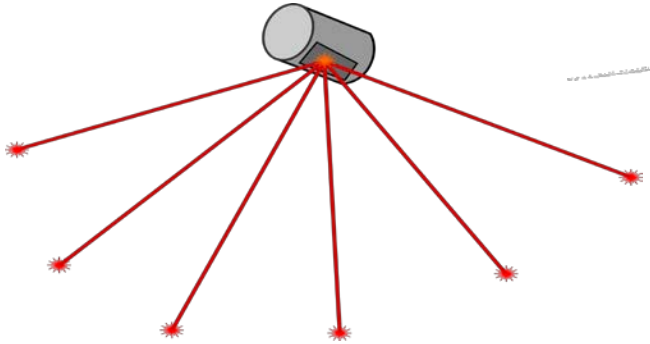
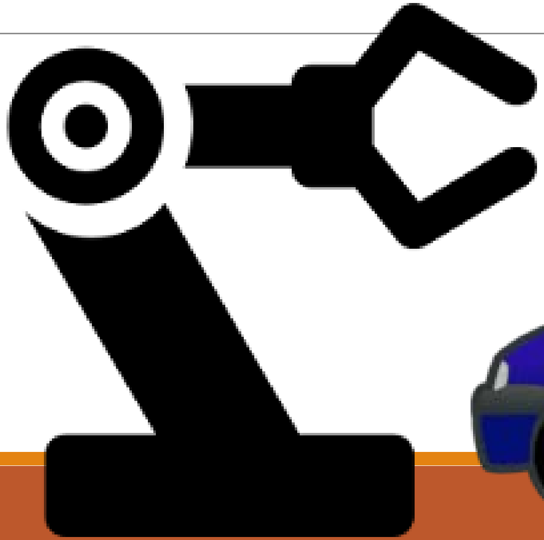
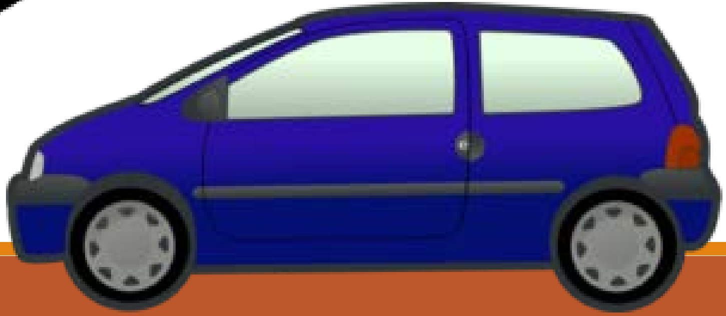


Towards Cyber Physical Systems in Construction

September 2016





Moderator:
Jiansong Zhang

Agenda

Kurt Hoffmeister, PE, CTS, Mechdyne Corporation

Pingbo Tang, Ph.D., Arizona State University

Robert (Bob) Arnold, FHWA

Jiansong Zhang (moderator), Ph.D., Western Michigan University

Kurt Hoffmeister

Kurt Hoffmeister is a recognized pioneer and worldwide expert in large-screen virtual reality and simulation system design, installation, and integration. As a licensed professional engineer with several patents, Hoffmeister is in charge of evaluating and implementing new AV/IT technology and components into Mechdyne's solutions. He has overseen more than 500 projects, including over 30 projects worth $1 million and more. Mr. Hoffmeister has has been serving in a variety of capacities in the past 15 years, including researcher, consultant, systems designer and systems engineer. Mr. Hoffmeister has a Master's degree in mechanical engineering from Iowa State University, he spent 10 years in technical and management roles with the Michelin Tire Company's north American Research center, was an early employee and consultant at Engineering Animation. Inc (now a division of Siemens), and a research scientist at Iowa State University.

Mr. Hoffmeister is an Osha 10, InfoComm Certified Technology Specialist (CTS), and Professional Engineer. Mr. Hoffmeister is a member of National Systems Contractors Association (NSCA), American Society of Mechanical Engineers (ASME), Society of Automotive Engineers (SAE), the Image Society, Inc. (a professional association for the advancement of visual simulations and related technologies), Society of Exploration Geophysicists (SEG), and International Society for Optical Engineering (SPIE).

Pingbo Tang

Pingbo Tang, Ph.D., is an assistant professor in Del E. Webb School of Construction within the School of Sustainable Engineering and the Built Environment at Arizona State University. He obtained his Bachelor Degree of Civil Engineering in 2002, and his Master Degree of Bridge Engineering in 2005, both from Tongji University, Shanghai, China. He obtained is PhD from the group of Advanced Infrastructure Systems at Carnegie Mellon University in 2009. Before joining ASU in July 2012, he completed his postdoctoral training in the Mapping and GIS lab at The Ohio State University from September 2009 to August 2010, and then worked as an assistant professor of the Civil and Construction Engineering Department at Western Michigan University from August 2010 to July 2012.

Pingbo Tang's research explores the remote sensing (e.g., LiDAR, Photogrammetry) and information modeling technology (e.g., Building Information Modeling) to support spatial analyses needed for effective management of construction job sites, constructed facilities, and civil infrastructure systems. His recent research efforts examined sensing and modeling methods for comprehending the Human-Cyber-Physical-Systems (H-CPS) in accelerated construction and facility management (e.g., nuclear plant outage control).

Pingbo Tang

Dr. Tang has published more than 60 peer-reviewed articles in these areas. The National Science Foundation (NSF), Department of Energy (DOE), Salt River Project (SRP), DPR Construction, and Phoenix Government have funded his research efforts. He holds memberships of several professional organizations, which include: TRB (Committee on Bridge Management, AHD35), ASCE (the Vice Chair of the Data Sensing and Analysis (DSA) committee), IABSE, ASPRS, and ASTM International (Committee E57: 3D imaging systems). He is serving as an associate editor of ASCE Journal of Computing in Civil Engineering, as well as a reviewer of multiple top journals and conferences in the general area of IT and Computing in Civil and Construction Engineering. He won one of the best paper award recipients of Construction Research Congress, ASCE, 2009 (within the domain of "Operation and Management"), the best poster award of Construction Industry Institute's 2011 Annual Conference, the 2013 Recent Alumnus Achievement Award of the Civil and Environmental Engineering Department, Carnegie Mellon University, and the National Science Foundation CAREER Award in 2015.

Robert (Bob) Arnold

Robert (Bob) Arnold is the Federal Highway Administration (FHWA) Director, Office of Transportation Management. This office is responsible for National programs focused on the reduction of roadway congestion. Its focus is mainly with recurring congestion in such areas as pricing, active traffic management, and traveler information. His office also manages connected vehicle programs; specifically Vehicle to Infrastructure (V2I) deployment activities. As part of the implementation of the Fixing America's Surface Transportation (FAST) Act he is responsible for the management of the Advanced Transportation and Congestion Management Technologies Deployment and Surface Transportation System Funding Alternatives grant programs.

As a member of the Agency’s Senior Executive Service Bob is responsible for contributing to the development of overall strategic planning, policy development, and developing legislative proposals for the Administration.

Robert (Bob) Arnold

Bob is currently serving as the Acting Associate Administrator for Operations which beyond the Transportation Management office responsibilities directs a staff that provides national leadership and advocacy for the development and implementation of strategies and programs to reduce congestion and improve the efficiency and reliability of both freight and passenger movement on the highway system.

Prior to taking this Operations position Bob was the Agency's New York Division Administrator from February 2001 until September of 2007. The Agency's Division offices work primarily with the various State Departments of Transportation to ensure the State's highway system is an integrated, effective, and efficient part of the National transportation system. He has also held positions with FHWA as the Assistant Division Administrator in New Jersey, District Engineer in New York, Field Operations Engineer in Oklahoma, Construction Engineer in the Agency's western Region, and as an Area Engineer in Baltimore, Maryland.

He received a Bachelor of Science in Civil Engineering from Ohio Northern University in 1983 and has worked for FHWA since graduation. He is also a 2006 graduate from the US Government - Office of Personnel Management's Federal Executive Institute.

VR and Collaborative Technologies for Design, Planning, and Monitoring

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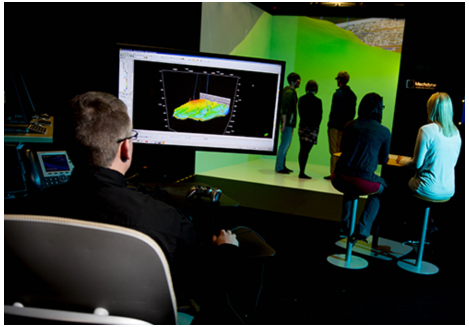
Mechdyne – Integrated Technology Partner

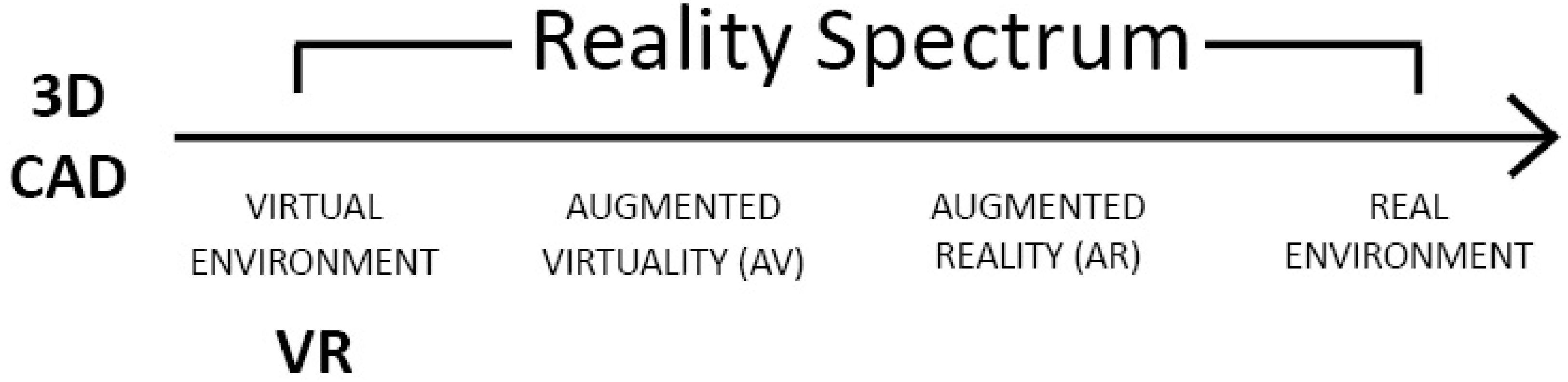


Agenda

- 3D/VR Technologies
  - Clarification/Definition
  - The “Reality Spectrum”
  - Applications
  - Considerations
- Non-3D Collaboration
- Sample Applications

What Makes Something VR and Not "Only 3D"?

- 3D Stereo
- Viewer Perspective
- Immersive and Wide Field of View (FOV)
- Interaction / Navigation
- Collaborative
- Realistic Rendering
- Scale 1:1


3D
CAD
Reality Spectrum
VIRTUAL
ENVIRONMENT
AUGMENTED
VIRTUALITY (AV)
AUGMENTED
REALITY (AR)
REAL
ENVIRONMENT
VR

VR = HMD

VR = ~~HMD~~

Large Immersive VR Displays Since 1992

HMD VR Considerations

- Typically a single person experience
- Multi-user possible with additions
- Does not promote collaboration

Augmented Reality

- "Holograms"
- Real world augmented with virtual models and data
- Multi-user, individual viewpoints better
- Limited scale to objects
- Limited FOV

- Source: University of Calgary Agile Surface Engineering Lab. Video available.

Data Challenges

- Infrastructure planning and engineering
- Instrumented cities / urban informatics
- Daily and emergency operations

» Multiple sensors
» Multiple data sources
» Intuitive visual presentation
» Rapid analysis
» Informed decision making

Design and Simulations

- Transportation routes
- Traffic studies
  Pedestrian studies
- Structural engineering

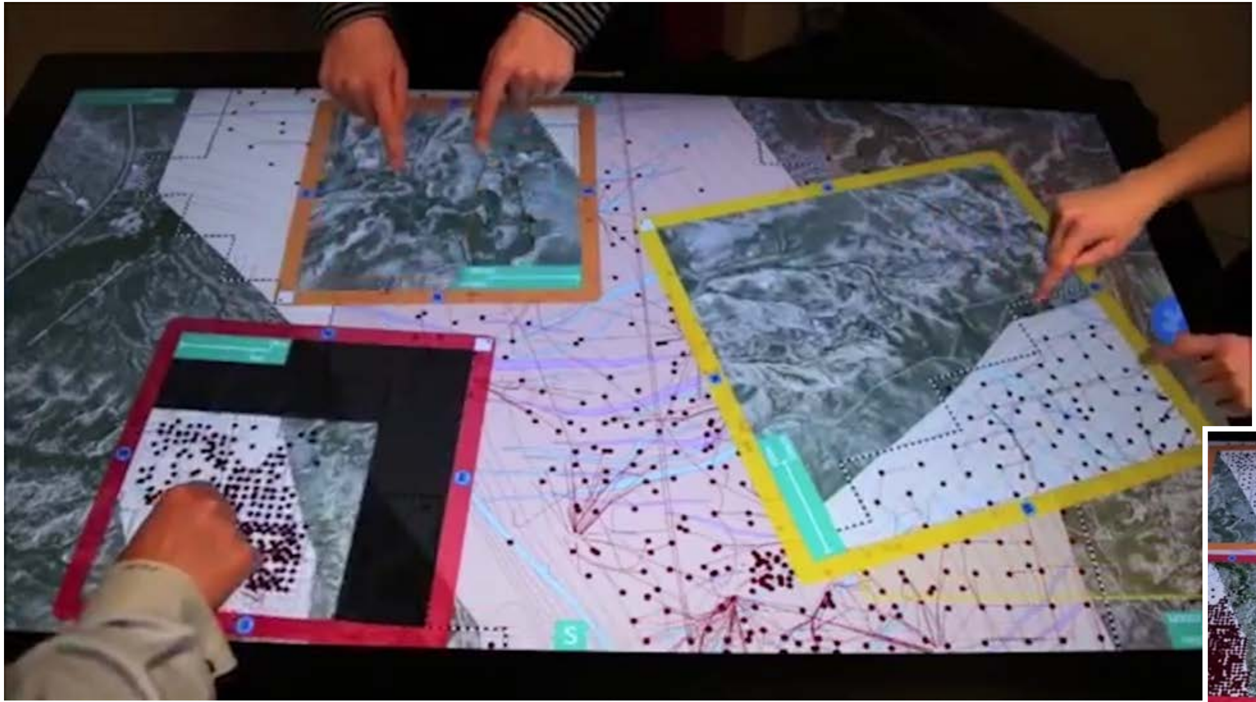
Training and Testing

- Driver training or test driving planned roads
- Pedestrian routes/issues
- 2D vs. HMDs vs. immersive
- Is 3D beneficial?
- Is 1:1 scale crucial?
- Is FOV/peripheral vision crucial?

Task - Intuitive View/Share

- Multi-user, hands-on data interrogation
- Intuitive data access
- Remote platforms
- View/share in one or between displays
- Presentation tool

Task - Intuitive View/Share

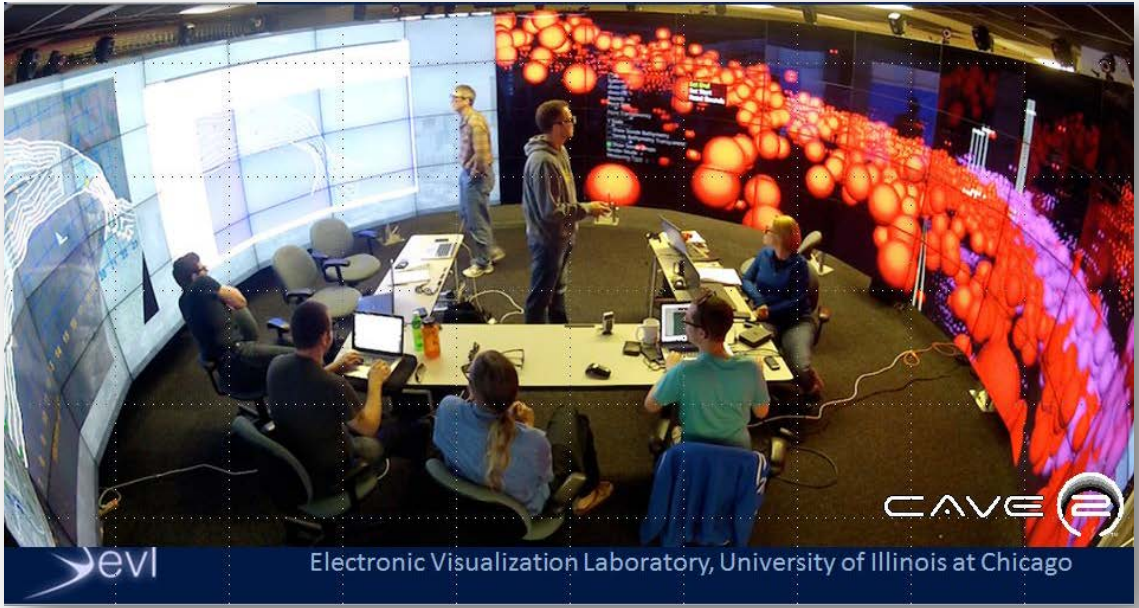


Source: Vizworx Inc.
Video available

Decision Making

- Longer work sessions
- Multi-disciplinary teams
  Multiple data sources
- Core information
- Contextual information

Decision Making



- Hybrid displays
- Simultaneous 2D & 3D in shared workspace
- 3D model - related 2D data for context

Content (is King)

- VR Compatibility considerations
- Google Earth
- ESRI Data
- SketchUp
- Game engines – Unity, Unreal
- Video sources
- 2D/3D/Hybrid
- In-house or outsource model development expertise

"Serious Gaming" for Planning

- Using simulation engines for urban modeling
- Set goals/objectives
- Key benefit – ability to reset
- Team analysis & decision making
- Team learning tool
- Team dynamics improvement

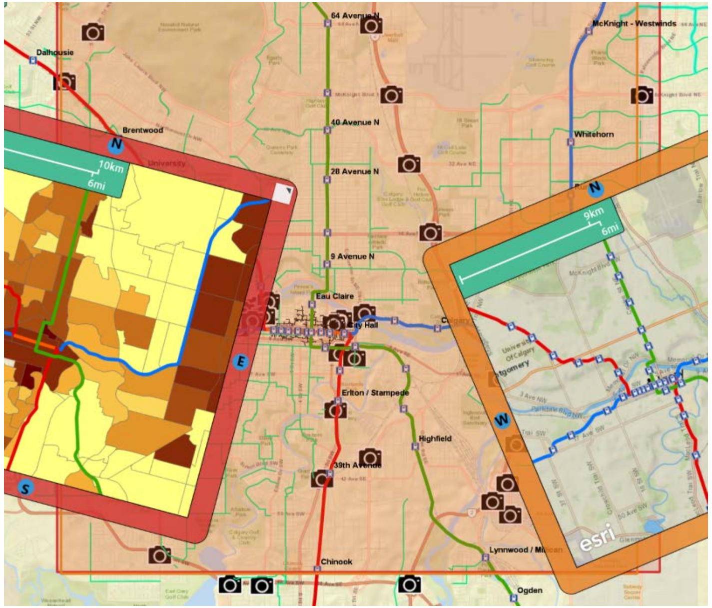
Source: "Serious Gaming" for urban planning and greencitystreets.com

Drone Data – virtual overlays on real world

Images Courtesy

Fovea Aero Systems

Example: City of Calgary Transit Planning

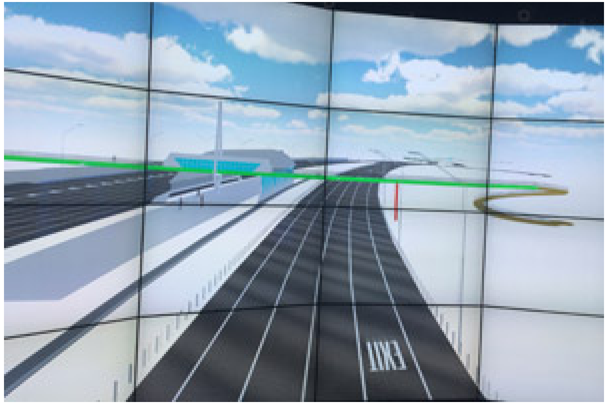


Source: Vizworx Inc.

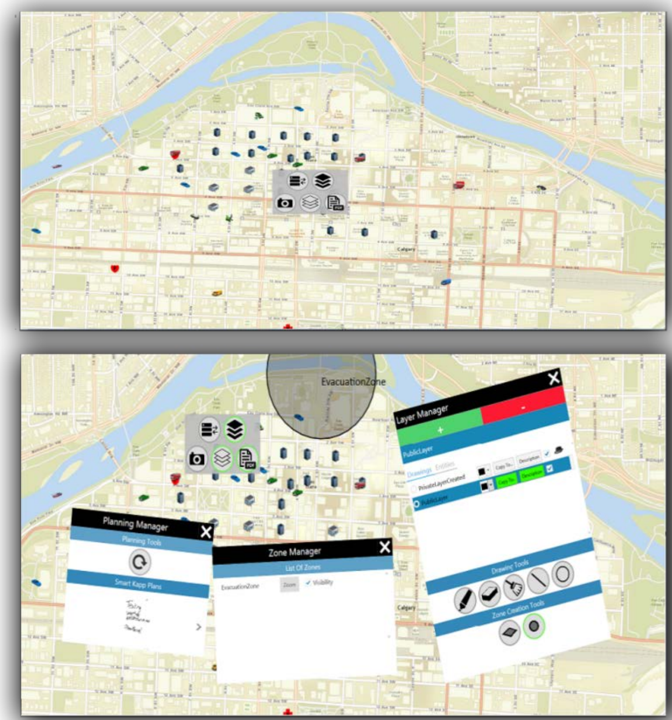
- Multi-layered data
- Interactive surfaces for analysis and community engagement
- Remote devices for in the field validation
- Passing of data between users and devices

Example: Monash University

Transportation Network Research



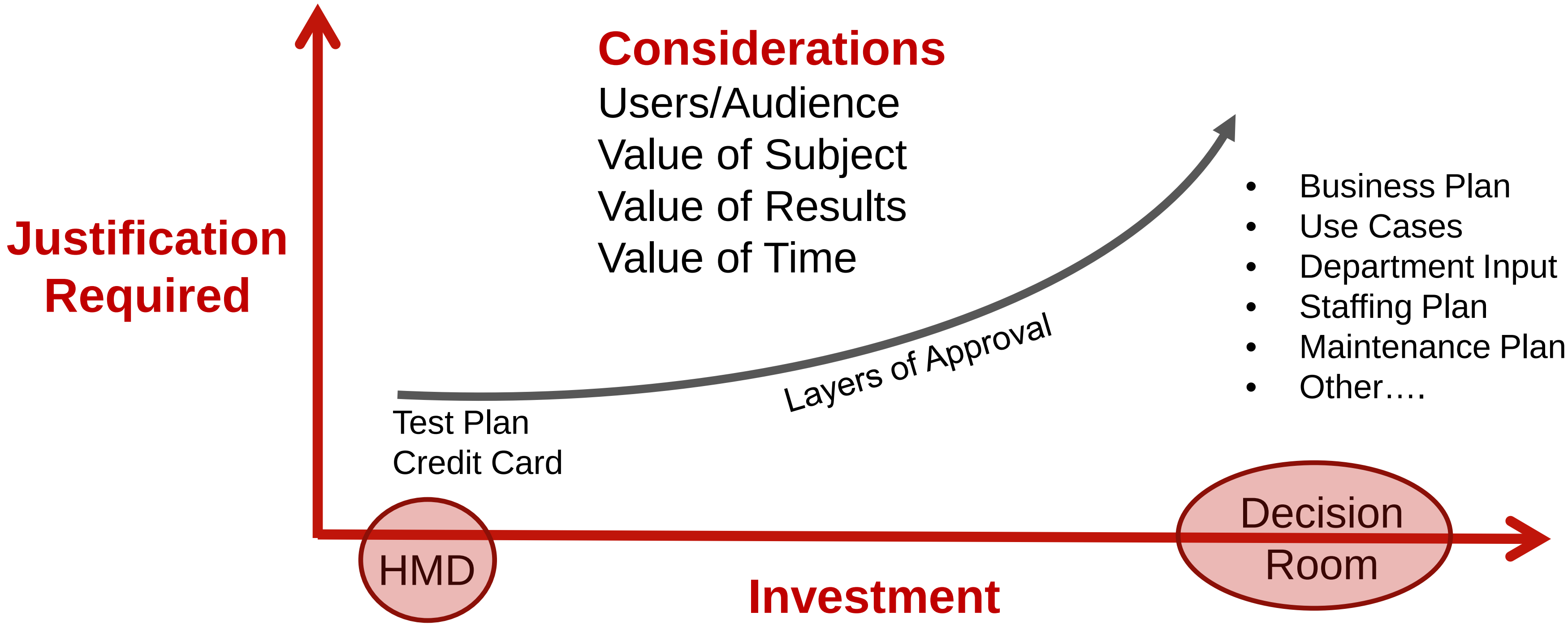
Example: University of Calgary Agile Lab



Emergency Operations Room of the Future

- Real-time sensor feeds
- Access and evacuation
- Highly interactive surfaces and connected displays
- User positions monitored
- Experimentation with augmented reality

ROI Considerations



Thank You

Kurt Hoffmeister
kurt.Hoffmeister@Mechdyne.com

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Human-Cyber-Physical-Systems Engineering for Robust Shutdown Control of Civil Infrastructures

Presenter: Pingbo Tang

Collaborators: Cheng Zhang[1], Alper Yilmaz[2], Nancy Cooke[1], Shawn W. St. Germain[3], Ronald Laurids Boring[3], Alan Chasey[1], Timothy Vaughn[4], and Samuel Jones[4], Ashish Gupta[2], Verica Buchanan[1], Saliha Hobbins[1]

[1]Arizona State University
[2]The Ohio State University
[3]Idaho National Laboratory
[4]Arizona Public Service Company

Outline

- Motivation – What is shutdown control? Why Human-Cyber-Physical-Systems (H-CPS) Engineering is critical for robust shutdown control of civil infrastructures and transportation facilities?
- A framework for diagnosing and controlling H-CPS behaviors in infrastructure shutdowns
- Technologies for supporting the diagnosis and control of H-CPS in shutdowns
  - Virtual world – Simulation for workflow diagnosis with human errors in the loop
  - Physical word – Video analysis and mobile sensing; Communication technologies; natural language processing
- Conclusion and H-CPS roadmap for complex transportation and civil infrastructure project control

What is a shutdown?

Stop the service of civil infrastructures, such as transportation networks or electricity infrastructures for maintenance with a very busy schedule.

For example, shutdown of a nuclear reactor for maintenance activities:

- About 20 days
- More than 2,000 workers
- More than 2,000 tasks
- Cost $1.5 million for one day's delay.

In transportation, some Accelerated Bridge Construction (ABC) project can be shutdowns

http://www.flickr.com/photos/iowadot/sets/72157628416564269/

http://www.businesswire.com/news/home/20160307006223/en/Palo-Verde-Nuclear-Generating-Station-Sets-U.S.

Shutdown Example: NPP Outage Control

Additional needs of inspection (data collection) for understanding delays, violations of safety policies, or unexpected sequences of activities and field conditions

Control

Physical World

Safety Management

Productivity Management

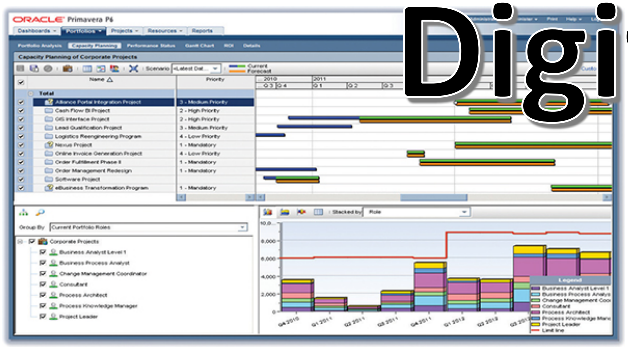
Inspection

Scheduling

Execution

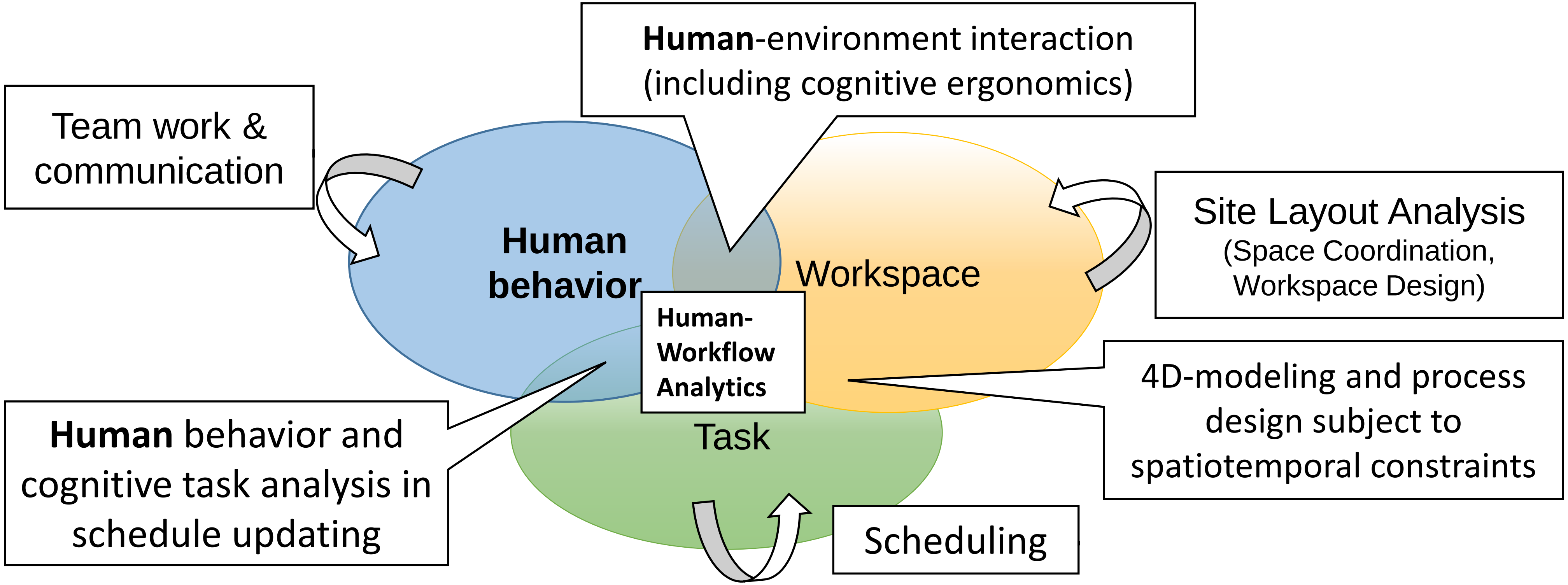
Discoveries (e.g., additional girders to be replaced, unexpected observations of the cooling system)

Updated schedule and resource allocation

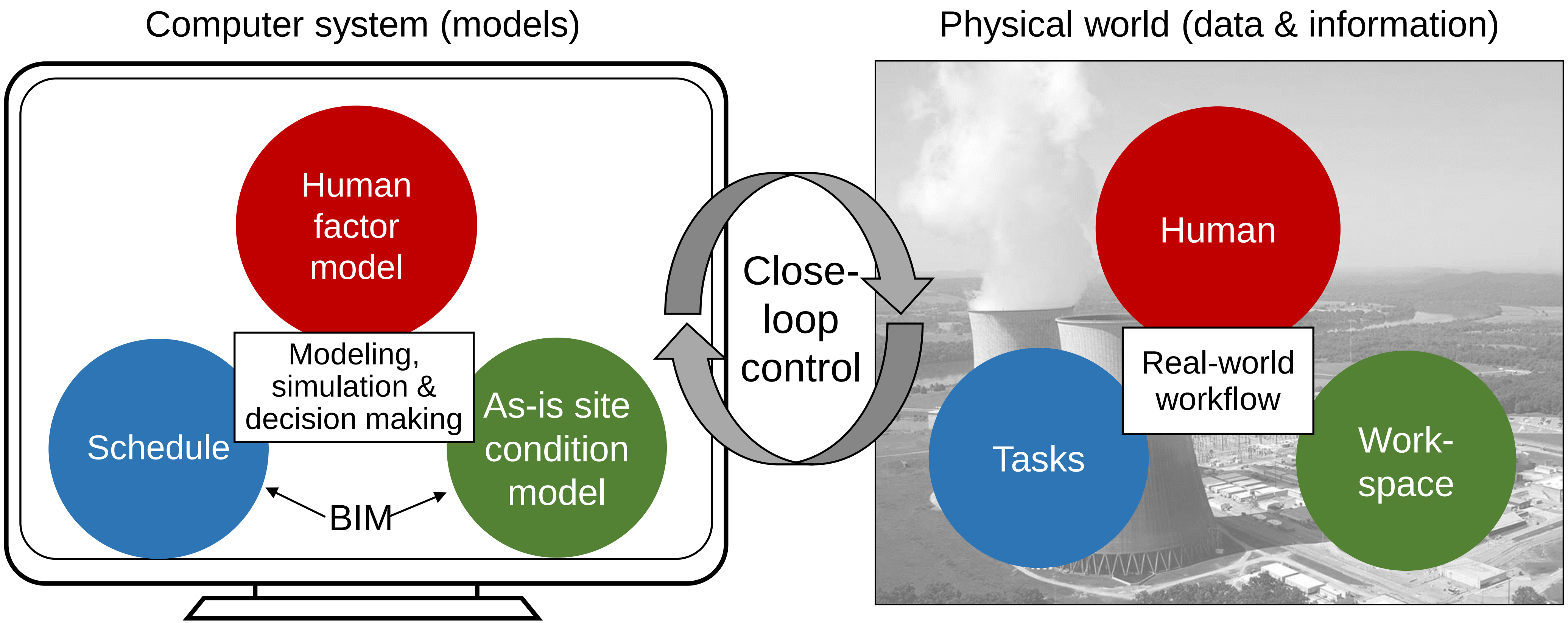


Digital World

Human Factors in Shutdowns of Civil Infrastructures



Human-CPS Engineering for Robust Shutdown Control



Importance of robust H-CPS for shutdown control

- Management team is suffering from the huge amount of manual work about maintaining the safety and productivity of the entire schedule and interwoven workflows.
  - Inspection
  - Field communication
  - Transportation of people and resources
  - etc…
- Every three hours, a 20+ people group meeting for outage control
  - Large amounts of human hour investments into coordination.
  - Inconsistencies and collaboration failures still occur.

Challenges of diagnosing and controlling H-CPS behaviors

- Field documentation and meeting minutes could hardly capture some spatiotemporal details
- Lack of information on detailed spatiotemporal interactions between human, equipment, facility, and materials cause difficulties in diagnosing delays and human errors
    - How delays occur with accumulation of small handoff problems?
    - How miscommunication and human errors happen?
    - How errors and delays influence each other?
    - How small errors and delays escalate into accidents or serious delays and wastes?

A framework for diagnosing and controlling H-CPS behaviors in shutdowns

Research Focus 1: Automatic Multi-Sensor-Based Workflow Performance Analysis	Research 2: Automatic Multi-Sensor-Based Human Performance Analysis

Object/Human Tracking in Multiple Data Sources

Real-Time Productivity and Status of Activities	Real-Time Relationships among Activities	Real-Time Human Interactions	Real-Time Trajectories of Human Individuals

Comparing Real-Time Information Against As-Planned Models and Spatiotemporal Constraints

As-Planned Schedule	As-Planned Spatiotemporal Constraints for Safety	As-Planned Human Interactions	As-Planned Trajectories

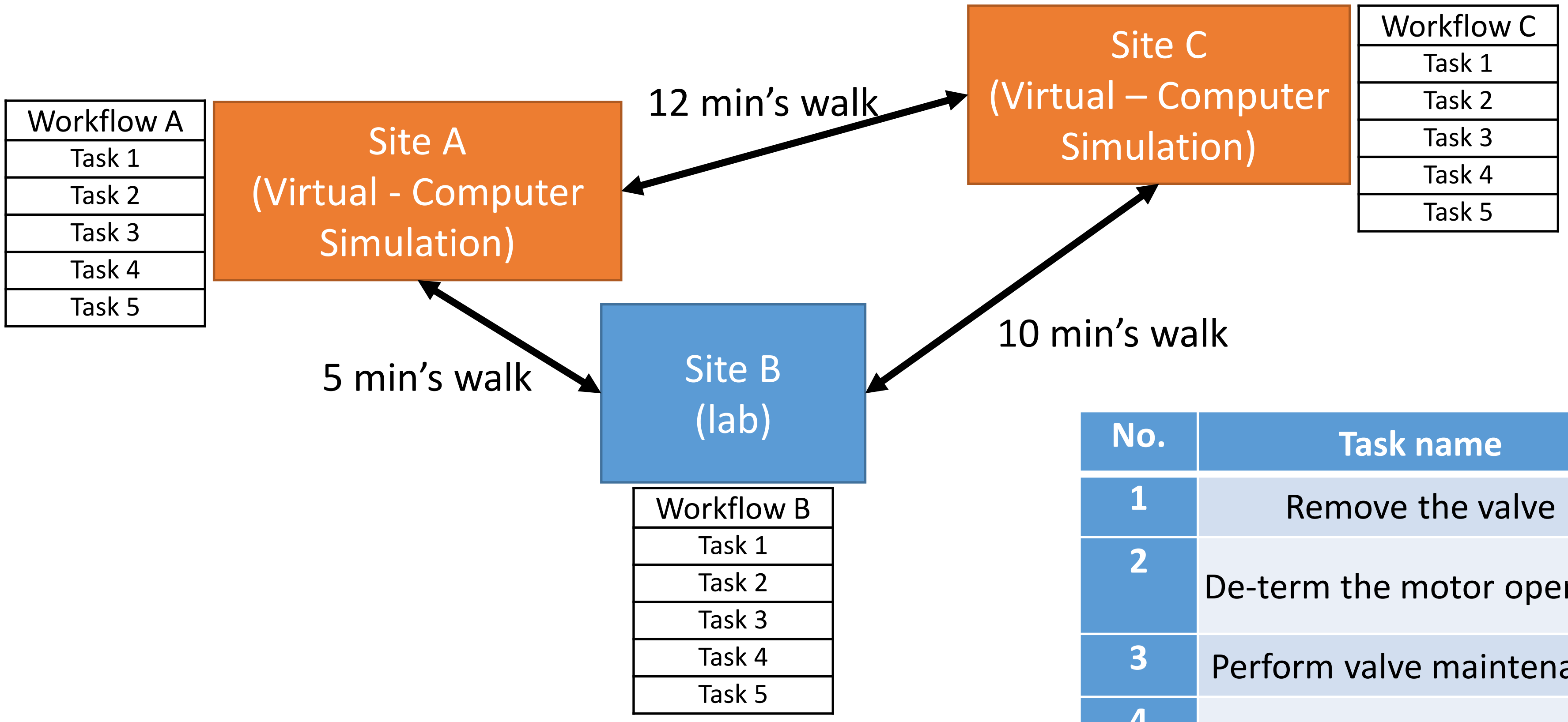
Outputs for Supporting Outage Coordination of Advanced Outage Control Center (AOCC)

Outage Schedule Updates	Safety Alarms of Irregular Spatiotemporal Relationships	Abnormally Long Human Interactions	Unexpected Trajectories of Individuals

Technologies for diagnosing and controlling H-CPS behaviors in civil infrastructure shutdowns

- Simulation of schedules and motions in the digital world
  - Schedule simulation that improve engineers' preparation for uncertainties in schedules
  - 4D simulation of field operations for identifying "clashes" between objects and activities
- Automatic data collection and analysis in the physical world
  - Automatic video analysis - Human motion analysis; Work order status tracking
  - Communication technologies – mobile device (e.g., Smart Watch), sociometric badges
  - Natural language processing for automatic analysis of work orders and event reports
  - Localization and tracking technologies – GPS, RFID, WiFi
- Human and team behavior modeling and prediction methods

Schedule simulation considering handoff processes and shared resources …



No.	Task name	Resource
1	Remove the valve	Crane
2	De-term the motor operator	Electricians
3	Perform valve maintenance	Mechanics
4	Re-term the motor operator	Electricians
5	Re-install the valve	Crane

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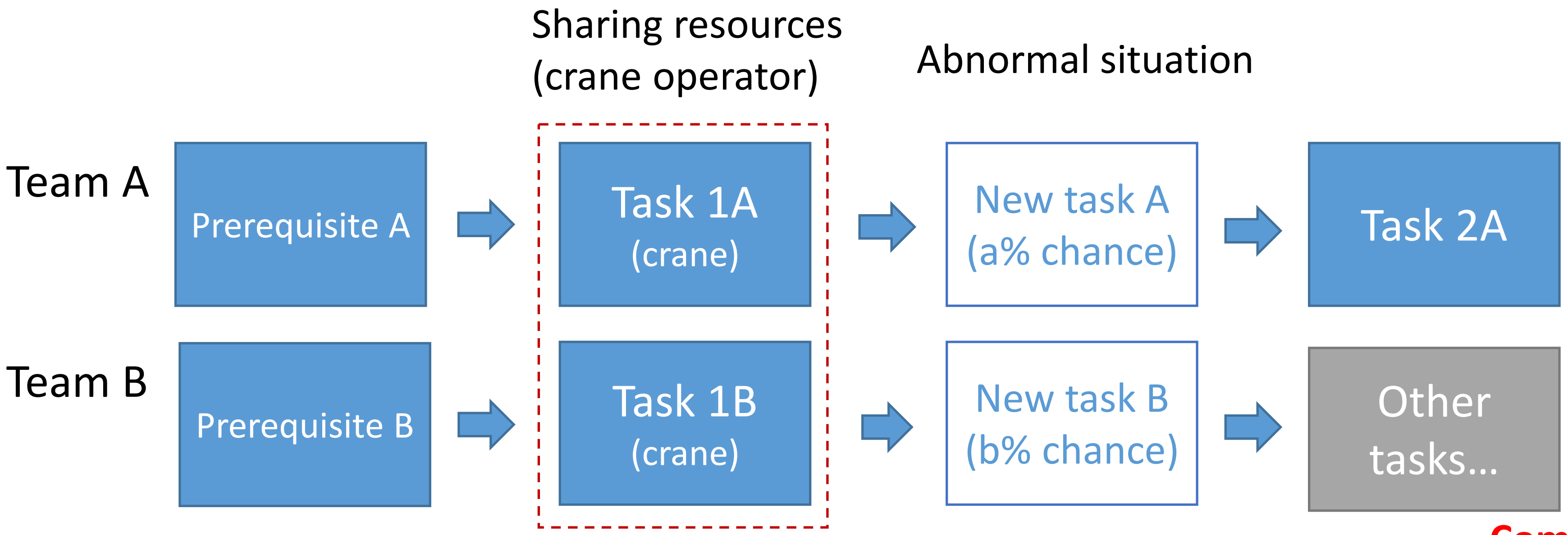
Schedule simulation considering handoff processes and shared resources …



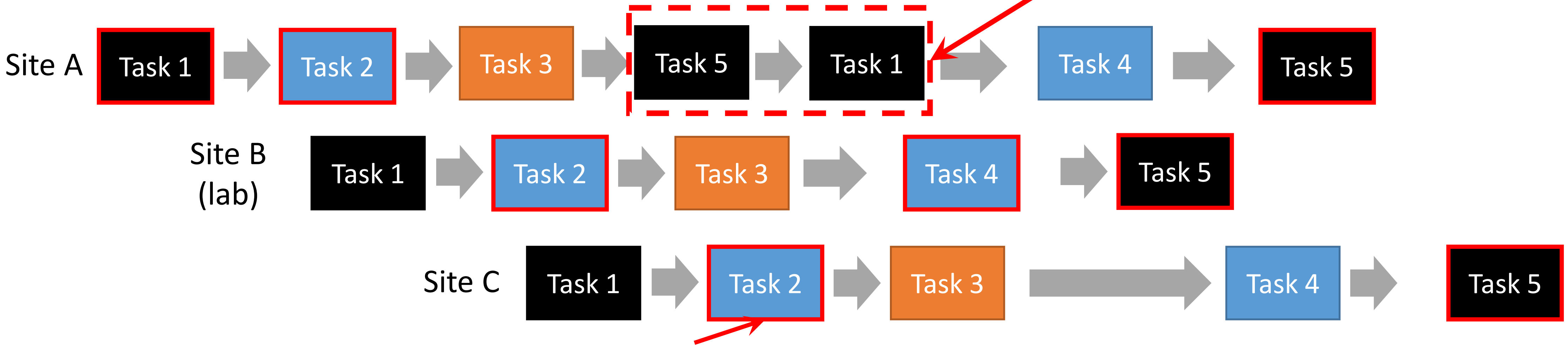
Task duration can be very uncertain …

Activity	Expected Time	Probability	STD	ES	EF
Prerequisite A	4	1	2/3	0	4
Prerequisite B	5	1	2/3	0	5
Task 1A	3	1	0	4	7
Task 1B	5	1	1/3	7	12
New task A	3	0.2	1/6	7	10
New task B	2	0.1	1/6	12	14
Task 2A	1	1	1/6	10	11

Communication and decision protocols can cause schedule updates at “handoffs”, sometimes generate “discoveries” and new tasks

Simulation for vulnerability analysis of the schedule and predicting impacts of human errors

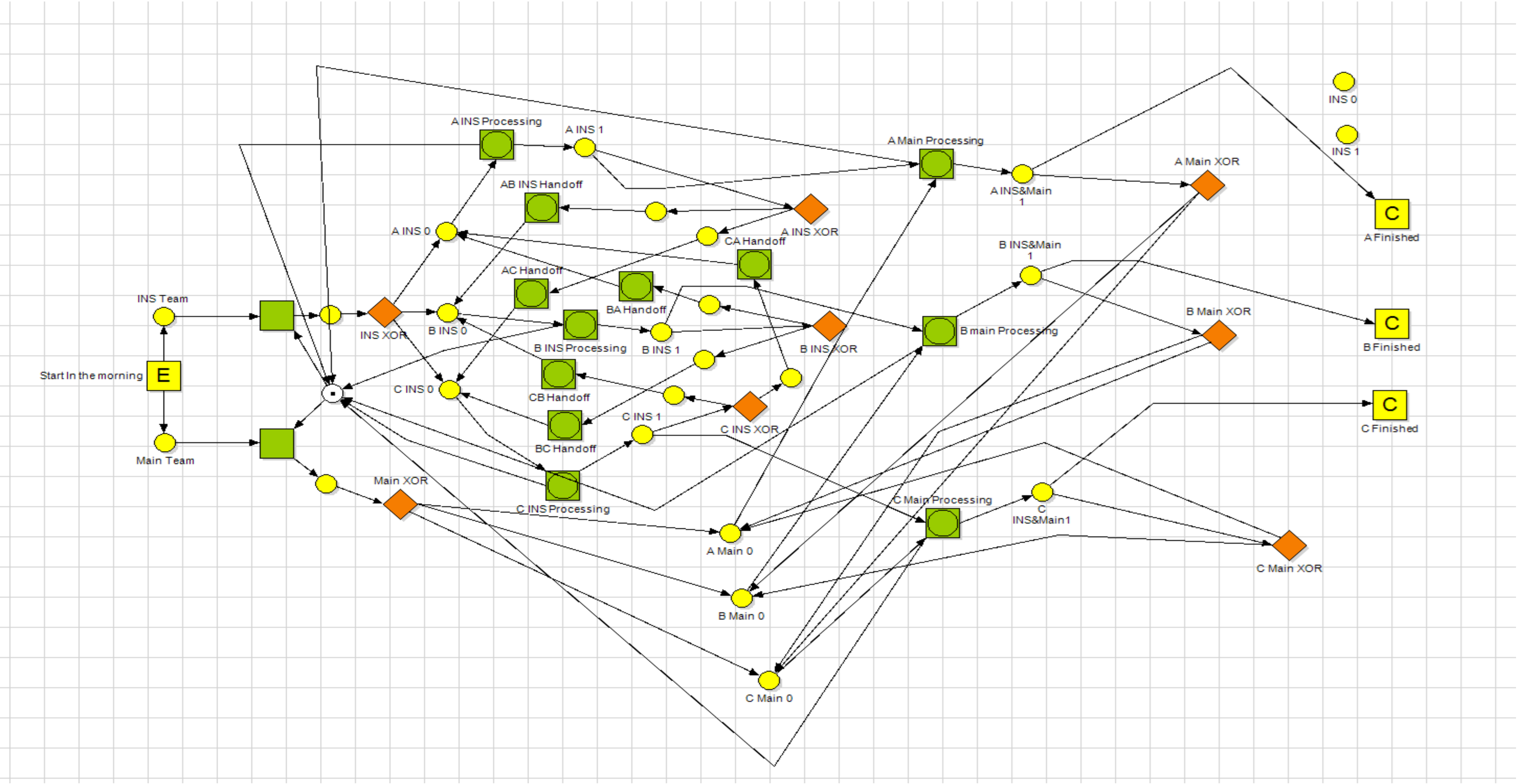
Mistake 2: After the crane operator finish Task 1 in site C, she didn't report to the OCC coordinator. She went to Site A for Task 5 instead.



Mistake 1: after Site A finished Task 3, the OCC coordinator forgot to send electrician to site A for task 4. The electrician went to Site C for Task 2 instead.

1.5 hour of delay for this 2-hour lab experiment

Large Petri-Net simulation



Simulation can do more for outages …

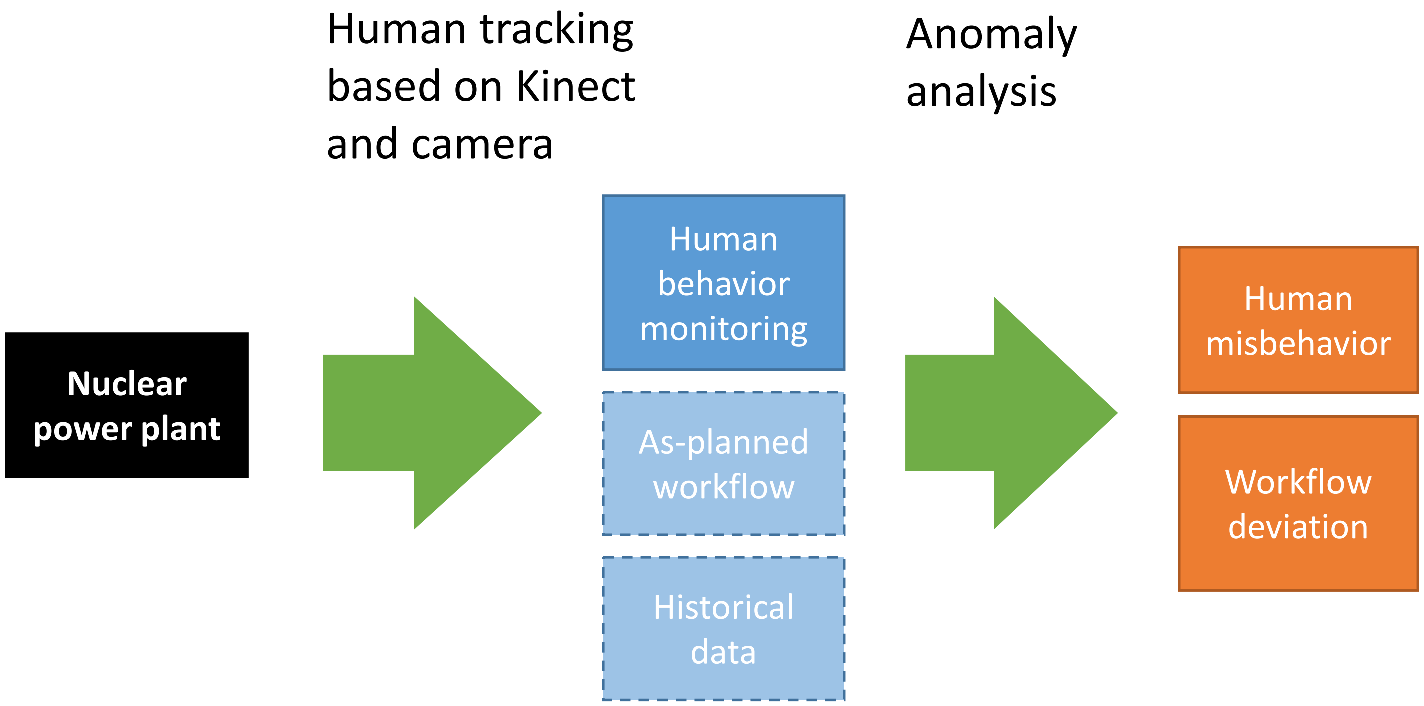
- Future study: 4D simulation for designing more resilient and reliable schedules

(Visual5D.com, https://www.youtube.com/watch?v=5uHzLV3gf78)

Technologies for diagnosing and controlling H-CPS behaviors in NPP outages

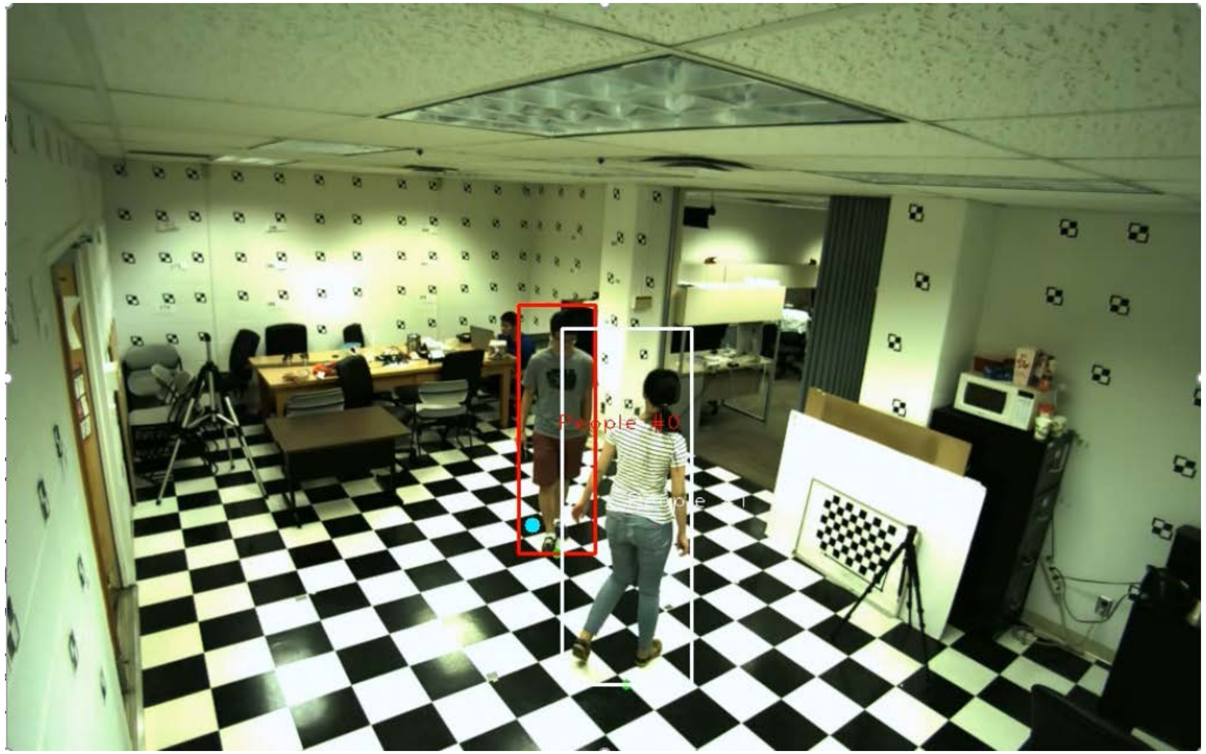
- Simulation of schedules and motions in the digital world
  - Schedule simulation that improve engineers' preparation for uncertainties in schedules
  - 4D simulation of field operations for identifying "clashes" between objects and activities
- Automatic data collection and analysis in the physical world
  - Automatic video analysis - Human motion analysis; Work order status tracking
  - Communication technologies – mobile device (e.g., Smart Watch), sociometric badges
  - Natural language processing for automatic analysis of work orders and event reports
  - Localization and tracking technologies – GPS, RFID, WiFi
- Human and team behavior modeling and prediction methods

Automatically capturing spatiotemporal details in H-CPS of NPP outages – computer vision



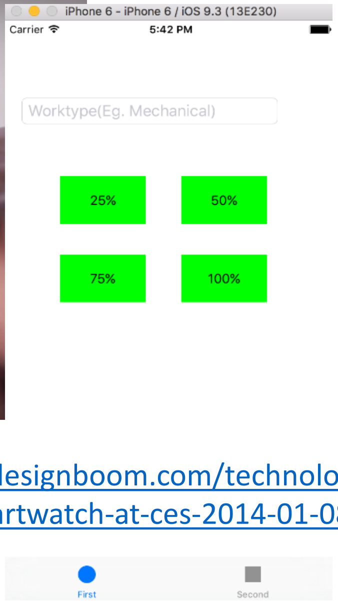
H-CPS abnormality analysis through automatic human counting & tracking

- Estimate the transportation time of different group of workers
  - Identify each individual human in the camera view
  - Label all humans to different groups
  - Locate different groups
- Identifying waiting and idling status
- Identifying the collaboration status between teams
  - Well collaborated
  - Quarreling
  - Having difficulties



Communication Technologies

- Using mobile devices for updating the status of work orders
- Using sociometric badges for capturing communication patterns and identifying anomalous communications that deviate from normal communication needs of certain tasks



http://www.designboom.com/technology/neptune-pine-smartwatch-at-ces-2014-01-08-2014/

(Ben Waber, http://www.slideshare.net/MassTLC/ben-waber-people-analytics)

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Natural language processing for automatic event report analysis

On 09/11/2008 the station experienced a loss of normal off-site power (LONOP) and a resultant reactor scram (ENS#44484). The Shutdown Checklist for the scram was approved to commence on 09/12/08 at 21:39. During a normal shutdown the Control Rod Drive (CRD) [AA] Reference Leg backfill system would be isolated prior to starting a CRD pump [P]. The backfill system was not completely isolated due to the individual performing the checklist having a question on how to safely access the valve [V]. The procedure was stopped and the individual brought the question to the lead operator. The checklist was set aside and not completed. The Control Room Reactor Operator did not notify the Control Room Supervisor (CRS) or Shift Manager (SM) of the safety concern or that the valve (CRD-141) was not closed. On 09/17/08 at 09:33 the Station experienced another LONOP due to the loss of 1R transformer [XFMR] with the 2R transformer isolated (ENS#44498). At 11:29 normal shutdown cooling was restored. Another Operating Lead sent an operator to close CRD-141 however vibration monitoring equipment was in the way. Again the CR Lead operator did not notify the CRS or SM of the difficulty in isolating CRD-141.

On 09/20/2008 at 21:35 while in the process of placing the CRD system in service with #12 CRD pump the plant experienced a Reactor Water Low-Low Level signal. Actual Reactor Water Level remained at 64 inches throughout the event. Initial investigation revealed that the transient was caused by a pressure surge through the Reference Leg Backfill system following the start of the #12 CRD pump.

The procedure for starting a CRD pump was reviewed. The procedure did not address the position of CRD-141 or have a precaution about the effect of starting a pump with CRD-141 open. The isolation of the Reference Leg Backfill System is only addressed in the shutdown procedure and the shutdown checklist. Due to the complexity of some shutdowns the need to startup the CRD system may occur before the shutdown checklist steps have been completed.

Legend

- Time info
- Object
- Precursors
- Status or Change
- Error/Anomaly
- Human Individual

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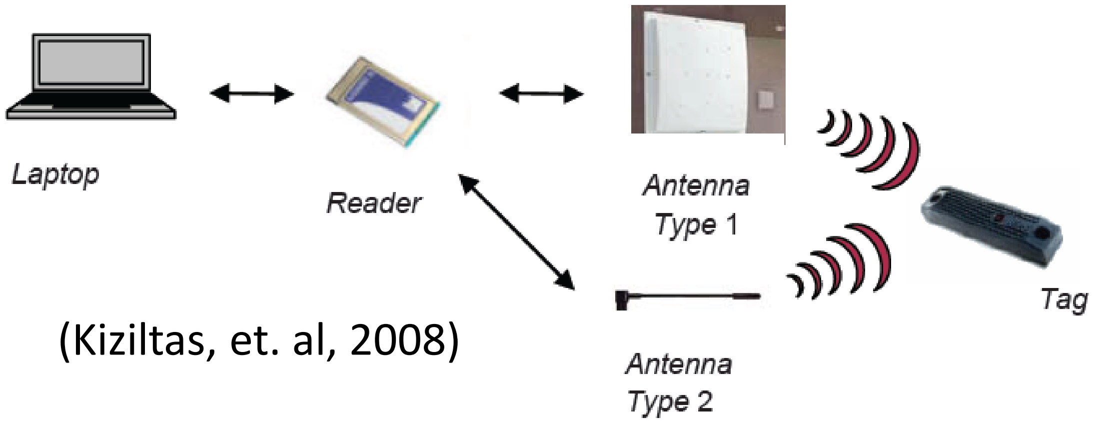
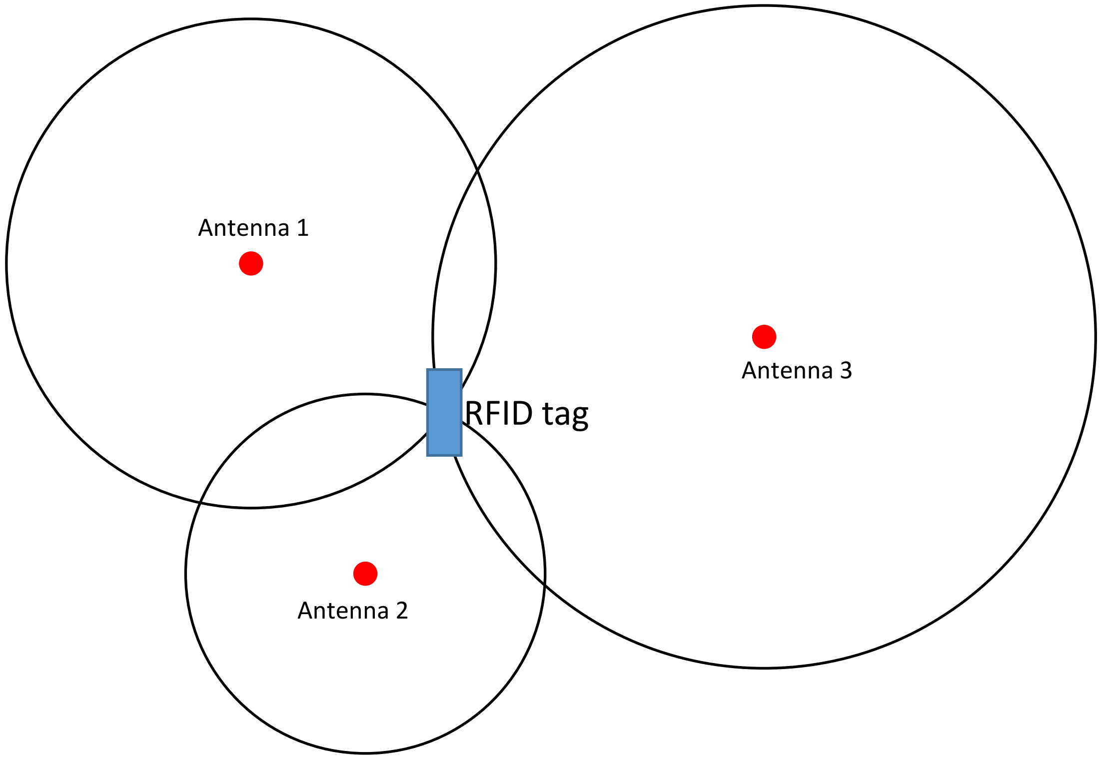
Localization Technologies

- Wifi
- GPS
- RFID
- Other localization technologies



(Kiziltas, et. al, 2008)



Triangulation localization of RFID tags
With 10 meter level accuracy

DEWSC
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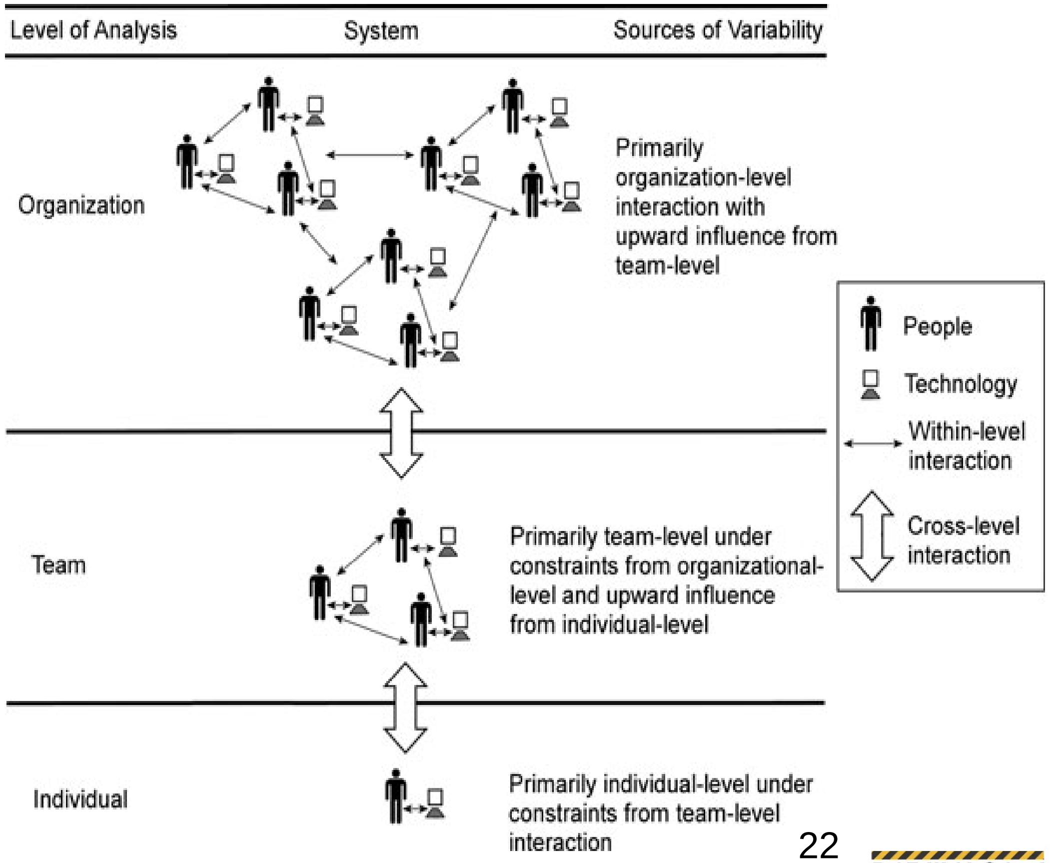
At the end of the day, understanding groups of human individuals in shutdowns!

- Interactive Team Cognition
- Team cognition is an activity, not a property or a product;
- Team cognition should be measured and studied at the team level;
- Team cognition is inextricably tied to context.

(Cooke et al, 2013)



Conclusions and Future Work

- Tight schedules and packed workspaces of shutdown projects of civil infrastructures and transportation facilities pose unique challenges of process monitoring and control
- Automatic spatiotemporal data collection and analysis is critical for understanding workflow and human performance in civil infrastructure shutdowns
- Multiple technologies are available for enabling a computational framework for automatic shutdown control and diagnosis Human-Cyber-Physical-Systems behaviors in shutdowns
- Further studies will focus on improving and integrating automation technologies based on the H-CPS framework proposed
- H-CPS is critical for complex transportation and civil infrastructure projects (large civil infrastructure/facility construction and maintenance under stringent time and resource limits, such as accelerated bridge construction)

Thank you!

Human-Cyber-Physical-Systems Engineering for Robust Shutdown Control of Civil Infrastructures

Presenter: Pingbo Tang

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[1]Arizona State University
[2]The Ohio State University
[3]Idaho National Laboratory
[4]Arizona Public Service Company

Will the New Connected and Autonomous Vehicle Technologies Impact Transportation Safety and Mobility?

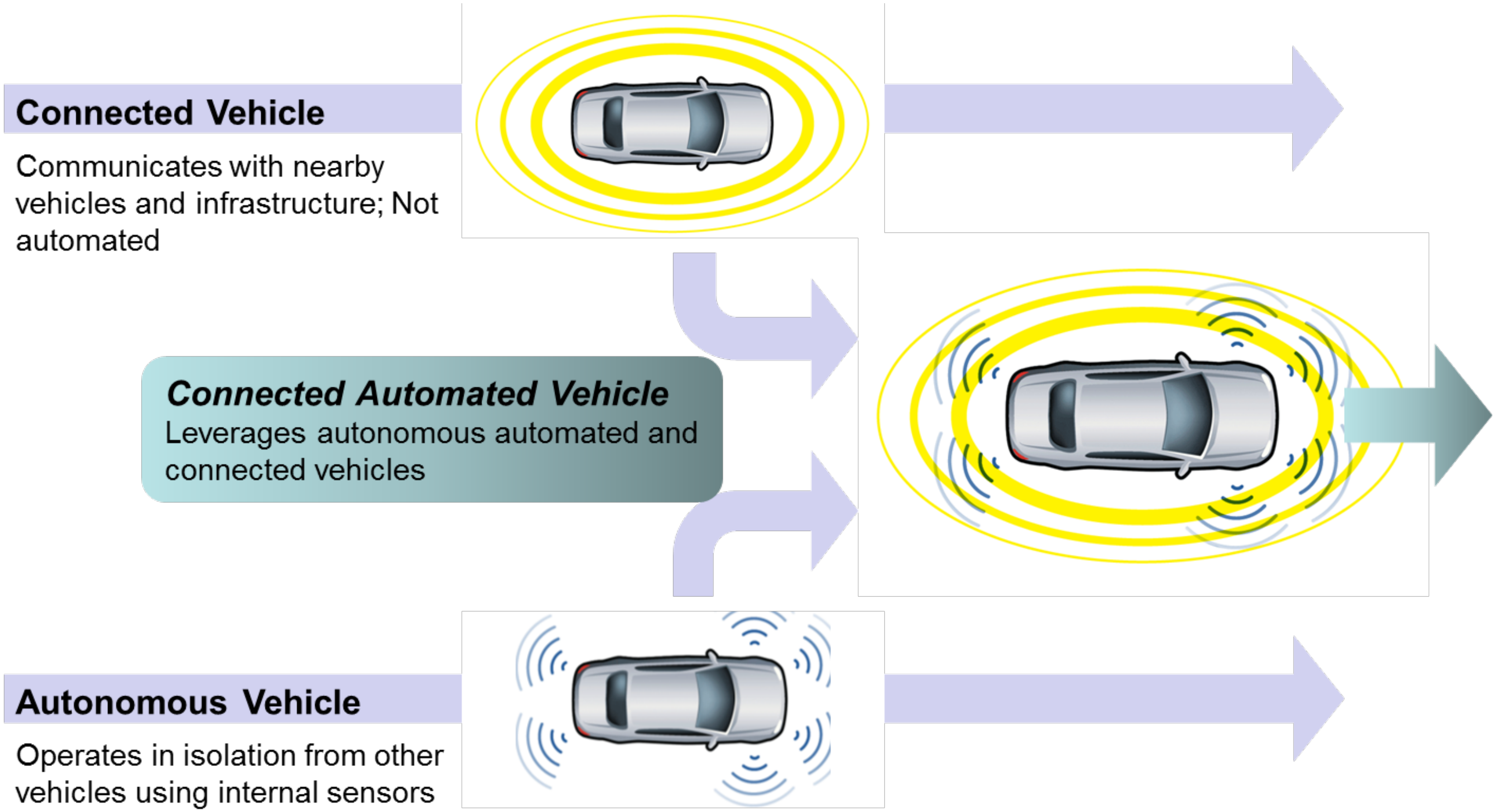
Federal Highway Administration

Director, Office of Transportation Management

Encouraging the Safe and Responsible Deployment of Automated Vehicles

The Evolution of Connected to Automated Vehicles

The path toward connected vehicles will ultimately lead to automated vehicles.



Areas Specific to Construction

Vehicle to Vehicle

- Safety
  - On Road Transportation to Work Site
  - Work Zone: Entering
  - Work Site Traffic
- Mobility
  - Work Zone: Exiting

Vehicle to Infrastructure

- Safety
  - Work Zone Operation
  - Worker Detection (V2P)
- Mobility
  - Energy Efficiency
  - Equipment Automation
  - Equipment & Material Coordination

Areas Specific to Construction

Automated / Autonomous

- Safety
  - On Road Transportation to Work Site
  - Obstacle detection (sensors)
  - Follow-on Truck

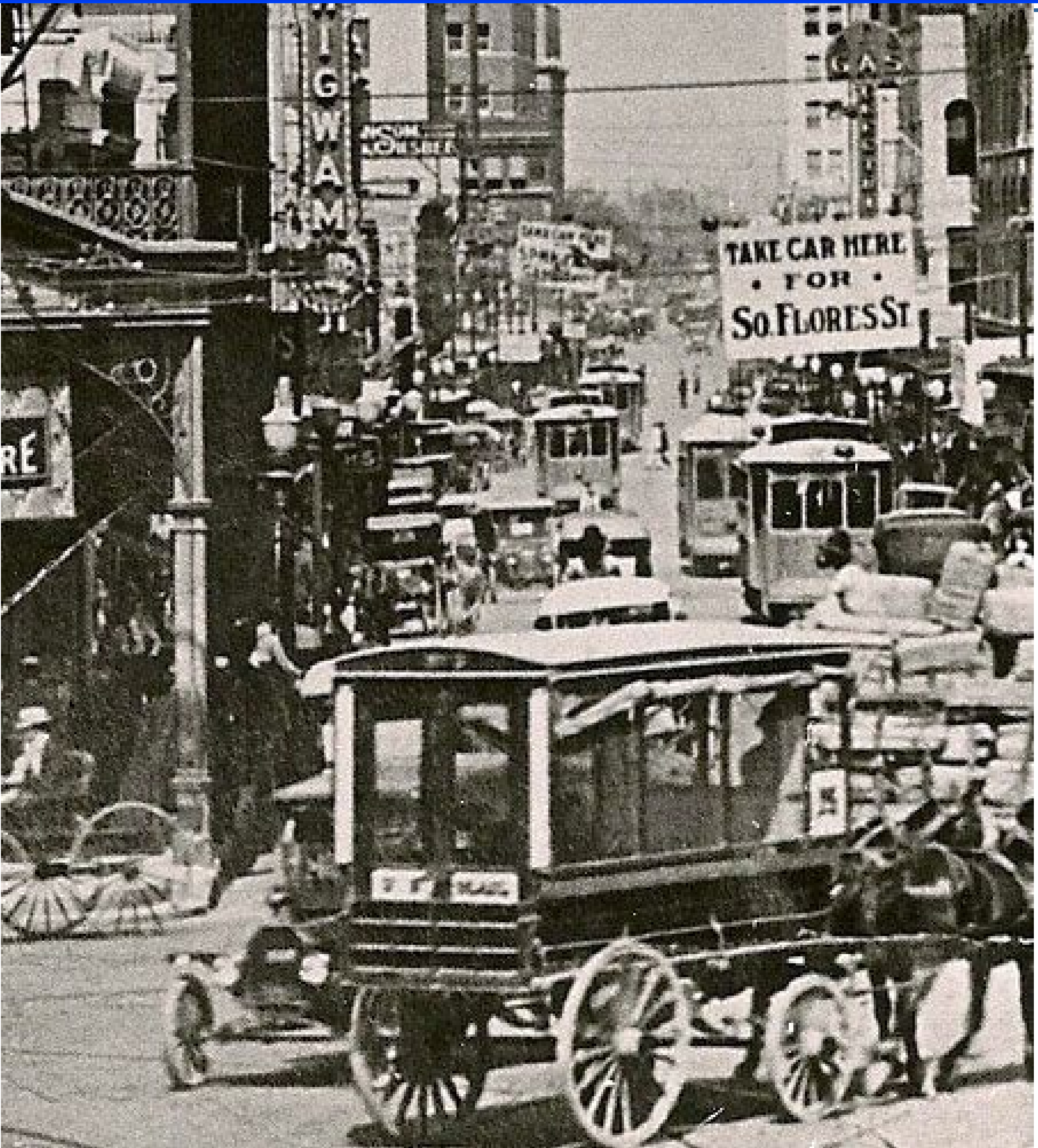
- Productivity
  - Earthmoving
  - Onsite Materials Handling
  - 24/7 Operations

Autonomous Attenuator Truck

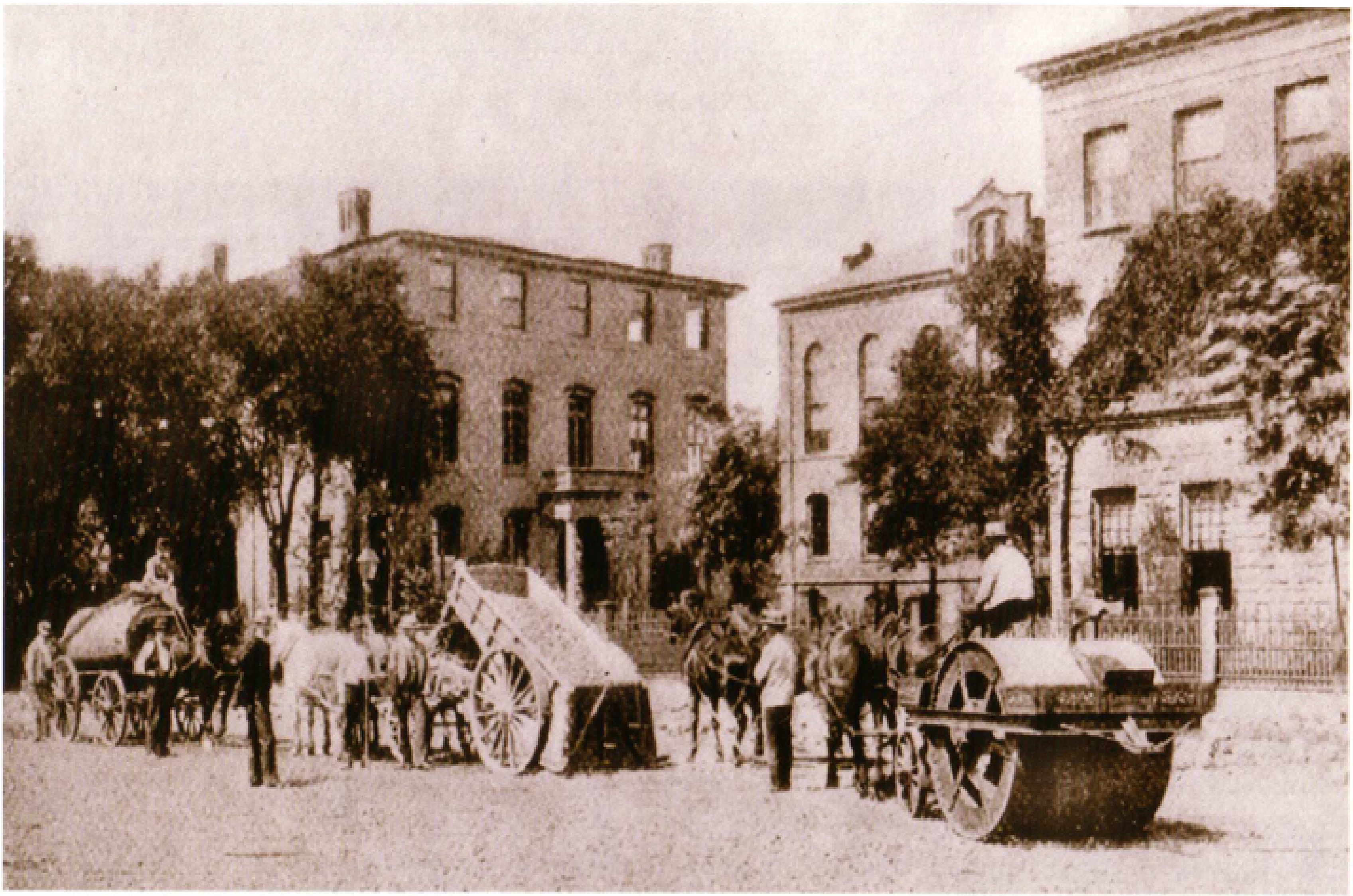
Could also be used to send out connected vehicle message warning of workers ahead

Worker Detection (V2P)

Vests with "connected" sensors can be embedded into highway construction workers' safety vest. These are now about the size of a cellphone but in the future can shrink to the size of a pack of gum.



Mixed traffic; wouldn't be the first time



Design

Enhancements

Lower lane widths

Increased capacity without larger footprint

Fewer signs

Accommodations

Refuge areas

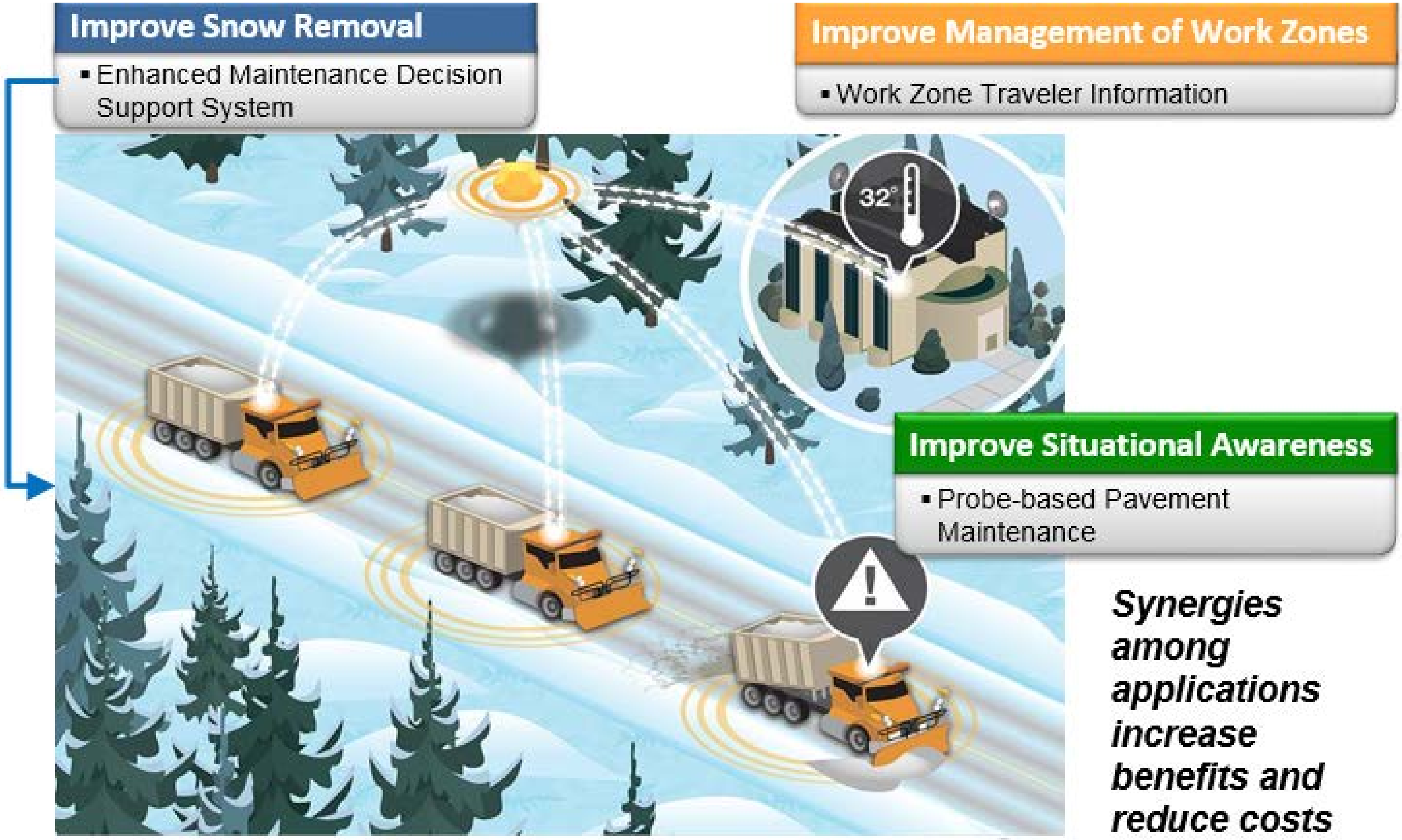
Improved markings

Roadside equipment maintenance / operations

Mixed fleets

Sample Deployment Concept

Improving the Efficiency of Road Maintenance

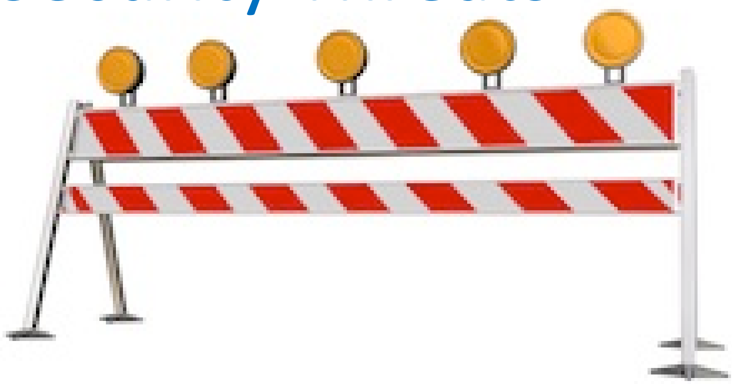


Synergies among applications increase benefits and reduce costs

Source: U.S. DOT

Roadblocks to Success

- Sustainable Deployment
- Cost to Consumer, Roadway Owners & Contractors.
- Maintenance and Operation Costs
- Adoption Rate in Fleet (V2V) & Operators (V2I)
- New Vector for Cyber-Security Threats
- Public Acceptance



Cyber-Security Dimensions of Threat

- Malicious attack
  - External
  - Internal
- Non-malicious operational error
- Improper firmware updates
- Lack of system reliability / maintenance
- Untrustworthy practices by the operator

Public Acceptance

DATA

Basic Safety Message

SECURITY

Public Key Infrastructure

PRIVACY

Certificate Management Security System

TRANSPARENCY

What it does & how its used

V2I Deployment Guidance/Products Website
http://www.its.dot.gov/V2I

National Work Zone Safety Information Clearinghouse
workzonesafety.org

National Operations Center of Excellence
http://www.transportationops.org/

Vehicle to Infrastructure Deployment Coalition
www.transportationops.org/V2I/V2I-overview

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