

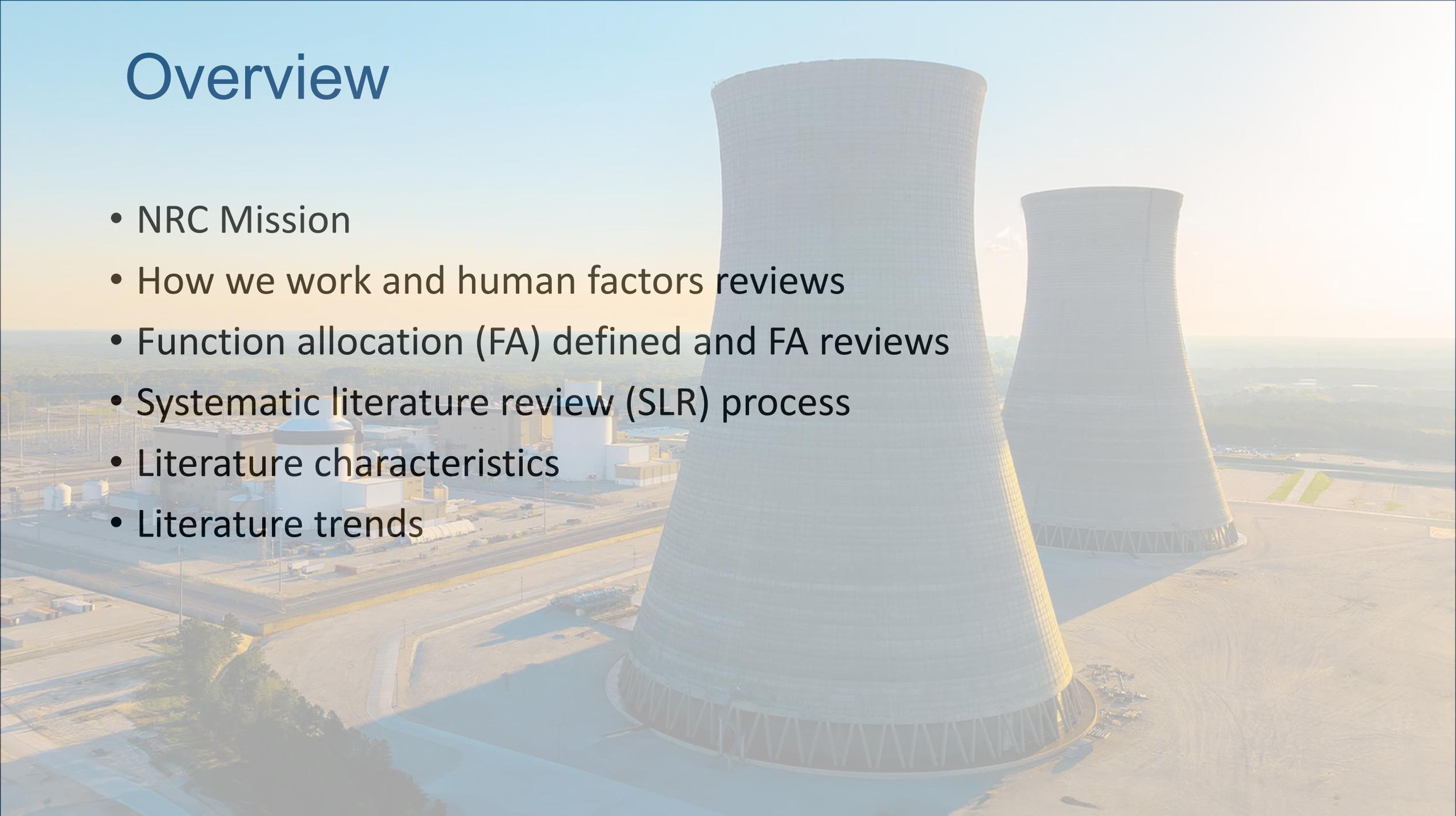
What Can the History of Function Allocation Tell Us About Advanced Forms of Autonomy and Safety Systems?



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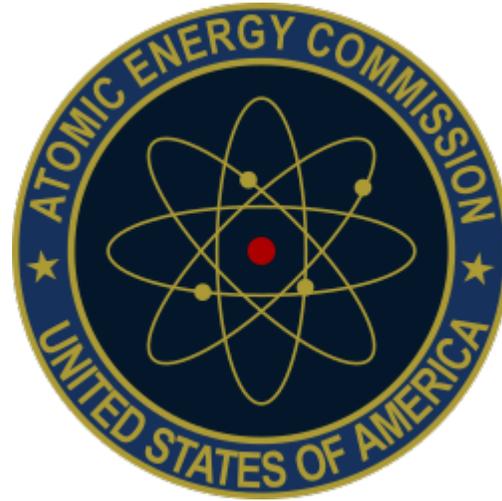
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Overview

An aerial photograph of a nuclear power plant. Two large, white, hyperboloid cooling towers are the central focus, standing tall against a clear sky. The towers are surrounded by a complex of industrial buildings, pipes, and infrastructure. The ground is a mix of paved areas and some greenery. The overall scene is brightly lit, suggesting a clear day.

- NRC Mission
- How we work and human factors reviews
- Function allocation (FA) defined and FA reviews
- Systematic literature review (SLR) process
- Literature characteristics
- Literature trends

Nuclear Regulatory Commission Origin



Energy Reorganization Act (1974) split the regulatory functions and energy promoting functions into two separate agencies. U.S. NRC regulates commercial use of nuclear materials; DOE promotes the use of nuclear materials and energy.

NRC Mission

The NRC protects public health and safety and advances the nation's common defense and security by enabling the safe and secure use and deployment of civilian nuclear energy technologies and radioactive materials through efficient and reliable licensing, oversight, and regulation for the benefit of society and the environment.



Some Numbers

94 operating reactors	46/94 operating more than 40 years	~19% of energy from nuclear
AI-associated estimated grid demand in 2026: 250 TWh	1 Major city grid demand in 2026: 1 TWh	6 new plants under construction
3 decommissioned plants restarting	Legacy control rooms: up to 2500 alarms installed	34 advanced reactor designs in pre-application phase

NUREG-0800
(formerly issued as
NUREG-75/087)

Standard Review Plan

for the Review of
Safety Analysis Reports
for Nuclear Power Plants

LWR Edition

**U.S. Nuclear Regulatory
Commission**
Office of Nuclear Reactor Regulation

June 1987



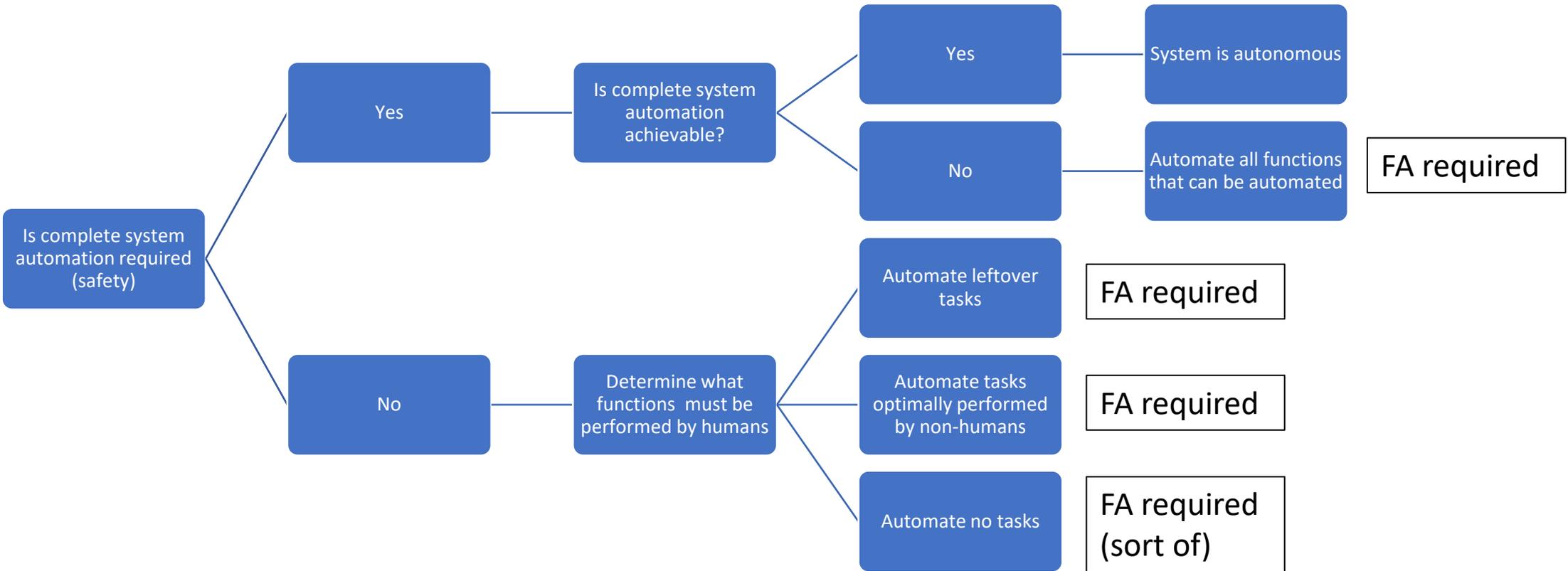
- NRC staff conduct reviews following the standard review plan.
- Each chapter focuses on specific review areas.
- Each chapter includes reference to relevant guidelines, regulations, and standards.
- Human factors reviews include 12 elements.

Human Factors Reviews Elements

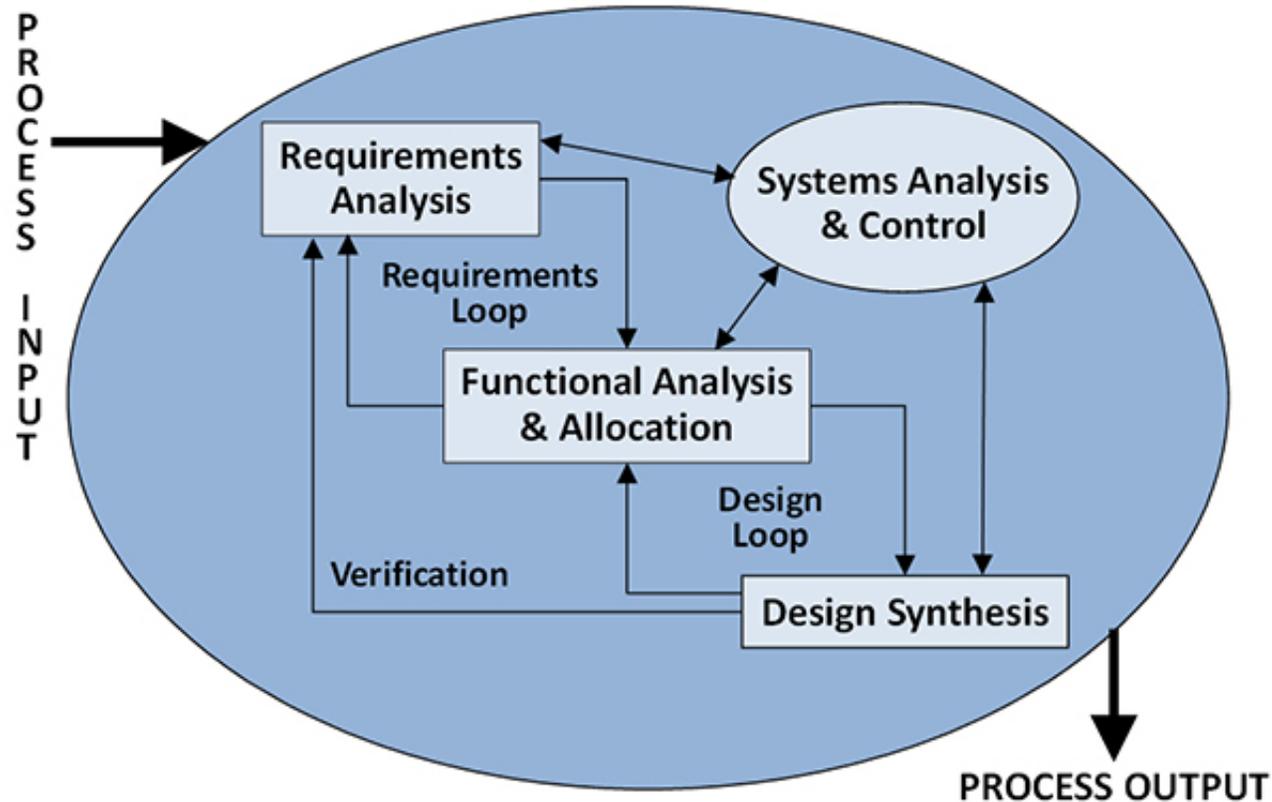
- HFE program management
- Operating experience review
- **Functional requirements analysis and function allocation (FA)**
- Task analysis
- Staffing and qualifications
- Treatment of important human actions
- Human-system interface design
- Procedure development
- Training and program development
- Human factors verification and validation
- Design implementation
- Human performance monitoring

Function Allocation Defined

The process of assigning tasks to human or machine resources to take advantage of the unique strengths and minimize the weaknesses of each agent to accomplish a set of goals.



Where does FA fit in systems engineering?



Requirements analysis – what does the system have to do and what are the parameters of “doing”.

What functions are necessary to meet the system requirements?

What are the relevant sub-functions?

As allocated, are the system goals achieved?

Is there a better way to allocation these functions?

Re-allocate to improve performance (system or human).

Contents of the FA review:

FA method

Plant's functional hierarchy

Iterative process

How and who does what?

LOA and automation scheme

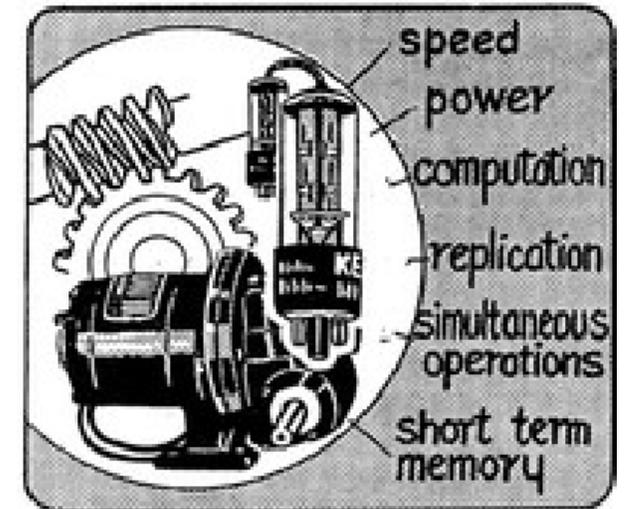
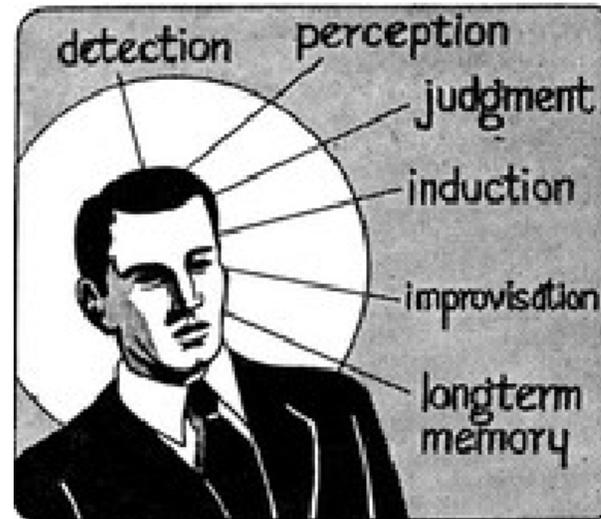
Primary and secondary functions

Holistic scope of human allocations

Did you meet the operational and safety objectives?

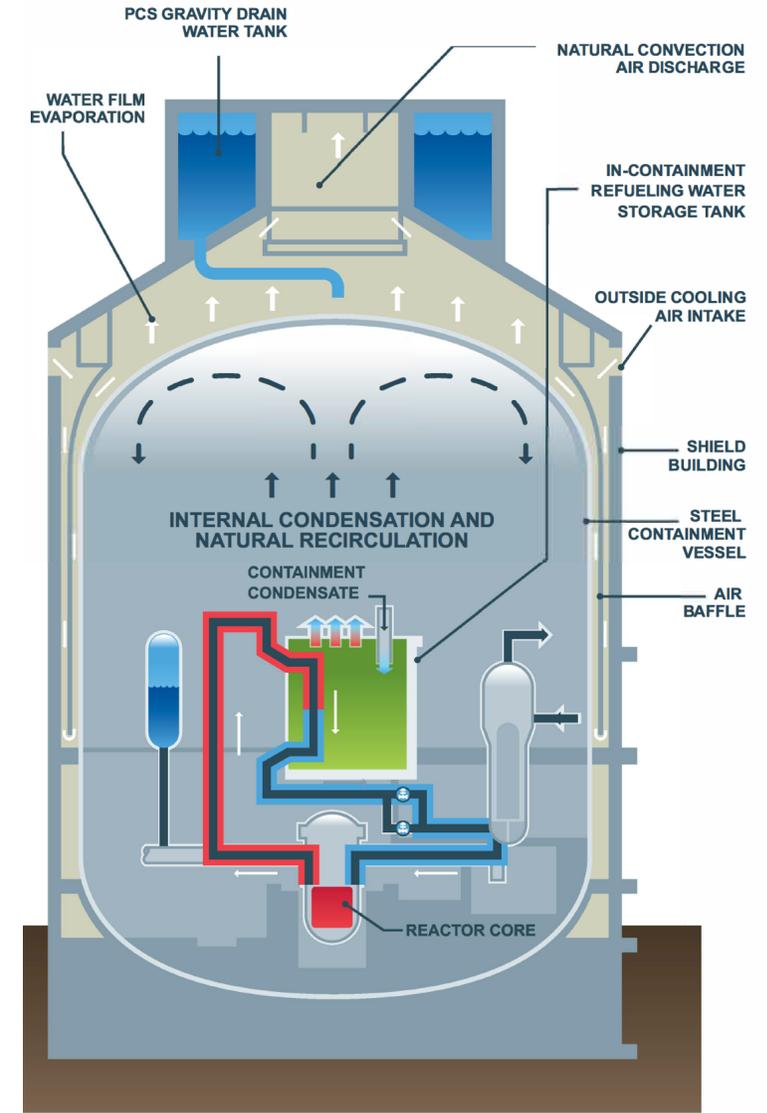
FA Review Guidance

- The review criteria for FA rely on research and standards from primarily the 1980s and 1990s.
- Those materials review methods from 1951-1982.
- Fitts list – complementary allocation strategy, based on “HABA-MABA”.



NRC FA Guidance: Updates Needed?

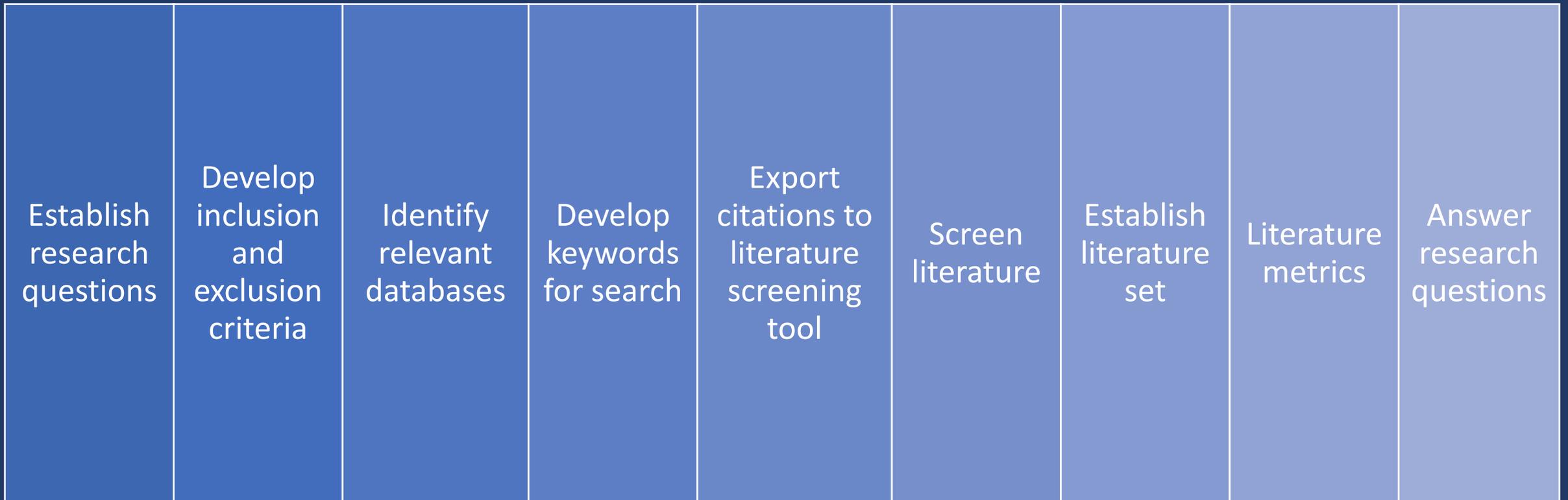
- Are methods from the 1980s and 1990s useful and applicable to new forms of autonomy?
- New designs expected to have more passive safety features and greater capability autonomous operations.
- Can you capture “the actions” of passive safety features with traditional FA methods?
- Are new FA methods needed?
- Does NRC need new or updated guidance that reflects new forms of automation and passive safety features?



Systematic Review Definition

- Systematic methodology for collecting, critically evaluating, integrating, and presenting information from many sources.
- Method established prior to beginning the literature search to avoid bias.
- No decisions made based on a single reviewer's judgement.

Approach | Systematic Literature Review Methods



Review Software | Rayyan

The screenshot shows the Rayyan review software interface. At the top, the title bar reads "Function Allocation and Functional Requirements Analysis" and includes a "Need Training?" link. Below the title bar, a navigation menu contains "Overview", "Review Data", "Screening", "Full Text Screening", and "Data Extraction". A search bar on the right contains the text "A Closed-Loop System for Examining Psychophysiology".

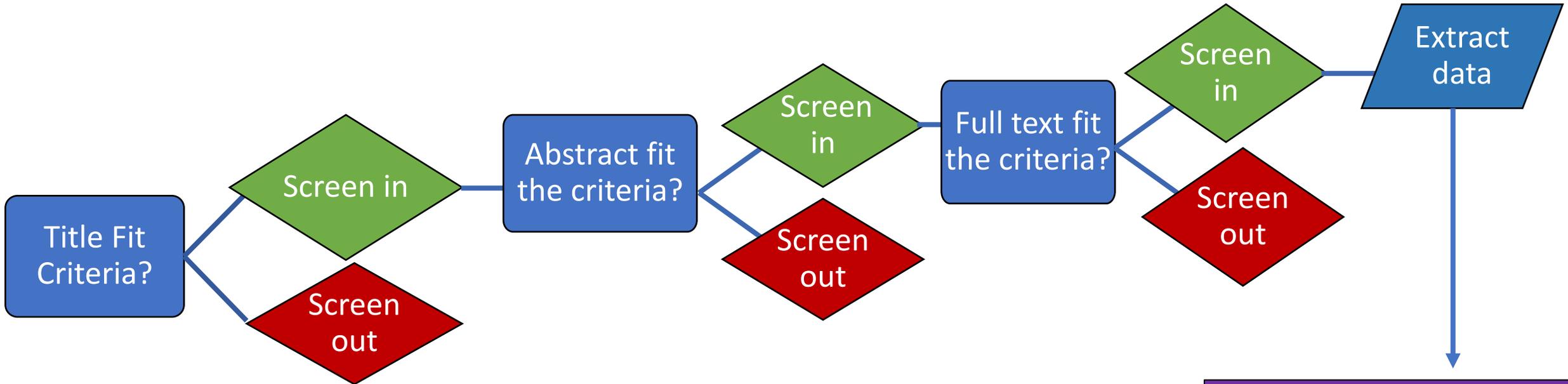
The main interface is divided into several sections:

- Source List:** Located on the left, it shows a list of articles. The first article is "A closed-loop system for examining psychophysiological measures for adaptive task allocation" by Prinzel, Lawrence J.; Freeman, Frederick G.; et al. (2000-01-01). It has been reviewed by Heather and Kelly, with tags "Evidence of new FA methods" and "Fitts - HITL".
- Review Window:** The central area displays the abstract of the selected article. The abstract text is: "Examined the utility of an airplane adaptive automation piloting system that determines optimal task allocation based on pilot EEG data. In a replication and expansion of the study of A. T. Pope et al (1995), EEG data were recorded for 48 undergraduate and graduate students (aged 18–40 yrs) while completing a modified version of the Multiattribute Task Battery (J. R. Comstock and R. J. Arnegard, 1992), which comprised monitoring, compensatory tracking, communication, and resource management activities similar to those undertaken by airplane crew members during flight. The system made allocation decisions as a function of the level of operator engagement based on EEG data. Results show that it was possible to moderate an operator's level of engagement through a closed-loop system driven by the operator's own EEG. More task allocations were made under multiple-compared with single-task conditions. The system exerted a psychophysiological correlates of workload as task load increased." Below the abstract, the publication type is listed as "Journal Article".
- Reviewer Decisions:** At the bottom of the review window, there are buttons for "Include", "Maybe", "Exclude", "Reason", and "Label".
- Reviewer Notes:** At the bottom of the review window, there is a text input field labeled "Add note" with a submit button.
- Filters:** On the right side, there is a "Filters" panel. It has two sections: "Keywords for include" and "Keywords for exclude". The "Keywords for include" section has a "Select All" checkbox and a list of keywords with counts: "compared with" (160), "trial" (67), "assigned to" (59), "randomized" (29), "control groups" (9), and "randomised" (6). The "Keywords for exclude" section also has a "Select All" checkbox and a list of keywords with counts: "trials" (81), "longitudinal" (66), "observational" (27), "meta-analysis" (20), and "regression analysis" (13).

Annotations in orange boxes point to the "Source List", "Review Window", "Reviewer Decisions", "Reviewer Notes", and "Filters" sections.

Reviewer Notes

Review Workflow



- Citation Data
- FA Framework
- Human in the loop strategies
- Method's development year
- Method's origin
- Use case/experiment
- Quant vs. qual

We reviewed MANY papers

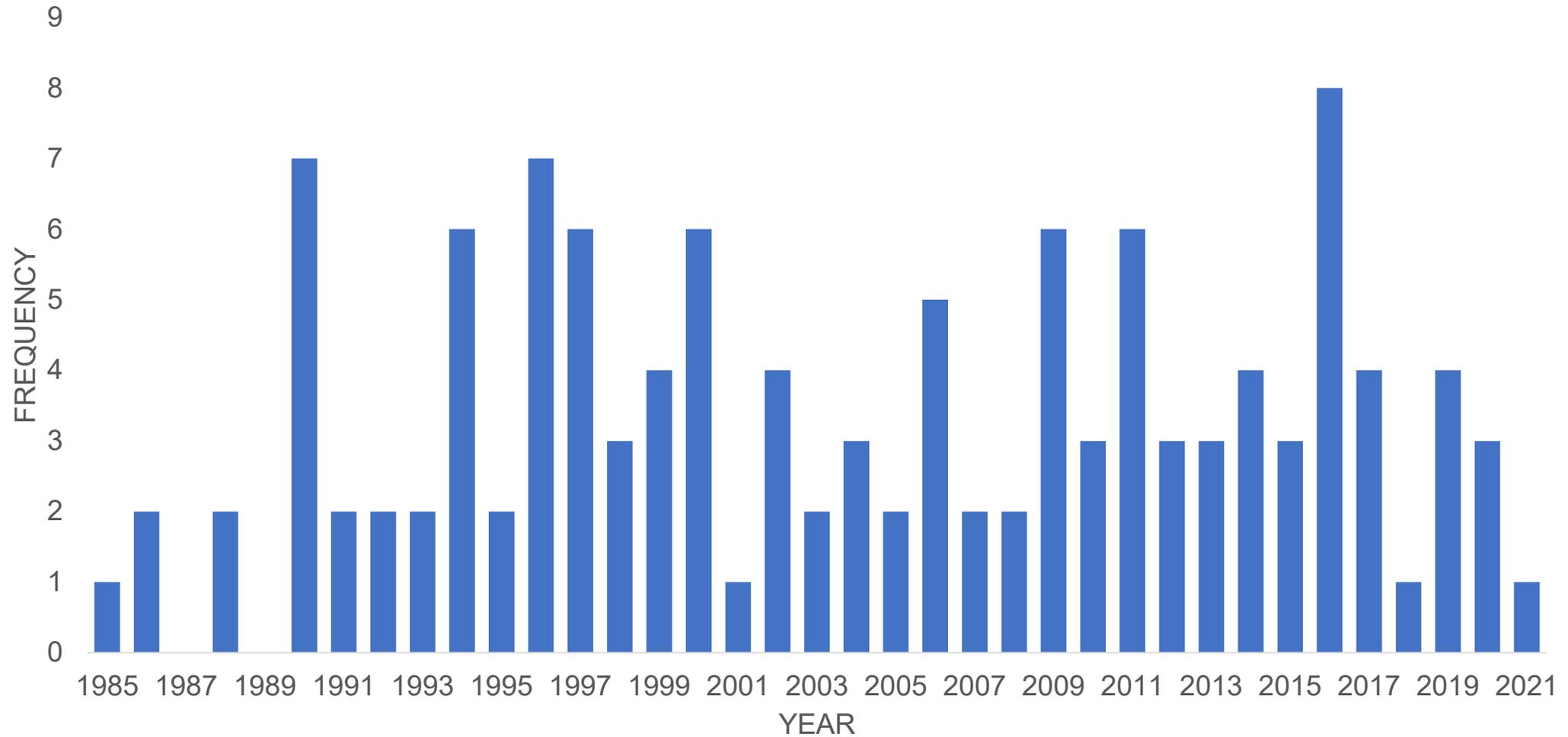
8,729 Citations added to screening tool

638 Abstracts reviewed

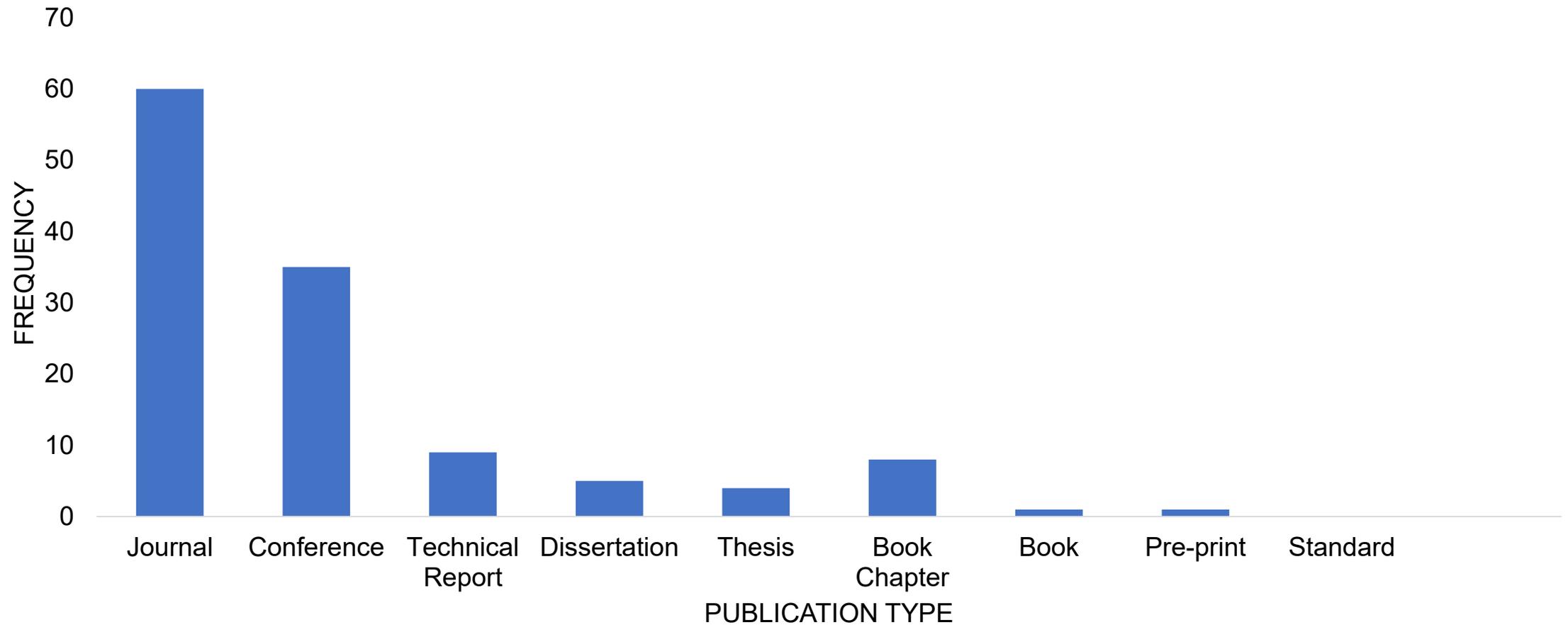
123 in the Review



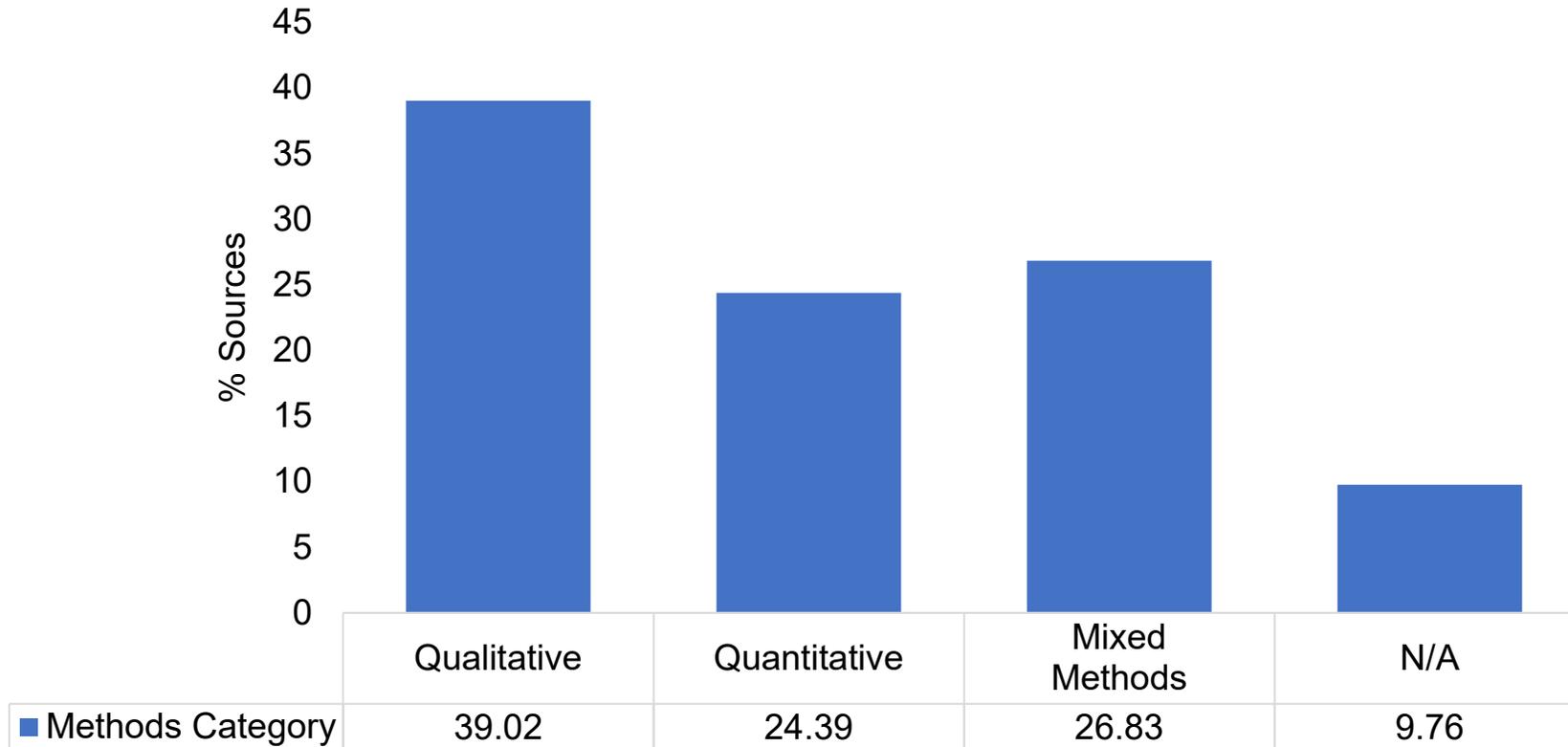
FA Research Prevalence: Post-1983



Publication Types



Qualitative or Quantitative?



Qualitative vs. quantitative? There's more to consider.

- Different frameworks seem to be used at different phases of design maturity.
 - Qualitative – Initial allocations in early system design.
 - Quantitative – Data driven allocations - later system design.
 - Hybrid approaches – Uses a categorical framework with human or system performance data (or estimates).
- Dynamic allocation will require a quantitative or hybrid approach.
- Static allocations can be assigned qualitatively, but they will be more accurate if they are based on some kind of data (qualitative or quantitative).

Are earlier methods still useful?

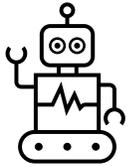
- Few invoke Fitts List (1951) by name, but its influence is readily observable.
 - Many papers discussed allocating functions based on maximizing strengths and minimizing weakness.
 - The literature also discussed alternatives - Cooperative allocation.
- LOA are the most common qualitative framework used for FA.
 - Parasuraman (1987) Levels of automation and Sheridan, Parasuraman, and Wickens (2000) are the most cited LOA frameworks.
 - Conceptual LOA frameworks can be evaluated and validated quantitatively.

Do FA methods need to change?

- Not necessarily...
- Introducing more advanced automation or AI changes the tasks available to the non-human agent, this lightens the load for the human.
- Giving the non-human agent more to do can cause poorer performance:
 - Humans may disengage (loss of SA and manual skills).
 - Increased cognitive load for monitoring and communicating.
 - Humans may not trust the non-human agent and take manual control at inopportune times, increasing risk.

Modern example, old method.

Coding with AI



AI's Contribution

- Writes python code to process, visualize, and analyze data
- Leverages access to the ENTIRE INTERNET to find potential approaches
- Sees syntax errors
- Iteratively optimizes code



Human Contribution

- Evaluates python code
- Develops the overall analytical strategy
- Evaluates data outputs
- Develops process for code and data verifiability
- Understands meaning of results

Most common human-in-the-loop strategies?

- Human-controlled automation invocation strategy (adaptable automation, not adaptive automation).
- If not human controlled, performance-based allocation triggers (human or task) – Dynamic allocation.
- Complementary allocation strategy (HABA-MABA).
- Moderate level of automation (management by exception, consent).

Can existing frameworks incorporate passive safety features?

- Binary frameworks – Can easily account for more advanced autonomy (AI).
 - The tasks distribution would change, but the allocation framework could remain the same.
 - Can they account for passive safety features, where no decision-making or intervention is required?

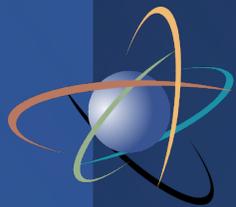
Dimensional vs. Categorical Frameworks

Assignment Philosophy		Critical event centered			Human performance centered		
What factors cause the change in automation status		External events cause automation status to change			Real-time assessment of human performance causes automation to change		
Task Strategy		Allocation	Partition	Transformation	Allocation	Partition	Transformation
How functions are changed by the automation		Complete Functions are shifted	Parts of functions shifted	Cognitive demands of functions are changed	Complete Functions are shifted	Parts of functions shifted (alarm highlighting)	Cognitive demands of functions are changed (CBPs)
Decision Stability	Stable –minimal diagnosis required	Passive safety features				Fault detection	Management by consent/exception
	Dynamic – Diagnosis and strategy required		Active safety features			Fault diagnosis and procedure selection	

SLR Methods Lessons Learned

- We did not register our review – if you plan to publish, register the review to avoid issues with your journal.
- It is impossible to do a review at this scale without SLR software.
- Have a plan for what to do when reviewers drop out of the project and document it in the review protocol.
- We spent 70 hours actively reviewing in the software. Another 160 (at least) reviewing and documenting full text papers.
- Save everything! We plan to conduct additional analyses on everything we surfaced.

The verdict? SLRs are a massive pain but we are confident that we found clear evidence and consensus on key topics related to human-agent interaction and safety.



Questions?



Read our paper!



**Want to read the
papers?**



Backup Slides

Inclusion Criteria

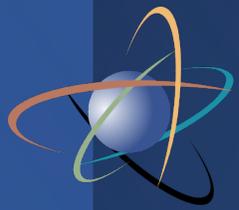
- Only studies published between 1983-2024
- Can be empirical, theoretical, methodological, or conceptual
- Can be from journals, books, white/gray papers, technical reports, standards, or any other primary source
- Can be a review or systematic review
- Can be a technical conference proceedings paper
- Written in English
- Full text available
- From human factors domains explicitly listed in NUREG/CR-2623
- From human factors domains explicitly listed in NUREG/CR-3331
- From human factors domains including autonomous vehicles (ground, sky, and space), driving, nuclear, oil and gas, maritime, manned aviation, command and control, and spaceflight operations
- From any other human factors domains including industrial or process control systems that the review team agrees will generalize to nuclear
- Function allocation studies that can be applicable to remote operations
- Results or methods can be applied to safety critical systems
- The source is related to one or more of the research questions

Exclusion Criteria

- Source material's primary focus is not function allocation or functional requirements analysis. For example, sources that use the term function allocation in reference to the allocation of governmental functions across municipalities.
- The source is a conference proceedings where the material is a description of the conference, table of contents, or other non-technical information.
- The source is a workshop or training summary.
- The source is a non-technical meeting summary.
- The source is general background material covering human factors and/or systems engineering broadly.
- The source is focused on system, user interface, or user experience design.
- Source is an opinion paper
- Sources where the primary focus is trust or an affective response to the division of tasks between the human and automation.
- The primary focus is on the ethical or legal implications of AI, automation, or human and automation interaction or collaboration.
- Sources that included the term human centered or human centered design in the title that did not also have the term automation/robotics (or analogous).
- Sources from the medical human factors literature.
- Sources that focus on specific age categories or populations associated with specific age categories (e.g., children, students, the elderly)
- The source has an erratum or correction associated with it.
- The source describes the functional allocation of business processes or the takeover of business functions.

Keyword List

Abnormal Conditions	Function reallocation	Normal operations
Abnormal Operating Occurrence	Functional allocation strategies	Nuclear
Abnormal Operations	Functional Analysis Methods	Off-normal operations
Adaptive task allocation	Functional requirement specification	Operating experience
Advanced reactor	Functional requirements analysis	Operator Action
Allocation of function method	Handoff or takeover / take over	Performance requirements
Allocation of functions	Human Action	Process control
Automatic Control	Human Factors Engineering	Reallocation of functions
Autonomy	Human -system interface	Requirements engineering
Aviation	Human-automation interaction	Safety functions
Cognitive work analysis/task analysis	Human-autonomy teaming	Shared allocation
Control room	Human-system collaboration	Static allocation
Design process	Human-system integration	Supervisory control
Economic feasibility	Level of automation	System components
Emergency Operations	Levels of automation	System design
Fitts list	Light water reactor	Systems engineering
Function allocation framework	Main control room	Systems requirements engineering
Function allocation method	Management requirements	Task allocation
Function allocation methods (FAME)	Man-machine interface	Task analysis
Function allocation process	Manual Control	Task distribution
Function decomposition	Military	Validation



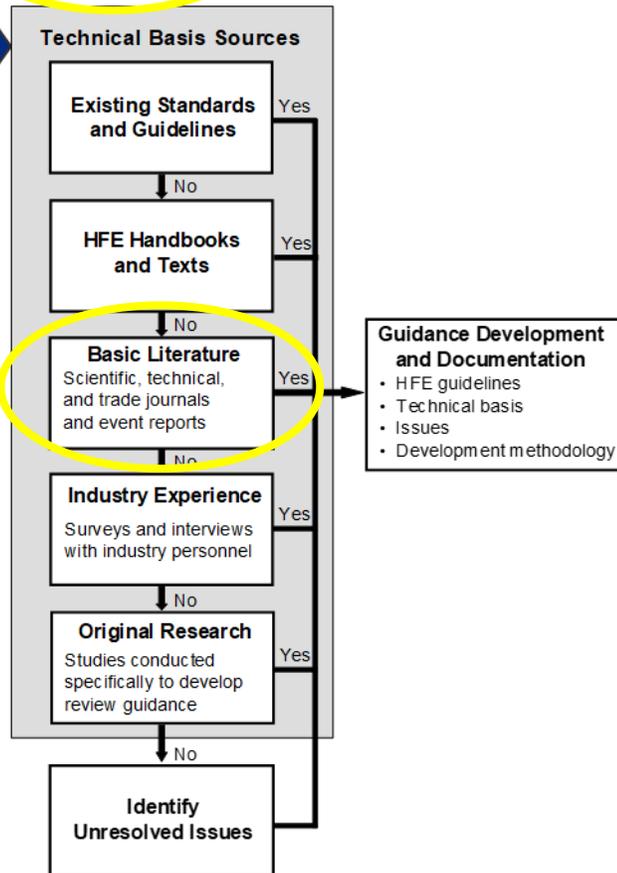
Excluded Search Terms and Term Combinations

Insurance	Legal
Underwriting	Ethical/ethics
Light water reactor and aviation	Natural language processing/NLP
Military and control room	Software
Military and main control room	Business requirements

Human/Technology Readiness Levels

Level	Human Readiness Level	Technology Readiness Level
1	Basic principles for human characteristics, performance, and behavior are observed and reported.	Basic principles observed and reported.
2	Human-centered concepts, applications, and guidelines defined.	Technology concepts and/or applications formulated.
3	Human-centered requirements to support human performance and human-technology interactions established.	Analytical and experimental critical function and/or characteristics.
4	Modelling, part-task testing, and trade studies of human systems design concepts and applications completed.	Component and/or breadboard validation in laboratory environment
5	Human-centered evaluation of prototypes in mission relevant part-task simulations – to complete design.	
6	Human systems design fully matured as influenced by human performance analyses, metrics, prototyping, and high-fidelity simulations.	System/subsystem model or prototype demonstration in relevant environment.
7	Human systems design fully tested and verified in operational environment with system hardware and software and representative users.	System prototype demonstration in operational environment.
8	Total human-system performance fully tested, validated, and approved in mission operations, using completed system hardware and software and representative users.	Actual system completed and qualified through test and demonstration
9	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance.	Actual system proven through successful mission operation.

Guidance Development Process



- Guidance documents are developed based on reviewer needs.
- Guidance documents are updated periodically and/or in response to changes in technology or regulations.

Binary Perspective – there are tasks and characteristics that are machine only and not part of an allocation process.

Perform Functional Requirements Analysis (FRA) to identify functions that will fall into one of the 6 following categories. That is, the function identified in the FRA is accomplished by/through:

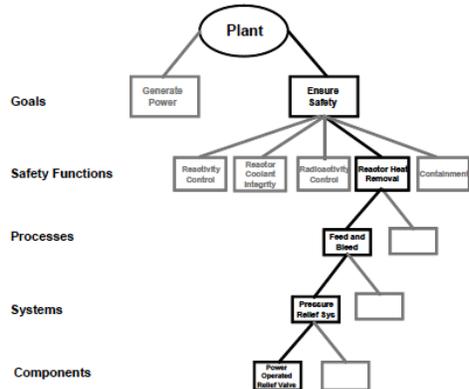


Figure 4-1 Vertical slice through a plant's functional hierarchy for ensuring safety

1. Inherent Safety Characteristics

2. Passive Safety Features w/ no human interaction

3. Passive Safety Features w/ varying degrees of human interaction

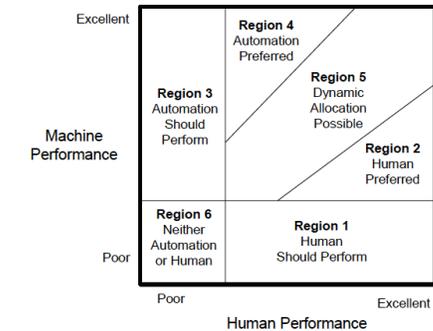
4. Active Safety System

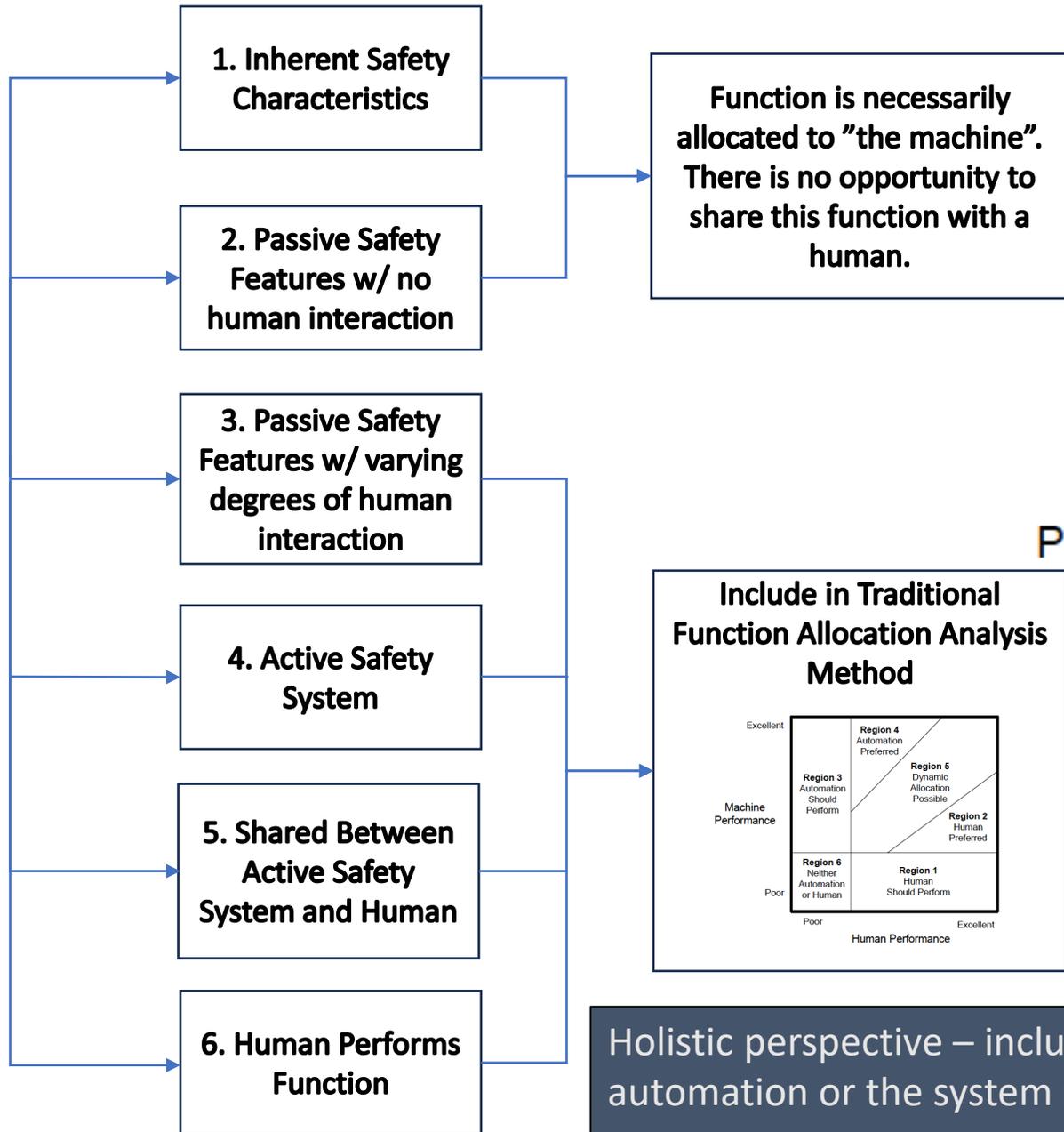
5. Shared Between Active Safety System and Human

6. Human Performs Function

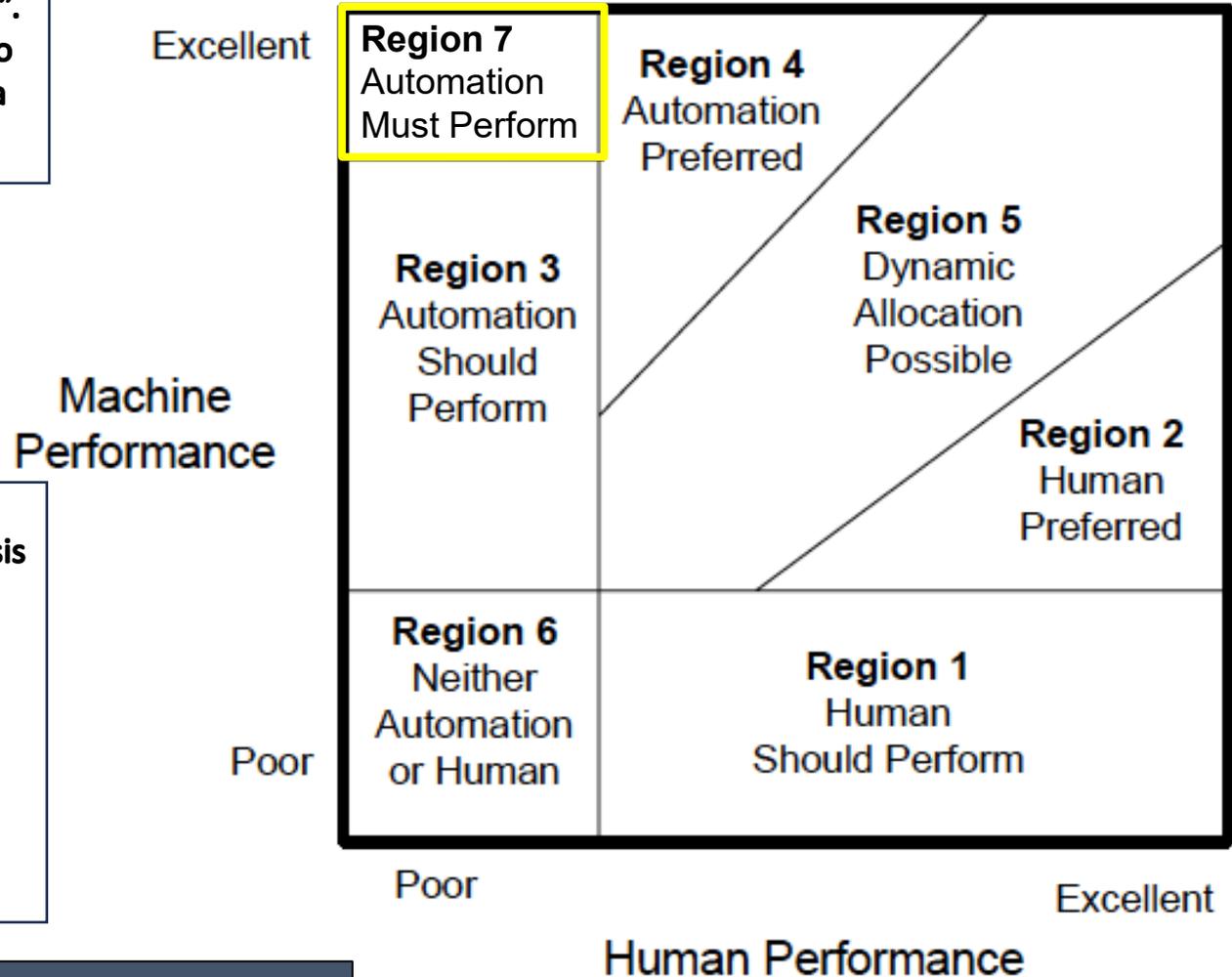
Function is necessarily allocated to "the machine". There is no opportunity to share this function with a human.

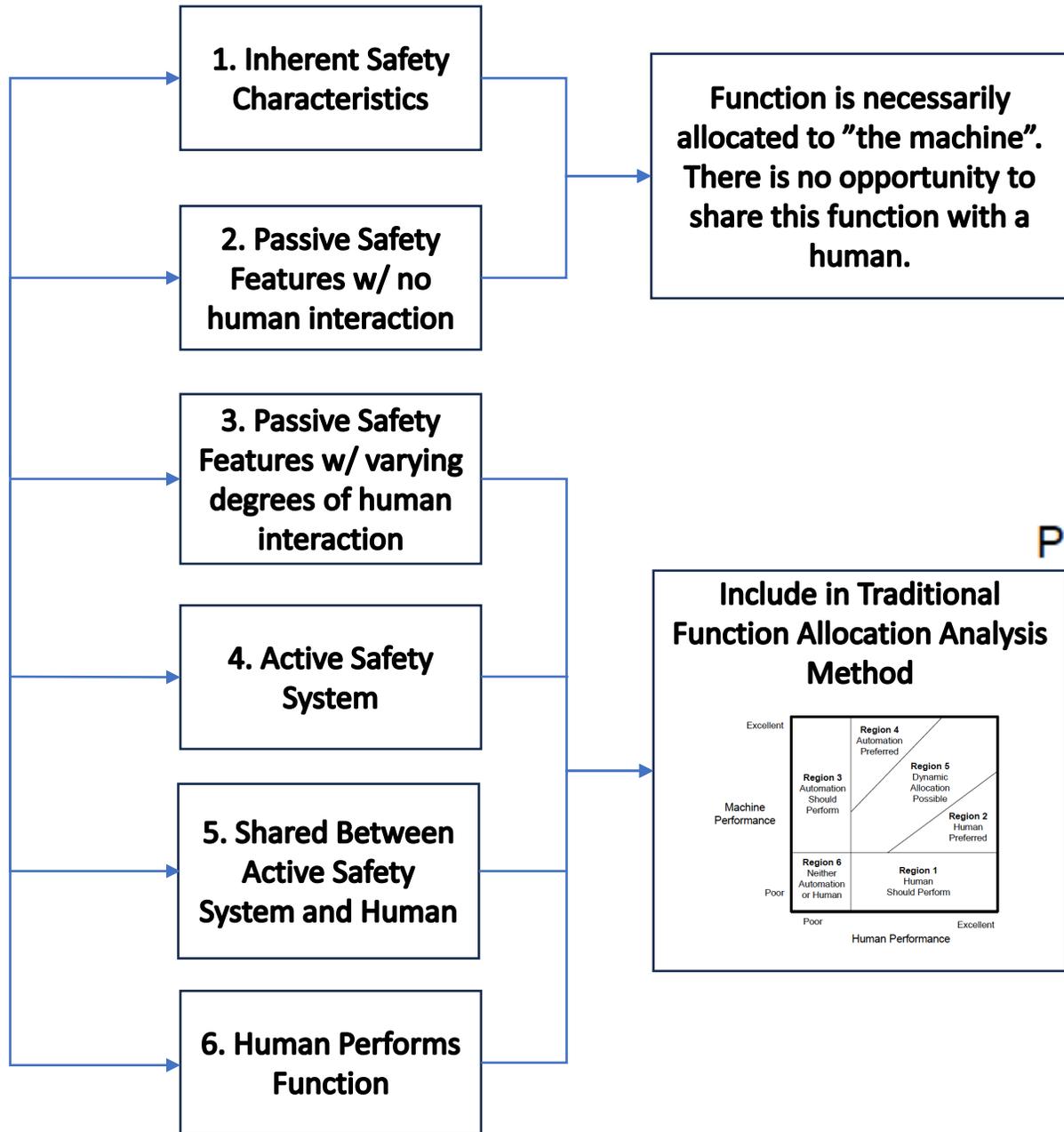
Include in Traditional Function Allocation Analysis Method





Holistic perspective – include tasks that automation or the system must perform.





What about AI?

