Off-Highway Autonomous Vehicles

A practical approach for assessing implications for industries and organizations

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Workshop Overview

Purpose

Present and illustrate a systematic method for assessing key implications of off-highway autonomous vehicles (AVs) for organizations

Intended Audience

- **Organizational Leaders & Planners:** Benefits and implications of AVs for operations and market opportunities
- **OEMs and Product Developers:** Enabling technologies and capabilities required for off-highway AVs
- **Service Providers:** Demands for new / expanded personnel competencies to support AV employment
- **Policy Makers:** Programs, resources, and regulatory structure to manage and support growth of AVs

Approach

Use sociotechnical system (STS) construct to identify implications of off-highway AVs for organizations

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Workshop Outline

- Background & Approach
- Process To Assess Organizational Implications of Off-highway AVs
- Key Considerations for Long-term Planning for Off-highway AVs

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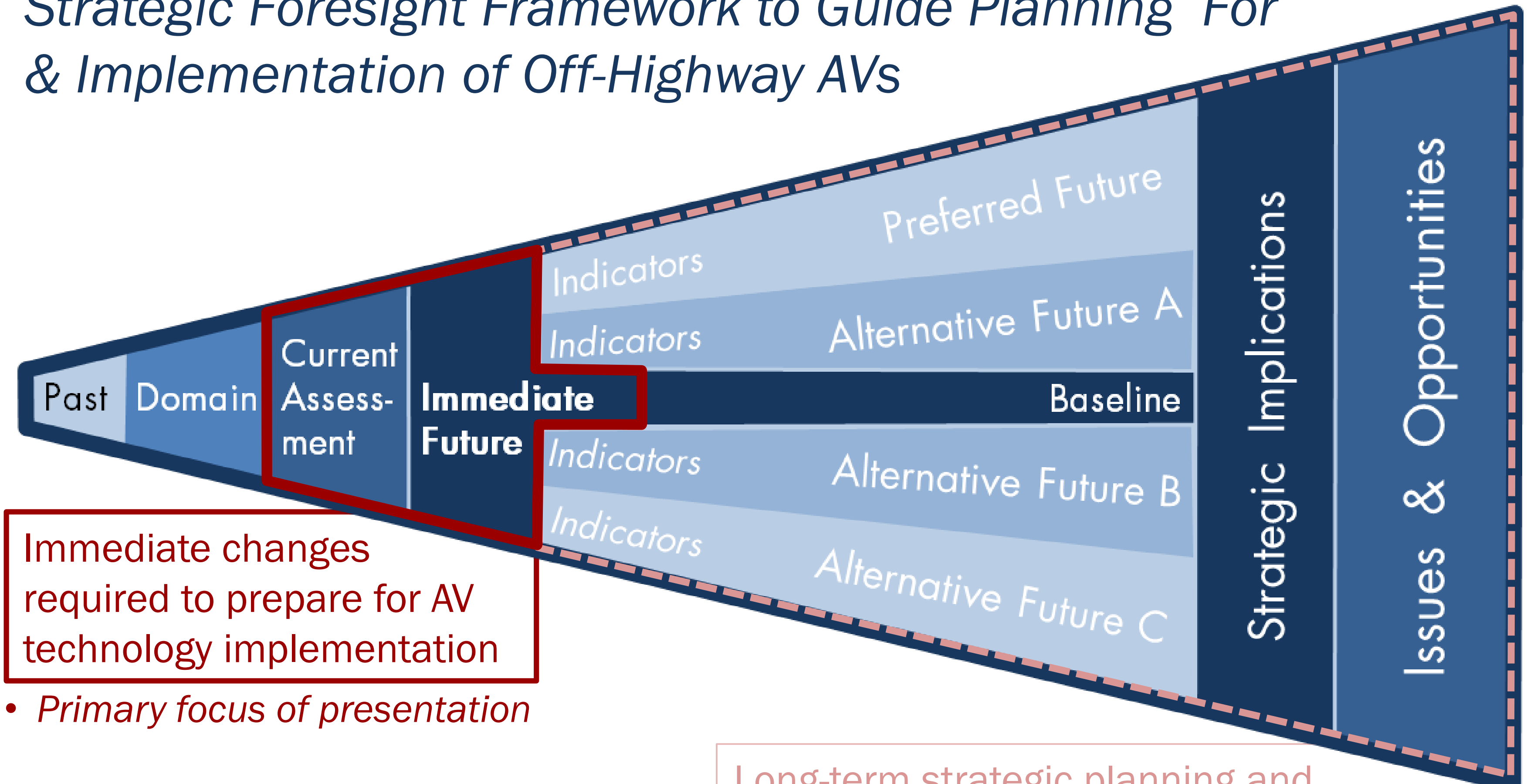
Strategic planning for AVs requires organizations to anticipate technical trends & commercial implications

Strategic Foresight Framework to Guide Planning For & Implementation of Off-Highway AVs



Immediate changes required to prepare for AV technology implementation

- *Primary focus of presentation*

Long-term strategic planning and investment required to plan for and realize AV-enabled growth opportunities

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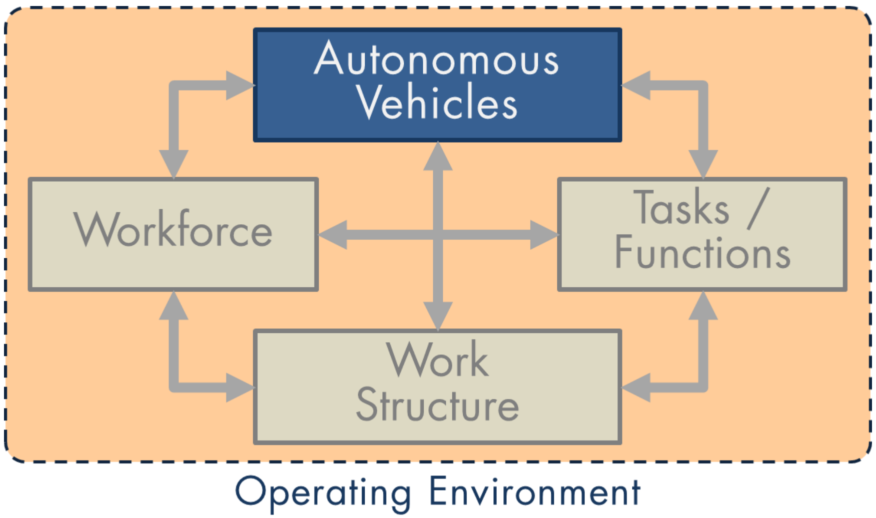
Billions of dollars of AV development is starting to deliver mature systems for off-highway AV applications

The Sociotechnical System (STS) <u>for AVs in Organizations</u>



Adapted from: Kwon & Zmud, 1987.

- Almost all attention has focused on the vehicle technology with little consideration of the wider implications for organizations

ASI Autonomous Dozer

Caterpillar Support Drone

Harvest Automation HV-100

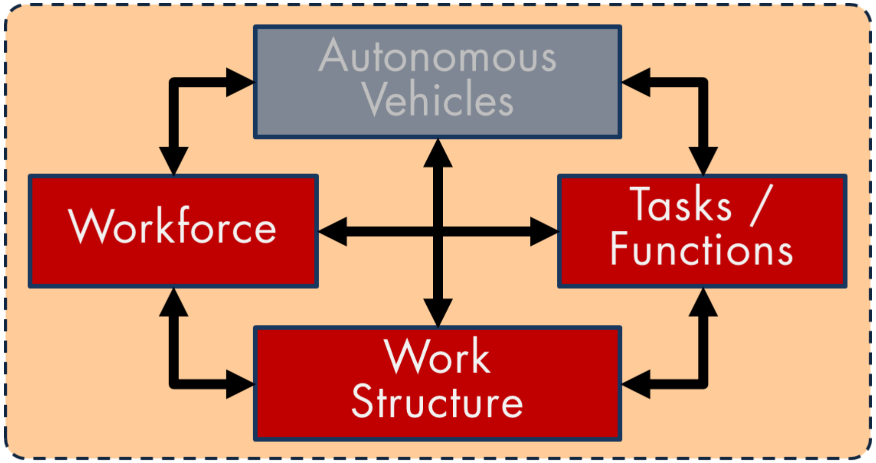
Terex Automated Guided Port Vehicle

Agile Robotics for Logistics (ARL) program

Jaybridge Autonomous Tractor

AVs have broader implications for organizations that require planning and investments to address

The Sociotechnical System (STS)
for AVs in Organizations



Operating Environment

Adapted from: Kwon & Zmud, 1987.

- AVs generally require enabling and supporting capabilities to realize their intended benefits
- System-level analysis and planning required to:
  - Identify market opportunities off-highway AVs present
  - Prioritize capital investments
  - Maximize potential AV benefits
  - Address long-term organizational impacts

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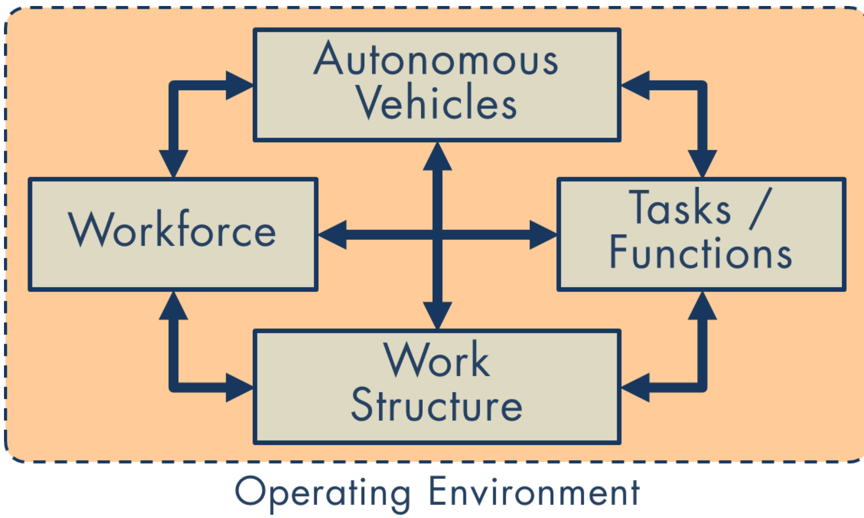
Organizational planning for AVs requires a systematic approach considering each sociotechnical system aspect

The Sociotechnical System (STS) for AVs in Organizations



Adapted from: Kwon & Zmud, 1987.

- The STS approach is especially important for considering the range of organizational implications for leveraging this new technology

STS Approach for Identifying Implications of AVs
1: Define Scope of the Socio-Technical System to Examine
2. Describe Key Aspects of STS Operating Environment
3.Describe the Planned AV Technology Changes for the STS
4. Define the Implications of the New Technology for STS Tasks & Functions
5. Determine Required to Changes to the STS Work Structure
6. Define the New STS Personnel Requirements
7. Identify And Prioritize Key Implications for Adaptation of the AV-enabled STS

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Off-highway AV implementation will have implications for many aspects of the sociotechnical system

Operational Planning

Training / Talent Acquisition

Workforce Planning

Off-Highway Autonomous Vehicle

Strategic Planning

Technology Investment

Market Strategy

Support / Enabling Capabilities

Terrain Mapping

Task Planning

Communications Infrastructure

Cyber / Info Security

Maintenance / Repair

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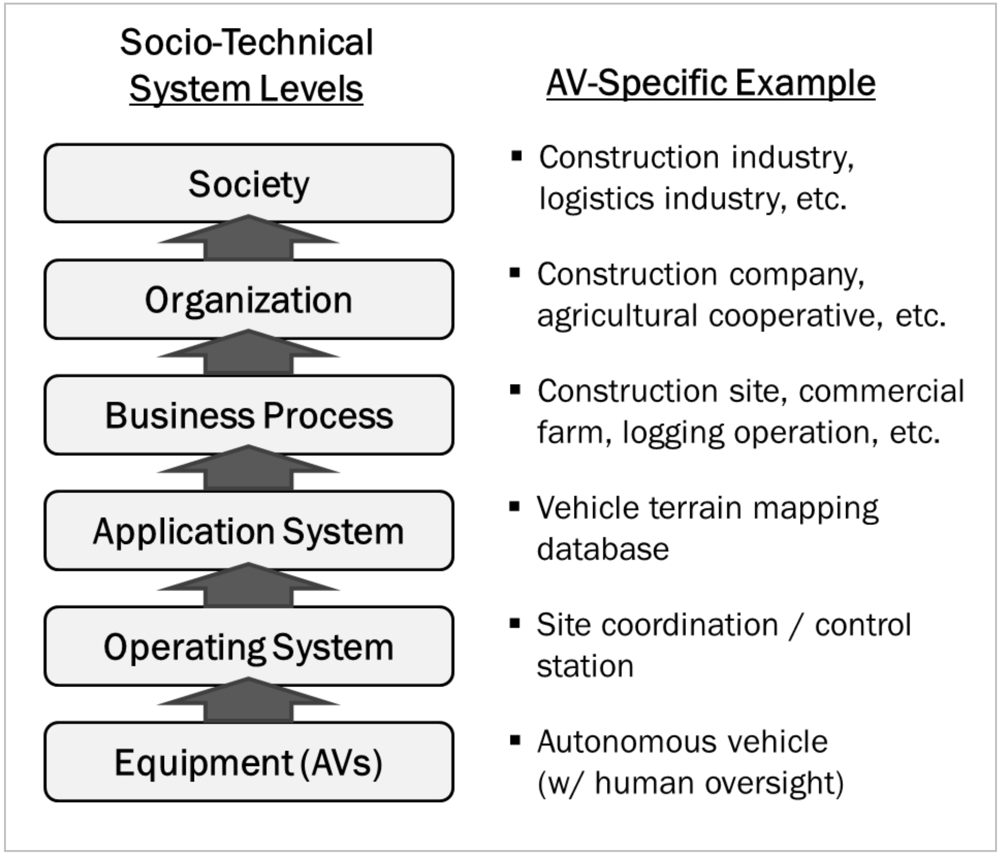
STEP 1: Define to scope of the socio-technical system for consideration



- **Sociotechnical System (STS): a set of interdependent systems and capabilities that include:**
  - Technical systems
  - Operational processes
  - The people who use and interact with the technical system

Organizations often consist of many discrete and nested STSs that may require explicit examination to assess likely impacts of AVs

STEP 2. Describe key aspects of the STS operating environment that impact AV use

Environmental Aspect	Description	Off-Highway AV Examples
Terrain (Natural & built)	Physical character of a piece of ground or area, especially with reference to its impact for operations	▪ Physical terrain, road or work site "furniture", static or dynamic obstacles, etc.
Infrastructure	The basic, underlying framework of facilities or systems features	▪ Availability and condition of transportation and communication systems to support AV operations
Legal/ Regulatory	Federal, state, and local laws and regulations that prescribe one more aspect of STS operations	▪ Occupational Safety & Health Act (OSHA) or International Safety Organization (ISO) requirements
Threats	An object, actor or event with ability to generate intentional harm or damage	▪ Cyber exploitation of vehicle data ▪ Denial of vehicle communications, GPS, etc.
Hazards	An object, actor or event with ability to generate unintentional harm or damage	▪ Human-vehicle, vehicle-vehicle, or vehicle-obstacle collision
Electro-magnetic	Of or relating to the interrelation of electric currents or fields and magnetic fields	▪ Sensor or communications signals ▪ Vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) communications
Weather / Atmosphere	The state of the atmosphere at a place and time as regards heat, cold, wind, precipitation, etc.	▪ Impact of participation, heat, or obscuration on AV sensor systems
Other Factors	Other aspects of the operating environment that can influence AV system and/or broader STS operating requirements	▪ Trade union agreements and negotiations (e.g., longshoremen's unions at ports)

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The off-highway regulatory environment is defined by many different guidelines, policies & standards

Airborne AVs (Drones, UAVs, etc.)

- Federal Aviation Administration (FAA) regulations

On-Highway AVs

- National Highway Traffic Safety Administration (NHTSA)
- State DOT laws, regulations, & policies

Off-Highway AVs

- IEC 61508: *Functional Safety of Electrical/ Electronic/ Programmable Electronic Safety-related Systems*
- OSHA STD 01---12---002 *Guidelines For Robotics Safety*
- ISO/TS 15066: *Robots and Robotic Devices -- Collaborative Robots*
- ISO 18497: *Agriculture and Forestry Tractors and Self-Propelled Machinery – Safety of Highly Automated Machinery*
- ISO/TC 204: *Intelligent Transport Systems*
- 29 CFR 1910 Subpart O: *Machinery & Machine Guarding*
- ANSI/RIA R15.06---2012: *Industrial Robots and Robot Systems Safety Requirements*
- UL 1740 *Standard Robots and Robotic Equipment*
- American Society of Agricultural and Biological Engineers (ASABE) standards
- ANSI/RIA R15.08– to be published???

Off-highway AV "operating space" can include immediate airspace for drone operation

- *400' AGL*
- *Max payload 55 lbs*

Due to the diversity of potential off-highway applications and operating environments for AV employment, there is a broad set of standards and regulations that can apply.

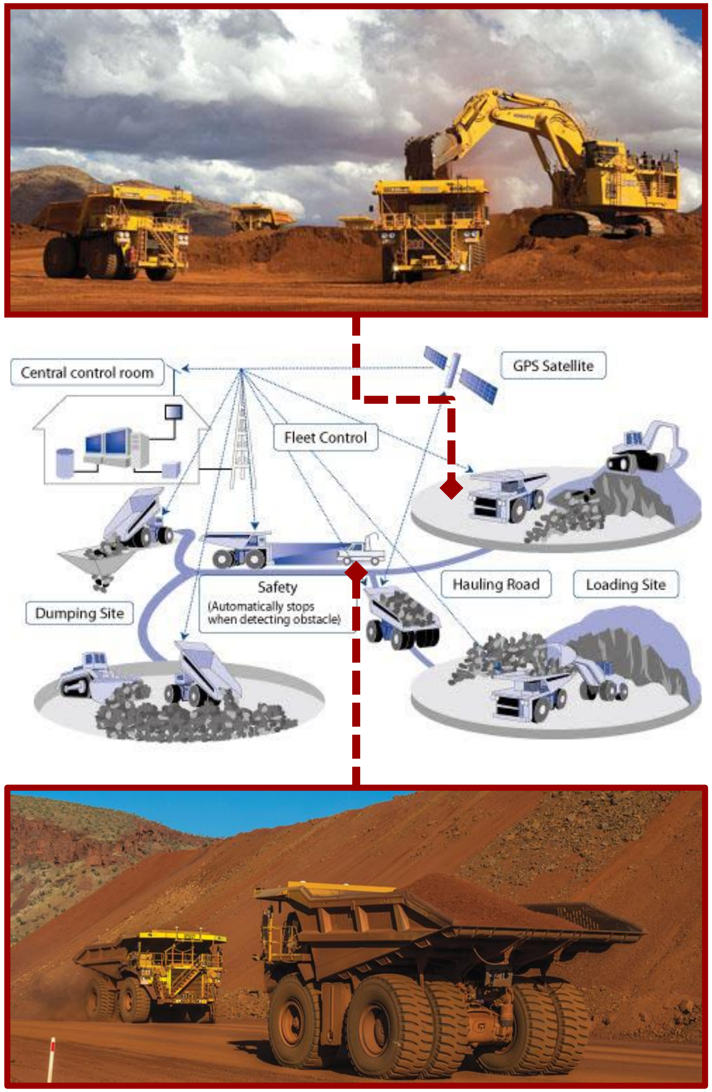
Example Case: Autonomous Operating Zones for coordination & safety of AV-enabled mines

Infrastructure (sensors, etc.) are used to dictate AV operations and ensure safe interaction of personnel and machines:

- **Autonomous operating zone:** specific area where automated operations occur and controlled access is needed.
- **Autonomous inclusion zone:** A more refined area limiting automated truck activity to a specific, controlled area

In this case the operating environment is closely related to the work structure aspect

- The autonomous operating and inclusion zones rare delineated by infrastructure (markings, etc.)
- Zones dictate explicit control of and segregation of human- and AV-executed tasks to ensure safety



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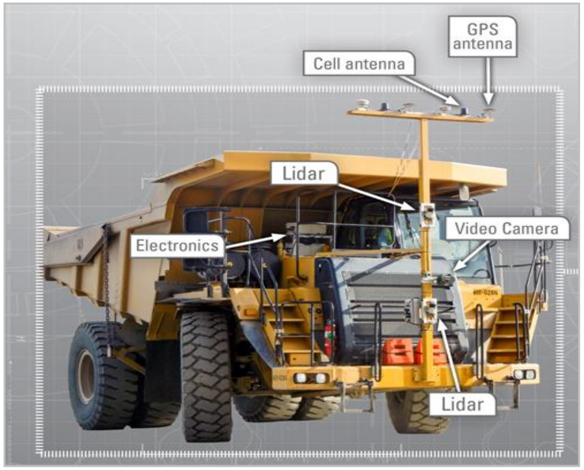
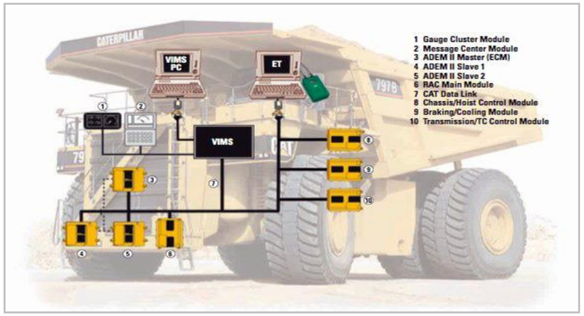
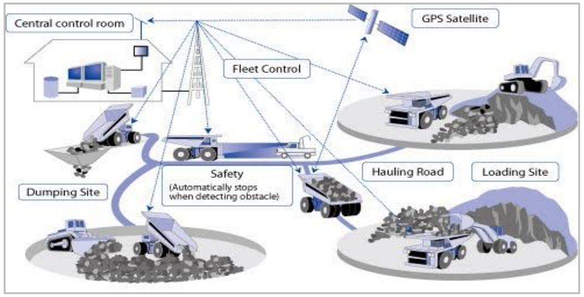
STEP 3. Describe the planned technology changes for the STS

- Requires systematic description of the technology changes that will change how key tasks are executed
- Should address the comparative functional benefits of the new technology
  - Rather than just technical specifications or performance characteristics, includes how the technology will benefit operation
- Often requires some initial assumptions based on newness of and limited experience with technology







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Example Case: Komatsu Intelligent Dozer with radio control changes operator tasks & function allocation

Standard Komatsu D155A-6 Crawler Dozer

- Manual in-cab control of vehicle movement
- In-cab operator controlled blade to execute dozing & grading tasks

Komatsu D155AXi-8 Crawler Dozer with Radio Control Option

Radio Control Features

- Line-of-sight remote control up to 100m away, without operator in cab
- Key machine functions controlled on remote transmitter
- Machine status indication via cab-top lights

intelligent Features

- Automatic blade control, rough to finish grade
- 3D GNSS technology for dozing of simple planes to complex surfaces9

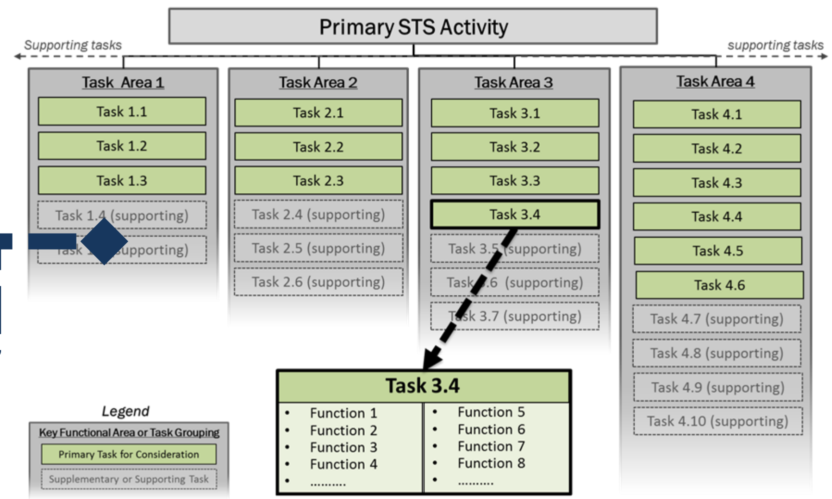
Komatsu's automated dozer could change tasks and allocation of functions within the man-machine STS that could ultimately impact work structure and the workforce

STEP 4. Define the implications of the new technology for the tasks and functions executed by the STS

- Assessing impacts of AV technology to tasks starts with task analysis
  - Task Analysis: Describing the physical tasks and cognitive plans required for the STS to accomplish its particular work goal
- There are multiple potential task analysis methods based on STS characteristics:

	Task Analysis Method
Action Oriented Techniques	▪ Hierarchical Task Analysis (HTA)
	▪ Operator Action Event Trees (OAET)
	▪ Decision/action flow diagrams
Cognitive Task Analysis Techniques	▪ Critical Action and Decision Evaluation Technique (CADET)
	▪ Influence Modelling and Assessment Systems (IMAS)

Illustrative STS Task & Function Hierarchy for Systematic Analysis



- Hierarchical Task Analysis (HTA) is often the preferred task analysis framework due to its simplicity and flexibility

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Identifying the impacts of and opportunities for task automation requires examination of the "task profile"

- Task Profile: The collection of tasks executed by the STS and frequency they are executed

Factors Influencing Feasibility of Task Automation	Example Considerations
Frequency of Task Execution	▪ How often and for what portion of total duty time is task executed
Consistency of Task Iteration	▪ Amount task execution can vary between iterations based on determinate factors
Risks Associated With Task Issues or Failure	▪ Probability and consequence of unintended impacts personnel, property, equipment, or task
Task Complexity	▪ Number of considerations, execution steps, and dependencies
Certainty of Task Determinate Factors	▪ Size and complexity of environmental and other variable factors influencing task execution
Predictability of Task Execution	▪ Objective and clear criteria identifying when task must be executed

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Example Case: Task profile comparison for different excavator applications based on task analysis

APPLICATION	TASK	TASK CONDITIONS
Operate an excavator for surface work at an extractive site 	1. Load and place materials for surface work at an extractive site 2. Excavate and strip materials for surface work at an extractive site	▪ Reversing , working on slope, working on “benches”, working on unstable ground, wet or dry conditions, day or night shift
Operate a hydraulic excavator on a demolition site 	1. Maneuver and control the excavator within the workplace slew and working clearances	▪ Overhead wires, underground services, proximity of people and vegetation, trenching works, structural works, handling loads
	2. Use an excavator and attachments for demolition work	▪ Wood shears, steel shears, cracker jaw, grapple, pulverizer, impact hammer, pusher arm, grapple
	3. Sort, place, and load materials	
	4. Move an excavator between sites positioning of attachments, parking machine	

Excavation is a more consistent and predicable task profile than the complex and highly varied task profile for demolition

Example Case: Potential for development of AVs for flue-cured tobacco harvesting

- For small tobacco allotments (under 100 acres), manual picking is still preferred due to impacts of task mechanization on quality
  - Profit adversely impacted by decrease in quality when using machinery
- Large tobacco farms currently leverage mechanized harvesters to increase efficiency and offset decrements to harvest quality
- Federal policies limit number and size of tobacco allotments, limiting market for automated systems

Despite tobacco harvesting being an apparently simple task to automate, market size and commercial opportunities dissuade AV implementation

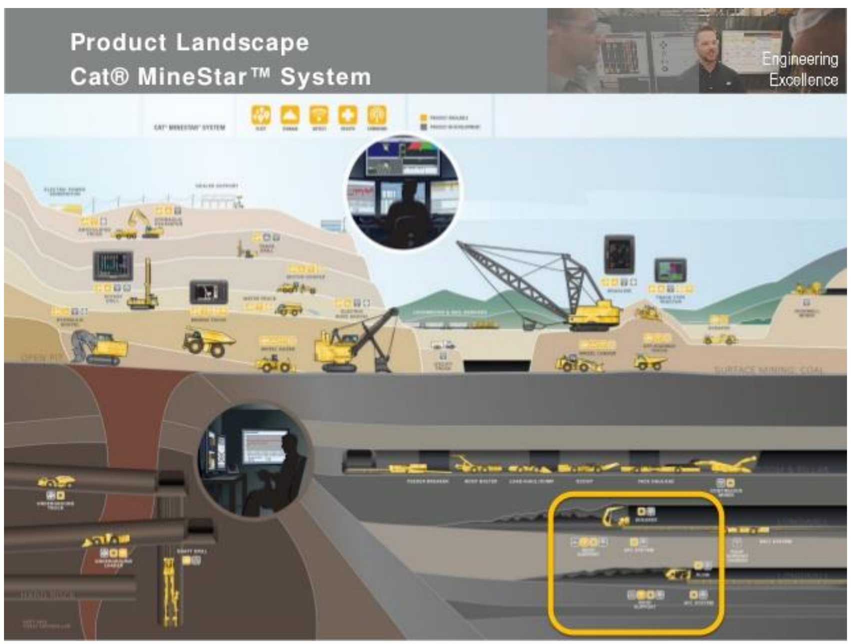
	Mechanized Tobacco Harvesting	Manual Tobacco Harvesting
		
Task Description	Picking leaves from tobacco plant based on set picking height	Identifying & picking ripe leaves from tobacco plant based color (maturity)
Benefits	▪ Increases speed of picking operation	▪ Provide judgement to determine ripeness of leaf based on color
Issues	▪ Does not consider leaf ripeness when picking ▪ Results in lower quality / price of tobacco bale ▪ Equipment major investment	▪ Requires grueling and sometimes hazardous labor ▪ Laborers only required for short harvest season
Technical Potential for Autonomous Solution	▪ High ▪ Primarily requires mature row keeping & actuation technology	▪ Moderate ▪ Would require sensors & dexterity to identify / pick only ripe leaves

STEP 5. Determine required changes to the STS work structure

- **Assessing work structure changes requires determining roles and responsibilities needed for STS to execute AV-enabled operations**
  - Roles & responsibilities major determinants of workforce changes needed (STEP 6)
- **Key areas of concern for AV-enabled operations include:**
  - Span of control issues
  - Cognitive
  - Communications requirements/ limitations (connectivity, etc.)
- **HMI and AI technologies can help mitigate challenges associated with AV-enabled work structure**

Example Case: Caterpillar MineStar System to support AV-enabled work structure in mines

- Cat MineStar System leverages interaction and communication technologies to support the AV-enabled STS work structure



Cat Minstar Components for Management of Mine Truck AVs	
FLEET	▪ Supports productivity management for mine truck AVs
COMMAND	▪ Adds additional levels of safety and control for AVs to Fleet System
TERRAIN	▪ Communicates commands from manned equipment to mine truck AVs such as queuing, spotting and capturing terrain survey data
DETECT	▪ Provides positioning and sensing to give mine truck AVs information about their location and proximity to other mine assets
HEALTH	▪ Provides critical event-based information for proactive AV maintenance management

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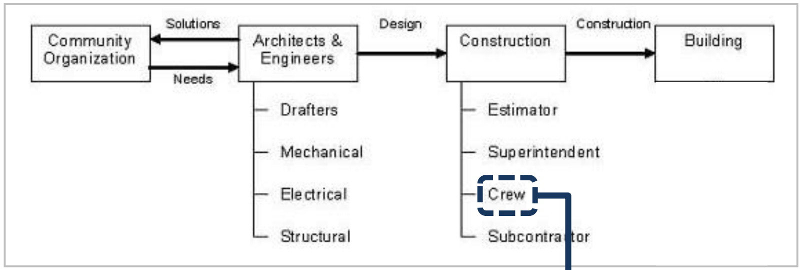
STEP 6. Define the personnel requirements for the AV-enabled STS

- Identify the knowledge, skills, and attitudes (KSAs) required for each role or position in the AV-enabled work structure (from STEP 5)
- Determine required changes to career progression for each role or position identified
  - To support growth of personnel across sequential roles of increasing responsibility
- Determine key changes in workforce requirements for AV-enabled STS
  - New KSAs required
  - Old KSAs / roles no longer need
  - 2nd / 3rd order impacts (e.g., recruiting)

Design and Construction Team Breakdown



Process Manager / Remote Vehicle Operator
(replaces one or more construction crew in AV-enabled STS)

Required KSAs for Role in AV-Enabled STS

Process Manager / Remote Vehicle Operator	
K	
S	
A	

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Example Case: Knowledge, skills, & abilities (KSAs) for Heavy Equipment Operator versus Robotics Technician

	Heavy Equipment Operator	Robotics Technician
Knowledge	▪ Truck and equipment safety ▪ Operation of front end loaders, dozers, graders, compactors, & other heavy equipment ▪ Equipment maintenance, cleaning, & storage procedures ▪ Workplace safety requirements and procedures	**Computers and Electronics:** Knowledge of electronic equipment , computer hardware, and software, including applications and programming. **Engineering and Technology:** Knowledge of the practical application of engineering science and technology. **Mechanical:** Knowledge of machines and tools, including their designs, uses, repair, and maintenance.
Skills	▪ Operate equipment in a safe manner ▪ Client service & public interaction skills ▪ Analytical & problem solving skills ▪ Decision making skills ▪ Ability to communicate effectively ▪ Time management skills	**Troubleshooting:** Determine causes of operating errors and deciding remedies **Critical Thinking:** Use logic & reasoning to develop & assess alternative approaches **Equipment Maintenance:** Perform routine maintenance on equipment and determine kind of maintenance needed
Abilities	▪ The incumbent must demonstrate the following personal attributes: ▪ honesty & trustworthiness ▪ respectfulness ▪ cultural awareness & sensitivity ▪ Flexibility	**Manual Dexterity:** Make precisely coordinated movements of one or both hands to grasp and manipulate controls. **Information Ordering:** The ability to arrange actions in a certain order or pattern according to a specific rule or set of rules

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STEP 7. Identify & prioritize key implications for developing and sustaining the AV-enabled STS

STS Area	Key Implications of Off-Highway AV Implementation
Tasks	
Work Structure	
Personnel	
Technology	
Other Implications	

Identify and prioritize the most significant identified implications of AVs for the STS based on:

- **Costs:** Amount of resources required to execute and sustain actions to address implication
- **Savings:** Opportunity to save money or resources through application of AV technology
- **Risk:** Probability and impact of secondary impacts from STS change
- **Comparative advantages:** Overall increase or decrement to one or more STS performance aspects based on addition of AVs
- **Breadth of organizational impact:** Extent to which implication will generate impacts to other aspects, levels, and/or functions of the organization
- **Consistency with Organizational Values:** Extent to which the implication supports or counters explicit and implicit organizational values

Example Case: Major implications of autonomous mine truck implementation for Rio Tinto's open mine STS

STS Area	Key Organizational Implications
Tasks / Functions	• **Some Existing Tasks Reallocated to AV Systems:** Routine and repetitive driving and dumping tasks executed by AV system; human intervention only for issues • **New Tasks & Functions Created:** Remote vehicle monitoring and oversight, detailed terrain mapping required for AVs to navigate and detect obstacles
Work Structure	• **Span of Control:** A "primary driver" & "copilot" must control 30-truck mine fleet • **Command & Control:** Developed a connected command center for required monitoring and control of autonomous trucks
Personnel	• **Workforce Reduction:** Technology enabled 93% reduction in workforce required to operate mine truck fleet • **Workforce Adaptation:** Significantly increased cognitive load and required knowledge, skills, and abilities (KSAs) for remaining personnel • **Reduced Site Manning / Life Support Costs:** Significantly reduced requirements for moving to and maintaining personnel at remote mines
Operating Environment	• **Benefit of Relatively Static Environment for AV Implementation:** Relatively constrained, static, and controlled mine environment key factor in successful implementation of AVs • **Communications Infrastructure Investments :** Robust communications network required for reliable connectivity with and control of autonomous mine trucks

Anticipating these implications requires examining the entire sociotechnical system

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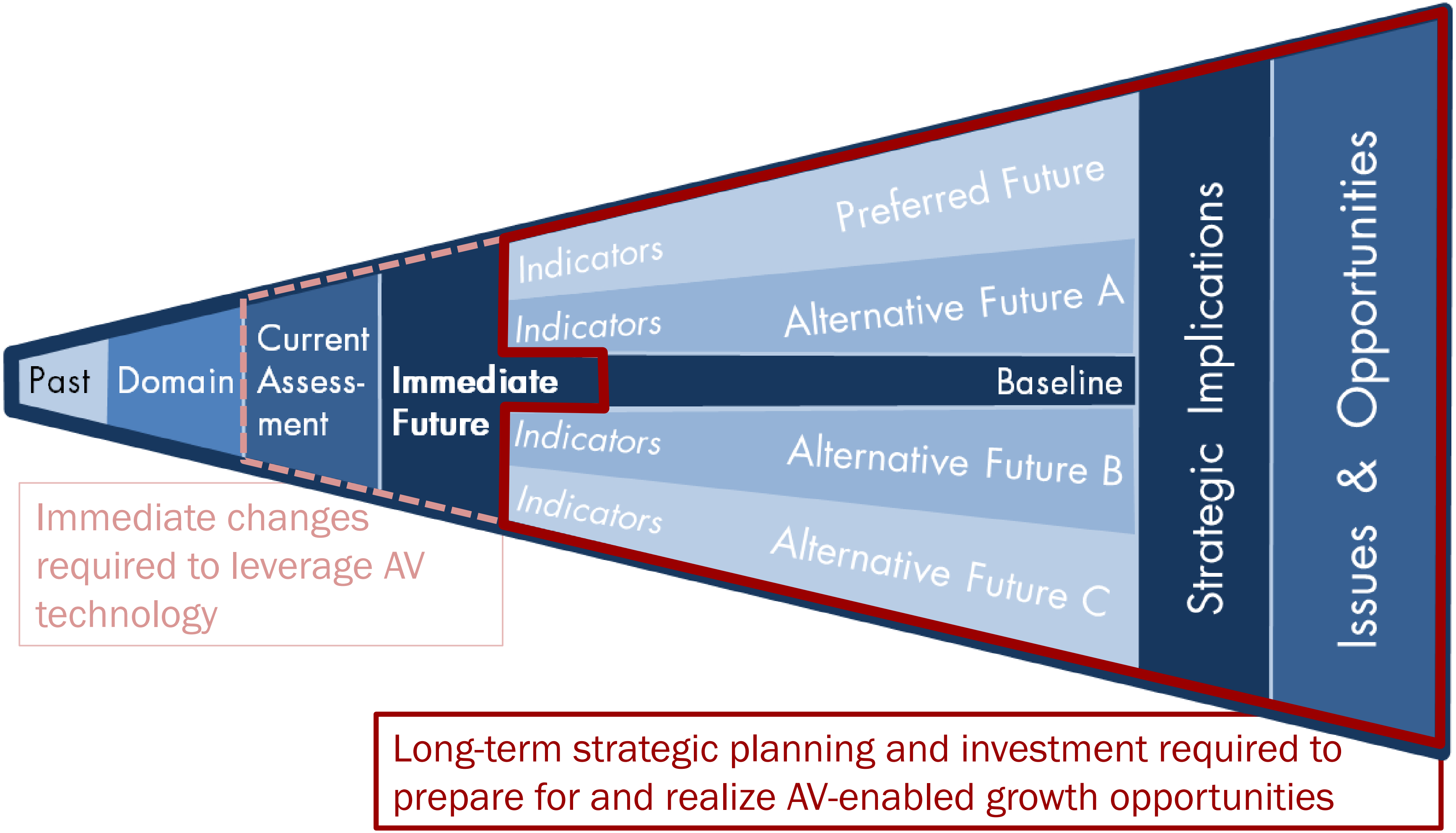

Determining the strategic direction of AV trends requires considering multiple potential futures based on variations in key indicators

Key considerations to guide organizational preparation for off-highway AVs

- **Off-highway AVs function within sociotechnical systems (STS) and will significantly change organizations**
  - Organization-specific consideration and planning is required to plan for and implement off-highway AVs
- **Anticipating impacts and opportunities of disruptive AV technology requires considering all the STS aspects**
  - The STS operating environment is often location- and organization-specific
  - Regulatory environment is a particularly significant STS constraint
  - Major workforce changes will often require long-term planning

This presentation provides a replicable process and example cases to guide organizational planning for off-highway AVs

Example Case: U.S. Army strategic concept for off-highway AVs to address battlefield logistics challenges

- **Concept:** The automation and optimization of moving, storing, tracking, modeling and managing supplies in an efficient and effective way to optimize battlefield logistics

- **Issue:** In forward combat areas supply points are large consumers of scarce resources and the cause of significant through-put delays/bottlenecks

- **Program Objective:** To demonstrate integrating the control and operation of an entire supply point which has been enabled with automation into a single globally-optimized system

U.S. Army Automated Supply Point Scalable (ASP-S) AV Concept & Execution Plan

Source: TARDEC Autonomous Ground Resupply (AGR) Science Technology Objective (STO)

This Army AV development program focuses on the AV technology, but requires consideration of the broader implications to all other aspects of the logistics STS

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Framework for Assessing Implications of Off-Highway AV for Organization (Part 1)

		Description
1. STS Description / Scope		
2. STS Operating Environment	Terrain (Natural & built)	
	Infrastructure	
	Legal/ Regulatory	
	Threats	
	Hazards	
	Electro-magnetic	
	Weather / Atmosphere	
	Other Factors	
3. AV Technology Description		

Framework for Assessing Implications of Off-Highway AV for Organization (Part 2)

			Description
Impacts of autonomous vehicle technology for STS…	**4. Tasks / Functions**	**Task 1:**	
		Task 2:	
		Task 3:	
		Task 4:	
	5. Work Structure		
	6. Personnel		
Other Impacts / implications			

Framework for Assessing Implications of Off-Highway AV for Organization (Part 3)

	Prioritized Implications	Implication Description	Organization Actions to Address Implications
y. Prioritized Implications for STS	Priority 1:		
	Priority 2:		
	Priority 3:		
	Priority 4:		
Other Impacts / implications			