33rd Annual INCOSE international symposium

hybrid event

Honolulu, HI, USA
July 15 - 20, 2023

Technological Advances and Human Performance: A Systems Engineering Approach to Reducing Human Error

Jonathan K. Corrado, PhD, PE

Agenda

- Research
- Findings
- The Relationship between Technological Improvements and Economic and Safety Factors
- Human Error Reduction Utilizing the Design Engineering Process

Research

Technological Advances and Human Performance

- Numerous adverse incidents have occurred at nuclear facilities across the United States, sometimes with considerable negative consequences for the facilities involved, the environment, human beings, and the nuclear industry
- These incidents occur for a number of varying reasons, but more often than not, human error is involved

This study focuses on incidents at U.S. nuclear facilities that occurred due to human error. A particular focus is the role of changing technologies and the people who interacted with the complex systems involved with a nuclear plant

Why Important?

- A great deal of benchmarking, evaluation, debate, and study revealed the underlying hindrance to successful operation:

A DISPROPORTIONATE DEPENDENCE ON "TECHNOLOGY-ONLY" ENHANCEMENTS

Research Question

- Do technological advances in the complex systems of nuclear facilities increase the cost associated with incidents caused by human error?

Human Error?

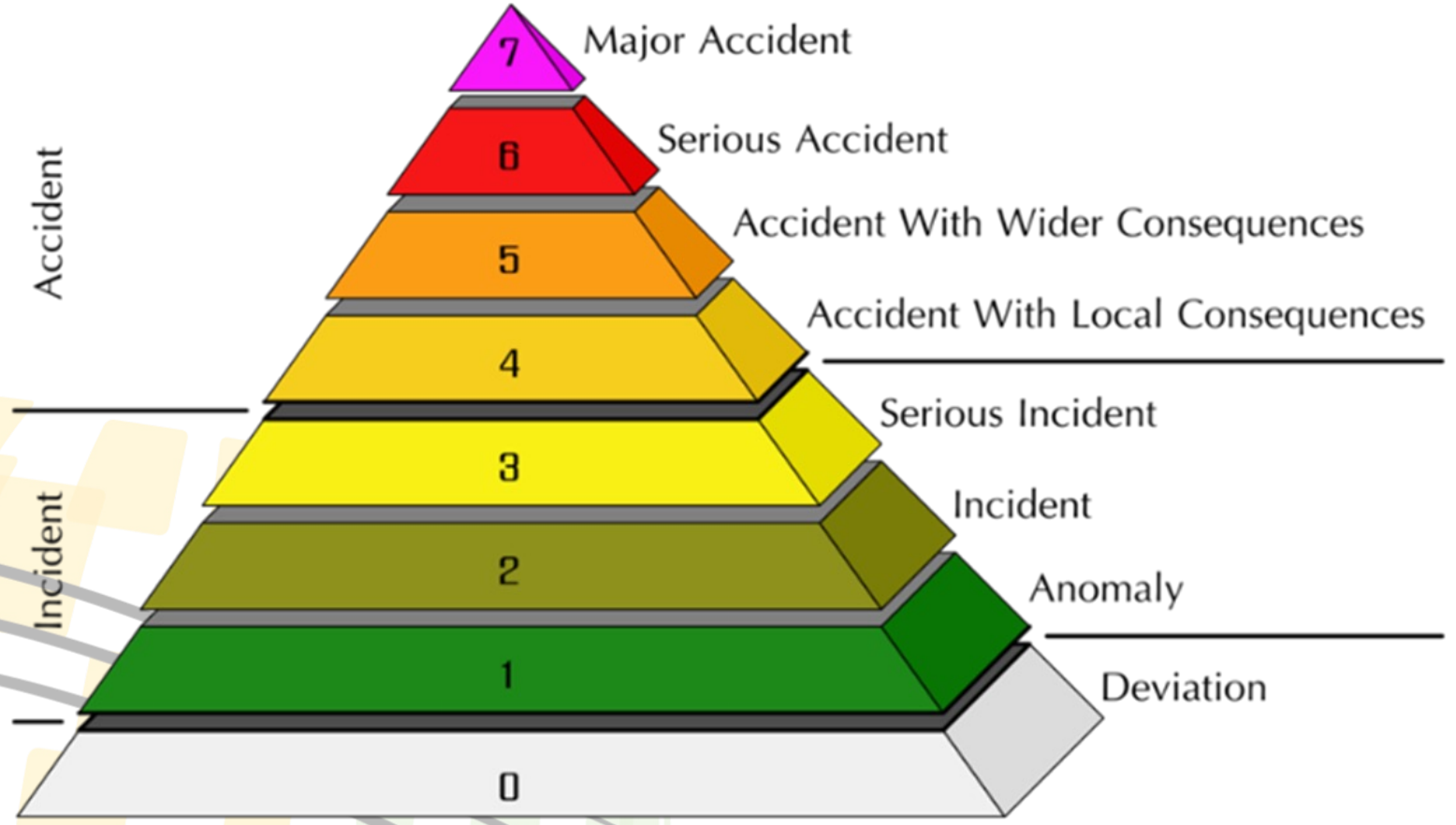
Performance Mode	Key Words	Error Rate
Skill-Based	•Habit •Not Thinking •Little or no conscious thought •AUTO PILOT 50 – 100 times Successfully in a short period <7 – 15 Discrete Steps	1:1000 Distractions Inattention
Rule-Based	•There is a rule and I know there is a rule •Application of Stored Knowledge •Conscious thought IF/THEN Written: Procedures, Hummingbird, Work Packages Unwritten: Training, Experience, Experts	1:100 Bad Rules Misapplication Short Cuts
(Lack of) Knowledge-Based	•You don't know what you don't know •You can't think your way out •Problem Solving Visual Clues: Scratching head, Staring up, Confused look, Sweating or Shaking Verbal Clues: "I'm pretty sure", "That's how we did it last time, I think", "What the hell?", "That's odd…"	1:2 to 1:10 Fork in the road

Research Methods

Research Design

- Observational Study
  - **Treatment Group**
    - Facilities that have had incidents determined to be the result of the introduction of technological changes which affect the way the operator interacts with the system
  - **Control Group**
    - Nuclear facilities that have had accidents, but determined not to be caused by the introduction of technological changes which affect the way the operator interacts with the system

Research Methods (cont'd)



International Nuclear and Radiological Event Scale (INES)

Research Methods (cont'd)

Data Collection, Processing, and Analysis

- INES Scale
- Events Studied: Severity Level 3 or Higher
- Date Range: 1955-2021
- Events Categorized
  - Events that were the result of technological changes
  - Events that were not the result of technological changes
- T-test conducted
  - Cost of the incident in U.S. dollars was chosen to quantify the deleterious effects of a nuclear incident

Findings

Researched and Compiled:

- Accidents which occurred in the United States at nuclear facilities (INES Level 3 or higher) from 1955 until 2021

53 incidents met this criteria

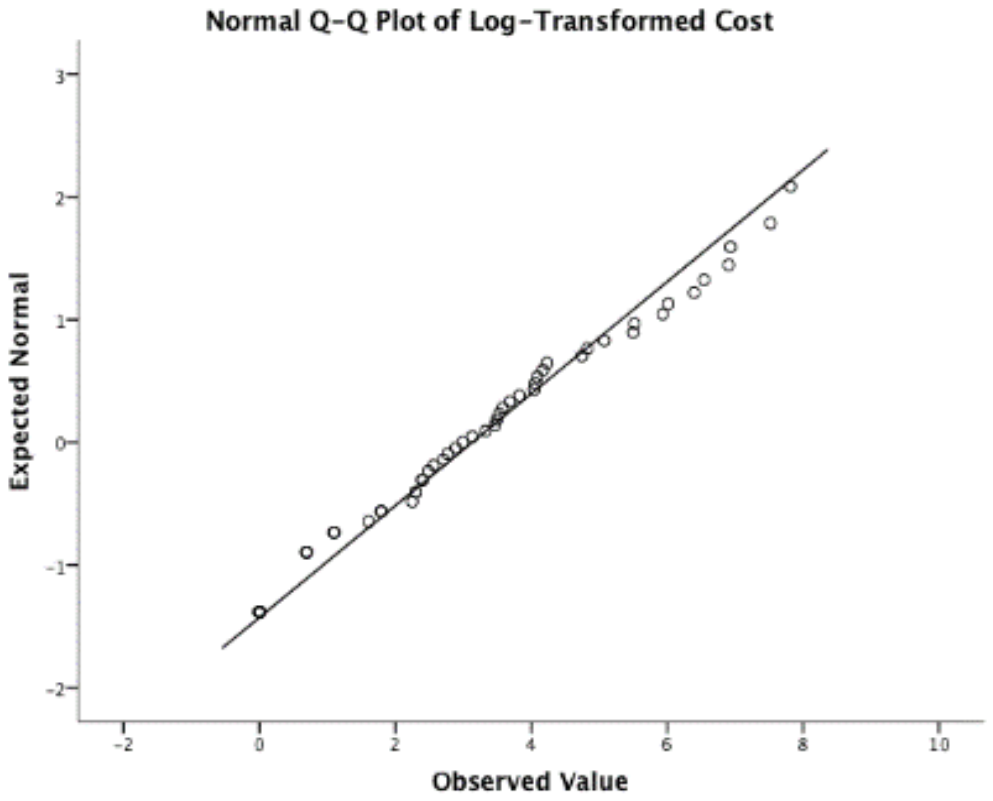
- Cost of the accident
- Whether the accident was due to human error after new technologies were installed

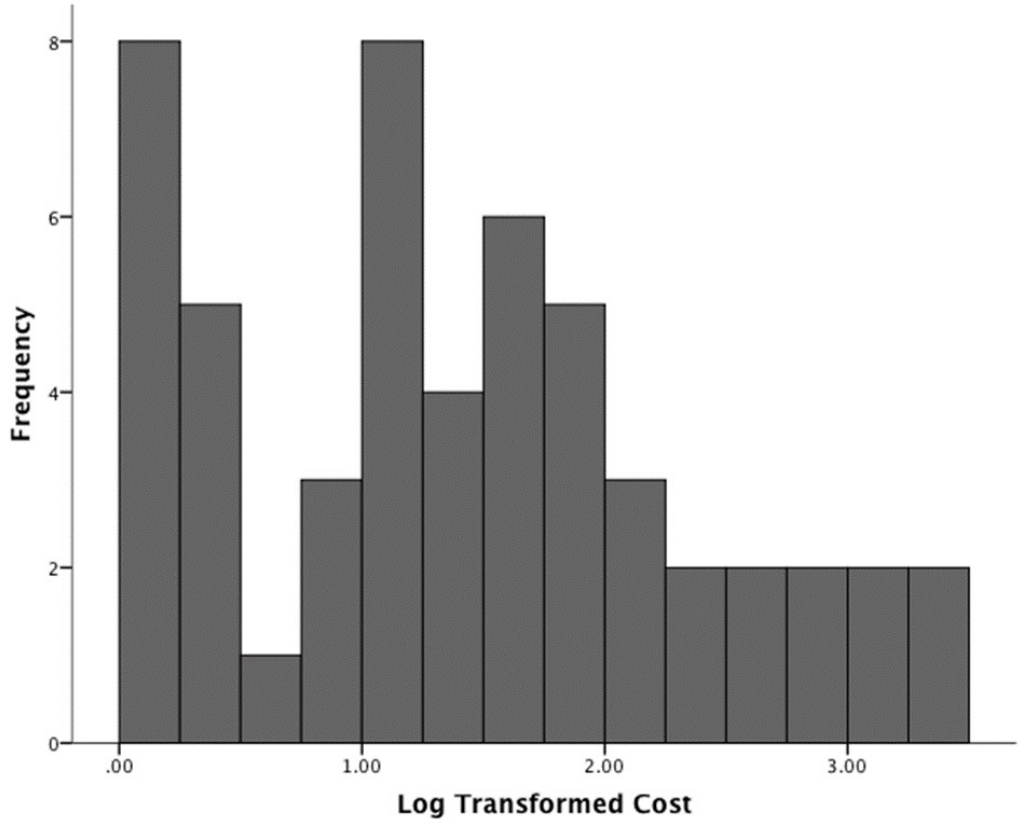
Findings (cont'd)

Of the 53 incidents:

- Average cost of the incidents was $190,518,900 (SD = 461,511,400)
- **31** were determined not to be due to human error as a result of technological advances
  - The cost of the incidents ranged from $1,000,000 to $695,000,000
  - The average cost of incidents was **$54,274,200 (SD = 142,559,800)**
- **22** of the incidents were due to human error as a result of technological advances
  - The cost of these incidents ranged from $2,000,000 to $2,483,000,000
  - The average cost of incidents was **$382,500,000 (SD = 657,543,610)**

Findings (cont'd)





Findings (cont'd)

Using the log-transformed data, an independent samples t-test was conducted

- Normality of data was checked using the Kolmogorov-Smirnov test. The test was non-significant (p = .200)
- To test homogeneity of variance, the t-test is conducted and Levene's test was used to see if the variances of the groups are equal or unequal. The test was non-significant (p = .953)
- On average, the log-transformed costs of incidents due to technological advances were lower (M = .92, SD = .81) than the log-transformed costs of incidents (M= 1.99, SD = .78), and this difference was significant, $t(51) = -4.81$, $p < .001$, one-tailed
- The difference between the log-transformed means of cost between the two groups represent a large-sized effect, d = 1.34

Incidents caused by human error related to technological advances were more costly than incidents not meeting this criterion

The Relationship between Technological Improvements and Economic and Safety Factors

- Are organizations better off from incorporating advanced technology at their facilities?

The Relationship between Technological Improvements and Economic and Safety Factors (cont'd)

- There were 12 facilities in the sample and the information was collected over 6 years
- This yielded 72 data points for the ANOVA
- The F-test yielded an F statistic of 208.86.
  - This is significant at the $p < 0.01$ level.
- The regression analysis indicated that the regression coefficient for capacity factor was 0.592 and for incidents was 0.075

Both of these coefficients indicate that increased levels of upgrades resulted in a higher capacity factor for the facility

However, the number of incidents also increased

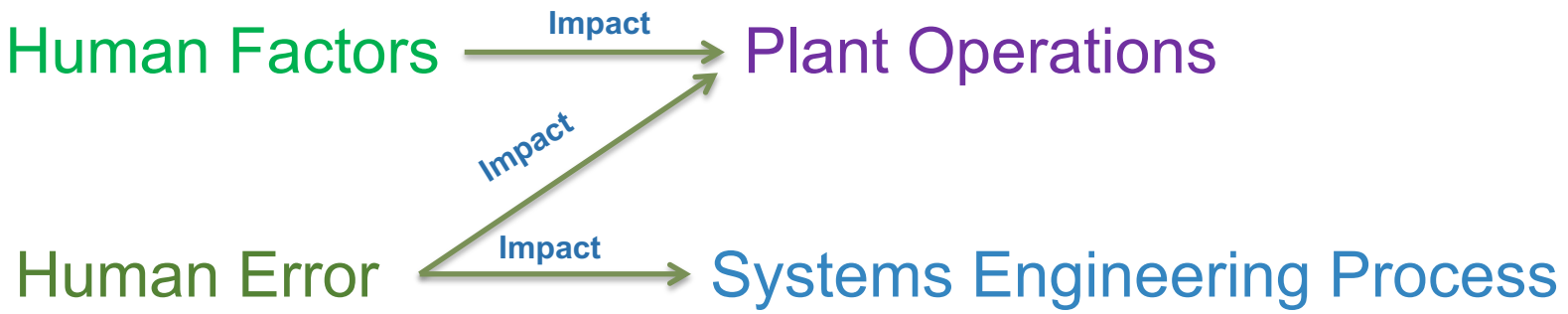
The Relationship between Technological Improvements and Economic and Safety Factors (cont'd)

- Inference

1) The data indicates that spending more money on upgrades can increase the capacity of the facility as well as the potential number of incidents

2) However, the incidents in the randomly selected facilities for this study over a six-year period of time were relatively minor

So What?



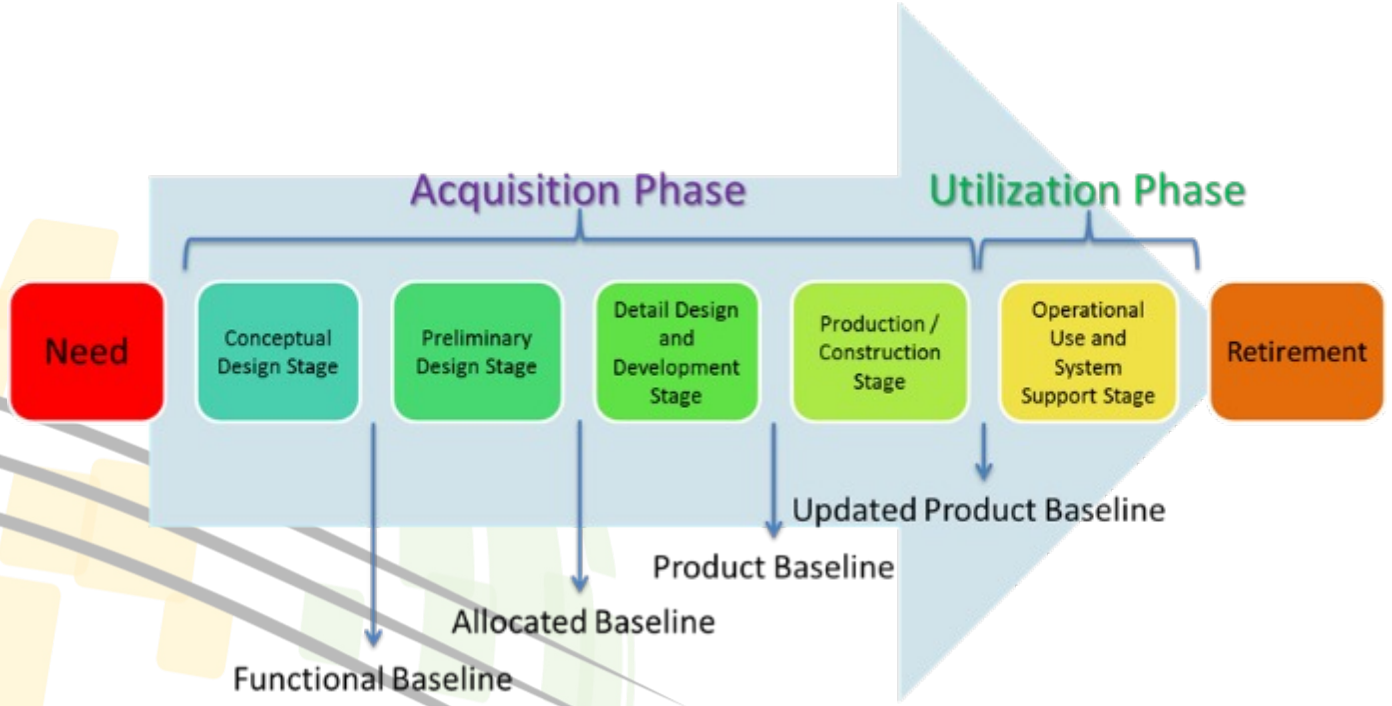
- The Impact of Human Factors on Plant Operation
- The Impact of Human Error on Plant Operation
- The Impact of Human Error on the Design Engineering Process

So What?

Human Error ⟶ Human Performance

So What?

Systems Engineering Process



Nuclear Facility Incident Reduction Using the Systems Engineering Process

What are the Issues Related to Advanced Technology and the 21st Century Operator?

- Improvement of Existing Systems
  - No Technical Alteration
- Upgrade of Existing Systems
  - Way Forward Leveraging the Systems Engineering Process
- Design of New Systems
  - Human-Machine System Optimization

How can Human Error be Reduced?

Human Error Reduction Utilizing the Systems Engineering Process

Difference between Human Factors and Human Performance:

Human Factors

- The study of designing equipment and devices that fit the human body and its cognitive abilities
  - anthropometric factors
  - human sensory factors
  - physiological factors
  - psychological factors
- Inherent consideration within and throughout the systems engineering process

Human Performance

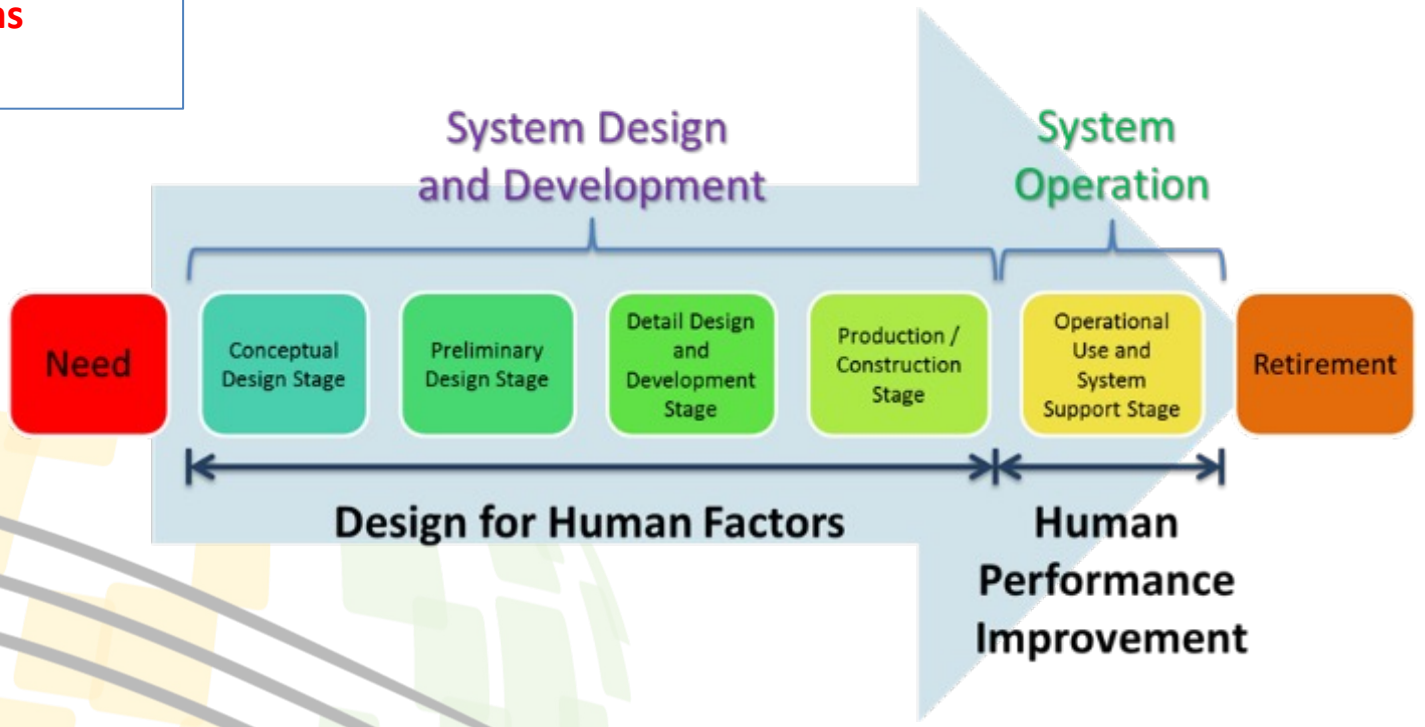
- The study related to process improvement methodologies to reduce human errors
  - Societal
  - Organizational
  - Process
  - individual performer
- Traditionally instituted after design and installation

Human factors influence human performance, but human performance does not necessarily influence human factors in the design of a system

Human performance, not human factors, is the concept in view

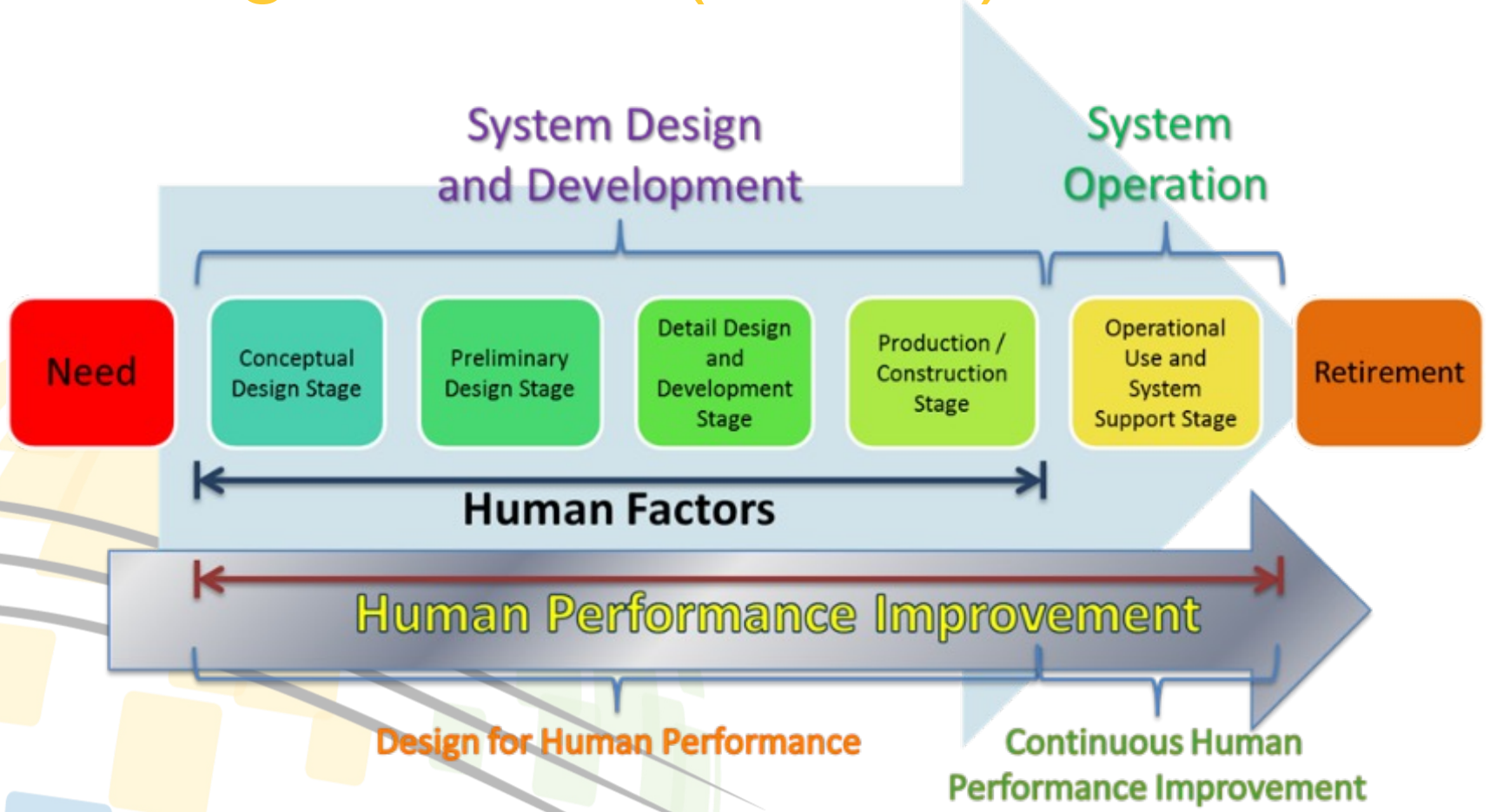
Human Error Reduction Utilizing the Systems Engineering Process (Cont'd)

- **Improvement of Existing Systems**
- **Upgrade of Existing Systems**
- Design of New Systems

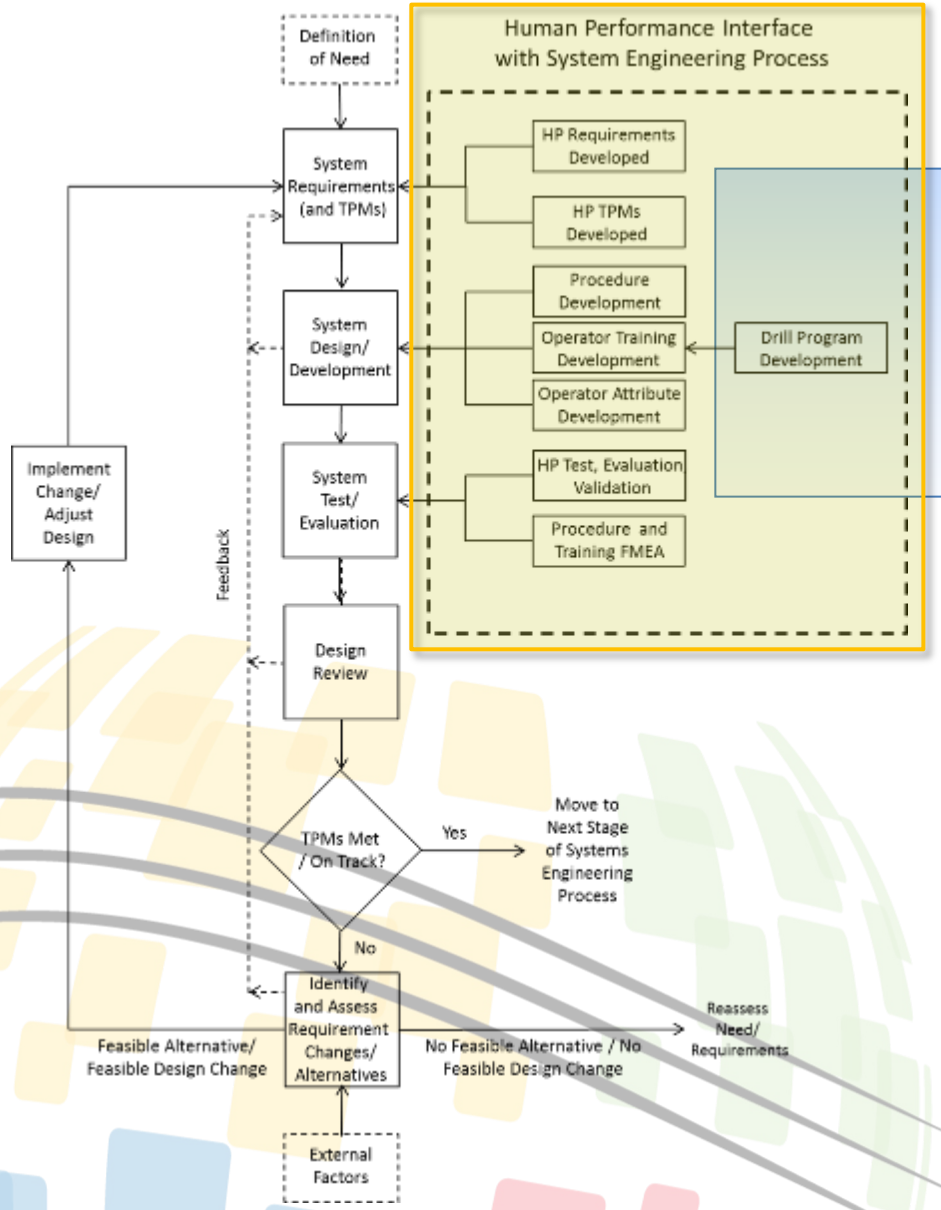


Traditional Human Performance and Human Factors Relationship within the Systems Engineering Process

Human Error Reduction Utilizing the Systems Engineering Process (Cont'd)

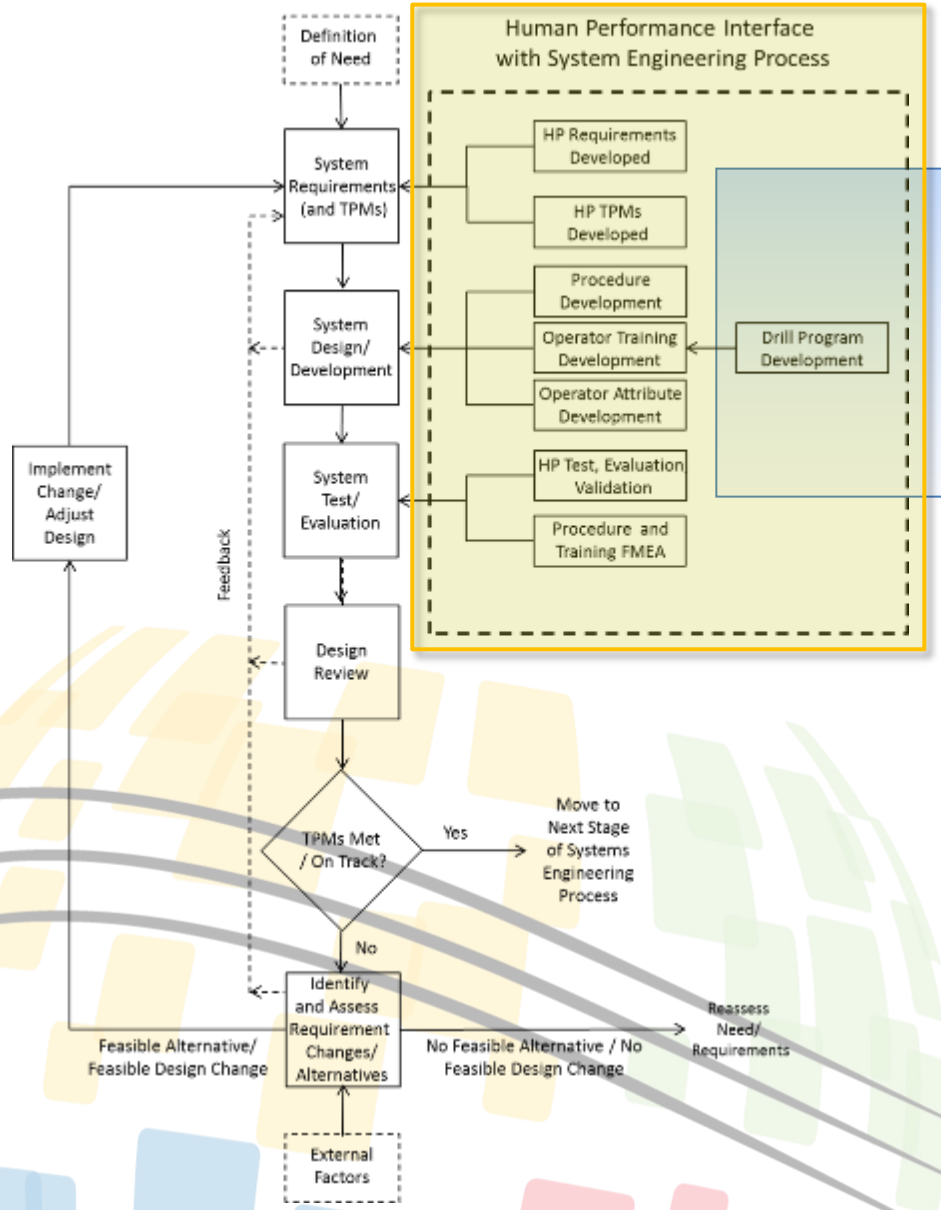


Human Performance Improvement Throughout the Systems Engineering Process



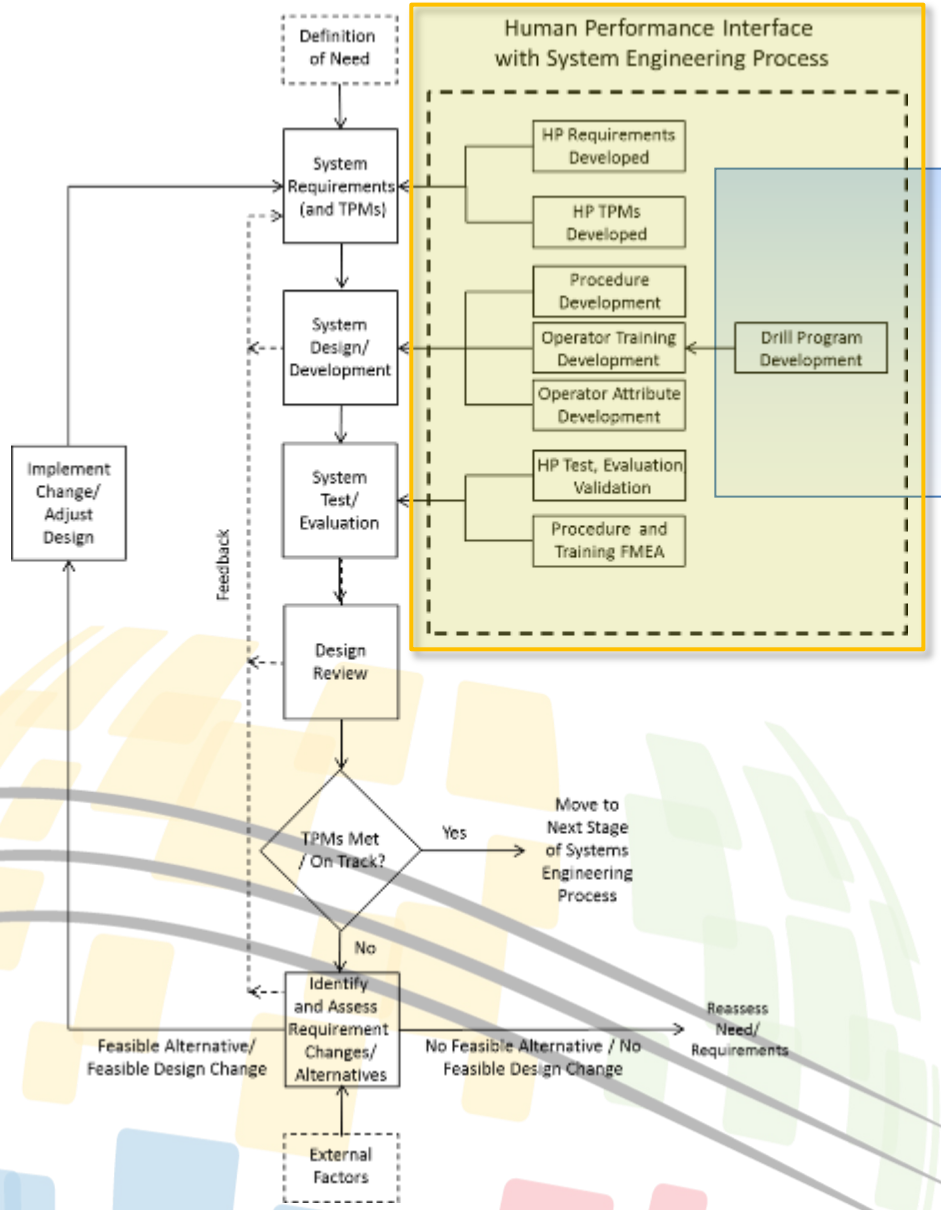
The cultivation of human performance enhanced system design and operation stems from:

1. Operator involvement in the systems engineering process
2. Human performance association with system operational requirements and system test, evaluation, and validation
3. Iterative procedure and operator training development throughout all stages of the systems engineering process
4. Selection and cultivation of aptly inclined operators chosen and groomed specifically for the systems in design



The cultivation of human performance enhanced system design and operation stems from:

1. Operator involvement in the systems engineering process
2. Human performance association with system operational requirements and system test, evaluation, and validation
3. Iterative procedure and operator training development throughout all stages of the systems engineering process
4. Selection and cultivation of aptly inclined operators chosen and groomed specifically for the systems in design



The cultivation of human performance enhanced system design and operation stems from:

1. Operator involvement in the systems engineering process
2. Human performance association with system operational requirements and system test, evaluation, and validation
3. Iterative procedure and operator training development throughout all stages of the systems engineering process
4. Selection and cultivation of aptly inclined operators chosen and groomed specifically for the systems in design

Human Error Reduction Utilizing the Systems Engineering Process (Cont'd)

- Error Precursor Examples

DOE-HDBK-1028-2009, DOE Standard Human Performance Improvement Handbook, Volume 1: Concepts and Principles

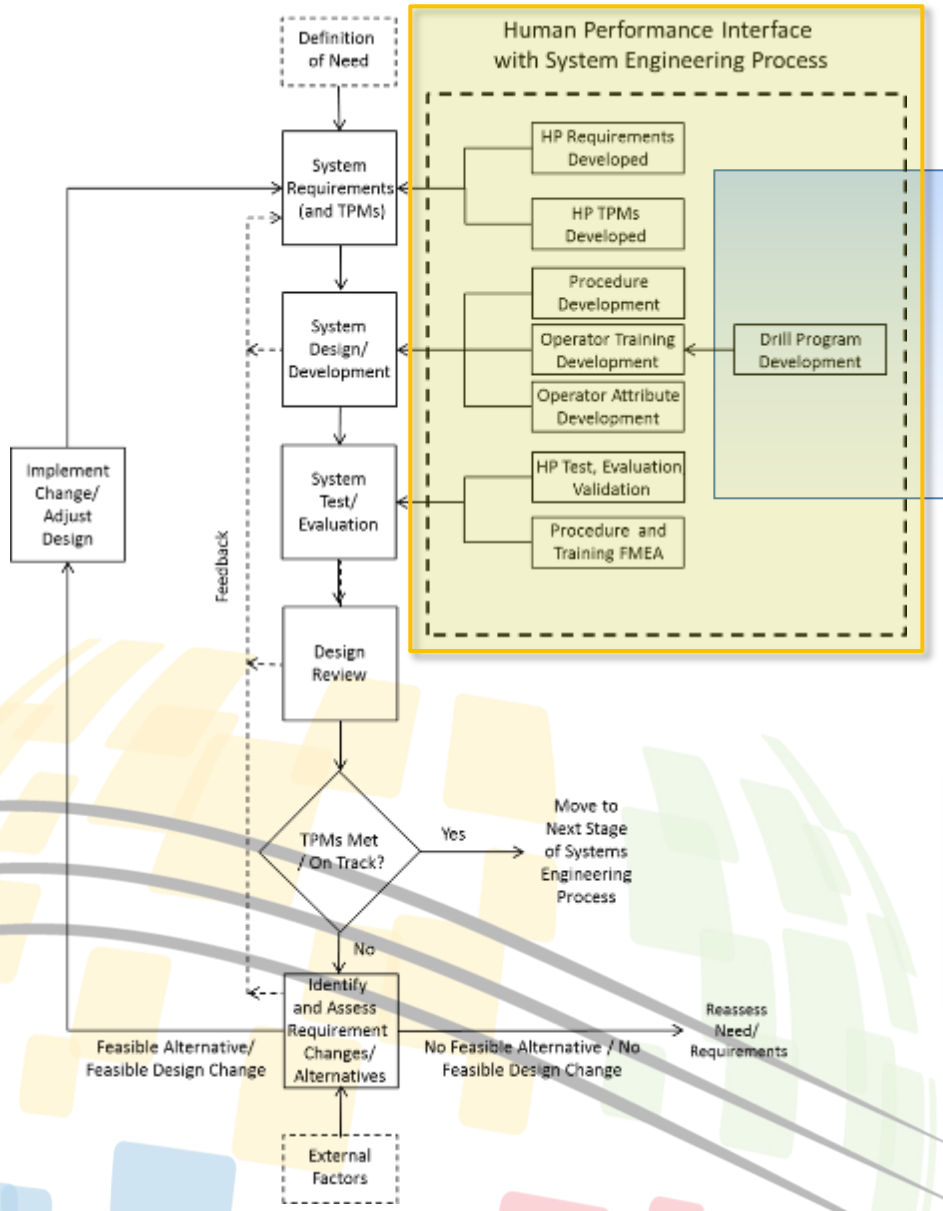
- Task Demands
  - Time pressure (in a hurry)
  - High workload (memory requirements)
  - Simultaneous, multiple tasks
- Individual Capabilities
  - Unfamiliarity with task / First time
  - Lack of knowledge (faulty mental model)
  - New technique not used before
- Work Environment
  - Distractions / interruptions
  - Changes / departure from routine
  - Work-arounds
- Human Nature
  - Stress
  - Habit Patterns
  - Complacency

Human Error Reduction Utilizing the Systems Engineering Process (Cont'd)

Technical Performance Measures	Quantitative Requirement (Metric)	Relative Importance (user desires) (%)
Absence of Confusing Displays and Controls	0 Significance Level 1 human errors	7
	Less than 1% Significance Level 2 human error rate per year	
	Less than 5% Significance Level 3 human error rate per year	
Absence of Repetitive Actions / Monotonous Operation	0 Significance Level 1 human errors	9
	Less than 2% Significance Level 2 human error rate per year	
	Less than 7% Significance Level 3 human error rate per year	
Scarcity of Irrecoverable Acts	0 Significance Level 1 human errors	10
	Less than 1% Significance Level 2 human error rate per year	
	Less than 3% Significance Level 3 human error rate per year	
		Will add up to 100

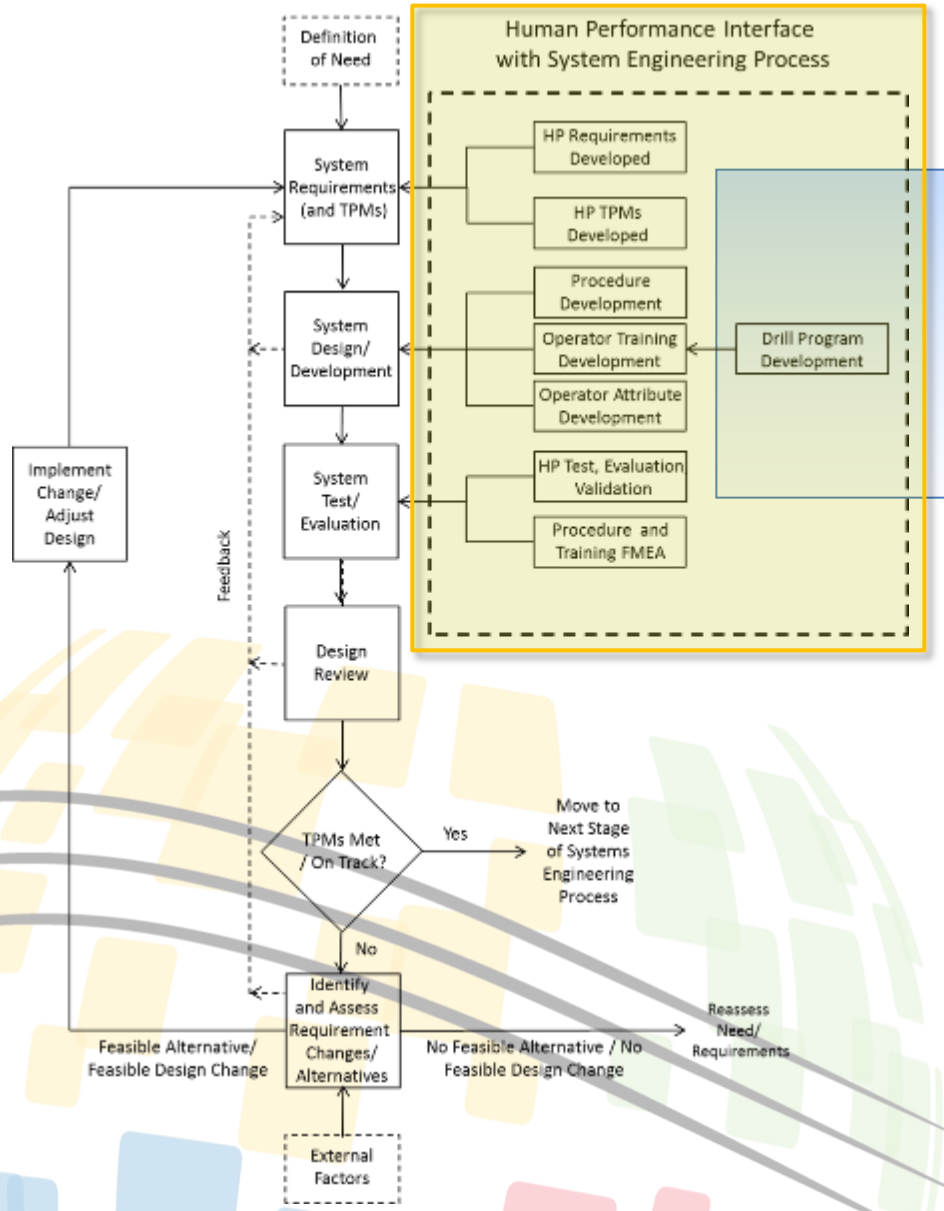
Human Error Reduction Utilizing the Systems Engineering Process (Cont'd)

Incident Category	Level 1	Level 2	Level 3
Plant Transients	• Repeat occurrences of organizational or programmatic breakdowns that affect nuclear safety. (Level 1, 2, or 3) • Significant event requiring use of safety features • Significant plant transients with analyses)	• Failures that could affect multiple safety systems or components • Misvalving operation or maintenance error on wrong equipment causing tripping or transient on operating equipment • NRC reportable event requiring a written response • Missed safety system surveillance • Significant program weakness in design, analysis, operation, maintenance, testing, procedures, or training.	• Minor program weaknesses in design, analysis, operation, maintenance, testing, procedures, or training identified by independent or management assessors • An auxiliary plant transient • M&TE that fails calibration but does not cause operational impact to safety-related equipment • Safeguards/security issues that do not meet the regulatory criteria.
Incident Category	**Level 1**	**Level 2**	**Level 3**
Personnel Safety	• Death not due to natural causes • Major disability injury	• Lost workday • Injury or near miss with fatality potential • Work-related injury requiring inpatient hospitalization • Individual exceeds regulatory dose limits • Violation of a	• Personnel contamination events occurring from procedural violations or poor radiation worker practice. • Personnel contaminations due to human error and which result in dose assignment • Defeated or missing LOTO with no potential for exposure to hazardous energy



The cultivation of human performance enhanced system design and operation stems from:

1. Operator involvement in the systems engineering process
2. Human performance association with system operational requirements and system test, evaluation, and validation
3. Iterative procedure and operator training development throughout all stages of the systems engineering process
4. Selection and cultivation of aptly inclined operators chosen and groomed specifically for the systems in design



The cultivation of human performance enhanced system design and operation stems from:

1. Operator involvement in the systems engineering process
2. Human performance association with system operational requirements and system test, evaluation, and validation
3. Iterative procedure and operator training development throughout all stages of the systems engineering process
4. Selection and cultivation of aptly inclined operators chosen and groomed specifically for the systems in design

The Final Product

The cultivation of human performance enhanced system design and operation stems from:

1. Operator involvement in the systems engineering process
2. Human performance association with system operational requirements and system test, evaluation, and validation
3. Iterative procedure and operator training development throughout all stages of the systems engineering process
4. Selection and cultivation of aptly inclined operators chosen and groomed specifically for the systems in design

The development of a well-qualified, capable, and equipped human operator for the given system

Human Machine System Optimization

- Improvement of Existing Systems
- Upgrade of Existing Systems
- **Design of New Systems**

- Considerations in Optimization
  - Consideration Given to Technology Options
  - Human Interaction is Inevitable
  - The Role of Complex Systems and Human Actors
  - Account for Human Limitations
  - Affordability
- Human Component Focus
  - Human Error Reduction and the Human-Machine Interface
  - Decisions and the Human-Machine Interface

33rd Annual INCOSE international symposium

hybrid event

Honolulu, HI, USA
July 15 - 20, 2023

www.incose.org/symp2023