ESD.33 Systems Engineering

Lecture 2

Systems Engineering as a Human Activity

Qi Van Eikema Hommes

Lecture Topics

- Role of Human in Systems Engineering
- The Human Cognitive Limitation
- Challenges facing organizations designing large systems
- Challenges facing systems engineers
- Introduction to Automotive Powertrain System

Systems Engineering is a Human Activity

- Users*
- **Designers—Focus of this lecture***
- Manufacturer*
- Part of the system of systems

* Baldwin, C., and K. Clark, Design Rules, The MIT Press, 2000.

Human as Users of Systems

Not the Focus of this Lecture

- Clip from the *Modern Times*. http://www.youtube.com/watch?v=AvNQiF89Pek&feature=related (until 3’32”)
- Stakeholder needs analysis, requirements development
  - Will discuss in the next lecture
- User interface design / Human-machine interface design
  - Not the focus of this class.
  - Professor Missy Cummings
    - 16.400 Human Factors Engineering
    - 16.422J Human Supervisory Control of Automated Systems

Human as Manufacturers of Systems

Not the Focus of this Lecture

- Clip from the *Modern Times*. http://www.youtube.com/watch?v=AvNQiF89Pek&feature=related (starting at about 4')
- Taylorism
- Henry Ford's Assembly Line
- Toyota Production System
- 2.810 Manufacturing Process and Systems
- 2.852 Manufacturing Systems Analysis

Systems Engineering is a Human Activity

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Lecture Topics

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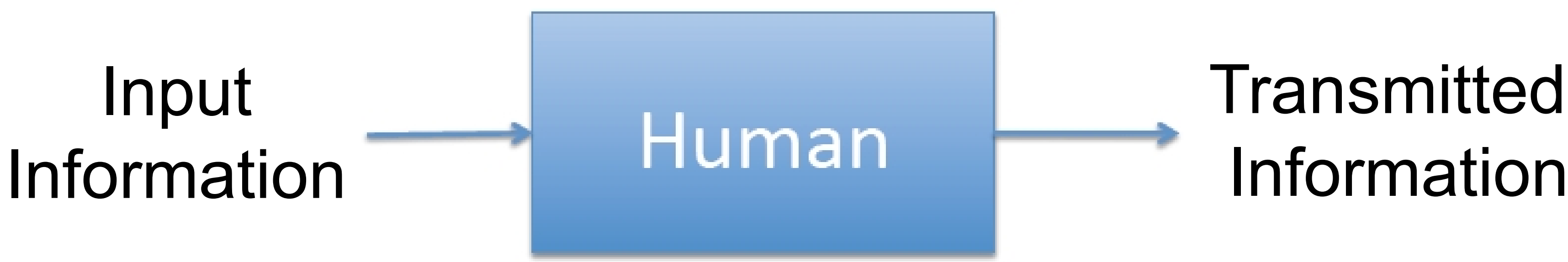
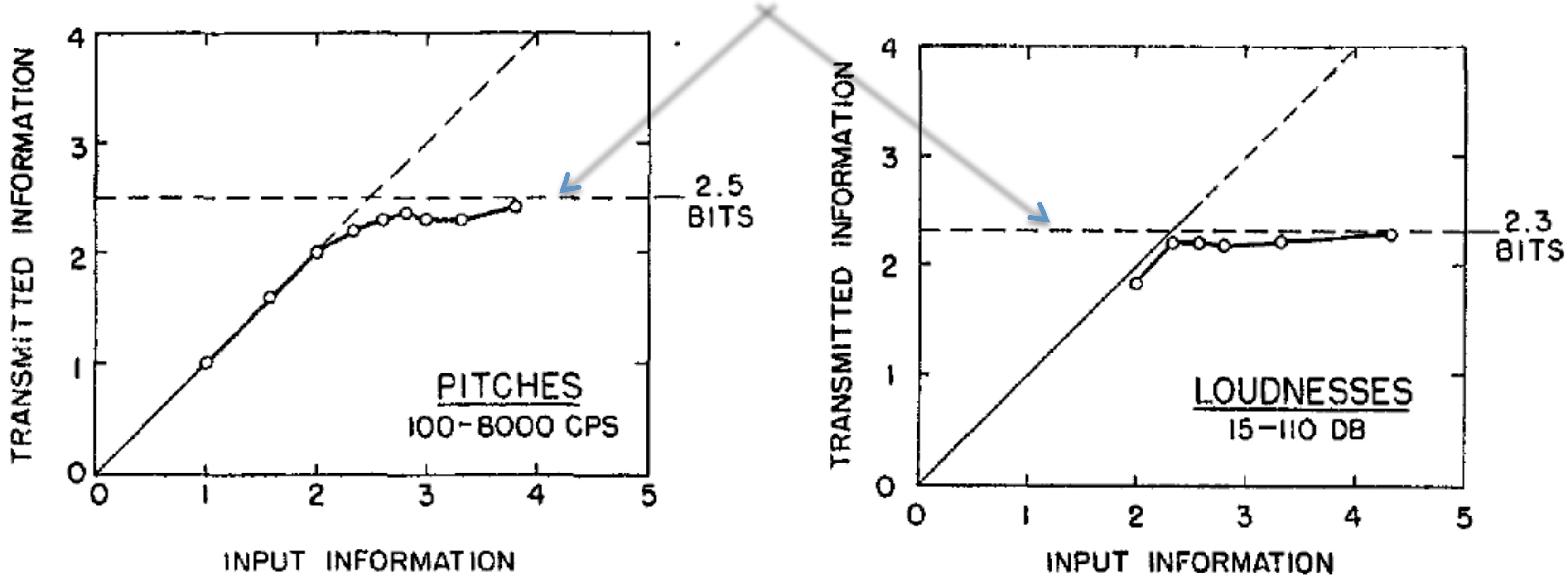
Human as an Information Processor



Information Theoretical View

The Limitation of Human Cognition

Channel Capacity of a Human Listener



Input Information = log2(number of distinctive categories)

Miller, G. A. (1956), "The Magic Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information." *The Psychological Review, Vol. 63, pp81-97.*

The Magic Number Seven

- The <u>Span of Absolute Judgment</u> is the accuracy with which we can identify absolutely the magnitude of a unidimensional stimulus variable.
- The span of absolute judgment and the span of immediate memory impose severe limitation on the amount of information that we are able to receive, process, and remember.

- Miller, G. A. (1956), "The Magic Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information." *The Psychological Review, Vol. 63, pp81-97.*

Complexity is Related to Human Cognitive Limitation

- Class Discussion:

  When Do You Start Calling Something Complex?

Complexity

- The point at which an artifact can no longer be
  - made by a single person
  - Comprehended by a single person

Simple ⟷ Complex

Baldwin, C., and K. Clark, Design Rules, The MIT Press, 2000.

Complexity and Systems Engineering

- Complexity calls for
  - Division of labor
  - Division of knowledge and effort that go into creating a design

Baldwin, C., and K. Clark, Design Rules, The MIT Press, 2000.

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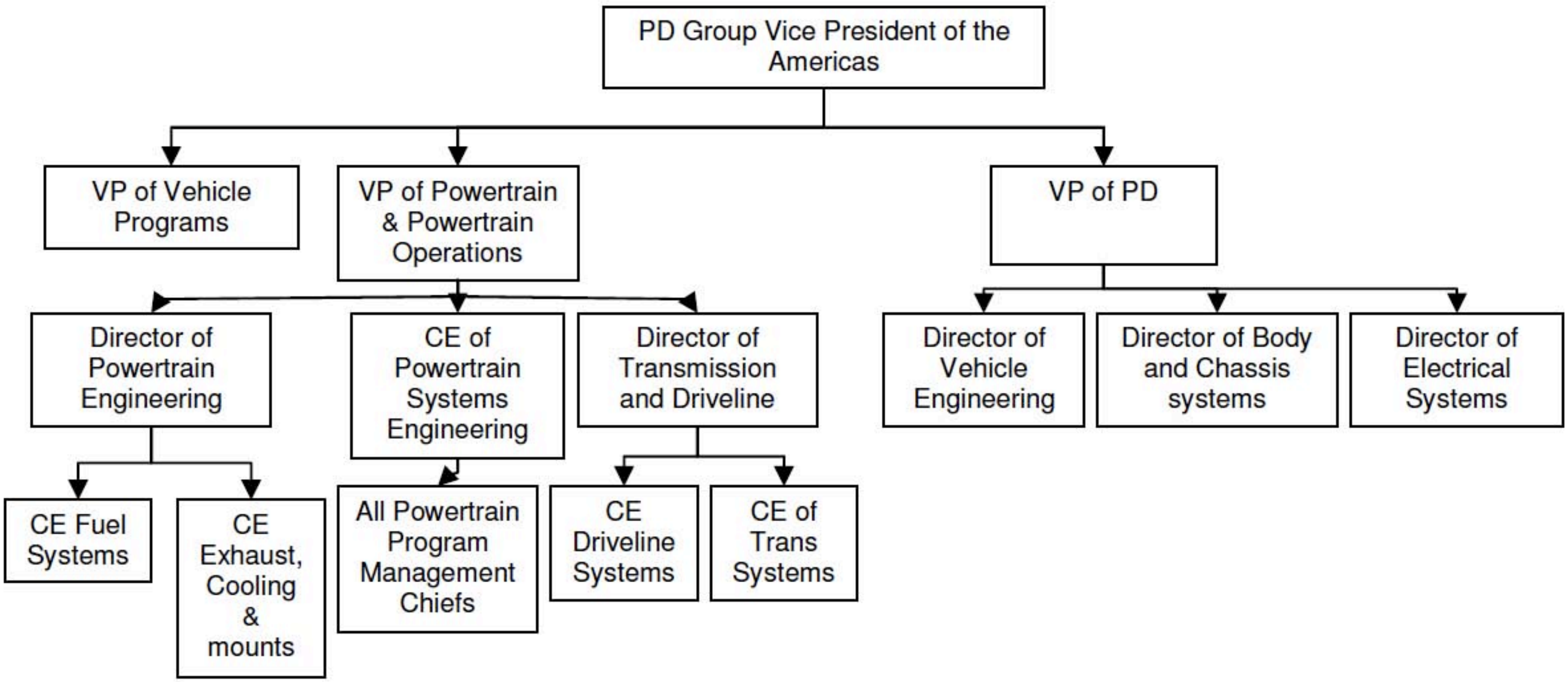
Ford Product Development Organization Breakdown



Source: Michelle Sackas, *A Systems Engineering Approach to Improve Vehicle NVH Attribute Management*. MIT SDM Thesis, 2008.

“Classical Project Organizations”

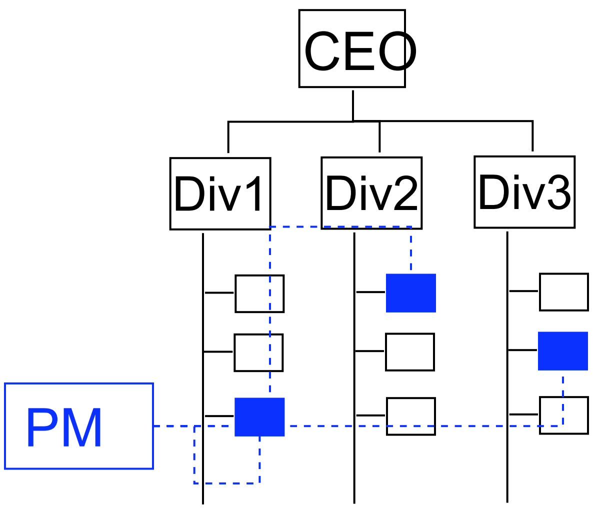
Oli de Weck, ESD.36 Lecture 5

- Dedicated Project Organization
  - Team members work 100% for the project
  - Empowered project manager
  - Organizationally recognized unit for a certain time
- Matrix Organization
  - Project manager has tasking and budget authority
  - Line manager has functional authority, promotions
  - Team members remain in their functional organizations (have 2 bosses)
  - Potential for conflicts
- Influence (Functional) Project Organization
  - Weakest form of project organization
  - “functional” organization, workers are “on loan” to project
  - Project coordinator, but has no budget or tasking authority

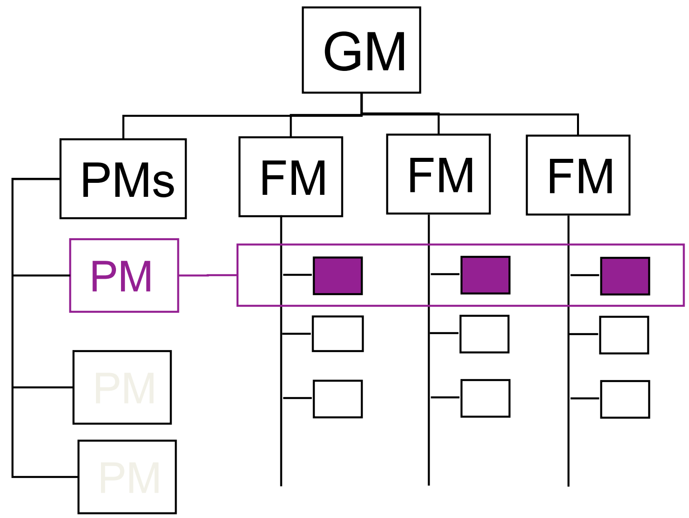
Organizational Charts

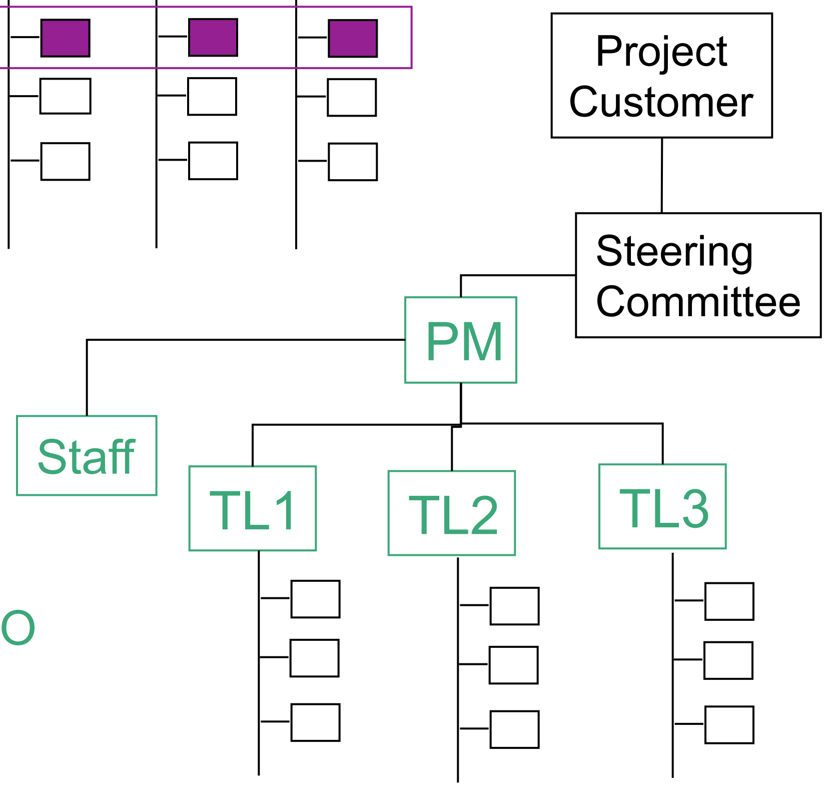
Oli de Weck, ESD.36 Lecture 5

Influence PO



Matrix PO





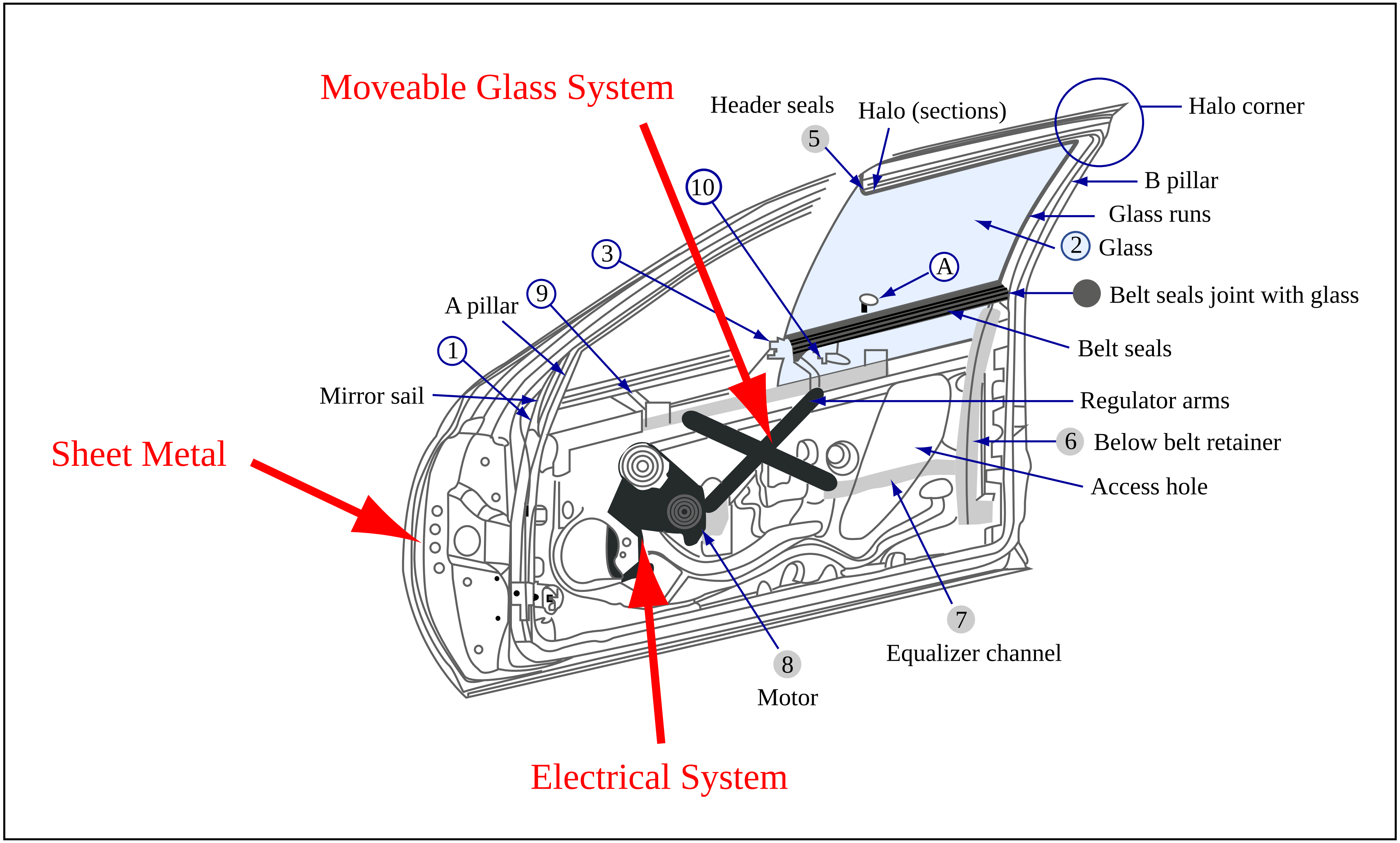
Dedicated PO

PO = Project Organization
CEO = chief executive officer
GM = general manager
PM = project manager
FM = functional manager
Tm= Team Leader

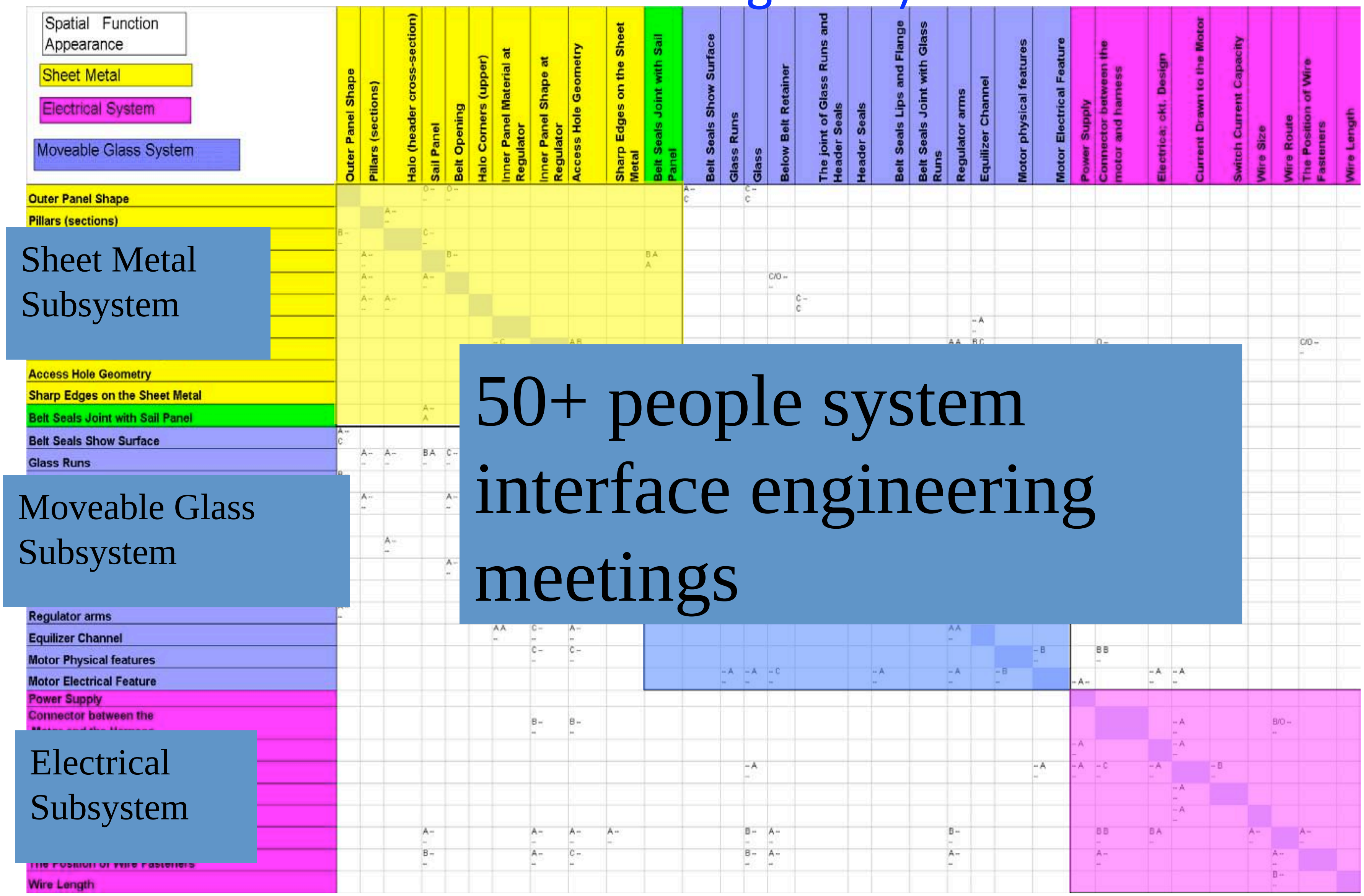
Do You Need an Introduction to Design Structure Matrix (DSM)?

This image is in the public domain and can be found at wikipedia.org

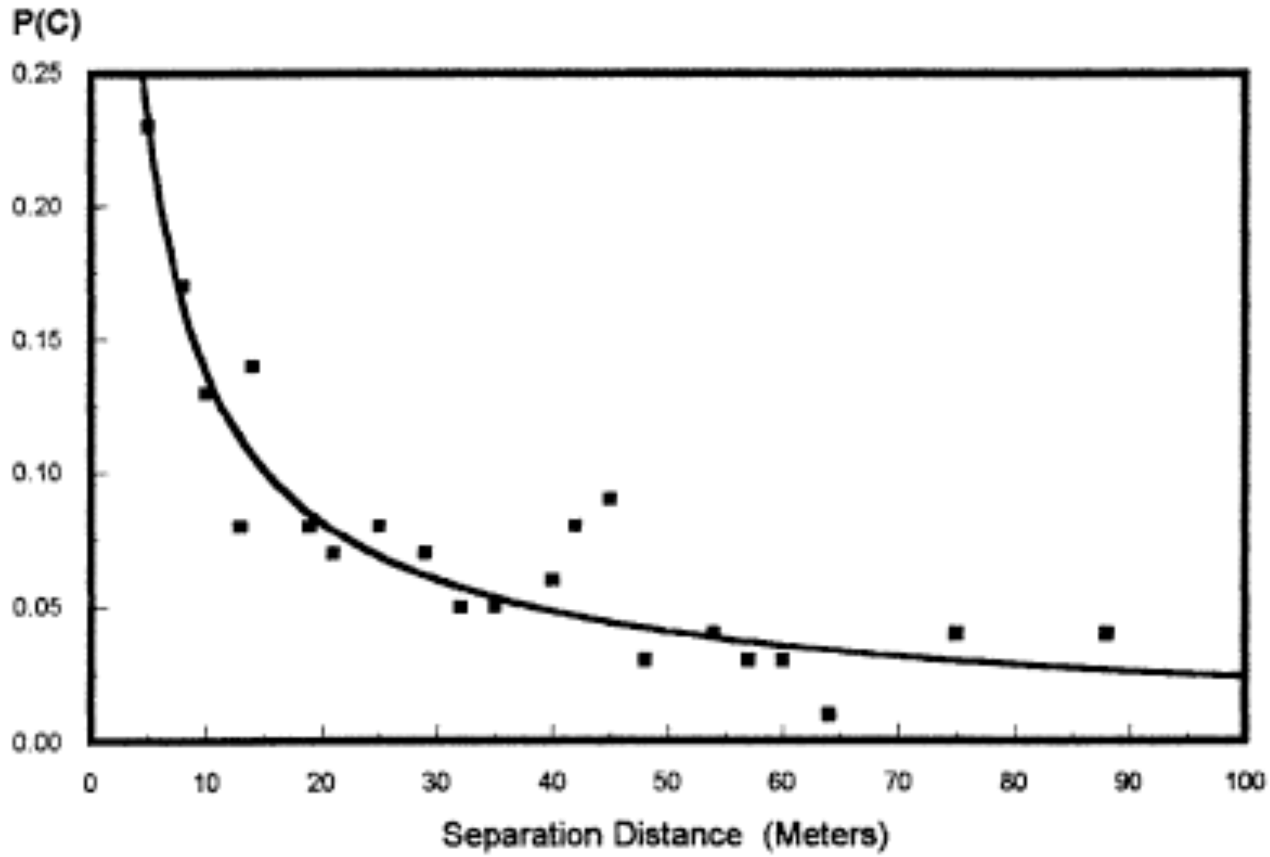
Car Door System Design



Car Door System Engineering Process (Before Partitioning DSM)



Probability of Communication vs. Distance



Allen, T., 1997. Architecture and Communication among Product Development Engineering, Sloan Working Paper 3983, 1997.

Probability of Communication Across Organizational Boundary

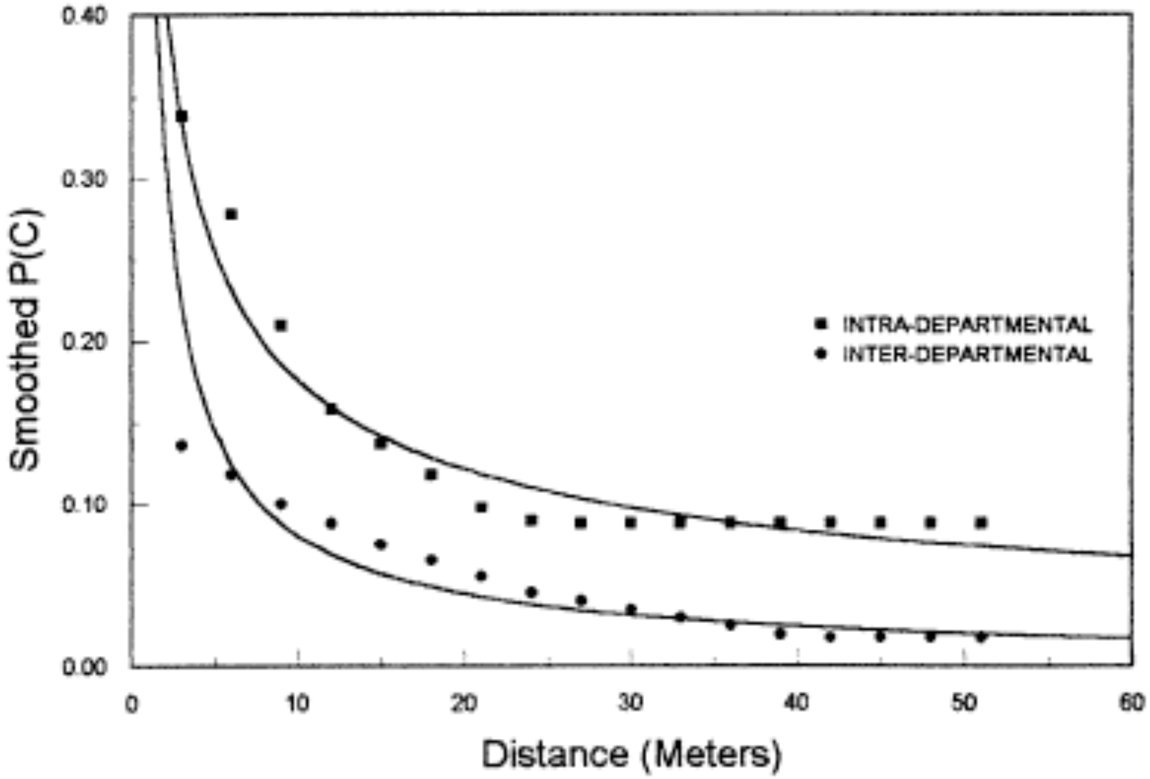
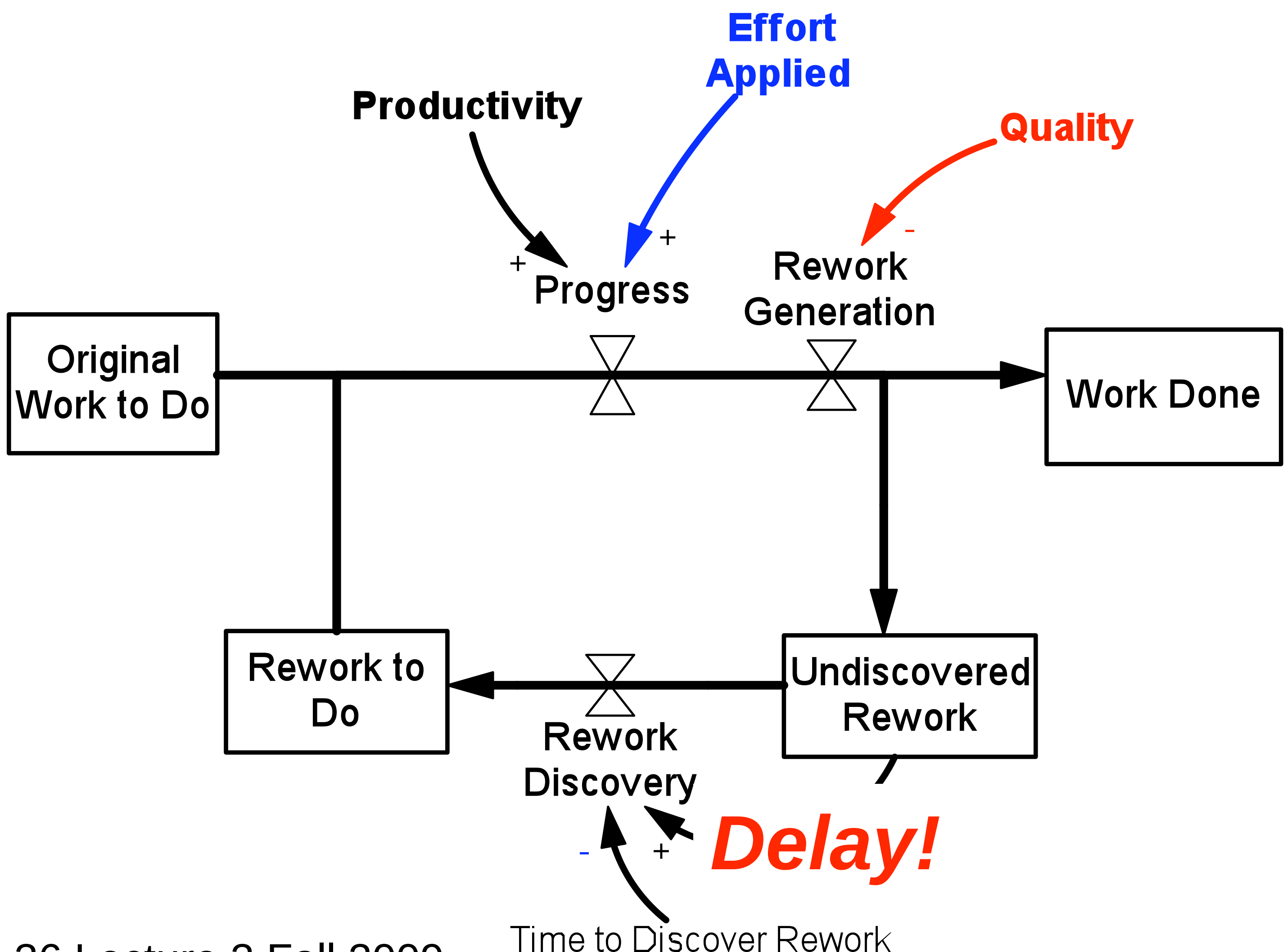


Figure 5. The Effect of Sharing or Not Sharing a Department, (Data taken from a single organization).

Allen, T., 1997. Architecture and Communication among Product Development Engineering, Sloan Working Paper 3983, 1997.

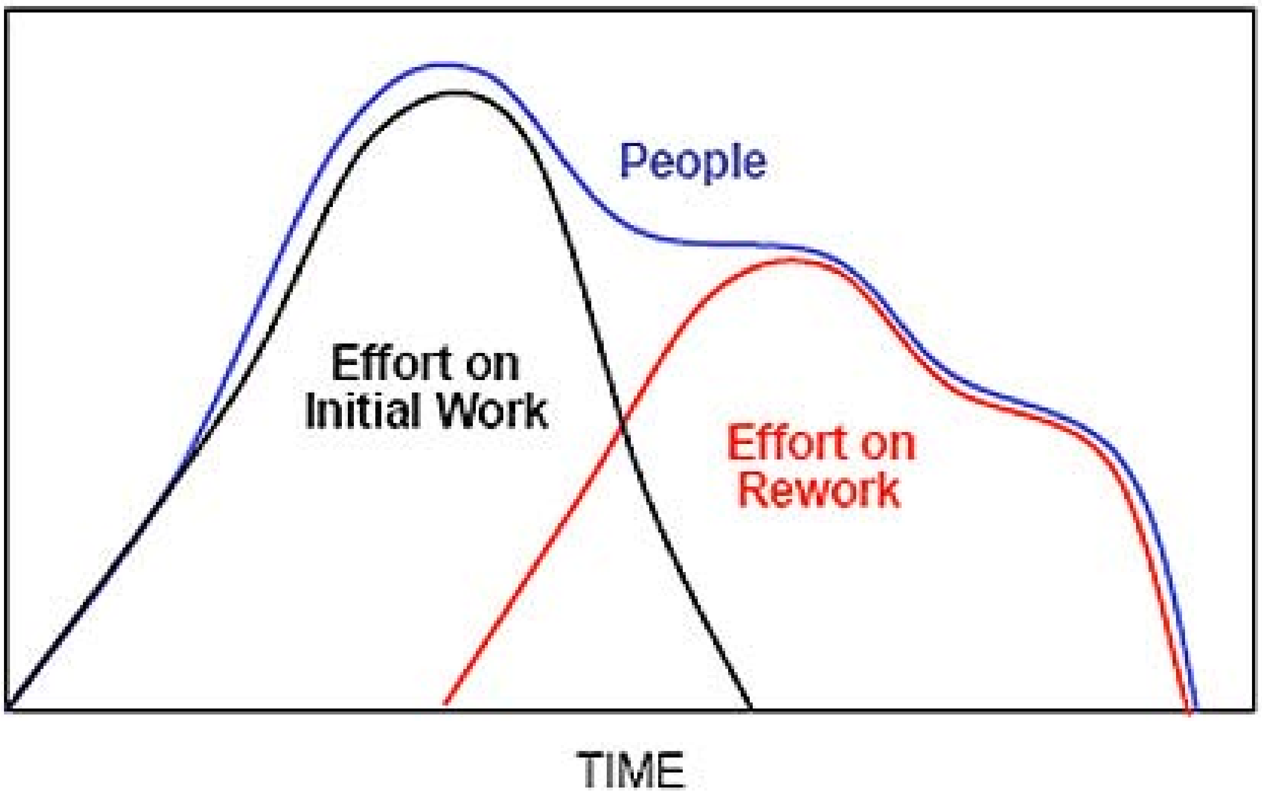
The Rework Cycle



ESD.36 Lecture 3 Fall 2009

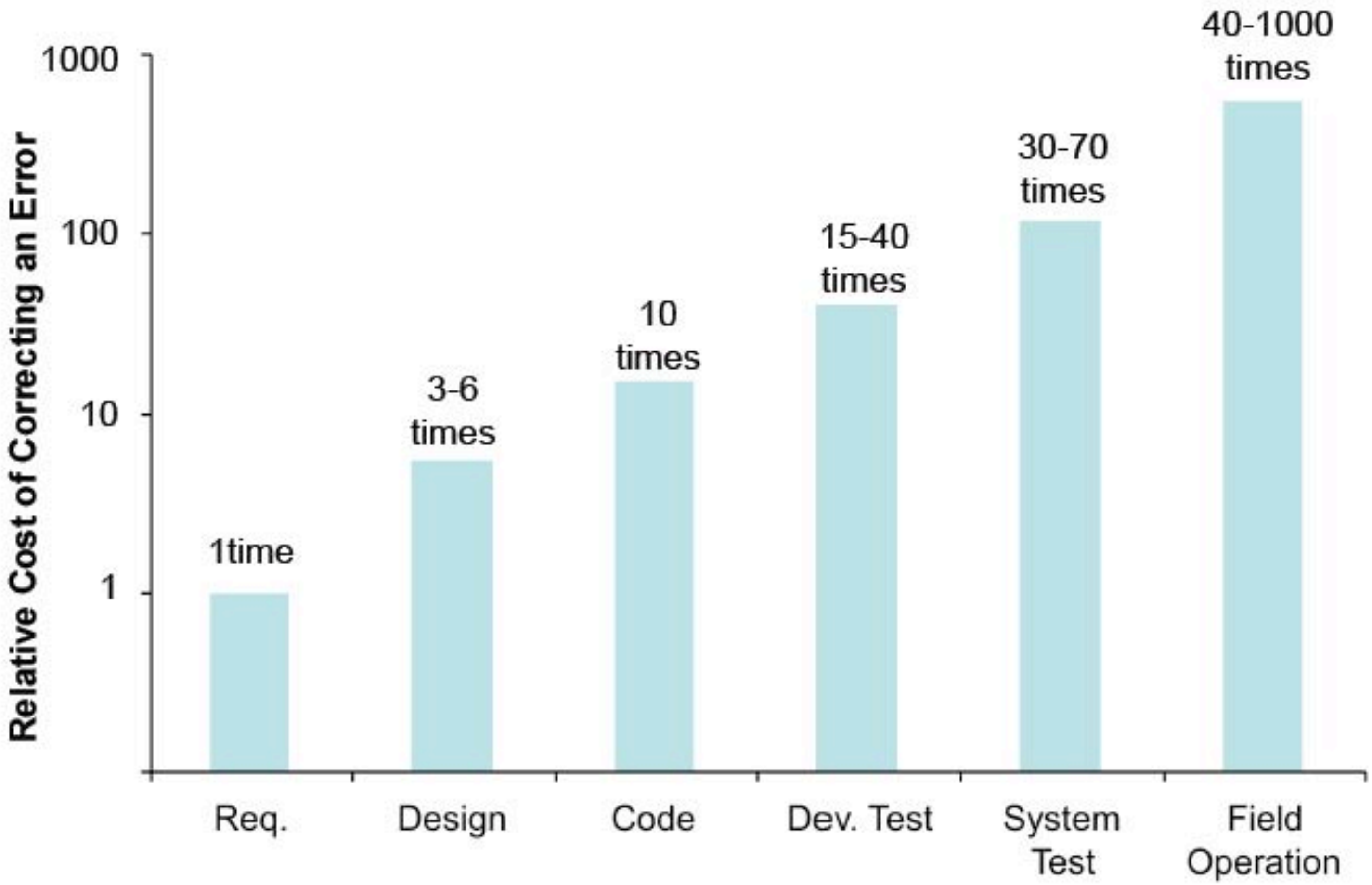
So, What Happens on Projects?

Changes (and management responses) create rework …



ESD.36 Lecture 3 Fall 2009

Relative cost of correcting an error

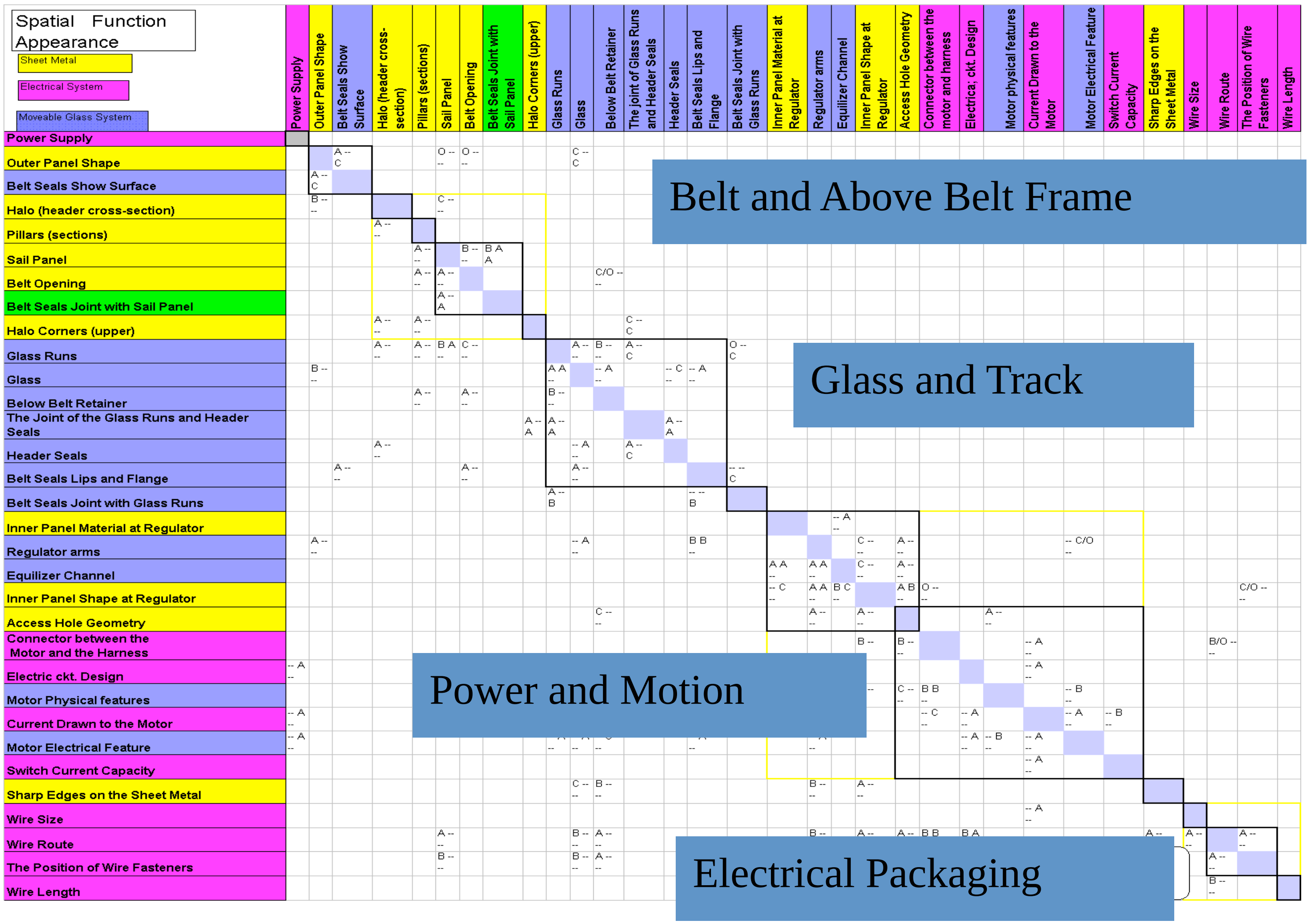


Pat Hale, ESD.33, Summer 2009

The Goal of Good Systems Engineering Efforts

- Address system integration issues as early as possible, and reduce late rework.
  - Good understanding of the system interactions
  - Good coordination among organizations

Car Door System Engineering Process (After Partitioning)



Qi Van Eikema Hommes

Two Types of Iterations

Planned Iteration

- Caused by needs to "get it right the first time."
- We know where these iterations occur, but not necessarily how much.
- Planned iterations should be facilitated by good design methods, tools, and coordination.

Unplanned Iteration

- Caused by errors and/or unforeseen problems.
- We generally cannot predict which unplanned iterations will occur.
- Unplanned iterations should be minimized.

Mapping Out Deliverables in a PD Process

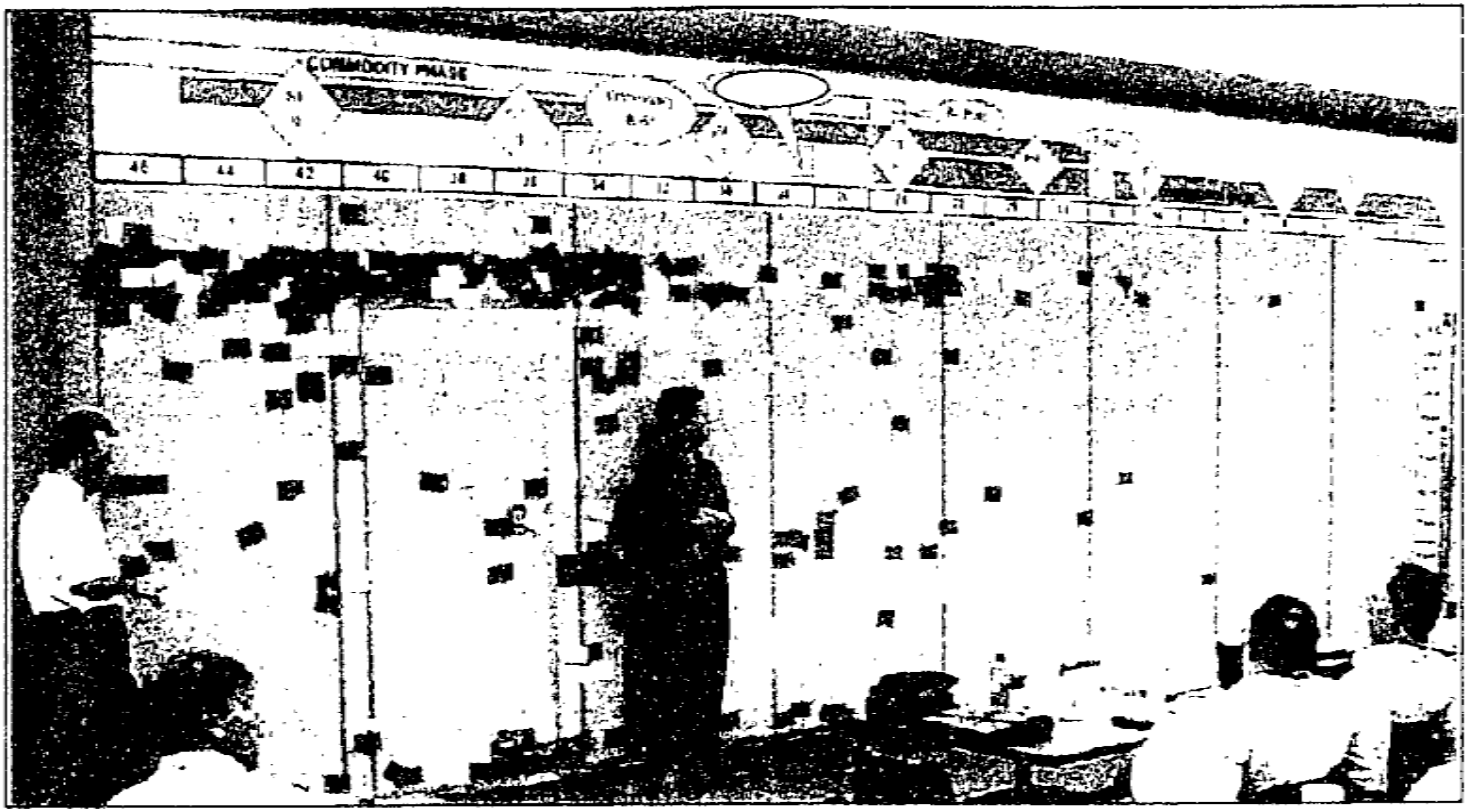


Figure 5.3.2: Wall covered by deliverable cards at the offsite meeting, June 4, 2002

How Many Interfaces Were Truly Understood?

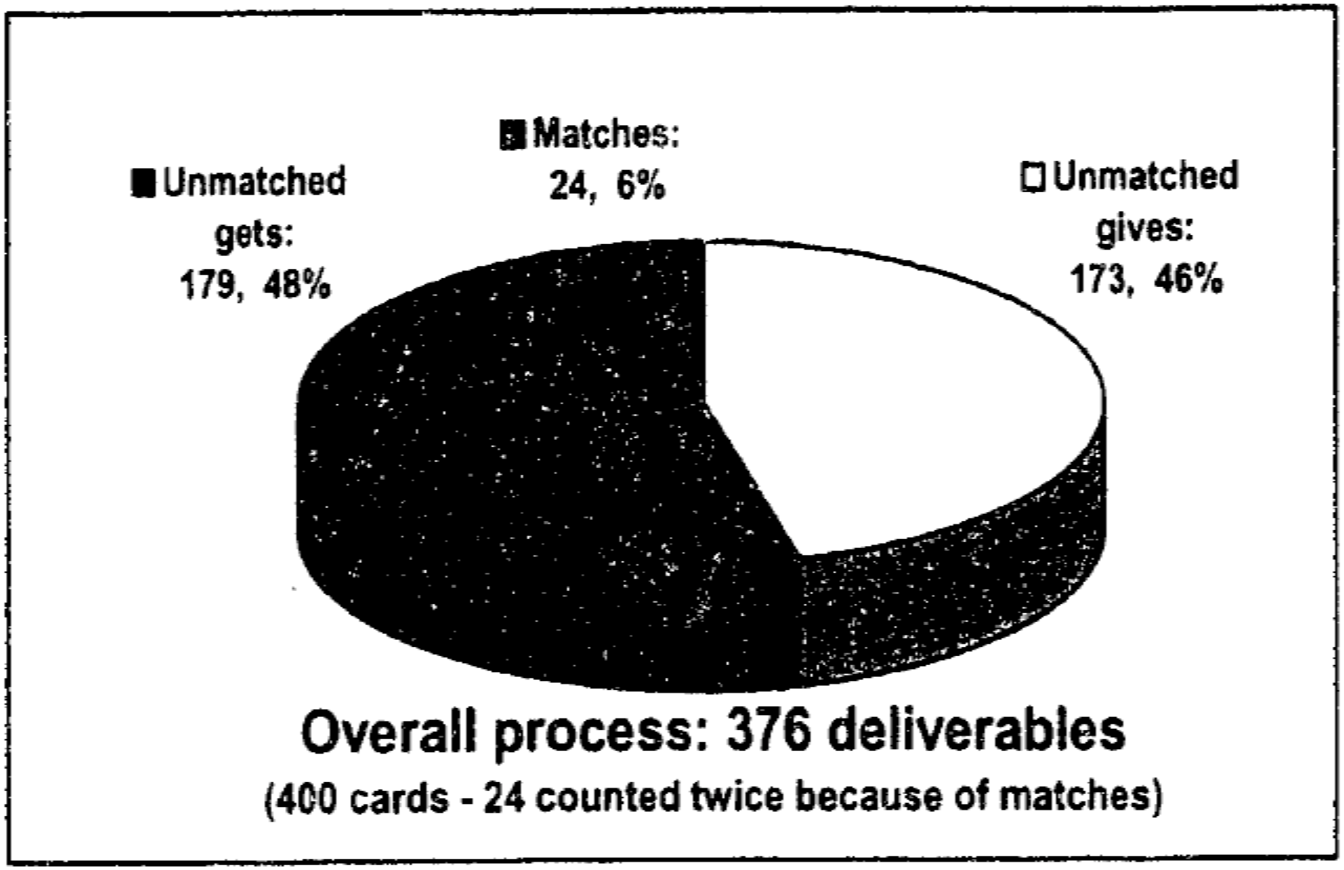


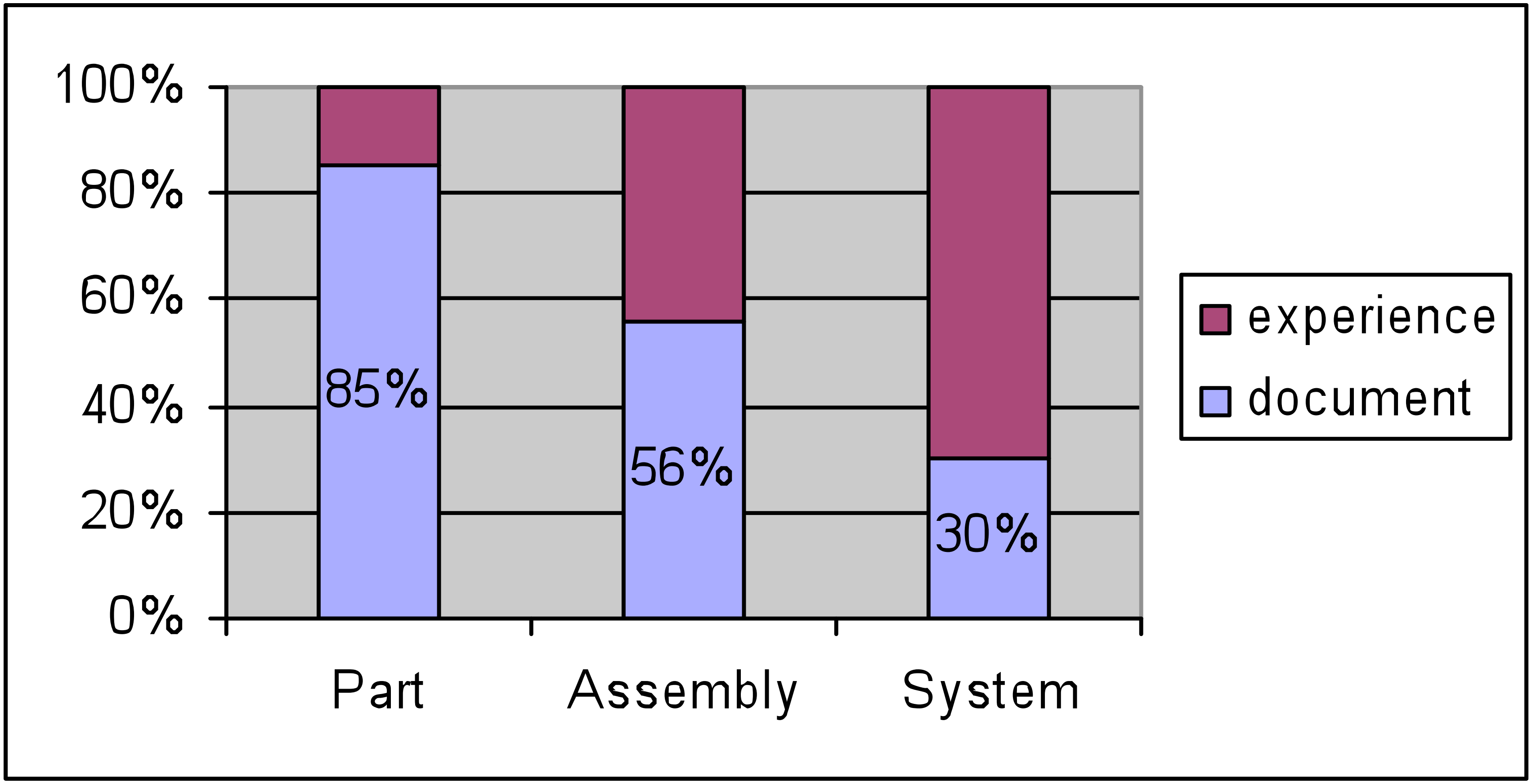
Figure 5.3.4: Gives and Gets analysis results for the overall process[1]

Complexity and Systems Engineering

- Complexity calls for
  - Division of labor
  - Division of knowledge and effort that go into creating a design

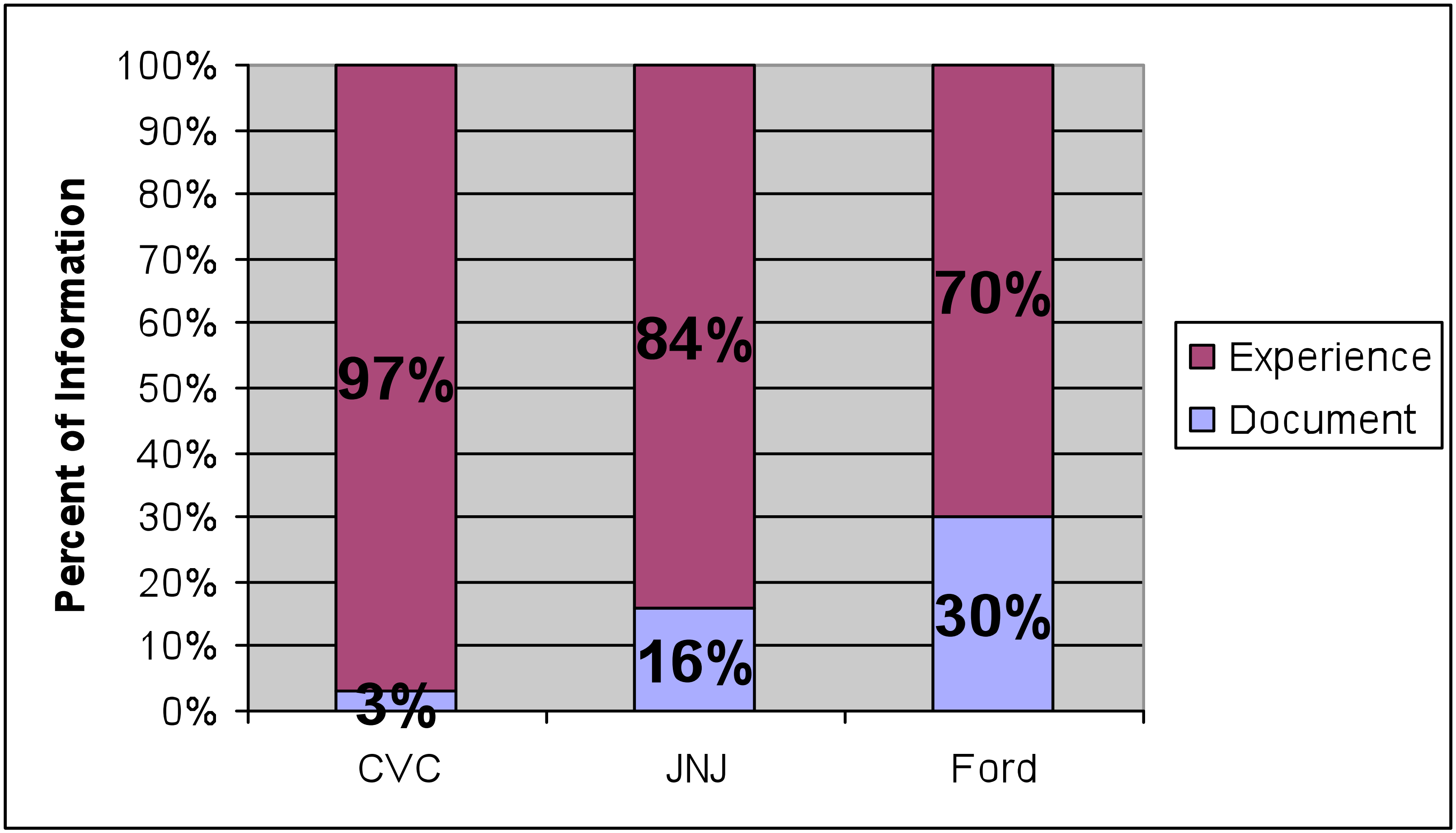
Baldwin, C., and K. Clark, Design Rules, The MIT Press, 2000.

How Well System Level Knowledge is Documented (Ford Throttle Body Design)



Ford Throttle Body Data

How Well Companies Document System Level Knowledge (Based on Three Case Studies)



System Interface Requirements Reconciliation

- **System Interface Requirements** are requirements whose fulfillment involve multiple subsystems. Not all subsystems involved own the requirement.
  - Example: The Oxygen sensor must reach __ degrees before closed-loop engine control starts. <u>Required of</u> Calibration, <u>by</u> Powertrain Electrical System. <u>Owned by</u> Powertrain Electrical System.
- **Interface requirements reconciliation** requires agreement among multiple subsystem requirement authors who may not have the same interest.

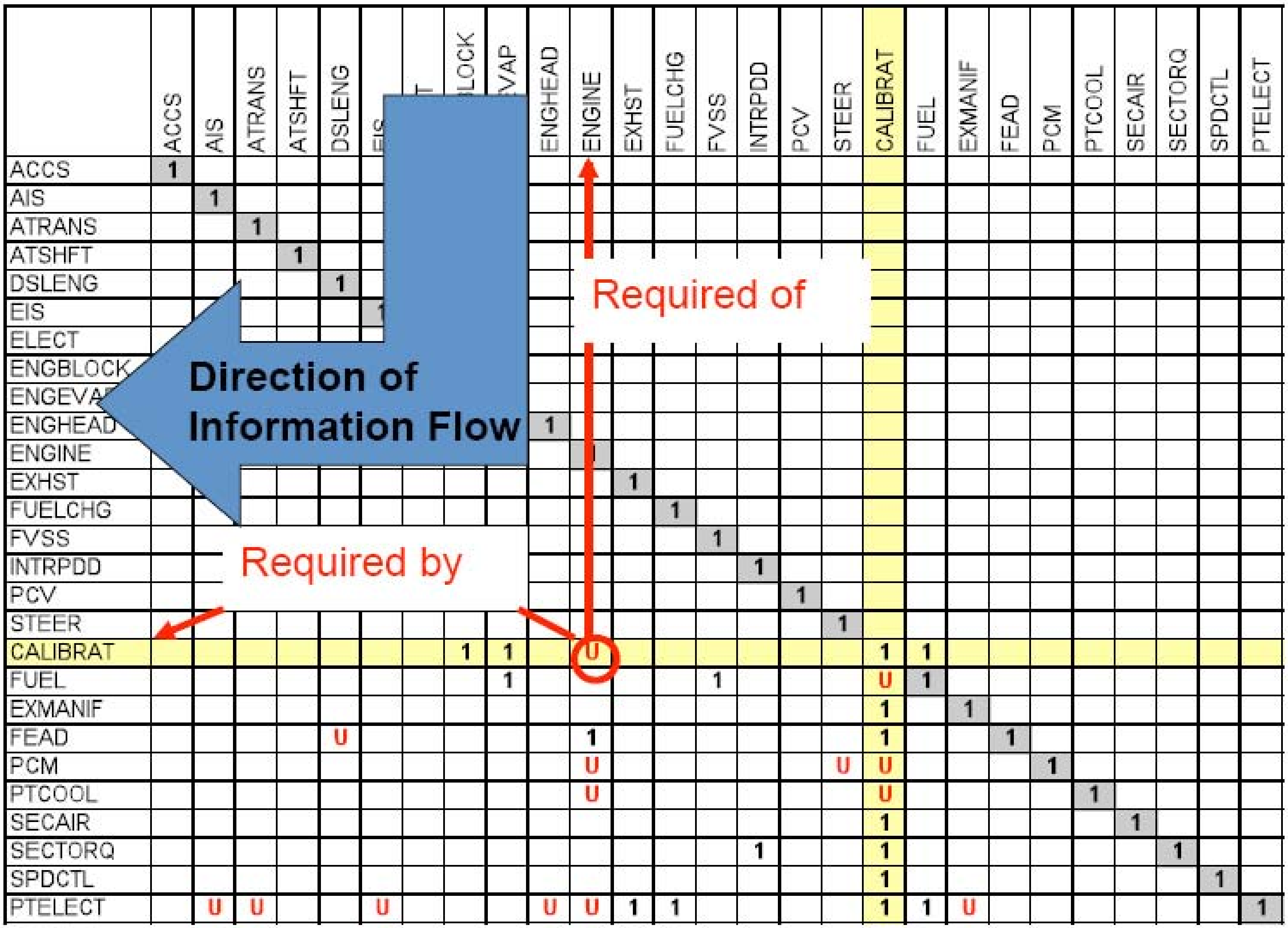
Project Objectives

- Discover the true workload associated with interface requirements reconciliation so as to:
  - correctly report the progress made.
  - make correct staffing decisions.
  - bridge the understanding between the requirement authors and the managers.

What Would You Do?

- Assume you are an engine subsystem manager. How would you estimate how much workload there is in your engine subsystem requirements document?

An Example of a Resulting DSM



U: unreconciled
1: reconciled

The DSM view of the Three Responsibilities

	ACCS	AIS	ATRANS	ATSHFT	DSLENG	EIS	ELECT	ENGBLOCK	ENGEVAP	ENGHEAD	ENGINE	EXHST	FUELCHG	FVSS	INTRPDD	PCV	STEER	CALIBRAT	FUEL	EXMANIF	FEAD	PCM	PTCOOL	SECAIR	SECTORQ	SPDCTL	PTELECT
ACCS	1																										
AIS		1																									
ATRANS			1																								
ATSHFT				1																							
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ELECT							1																				
ENGBLOCK								1																			
ENGEVAP									1																		
ENGHEAD										1																	
ENGINE											1																
EXHST												1															
FUELCHG													1														
FVSS														1													
INTRPDD															1												
PCV																1											
STEER																	1										
CALIBRAT								1	1		U							1	1								
FUEL									1					1				U	1								
EXMANIF																		1		1							
FEAD					U						1							1			1						
PCM											U						U	U				1					
PTCOOL											U							U					1				
SECAIR																		1						1			
SECTORQ															1			1							1		
SPDCTL																		1								1	
PTELECT		U	U			U				U	U	1	1					1	1	U							1

Local

First Order

Second Order

Results

- Verified the findings with requirements authors.
- Proposed improvements on the existing workload accounting system, and the improvements were accepted by the requirement authors and their manager.
- Provided Ford engineers and managers a mental model and a vocabulary to understand the workload associated with interface requirement reconciliation.
- Summarized the current requirement reconciliation status among major PT subsystems.
- Identified areas in the existing PT requirements that need to be improved.

What have We Learned So Far?

- Large organizations are needed to design large systems.
- Organization boundaries causes inefficiency in design information flow.
- System design knowledge is dispersed across organization in a tacit form.
- Managing the system design requires insights into the system interactions and their ramifications.

What DSM can Help with?

- Map out interactions
- Get people actually talking to one another
- Guide work process
- Knowledge management
- Should be vs As-is interactions (DSM exercises help with the understanding of how the team should work together)

Class Discussion Topics

- How do systems architecture design and modularity help?
- What about globalization of engineering efforts? What is the impact?
- What is the value of systems engineering?

Topics

- ✓ Role of Human in Systems Engineering
- ✓ The Human Cognitive Limitation
- ✓ Challenges facing organizations designing large systems
- ❑ Challenges facing systems engineers
- ❑ Introduction to Automotive Powertrain System

Complexity and Systems Engineering

- Complexity calls for
  - Division of labor
  - Division of knowledge and effort that go into creating a design
- **System engineers have to work with:**
  - A lot of people
  - Different kinds of people
  - People from different functions
  - People from different disciplines
  - …

Systems Engineering is about Working with People

The Interdisciplinary Nature of SE

- Must know many things, but don't have to be the expert in every field.
- Must work with many people in different org and from different disciplines.
- Exciting and challenging at the same time.

QBQ—Question behind the Question

- Making better choices by asking better questions.
  - Begin with “What” or “How” (not “Why”, “When”, and “Who”).
  - Contain and “I” (not “they”, “them”, “we”, or “you”)
  - Focus on action

QBQ Class Exercises

- Why didn't they tell me they have changed the design?
- Why aren't they writing proper requirements?
- Why don't customers follow instructions?

QBQ Class Exercises

- When will they take care of the problem?
- When are they going to give us the answer?
- When are we going to get better software for this?

QBQ Class Exercise

- Who dropped the ball?
- Who made these mistakes?
- A poor sailor blames the wind.

Dale Carnegie Principles
Gain the Willing Cooperation of Others

1. Get The Other Person Saying “Yes, Yes” Immediately.
2. Try Honestly To See Things From The Other Person’s Point Of View.
3. Be Sympathetic With The Other Person’s Ideas And Desires.
4. Appeal To The Nobler Motives.
5. Dramatize Your Ideas.
6. Throw Down A Challenge

Making the Short Talk to Get Action

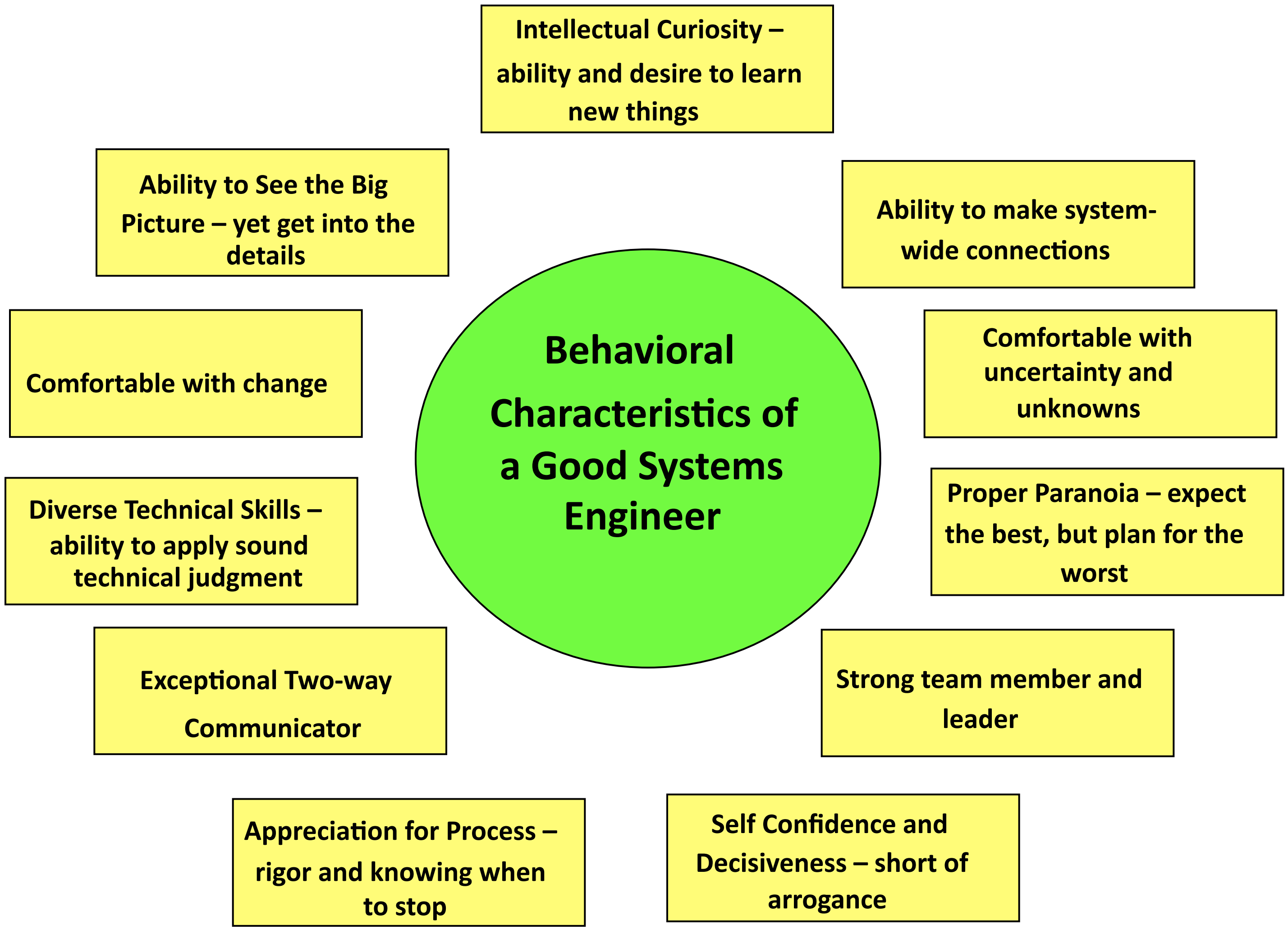
1. Give your example, an incident from your life.
   – Build your example upon a single personal experience
   – Start your talk with a detail of your example
   – Fill your example with relevant details
   – Relive your experience as you relate it
2. State your point with force and conviction
3. Give the reason or benefit the audience may expect

Class Exercise for Making a Short Talk to Get Action

What Kind of Inter-personal Communication Method has Worked for You?

Class Discussion

Gentry Lee's Critical Behaviors of Systems Engineering



Summary

- Human needs is the motivation for developing large complex systems.
- Human limitation is the cause of the many challenges in the development of large complex systems.
- System engineering is about understanding and managing the human activity of the design and development of large systems
  - Organization design and management
  - Individual system engineers' development

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- ✓ Challenges facing systems engineers
- ❑ Introduction to Automotive Powertrain System

Introduction to Automotive Powertrain System

Reference Book

- Internal Combustion Engine Handbook**Basics, Components, Systems, and PerspectivesAUTHORs: Richard Van Basshuysen, Fred Schaefer**
- Published By: SAE International and Professional Engineering PublishingPublished: December 2004Pages: 868Binding: HardboundProduct Code: R-345Product Status: Available