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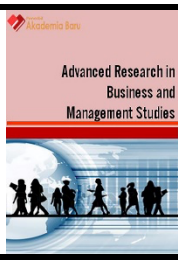

A Conceptualization of Industrial Internet of Things towards Manufacturing Safety Performance

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ABSTRACT

This paper conceptualizes the relationship between Industrial Internet of Things (IIoT) and manufacturing safety performance. Through a review on systematic literature review (SLR) articles from Emerald database from year 2018 and white papers, this paper proposes a conceptual framework on IIoT for manufacturing safety performance. Usage of sensors and wearables, virtual or augmented reality and AI and industrial automation are hypothesized to be contributing towards the safety improvement in the manufacturing industry. Manufacturing firms that adopt IIoT can minimize human interaction with equipment and thereby improve the overall safety of its employees and reduce workplace injuries. As the topic on the usage of IoT or IIoT in the context of safety is scarce in current academic literature, this conceptualization of the relationship between these variables are expected to pave way for more empirical research and literature enrichment.

1. Introduction

Every employee's basic right is the ability to work in a safe environment. It is important for employers to provide employees with safe workplace while performing their daily work [5]. Maintenance and safety are essential, as both guarantees productivity and a safer working environment. Improper maintenance and safety handling may cause accidents and serious health problems. In manufacturing firms, there are two types of maintenance strategies which are preventive maintenance and shutdown maintenance. Preventive maintenance has a schedule depending on the equipment or facilities that need an inspection which are manually tracked, while the shutdown of the equipment is an approach that modern manufacturing plants would want to avoid at all costs. Not only in incurs more loss to the firms but impacts productivity and generate more waste by turning off functional machines. Moreover, this strategy is also ineffective in today's manufacturing industry, where equipment and machinery have become more complex and are being operated to meet productivity and efficiency demands. More timely and in-depth insight is required to ensure that maintenance remains effective in these circumstances [12]. Given the cost and complexity of the maintenance processes, IoT, especially industrial IoT (IIoT) is being recommended as viable tool to aid in the safer management of complex systems where IIOT works to increase safety

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and efficiency in production facilities and is used in manufacturing and supply chain management. IIoT is essentially an IoT in industrial applications and sectors. However, the usage of IoT tool is a challenge for both researchers and firms [8], let alone the IIoT.

There are numerous opportunities to streamline processes and increase productivity using IIoT. Fundamentally an IoT technology enables manufacturers and users to address cost and technology issues more conveniently and affordably, although IIoT is more expensive than IoT applications. Regardless, in general IoT or IIoT instrumentation sensors provide more functionality and reliability. Furthermore, there are dependable wireless protocols that enable efficient data collection from sensors and transfer to a local gateway for instantaneous analysis and filtering. An Internet connection can then be used to access a cloud-based computing resource that provides software as a service to users of all sizes. This software is capable of storing data and performing the necessary analysis to identify trends and pinpoint potential problem areas. Therefore, IoT devices are used by many industries to increase safety and efficiency. An US statistic have shown that 71 percent of the manufacturers are using IoT for operational performance and lowering cost [23]. This affirms that the central focus of current IIoT adoption by manufacturers have been on operational efficiency and not on safety, because IIoT for safety is only an emerging concept. Similarly, many academicians have also published several works on the benefit of IoT in supply chain management, however the focus has been on operational efficiency but not on safety [24].

As a new buzzword attracting industry players and service providers, academics must catch up and contribute to awareness and adoption of IIoT for safety in manufacturing industry. Therefore, this paper acts as a research agenda on the subject and will outline IIoT for safety concepts and how manufacturers can adopt it to improve the safety of their employees and environment safety. The ensuing section are structured as follows; section 2 will discuss on Literature Review to unearth the current knowledge situation and highlight the gap noticed, section 3 elaborated the Method used, followed by section 4 on the Conceptualization of IIoT for Safety in manufacturing industry, which is then concluded by Section 5.

2. Literature Review

2.1 Manufacturing Safety Performance

Safety performance is defined as the avoidance of incidents that could harm people right away and quality work that is able to lower the risk of accidents. Wu *et al*., [31] stated that safety is critical in the industrial workplace, especially for employees who frequently work directly with equipment and machinery environment. Tomur *et al.,* [28] clarified safety's primary goal is preventing harm from unplanned incidents. The main source of risk in safety comes from passive resources such as accidents, human errors, or system errors. Overexertion, slips, trips, and falls, and contact with objects and equipment are the top three leading causes of work-related injuries in the United States, according to the National Safety Council (NSC). They are collectively responsible for more than 84% of all nonfatal workplace accidents [9]. Hard physical labour and the frequent use of heavy equipment increase the risk of strain or injury in the manufacturing industry. The International Labour Organization estimates that there are 340 million occupational accidents and 160 million victims of work-related illnesses worldwide each year [10]. Faeq *et al*., [6] emphasised employers must take initiative to make sure employee safety is their priority. Failing to do so will end in risk and firms will have to deal with incurring the cost of damage to their property, high employee compensation, and a bad firm reputation for workplace accidents. Being safety conscious can motivate employees, increase productivity, and even leave a positive impression on workers.

2.2 Internet of Things (IoT) and Industrial Internet of Things (IIoT)

Asemani *et al.,* [4] defined IoT is a network of physical objects—"things"—embedded with sensors, software, and other technologies for connecting and exchanging data with other devices and systems via the internet. Liu and Ma [17] reported that being an important component of modern intelligent systems, IoT or IIoT is essential in manufacturing firms and plays an important role in developing information and securing safety. The use of IoT in manufacturing under the term IIoT has become widespread on a global scale. IoT in general enables more efficient information gathering and communication between employees and potentially hazardous workplace conditions, resulting in more dynamic risk analysis [1]. Moreover, IIoT is expected to play a key role in not only the industrial paradigm shift but also future management change [21]. In the field of safety, the IoT offers a comprehensive set of technologies for monitoring and controlling the manufacturing environment at its source. As such, IoT is emerging as a critical tool for promoting safety in manufacturing industry [26].

On the other hand, besides the network of physical objects, IIoT includes the digital representation of products, processes, and manufacturing infrastructure [11]. The advancement of IIoT has been fuelled by recent industrial developments and IoT adoption. Smart IIoT technologies enable industrial systems to sense, gather, execute, and communicate in real-time [18]. Scholars have recognized the integral role IIOT is set to play in the manufacturing industry. Seetharaman *et al.,* [26], for example, hypothesised that in the long run, as IIoT pervades industry, it will create a demand-based economy powered by real-time demand and supply information.

2.3 Research Gap

The literatures on IoT or IIoT are abundant as scholars are attempting to uncover the many technologies associated with it [8], drivers [25], barriers, and challenges [14], and benefits of its adoption [15] in various industries. For example, the topic of IoT is vastly studied in construction industry [7], food safety [21] and cold supply chain [29]. Scholars in general were focusing on the operational efficiency gain, improved visibility, and cost-effective approaches for business owners to adopt IoT. Within the supply chain context, a systematic literature review conducted by Rebelo *et al.* [24] revealed that there were zero studies investigating the role of IoT or IIoT into achieving safety performance improvement in a manufacturing industry (Table 1).

Table 1
IoT studies in SCM context. Source: Adopted from Rebelo *et al*., [24]

SCM process	Number of papers	Percentage (%)
Customer relationship management	20	11.7
Customer service management	19	11.11
Demand management	27	15.2
Order fulfilment	126	73.68
Manufacturing flow management	84	49.12
Supplier relationship management	0	0
Product development and commercialization	15	8.77
Returns management	29	16.96

Another study by Sam *et al.* [25] reported that the driving factors for manufacturers adopting IoT is attributed to competitive, efficiency and productivity gains rather than improving the safety of the infrastructure and employees (Figure 1). Therefore, there remain a vast opportunity to enrich the literature on IoT or IIoT adoption in the context of improving safety performance in manufacturing industries.

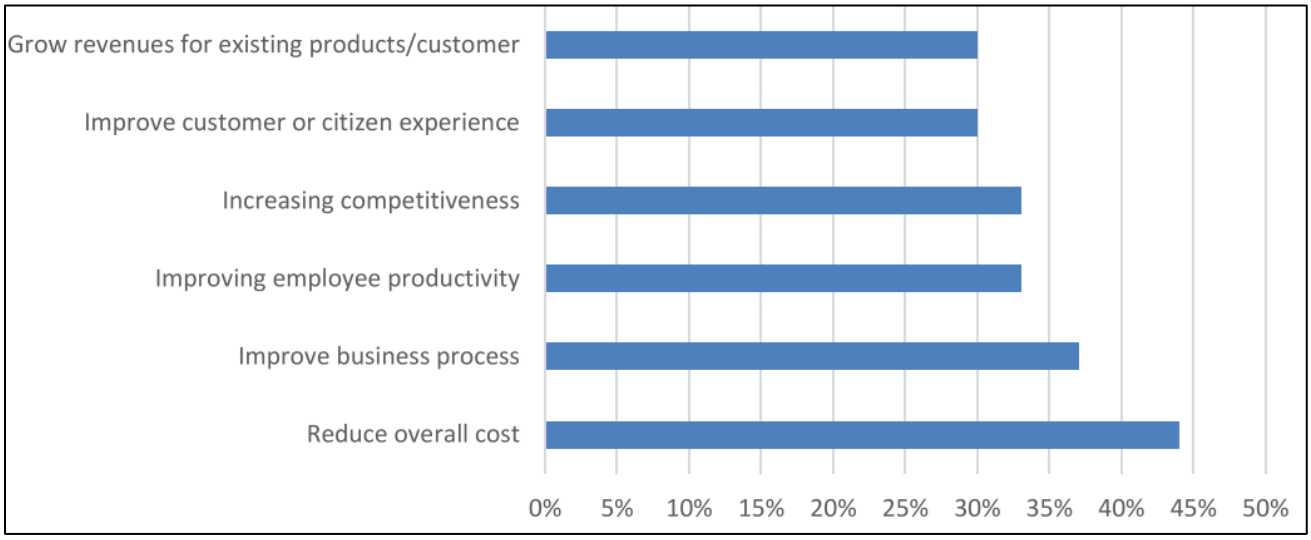

Fig. 1. Drivers for IoT adoption by manufacturers. Source: Sam *et al*. [25]

3. Method

A critical review on existing literature on IIoT in supply chain is undertaken with a specific focus on systematic literature review (SLR) papers using keywords "IIOT AND (systematic literature review) AND (MANUFACTURING) AND (SAFETY)". The scope of the SLR is limited to most recent papers published in Emerald database from 2018. There were 124 papers identified after initial search. The process of screening was then undertaken manually to select titles that are associated with IoT or IIoT in supply chain of manufacturing industry with priority on SLR articles. The screening process reduced the most relevant paper to safety to one paper only. However, to expand the scope further given the limited use of IIoT term, the usage of IoT from the result was considered as well. Identified papers were further screened for eligibility on the content using abstract to eliminate papers which does not fall within the context desired. The final count of papers considered for analysis were 4 papers. All the four papers were most recent with publication year ranging from 2020 to 2022. Thus, these four papers are regarded as the primary reference for this study due to its relevance and recentness. Other works are used as supplementary elements. The final count of papers considered for analysis in this study is captured in Table 2.

Table 2
Summary of papers considered for analysis in this study

Literature context	**Author and Year**
IoT in supply chain (SLR)	Rebelo et al., 2022 [24]
IoT for safety in process industry	Gnoni et al., 2020 [8]
IoT adoption in manufacturing industry	Sam et al., 2021 [25]
IoT adoption on supply chain performance	Lee et al., 2022 [15]

4. Conceptualization of IIoT for Safety in Manufacturing Industry

Gnoni *et al.* [8] proposed a vertical tools and functionalities to identify, visualize and manage safety alerts are deemed necessary in ensuring safety of equipment and employees. The enabler for a successful IIoT safety system lies in the high-level communication protocol as a means to convey the signals from IIoT's sensors alert on a safety risk. Lee *et al.* [15] highlighted the importance of IIoT integration with information communication technology, including RFID, wireless sensor network, machine-to-machine system, and mobile application for an effective application to reduce or eliminate human interventions when problems arise. Rebelo *et al.* [26] on the other hand argued that combination of IIoT and blockchain technology is paramount for an effective and efficient supply chain, to help firms overcome problems related to data integrity, security, and safety. Whereas Sam *et al.* [27] contended that without an infrastructure and strategy to support IIoT, no efficiency and effectiveness can be realized by the manufacturers, let alone the safety.

In synthesizing the articles above and white papers on IIoT, this study proposes a framework for IIoT for safety in manufacturing industry as shown in Figure 2.

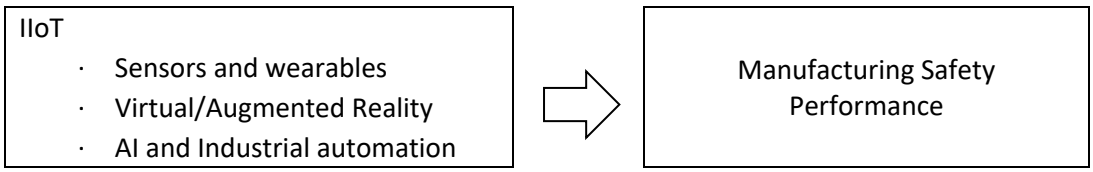

Fig. 2. Conceptual Framework on IIoT for Manufacturing Safety Performance

4.1 Sensors and wearables

Employees who use or are near heavy machinery run a higher risk of injury, especially if an internal part or safety feature fails. IIoT systems can send out maintenance alerts by using sensors to track a machine's temperature, sound, frequency, and vibration. Some firms use sensors in wearable technology to alert users or supervisors to signs of overexertion in environments that are particularly harsh or dangerous [22]. There are few functions that IoT can monitor and control such as predict employees move, vehicle navigation, monitor environment conditions, safety system activation, speed of rescue operations [19]. Figure 3 shows the summary of IoT functions.

Monitor

IoT can monitor, measure, and predict employee behaviour on the factory floor, identifying potential hazards or injuries. Sensor-equipped wearables, such as jackets, helmets, and watches, can collect data that can be used to demonstrate how employees interact with their surroundings [29].

Movement

Reduce risk of accidents and ensuring worker safety by monitoring the movement of equipment and vehicles in warehouse or storage areas or production floor [13]. To track inventory and observe worker interactions with supplies, tools, and materials, radio frequency identification tags (RFID) and monitoring tools interaction each other well [30].

Environment conditions

IoT can monitor potential hazards in the workplace, such as temperature, vibration, humidity, noise levels, and weather conditions. IoT can respond to temperature changes and send alerts when issues arise. IoT able to prevent of unintentional gas releases [29].

Employee health

Sensor that measures employee health indicate the temperature and blood oxygen level and detect employee that have other physical problem [27].

Safety system

IoT can monitor employee behaviour and alert for precautions and not follow the procedures. This will help to reduces injuries and increase employee awareness to safety [2].

Speed Operation

Real time data will support firms when have plant disaster or serious injury and the data will assist medical personnel or employer to understand the situation and making decisions on the response plan [16].

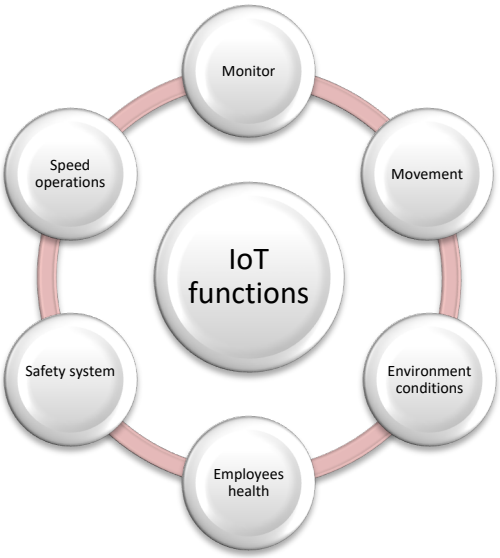

Fig. 3. IoT functions to increase safety performance

4.2 Virtual/Augmented reality

Augmented or virtual reality offers employees the freedom and abilities to simulate real life scenarios in a low-risk environment. For example, with augmented reality, technicians can identify parts and deliver step-by-step instructions by fusing live data with intelligent feedback via a headset, tablet, or mobile device, saving firms the cost of repair and downtime as well as ensuring no risk to the employees [3].

4.3 Artificial intelligence (AI) and industrial automation

There are some job duties that are too dangerous or precise for a human employee to perform in almost every industry. Manufacturing firms can use automation in these situations. Deep learning and neural networks advancements are making automated systems more versatile and adaptable, opening up new opportunities to reduce human exposure to hazardous environments [20].

5. Conclusions

Manufacturing industry is one of the highest industries that contributes towards workplace safety hazards. To prevent or reduce the hazardous environment, manufacturers should embrace IIOT. IIOT promises a step-change in manufacturing operations including improvements in quality, productivity, optimize operating efficiency and reduce operating cost. It will also simplify many aspects of safety and risk management such as reduce occurrence of accidents as employees is one of the most important factors to consider in this industry. Future workplace safety will be increasingly dependent on a manufacturers willingness to invest in cutting-edge technology. With manufacturing industry transforming into a digitized industry, it is possible to reduce workplace injuries by investing into IIOT solutions. As the topic on the usage of IoT or IIoT in the context of safety is scarce in current academic literature, this conceptualization of the relationship between these variables are expected to pave way for more empirical research and literature enrichment on the subject by scholars.

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