INL/CON-23-72909-Revision-0

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July 2023

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Human Error, Reliability, Resilience, and Performance, Vol. 82, 2023, 53–58
https://doi.org/10.54941/ahfe1003553

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ABSTRACT

An autonomous system refers to the system that has the power and ability for self-governance in the performance of system functions. Autonomous systems have been actively pursued in a variety of domains such as automotive, aviation, maritime, medicine, and nuclear fields. As an unmanned concept employing the highest automation level, the autonomous system basically performs most of the work in normal operations or emergency situations. However, despite advances in technology, many researchers have noted these systems still require human actions. The nature of human actions on autonomous systems is different than the human actions that are considered in existing systems. Nevertheless, only a few studies have been conducted on 1) characterizing the different types of errors and risks associated with human actions interacting with autonomous systems and 2) how to evaluate human actions in the autonomous operations. As a starting point, this study aims to investigate differences of tasks in autonomous operation compared to those in existing nuclear power plant operation using the Event Modeling Risk Assessment Using Linked Diagram (EMRALD) software. In this paper, insights aspect of human error and time are derived out and discussed based on the output of the EMRALD models.

Keywords: Nuclear power plant, Autonomous system, Human action, Dynamic risk assessment

INTRODUCTION

An autonomous system refers to the system that has the power and ability for self-governance in the performance of system functions (Lee, et al., 2018). Autonomous systems have been actively pursued in a variety of domains such as automotive, aviation, maritime, medicine, and nuclear fields. Relatively new types of reactors under development in the nuclear field such as Fission Battery and Microreactor Applications Research Validation (Agarwal, et al., 2021) and Evaluation (MARVEL) reactors (Arafat, 2020) have adopted autonomous operations in their reactor designs.

Despite advances in technology, many researchers have noted these systems still require human actions. The nature of human actions on autonomous systems is different than the human actions that are considered in existing human reliability analysis (HRA). Nevertheless, only a few studies have been conducted on 1) characterizing the different types of errors and risks associated with human actions interacting with autonomous systems and 2) how to evaluate human actions in the autonomous operations.

As a starting point, this study aims to investigate differences of tasks in autonomous operation compared to those in existing nuclear power plant (NPPs) operation using the Event Modeling Risk Assessment Using Linked Diagram (EMRALD) software. The EMRALD software is a dynamic simulation tool for probabilistic safety assessment (PSA). It supports realistic and dynamic modeling of human actions as they would be performed at NPPs. It is also favorable to simultaneously model the specific moment at which an action is performed, the time it takes to perform the action, and the failure probability of that action. In this paper, different characteristics of tasks in existing NPP systems and autonomous systems are discussed. Tasks in existing NPP and autonomous systems with relevant procedures are assumed with the two simple scenarios. The EMRALD models for the tasks are developed respectively. Then, insights aspect of human error and time are derived out and discussed based on the output of the EMRALD models.

CHARACTERISTICS OF TASKS IN AUTONOMOUS SYSTEMS

Autonomous systems employ an unmanned concept with the highest level of automation (LOA) that rarely requires human actions in comparison to existing systems, which require a number of human roles to operate the systems. Figure 1 shows types of system controls depending on LOA: manual, automatic, and autonomous controls. The manual control refers to the action that operators directly manipulate components such as pumps or valves in local or main control rooms. The automatic control means that operators manipulate a sub-system automatically controlling components using a switch or

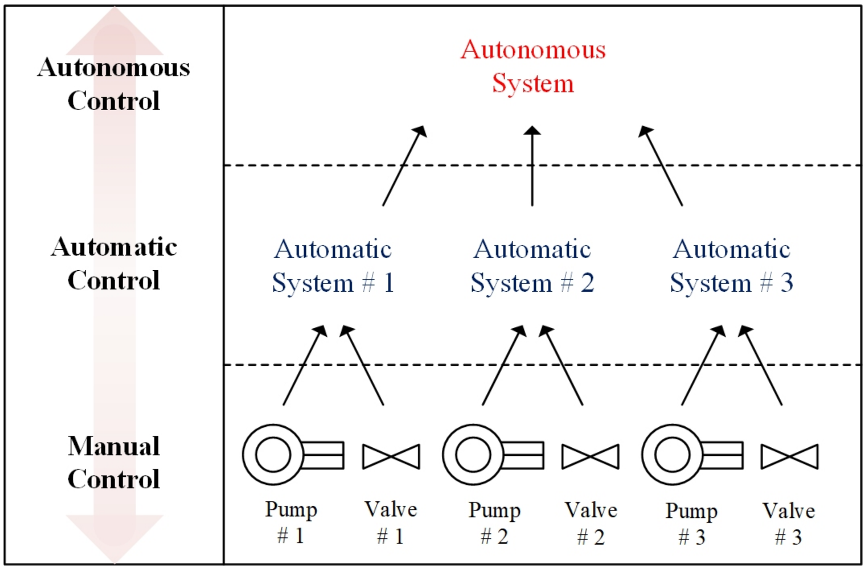

Figure 1: Types of system controls depending on LOA.

button in main control rooms. The autonomous control integrately manages all the automatic and manual controls by itself.

Autonomous systems are conceptually responsible to all works in a system, while they do not allocate their work to human. However, if an autonomous system is suddenly failed, it requires any test and maintenance on local components or the system itself, or there is any problem that the autonomous cannot handle, human operators need to diagnose these situations and solve the problems.

Many researchers have noted that these tasks getting in the middle of autonomous operation may show different characteristics compared to tasks in existing systems employing manual and automatic controls. For example, in the existing NPP operation, operators are understanding the overall situation for systems in real time. In other words, although operators take over their mission to the next shift team, the overall situation can be easily synchronized. On the other hand, once any work is given from the autonomous system to operators in the middle of operation, operators may need to pay more time and effort to understand what is going on with the higher workload and the less situation awareness. The followings are representative human performance issues stemmed from literature (Kim & Park, 2018).

- Reduced situation awareness due to out of the loop in automated system,
- Added complexity for operators to understand,
- Change of tasks with respect to automation,
- New sources of workload,
- Skill degradation and loss,
- Excessive passive monitoring raising vigilance and complacency issues,
- New type of human error,
- Human errors during the loss of automation, and
- Trust

Nevertheless, only a few studies have been conducted on 1) characterizing the different types of errors and risks associated with human actions interacting with autonomous systems and 2) how to evaluate human actions in the autonomous operations.

ANALYSIS OF TASKS IN AUTONOMOUS AND EXISTING NPP SYSTEMS

This paper aims to investigate differences of tasks in autonomous operation compared to those in existing NPP operation. Figure 2 shows a summary of work scope in this paper. First, this study assumes an existing NPP system from the generic pressurized water reactor (GPWR) (Lew, et al., 2020) and an autonomous system from recent research on the NPP autonomous operation (Lee, et al., 2018). For procedures in the autonomous system, these have been developed based on the GPWR procedures. Second, tasks implementable in the existing NPP and autonomous systems are assumed with two simple scenarios. The tasks are summarized in Table 1, while the two scenarios are below:

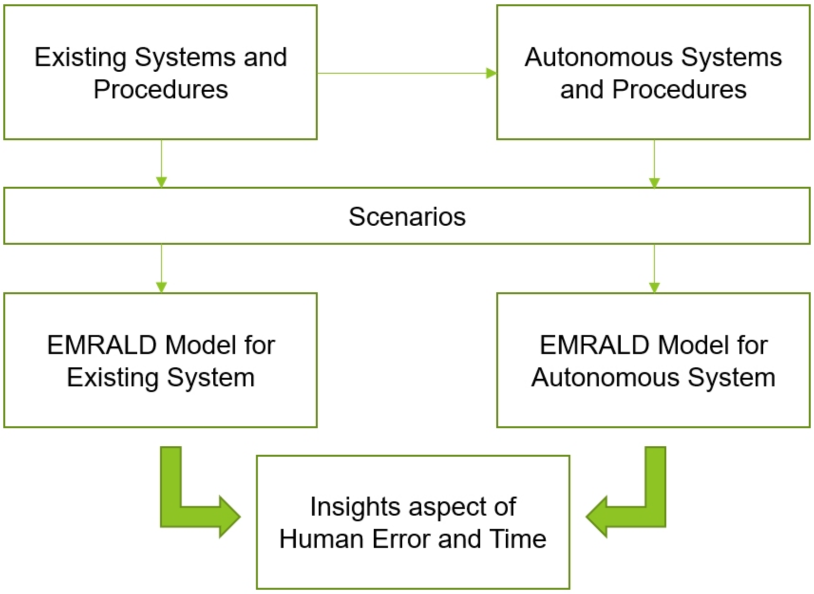

Figure 2: Summary of work scope.

Table 1. Human actions in the two simple scenarios.

No.	Human Action	Details
1	Operator fails to confirm the relevant information during the startup process or perform the initial reactor startup.	• Verify the setup/configuration is correct, • Verify sensor functionality, • Verify control system functionality, • Perform initial reactor startup and hold at criticality or target power, • Verify heat sinks functionality, • Synchronize to grid, and • Verify power ramping functionality.
2	Operator fails to identify the problem then determine if they can resume the startup.	• Identify the problem, • Reinsert all control drums, and • Request technical support.

- A normal startup scenario from operation mode 3 to 2 (i.e., hot standby to startup), and
- The same normal startup scenario plus a latent error (a control rod is unexpectedly dropped due to electrical problem).

Third, EMRALD models for these scenarios are developed based on a dynamic HRA method called as the Procedure-based Risk Investigation Method – HRA (PRIME-HRA) (Park, et al., 2022). Lastly, insights aspect of human error and time are derived out by simulating the EMRALD models. Table 2 shows the summary of simulation results. The EMRALD models are simulated for 100,000 trials. The main findings are summarized as below.

Table 2. Summary of simulation results (100,000 trials).

System Type	Scenario	Human Action No.	HEP	Time
Existing NPP System	Normal Startup	1	1.32e-3	26:45 +/− 07:22
		2	N/A	N/A
	Normal Startup + A Control Rod Drop	1	2.80e-4	07:49 +/− 04:26
		2	4.13e-3	14:37 +/− 01:52
Autonomous NPP System	Normal Startup	1	9.00e-5	00:20 +/− 00:15
		2	N/A	N/A
	Normal Startup + A Control Rod Drop	1	8.00e-5	00:40 +/− 00:20
		2	6.00e-5	01:06 +/− 00:28

- HEPs for existing systems are 15–70 times higher than those for autonomous systems.
- Time to perform tasks in existing systems takes 10–80 times longer than those in autonomous systems.
- Human errors in autonomous systems occur in the early step of scenarios.

CONCLUSION

The result of this analysis indicates that tasks in the autonomous system show the lower HEPs and require the less time to finish scenarios in comparison with those in the existing NPP system. However, it is yet difficult to say that the autonomous system is better than the existing one. There are a couple of challenges needed to be researched to get the more realistic simulation result from this approach.

First, the input data used for the EMRALD models relies on the data experimentally collected from the existing system. HEPs and time required for task units would be different when estimated from the existing and autonomous systems, respectively. Second, there would be new task types only available in the autonomous system. Representatively, the autonomous system may have a task type regarding adjusting LOAs (e.g., the high to low LOAs). It may cause new type of human error. For example, operators may be able to omit some tasks when changing LOAs from high to low by confusing that the system is still in the high LOA mode (e.g., the autonomous control). In addition, there have been human performance issues identified from many researchers introduced in the second section.

It is ongoing research to reasonably evaluate tasks in autonomous systems. In this time, fundamental research is further required to provide the better input data into simulation models.

ACKNOWLEDGMENT

This work was supported by the Risk-Informed System Analysis (RISA) Pathway of the U.S. Department of Energy's Light Water Reactor Sustainability Program and the Laboratory Directed Research and Development funding of Idaho National Laboratory.

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