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Abstract:

This paper analyses the role of the Internet of Things in increasing worker safety and productivity as well as improving performance appraisal methods in the factory setup. It examines how IoT can be used to benefit both workers and management, and strengthen the system of working in industrial plants. After reviewing literature on the topic, it is apparent that IoT helps in monitoring and controlling worker actions, optimising performance, and providing greater autonomy to employees. Advanced methods of evaluating worker performance leveraging the applications of IoT and AI have been explored as well. Furthermore, analysis of productivity levels has been carried out for workers in a steel plant in India on the basis of data collected from IoT tags. The study depicts how IoT can allow workers to perform tasks smoothly in their respective areas of expertise, along with a robust system of communication. By preventing accidents and boosting productivity, a win-win situation is created for workers and their families, as well as for factory owners and their clients.

Key words: IoT, Internet of Things, Worker Safety, Productivity, Appraisal, Communication

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1. INTRODUCTION

With the advent of the fourth industrial revolution, the world is moving towards increasingly advanced forms of digitization. Everything is integrated in ways previously unimaginable, whether it is in the field of manufacturing, services, or simply individuals' daily routines. The Internet of Things (IoT) plays a crucial role in this integration by simultaneously sending and receiving information, thus facilitating real time improvements in various processes.

The term Internet of Things was coined by Kevin Ashton in 1999 and was then defined in many ways by various researchers. IoT is an ecosystem through which technological devices interact with one another, to improve efficiency of operations and reduce costs. Sensors detect and/or measure some aspect of the environment in which they are present and convert the inputs gathered into electrical signals that can be processed by electronic circuitry (Olsen & Tomlin, 2020).

Compared to conventional methods, IoT devices carry out tasks much faster and can also be used in situations where humans cannot operate. Not only can devices be controlled and directed from distant locations, they can also be conditioned to perform tasks on their own with the help of IoT. For example, Tesla, the American electric vehicle and clean energy company, helps customers control and check devices from anywhere through their smartphones (Taylor, 2021). With such technologies being implemented in factories and industrial plants, actions that previously had to be manually initiated can now be carried out in an automated manner, thus saving time and effort.

Across the world, end-user spending on IoT solutions has increased almost 4 times since 2017, from around USD 110 billion to approximately USD 418 billion currently (Statista, 2019). It is estimated that spending is likely to increase substantially to more than USD 1.5 trillion by 2025. India has also seen a similar surge in IoT usage, witnessing a tremendous increase in the number of IoT connected devices from 250 million in 2019 to around 2000 million in 2021 (Zinnov, 2020). Furthermore, the manufacturing sector had the second highest revenue share (18%) of IoT in India in 2020 (NASSCOM, 2019). These figures indicate a remarkable shift to connected and smart devices across various industries.

It is estimated that by 2025, the combined monetary value of IoT usage in worksites and factories would be somewhere between USD 793 billion and USD 2.73 trillion per year (McKinsey Global Institute, 2015). Operating efficiency and predictive maintenance practices will be the key drivers of development in worksites, which could alone have an economic impact of around USD 830 billion per year. Improvement in worker well-being is expected to generate additional benefits amounting to USD 60 billion annually by that time.

Enhanced visibility of operations allows for shorter buffers to be incorporated and automation of worksites can easily lead to 10 to 20% labour-cost savings. IoT has the potentially to drastically change the interaction between manufacturers, lenders, distributors, and consumers. Manufacturers can improve productivity for individual workers and across various production facilities, thus leading to higher levels of profit. For distributors, retailers, and other downstream players, better pricing can be accomplished due to greater visibility into supplier economics with IoT-enabled production and inventory systems. Lending decisions also change as banks look into IoT data from factories.

However, despite advancements, there is still a long way to go to achieve improvements in worker safety and productivity despite extensive safety standards and regulations. According to recent statistics (International Labour Organisation, 2019), more than 2.87 million people die every year owing to accidents in the workplace and work-related diseases. While workers' deaths indicate loss of human capital, non-fatal work-related injuries amounting to around 374 million a year, result in prolonged absenteeism and thus lead to fall in productivity. The economic impact of poor work conditions is estimated at 3.94% of global GDP annually. Additionally, the loss of life caused by occupational hazards is unquantifiable and cannot be compensated for. Monitoring workers during operations is crucial to maintain worker well-being and safety. Workers are typically monitored at sites using a team of supervisors or monitored remotely using CCTVs. While human supervision is subjected to bias, CCTV images are typically analysed post the event occurrence. IoT provides a rich data-driven worker monitoring alternative where workers are tagged real-time and their movement coordinates are seamlessly captured in the cloud platform.

While injury and death occur only in the most severe cases, industries are often prone to many minor issues which may not even be noticed under usual circumstances. For example, some workers may be exposed to harmful substances or extremely high temperatures which may not cause immediate distress but negatively affect their health in the long run (especially at construction sites). In the areas that are not under the supervision of the manager, some employees could be working way less than others or taking more breaks than recommended. Appropriate emergency protocol may not be in place, and even if it is, there might be no way to predict a leak or explosion, or warn against such mishaps. A large number of workers continue to work in sub optimal and potentially dangerous working environments as they do not have alternatives, and many employers are ignorant until it is too late.

The aim of this paper is to explore how IoT can be used to benefit workers in terms of their safety and productivity, and improving their overall well-being with better working conditions and fair practices of performance appraisal. The role of IoT in worker safety and productivity is explained in Section 2 and furthermore, the intertwined aspect of people practices and performance management is reviewed in the context of IoT. Section 3 takes examples from the industry of the successful use of IoT technologies and their integration with the workplace. In Section 4, analysing the case of workers at a steel plant in India, we analyse productivity levels on the basis of data collected from IoT tags and provide recommendations along with the further course of action. Deriving insights in Section 5, we try to give a balanced view of IoT implementation and how it can generate positive results. Finally, conclusions and opportunities for future research are discussed in Section 6.

2. LITERATURE REVIEW

The first step towards understanding how IoT can be used to benefit workers is to analyse the role it plays in worker safety and productivity. Organisations have numerous safety issues that they might not even be aware of. With the help of accurate sensors, IoT helps identify these issues, provides warnings in advance to give enough time to act, and also facilitates rescue operations. Along with improving safety standards, it also helps improve worker productivity by tracking workers' vitals and providing suggestions accordingly.

This type of a dynamic workspace is nearly impossible to create without the use of the Internet of Things and thus, we delve deeper into how it makes it all happen. Additionally, we review various IoT based performance appraisal techniques. Conventional methods of evaluating worker performance are sometimes subject to biases of the manager and conducted only once in a few months. IoT on the other hand, gives continuous feedback and is free of any sort of bias. The idea is not to do away completely with conventional HR methods, but to strengthen them with the assistance of continuous and reliable feedback.

By reviewing these two topics, we are able to answer the important questions of how IoT can help and how it is used in the context of people practices. This further creates the base for our case study wherein IoT is used to track worker locations at different times to comprehend more accurately how much time which worker devotes to work.

ROLE OF IoT IN WORKER SAFETY AND PRODUCTIVITY

IoT has wide-ranging advantages with respect to worker safety and productivity. It helps improve internal factors such as worker well-being, preparedness and training, as well as external factors such as working conditions and equipment failures (Massey, 2018). Some specific ways in which IoT improves worker safety and productivity are discussed below.

Monitoring:

IoT monitors environmental conditions using sensors that detect various threats and dangers. Sensors have the ability to collect complex information which can be analysed to assess the status of multiple activities. This is made possible with the help of data fusion, a technique that collectively processes heterogeneous information to derive conclusions from data collected by sensors. It is a synthesis of numerous sources to obtain good quality and more relevant information in an economical manner (Castanedo, 2013).

Also, it is easy to pick up anomalies when data is being analysed in real time. Some indispensable sensors that are used are ambient temperature sensor, air quality sensor, humidity sensor, and flammable gas sensor (Digiteum Team, 2019). Enhanced security features made possible by these sensors make workers feel assured about their safety and thus improves concentration and productivity. Cloud computing clubbed with data from IoT sensors can facilitate discovery and mash-up of services involving varied devices (Atzori et al, 2016).

IoT systems monitor actions of workers and apprise them of any possible issues they might encounter. The technology also alerts employees if they are not following appropriate safety protocols intentionally or unintentionally. The four main vital signs that include body temperature, pulse rate, respiration rate, and blood pressure can be tracked using wearable technology, along with their actions and location. Data regarding these parameters and so many additional factors is collected using IoT devices such as smart watches, hard hats containing sensors, and augmented reality (AR) glasses, and is useful in diagnosing early signs of potentially serious health issues (Leland, 2020).With the implementation of the active technological invention, a sense of safety is fostered in the minds of the employees, thus boosting profitability by improving worker productivity and retention, and reducing pessimism connected to dangerous tasks.

Control:

With active and continuous monitoring in place, controlling both routine activities and emergencies becomes much easier. Workers can be easily located and notified about hazardous situations with the integration of GPS with schematics for worksite areas. Outfitting workers with RFID tags, for example, swiftly aids in ensuring that only authorized personnel enter designated areas, thus reducing the risk of inexperienced individuals putting themselves in danger unnecessarily (Leland, 2020).

Communication between sensors also improves estimation of critical operating-control variables that further allows for making decisions in a prompt manner (Saghafian et al, 2021). Machines and other equipment can be controlled remotely and turned off or slowed down whenever their indicators cross threshold levels.

While IoT does a good job at preventing potential mishaps, it also helps speed up rescue operations in case they do actually happen. The technology enables rescuers to detect the location of the trapped employees in a critical situation (Berman, 2021). Better connectivity and collection of data allows the medical personnel and rescue crews to construct evacuation plans and control the damage faced by workers before it's too late. Through effective record keeping, management can keep track of whether all employees underwent adequate training or not (Digiteum Team, 2019). IoT systems also establish better compliance methods with respect to safety standards.

Workplace fires are more common than are usually believed to be. In most cases, they are accidental and occur due to apathetic management systems. If IoT is put to good use, it can prevent frequent fires. Temperature spikes can be detected by fire safety sensors so that timely cooling effort or evacuation can be carried out (Digiteum Team, 2019). Tracking the vitals of firefighters and maintaining fire tracking systems would further upgrade the industrial plant.

Optimization:

With real-time monitoring and feedback mechanisms, it becomes possible to optimise processes in a swift manner and also create room for continuous improvisation. It also allows one to look out for new areas of improvement. Worker shifts can be scheduled in a way that every worker operates at their maximum efficiency level and does not work too much or too little on a given day. Allocation of workers to different zones can be made keeping in mind the layout of the factory, thus minimising time and energy wasted in moving from one zone to another. The idea of opportunistic IoT that addresses the concept of breaking down information and passing it on to opportunistic communities can further optimise workplace behaviour (Guo et al, 2013).

One of the major potential benefits of Industrial IoT is that it is capable of anticipating and preventing hazards ahead of time, thus being capable of 'predictive maintenance'. Predictive analytics fuelled by massive field sensor data coupled with artificial intelligence and machine learning algorithms can detect patterns that predict potential threats. For example, smart sensors attached to rock bolts in underground mines have the capabilities of foreseeing which shafts might collapse in the near future (BehrTech, 2019). Operations in such high-alert areas can be halted or precautionary measures can be introduced, thus saving lives and shifting focus to other areas that might be useful. Critical assets can be controlled and operated in a more efficient manner using predictive maintenance. Heavy machinery that requires maintenance can be identified through remote tracking. Hence, equipment accidents can be averted and performance can be optimised. IoT technologies can also track, measure and predict the patterns of workers on the premises, discovering risks that could lead to harm or wrongful actions. Thus, IoT is at the helm of transforming maintenance models from remedial to preventative ones.

Autonomy:

Once IoT has enabled monitoring and control, and facilitated optimisation, it is in a good position to take certain autonomous decisions. For example, IoT can restrict entry to certain areas when it detects a rise in temperature or the presence of harmful substances. Based on a worker's vitals, it can assess whether a worker is fit to operate in a specific area or not, and restrict them entry accordingly.

Yang et al (2019) explore the concept of smart manufacturing, which goes beyond basic control into autonomous decisions based on data-driven innovations. A huge amount of information from the real world is captured and then used extensively in cyberspace for processing, modelling, and simulation. Insights gained from the cyberspace can then be used to enhance activities automatically in the physical world. This cyber-physical integration is made possible with the application of IoT.

Additionally, IoT can provide even superior results when integrated with intelligent analytics that are driven by cognitive technologies. Real-time or near real-time data processing and analysis can be enabled with analytics tools such as complex event processing (CEP) leading to timely decision making and action (Banafa, 2017). Also, artificial intelligence models can be improved with larger and easily accessible data sets owing to lower storage efficiencies.

PERFORMANCE APPRAISAL & PEOPLE PRACTICES

Human Resources departments normally capture very little of an employee's day to day operations. Tagiya et al (2019) showcases the myopic view of current HR practices, particularly for performance evaluation and career management. The paper presents HRM inadequacies and describes how bias leads to clouding of judgement, indicating that there is a need to move from the ideals of singularly focusing on oneself or a few others to working in ways desirable to everyone.

With careful use of real time data captured by smart devices, HRM systems can be revamped to make assessments smoother, less biased, and more accountable. Sensors can be used to collect data continuously which can then be transmitted via an organisation network. Location sensors enhance understanding of the areas where workers spend maximum time which can be further used to train the employee in operations they find confusing or difficult (Gaur et al, 2019). As data is collected on behaviour of different employees, it is easier to recognise strengths and weaknesses and reassign tasks accordingly. IoT also identifies the number of times workers take a break. This information along with other indicators such as working habits, efficiency, and adherence to regulations proves to be handy while conducting performance appraisal.

Kaur and Sood (2017) use game theory based concepts for IoT based employee performance evaluation. Co-location sensors are used to track employee's involvement in an activity and conditional probability (CP) is used to filter the results. By defining reward and penalization strategies and coordinating strategies for employees, a pure strategy and mixed strategy Nash Equilibrium is achieved. It is found that the stable action set is the one where the industry is willing to reward employees for doing more work and the employee chooses to co-operate with the prescribed system of working. The amount of incentives provided to employees by the industry for their co-operation are crucial to this setup as they make sure that there is satisfaction from both ends, with higher output and adequate remuneration. Other action profiles prove to be unsustainable as non-cooperation by employees leads to lower productivity and penalisation strategies hinder worker performance, both of which result in low output and a negative work environment over time. One possible issue with this approach is that of applicability in varied industrial plants as it uses only co-location sensors and is also considered unrealistic.

Fuzzy logic approach used by Kaur and Kaur (2017) solves the issue of impractical methods as it yields to an outcome between yes (1) or no (0). Primarily based on data from sensors embedded with RFIDs and GPS trackers, positive, negative and neutral sets of activities are detected. Overall Participation Index (OPI) is created with the data collected and rewarding or penalising decisions are made using fuzzy logic. It reduces dissatisfaction among employees and has more diverse applicability. Even though it might lack consistency in results, the approach is quite simple and accurate.

In a more advanced version of the fuzzy logic approach, Dhir and Chhabra (2019) create a synergy of fuzzy and neural network for evaluating employees in an automated manner. It follows a methodology wherein employee activity is first closely monitored using IoT sensors, and then decisions are optimised with the help of artificial neural fuzzy inference system (ANFIS). ANFIS is a neuro-adaptive method for accurately recognising patterns that possesses the ability to comprehend and understand information according to the dataset provided. With the combination of IoT and AI, all four parallels of monitoring, control, optimisation, and autonomy can be achieved at a reasonable cost. It is not difficult for small organisations to adopt this method, although they would have to ensure that advanced IoT sensors are used for tracking employee movement. As all decisions are automatically made on the basis of data collected, it becomes imperative that it is accurate, which is only possible with advanced sensors.

A wide range of advanced sensors and devices, such as acceleration and gyroscope sensors, proximity sensors, meta sensor watchband, and edge computers are used in the study conducted by Forkan et al (2019) which aims at evaluating workers' performance via activity recognition. The idea behind this Industrial IoT solution is to refine conventional key performance indicators (KPIs) like cost and quality into more precise ones that capture processes, activity/steps, and related resource usage. Employee productivity is assessed via worker identification, activity recognition, and computation of corresponding KPIs. It is a highly accurate method but requires cutting edge technology which may not be available in developing or under-developed countries. Additionally, workers are required to wear meta sensor watchbands at all times, which may get destroyed or tampered with and can also restrict movement in certain tasks.

We now look at a few industry practices that leverage IoT to enhance worker well-being and performance in factories.

3. STATE-OF-THE-ART INDUSTRY PRACTICES

The idea of wearables and real-time management has been toyed around since a few years by various organisations. Many offer IoT based solutions and infrastructure to companies in different industries. Hitachi Solutions (n.d.) has curated an end-to-end cloud-based solution that gathers data, provides opportunity for real-time monitoring, and improves safety by cautioning whenever different parameters are not under control. Using IoT and AI technologies, the company’s service hub for worker safety ensures well-being of the workers, security of equipment, and a robust work environment. Bi-directional monitoring ensures safety and efficient implementation of productivity initiatives. Potential issues in workers’ behaviour are pinpointed and insights to decrease risks are provided. Wireless communications are used to monitor equipment and work environment while AI is used for continuously analysing data to discern actionable insights and improve machine learning models.

Virtusa (n.d.) aims to bring changes with its “Digital Transformation Studio” that delivers deep digital engineering and industry expertise through client-specific and integrated agile scrum teams. Its real-time IoT ecosystem enables terabyte-scale data intake from thousands of IoT sensors and operates in a secure environment. Customised dashboards are used to represent new insights for employees, supervisors, risk managers, and leaders of leaders. The innovative solutions also leverage IBM's Watson for cognitive computing to analyse and interpret unstructured data to uncover actionable insights for employee safety.

Infosys (2017) also developed a deep Industrial IoT expertise and supports its clients during the transformation process towards a smart connected enterprise. For Infosys, interoperability, virtualization, real-time visualization and processing capability, decentralization, modularity, and service orientation are key for improvement in efficiency and the development of new business models to maintain its competitive advantage. It concentrates on the four pillars of smart products, smart services, connected factory, and smart production.

Besides, enterprises have also made in-house effort to implement cutting edge technologies in industrial plants and worksites. One such example is that of Ford Motor Company that uses exoskeleton vets to reduce injury and fatigue (Ford Media Center, 2018).We now consider the case of a steel manufacturing company in India that uses IoT in its factory to understand workers’ productivity in a more precise manner.

4. CASE STUDY FROM A STEEL MANUFACTURING PLANT

About the Company:

The company is one of India's leading integrated stainless steel manufacturer and a world exporter for over 40 years. They offer a wide range of special steel products such as bright bars, duplex steels, equal angles, precipitation hardening steel and so on. It has a capacity of 140,000 metric tons per year owing to exceptional infrastructural facilities including an in-house steel melting shop (SMS), hot rolling mills, heat treatment, cold finishing, and packaging line. By achieving the right balance of people, processes, and technology, the company delivers high-quality output and has received numerous certifications for the same. It has trade-fair presence all over the world and has an interesting tagline 'the "stain"less people' depicting the two main characteristics of trust and stainless steel. Coupled with its focus on employee well-being, it strives for perfection when it comes to equipment used and the work done, which has led the company to utilising cutting edge technologies such as IoT.

Basis of Case Study:

The purpose of this study is to demonstrate the application of IoT in measuring employee productivity levels. We aim at understanding how information collected by IoT sensors can be analysed to get an actual view of how productive each worker is and in which areas. Furthermore, we also discuss what measures can be taken after getting a fair idea of worker performance.

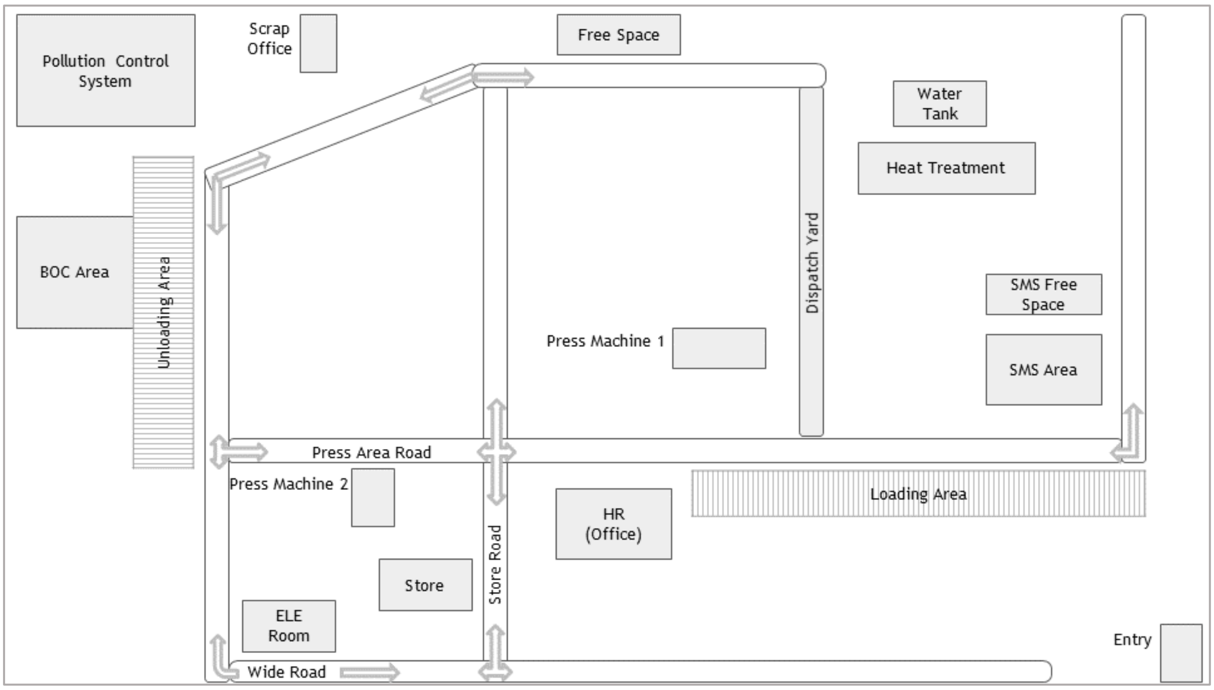

Figure 1: Layout of the Steel Plant

Data Analysis:

Methodology:

To understand the total number of productive hours invested by workers at the steel plant, data on the locations of 34 workers within the steel plant (Table 1) was recorded using IoT tags, and transmitted via LoRa, the proprietary low-power wide-area network modulation technique. IoT tags, with the help of Bluetooth beacons, transmit data to the gateway that is the mother device.

Table 1: Slice of Raw Data

Month Name	T_ZONE_ENTRY_DATE	T_ZONE_OUT_DATE	T_TAG_ID	T_WORKERNAME	T_ZONE
July	7/21/20 18:18	7/21/20 18:19	058F	V3	L1
July	7/21/20 13:58	7/21/20 14:00	058F	V3	L2
July	7/22/20 16:43	7/22/20 18:11	058F	V3	L3
July	7/21/20 16:24	7/21/20 16:41	058F	V3	UL1
July	7/21/20 16:53	7/21/20 17:00	058F	V3	UL2
August	8/19/20 11:36	8/19/20 11:44	591	V13	L5
September	9/17/20 21:43	9/17/20 21:44	058F	V3	L4
September	9/17/20 21:32	9/17/20 21:32	058B	V8	Office

The above table is an example of part of the raw data collected for each worker entering and exiting different zones of loading and unloading during the months of July, August, and September 2019. Each worker is provided with an IoT tag that monitors their movement across zones with exact time stamps, thus giving a clear idea of the time spent by them in a particular area. Similar data has been used in our study for the months of November and December 2019 capturing worker movement in various areas of the steel plant, not specific to loading and unloading zones.

We divided the time spent by each worker in intense work-related, leisure-related, and neutral areas and calculated the number of high-yielding hours invested by every worker over a period of 2 months. Division of high-yielding hours is such that intense work-related tasks and locations are called ‘positive’ and are counted fully, neutral work is considered ‘neutral’ and counted as $3/4^{th}$ of the actual time put in, and leisure related activities, termed as ‘negative’ get no credit, that is they are equivalent to no work done. Analysis was performed for November 2019 (33 workers) and December 2019 (34 workers) separately and the workers were further divided into categories based on the total number of hours put in every month for better analysis.

Performance Measures:

Performance of workers is evaluated on the basis of the high-yielding hours invested by them, rather than it depending on them just being present in the factory on a given day. The segregation of areas and their respective yields are shown in Tables 2 and 3.

Table 2: Segregation of Areas

Positive:	Neutral:	Negative:

Steel Melting Shop (SMS) Area	BOC Area (Oxygen)	SMS Free Space
Heat Treatment	ELE Room	Free Space
Press Machine 1	Press Area road	
Press Machine 2	Store	
Scrap Office	Store road	
Outer	HR (Office)	
Pollution Control System		

Table 3: Yield for Areas

Area	**Yield per hour**
Positive	1
Neutral	0.75
Negative	0

Sum total of the product of yield per hour and every area under the respective categories is calculated for every worker and termed as 'high-yielding hours'. The difference between the total time spent and high-yielding hours leads us to the 'sub-optimal hours' of each worker on a monthly basis. The purpose of this location-based division of work hours is to identify the actual productivity of each worker, thus going beyond the usual performance metric of total hours worked. Workers with maximum number of high-yielding hours can be rewarded and more work can be allocated to the ones with minimum amount of productive hours.

Furthermore, workers are divided into 4 categories based on the total number of hours worked in the month as shown in Table 4.

Table 4: Categorisation according to total number of hours worked

Category 1	Workers who worked less than 125 hours (<5 hours/day in a 25-day work-month)
Category 2	Workers who worked between 125-250 hours (5-10 hours/day in a 25-day work-month)
Category 3	Workers who worked between 250-375 hours (10-15 hours/day in a 25-day work-month)
Category 4	Workers who worked more than 375 hours (>15 hours/day in a 25-day work-month)

The aim of this exercise is to comprehend employee productivity at all levels of activity, and further identify whether high-yielding effort follows any pattern.

Data Visualisation:

November 2019 (Month 1)

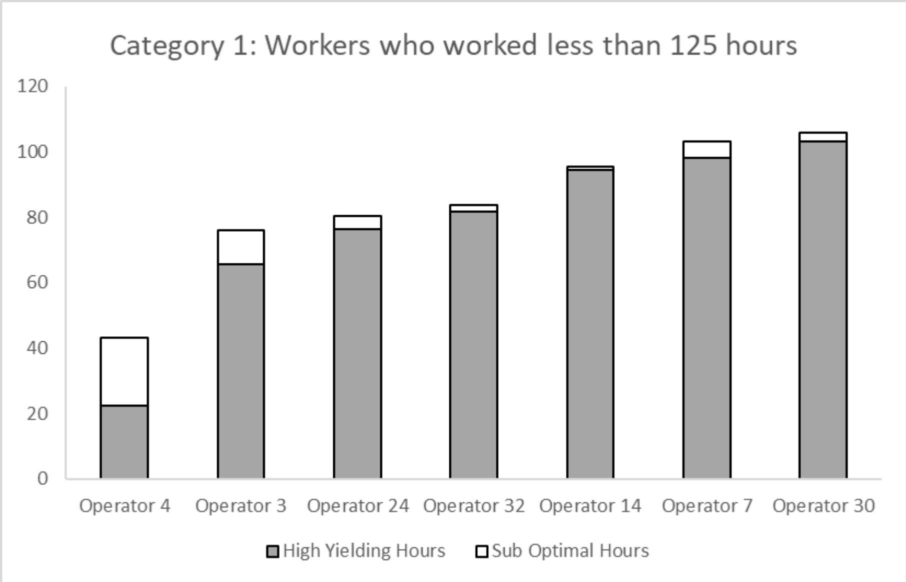

Figure 1A - Workers who worked less than 125 hours (<5 hours/ day)

Employees working less than 5 hours a day (Figure 1A) are essentially putting in much less time as compared to others. Most of the workers in this category have very few sub optimal hours of work and on an average, nearly 90% of the time invested by them has been in the most strenuous areas.

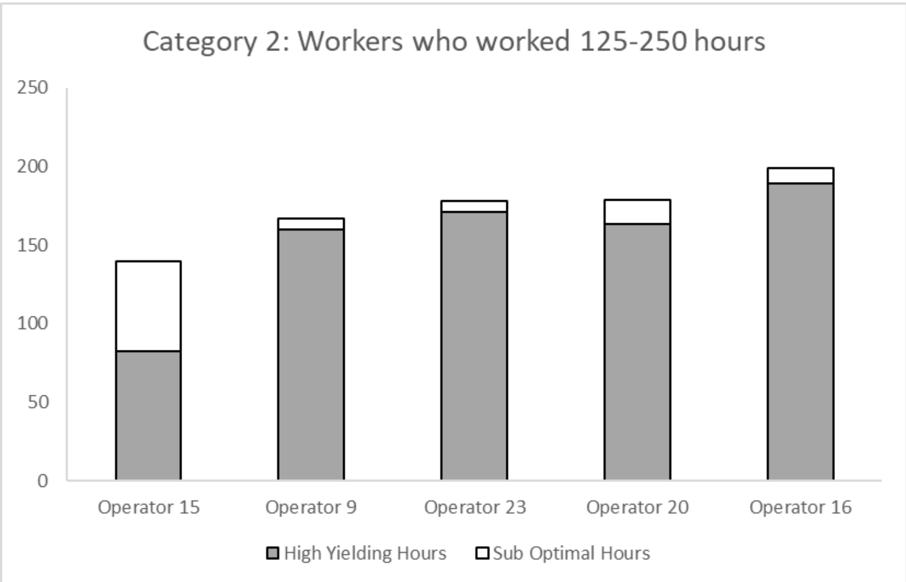

Figure 1B - Workers who worked 125-250 hours (5-10 hours/ day)

A small number of workers were found working in the range of 5 to 10 hours a day (Figure 1B) and normally had higher rates of high-yielding hours. On an average, around 87.5% of their work hours were spent doing the most productive work.

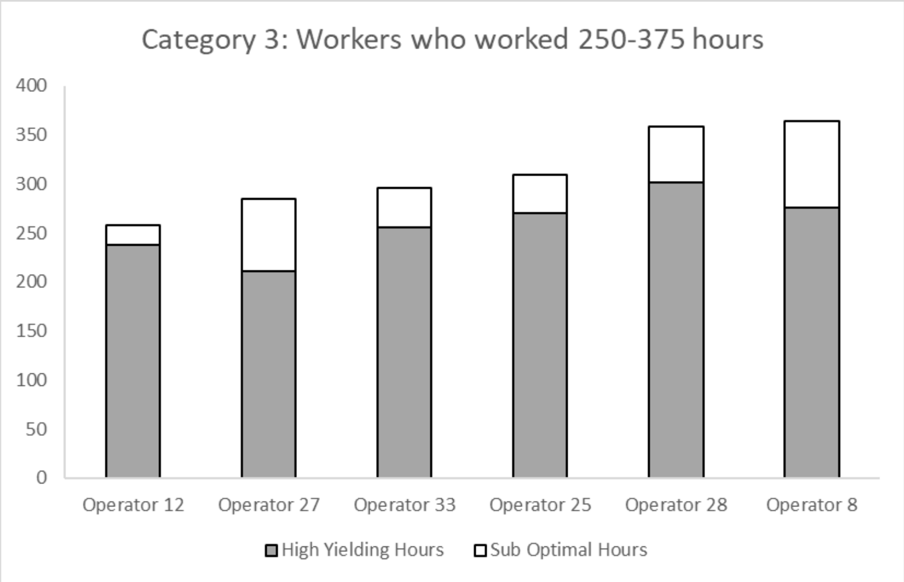

Figure 1C - Workers who worked 250-375 hours (10-15 hours/ day)

As we move towards the category of employees working 10 to 15 hours per day (Figure 1C), it becomes evident that their sub-optimal hours also increase. While half the workers managed to spend more than 85% of their work day carrying out high-yielding tasks, the other half struggled to maintain productivity levels over 80%.

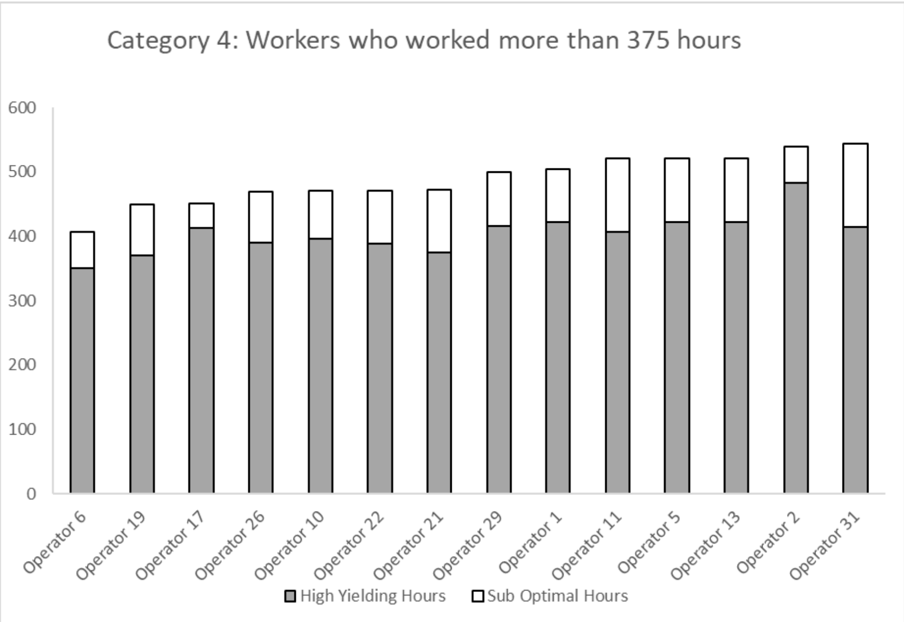

Figure 1D - Workers who worked more than 375 hours (>15 hours/ day)

In November 2019, almost half of the workers (14 out of 32) had shifts that lasted longer than 15 hours per day (Figure 1D). Naturally, this set of workers had lower percentage of high-yielding hours than the ones in the first two categories. On an average, workers invested 83% of their shift into high-yielding tasks.

December 2019 (Month 2)

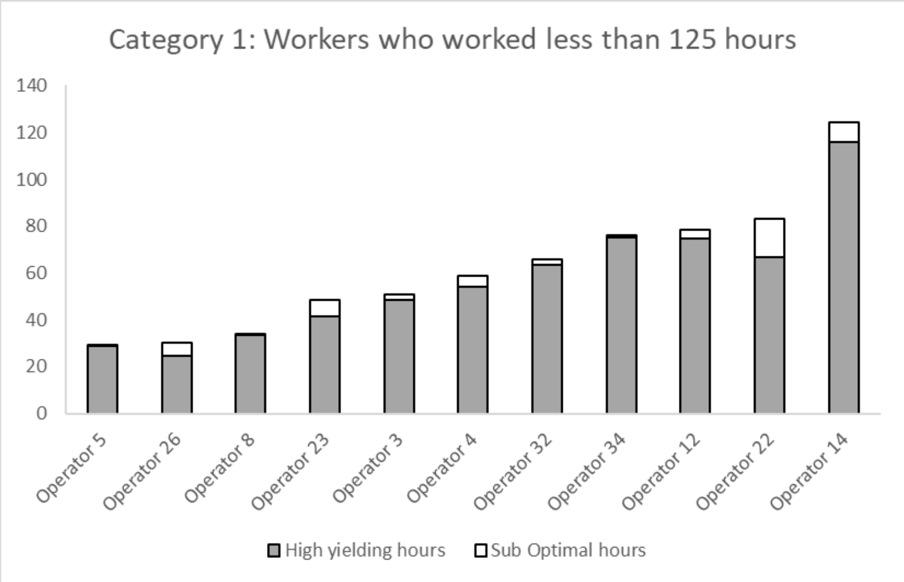

Figure 2A - Workers who worked less than 125 hours (<5 hours/ day)

As opposed to November, more number of workers spent lesser time working in the factory in December (Figure 2A). This could be due to low amount of work allotted to them or owing to other factors such as personal commitments. However, their productivity remained high with around 93% of their work hours invested in high-yielding areas.

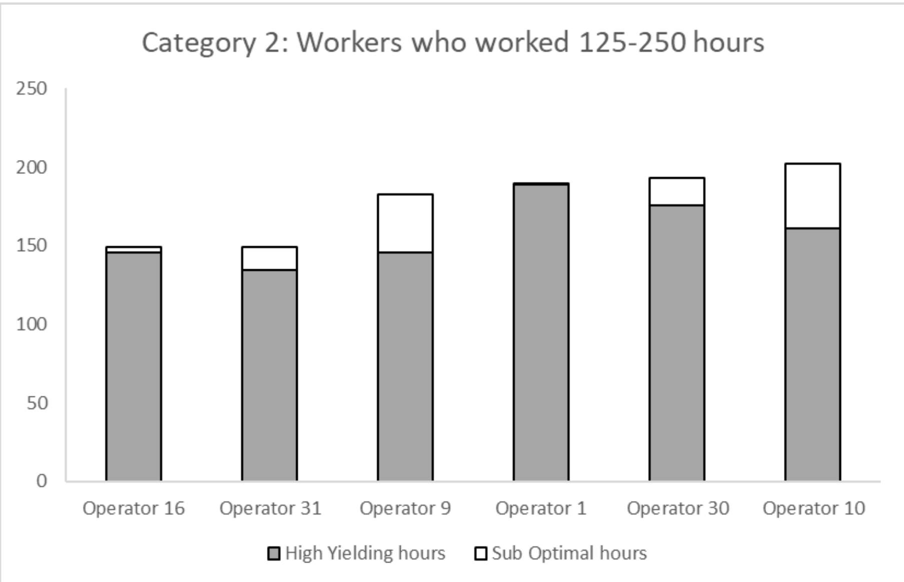

Figure 2B - Workers who worked 125-250 hours (5-10 hours/ day)

Figure 2B shows that two workers working for 5-10 hours on an average each day in December had exceptional yield, while others had a marginally lower percentage of high-yielding hours. On an average, around 90% of their time in the steel plant was invested energetically.

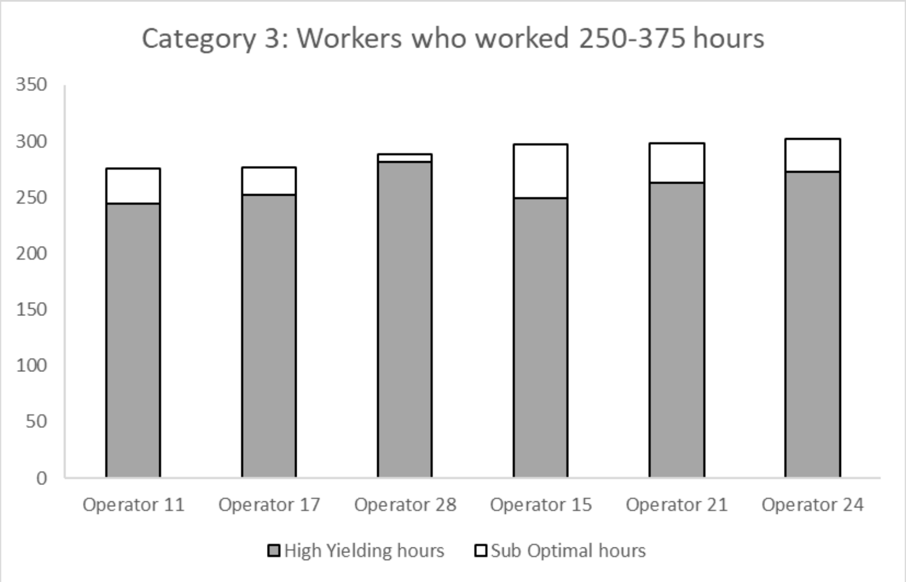

Figure 2C - Workers who worked 250-375 hours (10-15 hours/ day)

As shown in Figure 2C, most workers who worked 10-15 hours a day on an average, had some degree of inefficiency. Other than operator 28, all other workers had more than ten percent of sub-optimal hours.

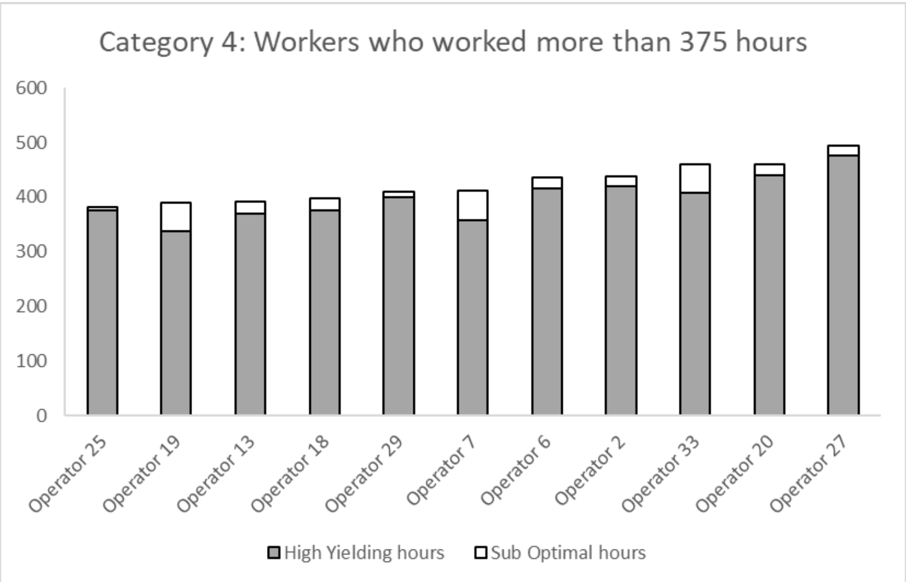

Figure 2D - Workers who worked more than 375 hours (>15 hours/ day)

Workers who worked for more than 15 hours a day in December (Figure 2D) interestingly had a large proportion of high-yielding hours as well. On an average, they spent approximately 94% of their time working in taxing areas.

Inferences:

From the above information and analysis based on data from location sensors, it can be observed that the ranks of workers based on high-yielding hours are different than the total hours worked by them. This implies that while certain workers take more breaks during their shift, some of them are able to complete their work without additional use of the free space. This system can be used to identify top performers better for rewards and analyse health risks for both sets of workers, those who opt for more frequent use of the free space, and those who do not require extra breaks. We also notice a strong correlation between the total hours worked and the high yielding hours, and the total hours and sub optimal hours. This is in line with expectations as workers are likely to be more productive as they put in more amount of time and will also have to take more breaks because of the difficult nature of the work.

Barring a few outliers, we observe a clear pattern of workers who work less than 10 hours a day not spending much time in the free space and thus having lesser sub optimal hours. As the number of total hours of work increases and goes beyond 10/15 per day, the count of sub optimal hours also increases. Not only does this point out the known fact of productivity lowering as one overworks, it also throws light on potential health hazards that these set of workers might face due to incremental exposure to potentially hazardous environments.

Overall, there is huge variation in total working hours of different workers, with some working less than 5 hours a day on an average, and some working more than 15 hours a day on an average. This can be resolved by distributing tasks in a more efficient manner, making proper work schedules, and ensuring that they are followed by all employees. With better schedules for everyone, working time for every worker can be capped at 375 hours per month, increasing productivity and minimising the risk of dangerous health implications. An important point to remember from this discussion that all workers should be wearing the IoT tags at all times in order to make optimum use of the technology.

Distributing workers' activities in an efficient manner:

Currently, each worker has to perform tasks in different areas of the steel plant. Moving from one end of the factory to another leads to wastage of time and energy, and also increases risk to workers as they would have to cross possibly unsafe zones. This issue can be resolved by equally dividing workers across different areas and assigning them tasks only within the particular region. Not only does this avoid accidents and reduce transit time, it also creates room for specialisation. The layout of the steel plant can be broadly divided into 3 clusters, on the basis of proximity of work areas to each other, as represented in Figure 3.

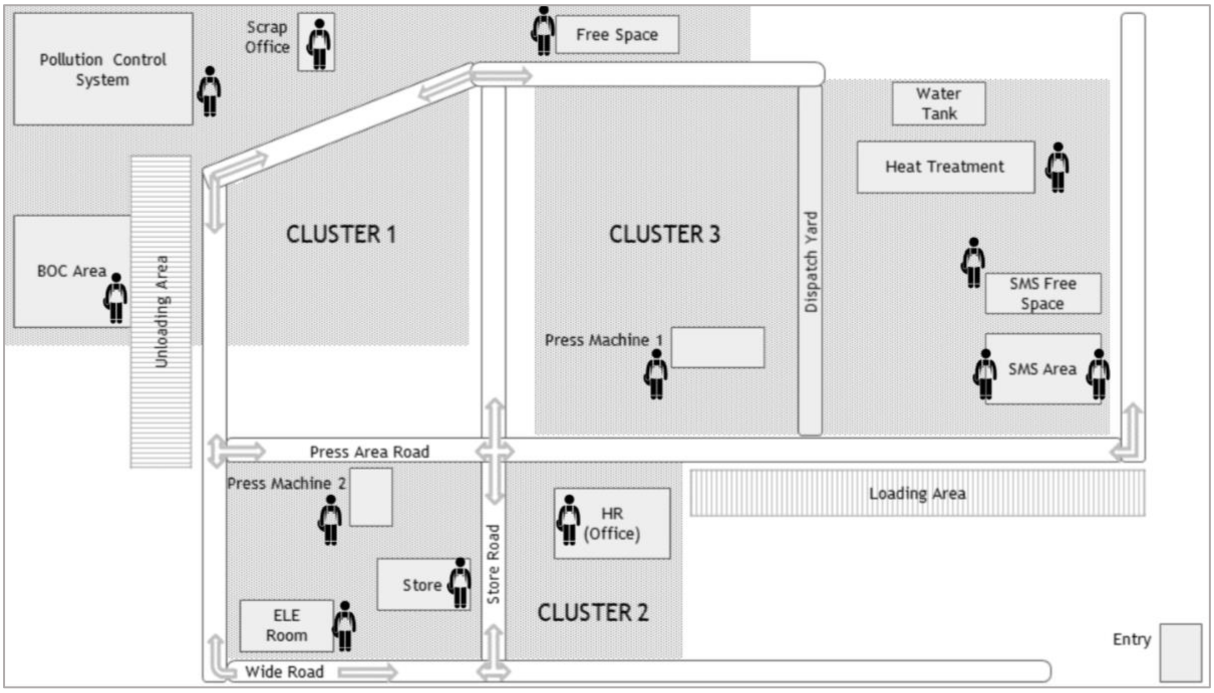

Figure 3: Division of Clusters in the Layout

Data recorded by IoT tags allowed us to analyse the total time spent by every worker in each of these clusters. On the basis of existing knowledge of worker specialisation, 10 workers each can be allocated to cluster 1 and 2, and 13 workers can be assigned to cluster 3. Operators 3, 9, 15, 16, 20, 23, 25, 27, 30, and 33 can be appointed to cluster 1, operators 4, 7, 8, 14, 18, 19, 22, 24, 28, and 32 can be assigned to cluster 2, and operators 1, 2, 5, 6, 10, 11, 12, 13, 17, 21, 26, 29, and 31 can be given sole responsibility of cluster 1 as they already spend more than 6 hours a day working within the area.

As workers operate within a clearly defined cluster, they do not have to enter distant or unpredictable zones which saves time and minimises the possibility of accidents caused due to lack of awareness. Workers can also enhance their understanding of specific tasks and specialise in their area of operations. This system limits overcrowding in any particular area and leads to a more evenly distributed set of workers all across the factory.

System of Communication:

Additionally, smooth running of the factory can be ensured by introducing a system of communication across clusters to facilitate secondary or tertiary movement for a task. If a worker performing his primary task in cluster 1 requires a secondary action to be carried out in cluster 2, he can communicate the same to workers already present there instead of having to go himself. This interaction could possibly take place with the help of wearables such as wristbands or smart watches. Thus, workers do not have to spend additional time and effort going across the factory to do one odd task separately. Figure 4 depicts a possible model of communication in which there is a main network of clusters and each cluster further has its internal network for distributing tasks in a seamless manner.

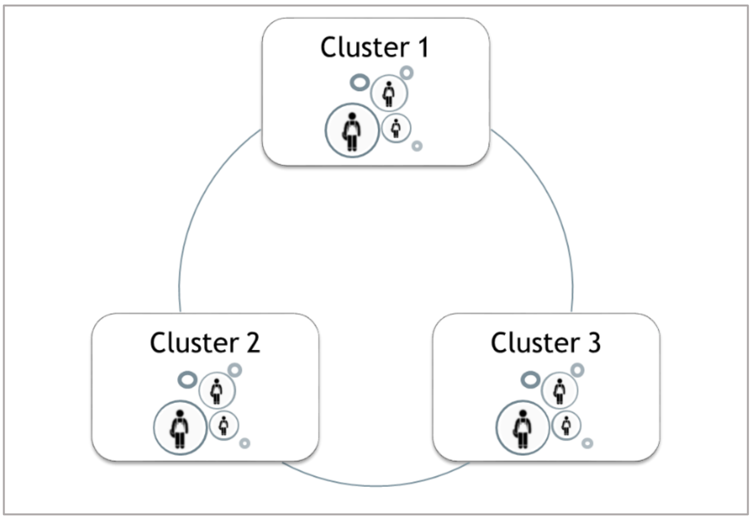

Figure 4: System of Communication via IoT

The communication network between workers in different clusters also facilitates preventive maintenance. For example, if an operator from the pollution control system in cluster 1 notices unusual emissions in the SMS Area, he can inform the workers in cluster 3. Workers in the SMS Area can evacuate immediately and then figure out a way to resolve the problem. Another one of the many possible cases is shown in Figure 5.

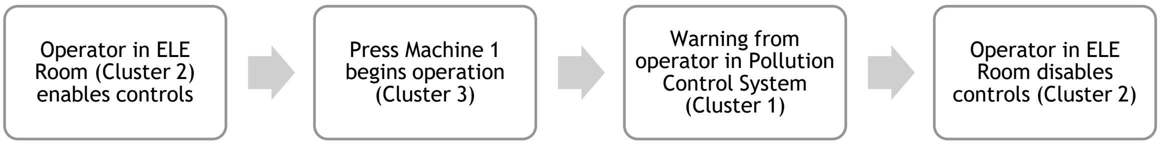

Figure 5: Application of the Communication System

5. KEY INSIGHTS

IoT is a powerful tool that is already widely used for various purposes, ranging from technical innovation to everyday activities. After having discussed different certain important terms and definitions, we moved on to the crux of the paper that is, the role of IoT in worker safety, productivity, and performance appraisal, and the impact of its implementation. IoT can track movement of workers in an industrial setup, a feature that enabled us to carry out a detailed analysis of worker productivity.

With knowledge of the time spent in each area by every worker, almost exact figures of total time spent on the premises could be calculated, which alone enables the management to get a clear view of the disparities between work-days of different employees. Furthermore, we could analyse one's locations and identify which worker had more number of high-yielding hours, that is spent more time working and less time in the free space. These estimates contribute towards creating a better system of rewards and more effective work-schedules. They also help in understanding who would be at a greater risk of health issues as compared to the rest, thus improving both worker productivity and safety. By redistributing tasks and assessing the scenario thereafter, the management can also take a decision on whether there is a need to hire more workers, so as to maximise both total and high yielding hours.

Additionally, understanding of employee's whereabouts helps identify their strengths and weaknesses. A worker spending more time in one work space is likely to be more skilled at it and hence has better productivity. Grouping workers into clusters according to their productivity levels can further refine their skills and enable them to work in a more focused manner. A comprehensive communication system can be fostered using IoT devices that caters to specific needs that arise in factories.

Experienced workers can be asked to mentor workers who are new to the system, and can also conduct training workshops. Workshops conducted by existing high-skilled employees are beneficial to the management as it avoids cost of external mentors, and is also more useful for the new employees as they get better guidance from those who've worked in the exact same setup. Mentorship can also be provided on how workers should navigate physically demanding tasks in a manner that minimises health damage.

6. CONCLUSION

From the combined perspective of theory, industry practices, and the specific case study, we can conclude that IoT is a huge asset in the industrial space in not only production and other processes, but also in matters pertaining to human capital. A coordinated approach to fulfilling tasks can be taken with the help of IoT devices for real-time improvements. Not only does IoT boost worker productivity by optimising shifts, it also serves the role of a virtual guard with its own way of predicting and preventing mishaps. An all-inclusive strategy can be used to evaluate worker performance and provide constructive feedback, while also taking hiring decisions based on current capacity levels.

It is important to understand that all of the above advancements do not benefit the workers or factory owners alone, but also improve product quality for clients and maintain high safety standards. Most importantly, preventing accidents saves an entire family's livelihood as in most cases the workers are the sole breadwinners of their families. It creates a sense of security for the family members of the workers as well as the end customers, who would not want production to take place at the cost of human lives. However, there is a need to recognise the fact that merely introducing IoT devices is not enough to utilise the technology properly. Effective use of IoT with the requisite infrastructure, proper analysis of information gathered by devices, and a follow-up plan to implement changes can together minimise health risk for individual workers and maximise overall productivity.

Opportunities for Future Research:

Worker health deserves more attention in factories and industrial plants, and research can also be further extended to other workplaces wherein employees might not be prone to physical dangers but may be on the verge of burnout due to overworking. Moreover, given the circumstances that the coronavirus pandemic has created, it has become a necessity to track workers' vitals such as temperature and pulse rate. With nobody having the exact solutions to how factories and offices should operate in this time period, there are many prospects for research into understanding how technology can be leveraged to enhance worker productivity in uncertain circumstances. A combination of IoT and AI could prove to be very powerful in this realm of possibilities.

The centre of discussion pertaining to worker safety, productivity, and appraisal is the human aspect of it. Thus, there is a need to explore beyond the boundaries of machine-to-machine (M2M) communication technology that IoT stands for. The Internet of Everything (IoE) is an extension of IoT that includes people to machine (M2P) and people to people (P2P) communication through technology along with the basic M2M communication(Shinkarenko, 2020). Thus, IoE broadens the perspective of IoT by adding the components of data, people, and processes to the original element of "things".

There is significant scope for improving outcomes, especially where processes include human involvement as well. Employees' hidden potential should be tapped and a better environment to ease out processes can be fostered. Employee productivity in the future will depend upon integrated use of IoE which will in itself entail newer technologies under both categories of people and machines. Smart, connected technologies will pave the way for new opportunities and alter the industrial landscape. Thus, companies need to be on the look-out for flexible patterns of work processes that are in tandem with the ever-changing technological landscape.

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