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Forensic Engineering Evaluation of an Automated Warehouse Accident

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Abstract

A worker was injured by fast-moving equipment inside an automated warehouse at a location where workers are supposed to be excluded during automated operations. The facility was designed with barriers, locking gates, lockout/tagout provisions, and a safety training program for operators. Despite the safety training, procedures, and equipment, a worker entered the danger zone and was struck by automated equipment. The worker knew he was in a restricted zone; however, he thought he had "locked out" the area where he was performing maintenance.

The safety equipment design and operator procedures will be discussed in this paper, along with deviations from operator procedures that caused the accident. The litigation issues involved design of the safety systems, training of operators, and additional safety components that the plaintiff's expert opined should have been in place. Conflicting opinions offered by experts engaged by the plaintiff and automation equipment designer/installer will be discussed.

Keywords

Forensic engineering, automation, warehouse, lockout, tagout, training

The Scene

The warehouse (**Figure 1**) is built around an automated storage and retrieval system (ASRS) designed and installed by the automation developer. The warehouse automatically stores and retrieves pallets loaded with cases of soft drinks, and can hold up to 250,000 pallets. The ASRS and building exterior are illustrated in **Figure 2**.

Figure 1
Warehouse exterior.

The apparatus within the ASRS consists of two storage and retrieval machines (SRMs). These operate and perform combined functions of a forklift and crane. The system also

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includes a central rail system on which the SRMs move back and forth. The center aisle of the ASRS has two SRM cranes, each extending 13 levels high. The cranes automatically deliver and retrieve two loaded pallets at a time, using rolling platforms called "satellites" that travel down long aisles called lanes. The lanes each have a pair of horizontal rack rails to guide the satellites and support the loaded pallets. The lanes, satellites, pallets, and SRMs are all within a central protected zone where automated equipment may start or stop without warning.

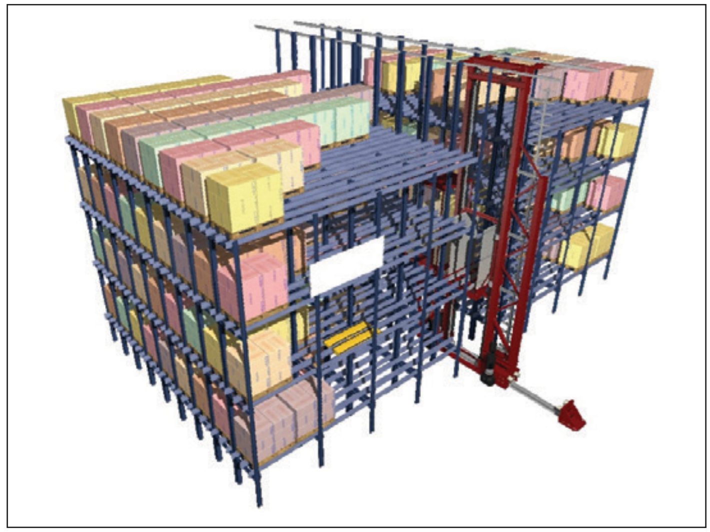

Figure 2
Automated storage and retrieval system (ASRS).

On the ground floor, some of the space is occupied by conveyors that carry loaded pallets in and out of the ASRS. The conveyors are protected within a peripheral protected zone where maintenance can be performed on the conveyor system. Workers must first gain entrance to the controlled peripheral protected zone before accessing the central protected zone. Access to the peripheral and central protected areas is controlled by limiting access only to qualified and trained workers using keys and passcodes.

The warehouse is equipped with multiple safety systems designed to prevent entry into the ASRS during operation. A system of interlocked entry doors and dedicated keys assures that the automation equipment within the ASRS must be shut down before the entry doors into the central protected zone can be opened. The key switch controlling ASRS operation must be switched off and the key withdrawn before the same key can be used to unlock the ASRS entry door (see **Figure 3**).

Before employees are permitted to work within the ASRS, the cranes are to be parked at the ends of the aisle, and large steel safety barriers are to be manually placed in front of the cranes, preventing them from traveling (see **Figure 4**). This step is a written administrative control without any physical interlock.

On the ground floor, conveyors carrying loaded pallets snake under and around the warehouse, carrying pallets of products into and out of the ASRS. There are also dedicated maintenance lanes within the peripheral protected zone

Figure 3
The ASRS must be switched off
before the entry door can be unlocked.

Figure 4
Storage and retrieval machine.

alongside and below the ASRS pallet rack lanes where workers can gain access to conveyors for maintenance while the ASRS is operating. Inside the central protected ASRS area, each crane delivers or retrieves a pair of pallets by means of a moving trolley platform (satellite) that travels down each lane as required to access the desired storage locations. The worker was struck by a moving satellite while standing on the ground floor in an active lane.

The Accident

At the time of the accident, the storage rack rails and steel support structure between the maintenance lane and active ASRS lanes formed a waist-high horizontal rail as a barrier to entry. The worker entered the automated area, bypassing the interlocked safety system doors and written procedures by climbing over or under the horizontal rack rail from the maintenance lane in order to gain entry to clean up a spill on the floor. The area where the worker was cleaning the floor at the time of the accident — and the satellite that struck the worker — are shown in **Figure 5**.

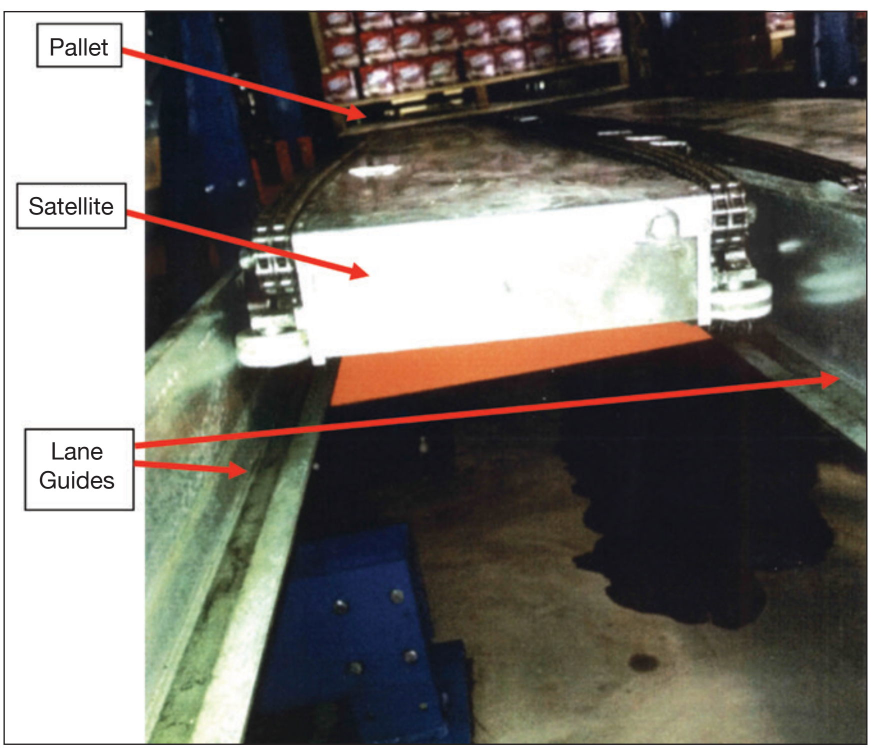

Figure 5
Accident location.

The worker bypassed controlled ASRS access doors by climbing over or under a horizontal rack rail from a maintenance lane to the adjacent ASRS lane while the equipment was operating (see **Figure 6**). He bypassed the electromechanical interlocks on the ASRS entry doors by entering through the rack system. He also propped open an emergency exit door from the maintenance area so that he could bring a shop vacuum from outside the building through that door to clean the floor under the rack system. Entering the ASRS by climbing through the rack system and propping the exterior door open were violations of the safety rules.

The worker did not believe he was putting himself at risk. He incorrectly thought that he had "locked out" two ASRS lanes adjacent to the maintenance aisle by entering commands into an ASRS control workstation to empty the lanes by preventing the system from filling these two lanes. This "work-around" was not an approved method of working inside the ASRS, nor was it effective.

Figure 6
The black mesh barriers were added after the accident.

Analysis

Entry to maintenance spaces in the warehouse is restricted to authorized, trained personnel by the use of keys and passcodes. Once inside the peripheral protected zone, barriers prevent workers from walking into the protected ASRS area from maintenance spaces. In this case, the barrier between the maintenance aisle and ASRS lane was nothing more than the horizontal rack rail. The rail was not marked with any warning. There are emergency exit doors from maintenance spaces that open from the inside only. The injured worker propped one of the exterior doors open, in order to re-enter the maintenance area with a shop vacuum, before being injured. These exterior doors are not alarmed or interlocked to shut down the ASRS.

Opposing Viewpoints

The plaintiff's expert opined that new barriers installed after the accident should have been installed in the original design. He also believed that a number of Occupational Health and Safety (OSHA) regulations and other industry standards were violated, including:

- OSHA Title 29 CFR 1910.212(a) Machine guarding.
- ANSI/RIA 15.06 -Safety Requirements for Industrial Robots and Robotic Systems
- ANSI/UL 1740 -Robots and Robotic Equipment
- ISO/ANSI/RIA 10218-1:2007 -Safety Requirements for Robots in an Industrial Environment
- ANSI B15.1 -Safety Standards for Mechanical Power Transmission Apparatus
- ANSI B11.19 -Performance Standard for Safeguarding
- ANSI B20.1 -Safety Standard for Conveyors and Related Equipment
- ANSI Z535.4 - Product Safety Signs and Labels

- OSHA 3067 - Concepts and Techniques of Machine Safeguarding
- OSHA 3170 - Safeguarding Equipment and Protecting Employees from Amputations

All of these regulations and industry standards provide guidance on protecting workers from injury by eliminating hazards, guarding the hazards that cannot be eliminated, and providing adequate training, warnings, and protective gear. The plaintiff's expert did not comment on any differences between the two defendants with respect to their roles and responsibilities. He had two critiques related to the equipment:

1. Without the mesh barriers shown in **Figure 6**, the only barrier between the maintenance aisle and adjacent ASRS lane was the waist-high horizontal rail used to support loaded pallets and guide the satellite. This horizontal rack rail was an inadequate barrier and was not marked with any warning.
2. In addition, it was suggested that the automation equipment should have been equipped with additional safety sensors to detect the presence of a worker during automated operation.

The automation developer hired two experts who opined that the safety systems and training materials prepared by the developer for use by the employer were robust and compliant with industry standards, including OSHA regulations. With regard to adequacy of the barriers between the maintenance area and points of operation, there was a difference of opinion. One defense opinion was that the waist-high horizontal lane rail met the minimum requirements for a barrier. In this case, a warning would not have deterred the worker, who believed (incorrectly) that he had made the two adjacent lanes "safe." Another defense opinion was that the equipment design was compliant with the noted industry standards but that the lane rail was not an adequate barrier.

The defense experts pointed out that OSHA only has jurisdiction over the employers' actions, not the equipment design. OSHA noted in its investigation report that the employer and employee should have followed the safety procedures prepared by the equipment developer. If the worker had followed those safety procedures, he would have had to shut down the equipment before entering the ASRS pallet rack lanes through the interlocked doors; therefore, the accident would not have occurred.

The parties also disagreed on the need for additional presence-sensing safety equipment to detect workers who may defeat the primary safety systems. If the primary controls are effective, there would have been no need for secondary controls. However, if the worker's intention was to defeat the safety control systems, he probably would have succeeded in doing so.

Opinions of the bottling company's expert were not disclosed to this author.

Why Did the Accident Occur?

The automation equipment was designed with current industry safety standards as a basis. OSHA regulations provide guidance on machine guarding and safety training requirements as they apply to the employer. The referenced ANSI standards provide additional guidance to equipment designers and users, and focus on the same basic principles applied to different kinds of equipment (elimination of hazards, guarding against hazards, warnings, operator training, and other measures to protect the public safety).

Training materials were prepared by the automation developer, and training classes were conducted for employees at the time the facility was commissioned. Following the initial training of bottling company employees by the automation developer, the training materials continued to be used over subsequent years to train new employees. Training was supervised by the bottling company after the initial employees were trained by the developer.

Employees attended weekly safety meetings where they learned about safety procedures and rules, including the proper procedures for entering the automation area. The injured worker had been promoted from the position of forklift operator, and had attended regular safety meetings. Despite this training, the employee decided to get creative, and attempt to “lock out” the lane where the floor needed cleaning. He attempted to make two lanes “safe” by entering commands into an ASRS workstation to empty the lanes and prevent the system from filling them. The “lock out” was not effective, and the employee was struck and injured.

How Could the Accident Have Been Prevented?

Regular work practices at the plant were to operate six days each week and perform maintenance on Sundays. The accident occurred on a Sunday when the plant was in operation due to an upcoming holiday. The injured employee’s solution was to invent a way to perform maintenance while the plant was in operation. If he had followed the standard work rules, maintenance would have been re-scheduled for the next plant shutdown.

Legal Issues

OSHA investigated this accident, and was critical of the bottling company’s practices and training. The injured worker filed a lawsuit against his employer (bottling company) and the equipment developer/installer. The employer was protected by workers’ compensation insurance laws.

All of the plaintiff’s theories lumped the developer/installer in with the employer, which, he claimed, had failed to provide and enforce proper training and therefore was in violation of numerous industry standards. The provision of a more substantial barrier between the maintenance aisle and active danger zone was a responsibility of both defendants. However, deficiencies in employee training and supervision could only be attributed to the employer. The question of responsibility on the part of the developer/installer involved two specific issues:

1. Was there a requirement for a form of presence-sensing technology to detect the presence of workers during automated operation capable of shutting down operations?
2. Before the incident, was the physical barrier between the maintenance aisle and active automation aisle adequate to guard against entry?

On the first question, no specific design of a presence-sensing system was suggested, and none was evaluated. The value of such a system is questionable because the design of the entire warehouse requires the absolute exclusion of people in the automation area. The potential for entry through the racks was apparently overlooked during the design.

Regarding adequacy of the physical barrier between maintenance aisle and automation zones, there was a difference of opinion. More robust steel grate barriers were installed after the incident, shown in **Figure 6**.

This author was of the opinion that the horizontal rack rails used to support pallets provided an adequate barrier. The rails were waist-high, requiring a person to intentionally climb over or under the rails to enter the automation area. Following the installation of the steel mesh barriers, it is still possible for a person to climb over or slip under the barriers. It was argued that such egress is needed to comply with fire safety considerations. However, a more appropriate solution would be floor-to-ceiling barriers with interlocked emergency exit doors between the central and peripheral-controlled areas.

Lessons Learned

Those who understand industrial safety principles can design very good systems with physical barriers, gates, guards, and controlled interlocks to protect workers from hazardous machinery. Industry standards require the application of recognized safety principles by competent engineers. However, physical barriers cannot prevent a creative worker from circumventing or otherwise defeating safety systems.

A strong safety culture is needed to complement the physical safety systems, but is not a substitute for proper design. When workers are in an environment where safety and safety training is highly regarded as a job benefit to protect them from harm, they are inclined to follow the rules. If, however, work flow is prioritized over safety — and safety precautions are regarded as a nuisance — workers are more likely to get creative and find work-arounds. In this case, the injured worker had good intentions and thought he had come up with a new way to perform maintenance without shutting down production.

The culture of safety in an organization is just as important as physical safety equipment and systems. Safety equipment design and safety training must be effective to prevent such accidents. However, attention to safety in the design process can eliminate or minimize the chances for human error in operation. The hierarchy of safe product design (**Appendix A and Appendix B**) prioritizes the importance of design controls over administrative controls.

Appendix A

Hierarchy of Safe Product Design

When a safety hazard is perceived by the designer, the options available are:

1. Modify the design to eliminate the hazard or reduce the danger to an acceptable level.
2. Design guards to isolate the hazard.
3. Provide effective warnings.
4. Educate and train workers to be aware of the hazard and follow safe procedures to avoid injury.
5. Anticipate common areas and methods of improper use and eliminate or minimize the consequences of the improper use.
6. Provide personal protection equipment to be used in conjunction with the product.

Appendix B

Reading on Hierarchy of Safe Product Design

- Petersen, Dan, “Techniques of Safety Management, A Systems Approach,” Goshen, NY: Aloray, 1989, P. 31.
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