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Error-Proofing of the Product Development Process

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A few words about Larry...

- ***School***
  - MIT, BS in ME (*1998*)
  - Stanford University, MS in ME (*1999*)
  - Currently pursuing PhD in dfM at Stanford
- ***Work***
  - GE Aircraft Engines (*Cincinnati, OH*)
  - MITI's Mechanical Engineering Laboratory (*Tsukuba, Japan*)
  - U.S. Department of Transportation (*Boston, MA*)
  - General Motors (*Warren, MI*)
- ***Fun***
  - tennis, movies, travel

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Outline

1) Motivation

2) Background

- common design process errors
- international industry survey results

3) Current Techniques

- tools and techniques currently used in industry to remedy errors

4) Proposed Research Roadmap

- **Prediction:** *design process FMEA*
- **Prevention:** *design process error-proofing*

5) Conclusions

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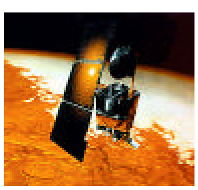
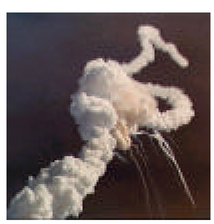
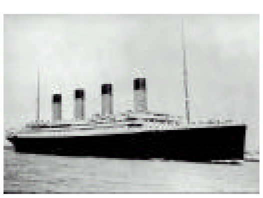
“Design Error Benchmarking”





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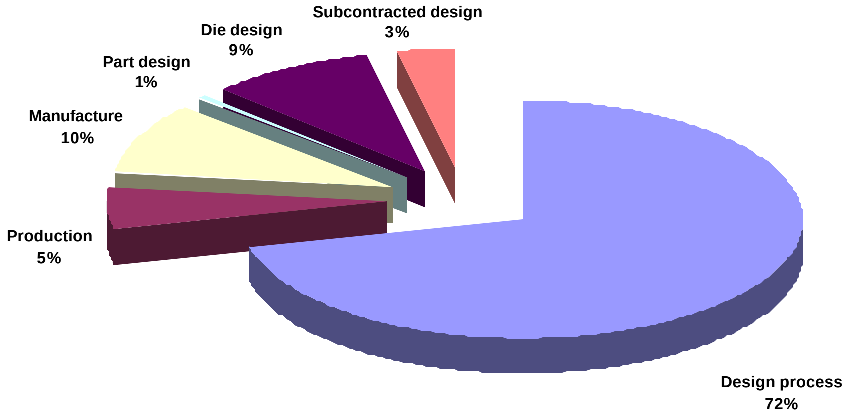
Sources of Quality Loss



(Japanese manufacturing equipment company 2000)

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Objectives

- Evaluate error and error management techniques and tools in the **design process**
  - Gather and **analyze common error modes** in the design process
  - Develop design strategies and tools to **predict potential errors** and problems in tasks during the design phase of a project
  - Determine **error prevention** strategies and methods for the design phase and suggest changes to the process to incorporate them

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Survey Method

- Reviewed detailed reports of errors at an airline engine manufacturer
  - TOPS-8D reports
    - incidents reported to the Federal Aviation Administration (FAA)
- Surveyed companies with a two-page questionnaire on the design process
  - includes general questions on common errors and managing error in the design process
  - survey on the design practices at the organization
  - interviewed design engineers and managers

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TOPS-8D example:
turbine blade shroud cracks

- **Process breakdowns:**
  - **inaccurate treatment** of heat transfer (*analysis techniques predicted lower running temperatures)*
  - **operating environment was not consistent** with pre-test predictions (*resulted in inadequate material selection*)
  - **inadequate or incomplete observations and documentation** of the post test condition of hardware (*resulted in inadequate assessment of the capability of the component*)
- **Corrective Actions:**
  - lessons learned incorporated into design **best practices**

Problems could be traced to deficiencies in the ***design process****.*

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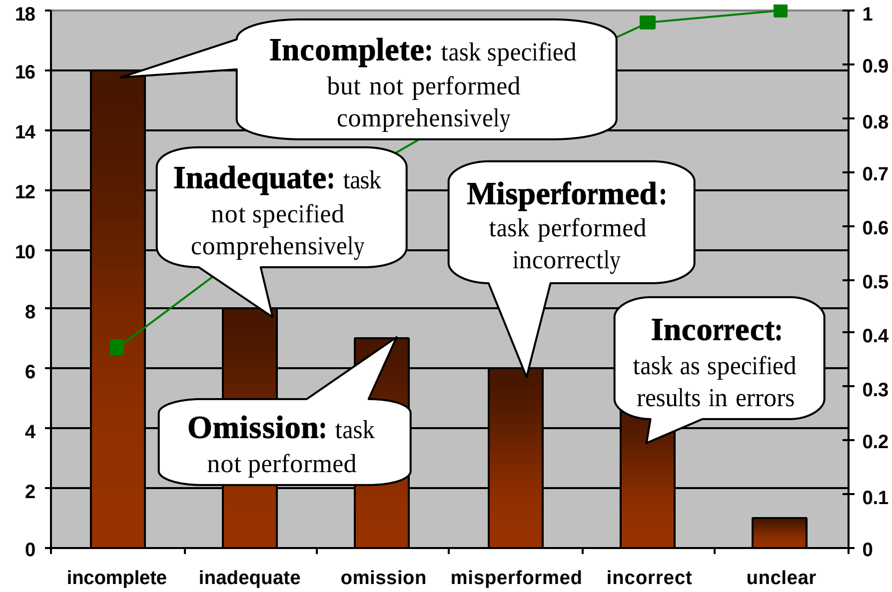
What types of errors are there?



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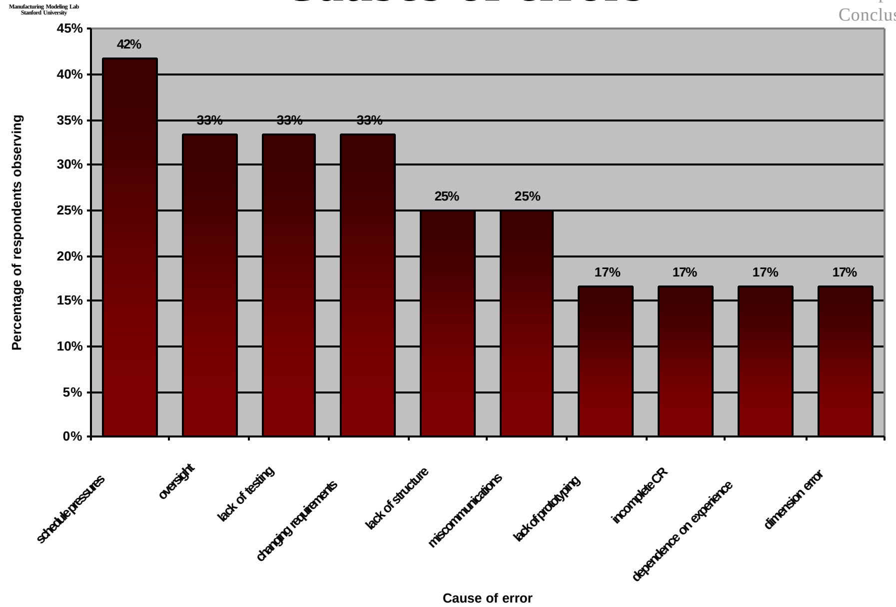
Causes of errors



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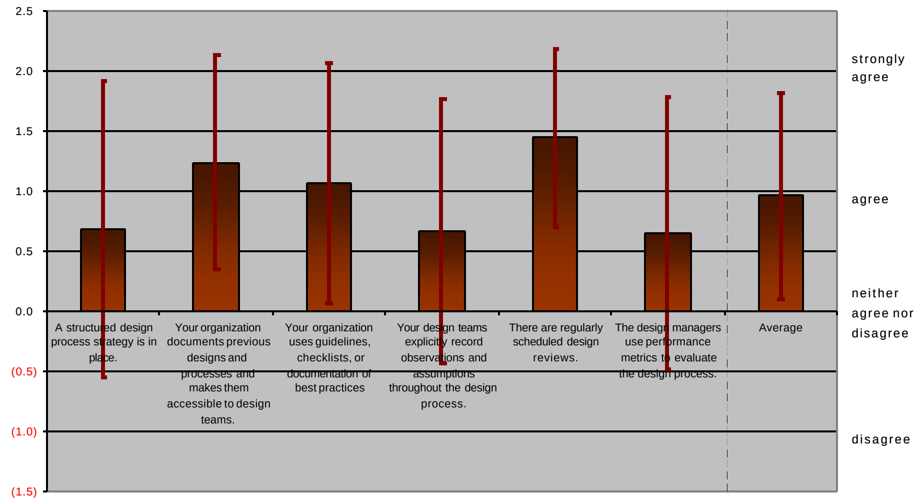
Response Averages



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Results

- **Range of scores: -1.0 to 2.0**
  - No negative scores ("disagree"/"strongly disagree") for "design review"
- **Mode:**
  - **2** for structure, documentation, design review
  - **1** for checklists, observations, metrics
- **Average standard deviation** of **~0.9**
  - highest variation for "structure"
  - lowest variation for "design review"

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Traditional error remedies

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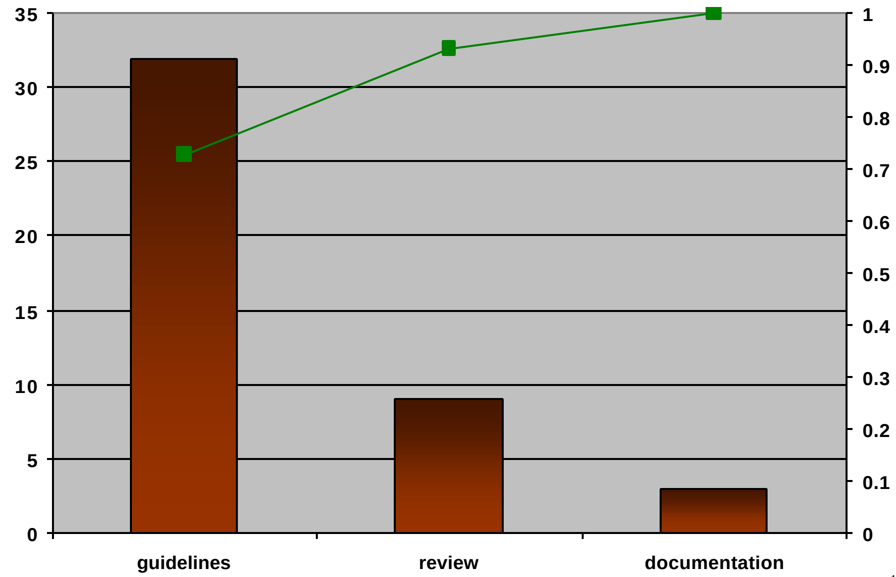

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Benchmark of design tools

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Industry	Country	esign eview	etrics	FMEA	Simulation	Process maps	Document ation	Checklists	Error-roofing
Aircraft engines		X	X			X	X	X	
Automotive		X		X	X				
Automotive		X	X		X	X	X	X	
Communications		X		X					
Computers		X	X	X				X	
Consumer electronics		X					X		
Consumer electronics		X			X				
Electronics components		X						X	
Lighting									
Medica								X	
Pri								X	
Production equipment		X	X	X		X	X	X	

Design reviews are "like 100% inspection with a so-so qaqe."

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Research Opportunity

- Adapt and **develop failure modes and effects analysis (FMEA)** for the tasks of the design process to predict errors that may commonly occur at an organization

- **Establish error-proofing** for the design process and develop specific poka-yoke examples as well as develop additional techniques to prevent design errors

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Definition: FMEA

- **failure modes and effects analysis**

  engineering technique used to define, identify, and eliminate known and/or potential failures, problems, and errors from the system, design, or process before they reach the customer

(Stamatis 1995)

Function or Requirement	Potential Failure Modes	Potential Causes of Failure	Occurrence	Local Effects	End Effects on Product, User, Other Systems	Severity	Detection Method/ Current Controls	Detection	R P N	Actions Recommended to Reduce RPN	Responsibility and Target Completion Date

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Types of FMEA

Type of FMEA	How it works/what it does
System FMEA	Use VOC's to assign risks to the failure of a system function
Design FMEA	Looks at components of the system
Assembly Process FMEA	Looks at impact of failures of the manufacturing and assembly process on the final system
Human Error FMEA	Narrows process FMEA to look at human mistakes and omissions in manufacturing

Current FMEA's are focused more on **manufacturing** *and* **operation** *errors*

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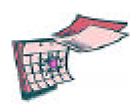
Why is process FMEA for design harder than for manufacturing?

- Design has **longer process interval** (weeks to years) versus manufacturing (hours or days).
  - *Must analyze design process in general rather than specific product or process.*



- **Greater variation** from one development project to the next.
  - *Harder to foresee all problems that may occur.*
- **Different value system** where "creative freedom" is emphasized.
  - *Engineers often don't want to be managed.*

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Design Process FMEA

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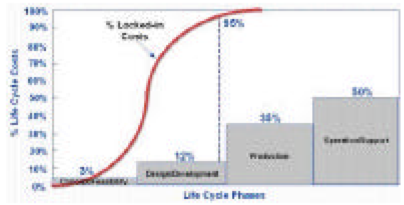
- Similar to Assembly Process FMEA
  - question-based analysis
  - quicker analysis
- Analyze and improve the **organization's design** or development **process** rather than a specific product
  - ☨ *Process can be continuously improved to optimize performance for many products*
- Decompose problem into **design tasks** instead of subassemblies



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QFD Matrix: Phase 1

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- Quality Function Deployment: a disciplined approach
- Customer Requirements vs. Engineering Metrics:
  - "9" Strongly Correlated
  - "3" Correlated
  - "1" Somewhat Correlated
  - "0" Not Correlated

		Brightness	Weight	Girth + width	Time/Tasks required to start	Distortion	Distance from presenter	Time to insert/pull-out slide	Attractive product
Brightness									
Weight									
Girth + width			+						
Time/Tasks required to start									
Distortion		-		-					
Distance from presenter		+			+	--			
Time to insert/pull-out slide					+		+		
Attractive product									
Prefer		up	dwn	dwn	dwn	dwn	dwn	dwn	nom
		Engineering Metrics							
Customer Requirements	**Customer Weights**	Brightness	Weight	Girth + width	Time/Tasks required to start	Distortion	Distance from presenter	Time to insert/pull-out slide	Attractive product
Good image	9	9				9			
Easy to transport	9		9	9					
Device sets up quickly	9		3	1	9		9	3	
Works well for short present.	9		1	1	9		3	3	
Keeps present. flowing	1				9		3	9	
Image visible in bad conditions	3	9				3			
Minimizes unplanned interruptions	1				3		1	9	
Design makes the product attractive	3		3	3					9
Technical Targets		lumens	< 6 pounds	< 22 inches	< 5 seconds	VTTF	< 3 feet	< 1 second	N/A
Raw score		108	126	108	174	90	112	72	27
Relative Weight		13%	15%	13%	21%	11%	14%	9%	3%

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Quantifying Design Process FMEA

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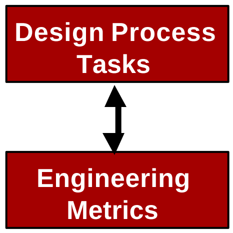

	EM#1	EM#2	EM#3
Task #1	1	9	
Task #2	9		3
Task #3			9

- Perform a ***QFD*** to determine customer requirements to engineering metrics relationship
- Determine the ***engineering metrics*** affected in each design process task
- Use the relative weights determined for each EM in QFD I to rank "importance"

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Parts vs. Engineering Metrics

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- ***Good correlation*** overall of normalized importance scores between using parts and engineering metrics
  - Correlation coefficient of *0.665*
  - More than half of the tasks have a difference in score of less than 1
- Using **parts** emphasizes the importance of tasks involving areas like ***industrial design***, ***layout***, or ***assembly/production***

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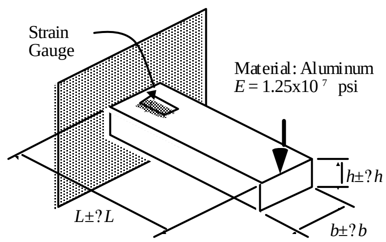
Example: Force Sensor

- Design of a ***force sensor*** comprised of a cantilever beam and a strain gage



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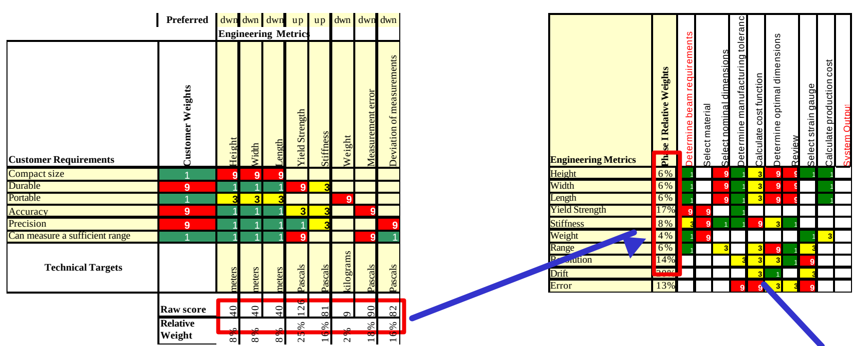
Force Sensor Design: QFD+FMEA



Design task	Potential Failure Modes	Occurrence	Severity	Detection	RPN
Calculate cost function	Arithmetic error	6	9	1	54
Calculate cost function	Calculus error	4	9	1	36
Calculate cost function	Didn't use calculus	2	9	1	18
Calculate cost function	Excel solver is slightly off	1	9	1	9
Calculate cost function	Forget to recalculate	1	9	1	9
Calculate cost function	Forget to specify answer	1	9	1	9
Calculate cost function	Mistake cost function for	1	9	1	9

5	Calculate cost function	9
6	Determine optimal dimensions	8.443114
8	Select strain gauge	8.281437
2	Select material	6.628743
7	Review	5.55988
1	Determine beam requirements	5.173653
4	Determine manufacturing tolerances	5.020958
3	Select nominal dimensions	4.562874
9	Calculate production cost	0.754491

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Definition: Error-Proofing

- **error-proofing**

  technique for eliminating errors such that it is impossible to make mistakes

- Shigeo Shingo started the concept in Japan - ***poka-yoke*** where "*poka*" means an inadvertent mistake and "*yoke*" means to prevent.
- Many poka-yoke devices are used for manufacturing and operation.

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Error-Proofing Strategies

- **Eliminate** the chance of making the mistake
- Provide automatic **feedback** to sense and fix the error
- Make incorrect actions correct
- Make wrong actions more difficult
- Make it easier to **discover** the errors that occur
- Make it possible to reverse actions - to "undo" them - or make it harder to do what cannot be reversed

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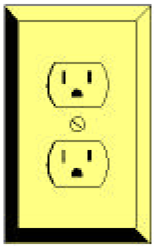
Categories of poka-yoke devices

prevention

makes it impossible to make a mistake at all



detection

signals the user when a mistake has been made so that the user can quickly correct the problem

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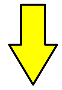
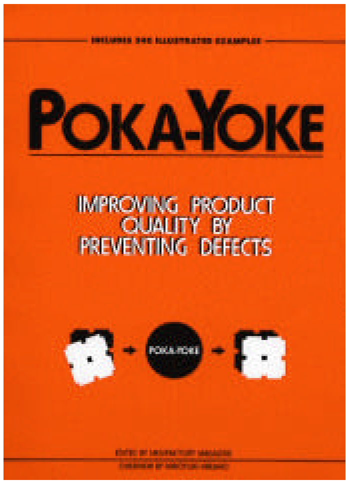
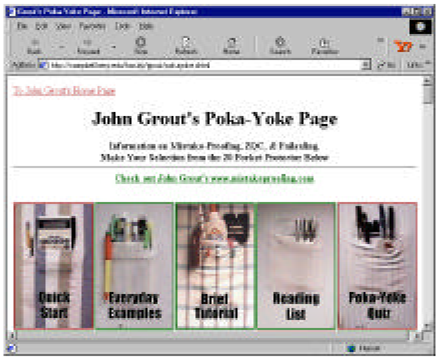


the

Some Error-Proofing Resources





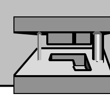
Approach for Error-Proofing the Design Process

- Start with categorizing **design process errors**
- Find **analogies** in manufacturing/assembly poka-yoke
- Active **prevention** rather than rely on detection
  - Prevent mistakes in communication and performance of analysis, verification
- Try to **build into design process** rather than adding "patches"

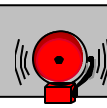
*Development of **design process poka-yoke** is more difficult due to the lack of a known desired outcome*

"Five Best Poka-yoke" for manufacturing

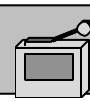
1. Guide pins of of different sizes



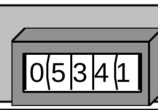
2. Error detection and alarms



3. Limit switches



4. Counters



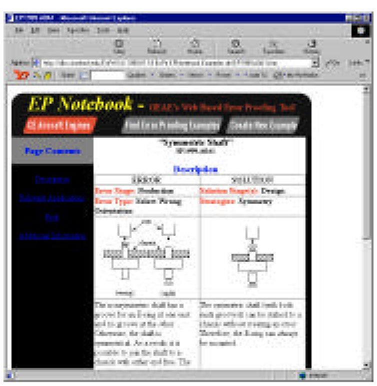
5. Checklists

(Nikkan Kogyo Shimbun 1987)

"Design Process Poka-yoke"

1. Uniform design environment (units, software, language/terminology)
2. Design reviews
3. Double check against specifications, experience, intuition
4. Receipts, checksums, regression testing
5. Design process templates and guidelines

EP Web Pages



Causes of Mistakes

- ***1. Mental***
  - Memory
  - Decision
  - Distraction
- ***2. Perception***
  - Misunderstand
  - Misread
  - Misidentify
- ***3. Communication***
  - Ambiguous
  - Incorrect
  - Incomplete
- ***4. Speed/skill***
  - Inexperience
  - Inadequate training
  - Inadequate skill
  - Too fast a pace
  - Lack of standards
- ***5. Coordination***
  - Incomplete motion
  - Adjustment error
- ***6. Intentional***
  - Shortcut
  - Sabotage
  - Crime

(Hinckley 2001)

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Error Commonality Index

- Determine the accountability of each of the 19 causes for an error on a **0-9** scale to calculate each score s_i
- Determine the error commonality index (***ECI***) by finding the average difference for two errors for each of the 19 causes

$$ECI = \frac{\sum_{c=1}^{19} \frac{9 - \left| s_{c,1} - s_{c,2} \right|}{9}}{19}$$

$$(0 \le CI \le 1)$$

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Error Commonality Index

		Missing parts (mfg.)	Missing information (design)	Commonality
1. Mental Errors	Memory	9	3	0.33333
	Decision			1
	Distraction		3	0.66667
2. Perception Errors	Misunderstand			1
	Misread			1
	Misidentify			1
3. Communication	Ambiguous	3	3	1
	Incorrect		3	0.66667
	Incomplete	9	9	1
4. Lack of speed/skill	Inexperience			1
	Inadequate training			1
	Inadequate skill			1
	Too fast a pace	3		0.66667
	Lack of standards			1
5. Coordination Errors	Incomplete Motion			1
	Adjustment error			1
6. Intentional Errors	Shortcut		3	0.66667
	Sabotage	3		0.66667
	Crime	3		0.66667
	Commonality Index:			0.86

- **"Index" search**
  - characterize errors and error-proofs by fundamental ***attributes*** such as
    - memory
    - training
  - facilitates intelligent and flexible searching

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Mapping the Matrices

- ***Occurrence*** - task and error attributes
  - map type of error with type of task

$$[\text{Error x Attributes}] \times [\text{Attributes x Task}] = [\text{Error x Task}]$$

- ***Severity*** - task importance
  - use QFD results to determine important customer requirements

$$[\text{CW x CR}] \times [\text{CR x EM}] \times [\text{EM x Task}] = [\text{CW x Task}]$$

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Design Structure Matrix (DSM)

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- a ***square matrix*** which maps out the information links among individual design tasks
- a ***systematic*** mapping that is easy to read
- offers ***compactness*** in representation
- can be used to ***analyze precedence relationships*** among various design tasks

(Mori 1999)

Feedback / Relies on information from

Forward / Delivers information to

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Conclusions

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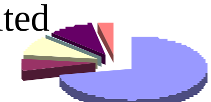
- Current research on ***prediction and prevention*** of errors in the **design process** is fairly limited
  - interest from industry is high
  - tools for predicting and preventing errors in other areas, such as manufacturing and assembly process, exist



- In addition to **creating** design process poka-yoke, it is necessary to ***establish*** the mentality of error-proofing the design process
  - design process error-proofing training and education

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Future Work

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- **Error Categorization and Strategies**
  - Refinement of ***categorization*** of errors and error-proofs
  - Build towards ***question-based analysis*** to identify type of error and ***strategies***
    - Assist Root Cause Analysis to design process problems
  - Quantifying errors: ***RPN*** vs. ***expected cost***
- **Identification and Development of EP Tools**
  - **Knowledge-Based Engineering** (KBE) - e.g. CAD add-ons
  - **Knowledge Management** (KM) - e.g. error-proofing, best practice, and/or corrective actions web sites

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Questions?

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