
  - Factory transportation
- Survey format:
  - Face-to-face interviews

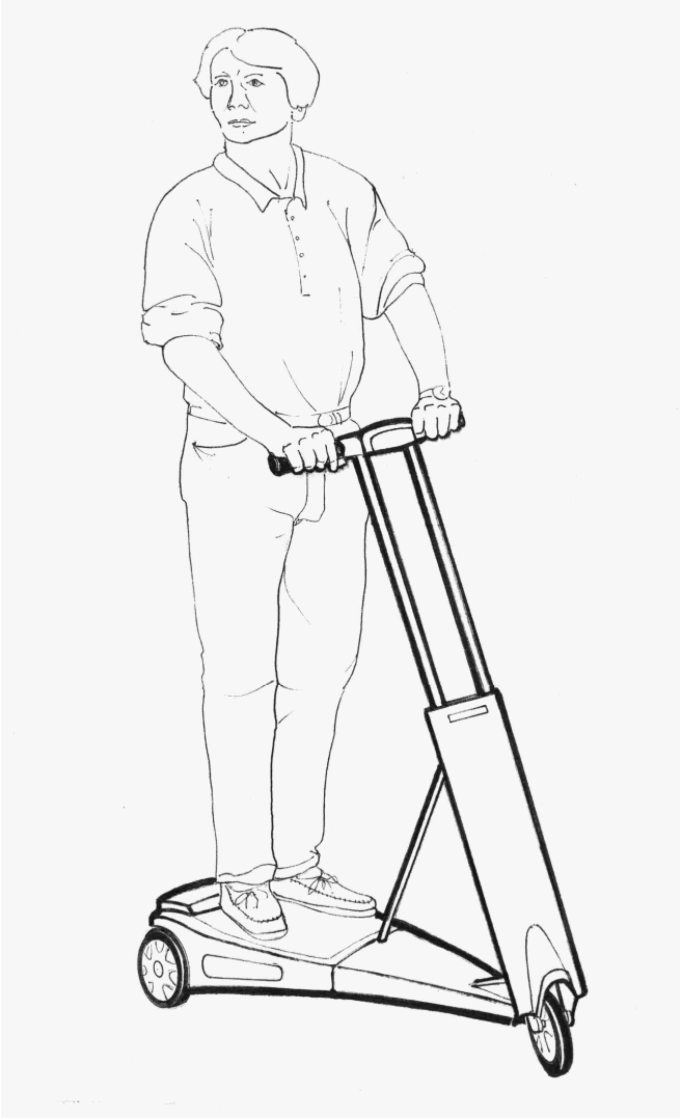
Communicating the Concept

- Verbal description
- Sketch
- Photograph or rendering
- Storyboard
- Video
- Simulation
- Interactive multimedia
- Physical appearance model
- Working prototype

Verbal Description

- The product is a lightweight electric scooter that can be easily folded and taken with you inside a building or on public transportation.
- The scooter weighs about 25 pounds. It travels at speeds of up to 15 miles per hour and can go about 12 miles on a single charge.
- The scooter can be recharged in about two hours from a standard electric outlet.
- The scooter is easy to ride and has simple controls — just an accelerator button and a brake.

Sketch



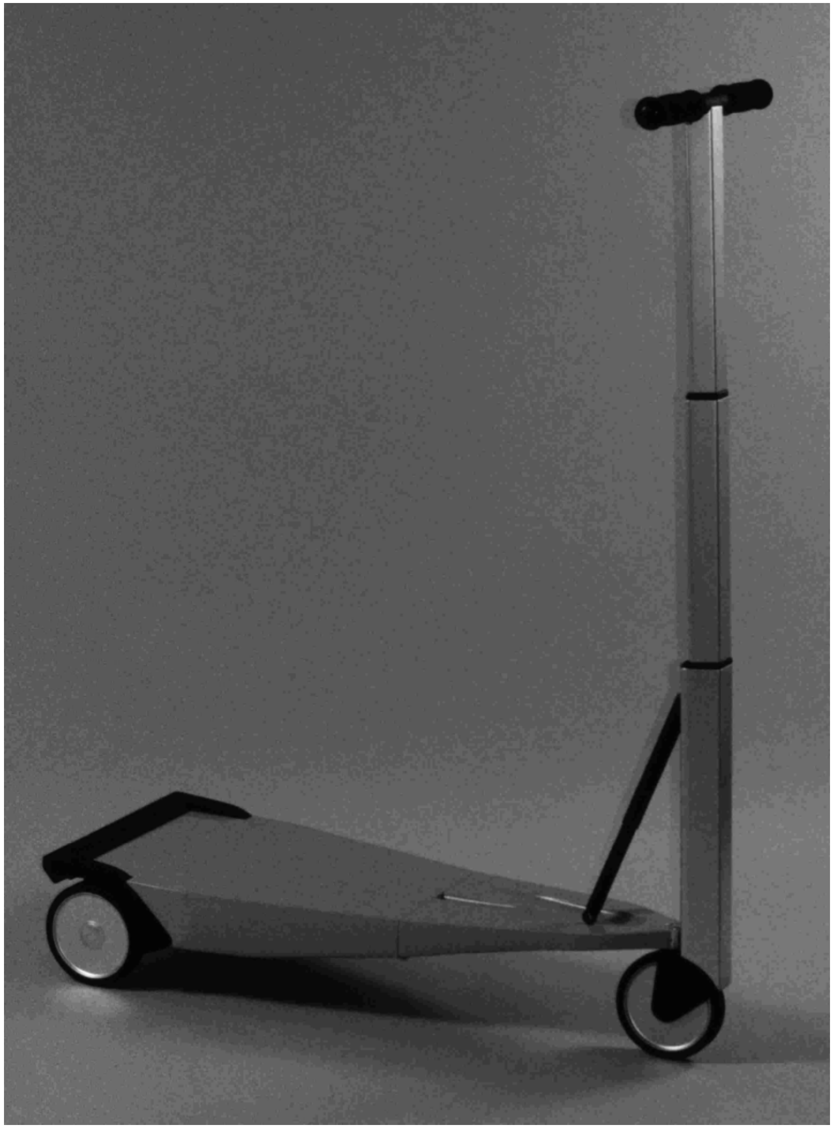
Rendering

Storyboard


EMpower tranSport
compact storage
portable
transportation
reduced
transit
time

3D Solid CAD Model

Appearance Model



Working Prototype

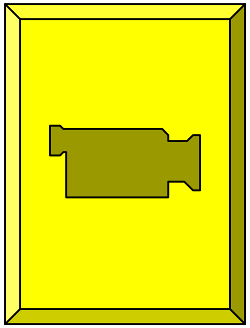
Beta Prototype

Video

Animation

Interactive Multimedia

Live Demonstration



Survey Format

- **PART 1, Qualification**
  - How far do you live from campus?
    - <If not 1-3 miles, thank the customer and end interview.>
  - How do you currently get to campus from home?
  - How do you currently get around campus?
- **PART 2, Product Description**
  - <Present the concept description.>

Survey Format

- **PART 3, Purchase Intent**
  - If the product were priced according to your expectations, how likely would you be to purchase the scooter within the next year?

☐ I would **definitely not purchase** the scooter.	☐ I would **probably not purchase** the scooter.	☐ I **might or might not purchase** the scooter.	☐ I would **probably purchase** the scooter.	☐ I would **definitely purchase** the scooter.
			↑ "second box"	↑ "top box"

Survey Format

- **PART 4, Comments**
  - What would you expect the price of the scooter to be?
  - What concerns do you have about the product concept?
  - Can you make any suggestions for improving the product concept?
- **Thank you.**

Interpreting the Results: Forecasting Sales

$$Q = N \times A \times P$$

- Q = sales (annual)
- N = number of (annual) purchases
- A = awareness x availability (fractions)
- P = probability of purchase (surveyed)

$$= C_{def} \times F_{def} + C_{prob} \times F_{prob}$$

"top box" — "second box"

Forecasting Example: College Student Market

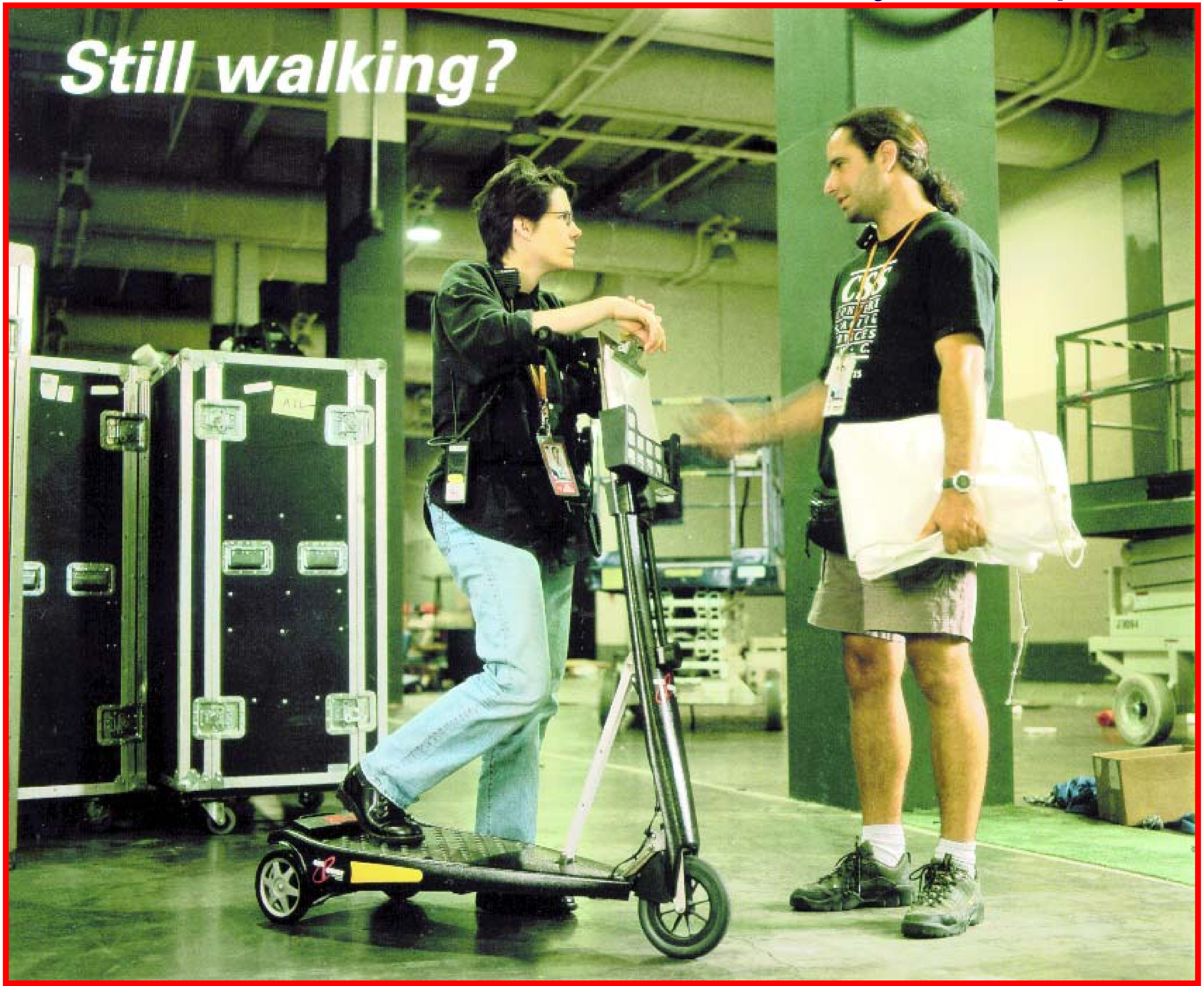
- N = off-campus grad students (200,000)
- A = 0.2 (realistic) to 0.8 (every bike shop)
- P = 0.4 x *top-box* + 0.2 x *second-box*
- Q =
- Price point $795

Forecasting Example: Factory Transport Market

- N = current bicycle and scooter sales to factories (150,000)
- A = 0.25 (single distributor's share)
- P = 0.4 x *top-box* + 0.2 x *second-box*
- Q = 150,000 x 0.25 x [0.4 x 0.3 + 0.2 x 0.2]

  = 6000 units/yr
- Price point $1500

emPower's Market Decision: Factory Transportation



Production Product

Sources of Forecast Error

- Word-of-Mouth Effects
- Quality of Concept Description
- Pricing
- Level of Promotion
- Competition

Discussion

- Why do respondents typically overestimate purchase intent?
  - Might they ever underestimate intent?
- How to use price in surveys?
- How much does the way the concept is communicated matter?
  - When shouldn’t a prototype model be shown?
- How do you increase sales, Q?
- How does early (qualitative) concept testing differ from later (quantitative) testing?

Managing Complex System Development Projects

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Sloan School of Management
Engineering Systems Division
Leaders for Manufacturing Program
System Design and Management Program

http://web.mit.edu/dsm

Session Outline

- **Motivation: Managing Project Structure**
  - Concurrent Engineering in the Large
- **Design Structure Matrix**
  - Information Flow Modeling
  - Task-Based DSMs
  - Sequencing Analysis
  - Example: Semiconductor Development
- **Managing Design Iterations**
  - Solving Coupled Issues Faster
  - Example: Instrument Cluster
- **Systems Integration**
  - Organization-Based DSM
  - System Architecture-Based DSM
  - Example: Engine Development
- **DSM Web Site**

Industrial Examples and Research Sponsors

DELPHI

hp

Kodak

Pratt & Whitney
A United Technologies Company

intel

ABB

VOLVO AERO

BOEING

GM

FIAT

Ford

ITT Industries

Concurrent Engineering *in the Small*

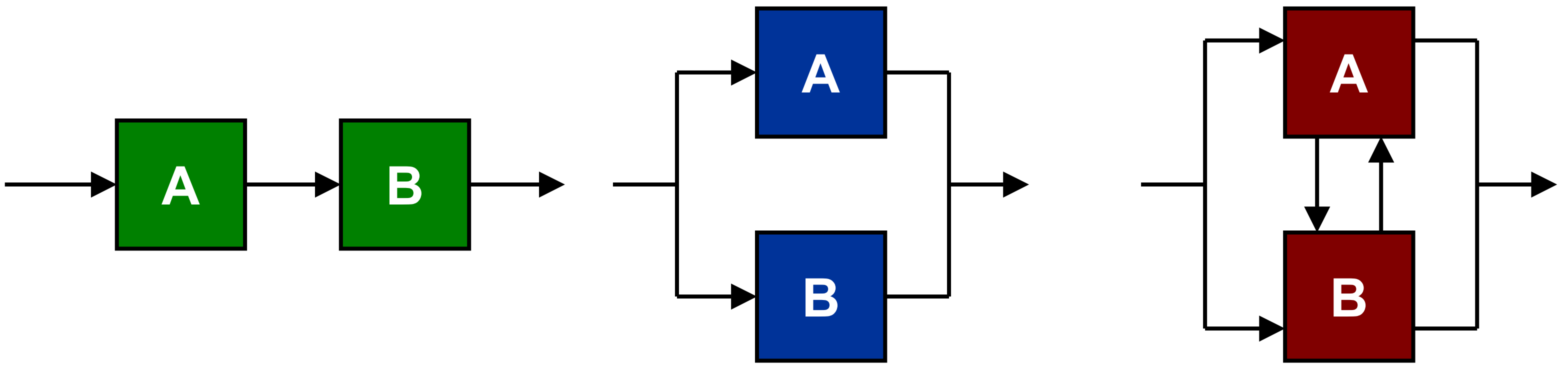
- **Projects are executed by a cross-disciplinary team (5 to 20 people).**
- **Teams feature <u>high-bandwidth</u> technical communication.**
- **Tradeoffs are resolved by mutual understanding.**
- **"Design and production" issues are considered simultaneously.**

Concurrent Engineering *in the Large*

- **Large projects are organized as a network of teams (100 to 1000 people).**
- **Large projects are decomposed into many smaller projects.**
- **Large projects may involve development activities dispersed over multiple sites.**
- **The essential challenge is to integrate the separate pieces into a *system* solution.**
- **The needs for integration depend upon the technical interactions among the sub-problems.**

Sequencing Tasks in Projects

Three Possible Sequences for Two Tasks

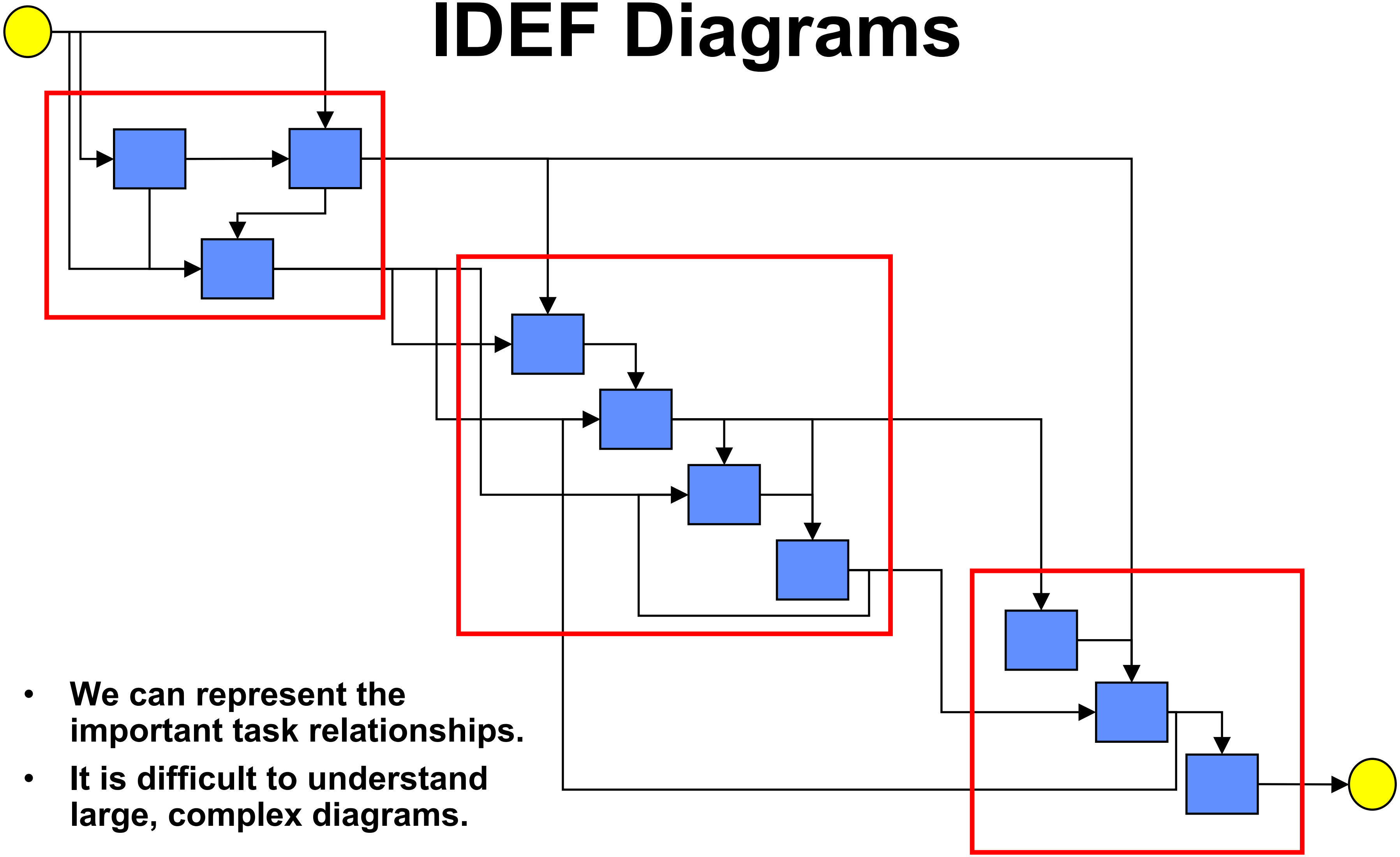


Dependent
(Series)

Independent
(Parallel)

Interdependent
(Coupled)

IDEF Diagrams



- We can represent the important task relationships.
- It is difficult to understand large, complex diagrams.

The Design Structure Matrix:
An 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			X
G		X					•				X	
H	X			X				•	X		X	
I			X			X			•	X		
J		X	X							•	X	X
K		X	X								•	
L	X								X	X	X	•

Interpretation:

- Task D requires information from tasks E, F, and L.
- Task B transfers information to tasks C, F, G, J, and K.

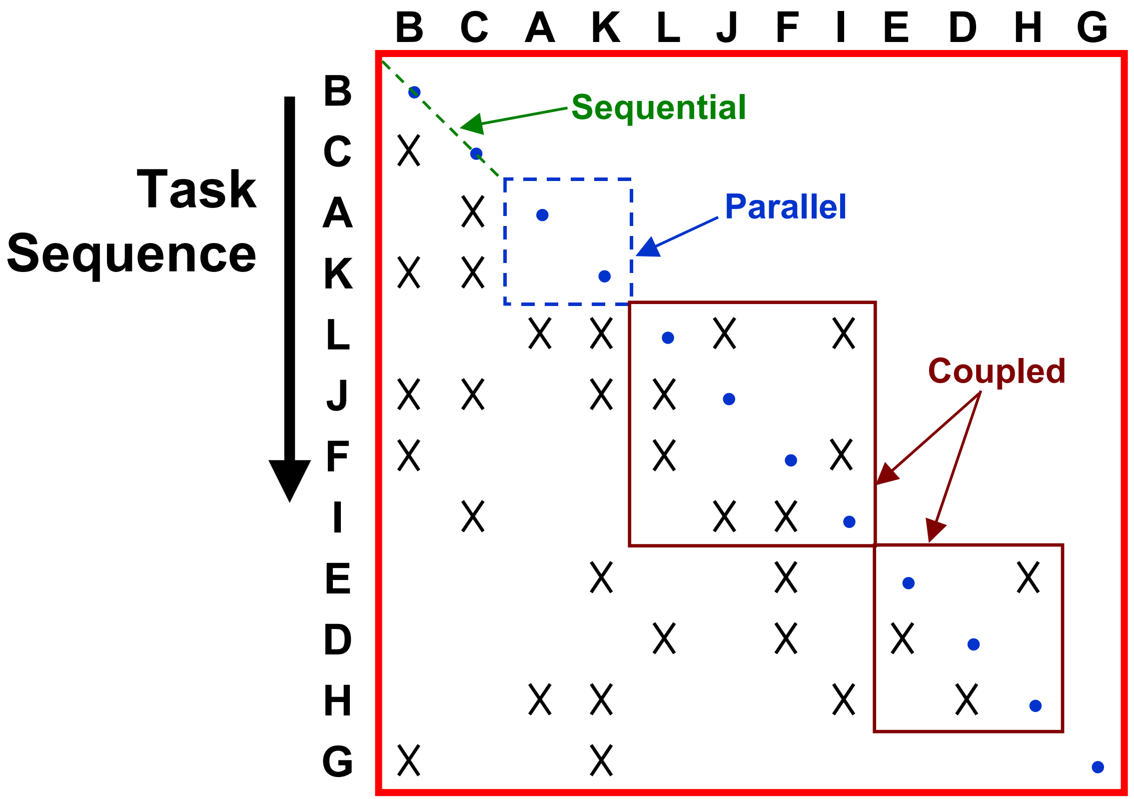
Note:

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

Donald V. Steward, Aug. 1981
IEEE Trans. on Eng'g Mgmt.

The Design Structure Matrix

(Partitioned, or Sequenced)

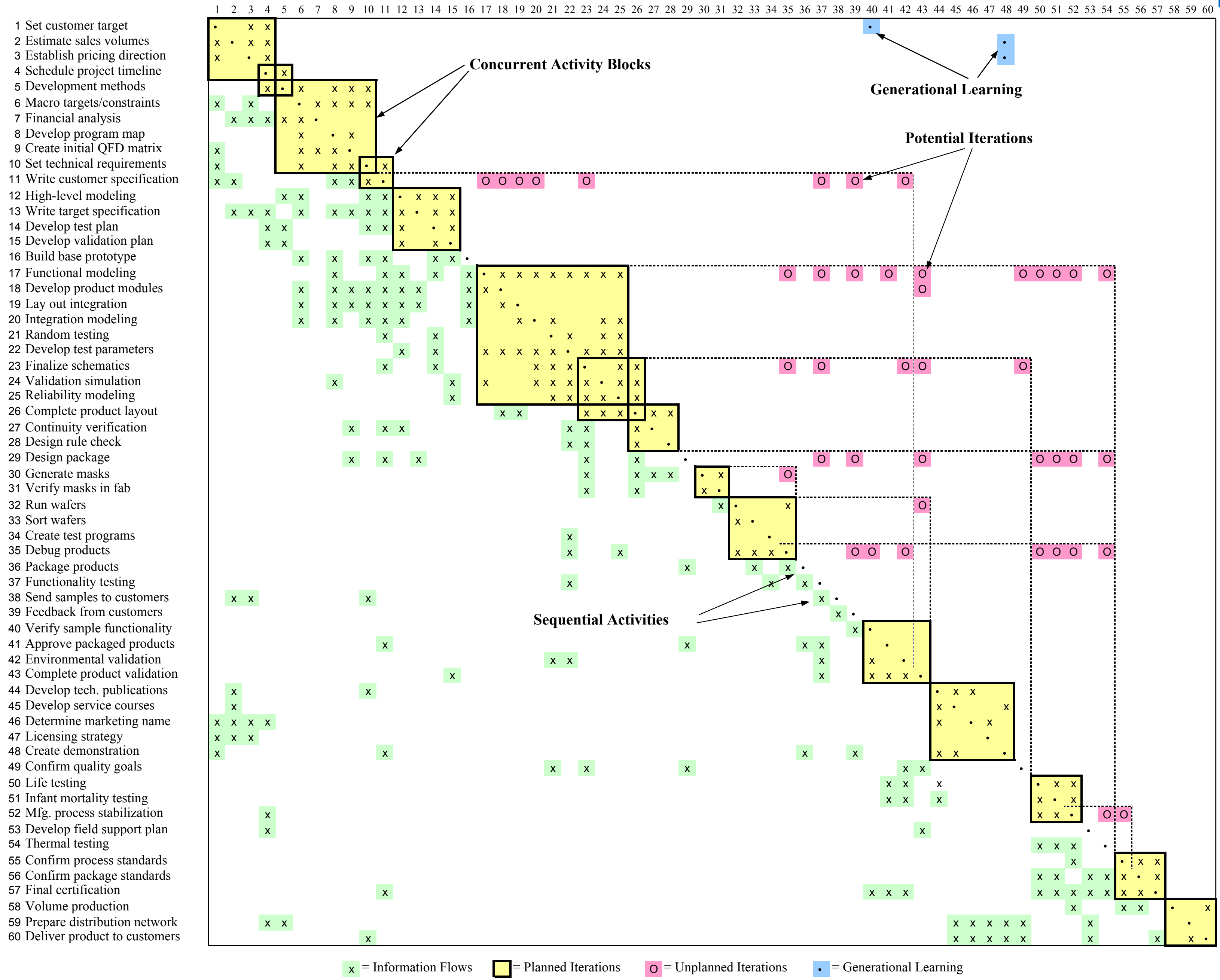


Note:

Coupled tasks can be identified uniquely.

The display of the matrix can be manipulated to emphasize certain features of the process flow.

Semiconductor Development Example



How to Create a Task-Based Design Structure Matrix Model

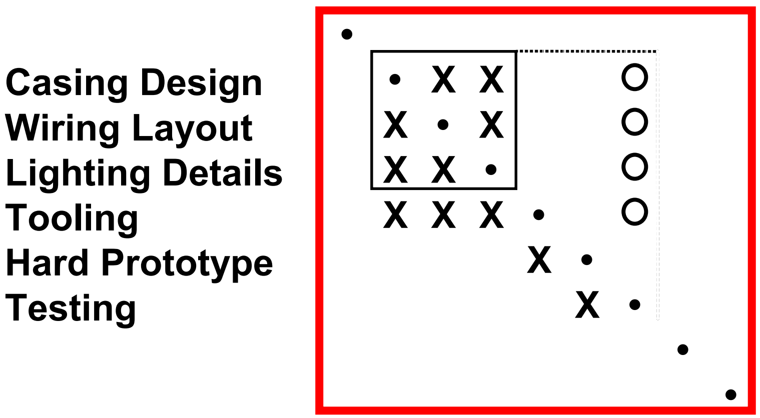
1. Select a process or sub-process to model.
2. Identify the tasks of the process, who is responsible for each one, and the outputs created by each task.
3. Lay out the square matrix with the tasks in the order they are nominally executed.
4. Ask the process experts what inputs are used for each task.
5. Insert marks representing the information inputs to each task.
6. Optional: Analyze the DSM model by re-sequencing the tasks to suggest a new process.
7. Draw solid boxes around the coupled tasks representing the planned iterations.
8. Draw dashed boxes around groups of parallel (uncoupled) tasks.
9. Highlight the unplanned iterations.

Design Iteration

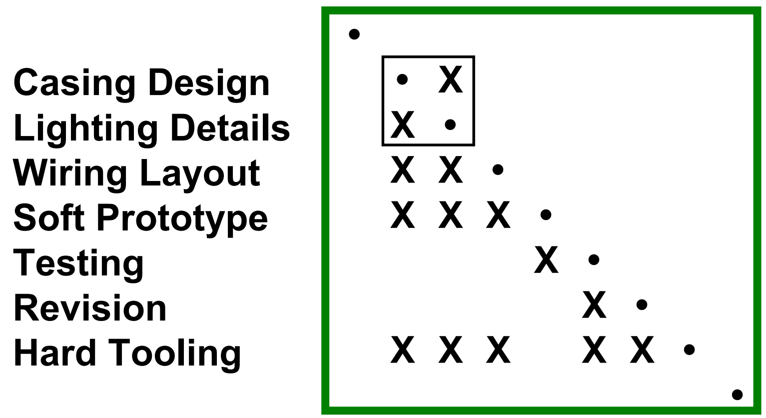
- **Product development is fundamentally iterative — yet iterations are hidden.**
- **Iteration is the repetition of tasks due to the availability of new information.**
  - changes in input information (upstream)
  - update of shared assumptions (concurrent)
  - discovery of errors (downstream)
- **Engineering activities are repeated to improve product quality and/or to reduce cost.**
- **To understand and accelerate iterations requires**
  - visibility of iterative information flows
  - understanding of the inherent process coupling

Instrument Cluster Development

Delco



Supplier



Slower Design Process

Several planned iterations

Usually one unplanned iteration

Faster Design Process

Fewer planned iterations

Planned revision cycle

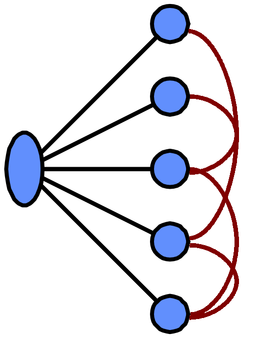
No unplanned iterations

Lessons Learned: Iteration

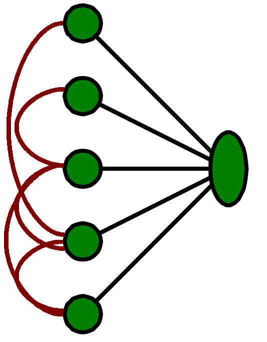
- Development is inherently iterative.
- An understanding of the coupling is essential.
- Not everything should be concurrent in concurrent engineering.
- Iteration results in improved quality.
- Iteration can be accelerated through:
  - information technology (faster iterations)
  - coordination techniques (faster iterations)
  - decreased coupling (fewer iterations)
- There are two fundamental types of iteration:
  - planned iterations (getting it right the first time)
  - unplanned iterations (fixing it when it's not right)

Decomposition, Architecture, and Integration

Decomposition is the process of splitting a complex system into sub-systems and/or components.



System architecture is the resulting set of interactions among the components.



Integration is the process of combining these sub-systems to achieve an overall solution.

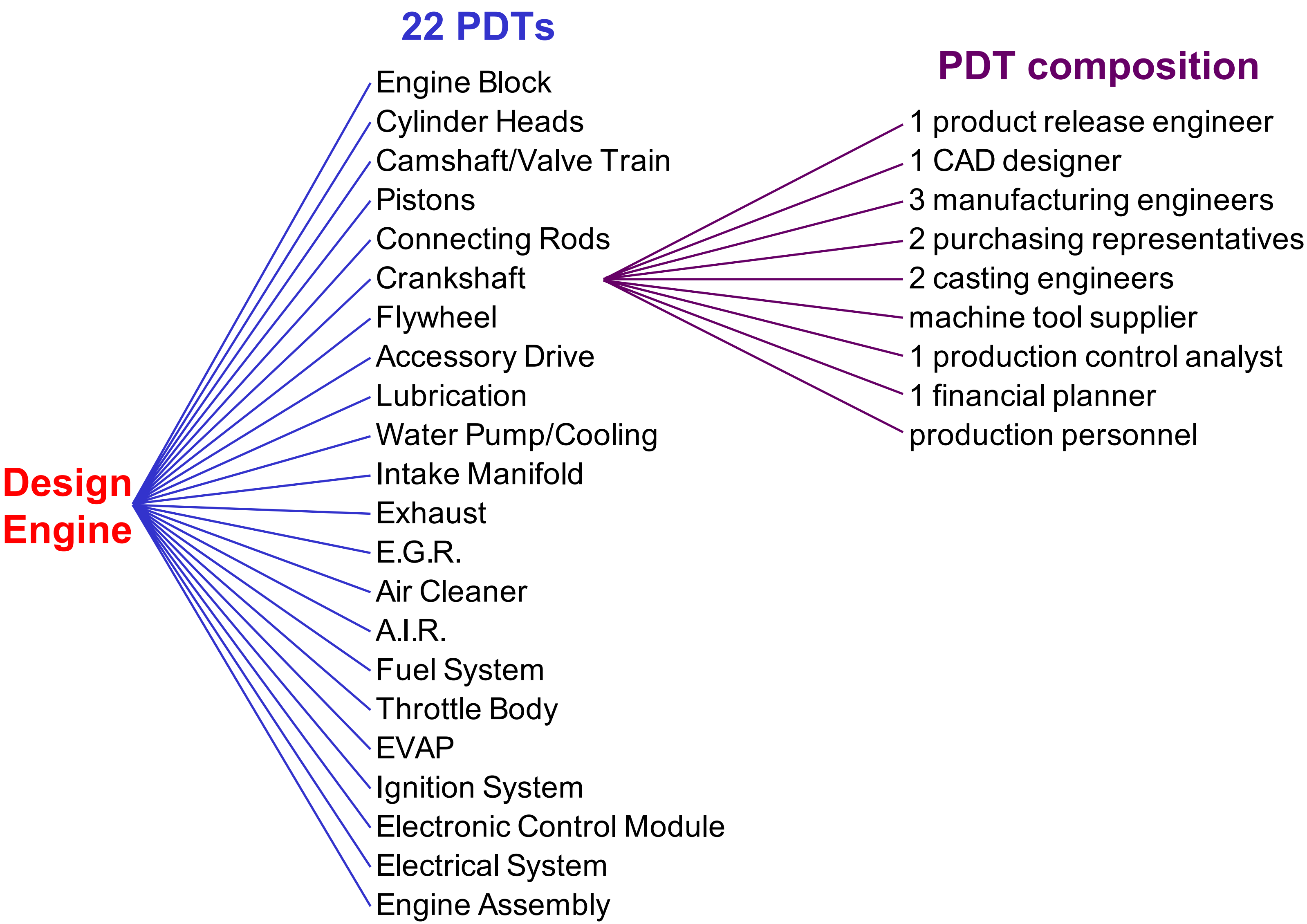
System integration needs are determined by the chosen decomposition and its resulting architecture.

We map the structure of interactions in order to plan for integration.

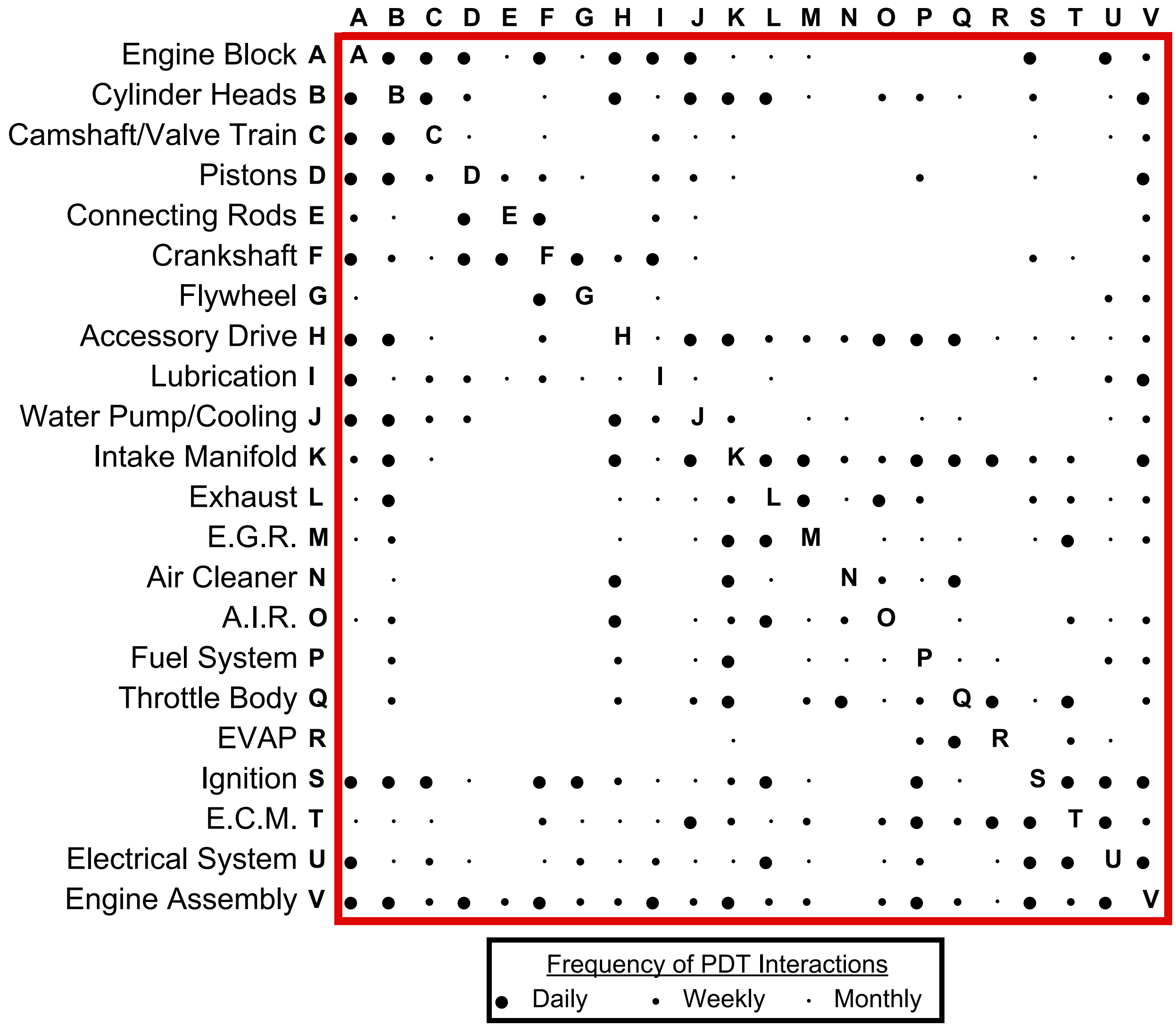
Organization DSM Application: Engine Development

- Site: General Motors Powertrain Division
- Product: “new-generation” engine
- Structure: 22 PDTs involved simultaneously

Decomposition of the Engine Development Project



PDT Interactions



System Team Assignments

Short Block

Engine Block
Crankshaft
Flywheel
Pistons
Connecting Rods
Lubrication

Valve Train

Cylinder Heads
Camshaft/Valve Train
Water Pump/Cooling

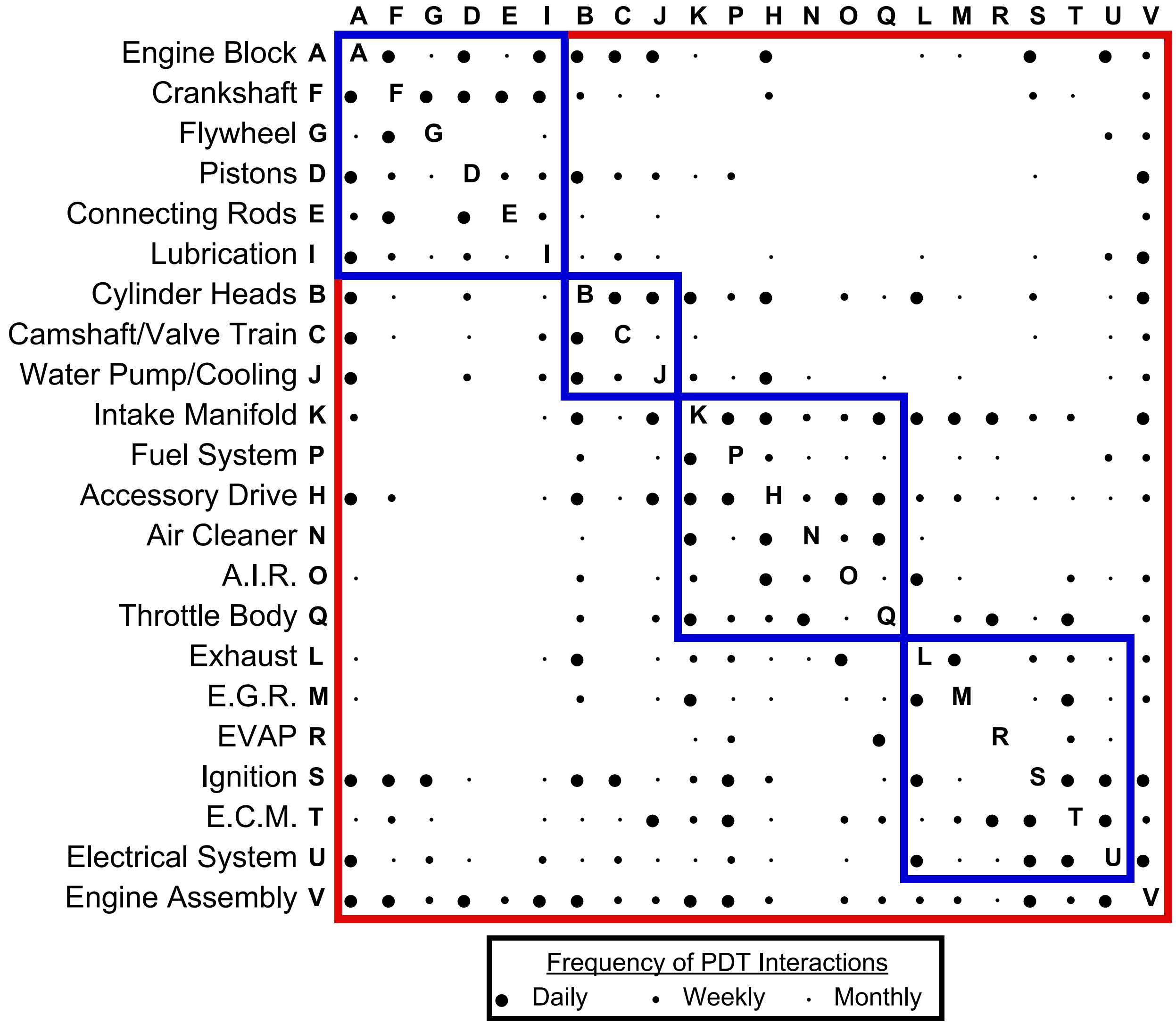
Induction

Intake Manifold
Accessory Drive
Fuel System
Air Cleaner
Throttle Body
A.I.R.

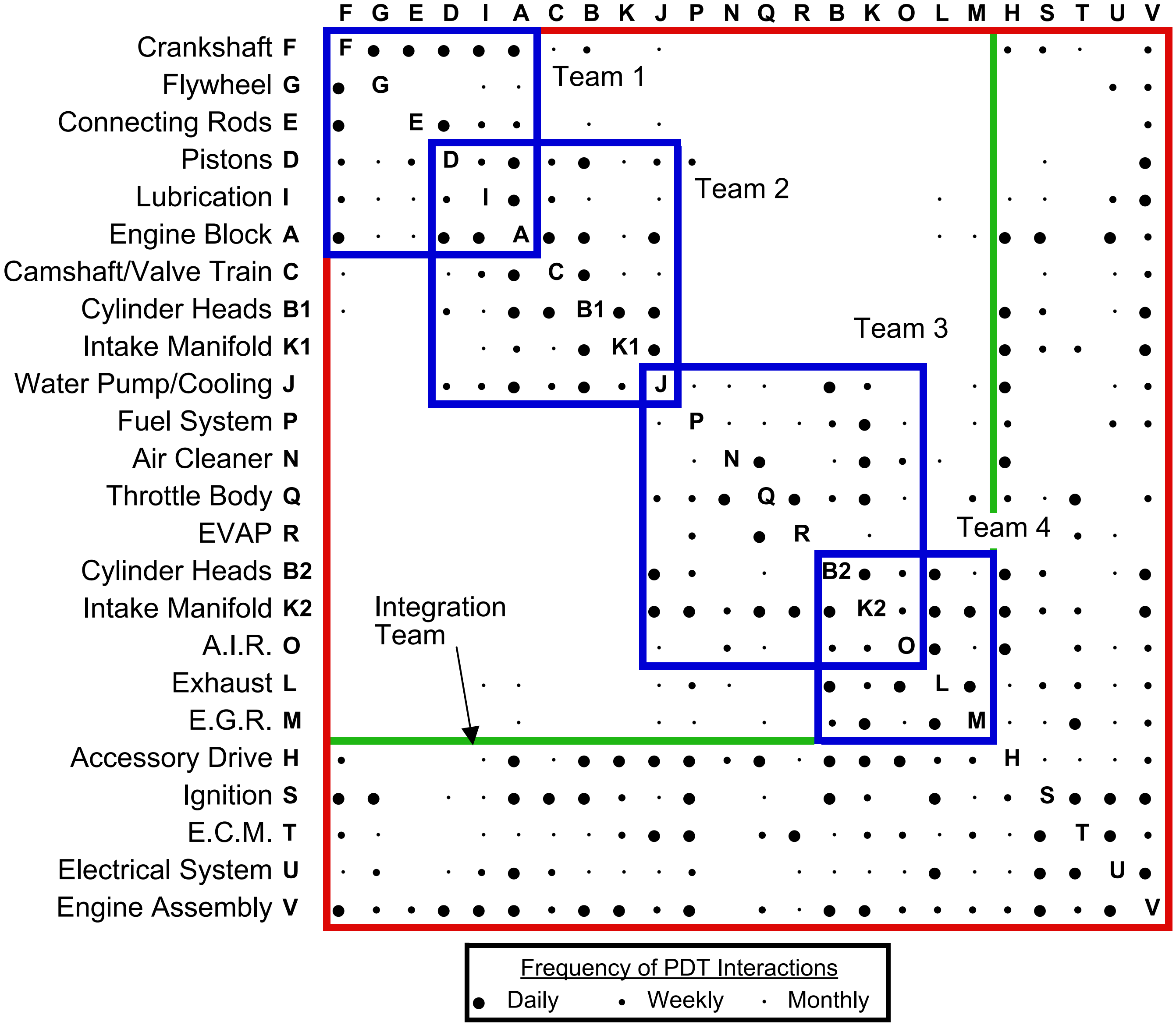
Emissions/Electrical

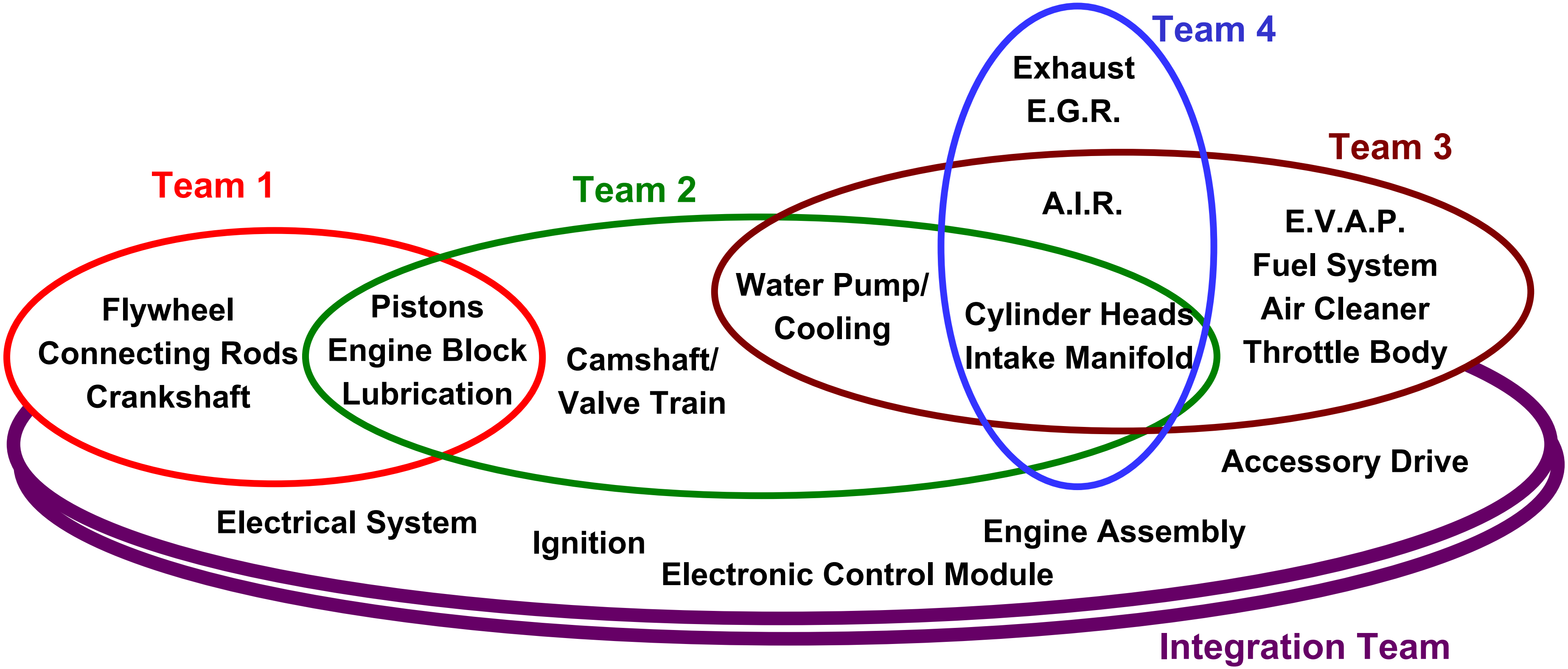
Exhaust
E.G.R.
E.V.A.P.
Electrical System
Electronic Control
Ignition

Existing System Teams



Proposed System Teams





PDT-to-System-Team Assignments

Lessons Learned: Integration

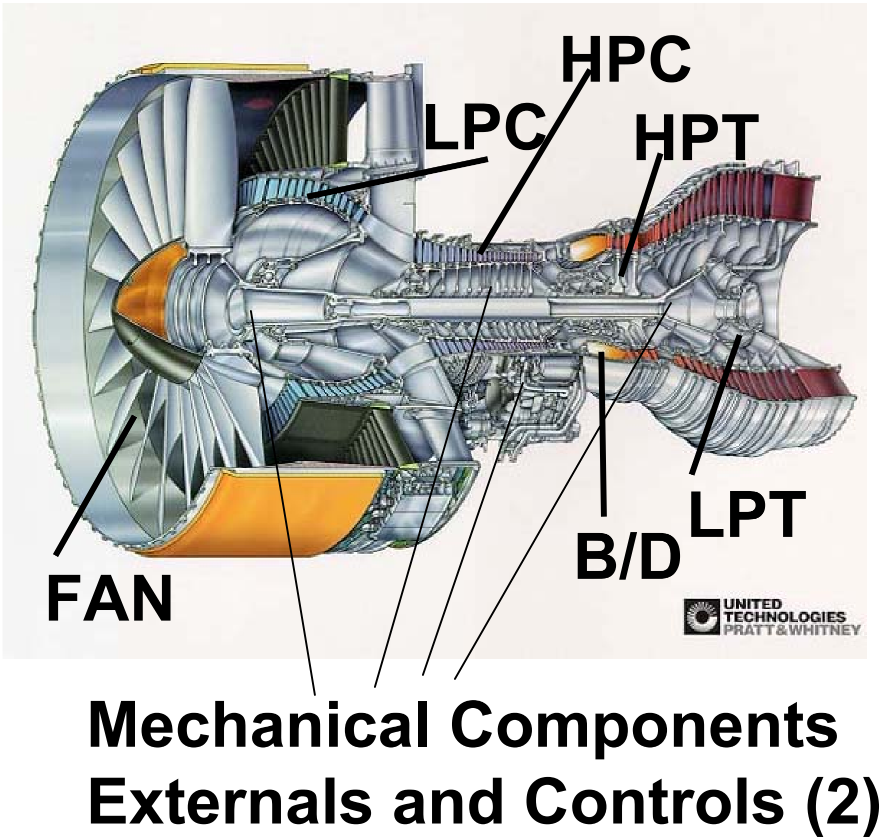
- Large development efforts require multiple activities to be performed in parallel.
- The many subsystems must be integrated to achieve an overall system solution.
- Mapping the information dependence reveals an underlying structure for system engineering.
- Organizations can be “designed” based upon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

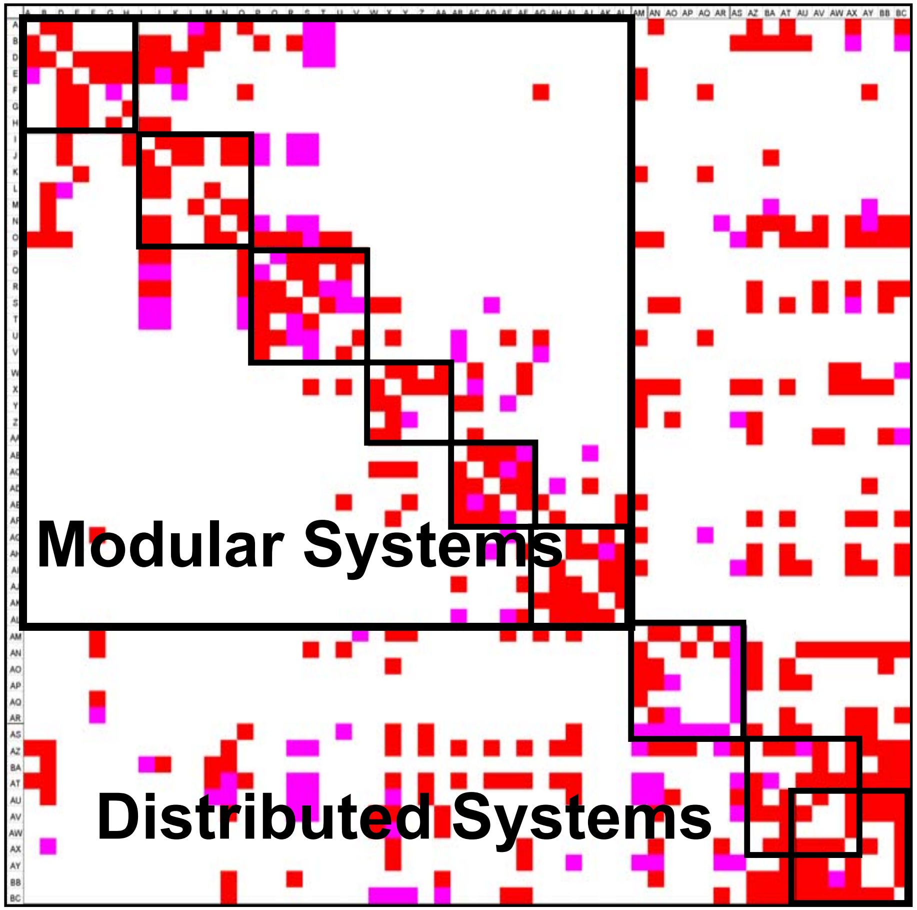
System Architecture Example: P&W 4098 Jet Engine

- 9 Systems
- 54 Components
- 569 Interfaces

Design Interfaces:

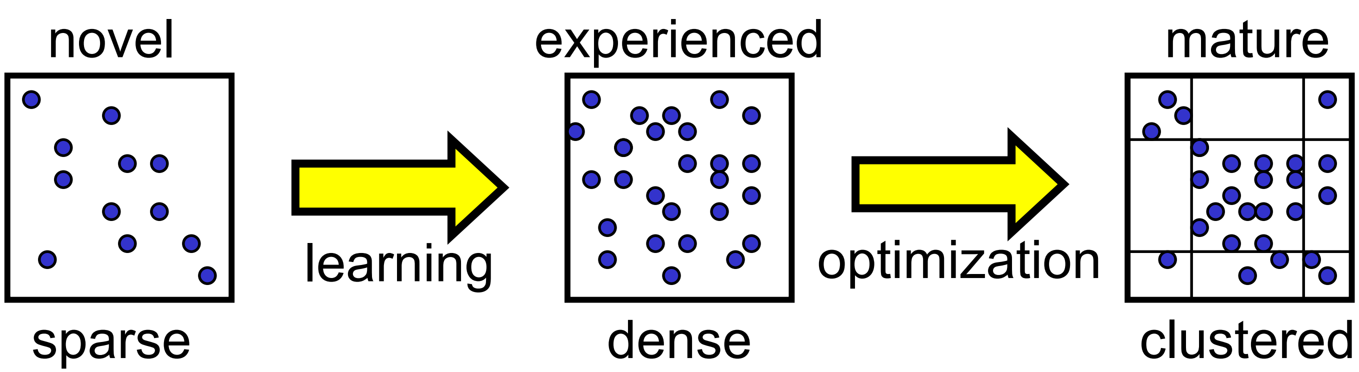
- Spatial, Structural
- Energy, Materials
- Data, Controls



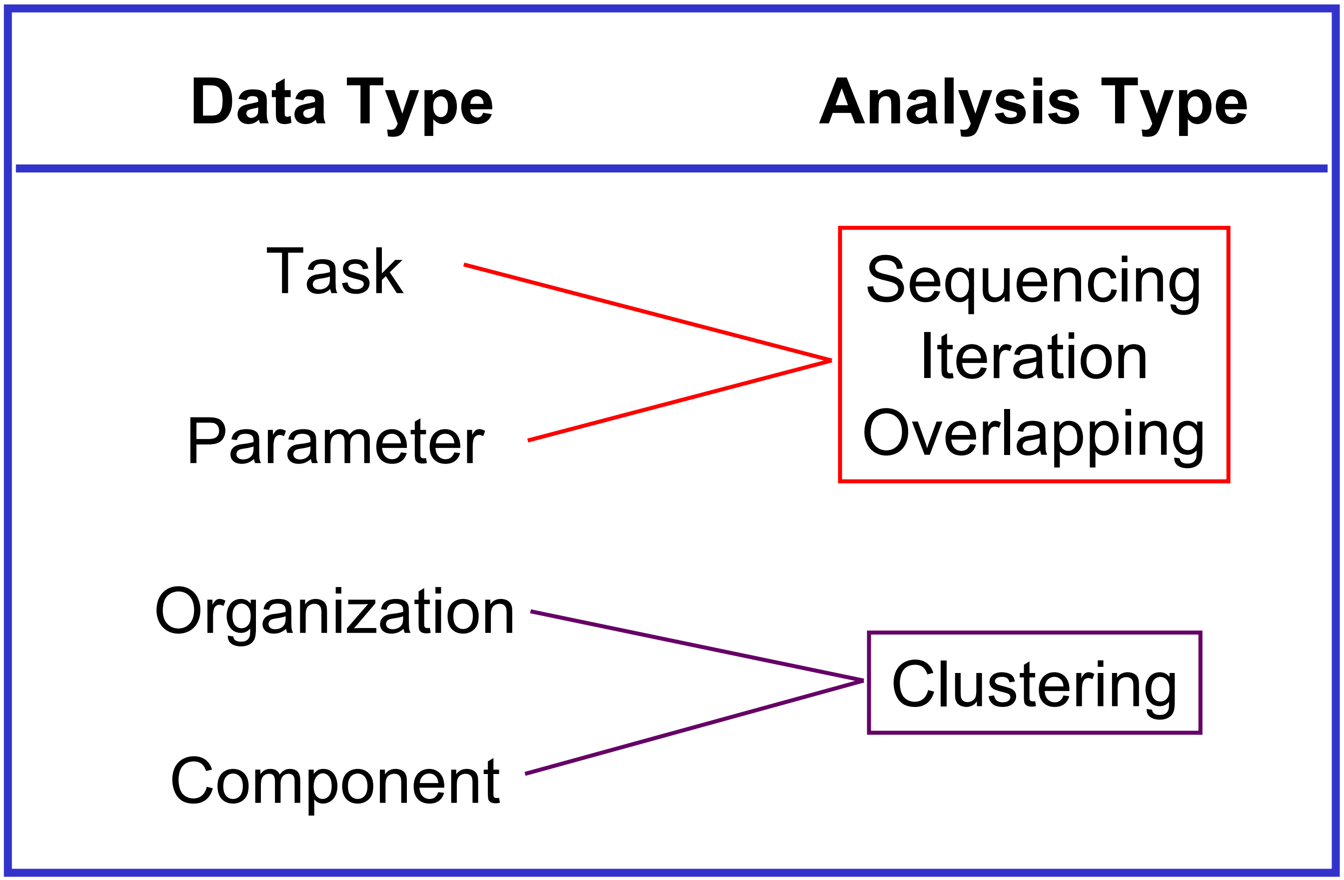


Lessons Learned: Product/System Architecture

- Hierarchical system decompositions are evident.
- System architecting principles are at work.
- There is a disparity between known interfaces and unknown interactions.
- Integrating elements may be functional and/or physical.
- Hypothesis: Density of known interactions–



Types of DSM Models and Analysis



MIT
Design Structure Matrix
Web Site

http://web.mit.edu/dsm

- Tutorial
- Publications
- Examples
- Software
- Contacts
- Events

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Chapter 14

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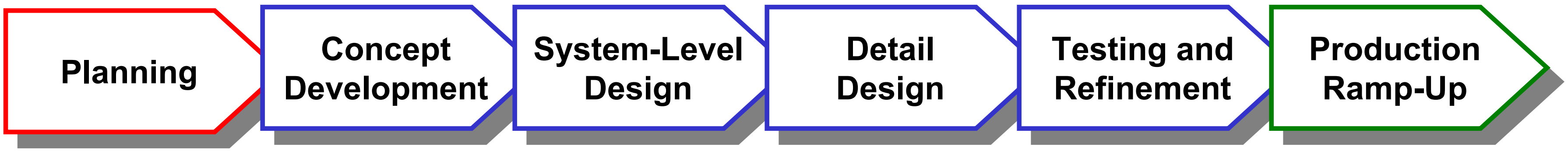
Product Development Process



Project management is necessary throughout the development process.

Product Design and Development

Karl T. Ulrich and Steven D. Eppinger

2nd edition, Irwin McGraw-Hill, 2000.

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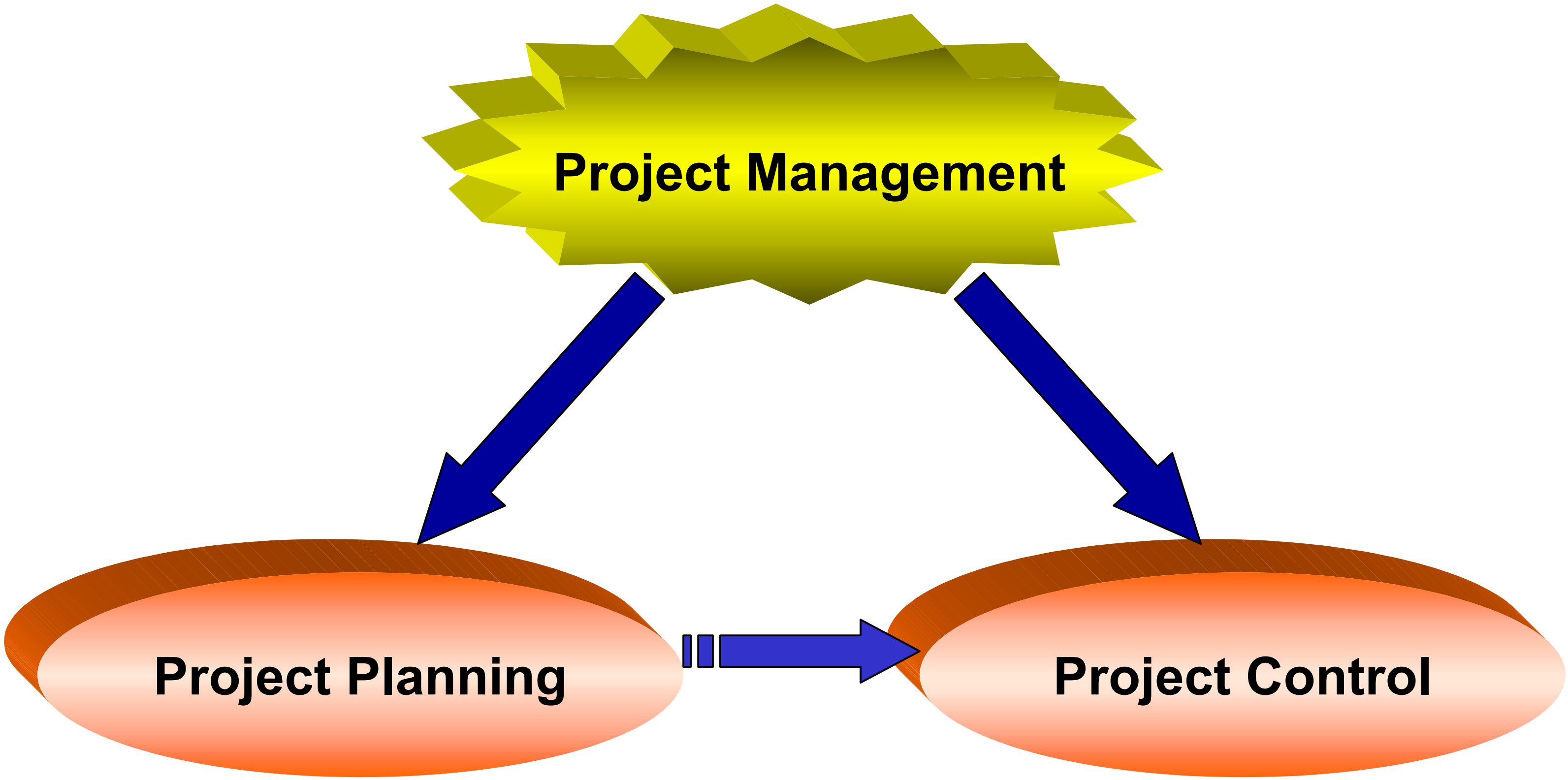
Two Phases of Project Management



The Design Structure Matrix:
An 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			X
G		X					•				X	
H	X			X				•	X		X	
I			X			X			•	X		
J		X	X							•	X	X
K		X	X								•	
L	X								X	X	X	•

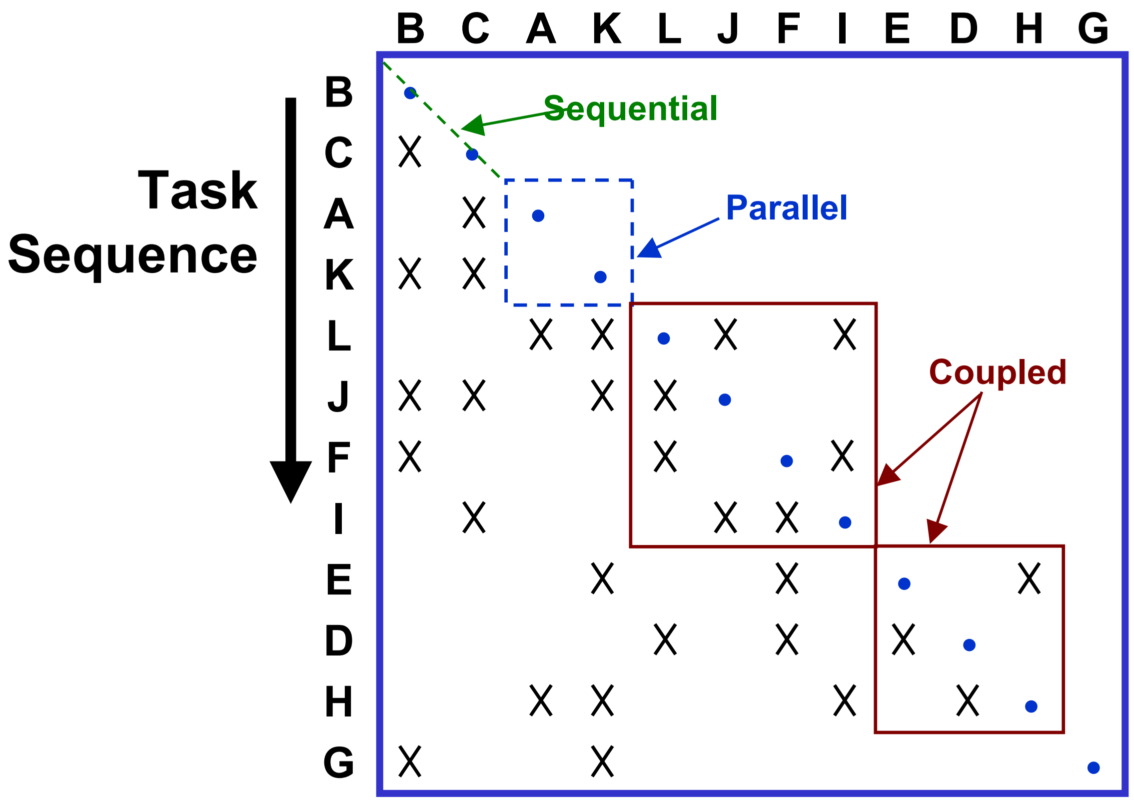
<u>Interpretation:</u>
- Task D requires information from tasks E, F, and L.
- Task B transfers information to tasks C, F, G, J, and K.

<u>Note:</u>
- Information flows are easier to capture than work flows.
- Inputs are easier to capture than outputs.

Donald V. Steward, Aug. 1981
IEEE Trans. on Eng'g Mgmt.

The Design Structure Matrix

(Partitioned, or Sequenced)



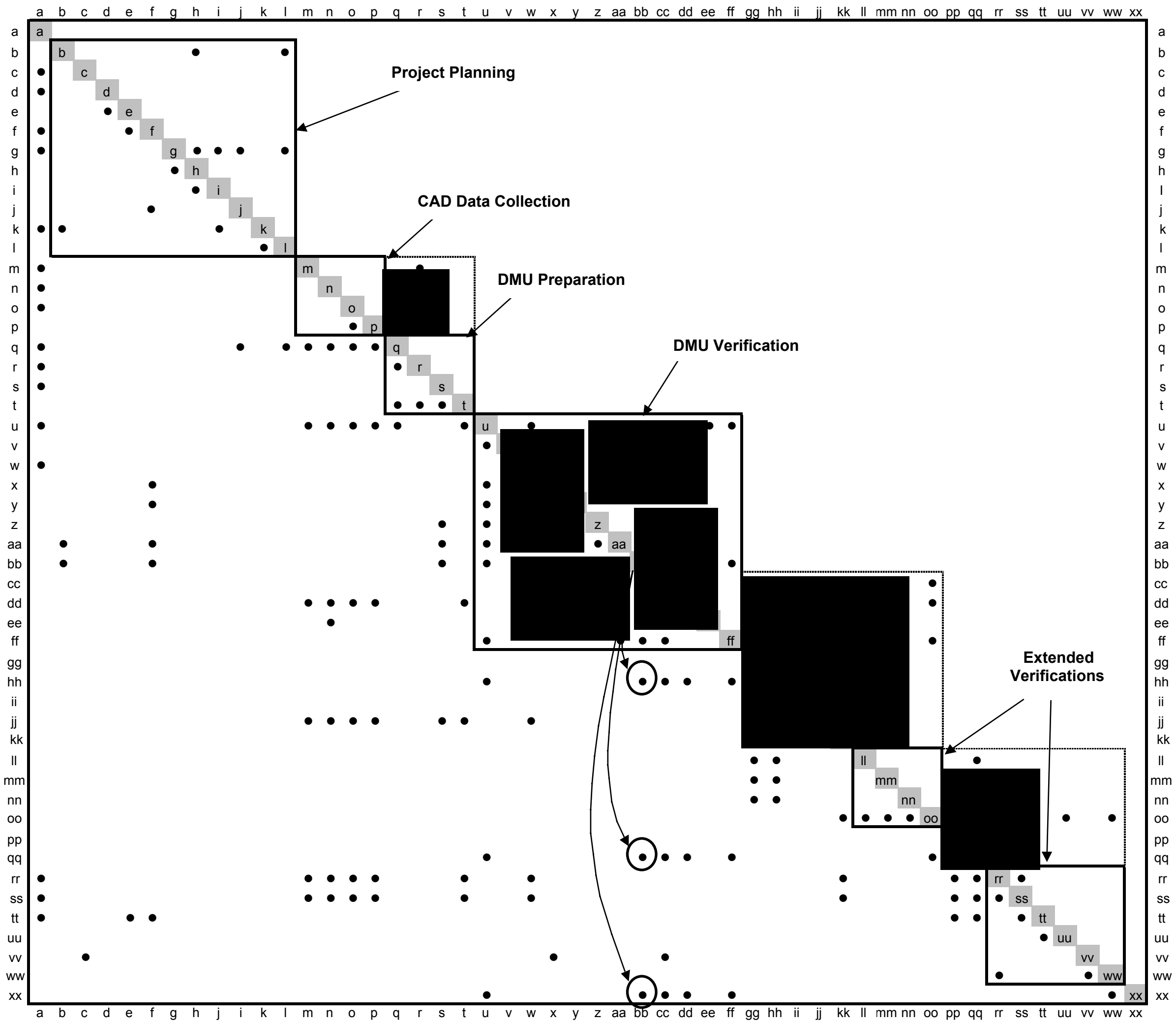
Note:

Coupled tasks can be identified uniquely.

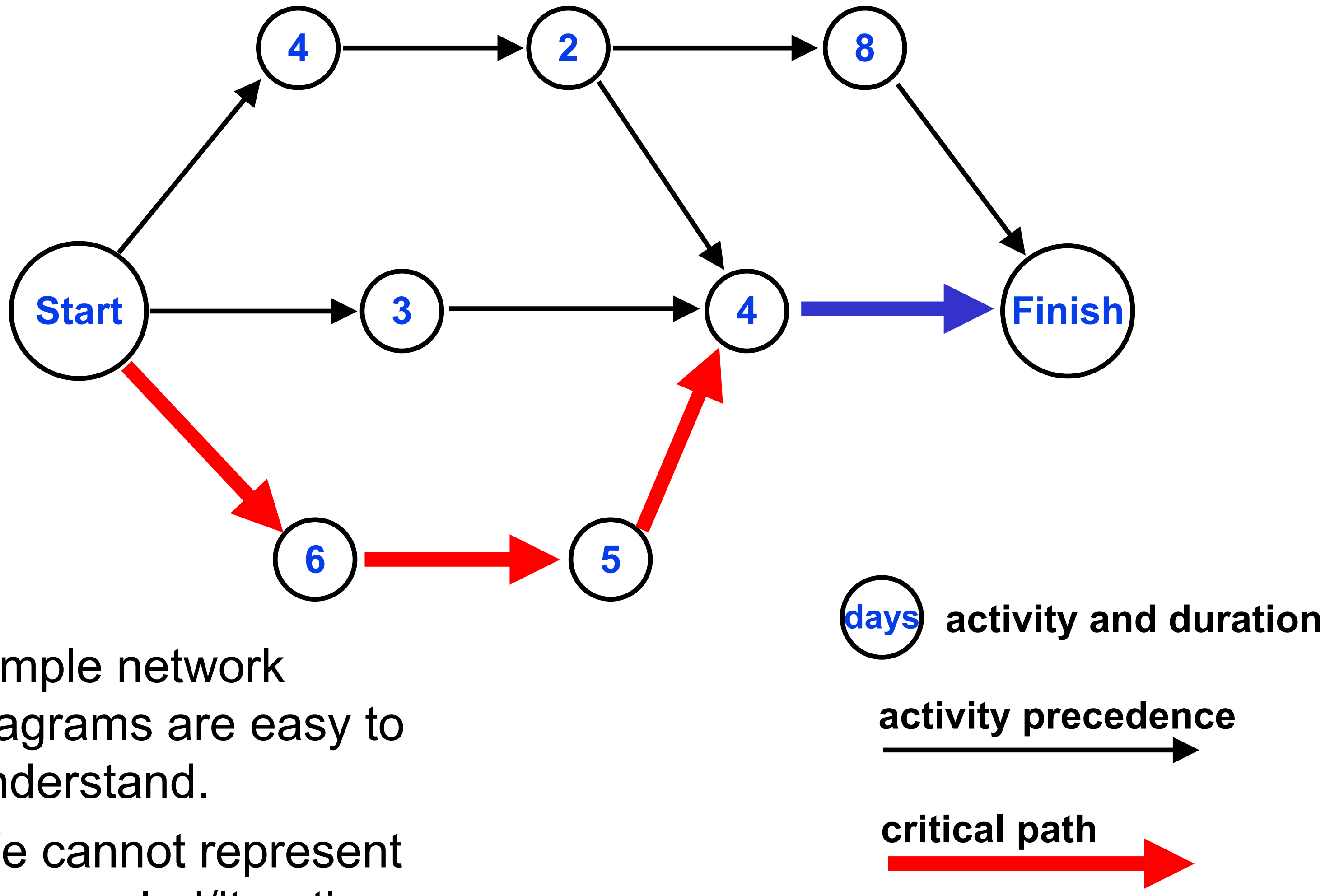
The display of the matrix can be manipulated to emphasize certain features of the process flow.

FIAT Auto – Digital Layout Process

Responsible	Activity	
Top Management	Approve product architecture/configuration	a
Layout Team Leader	Define extended layout team	b
Systems	Determine project quality objectives	c
Layout Team Leader	Establish the need for prototypes	d
Systems	Establish prototype specifications	e
Layout Team Leader	Establish DMU, PMU and prototypes to be developed	f
Layout Team Leader	Prepare activity/resource plan	g
Systems	Approve layout team leader's activity/resource plan	h
Planning	Verify the feasibility of the LO team's plan with other plans	i
Systems	Approve no. of DMU, PMU and prototypes to be developec	j
Layout Team Leader	Verify that planning phase is complete	k
Platform Director	Authorize go ahead to next phase	l
Concurrent Engineering	Provide CAD models in PDM	m
Styling Center	Provide style models	n
Core Layout Team	Extract CAD models from PDM	o
Concurrent Engineering	Convert non-standard CAD models	p
Core Layout Team	Construct DMUs from CAD models	q
Core Layout Team	Verify DMU completeness	r
Layout Team Leader	Review issues document from past project	s
Core Layout Team	Define volumes for new components	t
Core Layout Team	Construct DMU for the verification process	u
Layout Team Leader	Request missing CAD models	v
Concurrent Engineering	Provide missing CAD models in PDM	w
Core Layout Team	Verify DMU using checklist # 80195	x
Core Layout Team	Verify style compatibility	y
Core Layout Team	Prepare alternate solutions	z
Core Layout Team	Analyze issues with appropriate members of the layout team	aa
Extended Layout Team	Verify overall DMU with all stakeholders	bb
Core Layout Team	Update issues document	cc
Concurrent Engineering	Modify CAD models	dd
Styling Center	Modify styling	ee
Core Layout Team	Modify component positioning in DMU	ff
Top Management	Select two models of style	gg
Core Layout Team	Freeze DMU (STEP1)	hh
Layout TL/Production Tech	Define information required for assembly process	ii
Core Layout Team	Specify component connectivity constraints	jj
Concurrent Engineering	Perform detail design for component connectivity	kk
Production Technology	Verify assembly feasibility	ll
Safety Center	Verify safety objectives	mm
Vehicle Maintenance	Verify vehicle maintenance feasibility	nn
Layout Team Leader	Establish/communicate modifications to be done	oo
Top Management	Select one model of style	pp
Core Layout Team	Freeze DMU (STEP 2)	qq
Core Layout Team	Verify that all critical CAD models are present	rr
Core Layout Team	Prepare reference list of CAD drawings for prototyping	ss
Testing	Build prototypes for design validation (DV1)	tt
Road Testing	Run experiments on prototypes	uu
Core Layout Team	Verify project quality objectives	vv
Platform Director	Authorize go ahead to next phase	ww
Core Layout Team	Freeze DMU (STEP 3)	xx

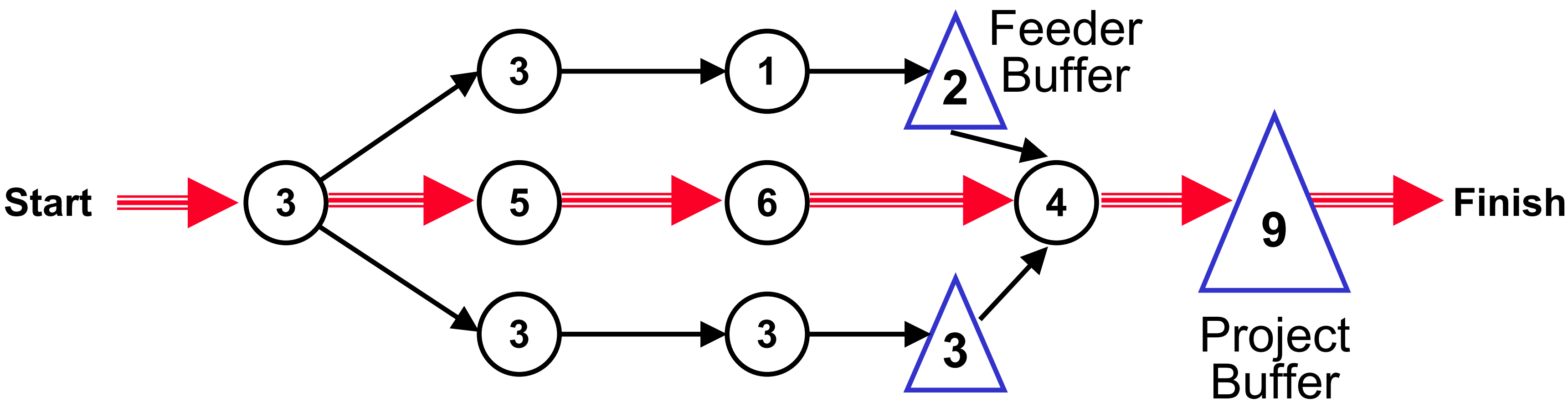


PERT and CPM Charts

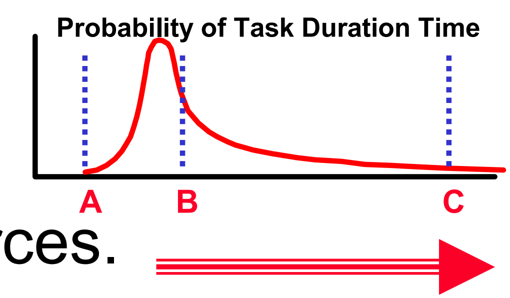


- Simple network diagrams are easy to understand.
- We cannot represent the coupled/iterative task relationships.

Critical Chain Method



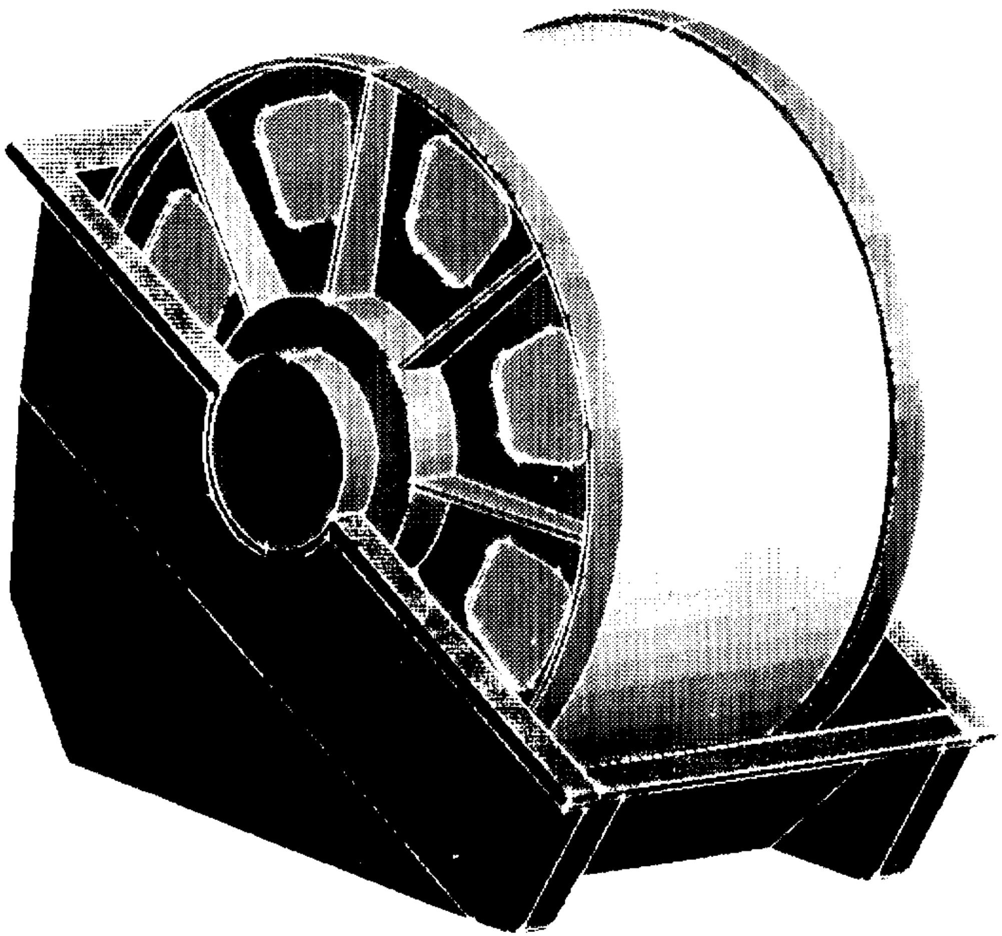
- Start with a sequential/parallel network.
- Use 50/50 task duration estimates.



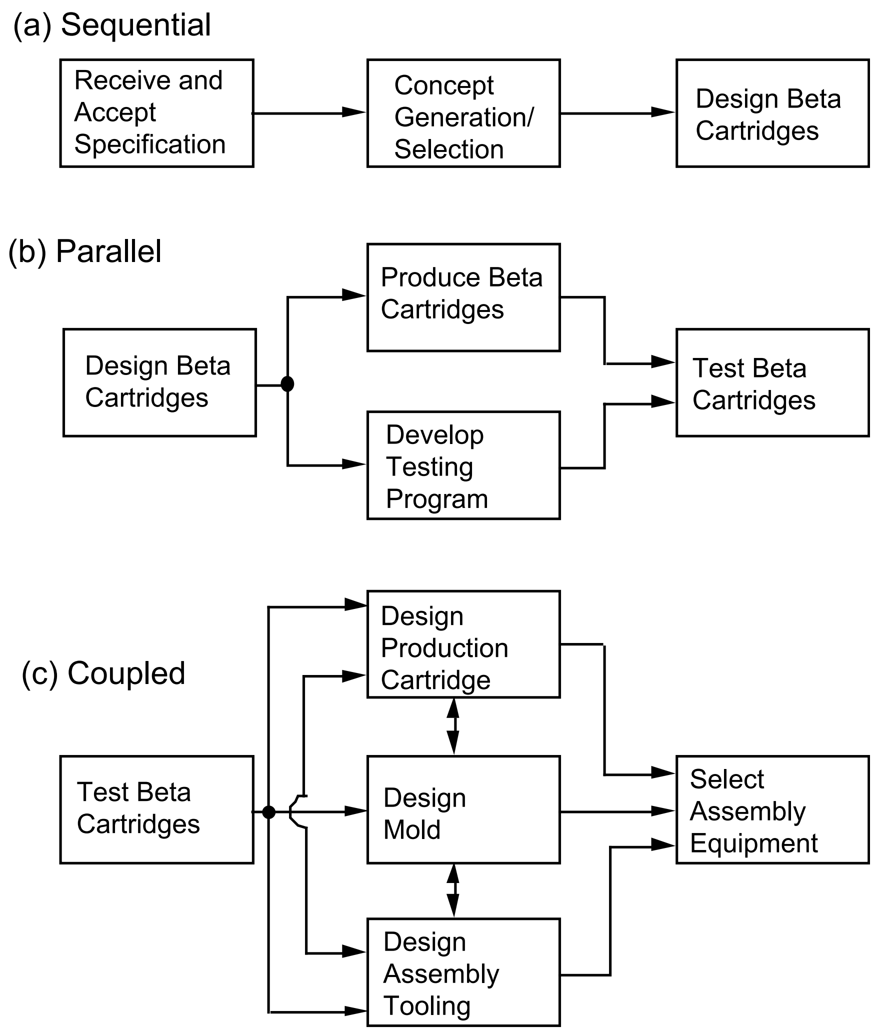
- Compute the critical path, noting resources.
- Insert feeder and project buffers as safety.
- Ideal buffers are 50% of path duration.
- Monitor buffer status.
- Reduce buffers when tasks overrun.

Ref: E.M. Goldratt, *Critical Chain*, North River Press, 1997.

Project Management Example:
Kodak Cheetah Microfilm Cartridge



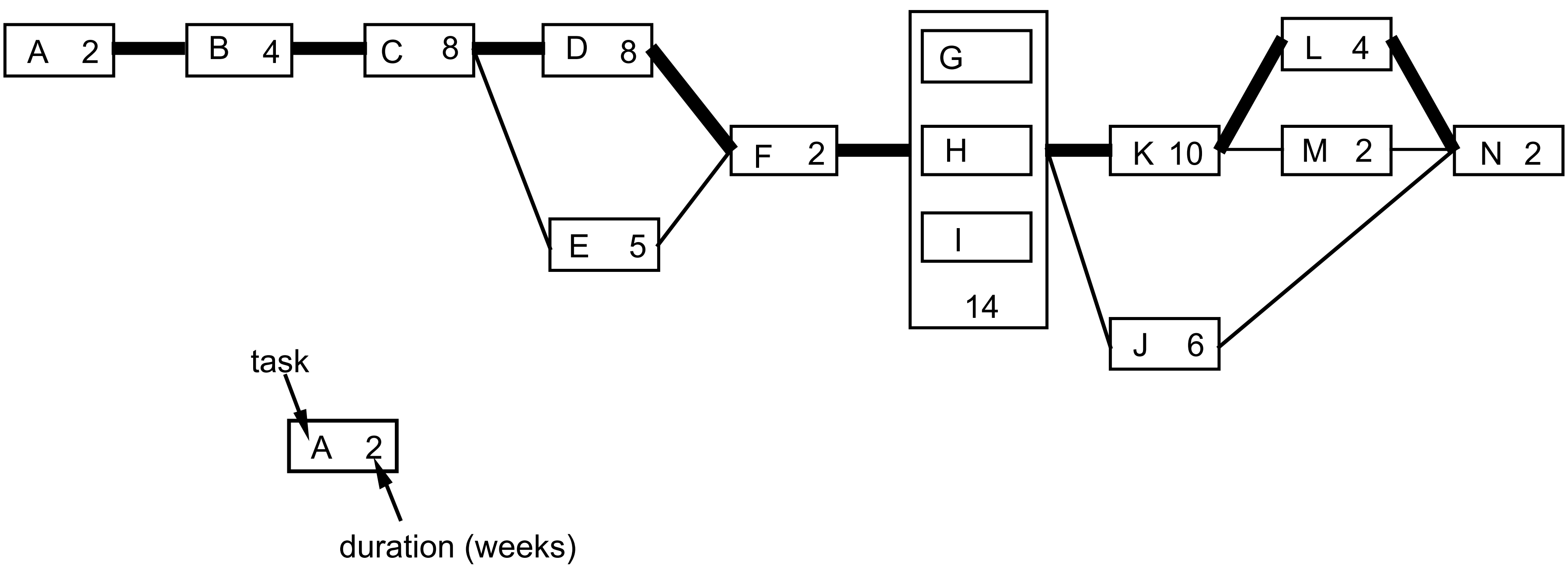
Three Fundamental Activity Relationships



Example: Kodak Cheetah Microfilm Cartridge

PERT Chart and Critical Path

A	Receive and Accept Specification	H	Design Mold
B	Concept Generation/Selection	I	Design Assembly Tooling
C	Design Beta Cartridges	J	Purchase Assembly Equipment
D	Produce Beta Cartridges	K	Fabricate Molds
E	Develop Testing Program	L	Debug Molds
F	Test Beta Cartridges	M	Certify Cartridge
G	Design Production Cartridge	N	Initial Production Run



Design Structure Matrix

TASK		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Receive and Accept Specification	A														
Concept Generation/Selection	B	X													
Design Beta Cartridges	C	X	X												
Produce Beta Cartridges	D			X											
Develop Testing Program	E	X	X	X											
Test Beta Cartridges	F			X	X	X									
Design Production Cartridge	G	X	X	X			X		X	X					
Design Mold	H	X	X				X	X		X					
Design Assembly Tooling	I							X	X						
Purchase Assembly Equipment	J					X		X		X					
Fabricate Molds	K								X						
Debug Molds	L							X	X			X			
Certify Cartridge	M					X						X			
Initial Production Run	N										X		X	X	

Sequential Tasks
Parallel Tasks
Coupled Tasks

Example: Kodak Cheetah Microfilm Cartridge

Tasks for Cooking Dinner

Wash and cut salad vegetables (15 minutes)
Toss the salad (2 minutes)
Set the table (8 minutes)
Start the rice cooking (2 minutes)
Cook rice (25 minutes)
Place the rice in a serving dish (1 minute)
Mix casserole ingredients (10 minutes)
Bake the casserole (25 minutes)
Bring the food to the table (2 minutes)
Call the family for dinner (1 minute)

Group Assignment

Part 1

- Prepare a baseline project schedule for cooking the dinner. Show the schedule in Gantt chart form.
- You will need to identify the dependencies among the tasks. State your assumptions.

Part 2

- Prepare an accelerated project schedule.
- Explain why you believe that the accelerated project is feasible. What are the risks?

Product Specifications

Teaching materials to accompany:

Product Design and Development
Chapter 5

Karl T. Ulrich and Steven D. Eppinger
2nd Edition, Irwin McGraw-Hill, 2000.

Product Design and Development

Karl T. Ulrich and Steven D. Eppinger

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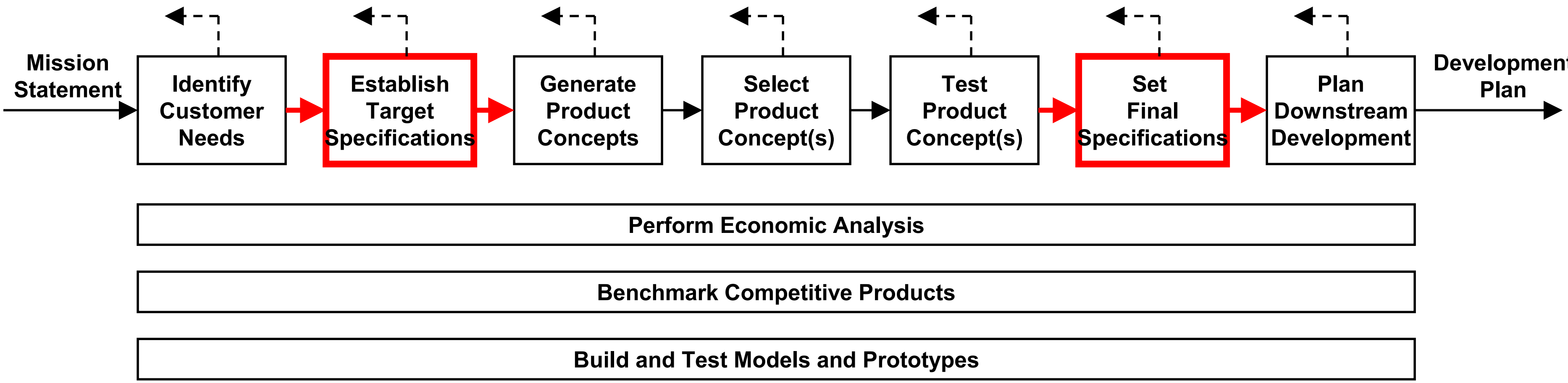


Target Specs

Based on customer needs and benchmarking

Final Specs

Based on selected concept, feasibility, models, testing, and trade-offs

The Product Specs Process

- Set Target Specifications
  - Based on customer needs and benchmarks
  - Develop metrics for each need
  - Set ideal and acceptable values
- Refine Specifications
  - Based on selected concept and feasibility testing
  - Technical modeling
  - Trade-offs are critical
- Reflect on the Results and the Process
  - Critical for ongoing improvement

Product Specifications Example: Mountain Bike Suspension Fork

Start with the Customer Needs

#	NEED		Imp
1	The suspension	reduces vibration to the hands.	3
2	The suspension	allows easy traversal of slow, difficult terrain.	2
3	The suspension	enables high speed descents on bumpy trails.	5
4	The suspension	allows sensitivity adjustment.	3
5	The suspension	preserves the steering characteristics of the bike.	4
6	The suspension	remains rigid during hard cornering.	4
7	The suspension	is lightweight.	4
8	The suspension	provides stiff mounting points for the brakes.	2
9	The suspension	fits a wide variety of bikes, wheels, and tires.	5
10	The suspension	is easy to install.	1
11	The suspension	works with fenders.	1
12	The suspension	instills pride.	5
13	The suspension	is affordable for an amateur enthusiast.	5
14	The suspension	is not contaminated by water.	5
15	The suspension	is not contaminated by grunge.	5
16	The suspension	can be easily accessed for maintenance.	3
17	The suspension	allows easy replacement of worn parts.	1
18	The suspension	can be maintained with readily available tools.	3
19	The suspension	lasts a long time.	5
20	The suspension	is safe in a crash.	5

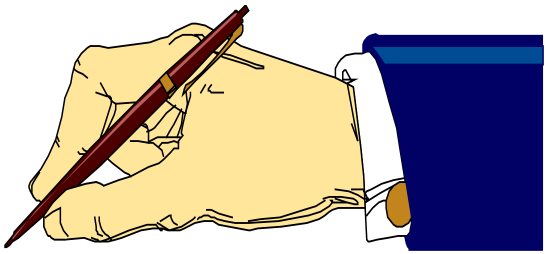
Establish Metrics and Units

Metric #	Need #s	Metric	Imp	Units
1	1,3	Attenuation from dropout to handlebar at 10hz	3	dB
2	2,6	Spring pre-load	3	N
3	1,3	Maximum value from the Monster	5	g
4	1,3	Minimum descent time on test track	5	s
5	4	Damping coefficient adjustment range	3	N-s/m
6	5	Maximum travel (26in wheel)	3	mm
7	5	Rake offset	3	mm
8	6	Lateral stiffness at the tip	3	kN/m
9	7	Total mass	4	kg
10	8	Lateral stiffness at brake pivots	2	kN/m
11	9	Headset sizes	5	in
12	9	Steertube length	5	mm
13	9	Wheel sizes	5	list
14	9	Maximum tire width	5	in
15	10	Time to assemble to frame	1	s
16	11	Fender compatibility	1	list
17	12	Instills pride	5	subj
18	13	Unit manufacturing cost	5	US$
19	14	Time in spray chamber w/o water entry	5	s
20	15	Cycles in mud chamber w/o contamination	5	k-cycles
21	16,17	Time to disassemble/assemble for maintenance	3	s
22	17,18	Special tools required for maintenance	3	list
23	19	UV test duration to degrade rubber parts	5	hours
24	19	Monster cycles to failure	5	cycles
25	20	Japan Industrial Standards test	5	binary
26	20	Bending strength (frontal loading)	5	MN

Metrics Exercise: Ball Point Pen

Customer Need:

The pen writes smoothly.



Link Metrics to Needs

	Need \ Metric	1 Attenuation from dropout to handlebar at 10hz	2 Spring pre-load	3 Maximum value from the Monster	4 Minimum descent time on test track	5 Damping coefficient adjustment range	6 Maximum travel (26in wheel)	7 Rake offset	8 Lateral stiffness at the tip	9 Total mass	10 Lateral stiffness at brake pivots	11 Headset sizes	12 Steertube length	13 Wheel sizes	14 Maximum tire width	15 Time to assemble to frame	16 Fender compatibility	17 Instills pride	18 Unit manufacturing cost	19 Time in spray chamber w/o water entry	20 Cycles in mud chamber w/o contamination	21 Time to disassemble/assemble for maintenance	22 Special tools required for maintenance	23 UV test duration to degrade rubber parts	24 Monster cycles to failure	25 Japan Industrial Standards test	26 Bending strength (frontal loading)
1	reduces vibration to the hands.	•		•	•																						
2	allows easy traversal of slow, difficult terrain.		•																								
3	enables high speed descents on bumpy trails.	•		•	•																						
4	allows sensitivity adjustment.					•																					
5	preserves the steering characteristics of the bike.						•	•																			
6	remains rigid during hard cornering.		•						•																		
7	is lightweight.									•																	
8	provides stiff mounting points for the brakes.										•																
9	fits a wide variety of bikes, wheels, and tires.											•	•	•	•												
10	is easy to install.															•											
11	works with fenders.																•										
12	instills pride.																	•									
13	is affordable for an amateur enthusiast.																		•								
14	is not contaminated by water.																			•							
15	is not contaminated by grunge.																				•						
16	can be easily accessed for maintenance.																					•					
17	allows easy replacement of worn parts.																					•	•				
18	can be maintained with readily available tools.																						•				
19	lasts a long time.																							•	•		
20	is safe in a crash.																									•	•

Benchmark on Customer Needs

#	NEED		Imp	ST Tritrack	Maniray 2	Rox Tahx Quadra	Rox Tahx Ti 21	Tonka Pro	Gunhill Head Shox
1	The suspension	reduces vibration to the hands.	3	•	••••	••	•••••	••	•••
2	The suspension	allows easy traversal of slow, difficult terrain.	2	••	••••	•••	•••••	•••	•••••
3	The suspension	enables high speed descents on bumpy trails.	5	•	•••••	••	•••••	••	•••
4	The suspension	allows sensitivity adjustment.	3	•	••••	••	•••••	••	•••
5	The suspension	preserves the steering characteristics of the bike.	4	••••	••	•	••	•••	•••••
6	The suspension	remains rigid during hard cornering.	4	•	•••	•	•••••	•	•••••
7	The suspension	is lightweight.	4	•	•••	•	•••	••••	•••••
8	The suspension	provides stiff mounting points for the brakes.	2	•	••••	•••	•••	••	•••••
9	The suspension	fits a wide variety of bikes, wheels, and tires.	5	••••	•••••	•••	•••••	•••	•
10	The suspension	is easy to install.	1	••••	•••••	••••	••••	•••••	•
11	The suspension	works with fenders.	1	•••	•	•	•	•	•••••
12	The suspension	instills pride.	5	•	••••	•••	•••••	•••	•••••
13	The suspension	is affordable for an amateur enthusiast.	5	•••••	•	•••	•	•••	••
14	The suspension	is not contaminated by water.	5	•	•••	••••	••••	••	•••••
15	The suspension	is not contaminated by grunge.	5	•	•••	•	••••	••	•••••
16	The suspension	can be easily accessed for maintenance.	3	••••	•••••	••••	••••	•••••	•
17	The suspension	allows easy replacement of worn parts.	1	••••	•••••	••••	••••	•••••	•
18	The suspension	can be maintained with readily available tools.	3	•••••	•••••	•••••	•••••	••	•
19	The suspension	lasts a long time.	5	•••••	•••••	•••••	•••	•••••	•
20	The suspension	is safe in a crash.	5	•••••	•••••	•••••	•••••	•••••	•••••

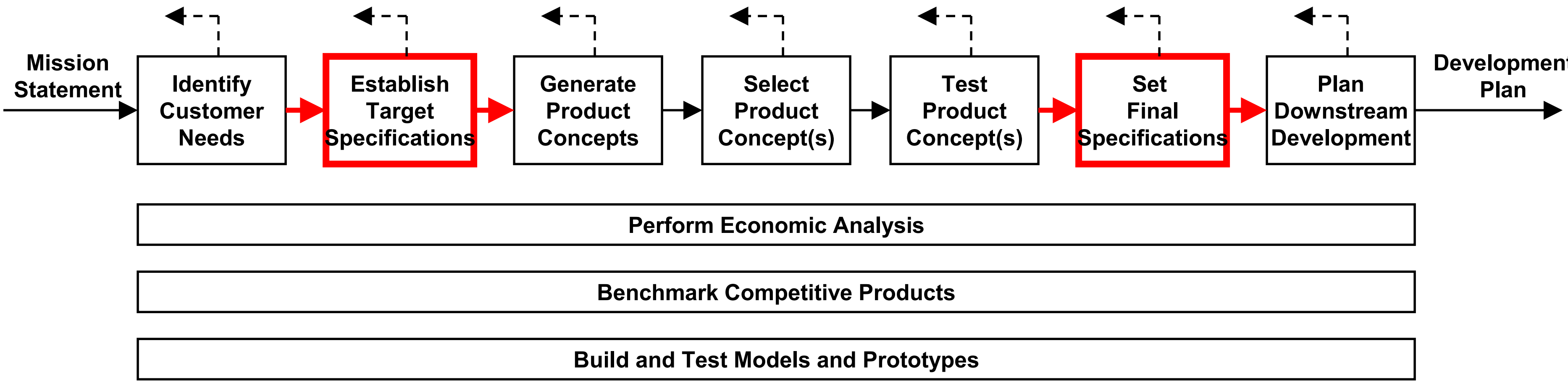
Benchmark on Metrics

Metric #	Need #s	Metric	Imp	Units	ST Tritrack	Maniray 2	Rox Tahx Quadra	Rox Tahx Ti 21	Tonka Pro	Gunhill Head Shox
1	1,3	Attenuation from dropout to handlebar at 10hz	3	dB	8	15	10	15	9	13
2	2,6	Spring pre-load	3	N	550	760	500	710	480	680
3	1,3	Maximum value from the Monster	5	g	3.6	3.2	3.7	3.3	3.7	3.4
4	1,3	Minimum descent time on test track	5	s	13	11.3	12.6	11.2	13.2	11
5	4	Damping coefficient adjustment range	3	N-s/m	0	0	0	200	0	0
6	5	Maximum travel (26in wheel)	3	mm	28	48	43	46	33	38
7	5	Rake offset	3	mm	41.5	39	38	38	43.2	39
8	6	Lateral stiffness at the tip	3	kN/m	59	110	85	85	65	130
9	7	Total mass	4	kg	1.409	1.385	1.409	1.364	1.222	1.1
10	8	Lateral stiffness at brake pivots	2	kN/m	295	550	425	425	325	650
11	9	Headset sizes	5	in	1.000 1.125	1.000 1.125 1.250	1.000 1.125	1.000 1.125 1.250	1.000 1.125	NA
12	9	Steertube length	5	mm	150 180 210 230 255	140 165 190 215	150 170 190 210	150 170 190 210 230	150 190 210 220	NA
13	9	Wheel sizes	5	list	26in	26in	26in	26in 700C	26in	26in
14	9	Maximum tire width	5	in	1.5	1.75	1.5	1.75	1.5	1.5
15	10	Time to assemble to frame	1	s	35	35	45	45	35	85
16	11	Fender compatibility	1	list	Zefal	none	none	none	none	all
17	12	Instills pride	5	subj	1	4	3	5	3	5
18	13	Unit manufacturing cost	5	US$	65	105	85	115	80	100
19	14	Time in spray chamber w/o water entry	5	s	1300	2900	>3600	>3600	2300	>3600
20	15	Cycles in mud chamber w/o contamination	5	k-cycles	15	19	15	25	18	35
21	16,17	Time to disassemble/assemble for maintenance	3	s	160	245	215	245	200	425
22	17,18	Special tools required for maintenance	3	list	hex	hex	hex	hex	long hex	hex, pin wrnch
23	19	UV test duration to degrade rubber parts	5	hours	400+	250	400+	400+	400+	250
24	19	Monster cycles to failure	5	cycles	500k+	500k+	500k+	480k	500k+	330k
25	20	Japan Industrial Standards test	5	binary	pass	pass	pass	pass	pass	pass
26	20	Bending strength (frontal loading)	5	MN	55	89	75	75	62	102

Assign Marginal and Ideal Values

	Metric	Units	Marginal Value	Ideal Value
1	Attenuation from dropout to handlebar at 10hz	dB	>10	>15
2	Spring pre-load	N	480 - 800	650 - 700
3	Maximum value from the Monster	g	<3.5	<3.2
4	Minimum descent time on test track	s	<13.0	<11.0
5	Damping coefficient adjustment range	N-s/m	0	>200
6	Maximum travel (26in wheel)	mm	33 - 50	45
7	Rake offset	mm	37 - 45	38
8	Lateral stiffness at the tip	kN/m	>65	>130
9	Total mass	kg	<1.4	<1.1
10	Lateral stiffness at brake pivots	kN/m	>325	>650
11	Headset sizes	in	1.000 1.125	1.000 1.125 1.250
12	Steertube length	mm	150 170 190 210	150 170 190 210 230
13	Wheel sizes	list	26in	26in 700c
14	Maximum tire width	in	>1.5	>1.75
15	Time to assemble to frame	s	<60	<35
16	Fender compatibility	list	none	all
17	Instills pride	subj	>3	>5
18	Unit manufacturing cost	US$	<85	<65
19	Time in spray chamber w/o water entry	s	>2300	>3600
20	Cycles in mud chamber w/o contamination	k-cycles	>15	>35
21	Time to disassemble/assemble for maintenance	s	<300	<160
22	Special tools required for maintenance	list	hex	hex
23	UV test duration to degrade rubber parts	hours	>250	>450
24	Monster cycles to failure	cycles	>300k	>500k
25	Japan Industrial Standards test	binary	pass	pass
26	Bending strength (frontal loading)	MN	>70	>100

Concept Development Process



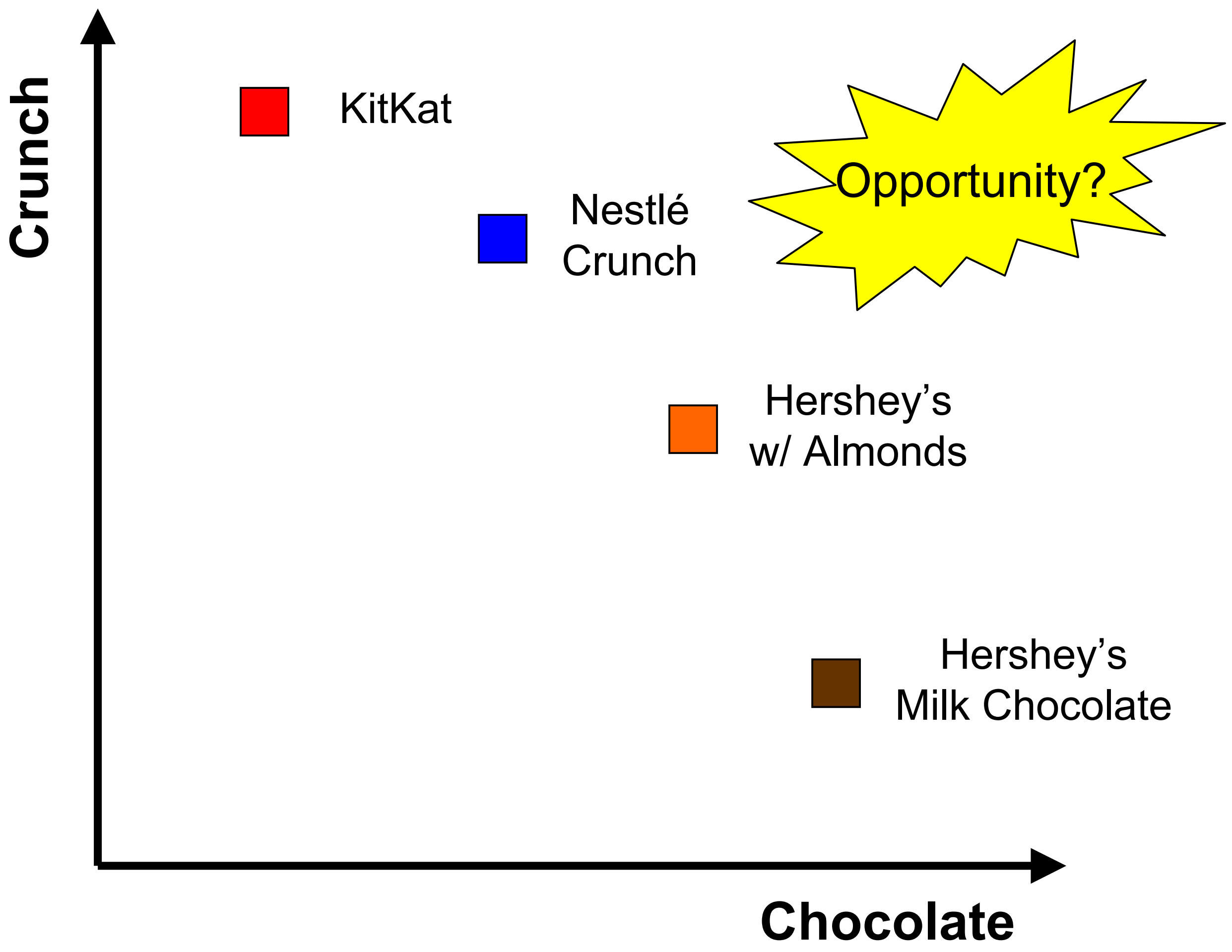
Target Specs

Based on customer needs and benchmarking

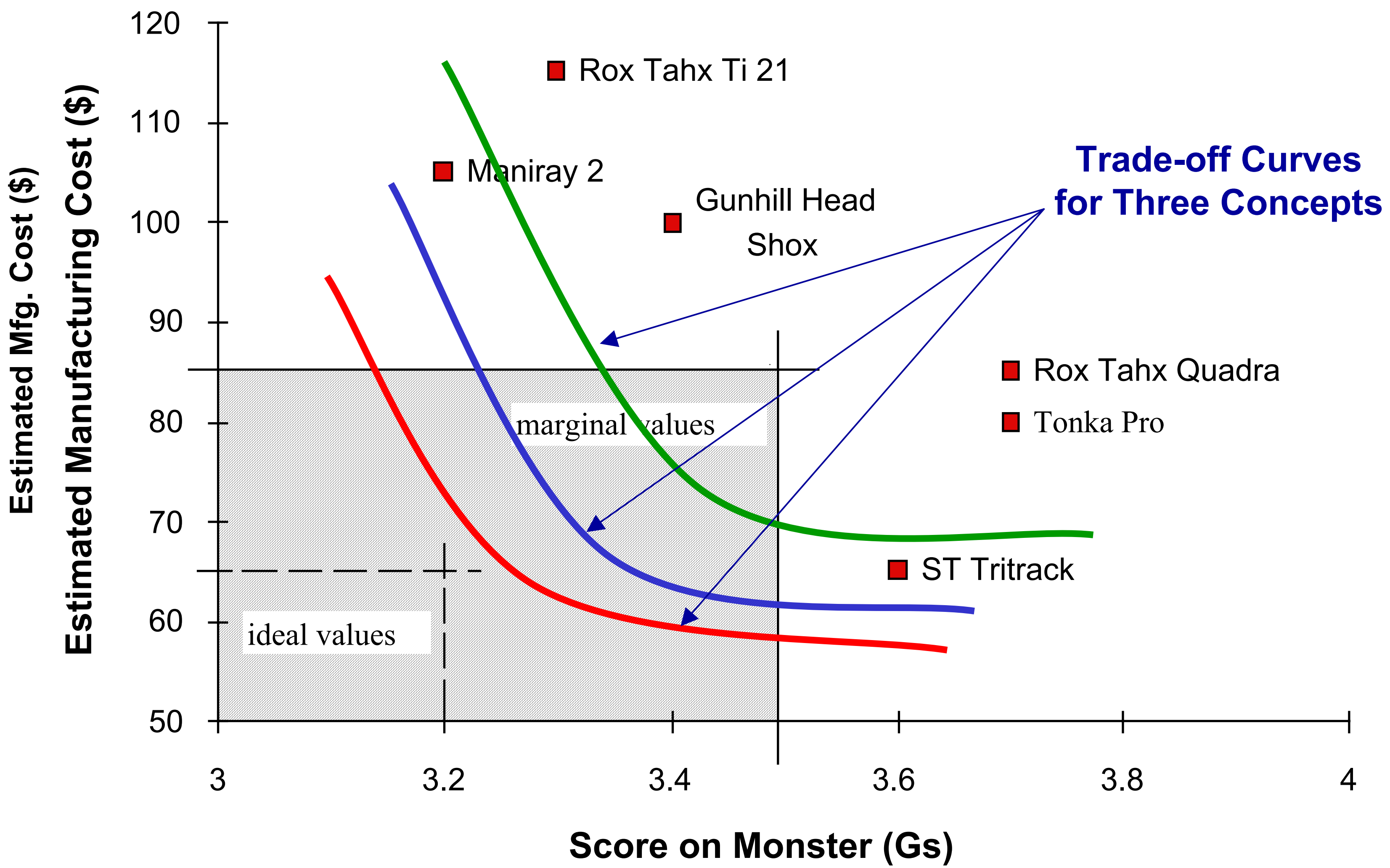
Final Specs

Based on selected concept, feasibility, models, testing, and trade-offs

Perceptual Mapping Exercise



Specification Trade-offs



Set Final Specifications

	METRIC	Units	Value
1	Attenuation from dropout to handlebar at 10hz	dB	>12
2	Spring pre-load	N	650
3	Maximum value from the Monster	g	<3.4
4	Minimum descent time on test track	s	<11.5
5	Damping coefficient adjustment range	N-s/m	>100
6	Maximum travel (26in wheel)	mm	43
7	Rake offset	mm	38
8	Lateral stiffness at the tip	kN/m	>75
9	Total mass	kg	<1.4
10	Lateral stiffness at brake pivots	kN/m	>425
11	Headset sizes	in	1.000 1.125
12	Steertube length	mm	150 170 190 210 230
13	Wheel sizes	list	26in
14	Maximum tire width	in	>1.75
15	Time to assemble to frame	s	<45
16	Fender compatibility	list	Zefal
17	Instills pride	subj	>4
18	Unit manufacturing cost	US$	<80
19	Time in spray chamber w/o water entry	s	>3600
20	Cycles in mud chamber w/o contamination	k-cycles	>25
21	Time to disassemble/assemble for maintenance	s	<200
22	Special tools required for maintenance	list	hex
23	UV test duration to degrade rubber parts	hours	>450
24	Monster cycles to failure	cycles	>500k
25	Japan Industrial Standards test	binary	pass
26	Bending strength (frontal loading)	MN	>100

Quality Function Deployment (House of Quality)