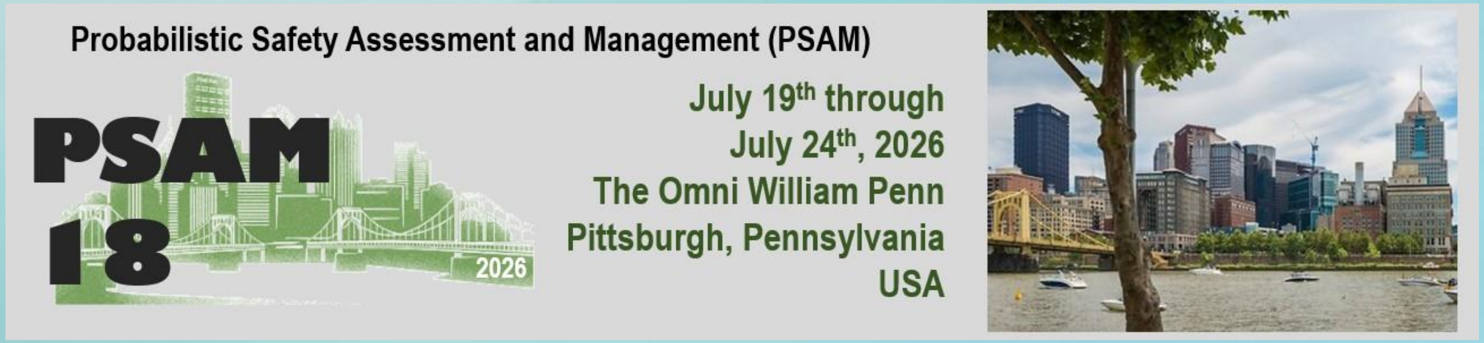
Carnegie Mellon University



Multi-Modal Data Analytics for Predictive Human-AI Collaboration in Civil Infrastructure Systems

- Lessons from Bridges, Flooding, Nuclear Operations, and Air Traffic Control for Safer Engineered Systems

Pingbo Tang

Department of Civil and Environmental Engineering

Carnegie Mellon University

Why this talk now? – Bridge Risk Management

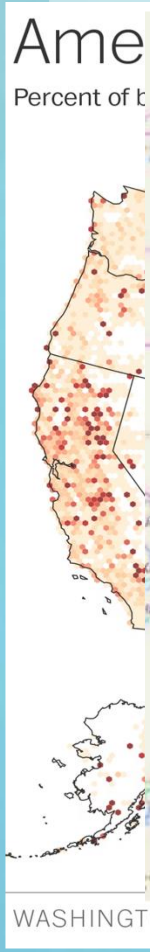
- 111 vehicles destroyed, 13 people died and 145 were injured, the Interstate 35W bridge over the Mississippi River on August 1, 2007

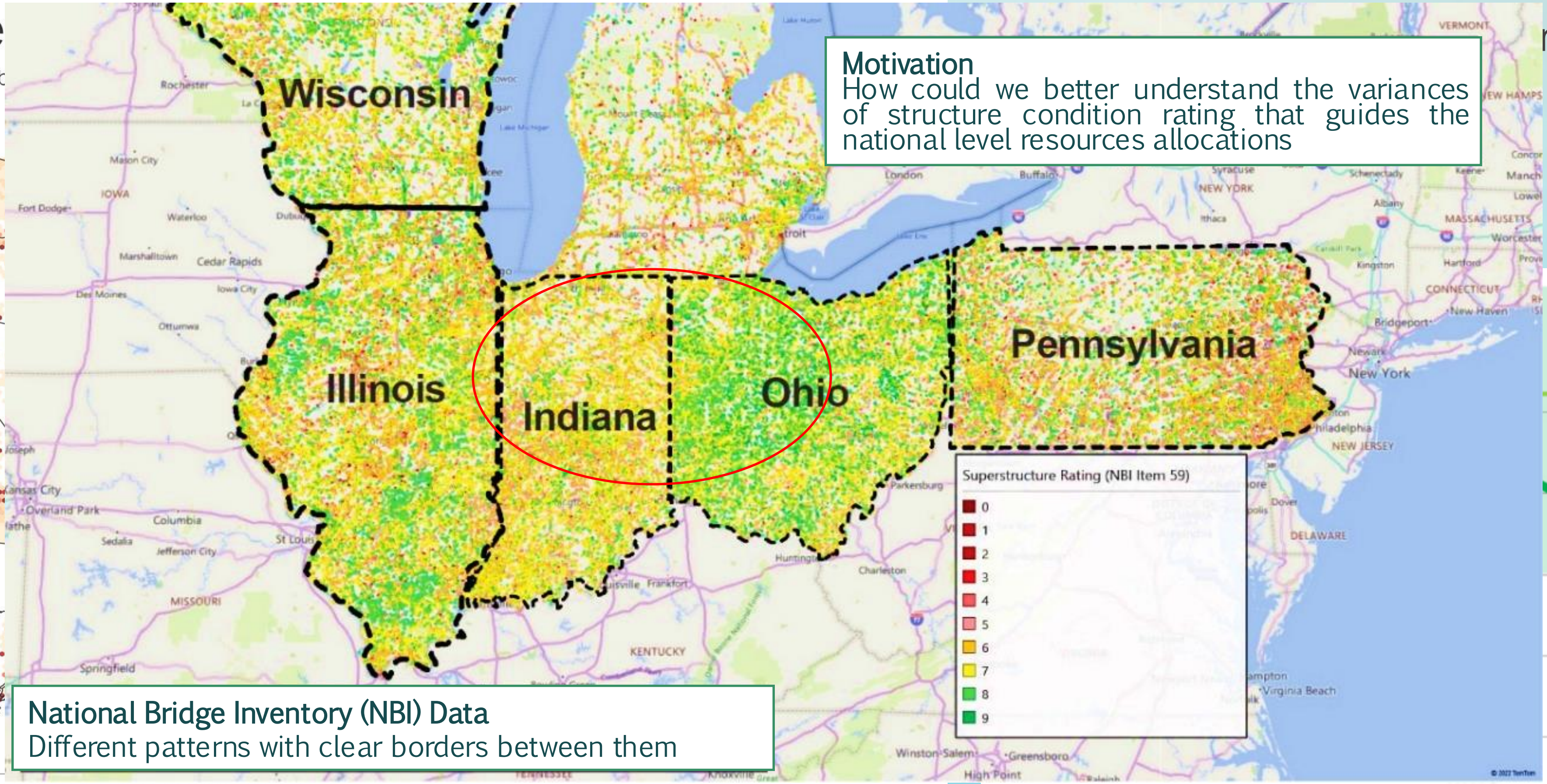
Baltimore Key Bridge, Maryland, US, March 26, 2024

Fern Hollow Bridge in Pittsburgh, PA, US, Jan 28, 2022

Why this talk now? – Bridge Risk Management

National-level Resources Allocation For Inspection and Retrofits

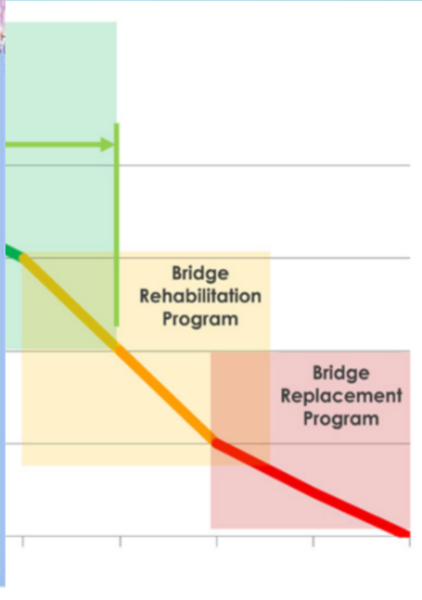




Motivation
How could we better understand the variances of structure condition rating that guides the national level resources allocations

National Bridge Inventory (NBI) Data
Different patterns with clear borders between them

Evaluation



A Comparison of Two Inspectors on the Same Bridge: Humans Can Bring Significant Uncertainties

- Different Strategies During Bridge Inspection — Experienced and Inexperienced

Human-Physical Systems

Virtual Bridge Inspection Environments

An Experiment Conducted with CMU Students

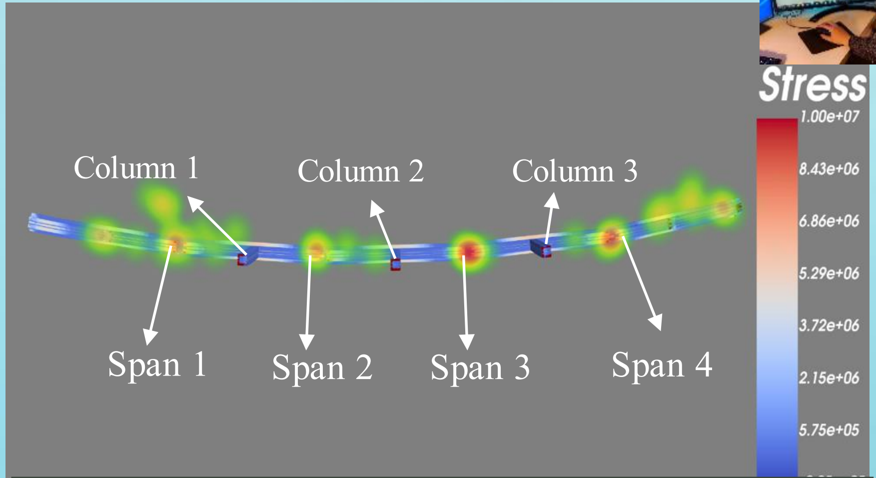
Humans having Different Backgrounds

The Same Bridge:

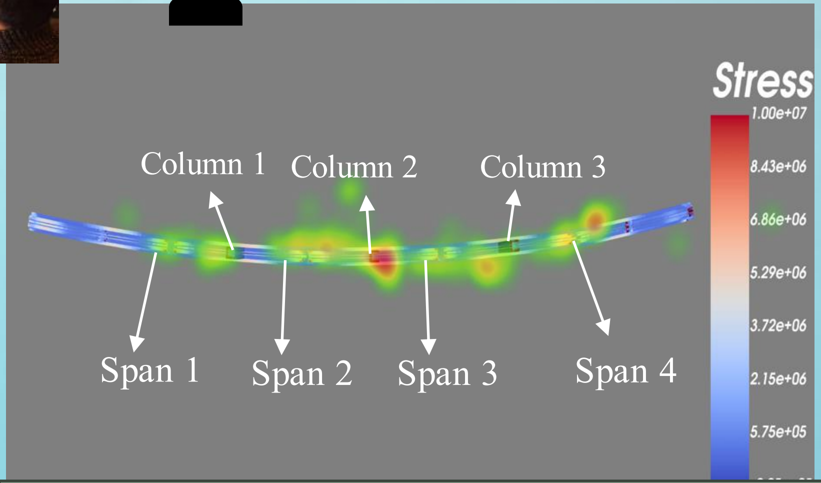
- Same environments
- Same defect locations

Not just students! 95% of condition ratings are questionable

Phares, B. M., Washer, G. A., Rolander, D. D., Graybeal, B. A., & Moore, M. (2004). Routine highway bridge inspection condition documentation accuracy and reliability. Journal of Bridge Engineering, 9(4), 403-413.



Structural Engineering Student



Transportation Engineering Student

Why Human-Machine Collaboration For Infrastructure

Human strength
- Handling tacit knowledge like physics-based reasoning
- Intuition in perceiving event correlations

Human weakness
- Intensive time and labor consumption
- Susceptibility to stress and bias
- Difficulties in managing large-scale systems

Machine strength
- Strong data analysis capabilities
- Automation capabilities

Machine weakness
- Challenges in utilizing tacit knowledge
- Hard to adapt to scenarios beyond training
- Ethical concerns in relying solely on AI that involve human lives

Humans learn by observation

Human biased in bridge inspection

Training scenarios

AI learn from demonstrations

AI Generalization

Why Human-Machine Collaboration For Infrastructure

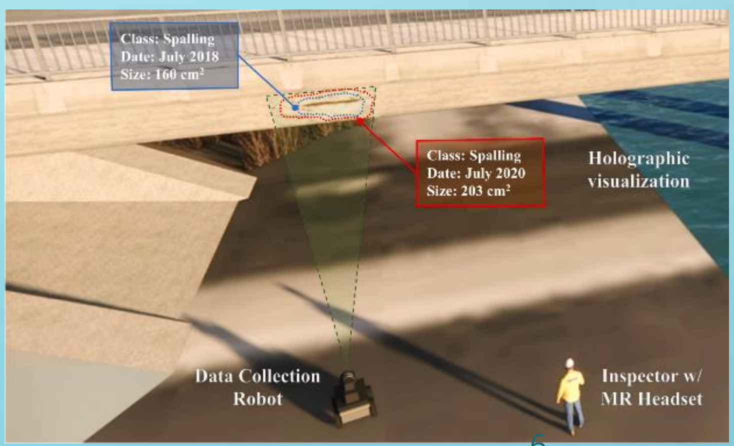
- **Physical degradation processes** - the diversity of contexts, the objects inspected, and the combination of defects and objects varying in time and space.
- **Condition assessment** - connecting these changing objects, defects, and their changes to the underlying physical deterioration patterns and mechanisms.

<u>Human</u>

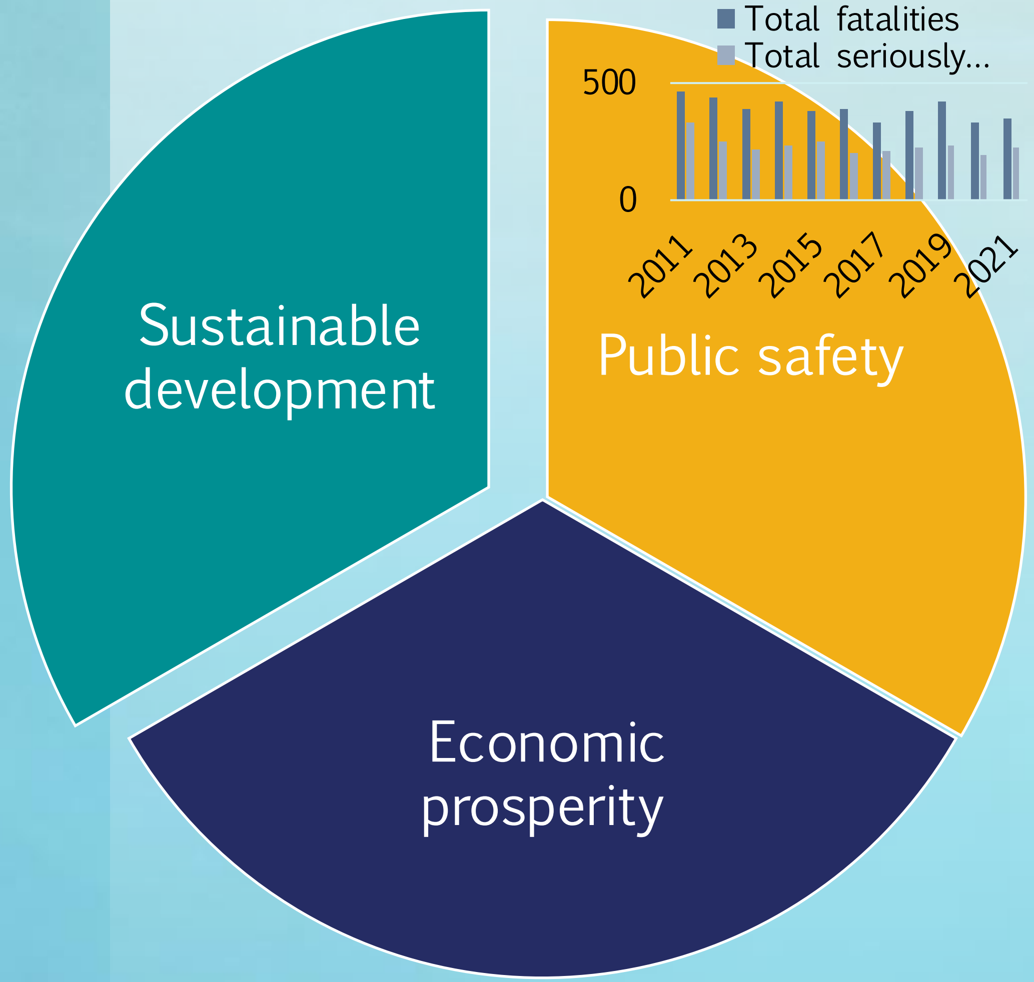
- Based on better local inspection behaviors, obtain a higher-quality overall picture
- Use physical knowledge and intuition to summarize the degradation mechanisms and hazard levels of the objects being inspected.

<u>Machine</u>

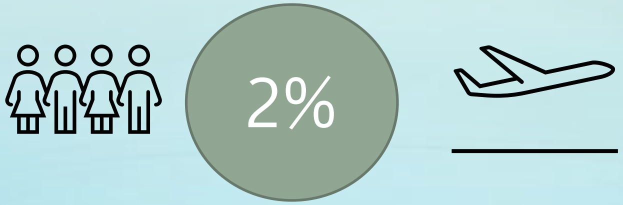
- Help humans correct local inspection behaviors



Another Example: Human-AI Collaborations to Explore Tradeoffs Among Many Objectives with Uncertainties

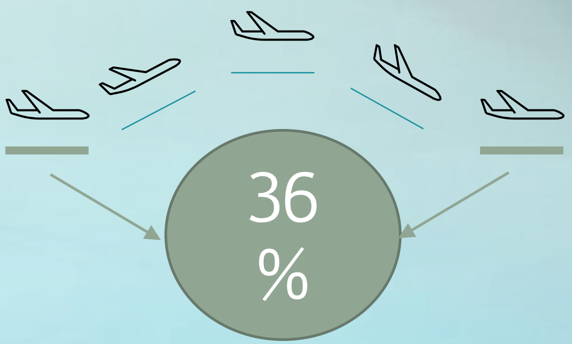


Air Traffic



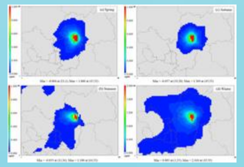
Carbon emissions [1]

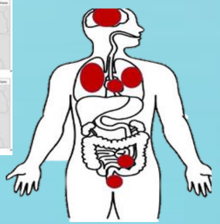
Ground operation



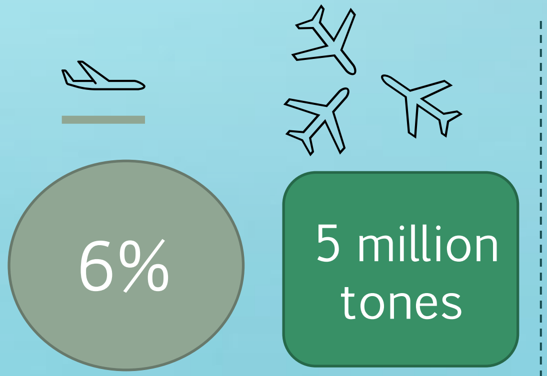
Fuel consumption [2]

Air pollution to the community





Congestion on ground

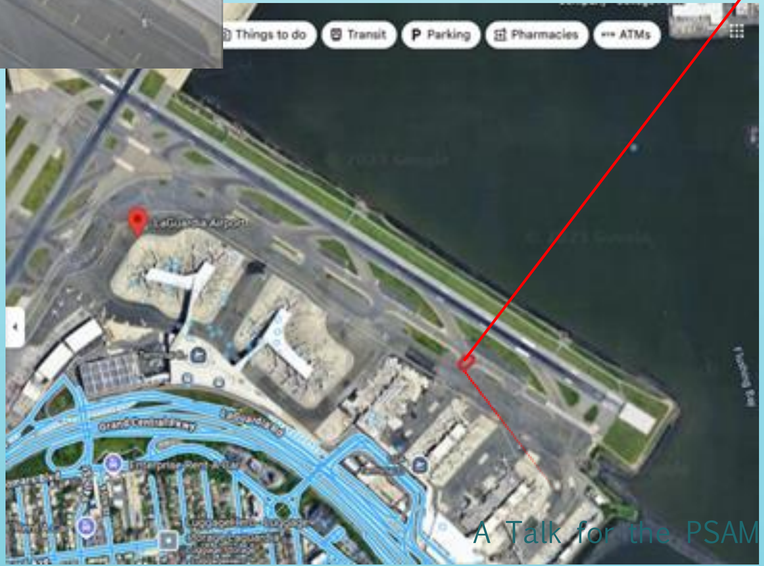


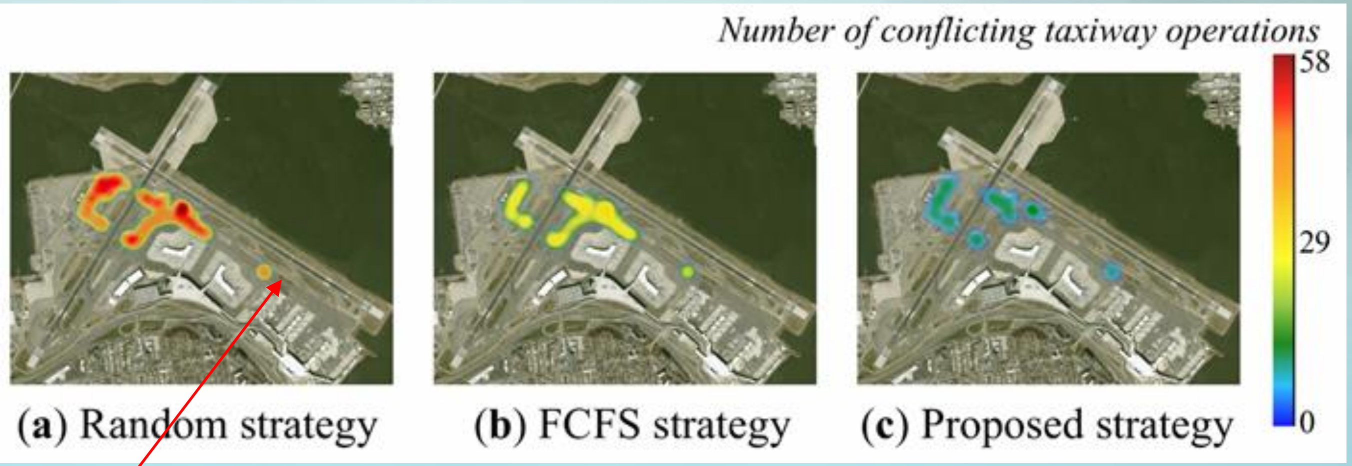
Fuel consumption [3,4]

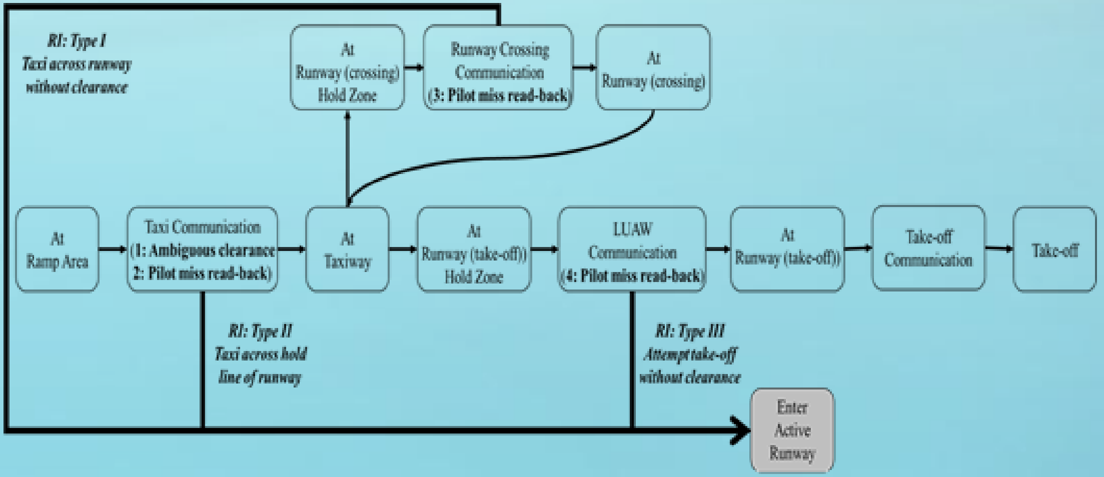
[1] M. Zhang, Q. Huang, S. Liu, and H. Li, "Assessment method of fuel consumption and emissions of aircraft during taxiing on airport surface under given meteorological conditions," Sustainability, vol. 11, no. 21, p. 6110, 2019.
[2] M. Stettler, G. Koudis, S. Hu, A. Majumdar, and W. Ochieng, "The impact of single engine taxiing on aircraft fuel consumption and pollutant emissions," The Aeronautical Journal, vol. 122, no. 1258, pp. 1967-1984, 2018.
[3] [2] M. Stettler, G. Koudis, S. Hu, A. Majumdar, and W. Ochieng, "The impact of single engine taxiing on aircraft fuel consumption and pollutant emissions," The Aeronautical Journal, vol. 122, no. 1258, pp. 1967-1984, 2018.
[4] X. Wang, A. E. Brownlee, M. Weiszer, J. R. Woodward, M. Mahfouf, and J. Chen, "A chance-constrained programming model for airport ground movement optimisation with taxi time uncertainties," Transportation Research Part C: Emerging Technologies, vol. 132, p. 103382, 2021.

Delta Airline Incidents and Delays

[Animation Shows Moment Two Delta Planes Collide at LaGuardia Airport]







I should study more and verify these simulations – no conclusion yet. Talk to me if you can help me achieve that!

[Bayesian Network Modeling of Airport Runway Incursion Occurring Processes for Predictive Accident Control | SpringerLink]

A Comparison of Two Retired Controllers' Performance on the Same Flight Plan.

How do we support humans working in such dynamic environments?

Human-Physical Systems

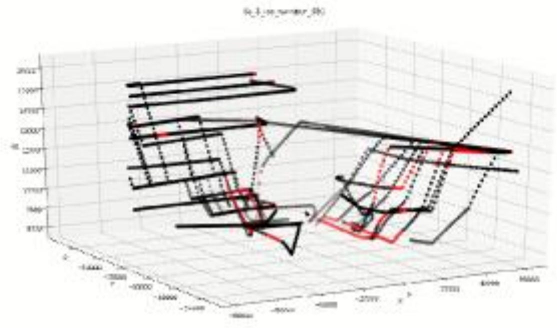
Physical Environments	Human

Same flight plan:

- Same arrival locations, schedules, and speed
- Same destination locations

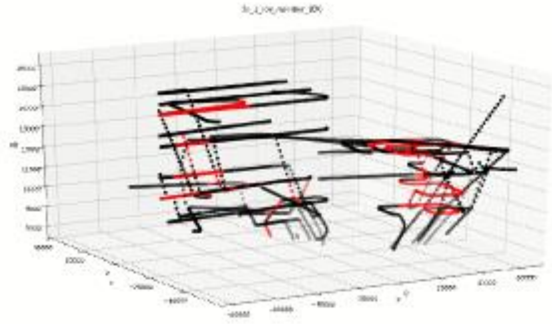
Air traffic controller 1

Number of LoS event: 389



Air traffic controller 2

Number of LoS event: 630



1.6 times loss of separation events

● : Location of aircraft

● : Location of loss of separation events – Safety risk indicators

* Acknowledgment:
Dr. Nancy Cooke, Dr. Sarah V. Ligda, Christopher Shane Lieber, Dr. Yongmin Liu with the NASA ULI program’s Task 3 to provide the data

Why Human-AI Collaboration in Air Traffic Control

Human-physical environment interactions

Human-Physical Systems

Physical Environments

Human

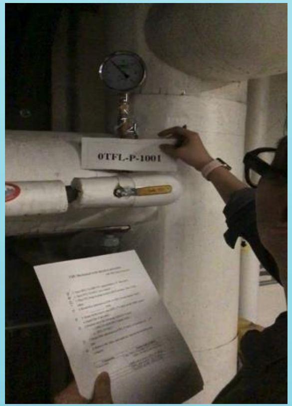
- Experience based operations
- Long-training time
- High workload

"…10 to 15% of Air Traffic Controllers are liable to suffer serious stress symptoms[1]."

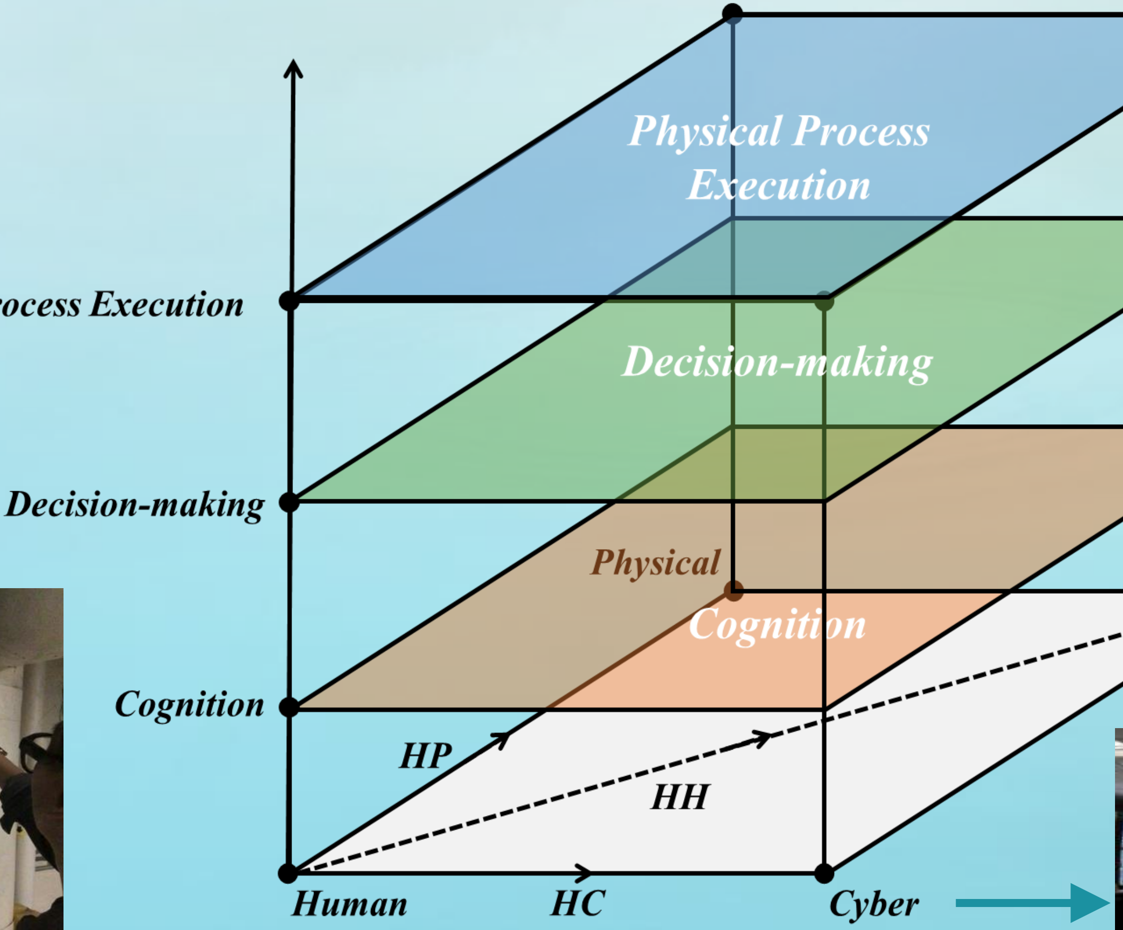
[1] Baumgartner, Marc. "Critical incident stress management in air traffic control." Trauma 1.4 (2001): 227-236.

Vision: Multi-Modal Data Analytics for Generating **“Virtual Labels”** in Videos and Real-Time Views of to Enable Human-AI Collaboration

Virtual labels for highlighting critical relationships between workspaces and their outage progresses

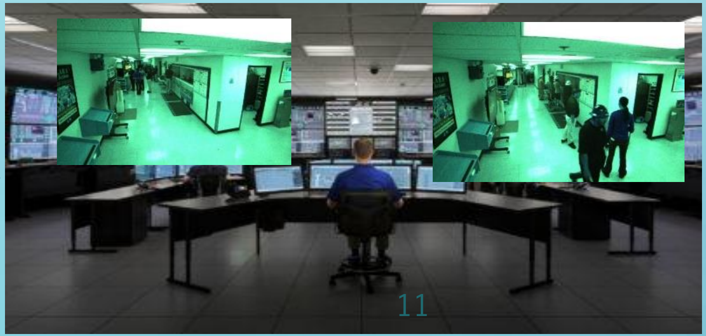


Virtual labels for highlighting critical objects and hazards that need the workers' attention

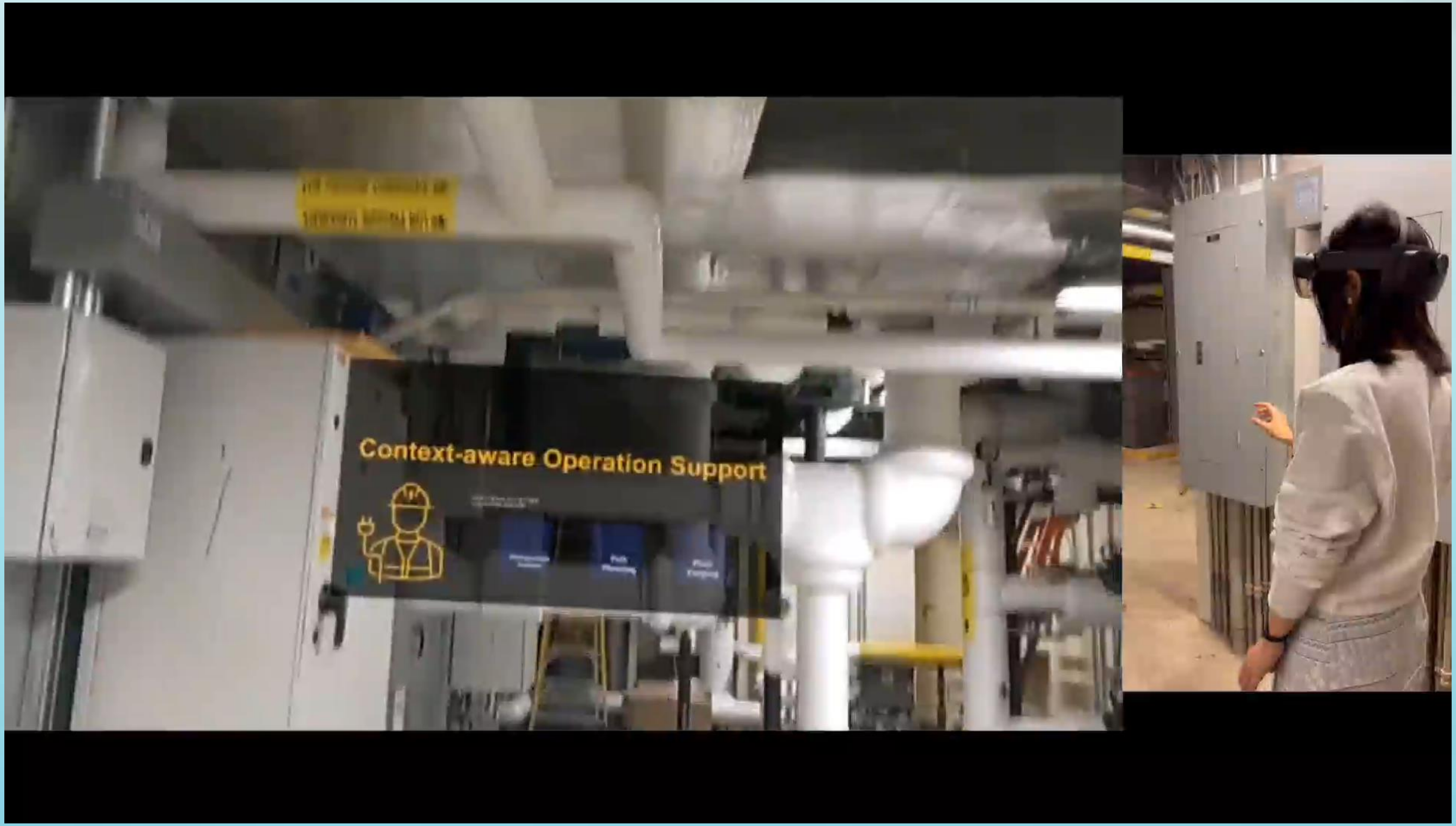


Virtual labels for highlighting target work location

Virtual labels for highlighting critical data and sensors that need actions

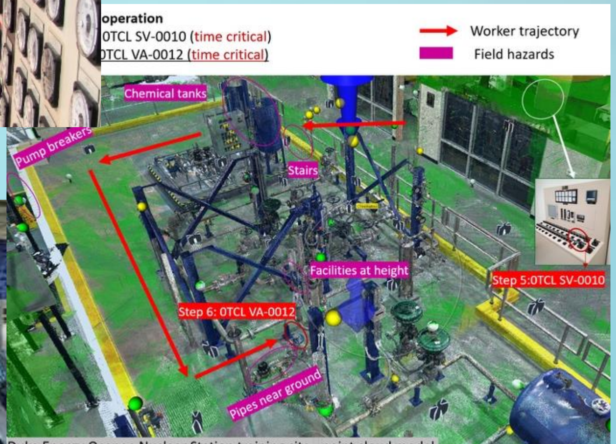


Virtual Label – A Demonstration Scenario



Capturing and Predicting Problematic Human AI Collaboration Parts

- Human-Physical Interactions (Field)
  - Field worker reliability problem
  - Using bridge inspection as an example
- Human-Cyber Interactions (Control Room)
  - Digital control reliability problem
  - Human data analytics for identifying anomalous behaviors of controllers, airport operation as an example
- Human-Human Interactions (Control Room-Field)
  - Communication reliability problem
  - Using nuclear power plant operations as an example



Duke Energy Oconee Nuclear Station training site - point cloud model.


http://www.scmp.com/news/asia/south-asia/article/2001820/air-traffic-controller-shortage-threatens-indian-airline-boom

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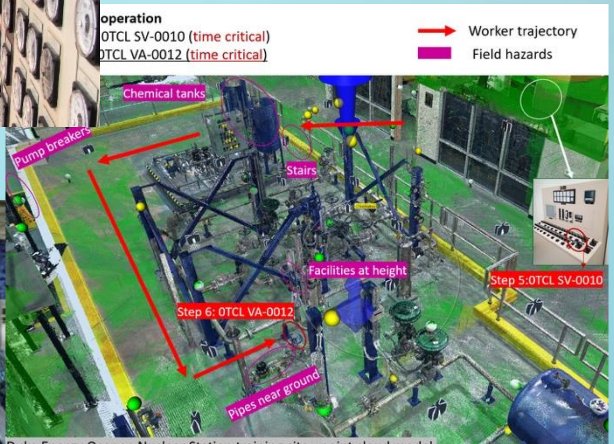

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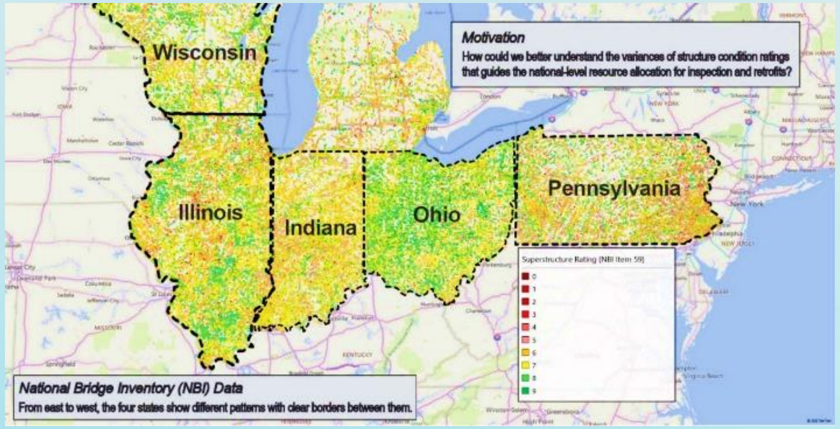
Human-Cyber-Physical Systems for Reliable Inspection

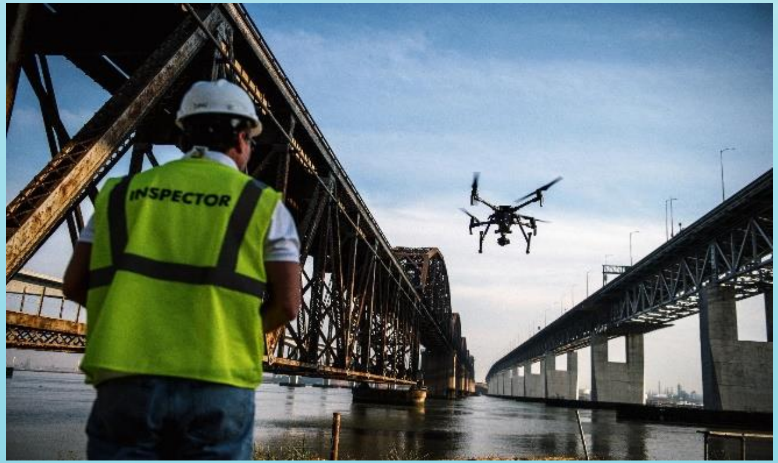
Cyber Systems (AI & Robots)

Human-Machine Control

Physical Systems



Cyber Infrastructure for Data Analytics



Physical Infrastructure Inspection

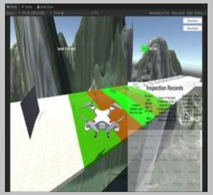
Human-AI Interactive Cyber-Physical Alignment for Reliable Inspection?

How do we do it?

Objective 1

Cyber-Physical Environments Interactions

- Digital twin and related capturing method to represent inspector behavior

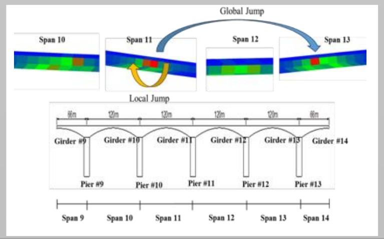


Inspection Process Data →

Objective 2

Human-Cyber Environments Interactions

- Causal discovery for inspection strategy

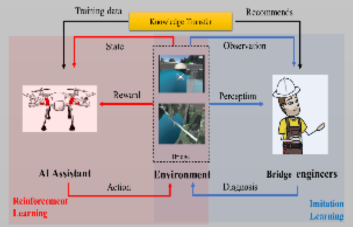


Explainable Inspection Strategies →

Objective 3

Human-Machine-Cyber Environments Interaction

- Exploring human-machine collaboration for stabilizing inspection results.

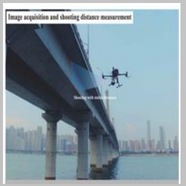


Human-Machine Recommendation →

Objective 4

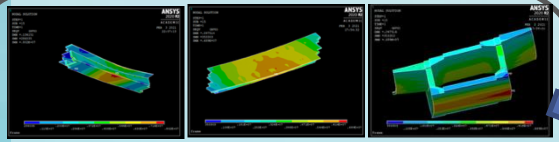
Human-Physical Environments Interactions

- Sim-to-Real transfer in bridge inspection

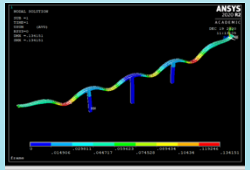


Step 1: Cyber-Physical Environments Interactions

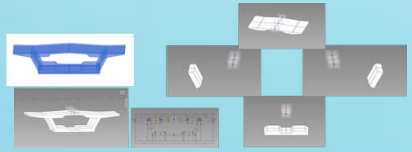
Gamification of Bridge Inspection



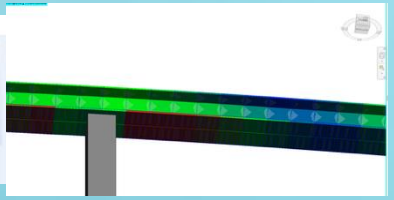
- Element positions(X, Y, Z)
- Element displacements and stress



Ansys APDL

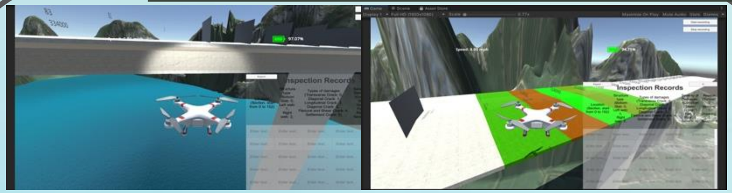


- Geometrical information

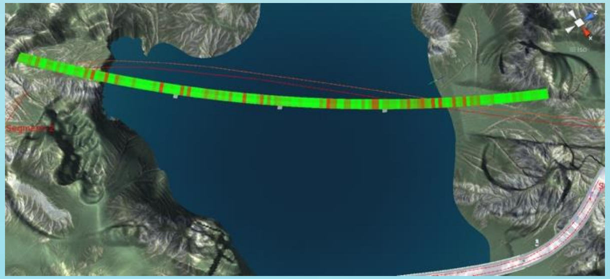


Revit

Computer Vision, Natural Language Processing



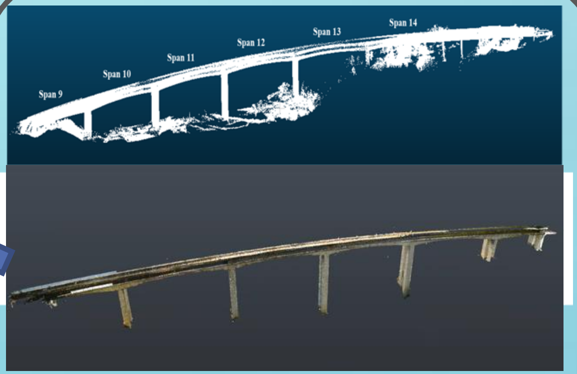
- **Element Surfaces, Element Properties**



Unity Game Engine

- **Crack images and locations**

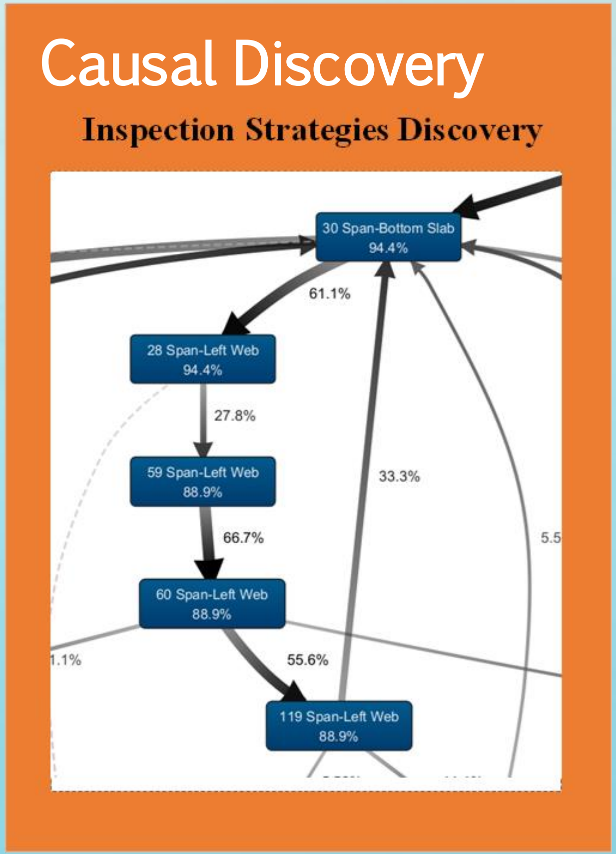
Inspection Reports



Point Clouds

Step 2: Human-Cyber Environments Interactions

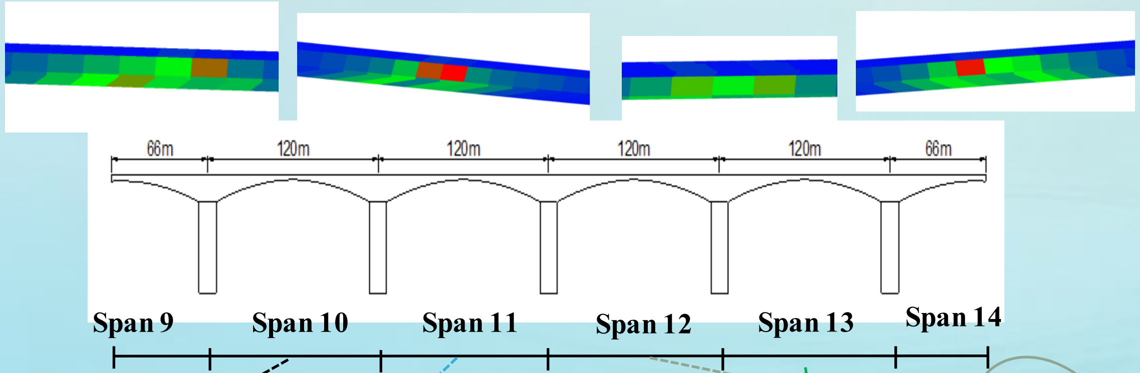
- A digital twin for collecting inspector behavioral logs
- Causal discovery for discovering inspectors' inspection strategies



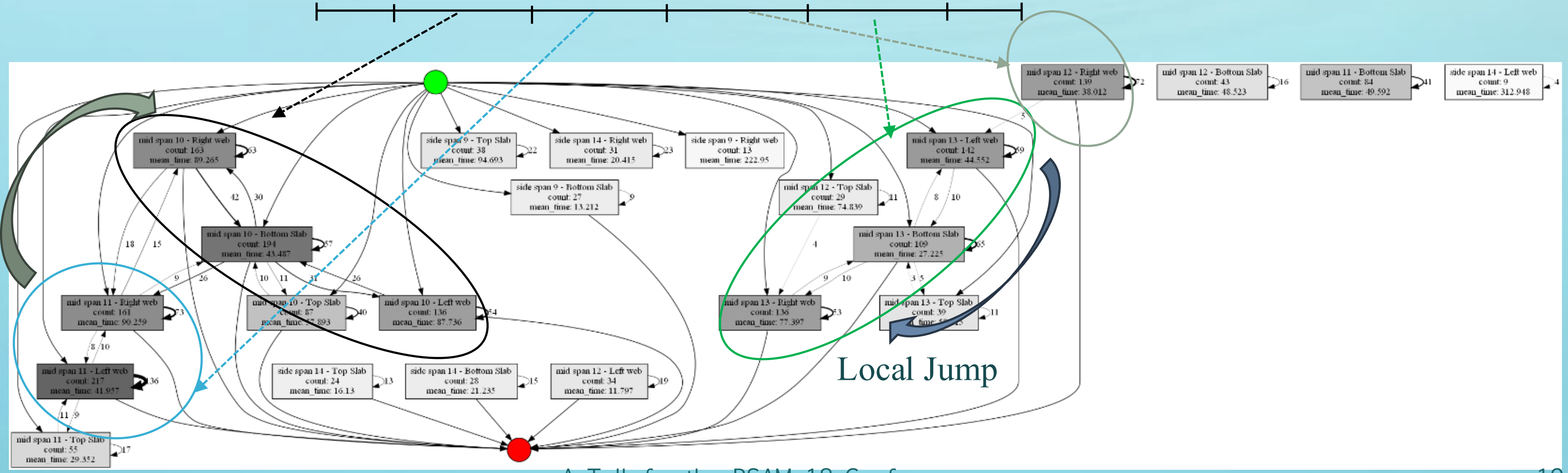
Step 2: Human-Cyber Environments Interactions

- Classify inspectors into low, middle, and high levels based on accuracy performances
- Discover the inspection strategies of **high-performance** inspectors

Low Middle High
Defect Possibilities based on FEM

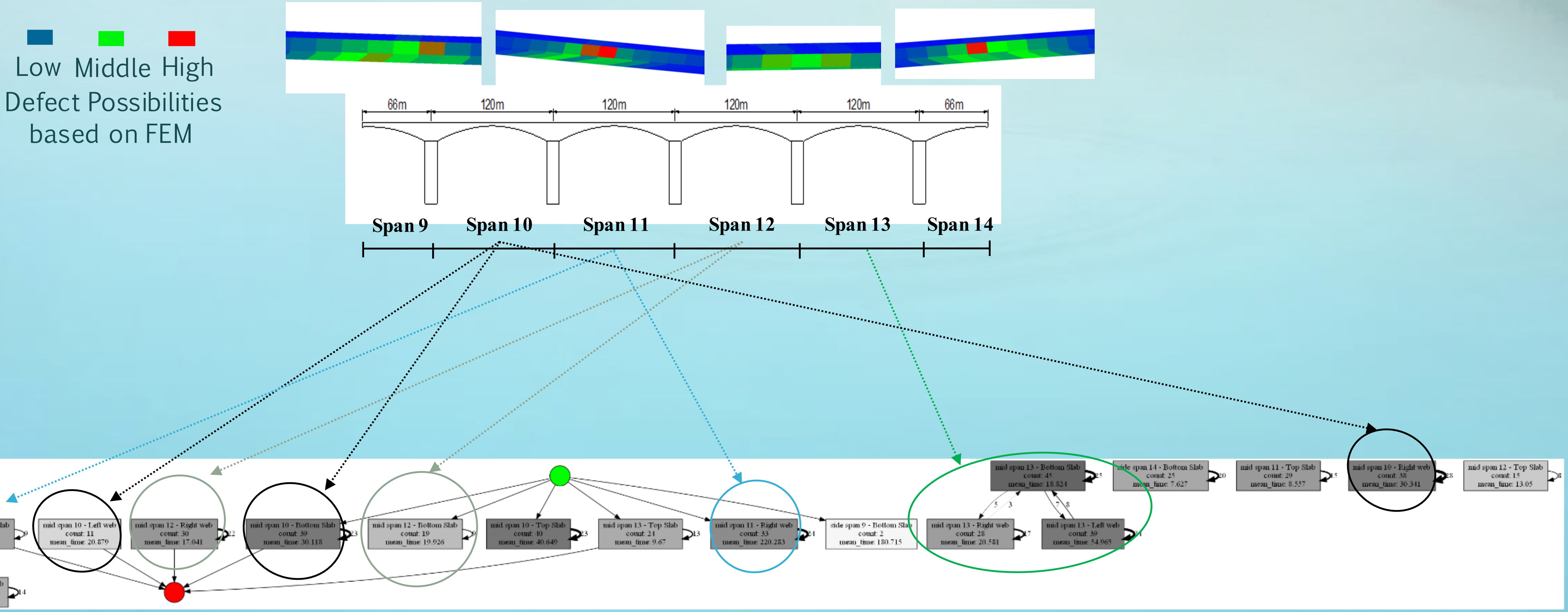


Global Jump

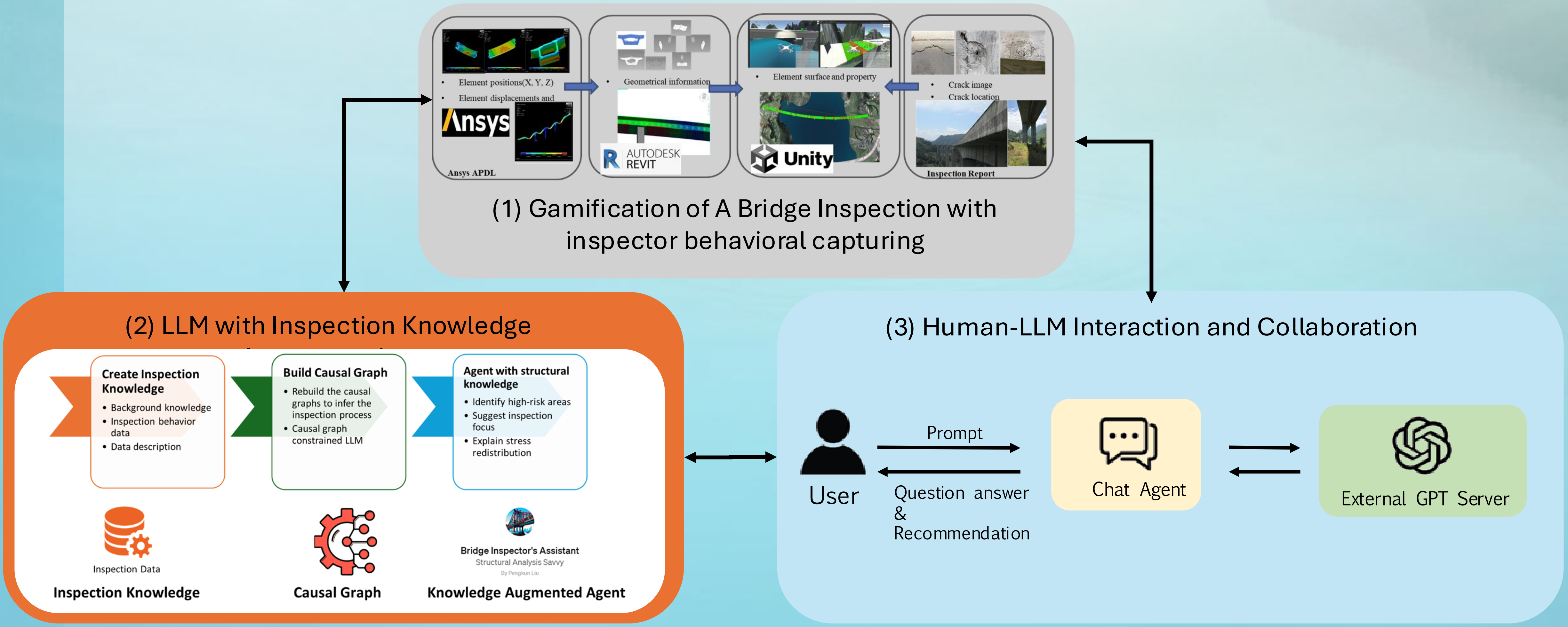


Step 2: Human-Cyber Environments Interactions

- **Low-performance inspectors**
- Lack of both local and global jumps (more dispersed due to unordered searching)



Step 3: Human-AI Collaboration



Explaining Inspection Behaviors and Diagnosis Results for Human –AI Collaboration in Bridge Inspection

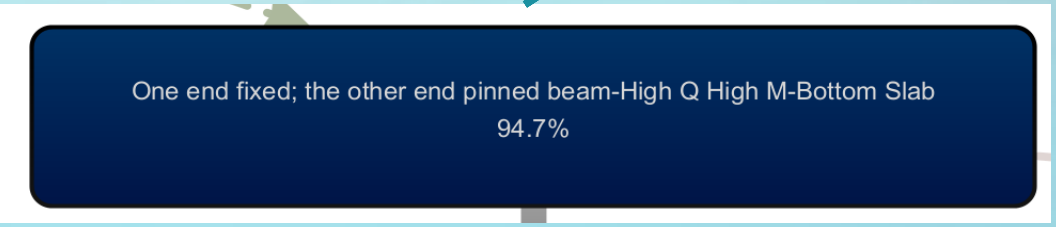
Inspection Knowledge

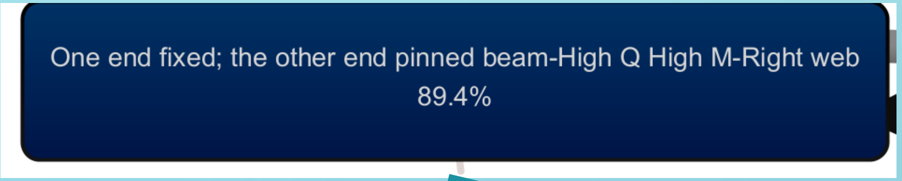
- Component type - internal forces – defect types
- Evaluation (condition rating) of the component with defect

Diagnosis Results

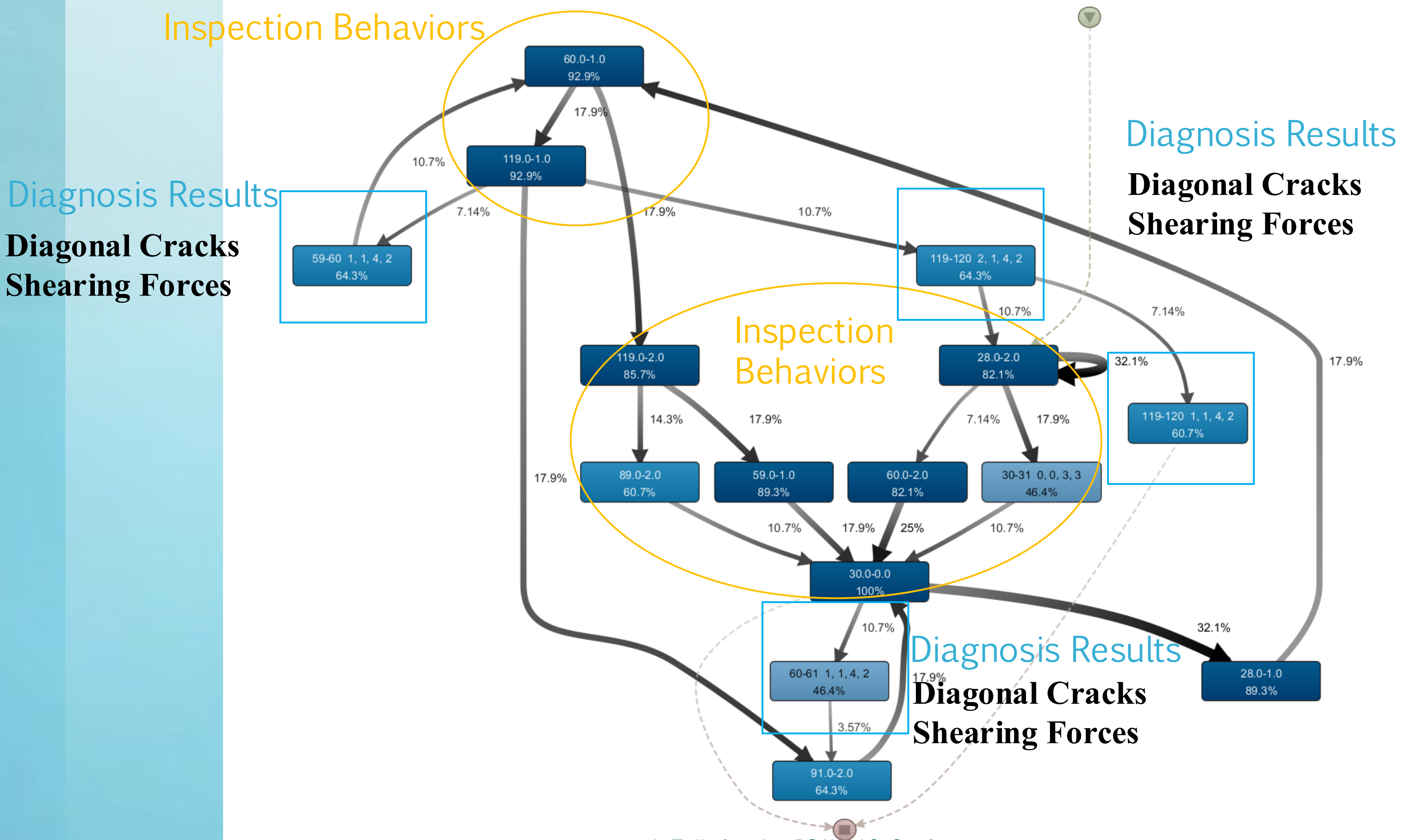
Transverse Cracks
Tension

Inspection Behaviors





Diagonal Cracks
Shearing Force


Inspection Behaviors
60.0-1.0
92.9%
17.9%
119.0-1.0
92.9%
10.7%
Diagnosis Results
Diagonal Cracks
Shearing Forces
7.14%
17.9%
10.7%
59-60 1, 1, 4, 2
64.3%
119-120 2, 1, 4, 2
64.3%
Diagnosis Results
Diagonal Cracks
Shearing Forces
10.7%
7.14%
Inspection
Behaviors
119.0-2.0
85.7%
28.0-2.0
82.1%
32.1%
17.9%
14.3%
17.9%
7.14%
17.9%
119-120 1, 1, 4, 2
60.7%
17.9%
89.0-2.0
60.7%
59.0-1.0
89.3%
60.0-2.0
82.1%
30-31 0, 0, 3, 3
46.4%
10.7%
17.9%
25%
10.7%
30.0-0.0
100%
10.7%
32.1%
Diagnosis Results
60-61 1, 1, 4, 2
46.4%
17.9%
Diagonal Cracks
Shearing Forces
28.0-1.0
89.3%
3.57%
91.0-2.0
64.3%

Capturing and Predicting Problematic Human AI Collaboration Parts

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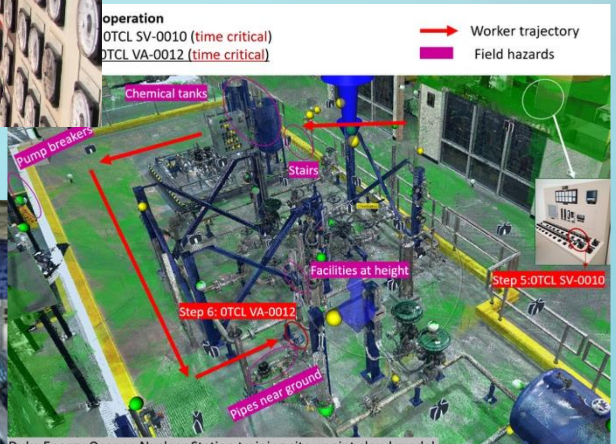


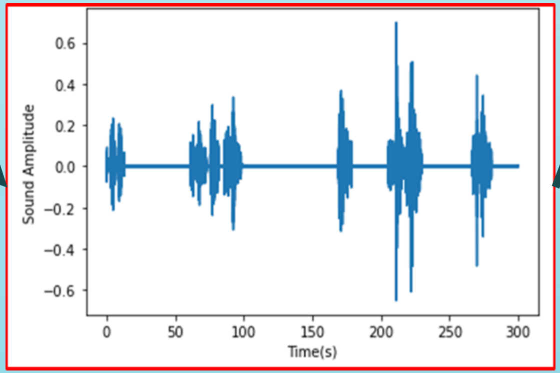
Duke Energy Oconee Nuclear Station training site - point cloud model.


http://www.scmp.com/news/asia/south-asia/article/2001820/air-traffic-controller-shortage-threatens-indian-airline-boom

Air Traffic Control Behavior for Predicting Control Failures

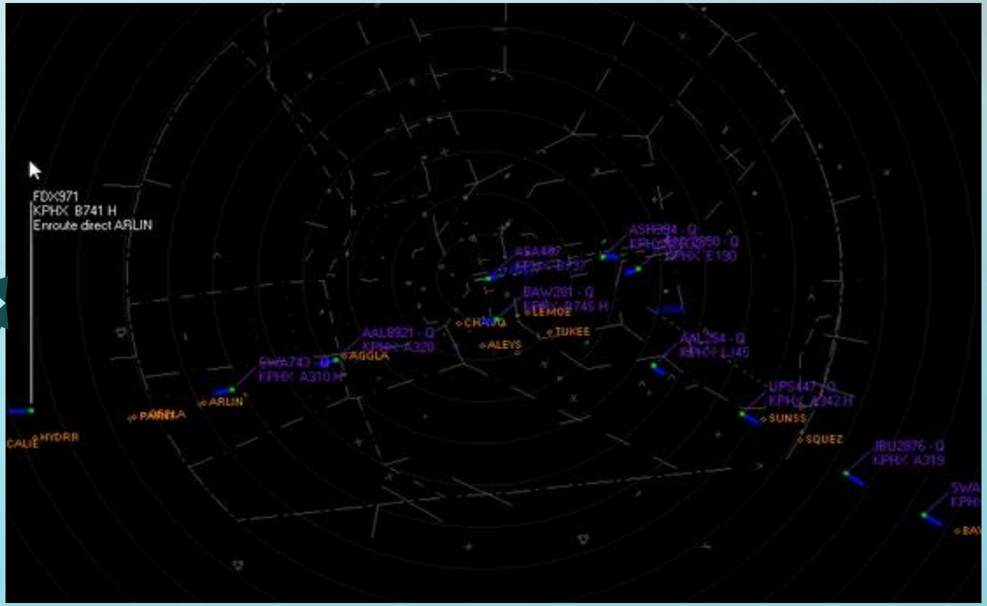
Air Traffic Controllers (ATCs)

Facial expressions/ Head poses



Talking behaviors

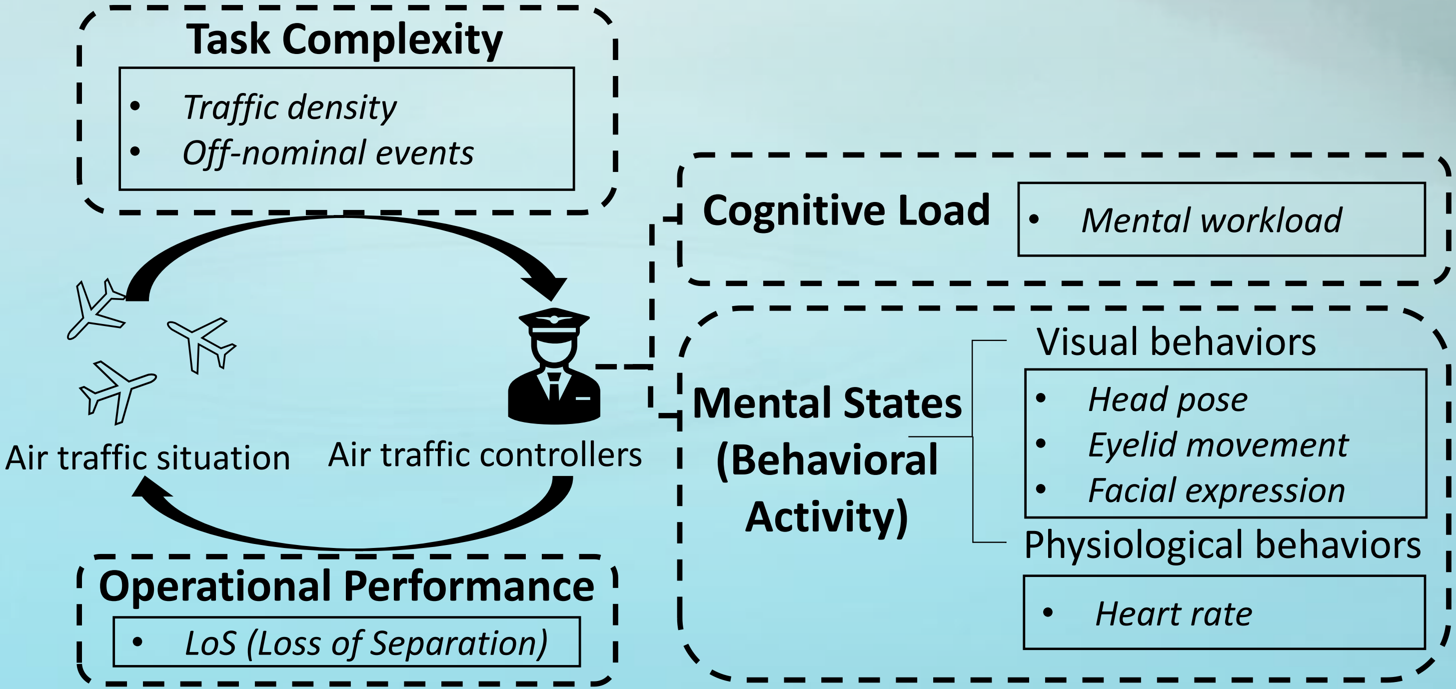
Aircraft trajectories



- Behaviors of ATCs that could be indicators of abnormal aircraft trajectories.
- Timely recognizing these abnormal ATC behaviors could help prevent loss of separation between aircraft.

What to Capture and Analyze?

Air Traffic Controllers (ATCs)

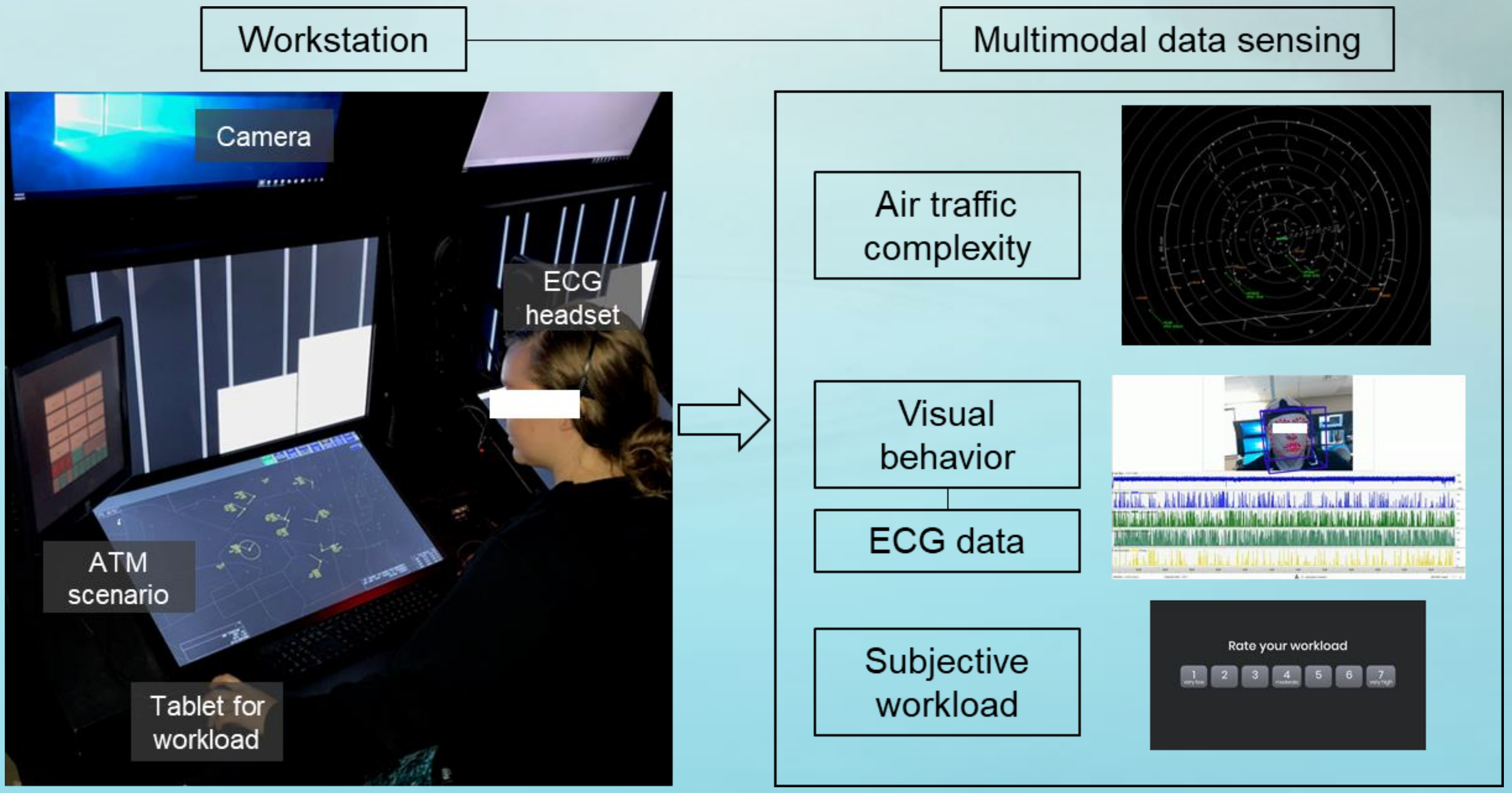


- Behaviors of ATCs that could be indicators of abnormal aircraft trajectories.
- Timely recognizing these abnormal ATC behaviors could help prevent loss of separation between aircraft.

Experiment Design and Data Collection

Multimodal data sensing

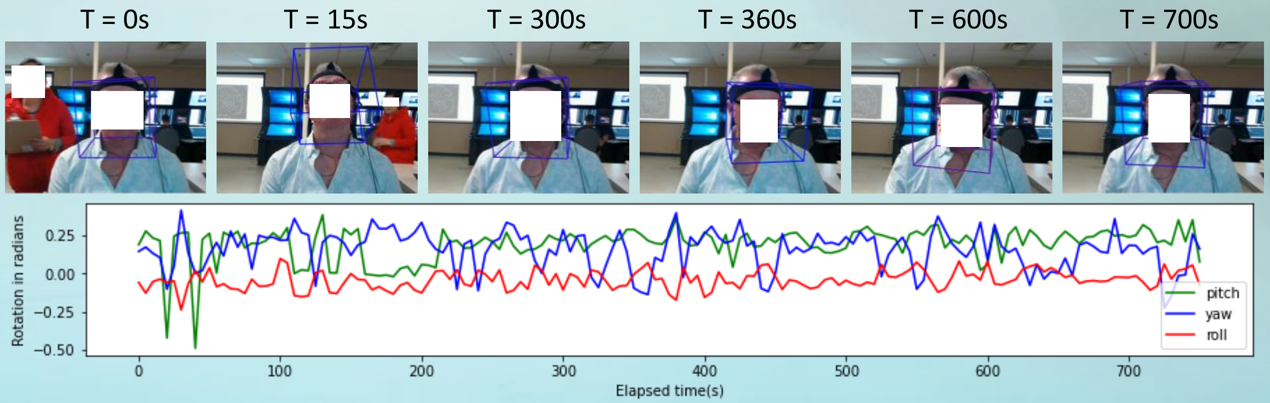
- **Simulator tracklog**
- **Video data**
  - ❑ Head pose
  - ❑ eye movement
  - ❑ facial expression
- **ECG data**
  - ❑ Heartbeat interval
- **Workload probes**

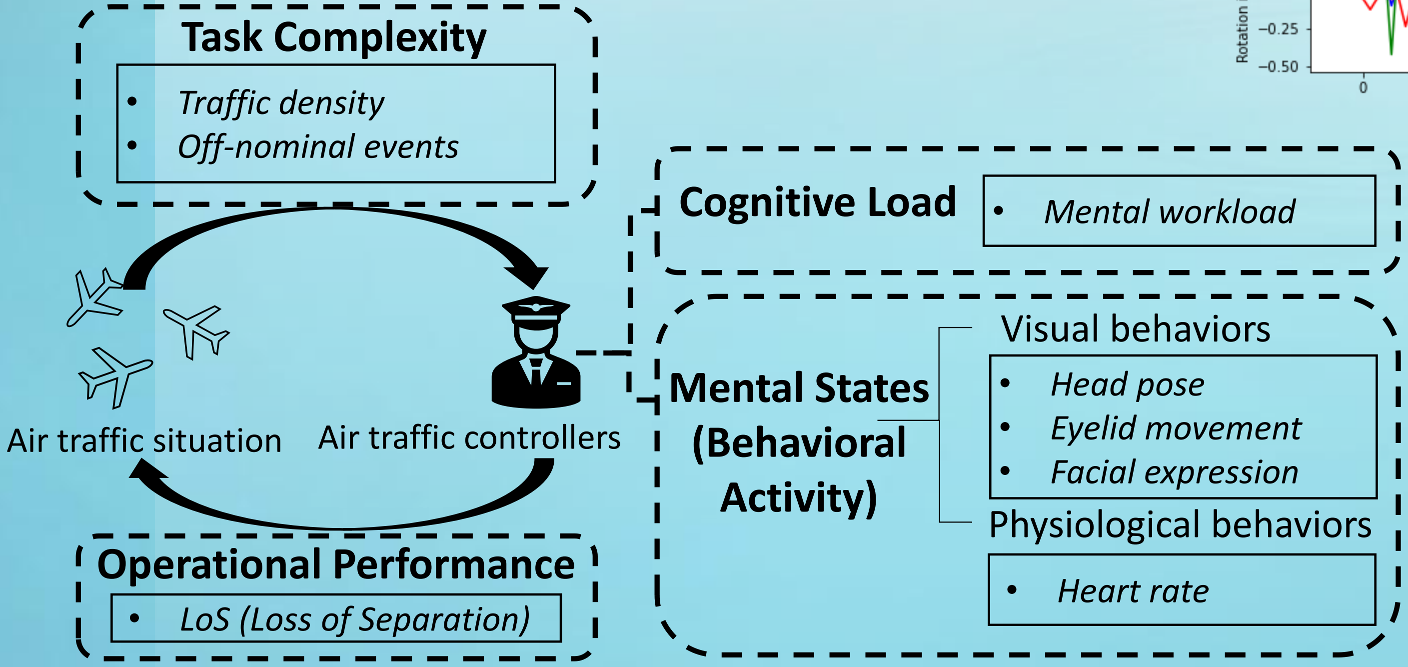


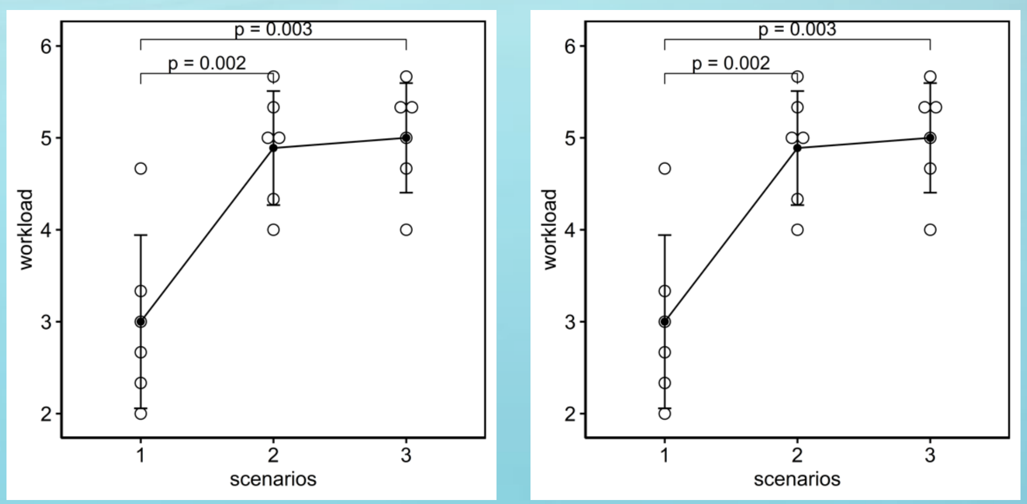
Controllers’ Separation Error Prediction

Multi-factorial model for controllers’ separation errors

Xiong, R., Wang, Y., Tang, P., Cooke, N. J., Ligda, S. v., Lieber, C. S., & Liu, Y. (2023). Predicting separation errors of air traffic controllers through integrated sequence analysis of multimodal behaviour indicators. Advanced Engineering Informatics, 55, 101894. https://doi.org/10.1016/J.AEI.2023.101894







*1=baseline scenario, 2=nominal scenario, 3=off-nominal-scenario

Controllers' Separation Error Prediction

Results and evaluation

- Using multimodal features could improve prediction performance
- Visual behavioral cues are sufficient and necessary for predicting controllers' separation errors

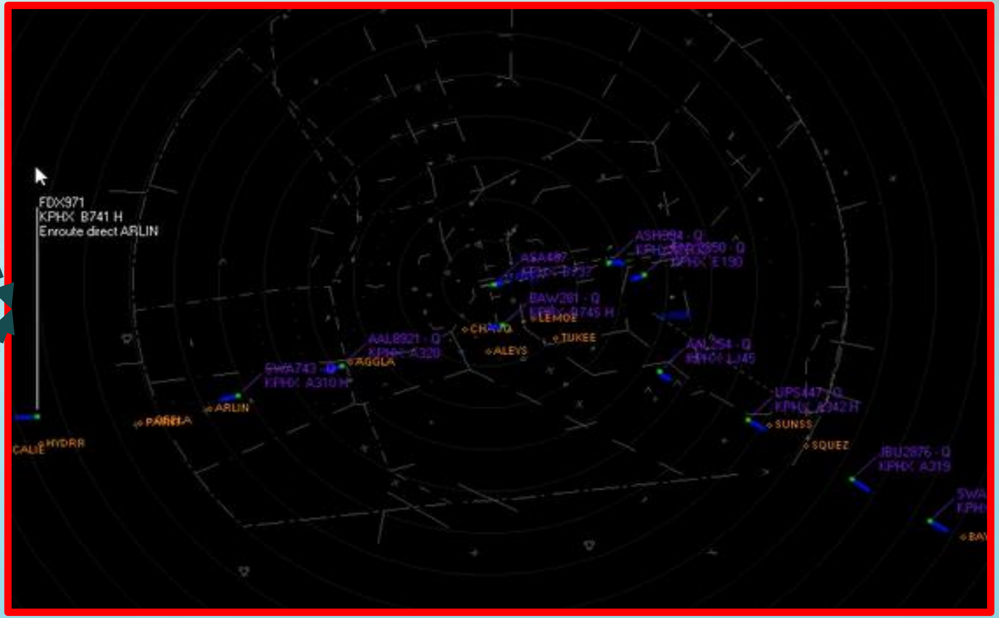
Models	2 steps	5 steps	8 steps	10 steps
$F_{head, eye, face}$	89.17 ± 0.88%	84.80 ± 1.89%	81.94 ± 1.23%	78.79 ± 1.97%
$F_{task, head}$	89.49 ± 1.29%	85.75 ± 1.32%	82.39 ± 2.06%	79.88 ± 1.43%
$F_{task, head, face}$	91.11 ± 0.50%	86.81 ± 0.88%	83.94 ± 1.46%	81.13 ± 1.32%
$F_{task, head, eye, face}$	**91.48 ± 0.87%**	87.55 ± 1.53%	84.70 ± 1.62%	82.13 ± 1.91%
$F_{task, ibi}$	86.26 ± 1.87%	80.94 ± 2.14%	77.05 ± 2.33%	74.79 ± 1.32%
$F_{task, head, eye, face, ibi}$	91.45 ± 0.81%	**87.63 ± 0.87%**	**85.20 ± 1.09%**	**83.20 ± 1.69%**

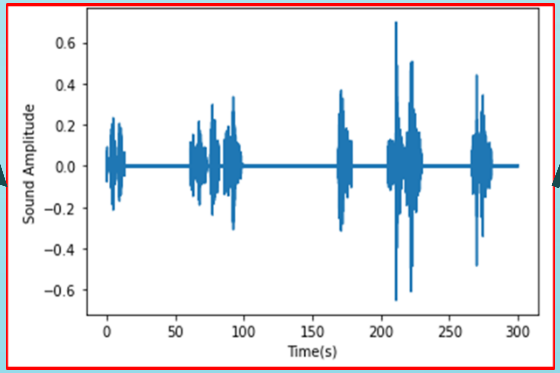
Within Air Traffic Complexity – Recognizing Routes from Navigation Signals, and Predict Trajectories

Facial expressions/
Head poses

Air Traffic Controllers
(ATCs)

Aircraft trajectories



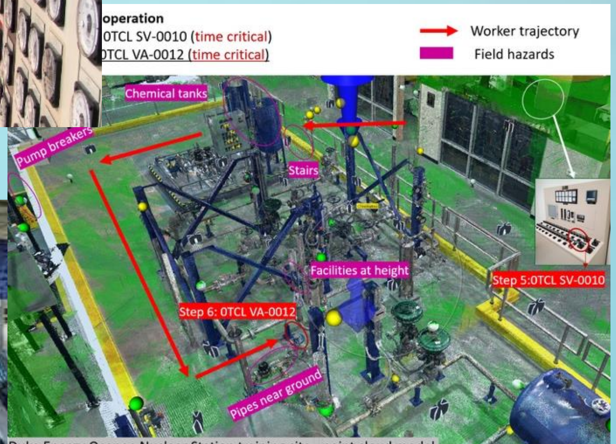


Talking behaviors

- Behaviors of ATCs that could be indicators of abnormal aircraft trajectories.
- Timely recognizing these abnormal ATC behaviors could help prevent loss of separation between aircraft.

Capturing and Predicting Problematic Human AI Collaboration Parts

- Human-Physical Interactions (Field)
  - Field worker reliability problem
  - Using bridge inspection as an example
- Human-Cyber Interactions (Control Room)
  - Digital control reliability problem
  - Human data analytics for identifying anomalous behaviors of controllers, airport operation as an example
- Human-Human Interactions (Control Room-Field)
  - Communication reliability problem
  - Using nuclear power plant operations as an example



Duke Energy Oconee Nuclear Station training site - point cloud model.

http://www.scmp.com/news/asia/south-asia/article/2001820/air-traffic-controller-shortage-threatens-indian-airline-boom

Field and Remote Operation of Nuclear Power Plants

NEUP Nuclear Energy University Program
U.S. Department of Energy

Predefined lists of information that need to be verified or collected

Inaccurate

Communicate/ report the collected information

Field operator

Control room operator

Human errors, miss critical information
or collect wrong information

Operator rounds - Collect information
e.g., Component status, Temporary modifications in the field

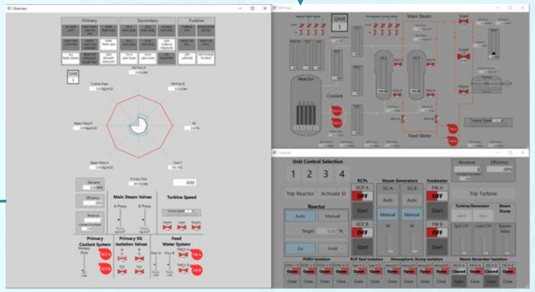
Control decision making and execution

Sensor data are not reliable, some information can't be captured by sensors

Information collected by field sensors

Control signals

Nuclear plant field



Control room

Field and Remote Operation of Nuclear Power Plants

Field operator

Inaccurate

Control room operator

Use control histories to generate contextual information lists that need to be verified before task executions (**field observations, computer vision**)

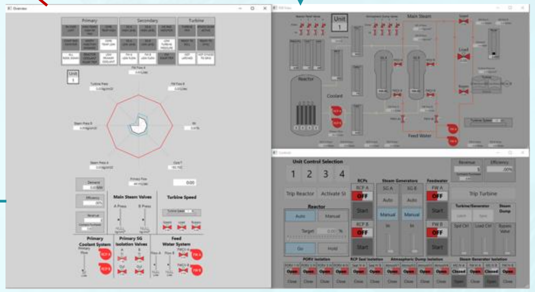
Control decision making and execution

Operator rounds - Collect information

Information collected by field sensors

Control signals

Nuclear plant field

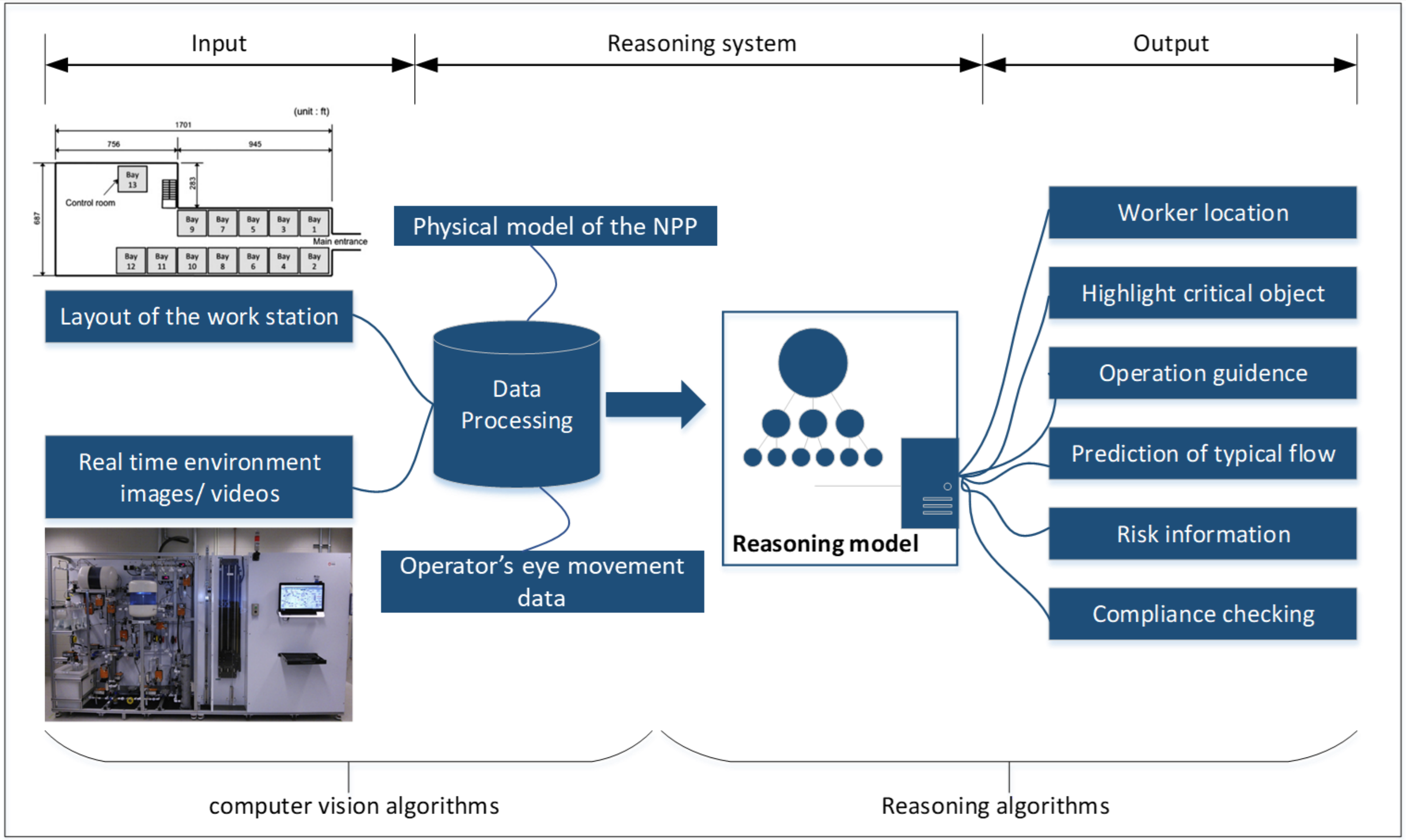


Control room

Intelligent Context-Aware Safety Information Display

NEUP Nuclear Energy University Program
U.S. Department of Energy

Field operator



Control room operator

A conceptual framework of the "Intelligent Context-Aware Safety Information Display" (ICAD) system

How to Achieve Context-Aware Safety Information Display for Nuclear Field Workers?

NEUP Nuclear Energy University Program
U.S. Department of Energy

Context-Aware Safety Information Display for Nuclear Field Workers

Objectives

- The developed display should integrate the real-time overlay of physical workspaces with maintenance processes and safety information visually displayed through Augmented Reality (AR) glasses.
- The purpose of the display is to assist and guide field workers in assessing workspace risks, locating task-relevant objects, and carrying out the tasks in the correct order in a safe manner.

Research areas

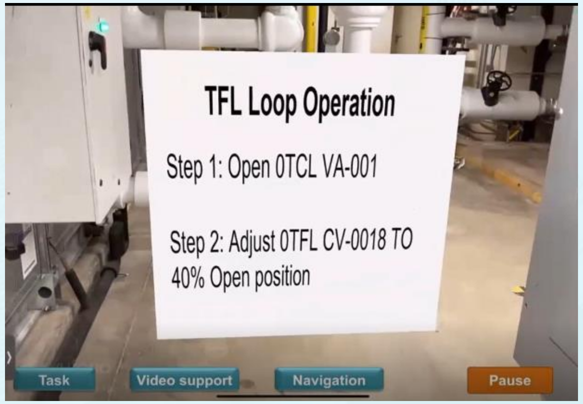
Human Reliability | Work Process Modeling | Operational Safety

Major techniques

Sensor Log Analysis | Survey and Interview | Natural Language Processing | Computer Vision | Augmented Reality

Outcomes

- Document and publish research progress in peer-reviewed journals
- Delivery of AR Glasses with context-aware safety information display functions



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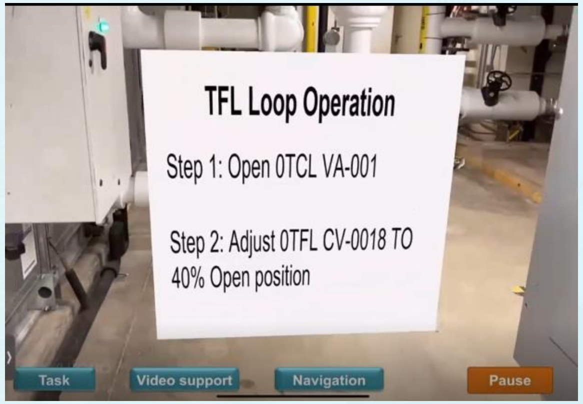

Why Sensor Logs are Not Enough and Human Judgment Is Inevitable?

- **Not all situations can be predefined or automated**

- Automation has reduced errors in many high-risk industries.
  •But it cannot handle every scenario.

- **Nuclear power plants are deeply intertwined systems** involving technical elements, procedures, sensors, and people.

- In such environments, **some conditions remain ill-defined**, making human judgment essential.

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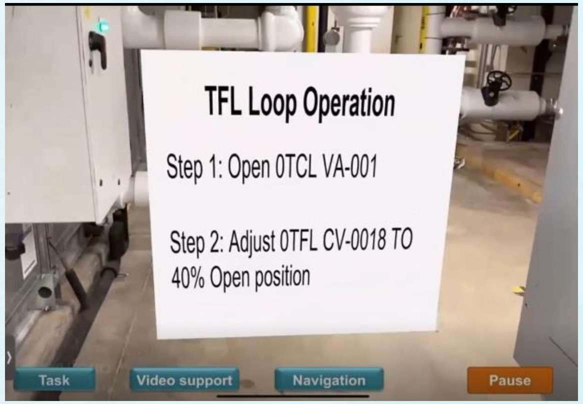
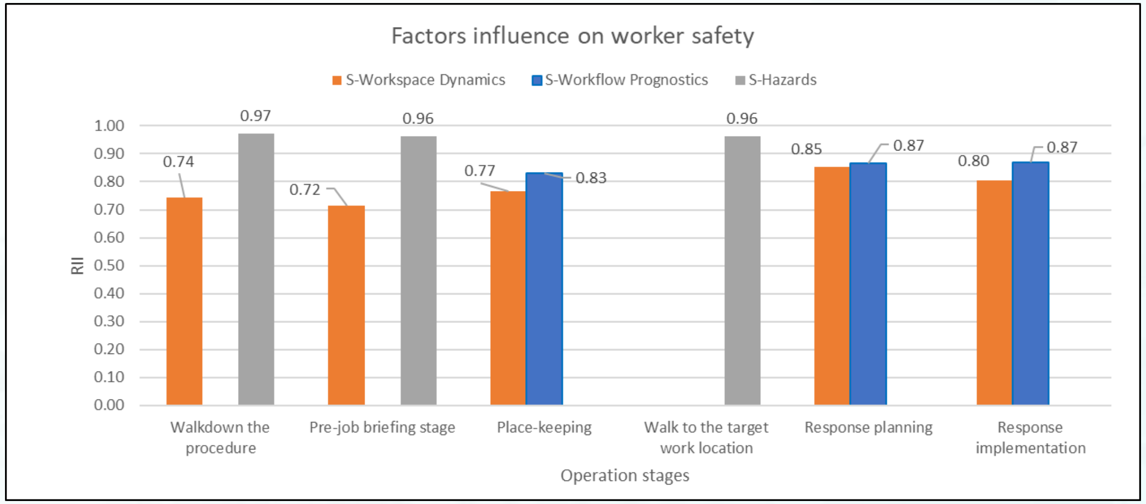
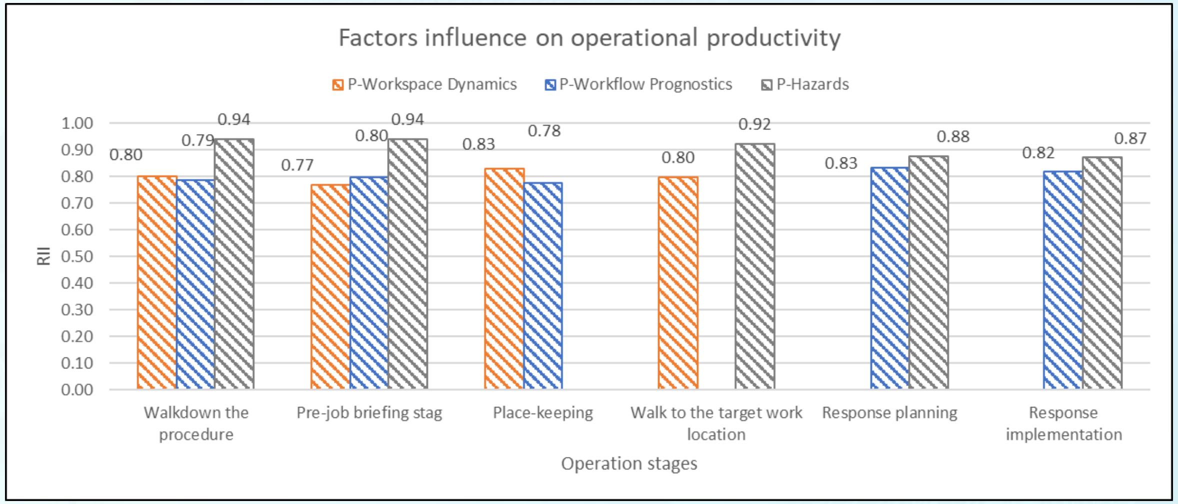


Survey Results

Uncovering the Fluctuating Importance Levels of Different Information in Different Stages of NPP Field Operations

- In different work stages, the operator considers different factors.
- The hazards factor plays a critical role in shaping the trend of safety and productivity
- BUT: dynamic factors “Workspace Dynamics” and “Workflow Prognostics” profile the safety of nuclear facility workspaces





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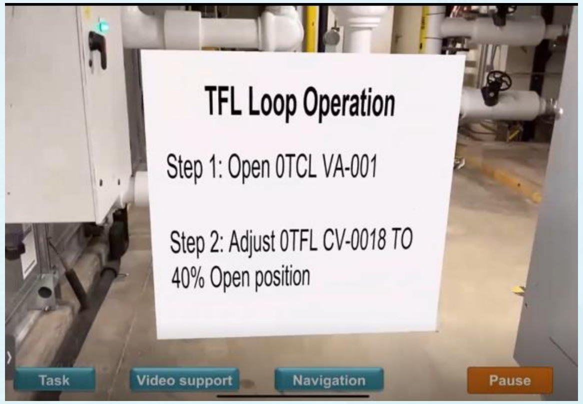
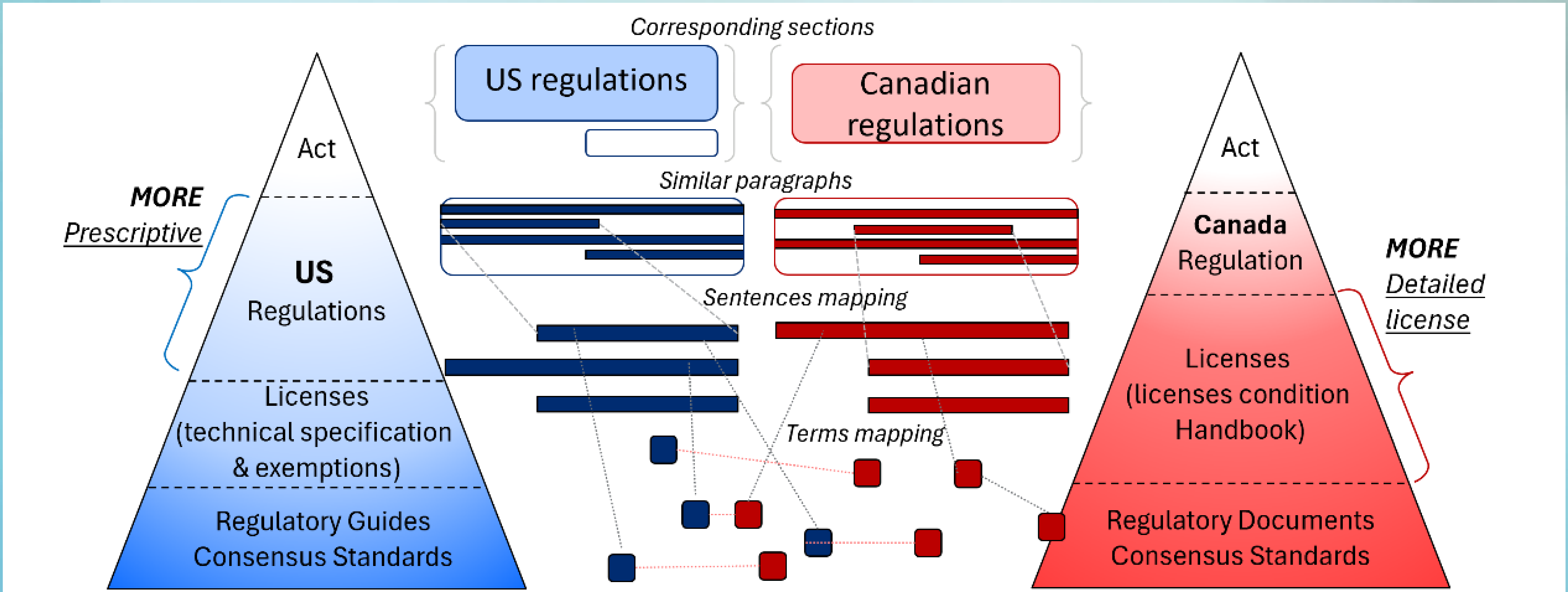


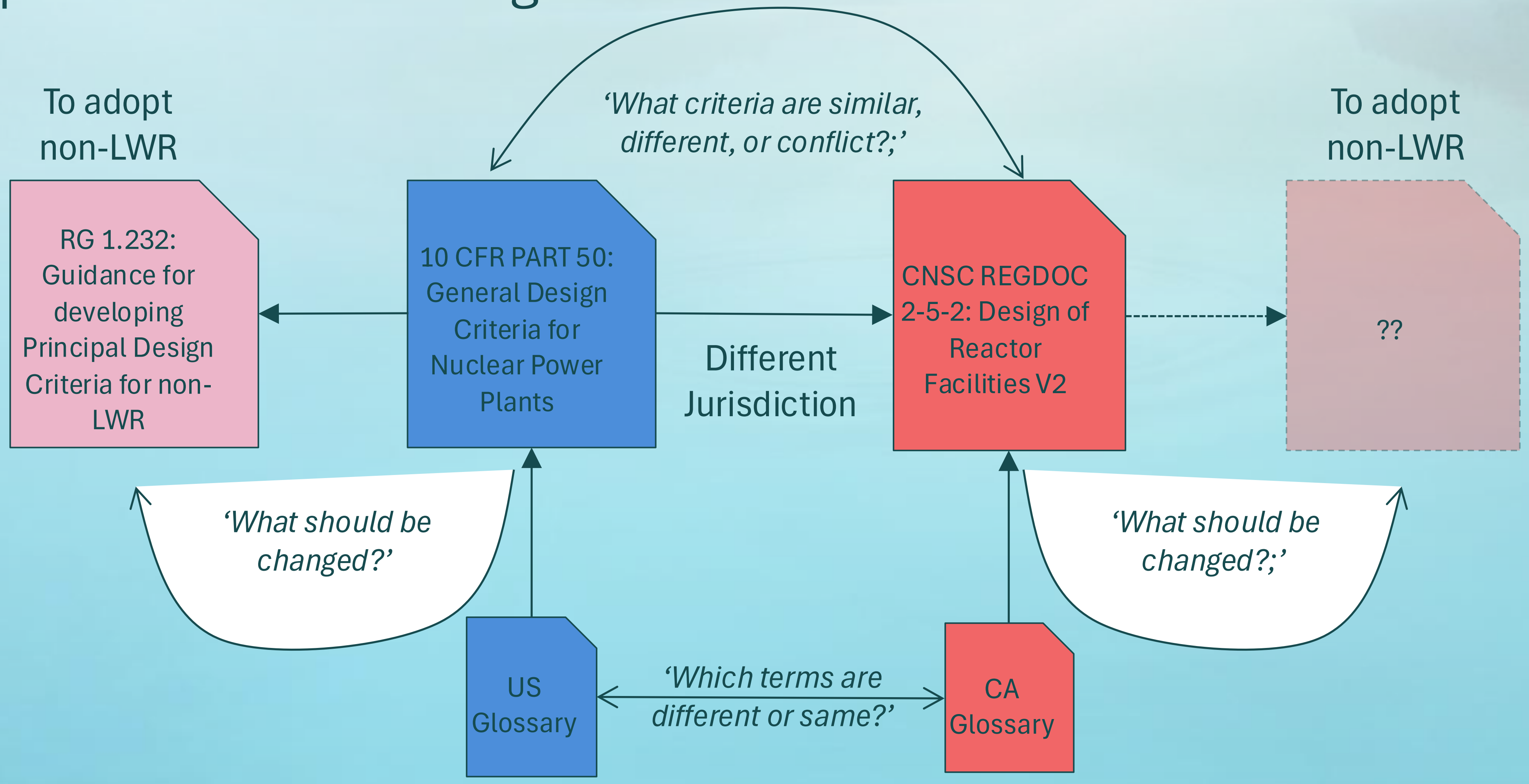
Three Aspects of Using NLP in Supporting Operations of Nuclear Engineering Facilities

Regulation Analysis	Knowledge Analysis
Operation Procedure Analysis	Manual and Information Analysis
License Event Report Analysis	Instance Analysis and Fact Investigation

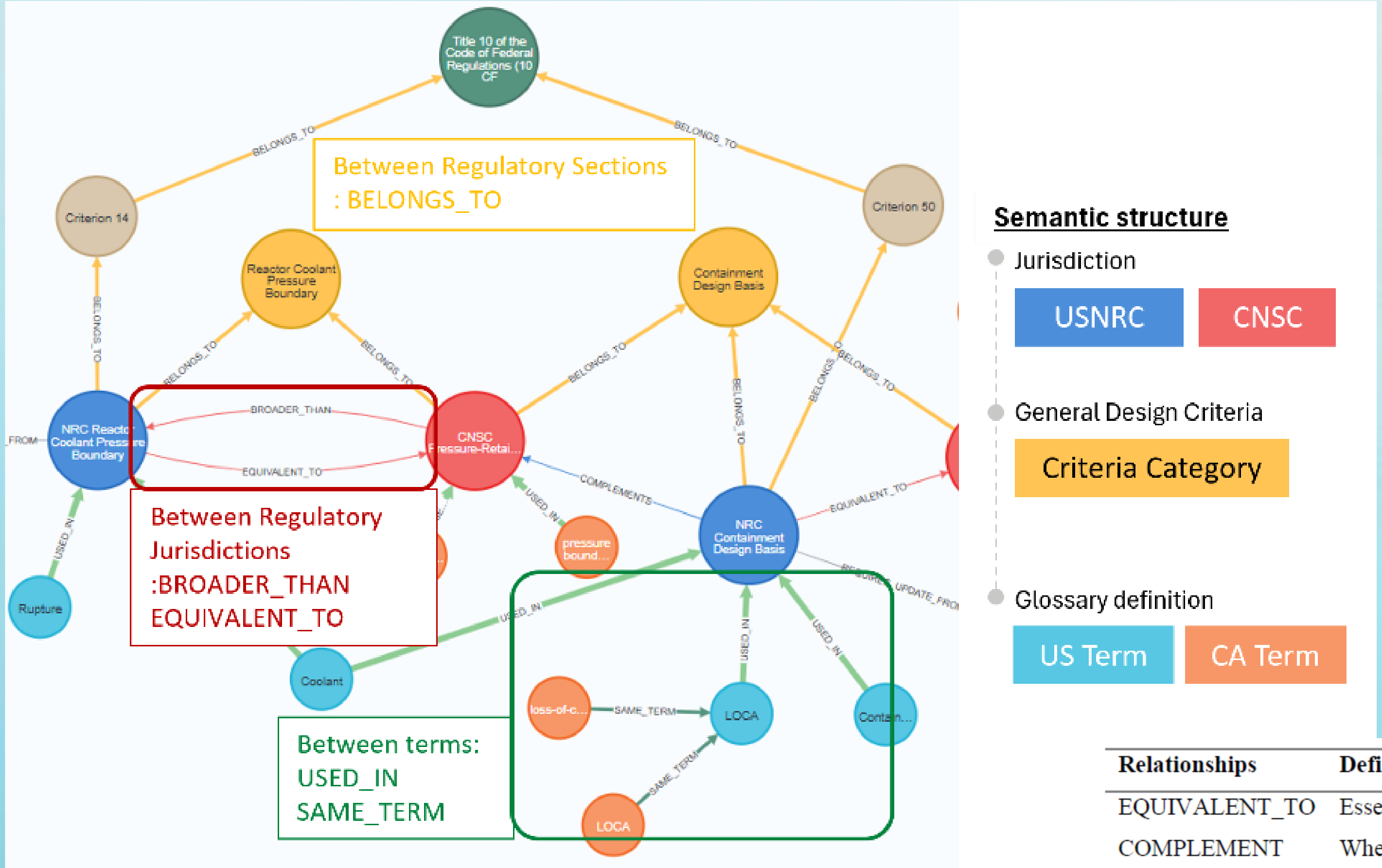
Regulation Analysis



If we know the relationships, we can accelerate the review process for new designs



LLM-generated semantic relationships representations in knowledge graph



Relationships	Definition	Ratio (%)
EQUIVALENT_TO	Essentially the same requirements or terms expressed differently	41.3
COMPLEMENT	Where one regulation fills gaps in the other	34.8
STRICTER_THAN	One regulation is more stringent, or narrower than the other	13.0
BROADER_THAN	One regulation covers more general and wide scope than the other	10.9
DIFFER_FROM	Clear differences in term definitions or requirements	8.7
CONFLICT_WITH	Contradictory or incompatible approaches	2.2

Visual Analysis of Operational Procedures

7.1 TFL Storage Tank Fill and Vent

_____ 7.1.1 **Ensure** Enclosure 9.2, TFL Valve Checklist is complete.

_____ 7.1.2 **Close** 0TFL VA-0010 (TFL TANK OUTLET VALVE).

_____ 7.1.3 **Open** 0TYM VA-0011 (TFL TANK MAKEUP WATER).

_____ 7.1.4 **Open** 0TYM SV-0010 (MAKEUP WATER) to fill TFL Storage Tank.

NOTE:
- TFL Storage Tank has open vent pipe located on top of tank.
- Leaks are reported to ONS instructor.

_____ 7.1.5 **Perform** the following while filling 0TFL TK-0001 storage tank to 70 inches (approximately 1000 gallons):
- **Verify** water is entering TFL Storage Tank
- **Check** for visible leaks around TFL Storage Tank
- **Monitor** 0TFL P-1000 TFL Tank Level (70 inches approximately 1000 gall

_____ 7.1.6 **WHEN** 0TFL TK-0001 TFL Storage Tank level reaches 70 inches, **THEN close** 0TYM SV-0010 (MAKEUP WATER).

_____ 7.1.7 **Close** 0TYM VA-0011 (TFL MAKEUP WATER).

_____ 7.1.8 **Open** 0TFL VA-0010 (TFL TANK OUTLET VALVE).

_____ 7.1.9 **Place** 0TFL SS-1000 (TFL Flow Control Selector Station) to Manual Mode.

_____ 7.1.10 **Ensure** 0TFL CV-0018 (TFL FLOW CONTROL) set to 20 %

_____ 7.1.11 **Open** 0TFL VA-0059 (UPPER VALVE STATION INLET).

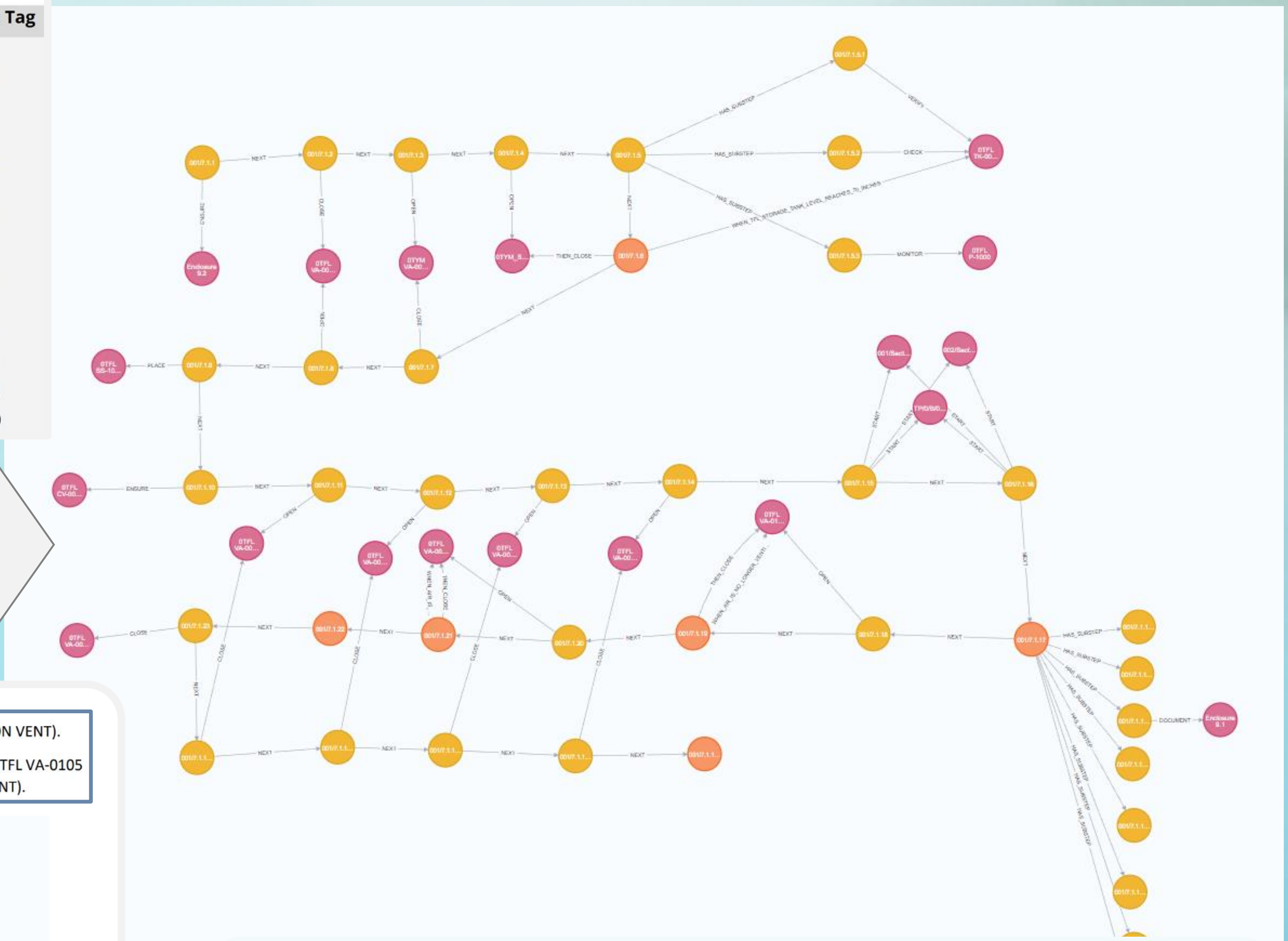
05

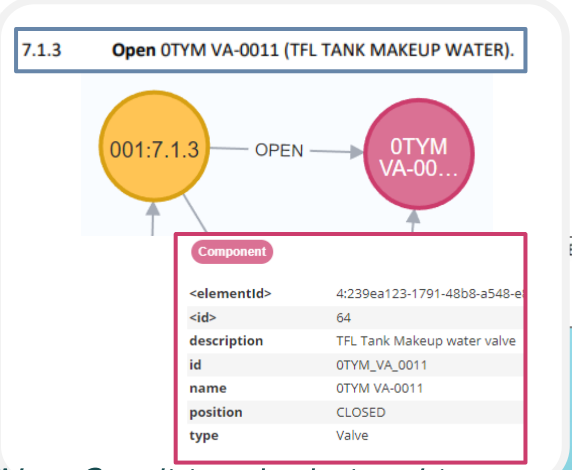
T VENT).

52

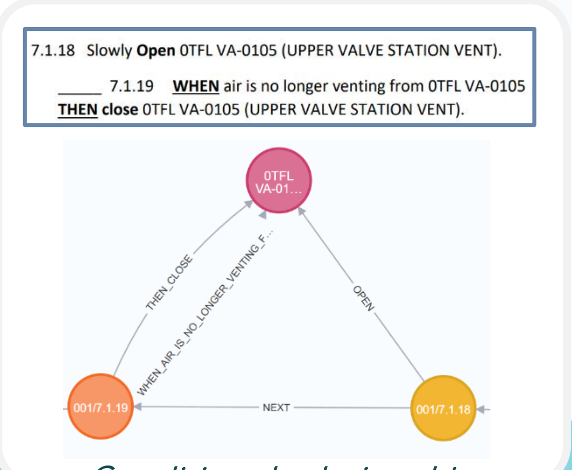
ET)

	Component Tag
Training Flow Loop	0TFL CV-0018
Control Valve	0TFL SS-1000
Selector Station	0TFL P-1000
Gauge	0TFL TK-0001
Tank	0TFL VA-0010
Valve	0TFL VA-0059
	0TFL VA-0062
	0TFL VA-0091
	0TFL VA-0092
	0TFL VA-0105
	0TFL-VA-0052
	0TFL-VA-0069
	0YTM VA-0011
	0YTM SV-0010





Non-Conditional relationships



Conditional relationships

- Yellow nodes: procedural steps (non-conditional)
- Orange nodes: conditional steps (e.g., IF–THEN, WHEN–THEN)
- Pink nodes: system components (valves, pumps, etc.)
- Blue notes: operator warnings or instructions

Licensee Event Report (LERs) Analysis

Is a formal written report submitted by a nuclear power plant licensee to the U.S. Nuclear Regulatory Commission (NRC), in accordance with 10 CFR §50.73, describing reportable events or conditions related to plant operation and safety.

NRC FORM 366
(08-2020)

U.S. NUCLEAR REGULATORY COMMISSION

LICENSEE EVENT REPORT (LER)

(See Page 3 for required number of digits/characters for each block)

(See NUREG-1022, R.3 for instruction and guidance for completing this form http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1022/r3/)

APPROVED BY OMB: NO. 3150-0104 **EXPIRES: 08/31/2023**

Estimated burden per response to comply with this mandatory collection request: 80 hours. Reported lessons learned are incorporated into the licensing process and fed back to industry. Send comments regarding burden estimate to the FOIA, Library, and Information Collections Branch (T-6 A10M), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by e-mail to Infocollects.Resource@nrc.gov, and the OMB reviewer at: OMB Office of Information and Regulatory Affairs, (3150-0104), Attn: Desk ail: oira_submission@omb.eop.gov. The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless the document requesting or requiring the collection displays a currently valid OMB control number.

1. Facility Name	2. Docket Number	3. Page
	05000	1 OF

4. Title

5. Event Date			6. LER Number			7. Report Date			8. Other Facilities Involved	
Month	Day	Year	Year	Sequential Number	Revision No.	Month	Day	Year	Facility Name	Docket Number
				-	-					05000
									Facility Name	Docket Number
										05000

9. Operating Mode	10. Power Level

11. This Report is Submitted Pursuant to the Requirements of 10 CFR §: *(Check all that apply)*

10 CFR Part 20	☐ 20.2203(a)(2)(vi)	☐ 50.36(c)(2)	☐ 50.73(a)(2)(iv)(A)	☐ 50.73(a)(2)(x)
☐ 20.2201(b)	☐ 20.2203(a)(3)(i)	☐ 50.46(a)(3)(ii)	☐ 50.73(a)(2)(v)(A)	**10 CFR Part 73**
☐ 20.2201(d)	☐ 20.2203(a)(3)(ii)	☐ 50.69(g)	☐ 50.73(a)(2)(v)(B)	☐ 73.71(a)(4)
☐ 20.2203(a)(1)	☐ 20.2203(a)(4)	☐ 50.73(a)(2)(i)(A)	☐ 50.73(a)(2)(v)(C)	☐ 73.71(a)(5)
☐ 20.2203(a)(2)(i)	**10 CFR Part 21**	☐ 50.73(a)(2)(i)(B)	☐ 50.73(a)(2)(v)(D)	☐ 73.77(a)(1)(i)
☐ 20.2203(a)(2)(ii)	☐ 21.2(c)	☐ 50.73(a)(2)(i)(C)	☐ 50.73(a)(2)(vii)	☐ 73.77(a)(2)(i)
☐ 20.2203(a)(2)(iii)	**10 CFR Part 50**	☐ 50.73(a)(2)(ii)(A)	☐ 50.73(a)(2)(viii)(A)	☐ 73.77(a)(2)(ii)
☐ 20.2203(a)(2)(iv)	☐ 50.36(c)(1)(i)(A)	☐ 50.73(a)(2)(ii)(B)	☐ 50.73(a)(2)(viii)(B)	
☐ 20.2203(a)(2)(v)	☐ 50.36(c)(1)(ii)(A)	☐ 50.73(a)(2)(iii)	☐ 50.73(a)(2)(ix)(A)	

☐ **OTHER** (Specify here, in abstract, or NRC 366A).

12. Licensee Contact for this LER

Licensee Contact	Phone Number (Include area code)

13. Complete One Line for each Component Failure Described in this Report

Cause	System	Component	Manufacturer	Reportable to IRIS	Cause	System	Component	Manufacturer	Reportable to IRIS

14. Supplemental Report Expected		15. Expected Submission Date	Month	Day	Year
☐ No	☐ Yes (If yes, complete 15. Expected Submission Date)				

16. Abstract (Limit to 1560 spaces, i.e., approximately 15 single-spaced typewritten lines)

LER

Gemini 2.0 flash

Automatic Extraction

Licensee Event Reports Analysis

Highlights Legend

Condition | Procedure or Regulation | Human Action | Outcome | Cause | CorrectiveAction

Text Graph

Previous Document 58/63 Next

LER Code: 4832021001R00
Title: Manual Actuation of Essential Service Water System
Facility/Unit: Callaway Plant. / 1
Event Date: 2/9/2021
Reported Basis: 50.73.(a)(2)(iv)(A)

Text View | Graph View

On February 9, 2021, at 0838 **operators commenced placing both trains of Essential Service Water (ESW) in manual alignments** in accordance with **annunciator response procedure OTA-RK-00014, Addendum 12A, "Service Water Pump Lockout."** The **manual actuation of ESW** was in response to a condition where two non-safety Service Water (SW) pumps tripped and locked out due to **low lubrication (lube) water pressure**. The cause of the trips and subsequent lockouts of the 'A' and 'B' SW pumps was attributed to low lube water pressure caused by fouling of the lube water Y-strainers. The fouling occurred since the normal weekly backflush of the Y-strainers could not be performed while a temporary alteration in support of maintenance (TASM) was installed in order to repair a leak in the permanent lube water piping. **Preventive Maintenance (PM) tasks had not been initiated** prior to the event to periodically clean the Y-strainers in order to compensate for the inability to backflush. **the section of the common lube water piping where the leak occurred** initial corrective action taken in response to the event was **cleaning of the Y-strainers in the lube water piping**. In addition, **PM tasks were created to clean the Y-strainers on a weekly basis** for the remaining time that the TASM was installed. The permanent corrective action was to **complete a modification to replace the section of the common lube water piping where the leak occurred**. Both trains of ESW were returned to standby alignments on February 9, 2021 at 1140.

Click on a highlighted entity to see its details.

Licensee Event Reports Analysis

Highlights Legend

Condition | Procedure or Regulation | Human Action | Outcome | Cause | CorrectiveAction

Text Graph

Previous Document 58/63 Next

LER Code: 4832021001R00
Title: Manual Actuation of Essential Service Water System
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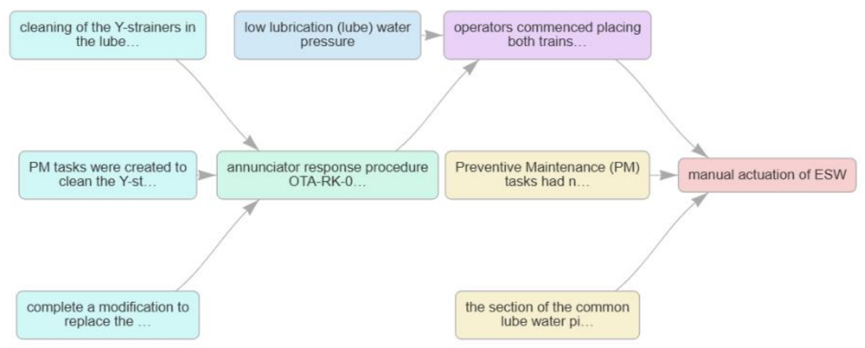
Event Date: 2/9/2021
Reported Basis: 50.73.(a)(2)(iv)(A)

Text View | **Graph View**



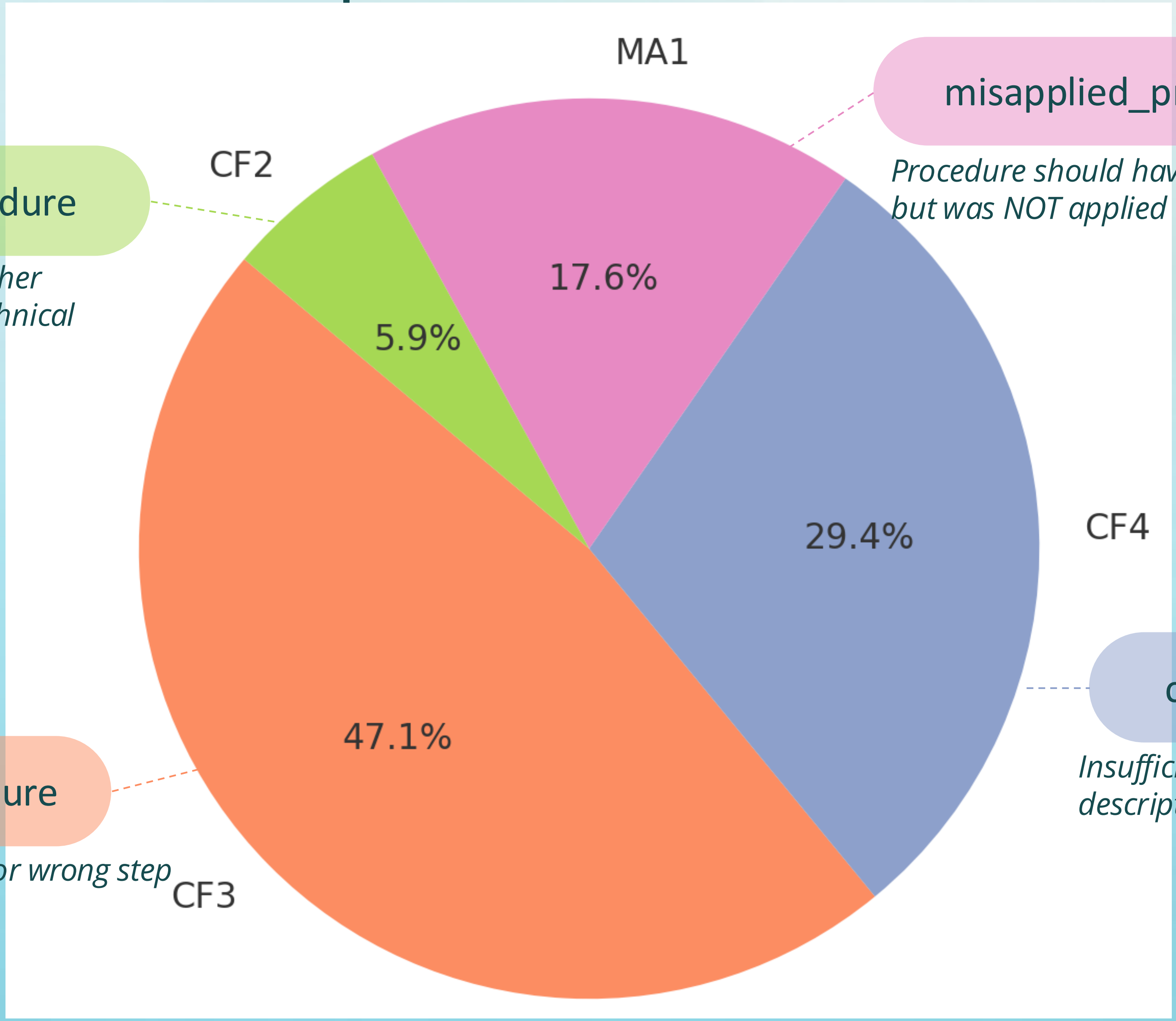
Click on a highlighted entity to see its details.

https://vis-ler.vercel.app

Type of Procedure-Related Causes

Category	Code	Description	Example
misapplied_procedure	MA1	Procedure should have been applied but was not applied.	Operator failed to enter an applicable EOP.
	MA2	Procedure should not have been applied, but was applied anyway.	Containment spray initiated though entry criteria not met.
misinterpreted_procedure	MI	Operator misunderstood or misread the step/intent.	“Pull-to-lock” step misread as “close valve.”
conflicting_procedure	CF1	Procedure assumptions conflicted with actual plant conditions.	Step required pump available, but pump was out of service.
	CF2	Procedure conflicted with other regulations/specifications.	OP-21 step inconsistent with TS 3.7.4 requirements.
	CF3	Procedure had an intrinsic defect or incorrect step.	Inadequate/incorrect step caused unnecessary trip.
	CF4	Procedure description was insufficient or ambiguous.	Step lacked detail, causing inconsistent operator responses.
not_applicable	NA	Cause was external and unrelated to procedures/regulations.	Lightning strike caused LOOP; procedures were followed correctly.

Patterns from LER Reports



conflicting_procedure

Procedure conflicts with other regulations/specs (e.g., Technical Specifications).

misapplied_procedure

Procedure should have been applied but was NOT applied

conflicting_procedure

Insufficient or ambiguous procedure description

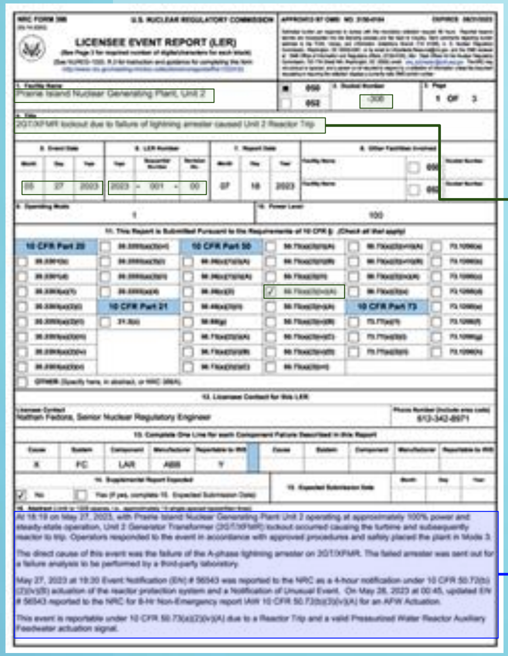
conflicting_procedure

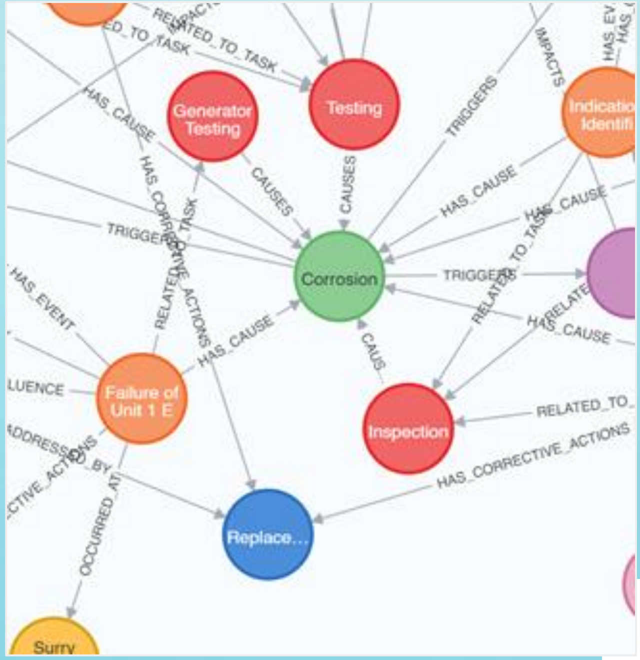
Intrinsic defect/incorrect or wrong step in the procedure.

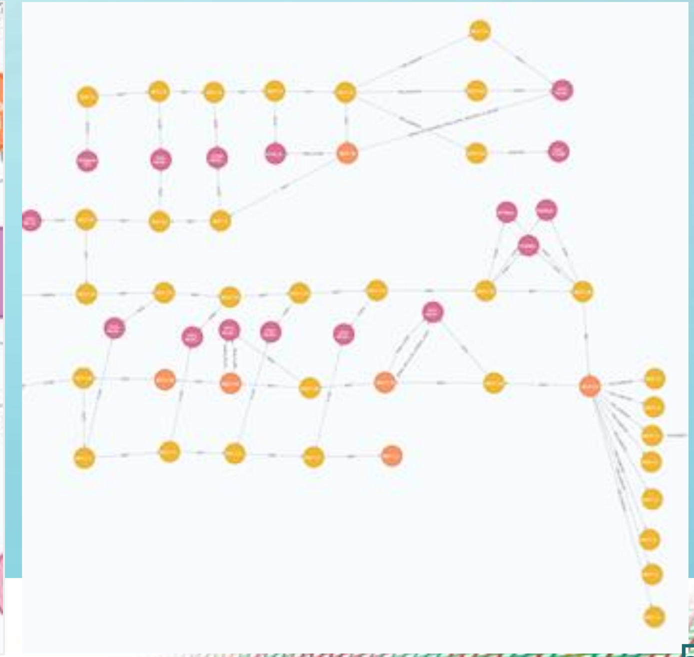
AI Tools for Analyzing LER and Operational Procedures

- **VisLER** – Automatically extracts causes, conditions, human actions, and procedures from Licensee Event Reports (LERs).
- **GraphLER** – Converts extracted data into knowledge graphs to visualize event relationships.
- **GraphProc** – Models procedures as graphs to detect logical ambiguity or conflicts.

These tools jointly support procedure improvement and operator training.







How to Achieve Context-Aware Safety Information Display for Nuclear Field Workers?

NEUP Nuclear Energy University Program
U.S. Department of Energy

Context-Aware Safety Information Display for Nuclear Field Workers

Objectives

- The developed display should integrate the real-time overlay of physical workspaces with maintenance processes and safety information visually displayed through Augmented Reality (AR) glasses.
- The purpose of the display is to assist and guide field workers in assessing workspace risks, locating task-relevant objects, and carrying out the tasks in the correct order in a safe manner.

Research areas

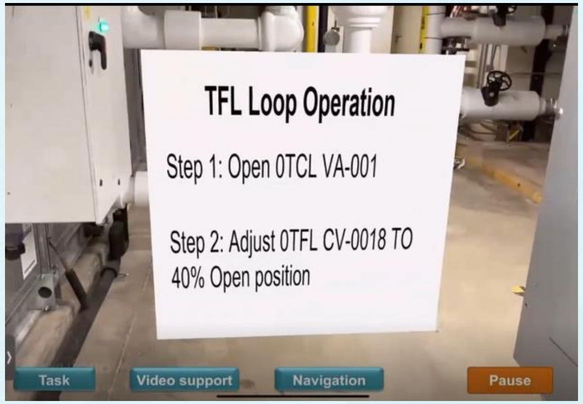
Human reliability | Work process modeling | Operational safety

Major techniques

Sensor Log Analysis | Survey and interview | Natural language processing | Computer Vision | Augmented Reality

Outcomes

- Document and publish research progress in peer-reviewed journals
- Delivery of AR Glasses with context-aware safety information display functions



Safety Control Object Detection: Computer Vision

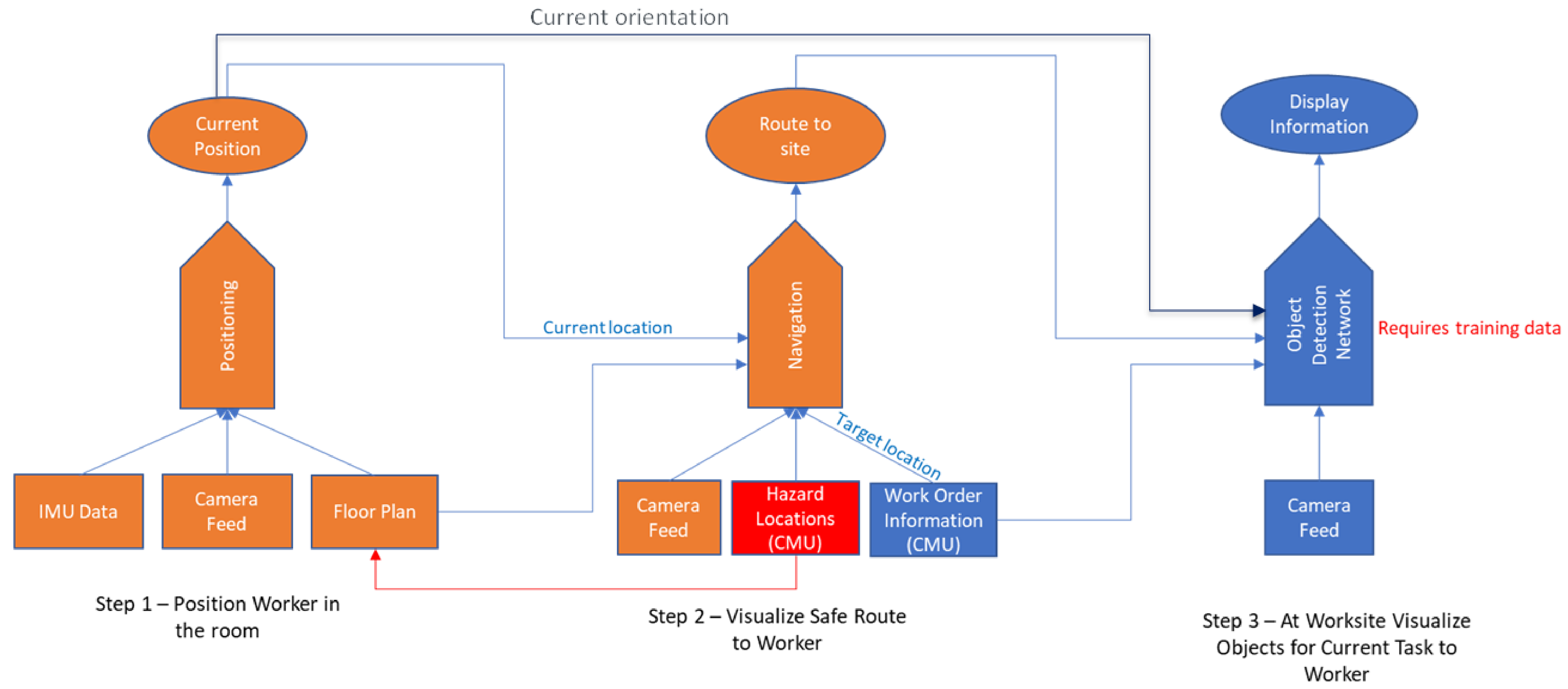


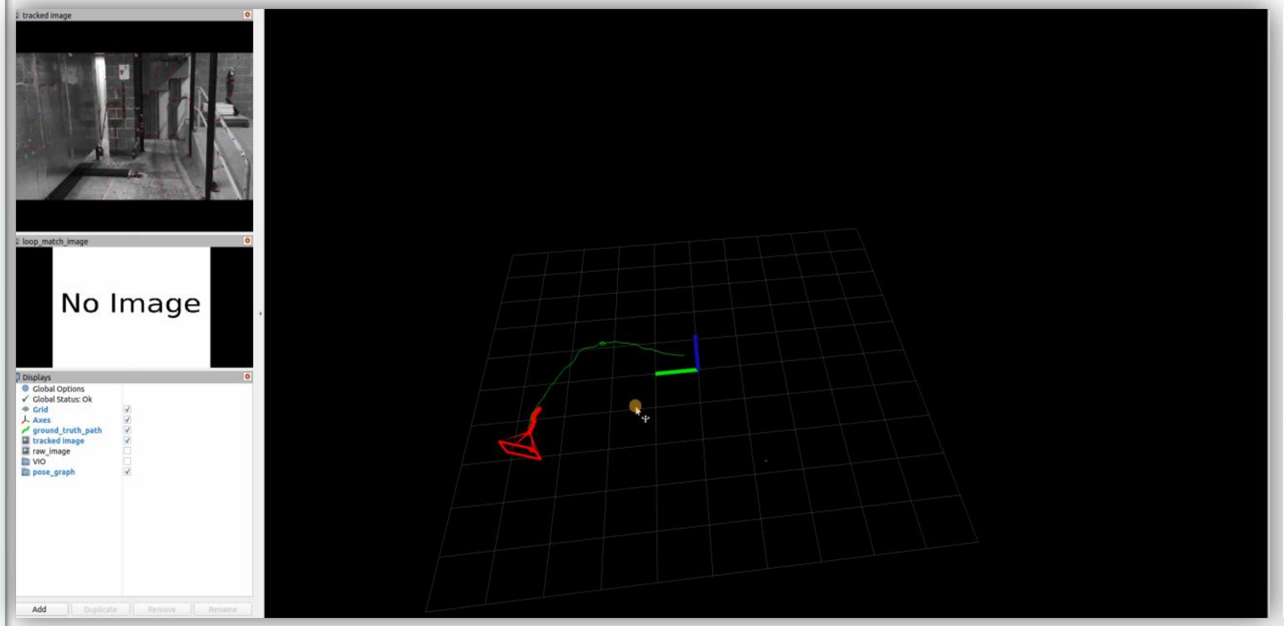
Figure 2. Computer vision research

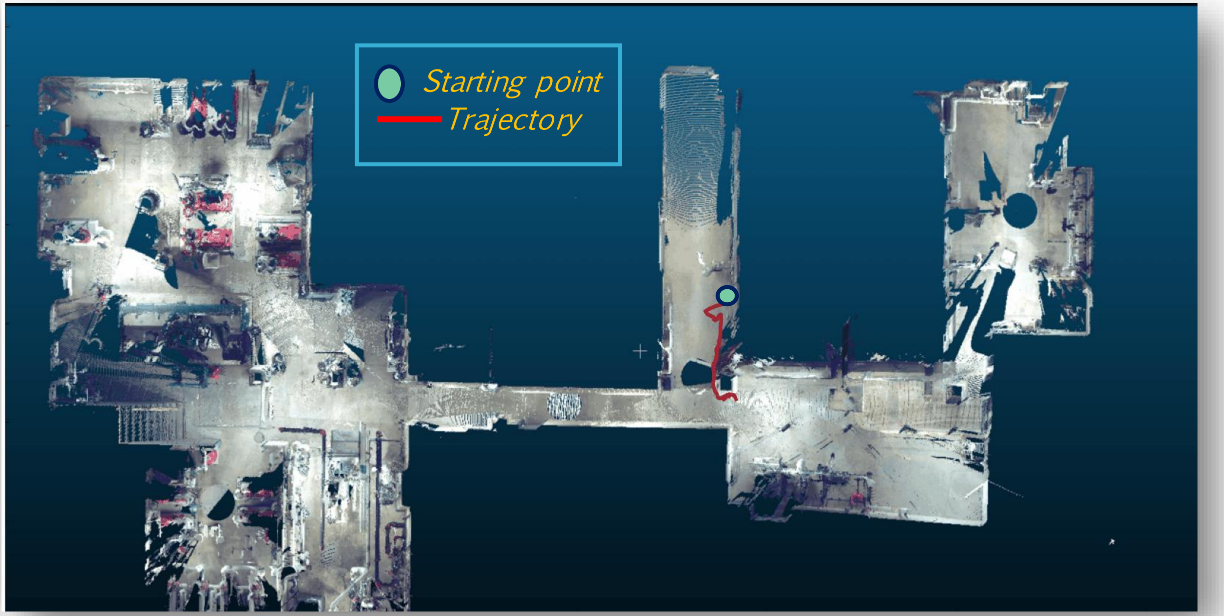
Worker location

Safe path navigation

Critical object detection

- Visual odometry is the process of determining the position and orientation of a robot/worker usually using:
    - Images (RGB camera)
    - Inertial Measure Units(IMU)

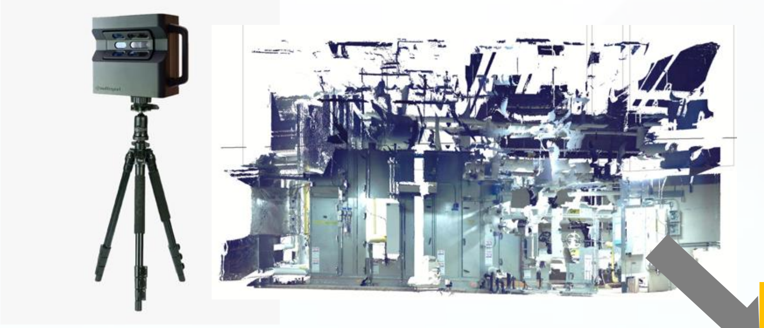




Rethink – Dynamic Context-Aware Augmented Reality

Marker-less AR for the NPP field operations

Matterport



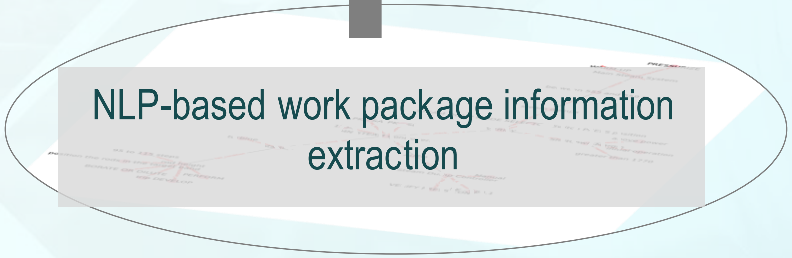
3D scan of the campus mechanical room (Matterport scanner)

Non-recursive Bayesian Filter based real time worker locating

unity

Unity engine as the development platform

Vuforia area target generator to extract visual features for AR tracking and registration of the augmented information

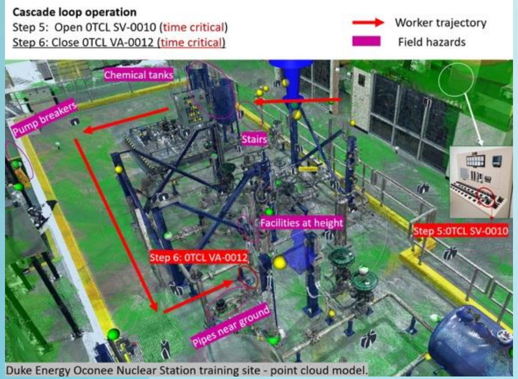


NLP-based work package information extraction

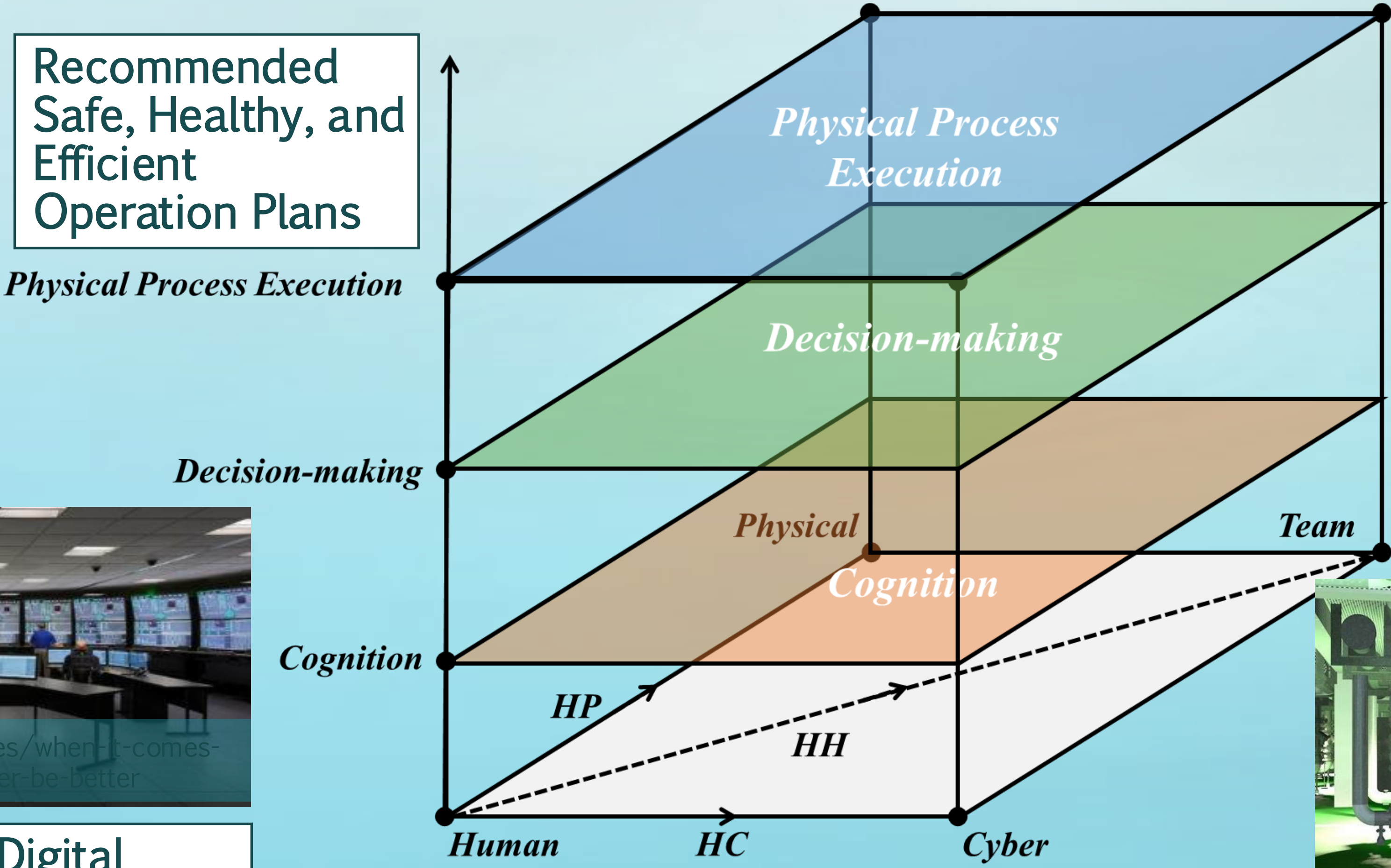
HoloLens 2 AR display for Nuclear Field workers

Scan the QR code to view the AR demo video

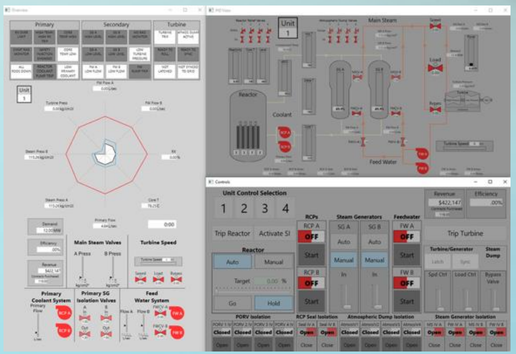
Vision – BIM and Explainable AI for Human-Centric Civil Infrastructure Operations



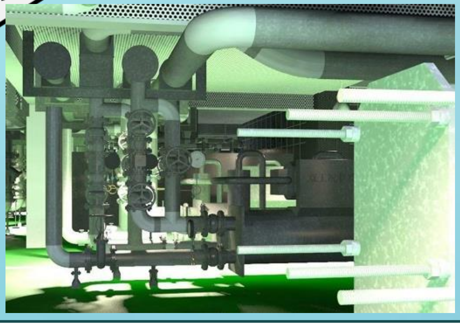
Recommended Safe, Healthy, and Efficient Operation Plans



Simulations



Human Data and Digital Simulations of Human-in-the-Loop Processes



As-Built Building Information Models (BIM)

Future Challenges and Research Roadmap

- AI for supporting the accumulation of design, engineering, and safe operation experiences of engineered systems;
- Integrated accident/incident reports, regulation, and design analysis for AI that can learn from human operators and train field workers in safe operations and maintenance;
- Automated maintenance of knowledge graphs and information systems for nuclear energy systems;
- Human interface for remote operations of critical infrastructure;
- Future of oversight of data centers, water and energy systems;
- AI that can automatically refine a conceptual process design (PID - Piping and Instrumentation Diagrams) into detailed mechanical systems installation drawings in physical spaces with site constraints (computer learn from human-computer interactions of designers and engineers to obtain capabilities of recommending refinements of given PID diagrams).

Thank You!

- PSAM 18
- My institutions
- Funding agencies
- My students
- Industry partners, collaborators, colleagues, and friends