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Some recent advances in human-automation interaction design methods and future research directions for safety

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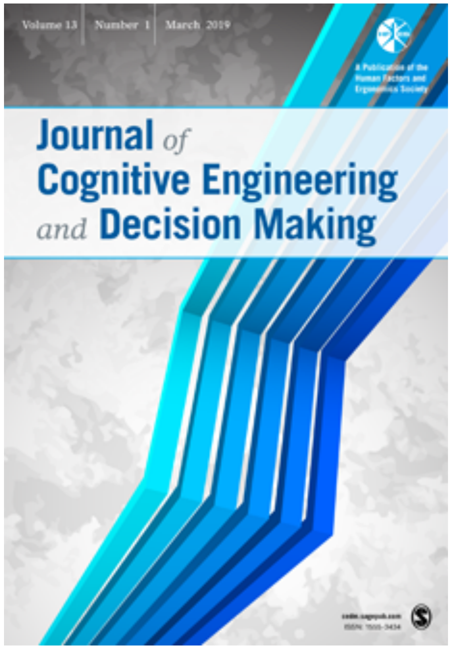
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Introduction

Level of Automation	Roles and Agent Allocation				System Performance Outcomes			Supported Driving Condition	Operational Risk
Manual Control	Vehicle Control	Navigation	Environment Monitoring	System Monitoring & Intervention	Driving task performance	Driver Workload	Driver Situation Awareness	Nominal Off-Nominal	→ L/M/H → L/M/H
Level 0	Human	Human	Human	Human	Moderate (M) / High (H)	H	H	Y Y	L L/M
Semi-AUTOMATED									
Level 1	Human + System	Human	Human	Human	M/H	M/H	M/H	Y N	L H
Level 2	System	Human	Human	Human	M/H	Low (L)/M	L/M	Y N	L H
Level 3	System	Human + System	Human + System	Human + System	M/H	L/M	L/M	Y N	L H
Level 4	System	System	System	System + Human	H	L	L	Y Y	L M
Fully-AUTOMATED									
Level 5	System	System	System	System	H	L	L	Y Y	L M
References	(Based (in part) on SAE Levels of Driving Automation)				(Must be empirically established)			(Must be empirically established)	

- **Conducted some recent research on methods for human-automation interaction (HAI) design:**
  - **Aimed at improving** design processes and **system usability, performance and safety**.
  - **Motivated by prior work on "levels" of human-machine system automation** and development of taxonomies of levels of automation (LOAs) as basis for conceptual design.
  - Kaber (2018, JCEDM) – **Need descriptive accounts of human responses to various LOAs** to create detailed frameworks for design.
    - **Provided example of further specifying new SAE (2014) taxonomy of automation for automated vehicles.**
      - **Idea was to make clear implications of task function allocation on driver performance, workload and situation awareness (SA) under nominal and off-nominal conditions.**

A constrained literature review



- Follow-on review of **special issue of *Journal of Cognitive Engineering and Decision Making* (2018) focused on "Advancing Models of Human-Automation Interaction".**
  - **Papers presented new ideas on how to approach automation design in future human-machine systems** effectiveness and efficiency of operation.
- After publication, we **reviewed studies to**…
  - **Characterize methods for practitioners**
  - **Classify studies in terms of contributions to existing design methods:**
    - Some studies focused on critiquing and extending LOAs approach
    - Others defined new approaches to applying existing types of HAI models
    - Still others defined brand new HAI modeling approaches
  - **Classify studies in terms of applicability to stages of system lifecycle**

Details on specific studies

- **LOAs are discrete, emergent and not the only factor in design…**

Authors	Method Descriptor	Extension of LOA	New Approach (based on Existing Type of Model)	New Modeling Approach
Miller (2018)	Contended that discretization of complex HAI problems **(using LOAs) can distill some causal relationships between automation features and human performance but approach also leads to missing details for design of interaction**; need to characterize shared agent mental models for negotiating task performance and address in design		X (Using mental models and common ground for task negotiation)	
Wickens (2018)	**Identified degree of system automation (DOA) as emergent feature of application of stages and levels of automation models**; simplification and **elaboration of LOA models is needed to account for observed discontinuities in human responses to LOAs.**	X		
Endsley (2018)	**LAO approach has utility but need exists for new model covering broader range of design factors. Developed Human-Autonomy System Oversight (HASO) model addressing automation interaction paradigm, automation interface and identifying LOA as a variable in monitoring and control of system.**	X		X (HASO model)

More studies and details

- **LOA taxonomies may take too long to develop and are not prescriptive.**
  - Other models (SRK) can be expanded for automation design.

Authors	Method Descriptor	Extension of LOA	New Approach (based on Existing Type of Model)	New Modeling Approach
Burns (2018)	**LOA approach may not be sufficient for rapid pace of system development.** Need to take advantage of real-time capture of big data on systems. **Identified novel integration of Cognitive Work Analysis (CWA) with degrees of automation analysis (Wickens et al., 2014) to support effective automation design.**	X	X (CWA)	
Naikar (2018)	Contended that **LOA approach does not account for system dynamics over time.** Assumed LOA approach describes actual state of system ("who does what") and is not prescriptive (i.e., "who can do what"). **Advocated for Work Organization Process (WOP) diagramming to identify specific limits of agent capability and approaches by which to exploit operational flexibility (overlap in agent capabilities). Facilitate dynamic function allocations.**	X	X (Extension of CWA)	
Cummings (2018)	**Said LOA approach does not have utility for design beyond system classification. Proposed extension of application of Rasmussen's (1983) Skills, Rules & Knowledge (SRK) model by considering human expertise (SRKE)** and uncertainty in agent and environment states. **Advocated use as basis for design of autonomous high risk systems**		X (SRK)	

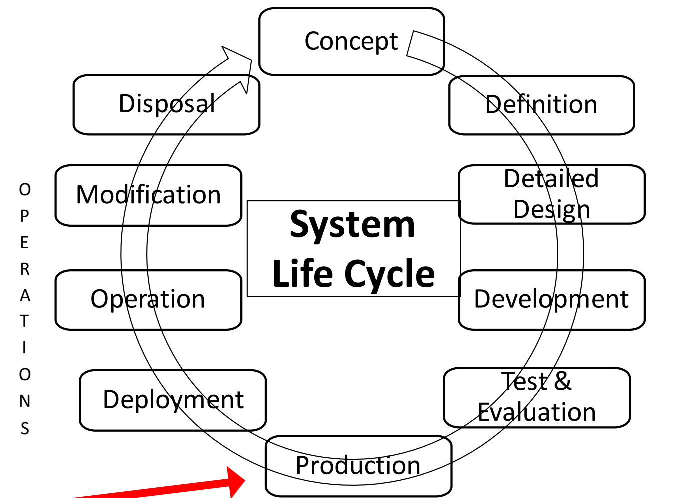
A few more studies

- **Human adaptive behaviors, agent interactions and multi-agent scenarios are key factors to consider in design of future autonomous systems.**

Authors	Method Descriptor	Extension of LOA	New Approach (based on Existing Type of Model)	New Modeling Approach
Kirlik (2018)	Contended that **critical issue in automation design is accounting for human adaptive behaviors** (vs. normative) in interacting with system. **Need to develop interfaces to exploit such behaviors**. Classified satisficing as one form of adaptive cognition and behavior; identified other adaptive behaviors and need to address in HAI models.	X	X (Adaptive behavior analysis)	
Johnson et al. (2018)	**Proposed new "co-active design" method for defining automation based on interaction with human as well as interdependence analysis for what "should" be automated.**	X		X (co-active design)
Lee (2018)	**Advocated for network analysis as a basis for defining HAI context and constraints on human and automation behavior. Said automation should not be viewed as single independent element and must account for capabilities of other agents in operating environment.**	X		X (Network analysis)

Method integration and system lifecycle

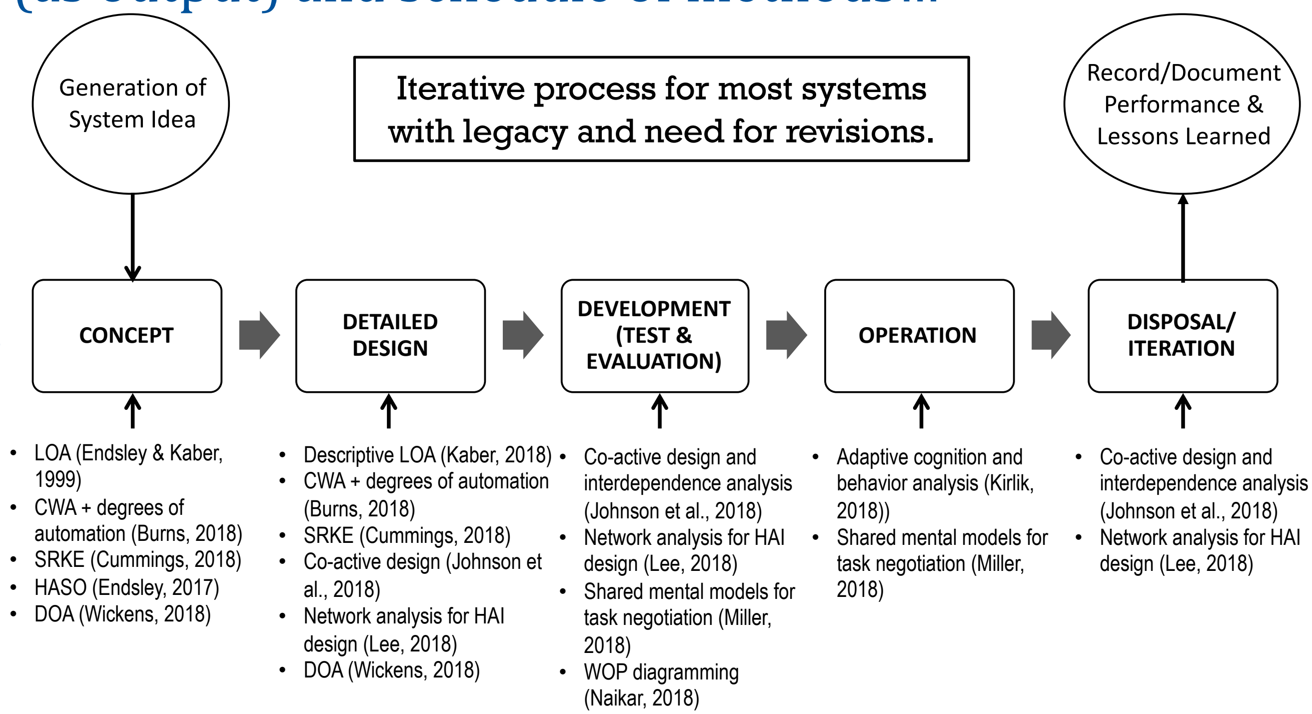
- May be possible to **determine integration of multiple conceptual and detailed automation design methods** to create better human-machine systems:
  - **Methods have similar inputs (e.g., agent capacity)**
  - **Outputs from one may support another** applied in sequential manner in design and engineering cycle
  - **What is "optimal" timing of application of each HAI design approach** for effective system implementation?
    - Two general phases: design and operation
    - **Intro of info should be proactive** (provided before it is needed) **and systematic** (throughout cycle; e.g., in test and evaluation for design refinement)



HAI knowledge should be considered in concept and design to prevent retrofitting or use of operator training to account for "bad" design.

Organizing methods according to lifecycle

- **Consider basic timeline from system idea** (as input) **to recording of outcomes** (as output) and schedule of methods…
  - **At which phases may various HAI methods be most impactful** for desired outcomes
  - **Some methods are still under development**
  - **Timeline does not include all methods in literature**



Some recommendations – System Concept Phase

1. **Apply an original LOA approach (e.g., Endsley & Kaber, 1999) to identify feasible human and machine function allocations** and project system outcomes

2. **Apply Burns (2018) integration of CWA and DOA to determine what "can" and "should" be automated relative to cognitive task performance demands**

3. **Use Cummings (2018) SRKE model to determine whether to develop a partial or fully automated system** (based on available forms of expertise)

4. **Use Endsley's (2017) HASO model for a "big picture" on all human, task, system and environment factors that should be considered in designing automated systems.**

5. **Apply Wicken's et al. (2014) DOA approach for initial function allocation decisi**ons relative to potential for automation failures and human out-of-the-loop performance

Detailed design phase

1. **Consider new descriptive LOA approach (Kaber, 2018) with detailed projections of potential system outcomes** (based on legacy system data or benchmarking)

2. **Return to Cummings (2018) SRKE model to highlight limitations of automation in addressing "rule" and "knowledge" based functions** (what "expertise" does automation lack for function performance).

3. **Apply Johnson et al. (2018) co-active design approach to account for coordinated agent activities** (requires data on agent capabilities and planned workflow)

4. **Consider Lee's (2018) network analysis approach to identify range of operating environment conditions, agent competition for resources, and interconnections among agents to ensure safety and performance.**

5. **Return to Wickens' (2018) DOA approach to identify alternate function allocation schemes to support failure mode performance.**

Development and test and evaluation phases

1. **Further apply Johnson et al. (2018) co-active design approach to fine-tune HAI by studying interaction with system prototypes.**
   - Extend with "interdependence" analysis to verify human-machine teaming or automation function as "teamplayer".

2. **Return to Lee's (2018) network analysis for fine-tuning automation design based on data from prototype testing and pilot assessments of interactions of agents within target task environment.**

3. **Consider Miller's (2018) concept of agent sharing of mental models as a basis for defining negotiation and allocation of tasks in on-going work mix.**

4. **Consider applying Naikar's (2018) WOP diagrams to identify work demands fielded by various actors and potential for constrained system organizational flexibility relative to demand states** (need prototype system and observations on agent adaptive behaviors).

Operation phase

- **Need to make observations of real-time task/function allocation negotiations based on operational circumstances.**
  1. **Consider Miller's (2018) concepts for effective agent communication and sharing of mental models** to refine and support function allocation approach

- **Need to verify accuracy of HAI model predictions of human use, misuse or disuse of automation based on system application.**
  2. **Consider Kirlik's (2018) approach to interface design for adaptive cognition and behavior.**
     - Operators develop heuristics during actual system use.
     - Patterns of adaptive behavior need to be observed and addressed through interface design revisions
  3. **Use performance data for refinement of HAI models (e.g., system outcomes added to descriptive LOA model; Kaber, 2018) for future designs.**

Disposal and iteration phase

- End of life - **Detailed operational data is available on patterns of user task performance** (prioritization, sequencing) and tool use:
  - **Data can be used as inputs to refine concepts of how HAI should occur in revisions of legacy system**, including refining Johnson et al. (2018) co-active design approach.
  - **Lee's (2018) network analysis for HAI design may also have utility for re-characterizing systems operating environment and well as multi-agent resource competition** (e.g., a driving environment with escalating automation and physical parameterization over time).
    - e.g., Identified demands can be translated to redefine human driver and automated assistance system relationships in iterations of vehicle design for new roadway "network" situations.

Domain specific research needs

- **Little work on conceptual approaches to HAI design to address systems safety issues:**
  - Consider case of advanced automated vehicles…
    - **What does automation mean for driver safety?**
    - **Safety issues are not addressed in current version of SAE levels of vehicle automation**
  - **State-of-the-art includes adaptive cruise control (ACC) and emergency braking systems (EBS; longitudinal control) and lane-keeping systems (LKS; lateral control):**
    - **Manufacturer objectives**:
      1. Greater trajectory control and efficiency in fuel use and travel times
      2. **Greater safety by reducing potential for driver errors**
    - **Current limitations:**
      - **Tech. is dependent on capability of designers to identify complex road conditions** and driving scenarios **that may lead to hazard exposures**
      - **Need for advanced automation of hazard detection and evasive maneuvering to prevent crashes**

Super Cruise (ACC+LKA) Control Interface in 2018 Cadillac CT6

Fatal Crash of Tesla Model S in Utah

Evolution of new vehicle automation

- **ACC and EBS have started with simple input conditions** (e.g., high-speed braking by lead vehicle).
  - More complex roadway conditions may develop (e.g., cross traffic illegally entering intersection in front of ownship)

- **There is a need for further development of advanced vehicle automation systems to ensure driver safety:**
  - **Current automation accounts for frequent but less severe hazard exposures**
  - **Need to address low frequency but high severity hazards**

Driver Complacency and paradox of advanced vehicle automation safety

- **Implications of current advanced vehicle automation** development:
  1. **Drivers rely on technology to manage minor infractions** of vehicle trajectory.
  2. **Drivers remain responsible takeover** (at moment's notice) **to manage highly complex and high criticality events.**
  3. **Driver reliance on early automation for minor hazard avoidance: (a) reduces regular manual skill use; and (b) may undermine capabilities to negotiate critical hazards when they occur.**

  (Paradox of design and incremental development of advanced vehicle automation for safety.)

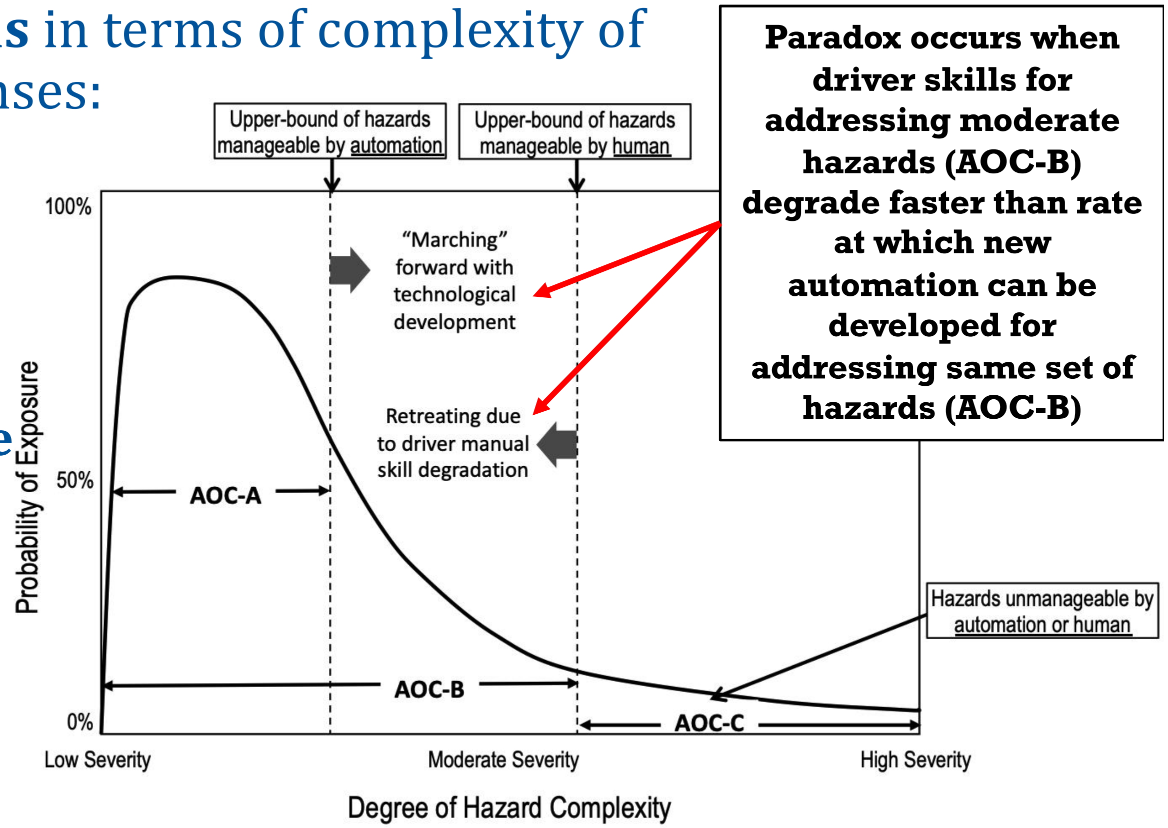
  (Note: This is also to say nothing of distraction and cognitive workload that new automation interfaces may also pose.)

Posture position stipulated in Tesla Owner's manual. (Who actually does this or will do this?)

What people may actually do!

Paradox of automation for safety in human systems

- **Distribution of roadway hazards** in terms of complexity of driver/automation control responses:
  - Less complex are more frequent
  - Some extremely complex hazards
  - **AOC-A – Target of early stage automation** (use of ACC or LKS)
  - **AOC-C – Currently unmanageable hazards** (automation and human)
  - **AOC-B – Hazards manageable by driver in takeover situation**
    - **AOC-B is also design target for next generation vehicle auto**



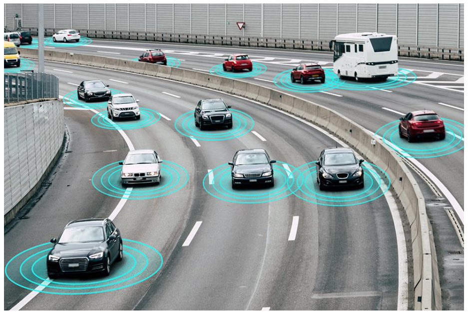
Some final thoughts

- **Paradox of automation for automobile safety is nothing new**; same paradox historically **emerged in advanced "glass" cockpit aircraft** and expert human use.
  - **Difference is that we have benefit of knowledge of 75 years of aviation human factors research!** (Time for concurrent engineering.)
- **How can we prevent paradox?**
  - **Consider use of timeline of HAI modeling and design methods** throughout system lifecycle
    - Need to **capture driver decision making framework** in automated vehicle control system design – **Consider Burns (2018) approach of CWA coupled with DOA**
      - **Characterize work demands** in specific driving situations **and driver responses**
      - May promote compatibility of automation design with driver mental models
    - **Apply Wickens et al. (2014) DOA approach to better account for human decision making and response capabilities in automation of vehicle control**
    - **Approach may accelerate rate at which advanced vehicle automation accounts for greater subset of roadway hazards** currently manageable only by human drivers (AOC-B).

More final thoughts

- **Need to design automation around specific driver behaviors** occurring under particular roadway conditions.
  - **Consider Kirlik's (2018) approach of accounting for adaptive cognition and behavior through automation interface design to support SA.**
    - May serve to **reduce effects of manual skill degradations and promote readiness for effective vehicle takeover under hazards**

- **Need for automated vehicles to account for specific environmental circumstances, including presence of other automated vehicles:**
  - Possible information sources for ownship or "competition" with ownship for roadway "resources" (e.g., lane, position, etc.).
  - **Consider Lee's (2018) network analysis approach to facilitate broader accounting of constraints or identification of 'crutches' to agent function** (not addressed by existing LOA design approaches).
    - **May allow human drivers and driving assistants to address currently unmanageable hazards (AOC-C).**



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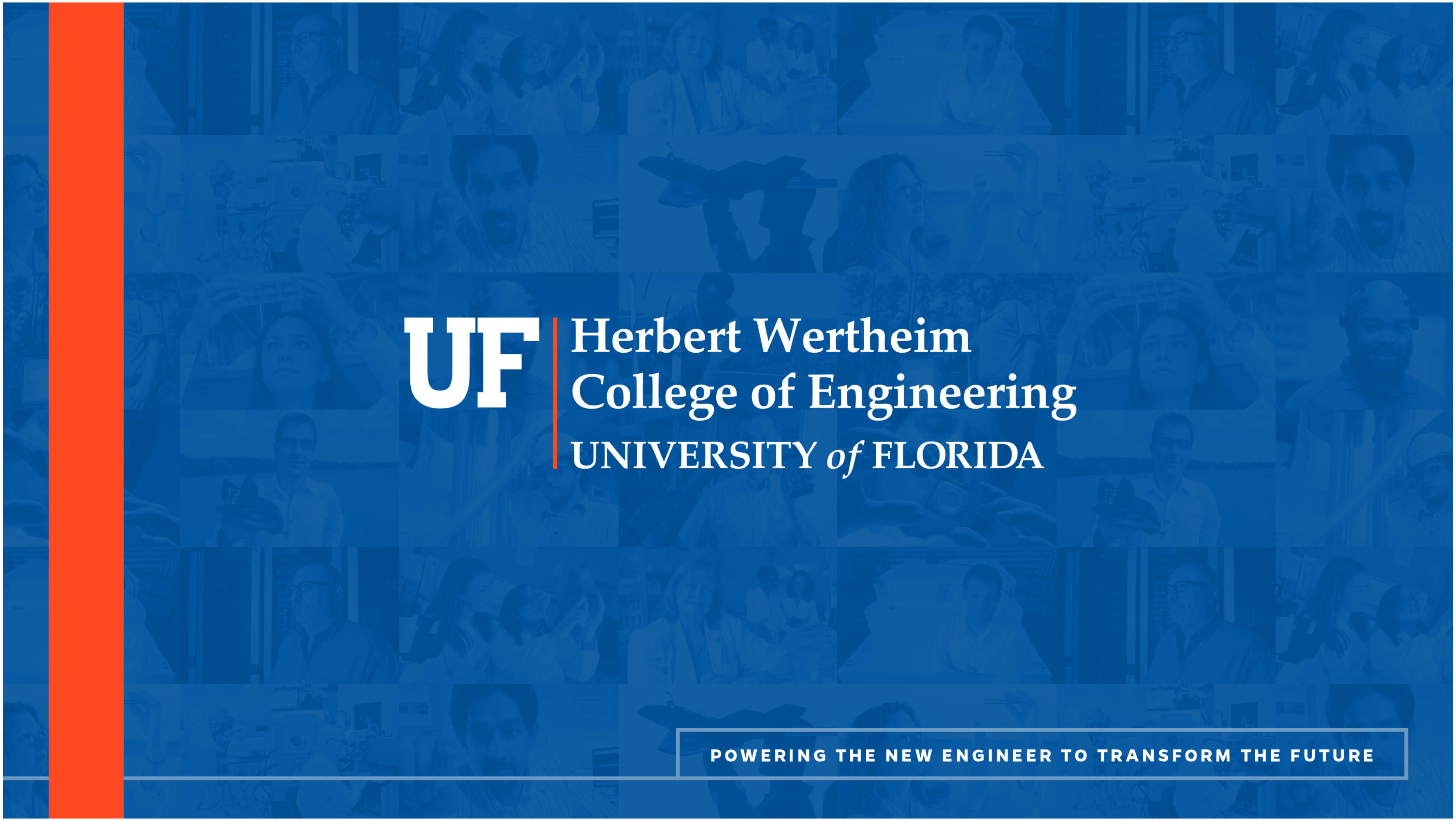
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