World Journal of Engineering and Technology, 2026, 14(1), 14-42
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

# Safety Implications of Automated Guided Vehicles in the Modern Workplace: Increased or Decreased Potential Hazards?

**Oluwaseun Adekoya[1], Josiah Olofinniyi[2], Oluwafunmilola Fasan[3], Qudus Bello[4]**

[1]Department of Mechanical and Materials Engineering, University of Cincinnati, Cincinnati, Ohio, USA
[2]Department of Mechanical Engineering, The Centrale Lyon Institute, Saint-Étienne, France
[3]Department of Design, Architecture, Art, and Planning, University of Cincinnati, Cincinnati, Ohio, USA
[4]Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria
Email: adekoyoa@mail.uc.edu

**How to cite this paper:** Adekoya, O., Olofinniyi, J., Fasan, O. and Bello, Q. (2026) Safety Implications of Automated Guided Vehicles in the Modern Workplace: Increased or Decreased Potential Hazards? *World Journal of Engineering and Technology*, **14**, 14-42.
https://doi.org/10.4236/wjet.2026.141002

**Received:** October 9, 2025
**Accepted:** December 12, 2025
**Published:** December 15, 2025

## Abstract

In a bid to stay relevant and help cater for global market needs, production and manufacturing industries have had to continuously automate majority of their work processes, thus calling for the need to introduce robots at the workplace. These robots may be human-controlled or autonomous, of which the most common types are articulated robots, humanoids, cobots, and hybrids, Autonomous Mobile Robots (AMRs), and Automated Guided Vehicles (AGVs). The advent of these industrial robots has brought about the replacement of human labor as operations are now automated and human intervention is made very minimal. In the modern workplace, robots are basically used for processes like welding, material handling, transport, dispensing, assembling, finishing etc., to mention but a few, including the inspection and gleaning of structures and equipment. In this paper, to analyze the potentialities of hazard at the workplace even with increased robot presence or automated processes, research was carried out on previously traditional and crude processes which were then automated or had robots introduced into the task execution procedures. This paper has primarily focused on Automatic Guided Vehicles (AGVs). Also, annual robot accidents were studied with respect to different industries such as Aerospace, Automotive, e-Commerce, Electronics, Manufacturing, Food and Beverage Preparation, Healthcare, Pharmaceutical, Quality Control and Inspection, and Warehousing and Distribution on a case-by-case basis and it was deemed that a case study on the use of Automatic Guided Vehicles (AGVs) is common to all and can be studied. Countermeasures are then provided. The paper then goes on to address some other potential hazards, the place of OSHA (Occupational Safety and Health Administration) and other Standard Organizations. Data from researchers portray that robot injuries and accidents have been on the rise recently and have not been stable. The incorporation of robots into the modern workplace presents its own risk and can be mitigated or avoided, but still cannot be completely eliminated even though advantages are a lot more than corresponding demerits. It is seen that whilst automated processes pose increased productivity and competitiveness of the company employing them, there is still the potentialities of experiencing hazards in a typical robotic industry. However, the place of occupational safety cannot be overemphasized and thus can help limit or eliminate a vast majority of them.

## Keywords

Robotics, Occupational Safety, Automatic Guided Vehicles, Automated Processes, Robots

## 1. Introduction

There has been a widespread use of robots and automation in the workplace ever since the first assembly lines were developed. Production and manufacturing are being revolutionized by the massive application of new technologies as a result of the increase in demand from end-consumers, quality requirements, and manufacturers are being forced to respond to them. The relevance of robot-monitored processes and operations in the areas of food processing, healthcare, pharmaceuticals and general production and manufacturing cannot be overemphasized. It is also not surprising that robots have even taken over a large number of tasks including the financial side of things. This is hugely due to the fact that robots do not get fatigued easily and do not get injured, and neither do they need vacations. However, the fact that robots and workplace automation might pose a hazard to surrounding workers and operators is of concern. Yes, it is an indubitable fact that the use of robots in the modern workplace has contributed to an unprecedented improvement and increase in health and safety but robotics nevertheless still has its own associated risks and hazards that may potentially affect a competitive work environment. Guidelines and requirements have been put in place with respect to owning and operating autonomous systems while simultaneously assessing the risks and hazards in the operations of the same. Generally, increased growth and improved standard of living in the United States and across the globe have been observed since the end of the last century and aided recovery from the Great Recession (a period of marked general decline observed in national economies globally that occurred between 2007 and 2009). According to Jorgenson, Ho and Samuels [1], the observable growth is greatly attributed directly to the innovative ideas brought up by industrial firms and indirectly via the impacts of the technological innovations on traditional sectors.

To realize a competitive workplace and achieve the goal of increasing productivity, the transformation of firms into automated companies as surveyed by Kraus *et al.* (2019) [2], requires a good deal of entrepreneurial transformation, both for start-ups and already established firms. In the current setting of the new industrial revolution, it is becoming more and more crucial to assess the effects of implementing one of these types of digital transformation including the usage of industrial robots and process automation. Despite the fact that many businesses are keen to implement new technologies in order to boost productivity, several worries have been expressed over the cost-impact of the transformation, and its effect on the workforce (for example, Acemoglu & Restrepo, 2019 [3]). In this paper, we will take a look at the trends in robot use at workplaces, different robot types, safe robot practices that can be implemented at workplaces with a case study on Automatic Guided Vehicles. The case study uses the Preliminary Hazard Analysis (PHA) method to identify these hazards and attempts are made to bring down the severity of these hazards whilst determining the potentialities of their realization. Next, we discuss the roles of certified organizations in robot use and occupational safety, as well as the observable data from the United States Department of Labor addressing robot accidents.

## 1.1. Robot History

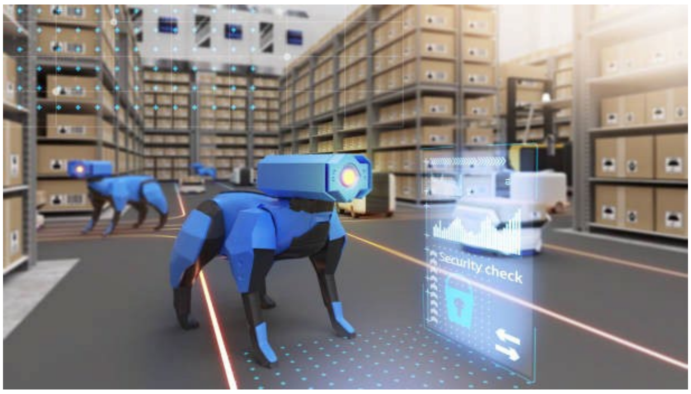
The basic characteristics of robots in that they are reprogrammable, manipulable and multi-functional have served as a motivation and fuel for the Industry 4.0 and Internet of Things (IoT) concepts [4]. Overtime, the design and use of human-like devices which are able to imitate the functions, behavior and movements of a normal human being has piqued the interest of mankind. The term "*automatos*" which has its source from the ancient Greek civilization was used to refer to such devices. For many centuries, a number of inventors including Leonardo da Vinci to the loom of Jacquard (in 1801), Albert the Great (1204-1282), and Roger Bacon (1214-1294) created "automatons", to mention just a few, created so many human-inspired art works and designs which portrayed human-like machines. The automaton is usually considered to be the forerunner of modern industrial robots. Research progressed and the first programmable industrial robot came to life from the hands of a group of adventurous and skillful men led by George Devol [5] although his counterpart Joe Engelberger is often referred to as the Father of Robotics [6]. Their efforts led to the setup of the first and largest (for years) robotics company (Unimation, Inc.) in the world. This literally infers that the innovations and actions of this company served as the pioneering efforts geared towards the realization of robot development. It is understood that the company ironically went all down in less than 30 years according to the book written by George Munson and edited by Leslie Ballard titled "Pity the Pioneer: The Rise and Fall of Unimation, Inc.", which is being prepared for publication.

## 1.2. Concept of Robotics, Types, and Classification of Robots

The term "*Robots*" since the time of its first use had always meant different things to different people. And there is no doubt that scientific fictions, books and even movies have impacted plus influenced our judgement of what a robot should look like. According to the "Institute of Electrical and Electronics Engineers—IEEE", a robot is an "autonomous machine capable of sensing its environment, carrying out computations to make decisions, and performing actions in the real world". The Robot Institute of America's definition [7], which is generally recognized, is that—"A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks". Thus, the term "Robotics" would be referred to as a branch of technology concerned with the design, construction, operation and application of robots as portrayed above. The end goal is usually to develop intelligent machines and systems that can easily serve as replacements for humans and successfully act as humans and imitate human actions. Most of the time, these intelligent machines are able to perform their tasks on their own without coming in contact with humans whilst they may need to be in contact with humans in some other situations. Yes, in some set-ups, electro-mechanical engineers and robot operationists might have to come in contact with these "intelligent machines" to aid in operations and this is one of the major sources of hazards in the robotics industry. Robots are classified based on different categories but the most common method of classification is based on mobility attributes and application attributes. The types of robots based on mobility is further divided into the fixed robots (shown in **Figure 1** below) and the mobile robots (shown in **Figure 2** below). Fixed robots are permanently stationed at a point while mobile robots are able to move from place to place and could be wheeled robots, legged robots, tracked robots or undulating robots. With respect to application attributes, robots can be either industrial robots or service robots. Industrial robots are set up for use in companies, professional organizations and industries while service robots are usually employed for domestic use. Other robots would include the Explore robots, Battlebots which are Hobbyist robots, military robots, entertaining robots and agriculture robots (for example, mango-harvesting robot).

(Source: https://www.istockphoto.com/)

**Figure 1.** A fixed robot.



(Source: https://www.istockphoto.com/)

**Figure 2.** A mobile robot.

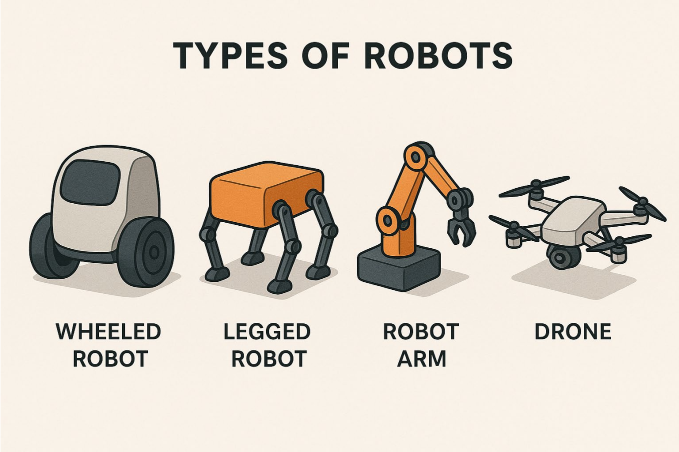


**Figure 3.** Different robot types.

**Figure 3** above shows four major categories of robotic platforms—wheeled, legged, articulated-arm, and aerial systems—to provide a high-level overview of common robot types. The first mobile robot "Shakey the robot"—an intelligent integrated system was built at the Stanford Research Institute (SRI). This mobile robot was the first ever, designed to be able to conceptualize its own actions before executing them. Then in 1973, "The Tomorrow Tool (T3)" robot was introduced by Cincinnati Milacron in 1973. The T3 robot was the first industrial robot which is controlled by a microcomputer and was subsequently also made commercially available. In the 1980s, the robotics systems industry entered a phase of rapid growth and disciplines, courses and programs focusing on robots research were introduced across many institutions. The following are some notable and groundbreaking robots developed from the year 1980 and upwards—AdeptOne, the first ever direct-drive SCARA robot developed by AdeptOne in 1984; the first humanoid robot by Honda developed in 1986 and was called H0; the first Asimo was also designed and introduced in 2000; a packaging robot by Demaurex was introduced in Switzerland in 1992; Intuitive Surgical, a company based in the United States introduced the Da Vinci surgical robot in 1999; iRobot designed and developed the first vacuum cleaner and named it Roomba in 2002; NASA also introduced its first Mars rover Sojourner in 2003; collaborative robot which Universal Robots, a company in the United States named UR5 was developed in 2008; and finally, the Tesla bot introduced by Tesla in 2021.

## 2. Robot Design Materials, Development, Safe Practices and Future Robots

In terms of design materials, soft robotic systems typically contain components that lack high strength while hard robotic systems contain components that are not soft *i.e.*, hard, and as such cannot change their physical properties. The soft autonomous earthworm robot at MIT [8] comes to mind. This is a beautiful example of a soft autonomous robot whose movement is defined by "peristalsis" *i.e.*, a rhythmic, wave-like contraction and relaxation of the segments of its body just exactly like an earthworm in a bid to propagate motion and to aid the digestion of food down its digestive tract. This robotic system made of entirely soft materials has been termed as "remarkably resilient". This is due to the fact that when trampled upon, or hammered by a very high impact force, it remains just unscathed. Although, the authors in [9] briefly reviewed some of the practical shortcomings of the Asimov "Laws of Robotics", these laws still do serve as fundamental guidelines to be considered while designing and developing a Robotic system. Initially, Asimov proposed three laws to which he then later added the "zeroth law". All these laws when critically observed, are seen to border on systems safety with respect to the terms of the responsibilities of those who design and deploy integrated robotic systems and safe practices pertaining to robotic systems. They are as portrayed below:

1) The zeroth law that a robot may not injure humans or through inaction or while at a state of rest, allow humans to come to any form of harm.

2) And also, the first law which is in some way similar to the first, although slightly modified to be that a robot may not injure a human being, while inactive (*i.e.*, while at a state of rest), or give room for a human to come to harm, and thus, this would result to the violation of a higher order law.

3) Asimov's second law of robotics states that a robotic system must obey the orders given it by human, unless situations where such order would ofcourse conflict with a higher order law.

4) Finally, Asimov proposed a third law that a robot must protect its own existence due to the fact that it's protection of itself does not in any way conflict with a higher order law.

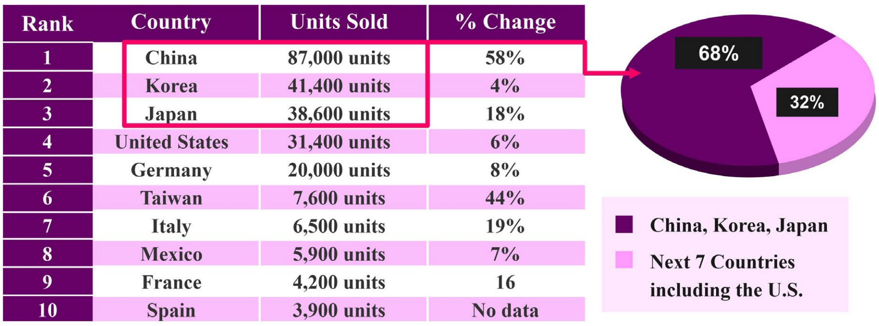
There have been concerns as to if future robots will be able to have a reasonable level of perceptual capabilities to indeed follow the laws propounded by Isaac Asimov. Amidst the discussion of these overwhelming concerns, there have also been a number of notable exceptions [10] [11]. There however appears to be correspondingly even less serious discussion as to whether Asimov's proposed laws are outside of cultural norms, genuinely workable as a framework for human-robot interaction. We note that the contemporary engineering standards discussed later in **Section 4** serve as the practical, enforceable counterparts to the ethical ideas captured in Asimov's Laws, since these standards translate broad moral principles into specific requirements for safe robot behavior, risk control and human protection.

In 2021, Tesla announced the design and introduction of Tesla Bot, an intelligent humanoid robot to be employed in assembly lines to build cars. This friendly plus intelligent robot which has been equipped with AI will be able to automatically conduct repetitive and boring tasks involved with car assembling, and will be able to interact with its environment with cognitive functions. In addition, the Tesla Bot, a typical example of what future robots will look like is able to enhance human lives, increase productivity, efficiency and quality, thus contributing to a safe and healthy work environment for humans. In terms of development, the basic elements that make up a typical robot include: a manipulator, a computer controller, and a power source. The manipulator consists of the grippers (sometimes robotic hands or other adapted specially designed devices) to help execute its task. The controller is deemed the robot's brain and contains a series of programmed sequences that coordinate the robot to execute its assigned tasks. It also provides a linkage to the sensors on the robots to direct the robot's motion. The robot's motion is electrically, pneumatically or hydraulically powered.

## The Status of Robotic Applications

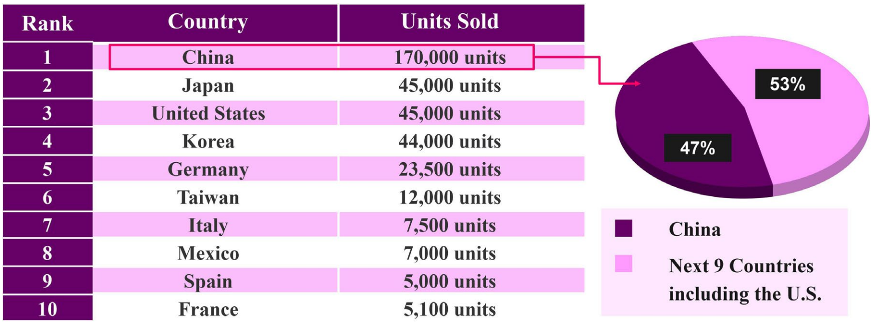
The terms "Robots", "Robotics", "Machine learning" and "Artificial Intelligence (AI)" are often used jointly. And of this three, AI has evolved as the main concept to characterize Industry 4.0. The term Artificial Intelligence refers to Next generation robots being able to execute tasks collaboratively compared to previously designed industrial robots in highly-controlled environments and are usually isolated in boxes and cages. As of recent, research confirms that China is the leading country in the industrial robotics market. It was estimated that China possesses up to 48% of the top-ten industrial markets in 2019. These estimations are summarized in **Figure 4** and **Figure 5** below. This is partly attributed to the electronics sector which took the lead in robot-deployment in East Asia, and has been proven to continuously increase in other parts of the globe. Recent studies do indeed confirm that the main challenge that is being faced and still remains a source of huge concern is the scarcity of enough manpower and trained labor to handle and execute robot-related task and technologies in the evolving field of industrial robotics. So many authors and scientists argue that Asimov's law only take cognizance of functional morality for robots, thus assuming that robots have all it takes to make moral decisions. They argue that Asimov propounded these laws without being concerned about operational morality. Yes, gaps have been identified between reality and aspiration in robot autonomy.

Depending on the power source, weight and accuracy vary from robot to robot. Precision in electric robots is higher than hydraulic ones and can carry moderate to heavy loads. Electric robots also do not have a high cost of maintenance requirement thus encouraging an increase in their use. Pneumatic robots on the other hand are usually light weight and perform excellently with pick-and-place tasks. Pneumatically powered robots are often employed in factory set-ups in which hydraulic or electric robots may not be used for safety reasons.



| Rank | Country | Units Sold | % Change |
|---|---|---|---|
| 1 | China | 87,000 units | 58% |
| 2 | Korea | 41,400 units | 4% |
| 3 | Japan | 38,600 units | 18% |
| 4 | United States | 31,400 units | 6% |
| 5 | Germany | 20,000 units | 8% |
| 6 | Taiwan | 7,600 units | 44% |
| 7 | Italy | 6,500 units | 19% |
| 8 | Mexico | 5,900 units | 7% |
| 9 | France | 4,200 units | 16 |
| 10 | Spain | 3,900 units | No data |

Figure 4. Countries with the top 10 industrial robots markets in 2016 [12].



| Rank | Country | Units Sold |
|---|---|---|
| 1 | China | 170,000 units |
| 2 | Japan | 45,000 units |
| 3 | United States | 45,000 units |
| 4 | Korea | 44,000 units |
| 5 | Germany | 23,500 units |
| 6 | Taiwan | 12,000 units |
| 7 | Italy | 7,500 units |
| 8 | Mexico | 7,000 units |
| 9 | Spain | 5,000 units |
| 10 | France | 5,100 units |

Figure 5. Expected industrial robotics market size by the end of 2019 [12].

## 3. Safe Robot Practices

The field of "Machine ethics" has the ultimate goal of creating a machine that follows an ideal ethical principle or a set of ethical principles. These ethical principles are meant to serve as a guide [13] to the machine in the decisions it makes. This is often interpreted as to some sort of "adding ethical dimensions" to a robotic machine. The practice of "adding ethical dimensions" to a robotic machine could be either of two approaches one, including limitations to the behavior of the robotic machine at the design stage with respect to an ideal ethical principle or principles that would be indeed followed by the human designer, or two, building the machine with some form of ethical principles and learning procedures together with which it can realize ethical principles to guide its own actions. In the former, humans follow the ethical principles and are concerned about actions from the robotic machine that may be harmful. This is a category of computer ethics as opposed to machine ethics while in the latter, the machine has been designed to be able to reason prior to its own actions and with respect to ethical matters. This indeed is the ultimate goal of machine ethics and we can say that the second machine is autonomous.

### 3.1. Potential Hazards Associated with Robot Use at the Workplace—A Case Study on Automatic Guided Vehicles (AGVs)

One of the current challenges still being faced by the robotic industry is the problem of data acquisition to program these robots. It is understood that a major problem for AI in general is getting enough data to be processed to obtain the information from which ethical judgements on the part of robots can be made [13]. Ethical dilemmas will be faced by robots during operation, and whilst being super-easy for humans to make drastic decisions within the twinkling of an eye, an autonomous machine that is expected to be moral, working safe, on the other hand, might have to just decide arbitrarily or even sadly not be able to act swiftly in such a situation. Automatic Guided Vehicles are a beautiful class of robots that can be programmed to perform repetitive tasks, that are dangerous and can maintain precision while doing such. AGVs are sometimes equipped with manipulators and the accuracy portrayed in the execution of industrial tasks has encouraged the increasing and continuous use of AGVs in a variety of industries and applications. AGV models vary with reach distance, payload capacity and the number of axes (can be up to six) of the manipulator. The manipulator which is a jointed arm is usually the most distinguishing characteristic.

Most industries employ Automatic Guided Vehicles in the transportation of raw materials, tools or even finished products. In this section, we will observe and study the strengths and potential hazards that are inherent in a magnetic tape guided Automatic Guided Vehicle system. In this study, the "system" is defined as the AGV itself, all the components that make it up, the magnetic path it follows, its immediate surroundings and the cart systems that transport products, tools and materials between the production floor and storage room.

A list of 26 hazards which have been analyzed using the Preliminary Hazard Analysis (PHA) are discussed in the discussion section. The Preliminary Hazard Analysis is one of the systematic approaches available for identifying hazards and recommending corrective actions. For this case study, we assigned severity and probability scores by evaluating the potential consequences of each AGV failure mode, reviewing incident trends reported in the literature, and considering operational behaviors such as speed, load handling, navigation patterns and human proximity in order to apply consistent, industry-aligned scoring criteria.

The stages of the defined system where the most significant risks are experienced are listed below in order of lowest risk to the highest risk overall:

1) Pre-transportation of materials to the storage room;
2) Unloading and loading of AGV carts;
3) Charging and storage of the Automatic Guided Vehicles;
4) Transportation of materials.

To further illustrate the sequence of steps taken in identifying, evaluating, and mitigating AGV-related hazards using sensor systems, the workflow in **Figure 6** presents an overview of our methodology.

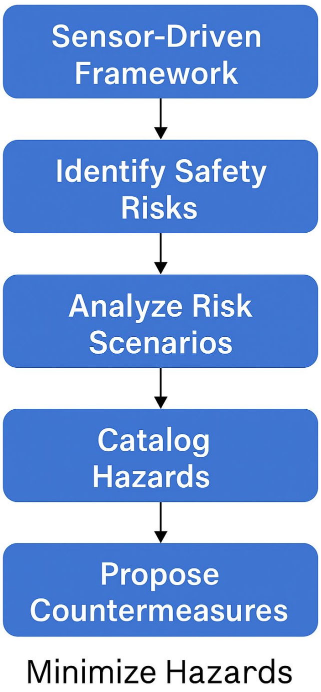


**Figure 6.** Sensor-driven workflow for AGV hazard identification and mitigation.

These hazards can be further broken down with respect to hazard targets which may be the operations personnel in charge of AGV use, or productions technician, equipment and machines, downtime, and environment around the AGV. Overall, a total of three notable hazards can be expected during pretransportation procedures, five obvious hazards are concerned with the loading and unloading of carts whilst an industry that employs can be expected to be at the risk of at least five hazards associated with charging and storage of the AGV system. Overall, a total of 23 hazards put personnel working around the Automatic Guided Vehicle system at risk, while 17 put equipment and machines at risk. A total of 16 hazards put the company's production time at risk, while just one hazard potentially endangers the environment. In the provided Preliminary Hazard analysis (PHA), countermeasures to help eliminate or otherwise limit these hazards have been provided. The acceptable level of risk and also the goal of the provided countermeasures would be to realize risks of code 3. It is imperative that level 1 risks are addressed with immediate effect and the countermeasures have been split over two broad sections, namely: one, the risks that have high costs of implementation with the greatest risk of mitigation and secondly, the risks that offer the lowest risk of mitigation with respect to the probability of occurrence and correspondingly offer low costs of implementation. A summary of the countermeasures is as portrayed below:

Section one (1) countermeasures:

1) AGV tracks should have guards installed around them.

2) Employee crossings should be installed.

3) Personnel flow path should be properly outlined in order to avoid personnel

crossing the path (except for of course the designed crossings) of the AGV during use.

Section two (2) countermeasures:

1) Automatic Guided vehicles should have lights installed on them.

2) Carts being pulled by AGVs should as well have lights installed on them.

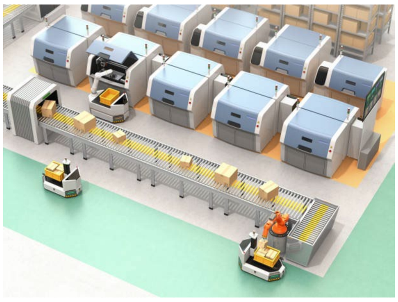
3) Wheels clean-up of the AGVs should be done periodically (may be bi-weekly or monthly).

4) Monthly inspections of the magnetic sensors on Automatic Guided Vehicles should be implemented on a monthly basis.

5) Thorough bi-weekly or monthly magnetic track maintenance should be implemented whilst simultaneously checking for any work areas that may present a high risk of degradation.

Wear and tear of installed magnetic tapes should be prevented via the installation of thin adhesive films.

The layout of a typical production company that employs Automatic Guided Vehicles (AGVs) and the AGV track robotic system in its production processes can be expected to look like what we have in **Figure 7** below:



(Source: https://unsplash.com/)

**Figure 7.** Sample layout of a production factory with AGV system.

For the purpose of this study, the case study has taken the following into consideration:

1) The paper has considered a tugger AGV (for example; Bidirectional 4 motor tugger system). This AGV system is being considered due to the cheap cost of acquisition, integration and implementation into a typical production factory and the customer support that comes with it.

2) In terms of a guidance system for the Automatic Guided Vehicle, magnetic tape is used thus compensating for a minimal set up. Other methods and ideologies may seem overly complex.

3) It is assumed that a single tugger can support up to five (5) towable carts. This increasingly multiplies production efficiency and also reduces physical strain on personnel, technicians and operators.

4) It is assumed that personnel pick up less than 50lb of material at a single time in an OSHA (Occupational Safety and Health Administration) correct fashion. As such, no injuries are directly involved with the lifting of an item.

5) At any given time, the heaviest piece of raw material being used does not weigh more than 50lb.

6) In the case of a product falling from the AGV cart which is as a result of mechanical or electrical faults in the AGV system, the hazard target is considered to be downtime. Finished products are however not considered in this scenario.

7) It is assumed that any component of the AGV which might need to be replaced during maintenance procedures is needed to be shipped.

8) The duration of the installed magnetic tapes is 10 years.

9) There is also the assumption that the full weight capacity of the AGV at any given time is 1500 kg (3306.934lbs).

10) It is assumed that the worst possible outcome is death whenever personnel is hit by an AGV.

11) The battery used in the AGV system has a weight of 34.02 kg (75lbs) and is a 72Volts 700 Amperes-Hour Flooded Lead-Acid pack.

12) The AGV can have up to five (5) carts attached to it at any given time.

13) The AGV is immobile unless prompted by personnel to move. During loading/unloading procedures, the AGV is stationary and does not move unless prompted by personnel.

Some other details we may need to be aware of is the fact that the OKAGV Bidirectional 4 motor tugger mentioned in this paper is capable of automatic charging as is possible with a lot of other AGV systems as well. The AGV is able to return to its charging station whenever the battery charge level is below a set threshold. Copper contacts are embedded in the ground which the Automatic Guided Vehicle travels over and stops on top of and this charges the AGV system. In addition to the full weight capacity of the AGV, in itself has a contained mass of 260 kg (573.20lbs) which includes its motors, battery, and overall structure. Thus, the total maximum operating mass of the system at any time is 1760 kg (3880.13lbs). The maximum linear speed of the fully loaded AGV is 3 km/hr *i.e.*, 50 m/min and has a 1.2 km/hr (20 m/min) turning speed. In this study, it is assumed that the AGVs are employed strictly for raw materials and tools transport during production and not for the transfer of finished products. In this section, we will analyze four sub-processes the AGV might follow on a typical workday which include pre-transportation processes, charging procedures, storage processes (all operational phases section of the analysis). Also, it is deemed that the operation period is 8-hours for a given day with the charging and storage stations designed in such a way that AGVs can be stored without a need to be charged.

In occupational safety and health engineering, we perform Preliminary Hazard Analysis in an attempt to uncover potential hazards that may not have been obvious without an in-depth study of the system in question. For a workplace with installed AGV systems, the PHA can be expected to focus on the space (path) traveled by the AGV in operation in greater detail. The system's boundaries are defined as: the distance the sensors can detect, the refresh rates of sensors, and the accuracy of the AGV sensors. The AGVs operational phases is a subset of or subject to the company's hours of operation. The following are some terminologies employed in PHA worksheets development:

1) **Process:** The overall system being considered is referred to as the process.

2) **Sub-process:** are subsets of the process or distinct parts which make up the overall system.

3) **Target:** Any system failure directly impacts or affects the target(s).

4) **Preliminary:** is an English word meaning that something takes place just before the start of an event.

5) **Analysis:** is defined as the breaking down of an integrated system into smaller units to enable efficient study of these sub-units as related to the overall system.

6) **Severity:** This is a measure of how bad the potential damage is or the level of the damage caused.

7) **Risk:** Sometimes defined as probability and severity combined. It is the expression of possible loss over a specific period of time or a number of cycles [14].

8) **Probability:** This is a measure of the chance or likelihood that an event occurs/happens. In mathematics, this is usually a value that lies between 0 and 1 inclusive.

9) **Failure:** A negative outcome which is as a result of a series of issues.

10) **Hazard:** condition or combination of conditions that if left uncorrected, have the potential to lead to an accident, illness, or property damage [14]. This usually leads to an exposure of targets (personnel, environment, assets, and equipment) to danger or harm.

11) **Mishaps:** An undesirable occurrence in which loss is experienced.

12) **Countermeasure:** Preventive measures which can help mitigate known risks of a given hazard.

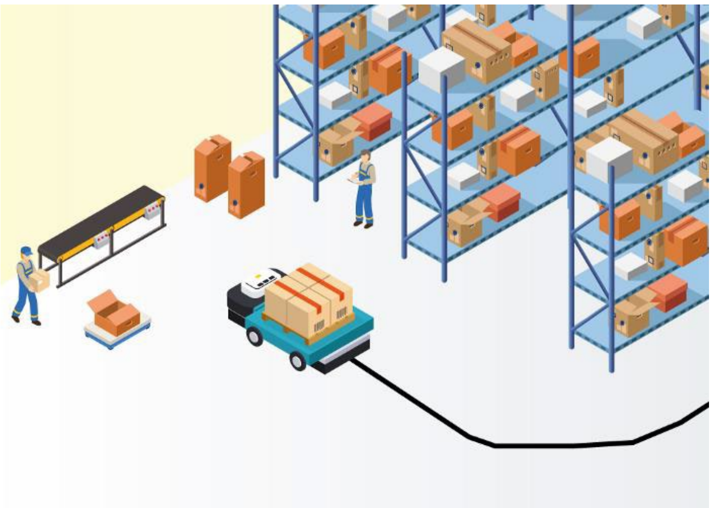
With the variously defined operational phases, we are able to identify hazards and worst-case scenario(s) for each operation. In Preliminary Hazard Analysis, it is usually recommended that operations be broken down into stages so that worst-case scenario(s) can be easily identified. For any hazards of risk code 3, countermeasures are not provided for them due to the fact that the frequency of those risks do not in any way interfere with daily operations. Furthermore, no significant loss is incurred as a result of them. Risk codes 1 and risk codes 2 are however provided with countermeasures as they pose highly significant financial burden. Risk codes 1 and 2 however do require countermeasures to be developed to enable a mitigation of the risk codes down to level 3. Often times, these countermeasures do not in any way reduce the severity of the impact of a hazard if it eventually occurs. Countermeasures are only usually exercised to reduce the frequency of an incident. This is usually done in various ways using fail-safe designs, design changes, warning devices, alert systems, engineering safety feature or even training/awareness programs. To add, some hazards are common across multiple operational phases and as such require special attention due to how widespread they are in the system under consideration.

## 3.2. Operational Phases

1) **Unloading and Loading Phases of AGV:** The process of loading and unloading of the AGV carts basically entail the stocking of the tugger's carts with the materials and tools to be transported. These very pivotal phases run through the whole process of circulation. There is a group of logistics employees tasked with this. At the production line where an AGV is to be used, the line worker places tools and raw materials for use for the next operation and sets the tugger into loading or unloading mode for the next operation. While in this mode, the tugger is stationary and it is impossible for it to start moving.

2) **Pre-Transportation Phase**: Just as the term "pre" implies, this is the stage directly preceding transportation of tools, raw materials and whatever items it may be that personnel want to move using the AGV system. The Automatic Guided Vehicle under consideration is classified as a fixed-AGV. This is a type of navigation system; another commonly used navigation system is the free-ranging type (https://www.automation.com). While in the pre-transportation mode, the AGV on its own (automatically) disconnects empty carts and tries to fix up with newly loaded carts which it senses via the transducers (weight sensors) installed on it.

3) **Transportation Phase:** During the transportation phase, the AGV system has the tugger carts attached to it which are fully loaded. It transports itself and the carts from the production area to the storage room or other areas as predetermined by personnel by moving along a defined path, a trajectory which in this case is marked out by the magnetic tape (an example shown in Figure 8 below) that guides the AGV. It should be noted that following loading and unloading procedures, the AGV always has to return to the cold storage area. The risks involved with this phase are outlined as the worst-case scenario of a failure or malfunctioning of a component whilst AGV is carrying full load.



(Source: https://unsplash.com/)

Figure 8. Image showing AGV guidance using magnetic tape.

4) **Charging and Storage Phases:** As previously mentioned, the AGV runs on a 34.02 kg (75lbs), 72Volts 700 Amperes-Hour Flooded Lead-Acid battery pack which can be drained and thus needs to be recharged from time to time. The recharging of the AGV system takes place during the charging phase. During this time, the Automatic Guided Vehicle system is not used for labor, and is inoperable due to low battery. The tugger is equipped with a system which notifies it of a need to be charged once battery level hits below set threshold. It does this automatically and navigates itself to the charging spot.

## 3.3. Analysis of Envisaged System Hazards

Here, we proceed to outlining the hazards that are concerned with the different phases involved with AGV use during a normal workday at a supposed industrial company that uses them with respect to similar details as portrayed in the previous sections. It should however be noted that this is only a case study and of course may extend to other robot types as well since robots have a lot of things in common. The most important of which is being automated. A combination of the two parameters (severity and probability) will be used to define potential hazards with risk levels from 1 to 3, with 3 being the lowest risk level and 1 correspondingly being the highest risk level.

To aid easy hazards identification, the following hazards identifiers will be used:

- Overall (all phases combined)—OA;
- Charging and storage—CS;
- Transportation—T;
- Pre-transportation—PT;
- Loading and Unloading—UL.

The way the hazards are identified is as presented below; we start with level 1 risks and then proceed to level 2 risks. The risk matrices used in presenting the severity categories and probability levels are shown in Figure 6 and Figure 9.

Also, Figure 10 depicts the Risk matrix used in performing PHAs.

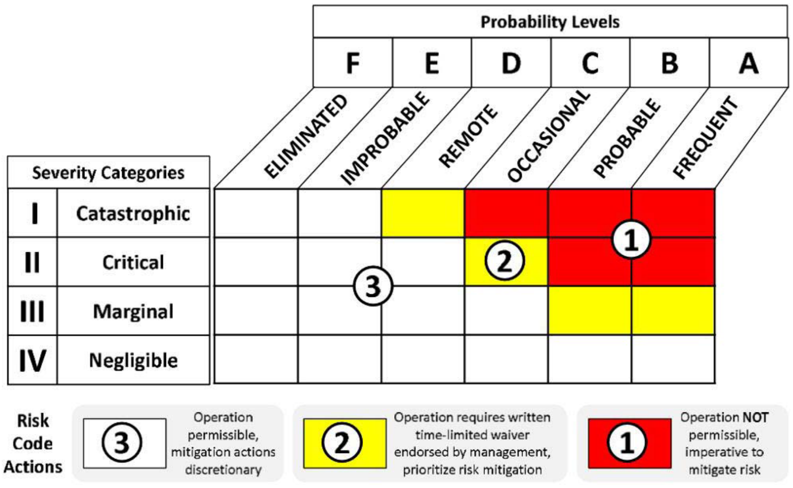
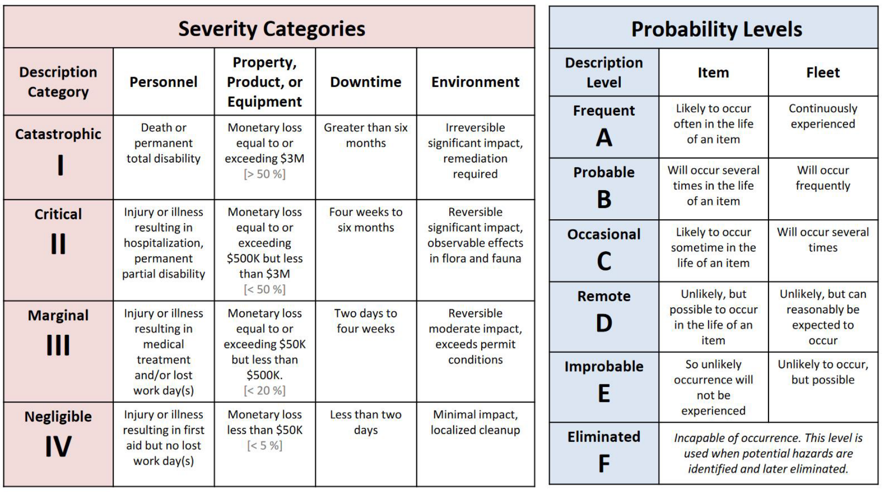


Figure 9. Understanding severity categories and probability levels.



| Severity Categories | | | | |
|---|---|---|---|---|
| **Description Category** | **Personnel** | **Property, Product, or Equipment** | **Downtime** | **Environment** |
| **Catastrophic I** | Death or permanent total disability | Monetary loss equal to or exceeding $3M [> 50 %] | Greater than six months | Irreversible significant impact, remediation required |
| **Critical II** | Injury or illness resulting in hospitalization, permanent partial disability | Monetary loss equal to or exceeding $500K but less than $3M [< 50 %] | Four weeks to six months | Reversible significant impact, observable effects in flora and fauna |
| **Marginal III** | Injury or illness resulting in medical treatment and/or lost work day(s) | Monetary loss equal to or exceeding $50K but less than $500K. [< 20 %] | Two days to four weeks | Reversible moderate impact, exceeds permit conditions |
| **Negligible IV** | Injury or illness resulting in first aid but no lost work day(s) | Monetary loss less than $50K [< 5 %] | Less than two days | Minimal impact, localized cleanup |

| Probability Levels | | |
|---|---|---|
| **Description Level** | **Item** | **Fleet** |
| **Frequent A** | Likely to occur often in the life of an item | Continuously experienced |
| **Probable B** | Will occur several times in the life of an item | Will occur frequently |
| **Occasional C** | Likely to occur sometime in the life of an item | Will occur several times |
| **Remote D** | Unlikely, but possible to occur in the life of an item | Unlikely, but can reasonably be expected to occur |
| **Improbable E** | So unlikely occurrence will not be experienced | Unlikely to occur, but possible |
| **Eliminated F** | *Incapable of occurrence. This level is used when potential hazards are identified and later eliminated.* | |

**Figure 10.** Risk matrix used in performing PHAs.

### 3.3.1. Risk Code One (1) Hazards

**IB**

- AGV.T.001—Hazard where small pieces of ferromagnetic materials interfere with the magnetic guide sensor on AGV which causes it to swerve off its defined path, leading to a collision with personnel.
- AGV.T.002—Forklift from work area loses control, crashes into AGV and collides with personnel.
- AGV.T.003—AGV is tipped by forklift over onto personnel.
- AGV.T.004—Dirt from work area gets stuck to AGV wheels and prevents AGV traction.
- AGV.T.005—Magnetic tape degradation overtime due to commuting AGV traffics results in AGV leaving defined tracks and running into personnel.
- AGV.T.006—AGV wheels get worn out from continuous use and movement preventing proper halting and increasing stopping distance which causes AGV to run into personnel.

**IC**

The hazards in this category present lower probabilities and are only likely to occur at some point within around 25 years of the system but are identified to lead to risks of serious injury or ultimately, the death of personnel. The hazards have been outlined below and countermeasures to reduce the probability of occurrence are provided in the sections that follow.

- AGV.OA.001—Ferromagnetic dust from the environment gets stuck on AGV and interferes with magnetic field and sensor communications, causing AGV carts to veer off path and collide with personnel.
- AGV.OA.002—Personnel crosses the path of a moving AGV, collision occurs and results in injury to personnel or death (it is assumed that the worst-case scenario whenever personnel is hit by AGV is death).
- AGV.CS.001—Electrocution of personnel as a result of free currents from charging base.

- AGV.T.007—Cart suddenly disconnects from AGV as a result of worn-out hooks over multiple years of use, and collides with personnel.
- AGV.T.008—Raw materials and tools being transported across magnetic track close to AGV throw off magnetic sensors and results to collision with personnel.
- AGV.T.009—Damage of magnetic field sensors by external misuse during transportation phases leading to collision with personnel.

**II B**: The last category of hazards under Risk Code One (1) hazards

- AGV.OA.003—Magnetic tape's wear, tear and degradation results in AGV losing track of path and running into personnel during operation and production hours. Other than resulting in serious injury to personnel, this hazard also has downtime as a target.
- AGV.OA.004—Same as above, but with machines and equipment as targets.
- AGV.CS.002—Discharge of static electricity built up from rolling resistance damages charging station beyond past remedy. If personnel is present, this causes downtime as a target.
- AGV.CS.003—Same as above but in the case that this affects equipment and machines as targets.
- AGV.PT.001—Personnel gets stuck in-between AGV and cart while trying to line up hooks.

### 3.3.2. Risk Code Two (2) Hazards

Here, we would take a look at hazards do not have a high likelihood of occurring but are however consequential when they do. The codes in this segment relate to personnel, operators, technologists and the possibility of death over 25 years of AGV system use (*i.e.*, 25 years probability interval).

**ID**

- AGV.PT.002—During a pre-transportation process while AGV is stationary, it loses internal braking traction and runs into floor machines/equipment and personnel and causes serious injury plus damage to the AGV. This leads to significant downtime.
- AGV.T.010—A scenario in which the AGV's proximity sensors become damaged or maybe non-functional leads to collision between AGV and personnel and results in death of personnel and damage of equipment.

**II C**: In the previous risk categories, we have considered hazards which can affect personnel as well. Here, we will take a look at hazards to personnel which do not have a tendency of resulting in the loss of life of personnel, but can cause limited damage to machines and equipment. It should be however noted that these hazards are not likely to occur within the set probability interval with the ideology that the personnel targets are actually facing the potentials of partial temporary partial disabilities and permanent partial disabilities and consequently bring about significant time away from work. In this section, the fleet of equipment may include a large number of machines or AGVs.

- AGV.UL.001—A scenario where cart is accidentally loaded beyond the maximum capacity which then stretches the cart casters beyond limit causing them to break off. Loaded materials are toppled onto the ground and onto floor workers resulting in very serious injury.

- AGV.UL.002—Loaded materials on carts are not uniformly distributed causing load to be imbalanced. Cart is then tipped over to another side during transportation causing loaded materials to fall onto floor workers resulting in serious injury.
- AGV.UL.003—Bottom of cart loading compartment becomes weakened as a result of continuous impact of heavy materials onto carts till failure. Failure results in major downtime and calls for a need to have AGV carts and trolleys replaced.
- AGV.OA.004—Ferromagnetic dust from industrial and manufacturing processes like machining cover up magnetic tape and interrupts signal causing AGV carts to lose track of path during transportation thereby causing damage to nearby machines and equipment.

**III B**: The hazards in this category all include risks to the personnel. They both are only capable of bringing about minor injuries to personnel, technicians, floor workers and technologies and just minimal time away from work.

- AGV.PT.003—There is worn down latch assembly between attached carts which suddenly disconnects prior to transportation. Personnel standing close to AGV carts is seriously injured.
- AGV.PT.004—While carts are being lined up by personnel with AGV hooks, personnel is pinched and left stuck in between the two elements bringing about serious injury to personnel.

**III A**: In this section, we consider hazards that are potentially targeted at personnel and has a tendency of occurring the most (hazard with the highest frequency). The severity of this hazard is however not expected to be that significant.

- AGV.UL.004—A scenario in which a worker catches limb on sharp edges of metal while performing loading procedures. This brings about deep laceration with immediate and urgent medical need.

All the risk hazards analyzed in this paper have been summarized in Table 1 and Table 2 below:

Table 1. Risk code 1 AGV hazards and sensor failures.

| Code | Hazard Description | Sensor Failure |
|---|---|---|
| AGV.T.001 | Magnetic interference veers AGV off path | Magnetic guide sensor failure |
| AGV.T.002 | Forklift collides with AGV | External event (N/A) |
| AGV.T.003 | AGV tipped by forklift | External event (N/A) |
| AGV.T.004 | Dirt blocks traction | Traction sensor blind spot |
| AGV.T.005 | Tape degradation misguides AGV | Path sensing failure |
| AGV.T.006 | Worn wheels increase stopping distance | Brake response delay |
| AGV.OA.001 | Dust interferes with magnetic field | Field communication loss |
| AGV.OA.002 | Personnel crosses path | Proximity/LiDAR failure |
| AGV.CS.001 | Charging shock risk | Electrical insulation failure |

**Continued**

| | | |
|---|---|---|
| AGV.T.007 | Cart detachment from hook | Lock sensor fatigue |
| AGV.T.008 | Tools disrupt sensor reading | Sensor overload |
| AGV.T.009 | Transport sensor damage | Housing vulnerability |
| AGV.OA.003 | Tape wear during operation | Path sensing error |

Table 2. Risk code 2 AGV hazards and sensor failures.

| Code | Hazard Description | Sensor Failure |
|---|---|---|
| AGV.PT.002 | Brake traction loss causes collision | Brake sensor fault |
| AGV.T.010 | Proximity sensor failure causes impact | Proximity/LiDAR loss |
| AGV.UL.001 | Cart overloaded and collapses | Load sensor absent |
| AGV.UL.002 | Load imbalance tips cart | Distribution sensor gap |
| AGV.UL.003 | Cart bottom failure due to wear | Wear tracking missing |
| AGV.OA.004 | Dust covers tape and disrupts path | Path signal obstruction |
| AGV.PT.003 | Cart latch fails near worker | Latch wear undetected |
| AGV.PT.004 | Pinched during hook alignment | Miscoordination risk |
| AGV.UL.004 | Sharp edge laceration during loading | Not sensor-related |
| AGV.PT.002 | Brake traction loss causes collision | Brake sensor fault |

## 4. General Overview of Robot Use at the Workplace—Data and Summary of Reported Incidents and Accidents

In [15], the authors proposed some hypothesis concerning the use of robots in the workplace, the first of which is the explanation that robotization is a turning point for performance and productivity, which are the two main business indicators of competitiveness. They also hypothesized that productivity is not a function of the company size, and increases in companies that adopt robotization. Thus, companies that employ robots in their everyday tasks evolve into a more efficient model of productivity compared to those that do not adopt it. The authors have shown in [16] that the reality of having all processes fully automated in a production company is a very hard one, and thus there are limits to automation. This brought about a third hypothesis being proposed in [15] that even if many tasks are automated, growth may remain restricted due to areas that remain fundamental yet are hard to improve even with an increase in capital investment. Thus, increase in productivity is not limitless, at some point, a saturation level is reached. The use of robotics in production processes would not bring about an indefinite increase in productivity, but rise in productivity is however guaranteed once a process that never involved robot use becomes automated. Again, the effects of robot use on worker's salary was studied and it was proposed in the paper [15] that Small and Medium-sized Enterprises (SMEs) employ robotization procedures which brings about an increase in the staff costs per worker. The use of robots brings about an increase in costs of human labor. Penultimately, it was hypothesized that robotically automated companies are more resilient to unfavorable financial crisis in that the increased productivity brought about the automated functions is a form of protection to the production/manufacturing company and its workforce. It is safe to say that the automation of a company's system or process by use of robotic devices is of great competitive advantage over non-robotic companies and is not limited to favorable environments alone but how well a company is able to recover from financial disappointments. Finally, both large businesses and Small and Medium-sized Enterprises are positively impacted or negatively affected in the same way by the robotization pr varies depending on the different characteristics of the involved companies themselves. In addition to the merits outlined above, the authors opined in [15] that both direct and indirect benefits are associated with industrial robots use as they bring about improved productivity, improved efficiency, improved product quality, improved quality of work, and improved competitive position. With robotization, the need for labor to execute repetitive tasks is minimized. Robots can work under extremely harsh conditions, and more quickly that humans. Robots are consistent, never get tired, and are not affected by sicknesses or diseases. They are even fast becoming more preferred in jobs where exposure to extreme heat and radiation is a primary concern.

There are many ways in which robotics help improve safety and health in a production company and this is primarily due to the fact that robots can take the place of employees in a potentially hazardous environment. For example, robots can reduce the risk of falls from a height. Where employees may be required to use ladders, the manipulators of a robot can easily reach. Also, robots would help reduce the risk of Musculoskeletal Disorders (MSDs) in that exoskeleton robots would help workers reduce their need to perform repetitive motion tasks. With robots, personnel do not need to lift very many heavy objects and as such, injuries associated with heavy lifting are reduced. Next, we will proceed to taking a look at some recorded hazards associated with workplace robotics.

A recent online article published by YaleNews by researchers from Yale University and the University of Pennsylvania provides evidence that the use of robots in U.S. manufacturing is fueling an increase in mortality rate among the working class. OSHA also claims on the other side that worker deaths in the United States of America are declining on average. Previous record shows 38 worker deaths a day in 1970, and a recent record of 14 a day in 2017. To add, worker injuries and illnesses are down from a total of 10.9 incidents per 100 workers in 1972 to 2.8 per 100 in 2017. A recent report also claims that the robotic workforce of some major companies in California have experienced injuries among workers nearly quadrupling within the recent years as shown in **Figure 11**. They went from decent 2.9 injuries per 100 workers in 2015 to an astonishing 11.3 in 2018. The question that robot introduction at the workplace helps to improve the overall safety at the modern workplace is thus still a major source of concern.

## Overcoming and Managing Potential Robot Hazards at the Workplace—The Place of OSHA and Other Regulatory Agencies

In 2015, there was a fatality case in which personnel at a bottled-water company was killed after being lacerated by the forks on a robotic driverless forklift. It is a laser-guided Vehicle (LGV). Although LGVs are equipped with sensors which are able to detect objects or operators in their path, the manufacturer's manual requires that operator initiate an "emergency stop" before getting rid of an obstacle. This way, the forklift does not automatically resume its normal activities once obstacle has been removed. The 2015 case was one in which the sensor's alarm was triggered by a small piece of plastic under the elevated forks. Worker forgot to initiate emergency stop and was left crushed as soon as obstacle was removed and LGV resumed its automated function. According to OSHA, many robot accidents do not happen under normal operating conditions, but usually during obstacle removal, programming, refinement, maintenance, program touch-up, repair, set-up, testing or adjustment. The most common hazards identified by OSHA which humans working with robots are to be careful of include control errors, unauthorized access, mechanical failures, environmental sources, power systems, improper installations and human errors themselves. OSHA provides a list of potential sources of hazards which are divided into two main categories of human factors and mechanical/physical factors. These hazards are generally addressed by applying fixed guards, stickers, placards, barriers or warnings. It is noteworthy that the discrepancies in conflicting data on robot-related injury rates often arise from differences in reporting practices across industries, the type and complexity of automation deployed, variations in human robot interaction levels and the degree to which each workplace has adopted a mature safety culture.

Majority of the hazards related to robot use at the workplace can be sabotaged, eliminated or minimized by ensuring proper planning prior to installation [15]. It is imperative that employees be part of the robots installation planning process to imbue their perception of the changes at the workplace. It is understood that employee involvement in the planning process would also better help to keep management's involvement in safety procedures under check. Following installation procedures, training must also be provided to workers before robots use, and should not be discontinued. Employee training is not supposed to be a one-time thing, but consistent one, before the installation of new robots, during and after the installations processes. Robot (Automatic Guided Vehicles) coordination is usually approached as and offline problem to be solved when installation is ongoing. The reasons for this is none other than that safety concerns are of necessity and management desires to maintain a constant rate of production. To manage hazards that workers may be exposed to while at work, some standards have been put in place to emphasize regulations. Some of them are listed below (where ANSI is short for American National Standards Institute, BS IS short for British Standards, ISO represents International Organization for Standardization, IEC is an acronym for International Electrotechnical Commission, and the IEEE is short for Institute of Electrical and Electronics Engineers).

1) ANSI B11.1-2010 addresses the safety of machinery, the general requirements and the risk assessments involved.

2) BS EN 1525: 1998 focuses on the safety of industrial trucks which encompasses both driver-less trucks and other systems involved with them.

3) BS EN ISO 3691-6:2013, BS EN ISO 369-1:2012 (which was originally BS EN 1726-1:1999) is concerned with the safety of industrial trucks, self-propelled trucks whose capacity run up to 10000 kg and also industrial trucks with a drawbar pull up to and including 20000 N.

4) IEC/EN 60204-1: 2006 addresses the safety of machinery, electrical machines, and the general requirements involving their use.

5) ISO EN 13849-1: 2008 is concerned with the safety of machinery and the safety-related parts of control systems and the general principles guiding their design.

6) IEC 61508-1: 2010 This standard is concerned with effectuating the safety of electrical/programmable/electronic-safety related systems.

7) IEC 61508-2: 2010 is the other part of the standard provided above and IEC 61508-3: 2010 is the third part of the standard which addresses the software concerned with robot deployment. Also, IEC 61508-6: 2010 is the Part 6 of the standard provided above and provides guidelines on the applications of IEC61508-2 and IEC61508-3.

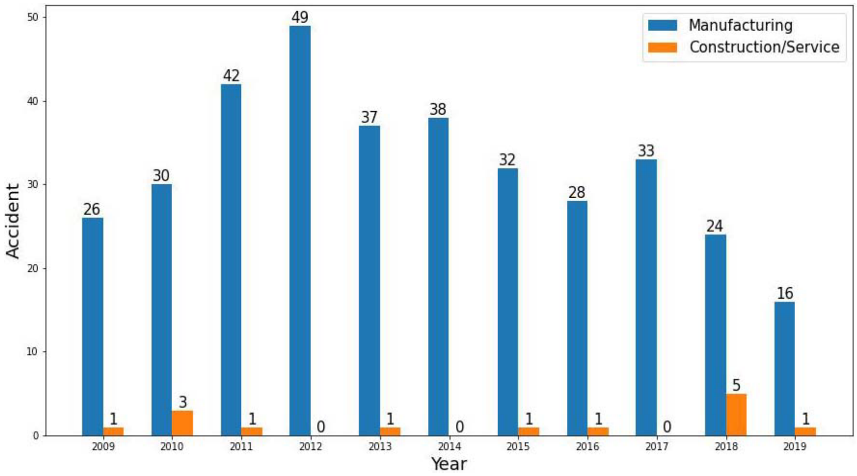


**Figure 11.** Reported Robot Accidents from 2009 through 2019 [17].

8) IEC 62061: 2005 addresses the safety of machinery, functional safety of safety-related electronic, electrical and programmable electronic control systems.

9) IEC/TR 62061-1 provides guidance on the application the standards ISO 13849-1 and IEC 62061 in the design and maintenance of safety-related control systems for machinery.

10) IEEE Std 1175: 1992 is a standard focusing on IEEE's Trial-Use Standard Reference Model for Computing System Tool Interconnections.

## 5. Discussion

Having discussed the risks, probability levels and severity categories of different potential hazards that are inclined to the use of Automatic Guided Vehicles at a manufacturing industry, it is of great necessity to discuss what countermeasures are best put to place to eliminate these risks or better still, minimize the occurrence or fatality of the same. Although, a number of the identified hazards share similar outcomes, there are multiple ways in which level one (1) risk hazards can occur, and thus, distinctive countermeasures should be directed towards each uniquely identified hazard. It is understood that the proposed countermeasures are able to reduce risk codes from an aggravating level of one (1) to three (3). The countermeasures will however be the most expensive to carry out. The first of which will be to install guards around the path the AGV travels around. Next, active personnel crossings and automatic physical barriers should be installed so that employees get protected from being hit by AGVs if AGVs would not stop during transportation whilst there's a potential collision with personnel. Whilst crossings are not being used, barriers would remain flushed with the floor, and level, so as not to impeded the movement of the AGV. Some of the other countermeasures that could be implemented for any industry that perfectly fits in the discussed case study which are not expensive to implement and correspondingly helps to lower the risk code from a level 1 to level 2 would include the following: Installing lights on all Automatic Guided Vehicles and the cars as well, implementing monthly cleaning of AGV wheels, executing yearly inspections of magnetic sensors, covering of the magnetic tape track in thin adhesive and timely replacement whenever need be, to prevent wear and tear, complete and thorough monthly magnetic track maintenance to manage areas with high risk of degradation. For level two (2) risk countermeasures which are associated with risk code 2 hazards, and are meant to mitigate or lower hazards from a risk level of 2 down to 3, they would require little to no cost. The first of this would be the performance of routine inspections of various sections of the system. The next would be increasing the wheelbase of the carts to provide an evenly distributed weight and a simultaneous reduction in the height of loaded materials. Also, Personal Protective Equipment should be worn by personnel and every other worker during work hours to cover up any exposed skin and prevent serious laceration in the circumstance of unfortunate events. Management should also require the use of safety gloves as Personal Protective Equipment for personnel. Training should be provided from time to time to personnel and other workers on the proper technique of lining up AGV carts with the AGVs themselves. Companies would also be encouraged to implement sensor inspection programs and checks on a bi-yearly basis. Installed magnetic tapes should be cleaned periodically and a detailed record of monthly maintenance checks on cart and trolley which can be fallen back to, at any point in time should be performed; where maintenance procedures are primarily focused on the surfaces and connecting hooks of AGV carts and trolley compartments.

Furthermore, we see that while multiple reports have confirmed an ease in which industrial tasks are being executed and set goals realized, the rate of fatality in some major companies have constantly been on the rise. A lot of regulatory agencies have come up with the idea that whilst it may be difficult to eliminate the hazards involved with robot use at the workplace, staying true to the set and provided standards is a way to have some of these hazards minimized. It is safe to say that hundred percent hazard free work environment cannot be realized but potential risks can be avoided as much as possible.

Table 3 presents a summary of key sensors identified in recent studies which, when integrated into human-robot collaborative environments, have the potential to significantly reduce—if not entirely eliminate—the twenty-six (26) hazards outlined in this work.

Table 3. Summary of key sensors, strengths, limitations, and cost of implementation.

| Sensors | Strength | Limitations | Cost of Implementation |
|---|---|---|---|
| Encoders [18] | Encoders are mounted on the wheels, counting wheel rotations of the autonomous mobile robot to estimate their precise location in complex layout of plants with the help of natural signals. This will reduce the risk of collision and navigation within the plant. | Reduced accuracy over longer distances and summed-up errors of odometry | Mid-tier |
| Wireless Sensor Network [18] [19] | The wireless sensor complements the encoders to evaluate the localization of the robot with reduced errors, giving better precision over long distances than encoders when used in hybrid-mode to aid navigation. | Interference or transmission collision with obstacles and changes in the factory leads to fluctuations of the received signal strength, signal path and communication conditions | High-cost |
| LiDAR (Light Detection and Ranging) [20] | This involves using laser light with a range of scans in 3D. It gives extensive data in robotics systems for mapping, object detection and environment scanning. The data includes the spatial coordinates of the 3D points making it easier to detect obstacles. The sensor aids optimal task allocation, good planning and control of the work-environment. | Computationally intensive by including irrelevant data acquisition. | High-cost |
| Stereovision Cameras [21] [22] | With the advent of machine learning incorporated into this system, the cameras can efficiently forecast obstacles in close range distance to aid the autonomous system in maneuvering during mobility. | The performance is dependent on the environment lightning. Poor lightning reduces the efficiency of the sensor. | Low-cost |
| Infrared [23] | These sensors are very sensitive when coupled with logic controller, making it suitable for static and dynamic environments. It helps robots work freely by avoiding contact with uncertain obstacles due to movement and tight environments. It provides good dynamic response leading to better accuracy of the robots. | Its efficiency is limited to a very short range of obstacles between 4 to 30cm, and sensitive to reflected surfaces. | Low-cost |

**Continued**

| | | | |
|---|---|---|---|
| RFID (Radio Frequency Identification) [24] [25] | This technology is very old and has evolved beyond the motive of traceability of products in supply chain. It has evolved into sensor tags to accumulate massive real-time data working as a smart label to detect dynamic obstacles.<br>It is an automatic wireless data-collection technology. | Its commercial availability is low, complex to develop and quite expensive to create and maintain. Also, it does not allow the use of a universal tag for any distance, instead the range depends on the frequency of each tag used. | High-cost |
| Ultrasonic [26] | Ultrasonic sensors utilize sound wave signals above 20kHz to determine the presence of nearby obstacles and range. They often have simple structures and are not interrupted with electro-magnetic fields. Its application is not limited to data acquisition and positioning control of the robots. | The accuracy and stability of the data obtained may vary due to signal interference and multipath effects. Also, its performance is limited in 'meters' order of magnitude range/distance. | Low-cost to Mid-tier |
| Radar (Radio Detection and Ranging) [27] | This sensor does not contain moving mechanical parts and allows reliable target detection in extreme environment. There is no risk of vibrations and shocks making it viable for determining the range, trajectory and relative speed between the sensor and target. | This complex system has poor spatial resolution and limited field of view. | High-cost |

As one of the main results of our hazard study, we suggest a sensor driven method that can help detect and reduce AGV risks in the workplace. This method connects each hazard we identified to the sensors that can help prevent it, such as LiDAR, ultrasonic sensors, RFID, encoders and stereo vision. Using several types of sensors together can make up for the weaknesses of any single sensor and help the AGV understand its surroundings more reliably. We present this method as an important way to lower the chances of accidents and to improve the safety of AGV operations. To support safety engineers and electronic system designers, **Table 4** provides a practical summary that links each identified hazard to one or more sensor technologies most suited for its detection and mitigation.

Table 4. Recommended Sensor Assignments for Risk Mitigation.

| Hazard Category | Representative Hazard(s) | Recommended Sensors |
|---|---|---|
| AGV Path Deviation | Tape degradation, magnetic interference | Magnetic field sensor, path tracking sensor |
| Collision with Equipment | Forklift collision, brake traction loss | Proximity sensors, LiDAR |
| Human-Robot Interaction | Personnel crossing, hook-up pinch | Stereo vision camera, IR sensors |

**Continued**

| | | |
|---|---|---|
| Charging Station Risks | Electrical shock, static discharge | Grounding sensors, voltage detection |
| Load Instability | Cart imbalance, overload collapse | Load sensors, distribution sensors |
| Sensor Signal Loss | Dust or tool obstruction | Sensor housing protection, sensor redundancy |

## 6. Conclusion and Recommendations

In a bid to better help uncover the flaws of robot use in a robotic industry, it is hoped that the designs of employed robots and robot systems (AGV was used in this paper) can be improved upon to help the system protect named targets and fragile assets that are usually a subject of high-level risks during operations against potential hazards at the workplace. In Section 3 of this paper, we have visualized what a typical robotic workplace would look like, identified targets and the whole system and made assumptions as necessary. This was done so that the Preliminary Hazard Analysis (PHA) report can portray even the slightest of risks involved with robot use at the workplace. The PHA analysis consists of a list of envisaged hazards and level of associated risk. Whilst it is understood that Preliminary Hazard Analysis may be carried out at any point in a system's life cycle, it is recommended that they be performed at the design phase when plant is being set up or systems are being installed. PHAs can also be used on an already set-up system as its first analysis.

To address the central question posed in the title and to determine whether AGVs increase or decrease potential hazards, our findings indicate that the outcome is not inherent to the AGV technology itself. Instead, workplace safety is determined by the quality of risk management, adherence to established standards, and the rigor of safety protocols surrounding AGV deployment.

Within the four (4) operational phases defined (Loading/Unloading, Charging and Storage, Transportation, Pre-transportation), a total of twenty-six (26) potential hazards have been identified. They have a tendency of impacting the machines, equipment, personnel, environment and company's production hours (time) which are the targets. The targeted hazards can be fully portrayed on a hazard plot for use by the management of any company that may want to use them, but this paper has however not dealt with that. This could be some motivation for future work.

Also, available reports as to mortality rates with robot use in the industry are conflicting in some ways. Some authors and production companies claim that whilst efficiency was improved, the injury rates among their workers have increased significantly since the introduction of robots at the workplace. Some others confirmed that sticking to set rules, standards and the provision of continuous maintenance and guidelines to operators, users and floor workers has been enough to keep mortality rate and injuries within the barest minimum.

This study further presents a sensor-driven framework in the Discussion section that connects each identified hazard to the sensing technologies best suited for its mitigation, emphasizing that robust multi-sensor integration and ongoing system validation play crucial roles in reducing AGV-related incidents.

In summary, AGVs can either increase or decrease potential workplace hazards depending entirely on how effectively they are implemented, monitored and governed by safety standards. When risk management is strong, AGVs reduce hazards. When it is weak, hazards increase.

## Acknowledgements

We gratefully acknowledge the guidance, feedback, and support provided during the development of this work. We also appreciate the resources and technical assistance of the editor who contributed to the successful completion of this study.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

[1] Jorgenson, D.W., Ho, M.S. and Samuels, J.D. (2012) Information Technology and US Productivity Growth: Evidence from a Prototype Industry Production Account. In: Mas, M. and Stehrer, R., Eds., *Industrial Productivity in Europe*, Edward Elgar Publishing. https://doi.org/10.4337/9780857932105.00009

[2] Kraus, S., Palmer, C., Kailer, N., Kallinger, F.L. and Spitzer, J. (2018) Digital Entrepreneurship: A Research Agenda on New Business Models for the Twenty-First Century. *International Journal of Entrepreneurial Behavior & Research*, **25**, 353-375. https://doi.org/10.1108/ijebr-06-2018-0425

[3] Acemoglu, D. and Restrepo, P. (2019) The Wrong Kind of AI? Artificial Intelligence and the Future of Labor Demand. *Cambridge Journal of Regions, Economy and Society*, **13**, 25-35.

[4] Grau, A., Indri, M., Lo Bello, L. and Sauter, T. (2021) Robots in Industry: The Past, Present, and Future of a Growing Collaboration with Humans. *IEEE Industrial Electronics Magazine*, **15**, 50-61. https://doi.org/10.1109/mie.2020.3008136

[5] Ballard, L., Sabanovic, S., Kaur, J. and Milojevic, S. (2012) George Charles Devol, Jr. [History]. *IEEE Robotics & Automation Magazine*, **19**, 114-119. https://doi.org/10.1109/mra.2012.2206672

[6] Tantawi, K.H., Sokolov, A. and Tantawi, O. (2019) Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0 Collaboration. 2019 4*th Technology Innovation Management and Engineering Science International Conference* (*TIMES-iCON*), Bangkok, 11-13 December 2019, 1-4. https://doi.org/10.1109/times-icon47539.2019.9024658

[7] Considine, D.M. and Considine, G.D. (1986) Robot Technology Fundamentals. In: Considine, D.M. and Considine, G.D., Eds., *Standard Handbook of Industrial Automation*, Springer, 262-320. https://doi.org/10.1007/978-1-4613-1963-4_17

[8] Seok, S., Onal, C.D., Wood, R., Rus, D. and Kim, S. (2010) Peristaltic Locomotion with Antagonistic Actuators in Soft Robotics. 2010 *IEEE International Conference on Robotics and Automation*, Anchorage, 3-7 May 2010, 1228-1233. https://doi.org/10.1109/robot.2010.5509542

[9] Murphy, R. and Woods, D.D. (2009) Beyond Asimov: The Three Laws of Responsible Robotics. *IEEE Intelligent Systems*, **24**, 14-20. https://doi.org/10.1109/mis.2009.69

[10] Clarke, R. (1993) Asimov's Laws of Robotics: Implications for Information Technology—Part I. *Computer*, **26**, 53-61. https://doi.org/10.1109/2.247652

[11] Clarke, R. (1994) Asimov's Laws of Robotics: Implications for Information Technology—Part 2. *Computer*, **27**, 57-66. https://doi.org/10.1109/2.248881

[12] Litzenberger, G., Tsuda, J. and Wyatt, S. (2018) Executive Summary: World Robotics 2018 Industrial Robots. International Federation of Robotics, 13-22.

[13] Anderson, S.L. (2007) Asimov's "Three Laws of Robotics" and Machine Metaethics. *AI & SOCIETY*, **22**, 477-493. https://doi.org/10.1007/s00146-007-0094-5

[14] Goetsch, D.L. (2011) Occupational Safety and Health for Technologists Engineers and Managers. 7th Edition, Prentice Hall, 1 p.

[15] Ballestar, M.T., Díaz-Chao, Á., Sainz, J. and Torrent-Sellens, J. (2021) Impact of Robotics on Manufacturing: A Longitudinal Machine Learning Perspective. *Technological Forecasting and Social Change*, **162**, Article ID: 120348. https://doi.org/10.1016/j.techfore.2020.120348

[16] Aghion, P., Bergeaud, A., Boppart, T., Klenow, P.J. and Li, H. (2019) Missing Growth from Creative Destruction. *American Economic Review*, **109**, 2795-2822. https://doi.org/10.1257/aer.20171745

[17] Lee, K., Shin, J. and Lim, J. (2021) Critical Hazard Factors in the Risk Assessments of Industrial Robots: Causal Analysis and Case Studies. *Safety and Health at Work*, **12**, 496-504. https://doi.org/10.1016/j.shaw.2021.07.010

[18] Fu, G., Zhang, J., Chen, W., Peng, F., Yang, P. and Chen, C. (2013) Precise Localization of Mobile Robots via Odometry and Wireless Sensor Network. *International Journal of Advanced Robotic Systems*, **10**, Article 203. https://doi.org/10.5772/56217

[19] Ohori, F., Itaya, S., Osuga, T. and Kojima, F. (2020) Estimating Wireless Link Quality Using Multiple Remote Sensors for Wireless Control of AGV in a Factory. 2020 23*rd International Symposium on Wireless Personal Multimedia Communications* (*WPMC*), Okayama, 19-26 October 2020, 1-6. https://doi.org/10.1109/wpmc50192.2020.9309467

[20] Li, B., Zhang, T.L. and Xia, T. (2016) Vehicle Detection from 3D Lidar Using Fully Convolutional Network. arXiv:1 608.07916.

[21] Syed, T.N., Zhou, J., Marinello, F., Lakhiar, I.A., Chandio, F.A., Rottok, L.T., *et al.* (2025) Definition of a Reference Standard for Performance Evaluation of Autonomous Vehicles Real-Time Obstacle Detection and Distance Estimation in Complex Environments. *Computers and Electronics in Agriculture*, **232**, Article ID: 110143. https://doi.org/10.1016/j.compag.2025.110143

[22] Dang, T. and Bui, N. (2023) Obstacle Avoidance Strategy for Mobile Robot Based on Monocular Camera. *Electronics*, **12**, Article 1932. https://doi.org/10.3390/electronics12081932

[23] Al-Mallah, M., Ali, M. and Al-Khawaldeh, M. (2022) Obstacles Avoidance for Mobile Robot Using Type-2 Fuzzy Logic Controller. *Robotics*, **11**, Article 130. https://doi.org/10.3390/robotics11060130

[24] Guo, Z.X., Ngai, E.W.T., Yang, C. and Liang, X. (2015) An RFID-Based Intelligent Decision Support System Architecture for Production Monitoring and Scheduling in a Distributed Manufacturing Environment. *International Journal of Production Economics*, **159**, 16-28. https://doi.org/10.1016/j.ijpe.2014.09.004

[25] Duroc, Y. (2022) From Identification to Sensing: RFID Is One of the Key Technolo-

gies in the IoT Field. *Sensors*, **22**, Article 7523. https://doi.org/10.3390/s22197523

[26] Gong, L., Gao, B., Sun, Y., Zhang, W., Lin, G., Zhang, Z., *et al.* (2024) Preciseslam: Robust, Real-Time, Lidar-Inertial-Ultrasonic Tightly-Coupled SLAM with Ultraprecise Positioning for Plant Factories. *IEEE Transactions on Industrial Informatics*, **20**, 8818-8827. https://doi.org/10.1109/tii.2024.3361092

[27] Zlatanski, M., Sommer, P., Zurfluh, F. and Madonna, G.L. (2018) Radar Sensor for Fenceless Machine Guarding and Collaborative Robotics. 2018 *IEEE International Conference on Intelligence and Safety for Robotics* (*ISR*), Shenyang, 24-27 August 2018, 19-25. https://doi.org/10.1109/iisr.2018.8535983