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UCL

An STPA-Based Framework for Integrating Emerging Technologies in Infrastructure

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Content

1. Background
2. Case Study 1 – Airports - Remote Air Traffic Towers (RTS)
3. Advancing the Safe Integration of RTS
4. Case Study 2 – Hospitals – Neonatal
5. Next Steps & Contributions

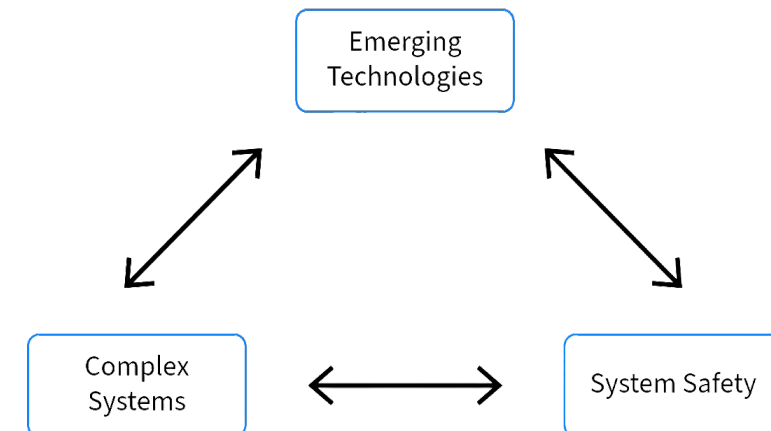
Background

Emerging technologies are transforming infrastructure systems; they create opportunities for improved performance but introduces new human-automation interactions and evolving system safety considerations.

Research Aim: To explore how emerging technologies can be safely integrated into complex infrastructure systems, focusing on human-automation interaction.

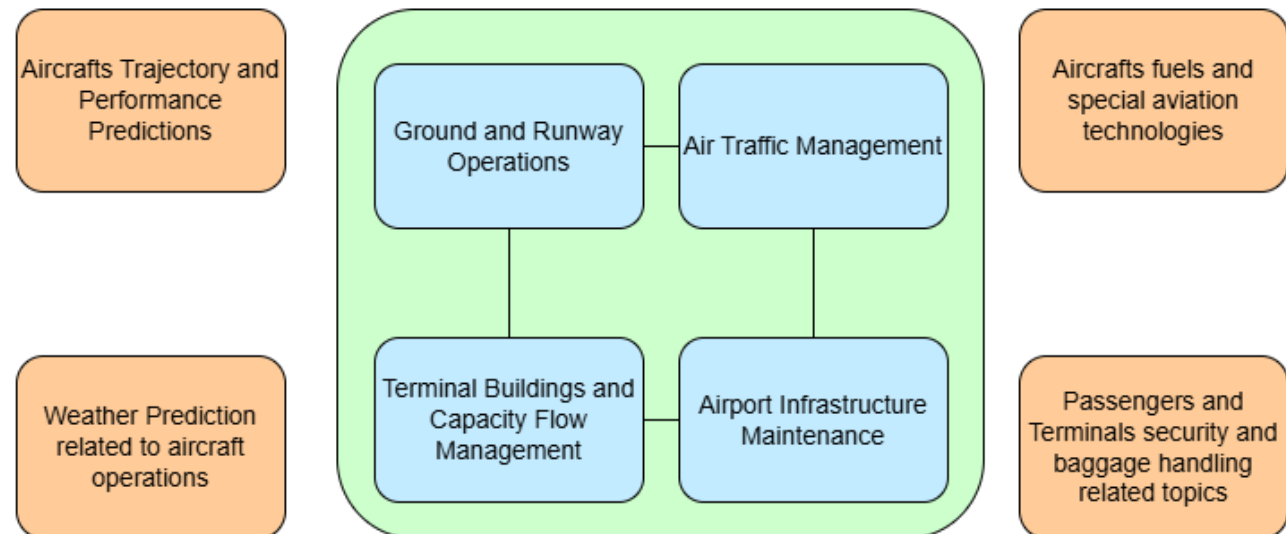
Research Objectives:

- Map the research landscape of emerging technologies in safety-critical infrastructure.
- Evaluate human-automation interaction with a focus on socio-technical factors.
- Apply STPA (Systems-Theoretic Process Analysis) hazard analysis to infrastructure case studies (e.g., airports).
- Develop a framework for the safe integration of technology into socio-technical systems.



Case Study 1 – Airports

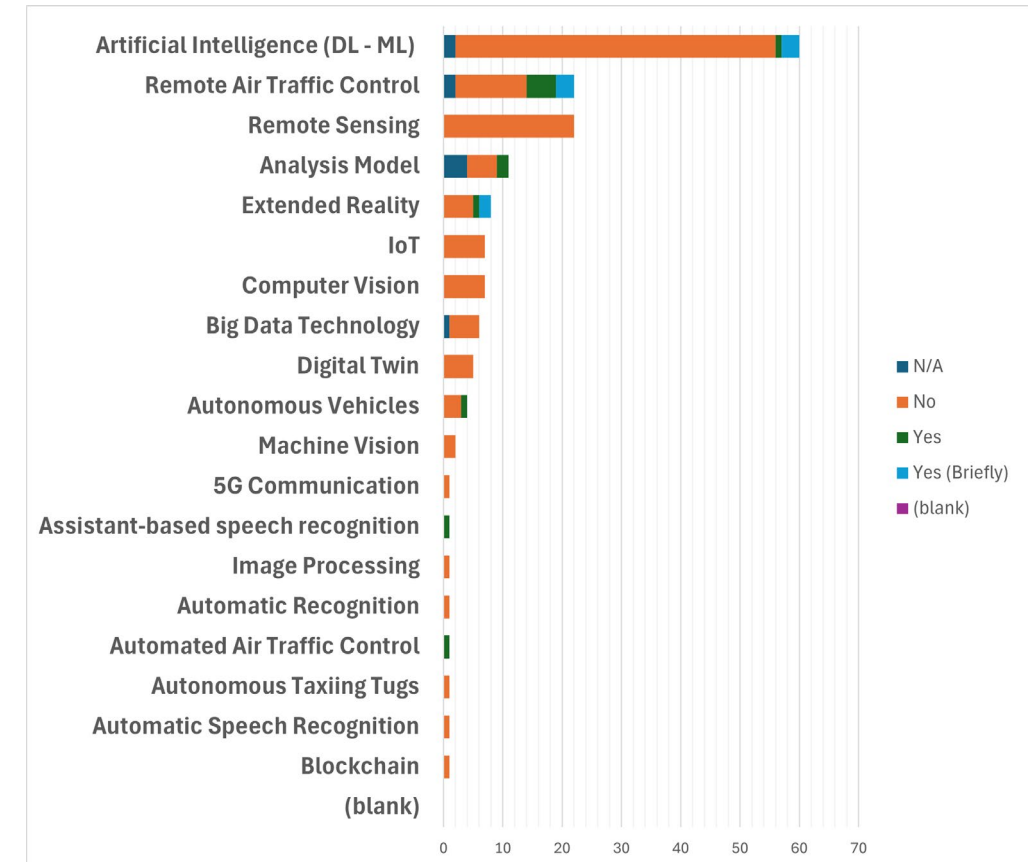
Airports are selected as a case study because they are active experimental environments for innovation¹, with scope focused on airport operations affecting the physical airport system, excluding wider aviation activities.



Systematic Literature Review Results 1/2

- A wide range of emerging technologies is being developed for airport operations, reflecting strong innovation and growing research interest.
- Only around 12% of studies investigate the safety implications of integrating applications developed using these technologies into existing infrastructure systems, revealing a clear gap for deeper safety-focused research.
- System-level impacts, such as changes in workflows and socio-technical interactions, remain relatively underexplored, with some initial attention in Remote Air Traffic Control Towers and Augmented Reality (AR) studies.

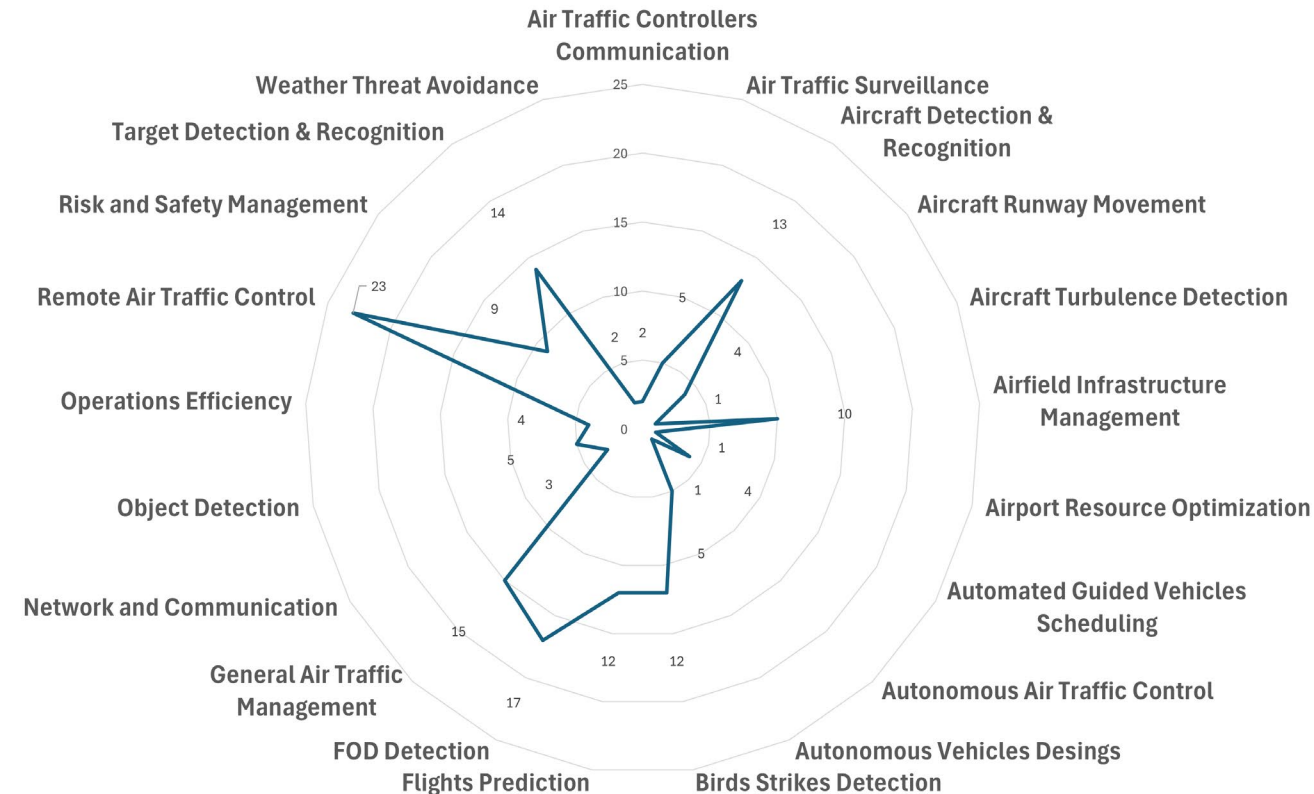
Inclusion of Safety Implications Across Technology Types



Systematic Literature Review Results 2/2

The most common technology functions relate to operational monitoring and air traffic control, which indicate a strong research focus on detection, surveillance, and real-time decision-support capabilities in airport environments.

Distribution of Technological Functions Identified in Reviewed Publications



The Selected Case Study – Remote Air Traffic Control Towers (RTS)

RTS replaces physical towers with specialised cameras, surveillances and communication systems, which allows controllers to manage one or multiple airports remotely⁷.

Why RATC was selected:

1. Increasing global adoption (e.g., London City, Örnköldsvik Airport)⁸. LFV, FAA, DLR
2. Complex socio-technical system where significant human-automation interactions occurs^{9,10}.
3. Widely covered in the literature, particularly on human-automation interaction and performance.
4. Involves multiple stakeholders (ANSPs - Air Navigation Service Providers, vendors, regulators), which would enable analysis across technical, human, and organisational dimensions.



Edinburgh Airport Conventional Air traffic Control Tower. Source: <https://www.nats.aero/>

Vs



London City Remote Air traffic Control Tower. Source: <https://www.nats.aero/>

Advancing the Safe Integration of RTS

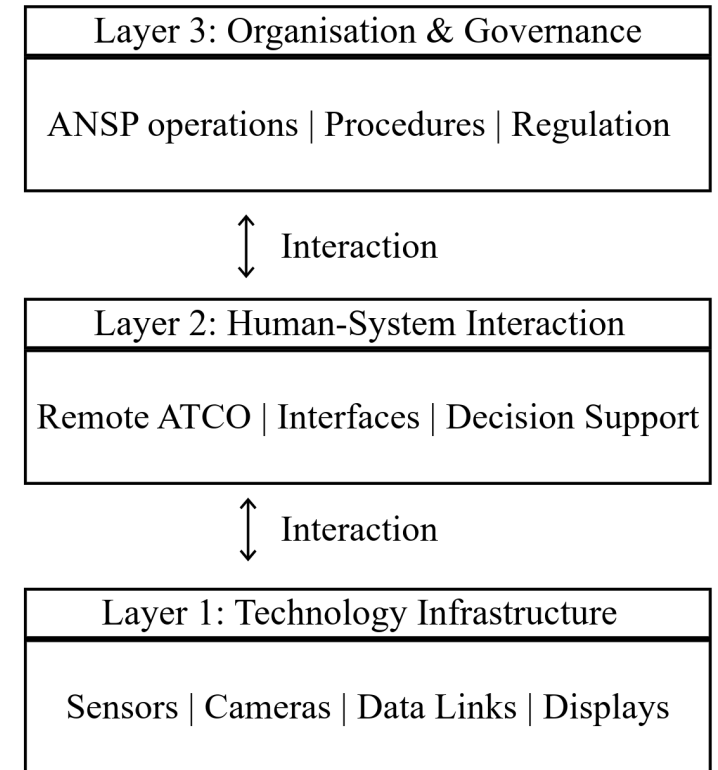
RTS have already demonstrated technical feasibility and operational capability. The next opportunity is to further strengthen system-level safety understanding

Current research has made strong contributions in:

- Technical performance
- Human factors and controller interface studies
- Economic and operational benefits

Opportunities for deeper system development and understanding:

- System-level hazard modelling across interacting components
- Socio-technical readiness assessment during digital transition
- Control-loop interactions between humans, automation, and infrastructure
- Organisational and governance integration across stakeholders



Case Study 2 – Hospitals

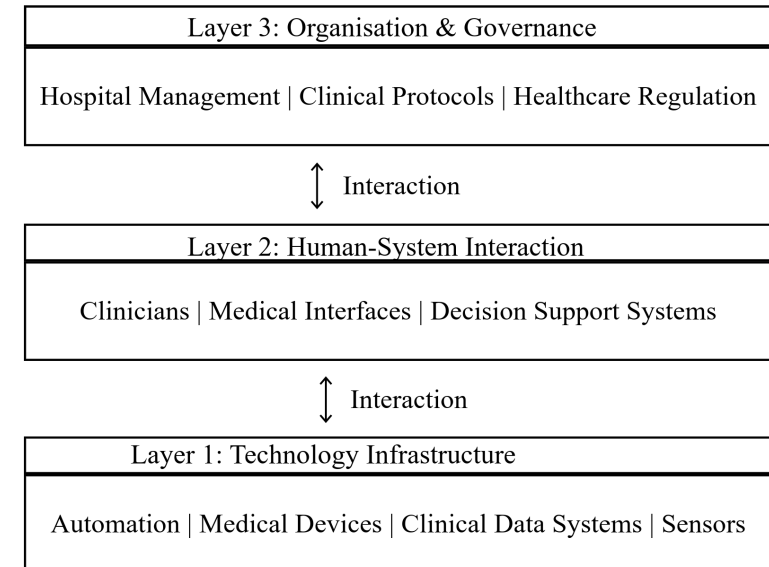
Hospitals represents an opportunity to test and generalise the framework across diverse operational environments.

Focused Operation - Neonatal Intensive Care (NIC)

- Highly safety-critical environment with Intensive human-automation interaction
- Continuous monitoring and decision support technologies
- Complex coordination across multiple organisational layers (hospital management, clinicians, and medical systems).

Collaboration: Research conducted with UK National Health Service (NHS).

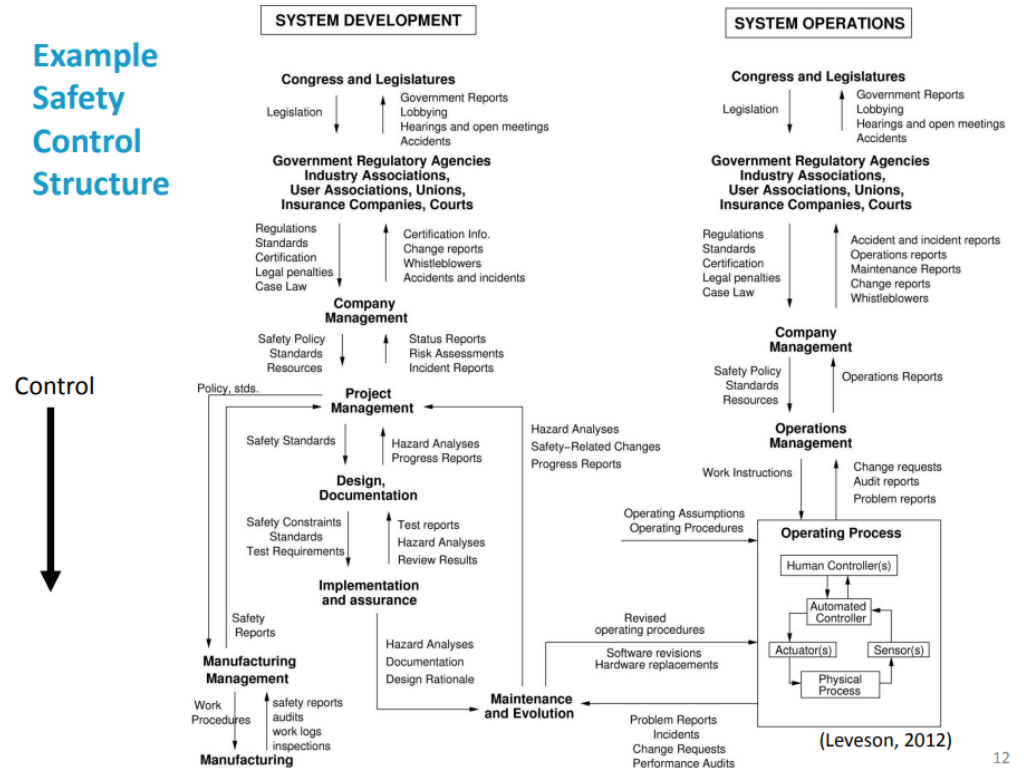
<https://www.nth.nhs.uk/>



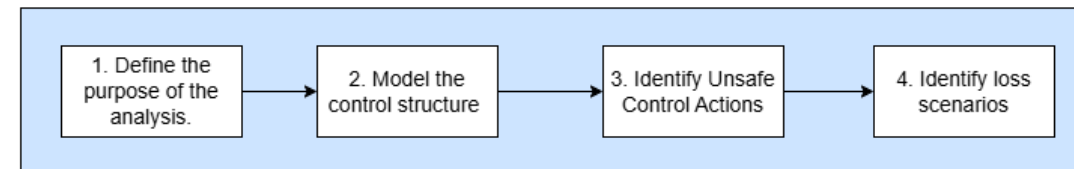
The Employment of STPA as the Hazard Analysis Tool

- STPA is chosen over FTA (Fault Tree Analysis), FMEA (Failure Mode and Effects Analysis), and HAZOP (Hazard and Operability) because those linear methods focus on single-point or components failures^{6,11}.
- STPA identifies hazards from unsafe control actions and emergent interactions in complex and software-driven systems.
- It supports early life-cycle analysis to define safety requirements before deployment.

Example of control structure drawn during STPA analysis processes⁶

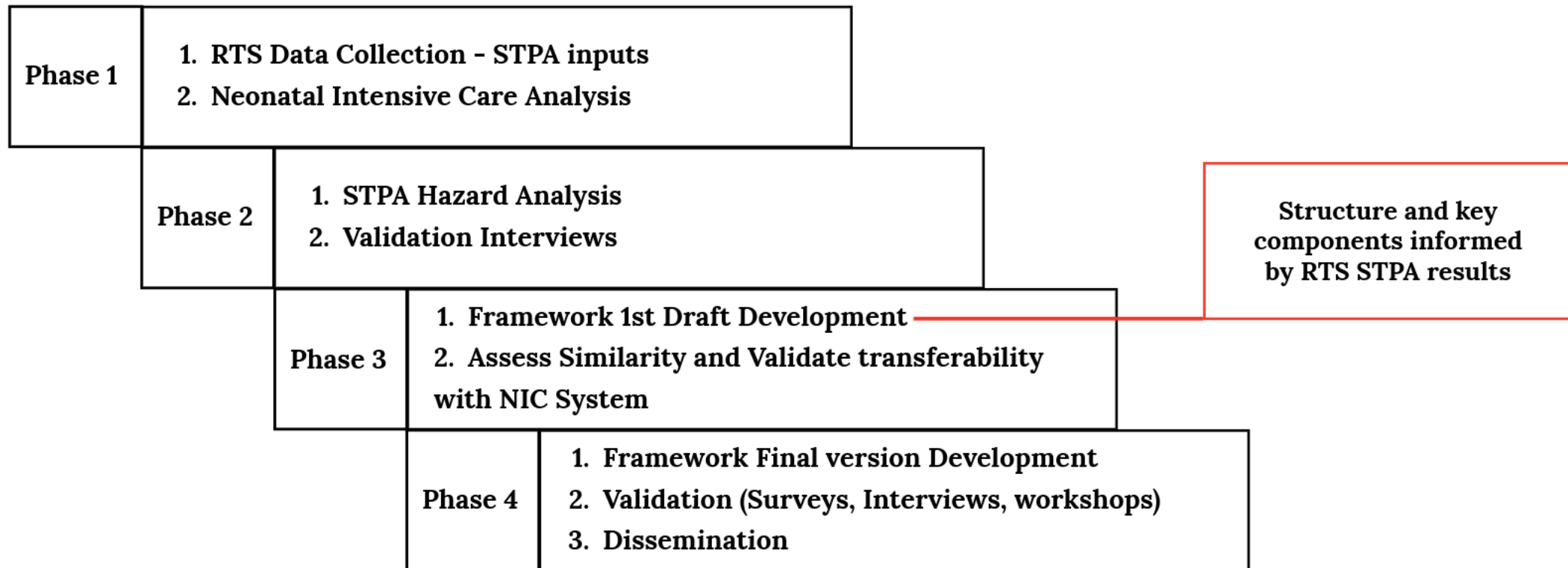


STPA analysis main steps⁶



Planned Work and Next Steps

Looking ahead, the research will proceed in phases:



Expected Contributions

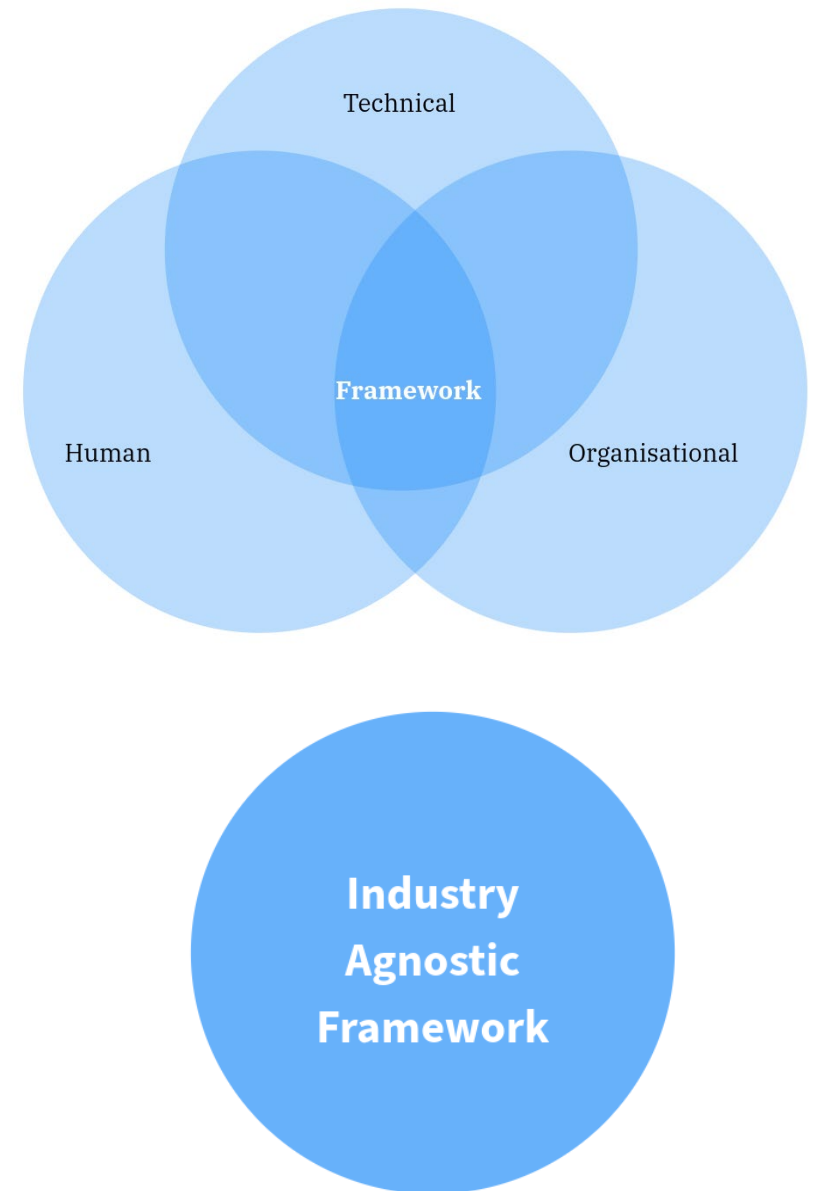
Research Novelty:

- Introduces a framework for the safe integration of technology into socio-technical systems that extends beyond technical maturity.
- Combines STPA with readiness assessment - currently not done in academia or industry.
- Uses evidence from real and deployed case studies (i.e., RTS and NIC).

Practical Contributions:

- A decision-support tool for regulators (e.g., CAA, LFV, NATS, NHS) to evaluate safety before technology deployment
- Generate safety requirements that act as evidence for ensuring safe human–automation interaction and effective governance within complex systems.

Overall, this research will contribute an STPA-based framework that supports safer, more transparent, and accountable technology adoption in safety-critical infrastructure.



Thank You – Questions

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