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INTEGRATED APPROACH TO HAZARDOUS AND RADIOACTIVE WASTE REMEDIATION[a]

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I. ABSTRACT

The U.S. Department of Energy Office of Technology Development is supporting the development, demonstration, and evaluation of a suite of waste retrieval technologies. An integration of leading-edge technologies with commercially available baseline technologies will form a comprehensive system for effective and efficient remediation of buried waste throughout the complex of DOE nuclear facilities. This paper discusses the complexity of systems integration, addressing organizational and engineering aspects of integration as well as the impact on human operators, and the importance of using integrated systems in remediating buried hazardous and radioactive waste.

II. BACKGROUND

The amount of buried waste located throughout the complex of U.S. Department of Energy (DOE) facilities is estimated at approximately 3.1 million cubic meters. Approximately half of all DOE buried waste was disposed of before 1970. At the time, disposal regulations permitted the commingling of various types of waste (i.e., transuranic, low-level radioactive, and hazardous waste). As a result, much of the buried waste is believed to be contaminated with both hazardous and radioactive materials. Interstitial soils are also believed to be contaminated as a result of these disposal practices, significantly increasing the volume of materials that require remediation.

Subsurface Disposal Area (SDA) waste pits were excavated to the underlying basalt layer and generally backfilled with 2 to 5 feet of soil to provide a level floor. SDA trenches were excavated to the basalt layer approximately 10 feet below the surface and averaged 7 feet in width by as much as 1,800 feet in length. Following excavation, wastes were placed or dumped into the pits and trenches. Typical buried waste includes construction and demolition materials (e.g., lumber, concrete blocks, and steel plates), laboratory equipment (e.g., hoods, desks, tubing, and glassware), process equipment (e.g., heat exchangers, valves, ion exchange resins, and air filters), maintenance equipment (e.g., hand tools, cranes, oils and greases), and decontamination materials (e.g., paper, rags, and plastic bags). A variety of disposal containers were used including steel drums (i.e., 30, 40 and 55-gal. capacity), cardboard cartons, and wooden boxes (i.e., up to 105 × 105 × 14 inches). Larger individual items were disposed of separately as loose trash. Degradation of the waste containers is believed to have resulted in contamination of the surrounding soil.

During the summer of 1995, the Buried Waste Integrated Demonstration (BWID) Program will

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DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED perform an integrated field demonstration at the Idaho National Engineering Laboratory (INEL). The demonstration will be conducted using several equipment systems and a simulated buried waste test pit. The scope of the demonstration includes the characterization and retrieval of the simulated waste within the confines of a containment structure, and removal of the simulated waste from the site. System equipment will include an excavator, gantry crane, and a conveyance mechanism. Tasks will include removal of overburden soil, isolation of waste, movement of waste material to a transport container, and conveyance away from the dig site. All aspects of this process will be operated remotely from a control station housed in a separate building. This remote operation poses many difficulties, including visualization of the dig site and equipment positioning, effective control and manipulation of equipment, and coordination of equipment movement to avoid collisions and other potentially dangerous situations. The purpose of the test is to demonstrate not only the different functions of the equipment systems, but also the capability to operate these systems in a coordinated manner. The integration of these difficult operations results in a technically complex task of coordination and control.

III. SYSTEMS INTEGRATION

Systems integration involves the orchestrated use of multiple systems (including equipment and personnel) toward accomplishment of a task. The integrated quality of a system may involve equipment/hardware, software/programming, control interfaces and staffing. Integration requires attention to program planning and organization as well as engineering of system hardware and software. The degree to which systems can be integrated may affect system safety, efficiency, and operator performance.

A. Organizational Aspects

Systems integration is easier and best done at the initial stages of design. From the outset, project planning must include integration as both a process and a goal. Integration as a process is the coordination of individual efforts with each other, the sharing of strategies for development of system hardware, software, tasks and functions. An integrated operation will be evidenced by a high degree of coordination among operators, synchronized simultaneous maneuvers of equipment, clear operational boundaries for different systems/operators, and efficient, safe overall operation.

In complex operations such as the BWID test, a specific, large-scale mission needs statement should be established and understood by all individual system developers. Responsibilities should be assigned and global concerns (e.g., sufficient lighting and ventilation) addressed by high level management. Individual system development efforts should be coordinated to account for parameters and geometries of other equipment functions. The sequencing of operations and the timing of tool deployment and coordination between tools (and, thus, operators) must be managed and organized.

System integration requires that personnel be aware of the information needs of each subsystem and that the data be translated and optimized for use by all subsystems. Internal communications are essential for achieving awareness of the needs of each subsystem and of the interactions between these subsystems. Without internal communications, subsystem requirements cannot be optimized and translated for other dependent subsystem, making integration difficult to achieve.

Both lateral and vertical integration are necessary to completely integrate complex systems. Lateral integration requires determining how the individual technologies can best work together. For the entire system to be efficient and effective, the input and output needs and the tasks being performed within these systems must be analyzed, combined, and integrated. Vertical integration requires an analysis of the functions and tasks to be performed in order to provide input to the design, control, management, use, and sequencing of the subsystem activities. Vertical integration helps to reduce the likelihood of human error, which is widely recognized as the most significant contributor to complex system failures. To ensure vertical integration, training, procedures, skills assessments, human reliability assessment, materials handling and personal protective clothing requirements need to be integrated with (and to some extent across) the various technologies.

For complete and successful integration of a complex operation, the following elements should be addressed:

- Information input and output needs for the entire system and for the individual subsystems

- Means by which operators will use the technology to gather and manipulate the data provided and to control the equipment

- Sequencing of operations to be performed

- Capabilities of the dependent subsystems to provide the necessary data and/or functions in a timely manner

- Human-machine responses during abnormal events.

Additionally, data collection and transmission must be standardized across all subsystems to provide useful, consistent information for the human operator to access and use in making decisions about equipment manipulations.

B. Engineering

From the standpoint of systems engineering in a complex operation utilizing several equipment systems in concert, integration is necessary for collision avoidance, coordination of motion, and equipment interactions.

Engineering considerations include the integration of hardware and control software. This can be a difficult task if multiple systems are being pulled together to accomplish a task such as buried waste retrieval and characterization. Various pieces of equipment need to interface and not collide. Positioning beacons can be used to provide position information to a collision avoidance system. Independent systems can operate with their own control software but should be able to share data and video. This requires programming in the same or compatible languages across systems, setting-up for data exchange between equipment/operator stations, and supervisory control of all systems for safety-related override of operations.

Software and electrical integration ensure that the systems can transfer and share information, data, and video. Information transfer and sharing provide the operators with access to all relevant information at the appropriate time. This can be accomplished using a broadband coaxial cable to transmit signals (data and video) and by providing a local area network to share data, files, and video.

Hardware integration is another element of the process. In the BWID test scenario, the excavator and gantry crane need to interface to achieve a common goal. They must work in concert to retrieve waste, characterize waste, and control the spread of contamination. In addition, both of these systems need to interface with the remote conveyance system. The excavator end-effector needs to disconnect and be carried away by the remote conveyance vehicle. The gantry crane needs to put waste into the conveyance system box.

To illustrate the complexity of integrating this operation, Figure 1 shows the overall system as multiple and mirrored loops. The methodology for developing this figure was modified from T. Sheridan's methodology of breaking down supervisory control for a single task.[1] The various interfaces illustrate the complexity of integrating multiple independent systems.

At the top of the figure is the supervisor. For this size of system, a design was developed consistent with keeping employees on the same strategy and maintaining safety through a supervisor (and potentially assistant). As the figure indicates, the supervisor interfaces with controls and displays at his/her workstation. Controls include camera pan and tilt units, emergency stop switches, and controls for accessing data and monitoring the process. The displays support the supervisor by supplying data and video information. There are four operators, one for the excavator, one for the conveyance system, and two for the gantry crane. Each of these operators also interacts with the controls and displays. Signals are transferred from the control station to the containment structure and back, through a broadband coaxial cable. Once inside the containment building, the signals are dispersed to the remote equipment through several methods including a tether and some radio frequency links. Each piece of equipment is equipped with sensors and actuators. The figure also depicts multiple tasks that each piece of equipment must accomplish. This high level diagram only hints at the difficulties and complexities of integrating previously independent equipment.

C. Impact on Human Operators

The key function of integration is to ensure safe and efficient operations. Systems that are integrated can be operated in a manner that supports an efficient staffing scenario. Control workstations should be human engineered to provide appropriate interfaces that are consistent with good human factors principles. In some cases, workstation design and staffing may compensate for an otherwise poorly integrated operation.

The inherently chaotic nature of a complex operation that is NOT integrated may result in the following conditions.

- Increased operational safety risk and associated costs (e.g., equipment collisions).

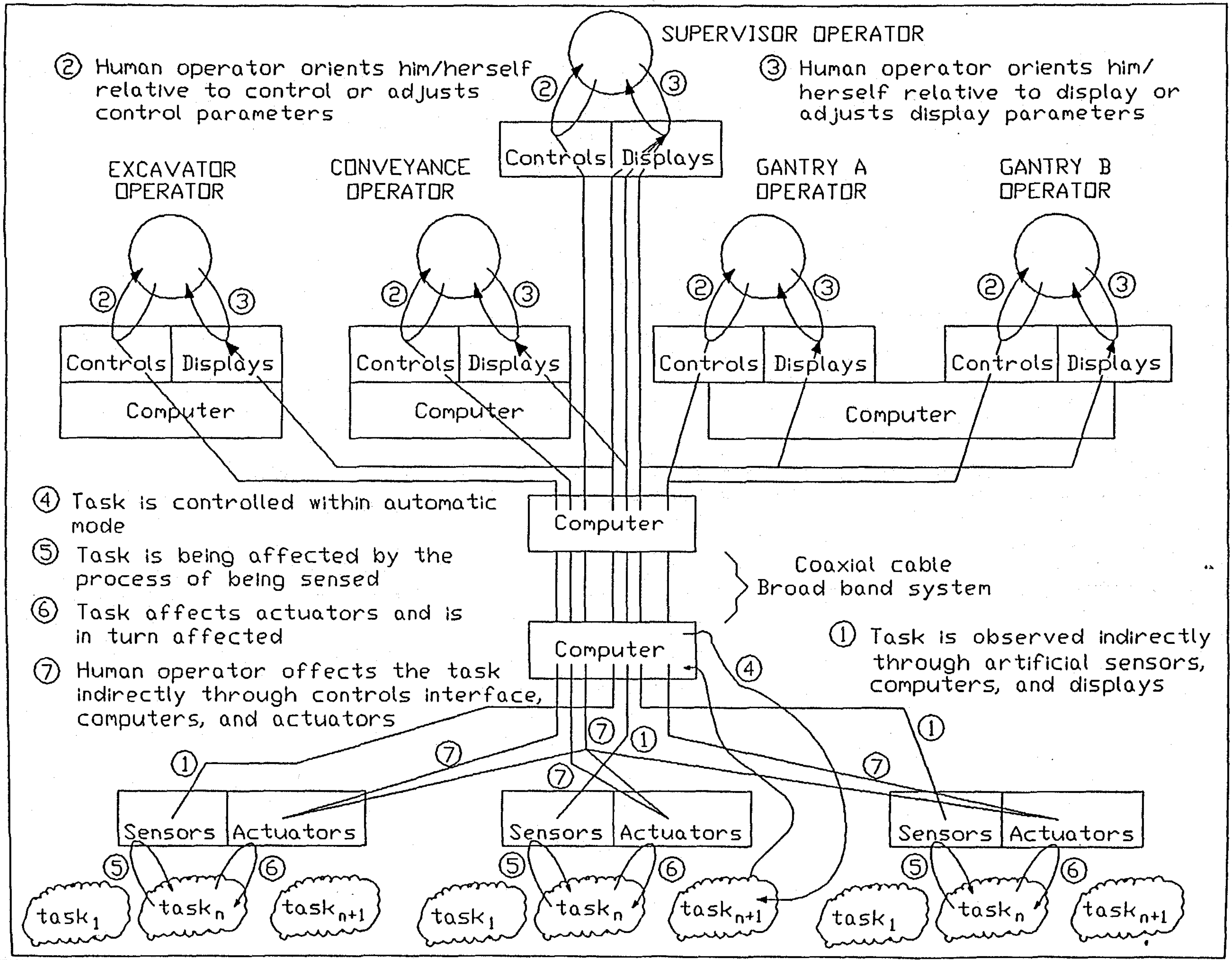

Figure 1. Overall view of systems integration.

- Increased operator workload due to increased cognitive complexity of the task (i.e., need to monitor all other systems as well as control the operation of a specific equipment system) and higher psychological stress associated with imminent collision risks.

- Decreased efficiency of operation (slower waste retrieval to compensate for lack of global/supervisory controls; need for operators to coordinate each action with other equipment in operation; or delays from sequenced operations instead of coordinated simultaneous activities).

IV. APPLICATION TO WASTE REMEDIATION

DOE is committed to remediating buried waste sites at its facilities. The BWID program at the INEL was initiated to investigate the application of advanced technology for remediation of buried hazardous and radioactive waste. Specific technologies will be integrated to form a comprehensive system for efficient, safe and effective buried waste retrieval.

Because of the increased need for reliable operation, integration is extremely important in the development of systems to perform radioactive and hazardous waste remediation. Safety to equipment, personnel and the public are paramount in operations supporting the handling of waste materials. In accordance with the philosophy of the Comprehensive Environmental Response, Compensation and Liability Act, systems selected for use in remediating Superfund sites shall be easily implementable, providing a cost-effective solution that protects workers, the community and the environment. System risk and the potential for critical human errors are reduced through effective organizational and engineering-based integration. An integrated program can increase productivity and thereby reduce overall costs associated with site remediation.

With the type of contamination possible at various sites, remote handling techniques and robotics technologies will play a significant role in waste recovery and restoration. Integration is crucial for interfacing systems in complex operations such as that proposed in the BWID test.

V. REFERENCES

1. T.B. SHERIDAN, *Telerobotics, Automation, and Human Supervisory Control*, The MIT Press, Cambridge, MA (1992), pp. 25–27.