POLITECNICO DI TORINO

Thesis

Industry 4.0 solution for safety and quality optimization in manufacturing

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【Abstract】

Due to different levels of tasks and working conditions, workers in the industrial production process are faced with various unavoidable risks. Unfortunately, the death, injury, and disease caused by work have become too common, and with the emergence of more and more safety problems, it not only seriously damages the physical and mental health of workers but also brings unpredictable economic consequences to production plants. This thesis analyzes the safety hazards in the industrial production process and identifies the possible risk factors in the production process according to the definition of the Customized Risk Assessment matrix. After that, based on the technical background of Industry 4.0, several possible advanced technologies are proposed to monitor and control these variables in the process of risk assessment, and it is assumed that wireless sensors technology and other technologies are used to collect the data and for subsequent calculation. Finally, these results are integrated into the existing risk matrix to assessing the risk severity of each work position through analysis of these variables flexibly and more reliably, to further reducing risk events and optimizing product quality.

【Keywords】

HP Model   Risk Assessment   Internet of Things   Wearable Technology

Condition Monitoring   RFID tags   Smart Sensor   Human Model Simulation

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Introduction

Within any developed country, the thriving manufacturing industry is a major driving force of economic prosperity. The key to maintaining a competitive manufacturing capability is the manufacturing system design process and the decisions made within it, but the safety issues that accompany it have received increasing attention from all sectors of society. With the appearance of Industry 4.0, more and more manufacturing industries are developing in the automation, mechaniza-tion, and intelligent way. In practice, inevitably there a lot of manual workers are required in production. The workers are the major players in the manufacturing production process. High operating intensity, long working time, and complex operations will cause many affects such as doubled working pressure, harsh environment, and low-level management, which may cause hidden safety problems for workers. Mainly the symptoms of memory loss, decreased vision, negative work, low mood, physical pathology, etc., influence workers to be prone to operate improperly, thereby reducing production efficiency and causing more safety accidents. It shows that the safety of workers is one of the critical points during industrial production. Therefore, it is necessary to identify the factors that affect the safety of workers in the manufacturing process and further propose solutions. After defining the corresponding risk factors, this thesis from the existing solutions which refer to the environmental assessment-risk matrix method (Duijim et al., 2015) and further discussion on the basis of the HP-model proposed by (Comberti et al., 2017) that involves the consideration of the worker's characteristic (human factor) within the risk assessment. From the data model that has been successfully implemented in the HP-model and the final result to define the variables that could be observed, and make an assumption about them based on the industrial IoT technology under Industry 4.0, whether the relevant variables can be monitored directly thus for further control; Or, suppose other possible technologies under Industry 4.0 to monitor these variables for improving efficiency. A flow-chart representing the theoretical framework of the thesis shows as below (Figure 1). Finally, the research of this work is summarized, and the limitations are figured out. Based on the conclusion, some solutions can be stimulated according to the aspects of these supposed technologies under industry 4.0 in order to achieve risk reduction and product quality optimization.

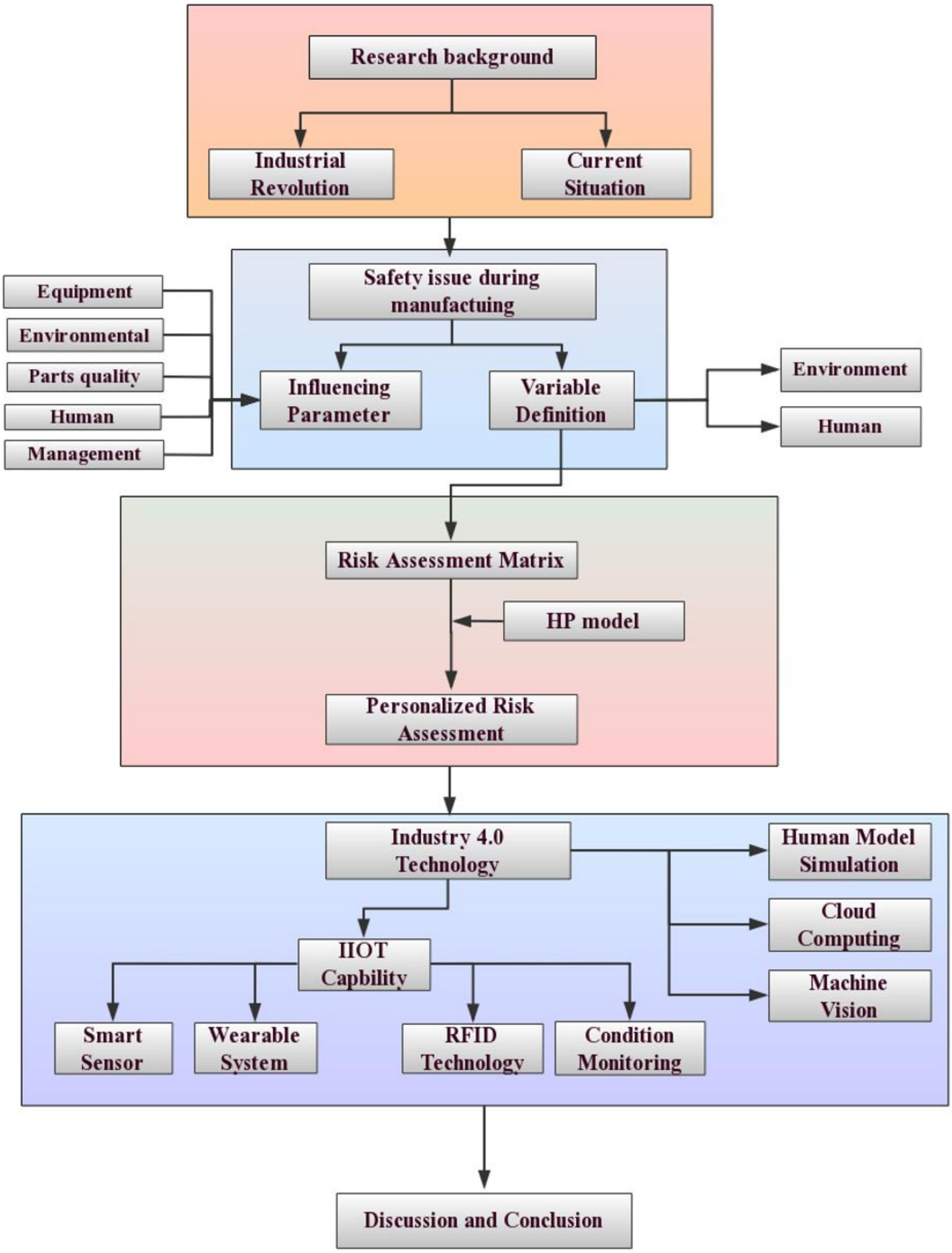

Figure 1. Theoretical Framework

1. Research background and purpose

1.1 Research background

1.1.1 The evolution of the industrial revolution

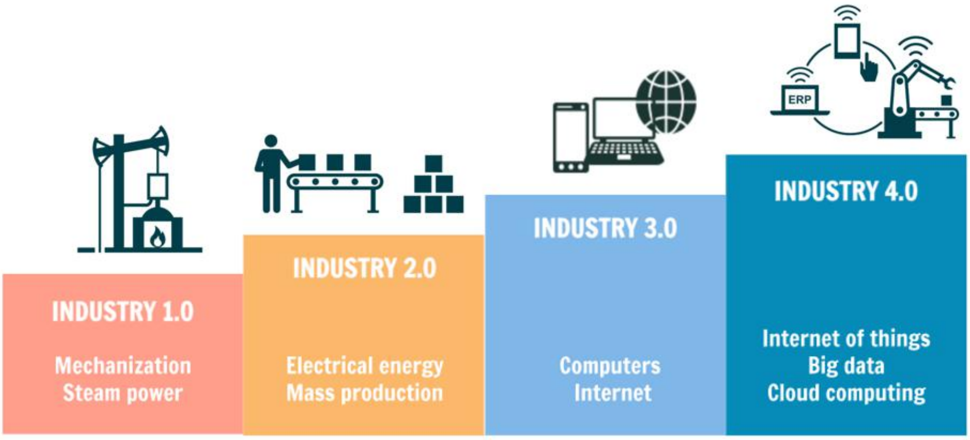

Figure 2. Industrial revolution

In the 18th century, Britain initiated a huge revolution in the history of technological development, which we call the first industrial revolution. Since then, the era of replacing manual labor with machines has been created. It is not only a technological change but also a social change of profound significance. The birth of industrial machines is the cornerstone of the development of this revolution, and also symbolizes the widespread use of steam engines as power machines. This change due to the technological revolution and related social relations is called the first industrial revolution or the industrial revolution. This revolution allowed factory systems to replace traditional manual workshops and machines to replace manual labor.

The mid-19th century ushered in the second industrial revolution. The completion of bourgeois reforms in the United States, Japan, Europe, and other countries promoted economic development. The second industrial revolution originated in the 1870s. It symbolizes that human has entered the Electric Age. The industrial revolution promoted the development of social development and had a profound impact on the political, cultural, scientific, technological, economic, and military aspects of human society.

Following the previous two revolutions in steam technology and power technology, the third industrial technology revolution-the Information Age that came in 1970, and has continued to this day and is also another significant progress in the field of human science and technology. It is marked by the widespread application of atomic energy, space technology, and electronic computers, and the revolution in information control technology in many fields involving information technology, new energy technology, space technology, and biotechnology. This technological revolution has not only greatly promoted the transformation of human in the economic, political and cultural fields, but also affected the way of life and thinking of humans, and promoted social life and modernization to a higher level.

1.1.2 The Situation of the traditional industry

From the paper of Bian Jinghao discussed in "Strategic transformation of traditional machinery manufacturing industry in the context of Industry 4.0 development" in 2018, we learned that the traditional manufacturing industry is mainly characterized by two features, i.e., lack of inventory and lack of innovation capacity. First, the shortage of stocks in traditional machinery manufacturing enterprises is mainly caused by insufficient funds. The entire machinery manufacturing process is mainly implemented by humans. Therefore, there is a certain gap with modern enterprises in terms of scientific and technological content and product quality, which has caused them to be in the market. Insufficient competitiveness of the company, the problem of insufficient capital stock will inevitably lead to the development of the enterprise. However, it is difficult for single capital investment to ensure the sufficient power of the enterprise. Therefore, it is necessary to attach great importance to technological innovation and upgrading and solve the problems existing in traditional manufacturing.

Secondly, the traditional manufacturing industry needs to use a large amount of industrial input into actual production, production, and manufacturing according to product design, so the demand for manufacturing innovation is relatively low, and the number of high-end products in the entire production process is relatively small, resulting in the existence of corporate brand concepts. The problem is that if there is no effective innovation, the traditional manufacturing industry will definitely be separated from the market.

A comprehensive analysis of the current situation of the traditional machinery manufacturing industry mainly faces two difficulties. First, it faces internal difficulties. From the perspective of the traditional machinery manufacturing industry, it mainly faces high labor costs, excess capacity, and low production efficiency. Among them, the level of production technology cannot meet the times. The development needs are relatively low in science and technology. With manual manufacturing, it is difficult to guarantee production efficiency and affect the quality of machinery manufacturing products. At the same time, it also greatly reduces the production efficiency of enterprises.

The traditional manufacturing industry is mainly oriented to the production volume trend, resulting in a relatively low market share, a large number of products difficult to reach consumers in a timely manner, resulting in overcapacity problems, and adversely affect the development of the machinery manufacturing industry. The second is the external dilemma faced. The external dilemma faced by the traditional machinery manufacturing industry is mainly based on information technology, which is mainly manifested in market competition and the promotion of information technology.

First, under the context of the development of Industry 4.0, the level of informatiza

-tion in various sectors of society has been rapidly improved, effectively improving industrial production efficiency, promoting the improvement of industrial efficiency of enterprises, and providing a guarantee for enterprise development. However, the traditional machinery manufacturing industry is mainly moving towards a labor intensive road. In the production process, due to the relatively small number of new equipment and new technologies of employees, the overall level of informatiza -tion is low, which not only affects economic efficiency and production efficiency but also is not good for the market further competition.

Second, economic globalization has promoted greater ties between countries, while the market competition faced by traditional machinery manufacturing has expanded internationally, and enterprises are facing both foreign and domestic pressures, leading to the development of industrial manufacturing enterprises facing huge challenges.

1.2 Research purpose

Through the study of Industry 4.0 technology, we found that the Internet of things technology, cloud computing, machine vision, human modeling and simulation, and other disciplines are widely rising. Also realized that the application of relevant technologies provides strong technical support for the existing industrial safety production process and product quality optimization. The main research content of this topic is: Based on the current feasible industrial risk assessment process, analyze and define the relevant risk factors that affect the production and manufacturing process of workers, and apply advanced technology to monitor the relevant variables, so as to ensure the safety of personnel and product quality; in order to better realize this idea, this project first carries out a specific analysis of the possible risk factors, later defines the relevant monitorable and controllable variables and puts forward the technical hypothesis that can be used to monitor the relevant variables. Then, the basic principles of the relevant technologies are clarified and further solidifies the assumptions by combining them with the practical application of this technology.

2. The safety problem relevant to the manufacturing process

It is well known that an important prerequisite that affects the safety of the production process is the safe state of the hardware base. In the machinery industry, the main elements involving equipment and facilities, all tools, raw and auxiliary materials, discharges, and operating environment. The unsafe state of these elements is a kind of invisible danger and risk of accidents in the production process. For instance: mechanical design isn't reasonable enough; doesn't meet the requirements of safe man-machines; the safety factor is not enough, the calculation error occurs; the estimation of the use condition is insufficient; the manufacturing method is wrong, the safety device is defective; necessary safety protection is lacking Measures, brutal operations of individual personnel during transportation, and the poor operating environments such as operating conditions exceeding safety limits or exceeding sanitary standards, without exception will become the source of hidden dangers, leading to reduced system safety functions or even failure.

Also, accidents due to unsafe operation of workers are one of the main manifestations of hidden dangers. Because human behavior is affected by various factors such as physiology and psychology, performance is diverse. For instance: the relevant staff does not understand the possible dangers of the equipment and facilities they use; lack self-protection awareness; fail to operate according to the recruitment safety regulations; and the ability to deal with unexpected situations, which are all concrete manifestations of human unsafe behavior. In daily mechanical work, these behaviors typically manifested in poor work habits. Such as, some personnel randomly place tools or measuring tools during the work process, personnel leave, or under other circumstances when measuring the work-piece without stopping, and the equipment runs over the running tool to fetch and deliver materials.

At the same time, the accident caused due to inadequate safety management also can't be ignored. Safety management includes managerial-level safety awareness, the deployment of safety management agencies and related personnel, the supervision of equipment and safety of workers, professional education and training, establishment, and implementation of safety rules and regulations, etc. Deficiencies in these aspects are also the critical cause of accidents and have a remarkable impact on the safety of the enterprise's production.

2.1 Influencing parameters in the manufacturing process

2.1.1 Mechanical equipment factors

The main equipment factors that affect the safe production of the machinery manufacturing process include the performance of the relevant machinery and equipment, the life cycle, the use of each component and its operating status, etc. Changes in some surrounding conditions may also directly affect the ordinary operation of the equipment, leading to safety accidents. For human safety, the design of mechanical equipment needs to be reasonably improved in terms of parameters, spacing, volume, etc. So maintenance and strict safe-distance management must be carried out.

2.1.2 Environmental factors

A better working environment is the foundation of factory production and workers' lives, and the working environment of machinery manufacturing includes both internal and external environments. The internal environment mainly refers to the workshop site of machinery manufacturing and related worker and mechanical equipment. The internal environment and external environment of machinery affect the safe production of manufacturing, and also easily induces hazard events that occur during the process of machinery manufacturing. The bad natural environment and serious environmental pollution will directly affect the physical health and working mood of factory workers, and even increase the occurrence of errors, causing more safety accidents. In serious cases, such as the natural environment around the factory is too humid, it will shorten their life cycles set up, and even directly affect the working states. Moreover, it will also prevent workers from focusing on safe operations and thus cause safety accidents.

2.1.3 Parts quality factors

A key part of the quality of mechanical equipment is the quality of each component, which affects the reliability and safe operation of the machinery. During the manufacturing, if these components with quality defects and cannot undertake its function, it will be necessary to manufacture and produce the machinery, equipment, and parts following national and industry internal safety regulations. In addition to guaranteeing the quality of the components themselves, special attention should also be paid to the maintenance and repair of the manufactured machinery and equipment parts to reduce the occurrence of safety accidents instead.

2.1.4 Human factors

The traditional manufacturing process was done by workers typically. But the safety issues are not only related to the operators, there are many complex factors that cannot be ignored besides the simple mistakes made by the operators. Under normal working conditions, the operators are proficient with the relevant skills that will reduce or even avoid the occurrence of safety accidents. Therefore, most general safety accidents can be avoided by the skill training of operators. In addition to the skills training for operators, attention should also be paid to and strive to improve the mental capacity of workers, to increase their level of caution in operations to reduce or avoid errors, and to improve their response to emergencies to minimize losses. It must be emphasized that operating errors during manufacturing are generally the top priority of safety accidents. Once the workers do not operate the equipment in accordance with the safety regulations of the production management or make unauthorized modifications to the equipment, it may cause safety hazards or directly lead to safety accidents during the manufacturing, resulting in human and economic losses.

2.1.5 Operating procedures and management system

Due to the separation of government and enterprise, manufacturing safety management work is actually not centralized and decentralized, which is not conducive to achieving uniform manufacturing safety management standards and models, and it is also easy to cause safety accidents and unclear management responsibilities, which are mainly manifested by enterprises research on safety technology is weak, and safety work is relatively lagging; enterprise production is synchronized and the degree of industrialization is relatively low; the quality of worker is relatively low, and it is impossible to fully grasp and reasonably use enterprise safety management knowledge; the progress of machinery manufacturing is poorly controlled; the temporary wiring of the manufacturing enterprise is interrupted, and the electrical wiring installation is not standardized enough, especially the private pulling and alternating movement of the dormitory wires are serious, which can easily cause the short circuit of the wires and cause fire hazards; the relevant staff and even department heads have no awareness of electrical safety, lack fire protection knowledge, and cannot manage effectively. This aspect leads to a common phenomenon that once a disaster occurs, the degree of harm is generally relatively large.

2.2 Definition of risk variables of Environment

In order to further analyze the risk variables for targeted control, these micro factors separated here came from the industrial environment, and the relevant risk variables as the case study were mentioned in "Special environmental problems associated with mechanized sorting offices" by P. E. Marriott et al. (1969), which discussed the same considerations involved in the provision of a good working environment in mechanized sorting offices, particularly these factors, such as heat, noise, dust, and lighting.

Therefore, it can be concluded the impact of the industrial environment on workers' safety mainly includes the environment where the workers are located: atmospheric conditions, lighting conditions, temperature and humidity, and so on. For instance: the harmful gases generated during factory production cannot be exhausted to harm the respiratory tract of workers; and excessively strong or weak light will cause Visual fatigue of workers; too high or too low temperature in the factory will cause workers to consume energy and reduce efficiency. Waste accumulations, dust, and dangerous materials generated in the production halls will also take physical and mental influence on workers.

Noise and vibrations: Various power machinery is frequently used in the manufacturing process. they produce noise vibration and make the working environment become noisy which will affect the mental and physical health of workers thereby reducing efficiency (E. Öhrström et al., 1979).

Temperature and humidity: It is the temperature and humidity of the air in the work environment, as well as the temperature and humidity of the human body. Too high a temperature can cause workers to feel uncomfortable and sleepy, which can lead to operator error and accidents. Temperatures that are too low can also limit the activity of humans. That can further affect the efficiency of production. More recommendations were given in "Occupational Exposure to Heat and Hot Environments" by Jacklitsch B. et al. (2016).

Lighting conditions: The lighting effects not only the manufacturing industry but also the various workplaces, as a case study is from the paper "Effects of Lighting Quality on Working Efficiency of Workers in Office Building in Tanzania" by M. K. Justine et al. (2019). The most common among manufacturing industries is assembly line production operations, which are characterized by long working hours, high intensity, fast-paced, and high frequency of eye use. The quality of lighting conditions directly affects the visual system of workers. Better lighting conditions can ensure safe production and meet the physiological and psychological health needs of workers; and worse conditions can easily cause visual fatigue. For workers engaged in manual assembly processing or other manufacturing processes, too strong or too weak lighting intensity, the muscle tension of the visual system is very high, will cause local discomfort and even vision loss. Therefore, proper lighting conditions are essential to the visual function of the operator

Ventilation conditions: As stated in a paper from A.M. Leman et al. (2010), each workroom must provide adequate ventilation in order to prevent workers from suffocating and breathing polluted air. An overly enclosed working environment prevents the fresh air to be replenished in time, workers will feel uncomfortable. Generating a large amount of irritating gas and harmful gases during the production process (such as gas produced by welding including nitrogen oxides and ozone or metal fumes) will induce varying degrees of damage to workers' breathing and nervous system, thereby reducing production efficiency. Better ventilation is a necessary condition to avoid these effects.

Hazardous sources: hazardous source equipment includes metal cutting beds, industrial gas cylinders, flammable and explosive materials, boilers, cranes, etc. Due to the existence of these dangerous factors, workers must always be careful when working, and time is highly stressful, which affects work enthusiasm and reduces work effectiveness. Once the incidents occur, they will take a huge physical injury to workers, as well as the economic loss for companies.

Dust source: as the article "Dust in Industry" in 1918 by Smyth, H. discussed is that there is too much danger of infection as well as mechanical injury from dust in the factory. Typically it was generated by material handling, transportation, use, etc. During the production process will adversely affect the physical and also the mental health of the workers, and lead to respiratory discomfort of workers, which will result in various aversions and adverse emotions; More critical cases can lead to respiratory infections.

In summary, these factors we may encounter during the manufacturing process. Based on our research direction, when we consider the impact of these factors on our personalized risk assessment process to workers and take into account the specific discussions that facilitate data collection and analysis.

2.3 Definition of risk variables of Human

From the paper of Christiernin L. et al. (2016), we understand the sources of OHS risks and list them below.

- Eye related diseases.
- Mental fatigue.
- Disease caused by long-term static position work.
- Contact with unknown hazardous particles.
- Psychological stress (from adapting to job functions that require creativity).

According to the findings of "OHSA in industry 4.0" by Aylin ADEM et al. (2020), they believe that mental fatigue and psychological stress are the two most important risk factors for workers. The conclusion that mental fatigue is a critical risk factor due to the interaction between humans and machines is not unexpected. Psychological stress cannot be explained in the same way as mental fatigue cases. Therefore, psychological aspects need to be further studied. Because this will continue to grow under the influence of the company (schedule, overtime, emergency orders, etc.), employees (work cycle, skills, uncertainty, etc.), and management (responsibilities, communication, relation-ships, problems, etc.). It has been pointed out that programmers and engineers operating complex equipment sometimes ignore this threat, leading to problems. In terms of regulations and OHS management framework, the psychological impact has become a problem that must be paid attention to it.

For this purpose, we classify the remaining risk categories as Eye-related diseases, Diseases due to static working position, and Exposure to unknown dangerous particles. For example, prolonged interaction with electronic screens can also cause eye health issues. Therefore, according to these results, we can prevent employees from working long hours by making them rest during the production and working environment, in order to reduce eye fatigue. Or through the effective use of the work rotation method, the disease caused by long-term static position work can be prevented.

3. Addressing method under modern methodology

3.1 Addressing method related to the risk assessment matrix

When risk accidents occur in the production process, we can not solve all the problems at one time. It is essential to have the correct methods and solutions. The use of risk matrix (Duijim et al., 2015) here is more conducive to solving problems that may or have occurred during the manufacturing process. It can provide a clear and reasonable priority for the occurrence of these risk events, and arrange the processing order of all hazards according to the risk index derived from the probability and severity of events in the risk matrix. Prioritize events for more reliable and efficient purposes.

Since we already know that all the risk factors mentioned before may cause injuries and more serious safety hazards, we must propose targeted solutions to these factors to solve the issues caused by these risk factors. Therefore, We must figure out when, where, and how these factors affect the manufacturing process. It is helpful for us to take measures quickly for recovery or predict potential hazards in advance when problems occur. Therefore, we must have an assessment of all risk factors or events. The relevant risk-based approach has to be documented in companies by a report, the DVR (Document of Risks Assessment) for the Italian Regulations; it generally based on the technological risk definition:

$R = S \times P$ (1)

Where S is the severity of events that caused a potential accident or health impairment, and P represents its probability of occurrence. The way "S" and "P" are calculated is a crucial factor in how an assessment proceeds.

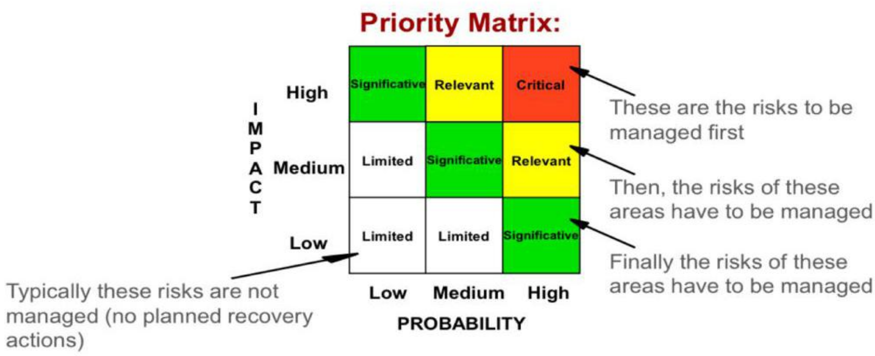

Figure 3. The priority matrix

A wide range of methods have been developed with the common aim of ranking risks in manufacturing equipment and work environments, as in Etherton J. (2007) for the machine risk assessment, or Moatari Kazerouni et al. (2015), for manufacturing systems in general.

In this field, the RA process can be summarized generally by the following phases:

1. Identification of all possible hazards related to all kind of work activities;
2. Risk assessment (RA) of all-hazard identified and for all working activities

3. Risk mitigation when risks were classified as not tolerable, through the definition of preventives and protectives measures.
4. Information and training for all workers with regard to risk assessment results.

There are kinds of technologies can be applied to support the first step of the identification phase as follow:

Brainstorming: group and cross-functional sessions, there is a potential too big amount of identified risk events.

SWOT analysis: structured group session.

Delphi Technique: risk identification individually made, then subsequently validated by an expert panel.

Checklist: based on a company formalized risk knowledge.

In practice, all these techniques can be mixed in various ways according to the project complexity and the company processes.

The risk matrix method was introduced in "Recommendations on the use and design of risk matrices" by Duijim et al. (2015), which applied for the classification and tolerability evaluation of the risks. An example of a risk matrix shown in Figure 4: the risks, according to the associated numerical value, are classified into four classes from acceptable to high. Once we get the conclusion through the risk matrix, we can propose corresponding solutions to different problems.

Probability of occurence of Harm		Severity of Harm			
		Catastropic 4	Serious 3	Moderate 2	Minor 1
Very Likely	4	16	12	8	4
Likely	3	12	9	6	3
Unilikely	2	8	6	4	2
Remote	1	4	3	2	1

Severity level	Meaning
1 Minor	First-Aid case
2 Moderate	Lost-time injury
3 Serious	Hospitalization
4 Catastropic	Fatality

Probability	Meaning
1 Remote	10^{-4}
2 Unlikely	10^{-3}
3 Likely	10^{-2}
4 Very Likely	10^{-1}

Risk value	Rank
1-3	Acceptable
4-7	Low
9-11	Medium
12-16	High

Figure 4. An example of Risk Matrix

Considering the above method to define the risk events and to give the relevant solution in the further step, which is not a very accurate and humanized way for workers to estimate the risk index of these risk events. Because we did not consider the impact of human factors on the assessment process. Therefore, we have to introduce the concept of "Personalized risk assessment" which came from the paper of Comberti et al. (2018) defines how human characteristics will affect the process and to get a more comprehensive assessment.

3.2 Addressing method related to the HP model

From the human performance model with the consideration of the worker's behavior, if we manage the safety issue during the working condition, take account of the risk tendency raised from the human must translate it from the qualitative way into the quantitative to realization. Therefore, the workload related to the worker, both from the physical and mental aspects can't ignore, so a typical scale of quantitative comparison between the human capacity and workload was needed to represent the human performance. A graph from the paper of Comberti shown below (Figure 5) summarized the relationship between the TC and HC :

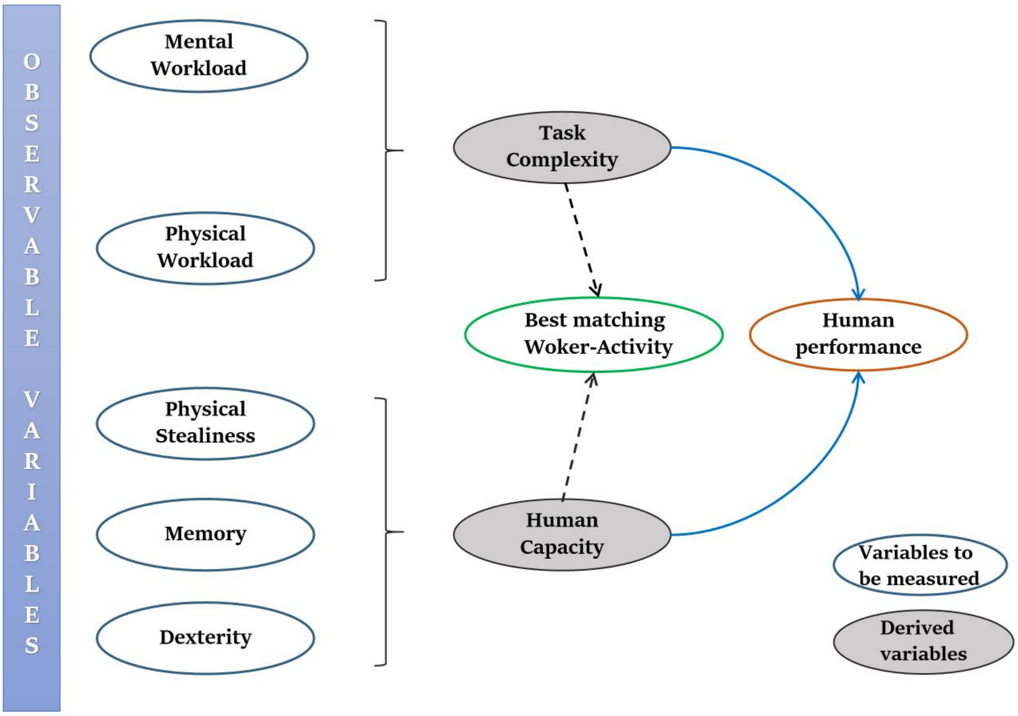

Figure 5. Conceptual of Human performance model

HCworker – TCtask = HP (2)

• HP minus: It represents the sum of all value of the relevant matching index is negatives and it means a lack of resources;

• HP plus: It represents the sum of all of the matching index is positives, and it means the over-capacity compared to those capacity required by its TC level.

Here mentioned TC tasks that include all factors involved in the mental and physical needs of a specific operational task, as well as multiple factors of the work environment. In order to the evaluation of mental workload (MW), we think it can be characterized by three variables as following:

• Task variability: Consider that the assembly line is a series of working positions as moving parts from one location to another. Each assignment contains multiple operations that depend on the type of product that needs to assemble. Therefore, it was assessed by considering the percentage of variation of operations composing the task. MV (Task variance) reflects the percentage of the variance observed in each workstation. This value of MV is 1 when the operating process does not change (i.e., the parts to be assembled are of the same type of task). When the most frequently active component type accounts for only half of the total assembly activities (i.e., 50%), the value is 10.

• Task Complexity: This variable is used to define the complexity of the task and is related to the number of decomposable sub-operations. The complexity index (CI) is defined according to the number of basic operations and vary from the range 1 to 10. When the number of operations is less than 10, the index is 1, and when the number of operations is greater than 75, the value is set to 10.

• Choice: Considering the existence of multiple similar components in the assembly process (such as screws of different specifications and similar sizes), this variable is related to the correct choice between several similar parts. The defined frequency similarity index (FS) ranges from 0 to 3, indicating that there are no similar parts and the percentage of similar numbers exceeds 20% of the total managed parts.

Here, the factors related to posture, movement, and physical strength required for a specific task generally included in the Physical Workload factor. Workstation with poor ergonomics, such as the need to maintain uncomfortable posture and load, directly results in a significant drop for performance. At the same time, due to long-term repetitive actions, static work and over-time are considered important causes of accidents and inefficiency.

Factors related to saturation time (that is, the percentage of beat time required to complete a given task) are also factors that cannot be ignored in the physical workload. The lower the saturation, the longer the time available to complete the tasks. Besides, several factors can be summarized as environmental variables (Jung, 2001), including lighting, excessively high or low temperature, noise, long-term exposure to chemical and physical environments such as dust and harmful gases, etc. Those factors have a certain impact on MW and PW. Under such environmental factors that have a great influence on industrial conditions, it will lead to an increase in the pressure level of workers, thereby affecting the reliability of human.

So the following variable can be used for assessing the physical workload:

• Handling: the definition of this variable involves the number of small parts that need managing during the task execution. If they are not small parts managed, the part number index is defined as 1, and when the parts more than 50 require managed, it sets to 7. We integrate this index with the FS index mentioned above to obtain equation 3:

$$DRI = PN + FS \qquad (3)$$

The Dexterity Required Index (DRI) is mainly used to measure the workload associated with manual activities and refers to equation 3, its value is defined to vary from 1 to 10, which taking into account the previously mentioned range of observable values for assessing PN and FS.

• Physical effort and Coping with pace: this variable mainly depends on the ergonomic index and saturation index, and these two values vary from 1 to 5. EI is defined by the ergonomic standardization method of each workstation, and the work analysis useful to identify the saturation level of takt time. The physical workload index (PWI) expressed in equation 4:

$$PWI = EI + SI \quad (4)$$

The main adopted measure methodologies are the Likert scale from 1-10, and it has to be stated that each scale is calibrated concerning the original unit measurement of those variables. At the end of this process, according to the consequence of the TC operational model, each TC was characterized by the variability index, complexity index, dexterity index, physical effort index(VI, CI, DRI, and PW) as Figure 6 from the article of Comberti.

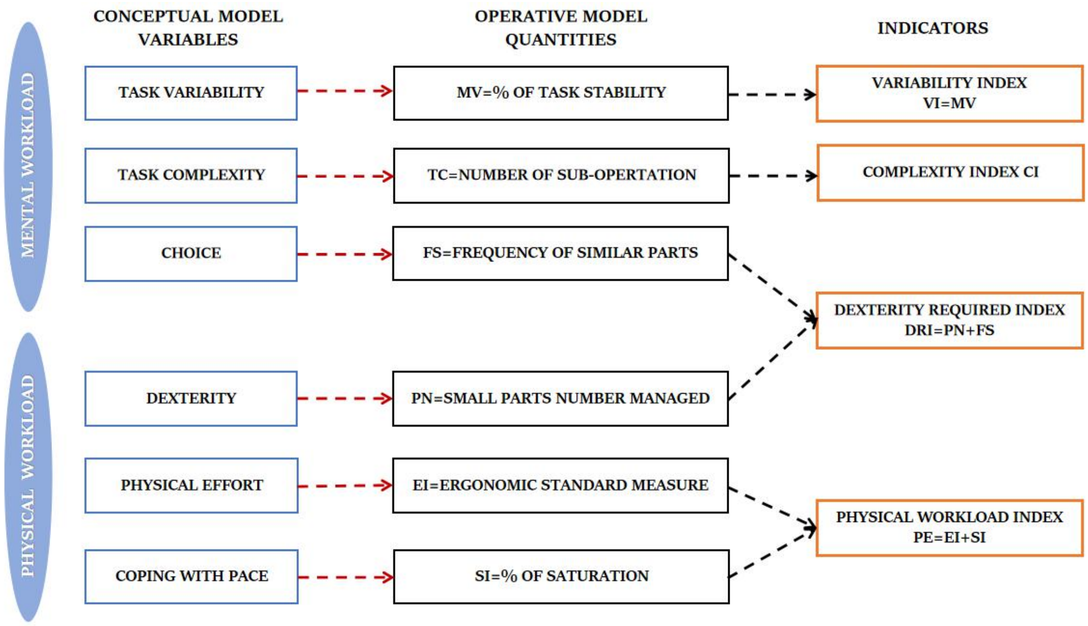

Figure 6. TC operational model

During working conditions, workers can potentially provide their total amount of resources to perform a given task, which is called human capacity. Several tests have been performed on workers during the working activity, with the key consideration following :

• The relevant test must represent operations that are close to those performed frequently in a given assembly line.

• Since tests must be carried out during the general working period for workers, therefore the length of the time has to control to lower than 10 minutes.

Related to Human Capacity, the key indicator is manual skills, memory, physical skills:

1. Precision test: This specific test is to require the worker to move the iron ring along the non-linear contour and does not contact the line. The purpose of this test is mainly useful for a large number of tasks that require manual precision. During the tests, the relevant technicians will record the number of errors in the test and the time of completing the path.

2. Coordination test: Workers during the test will be asked to perform a series of simple actions by hand. At last, the time and accuracy of the coordinate movements

were recorded by technicians.

3. Methodology test: In this test, workers have to complete a series of simple assembly steps composed of small parts, and relevant technicians shall collect time and error times.

4. Memory test: During the test process gives workers a few seconds to observe the sequence of geometric schemes and then ask them to copy it on paper. Finally, the time and accuracy to complete the task have to record.

Based on the analysis of the above test results, three indicators are determined to characterize the HC:

• Physical endurance index: This index takes into account the different performance variance of each worker in the test, and defines its value range from 1 to 10 Likert scale, where 1 represents the capability to attain the lowest consistency in work performance and 10 indicates the capability to achieve the best consistency.

• Memory index: This index is closely related to the results of memory tests, and its value ranges from 1 to 10, where 10 indicates that there is no error during tests.

• Manual skills: The index combines the results of the Coordination, Precision, and methodology tests as mentioned before. It is also defined as the Dexterity index since those tests are all related to the measure of dexterity.

As shown in Figure 7, the operation model of human capacity, all workers in the assembly line will evaluate their capability according to the above three indicators (PSI, MI, DI).

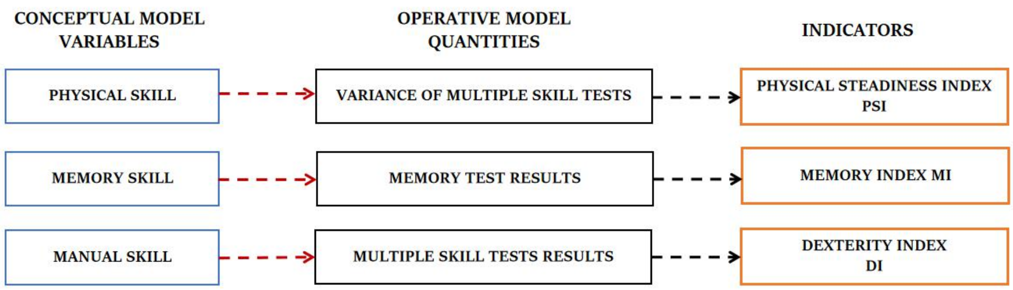

Figure 7. HC operational model

Finally, we integrated this human performance model into the risk matrix. HPm gives tools to quantify the goodness of a matching worker-task on the basis of task characteristics and operator's skills. This information can be integrated into the RA process according to the following point:

a) Risk can be estimated according to equation 1;

b) The Probability can be calculated with a semi-quantitative scale ;

c) HP as assessed by the HPm model with the HP_{minus} index can be included in P-value calculation with the introduction of a coefficient proportional to the HP minus. On the basis of these statements the Risk equation (1) can be modified as follows:

$$Rc = (P + P_{HP}) \times S \quad (5)$$

where:
Rc represents the Customized Risk;
P represents the probability of occurrence;
PHP represents the Probability of occurrence related to the individual HP;
S represents the severity.

PHP can be estimated in relation to the HPminus values calculated with the HPm model. On the basis of previous work on HPm application, a correspondence was defined and it is summarized in Table 1.

HPminus Range	PHP Value
From -2 to any value >0	0
From -10 to -3	1
From -16 to - 11	2
Minor than -17	3

Table 1. PHP Values

A famous case study from the trial approach of personalized risk assessment in manufacturing (Comberti et al., 2018c): The assembly line consisted of 23 work-stations involving 50 workers task and the complexity analysis was implemented on the line which consisted in 20 different working-station; Those related assessment activities and tests involved 25 workers directly and who were employed in the assembly line selected.

The result shows the assignment of workers on the different tasks cannot be left only on the decision of the line supervisor, on the basis of his judgment which is too subjective. In contrast, the concept that humans have a different level of skills is commonly accepted, with the Hpm model it is possible to quantify the skills and to distinguish workers based on a relative scale of comparison based on the skills identified. Some data collected after analysis could highlight the composition of any single capabilities for all workers involved in this work. These indices adopted allowed a quantification of the human capabilities and showed significant differences between workers both in terms of the composition of HC and in terms of total HC.

For example, a worker’s Memory Indexes is very high, while other indexes such as Dexterity indexes and physical endurance are very low. According to this conclusion, we can assign them to workplaces with higher requirements in Memory and lower in Dexterity, Physical endurance, and strength. It means "a shift from subjective assessment to an empirical and theoretical assessment of required workload and available capabilities" (Comberti et al., 2019).

This information brings innovation to safety management. The CRM matrix allows a quantitative comparison of potential risks for all workers involved. Using CRM matrix in human resource allocation will reflect a transferring from subjective assessment to an empirically and theoretically based evaluation of available human capabilities, the workload required, and the effects of this in terms of incremented risk.

So far, we have analyzed various parameters of the environment and worker operation process and determined the priority of risk events according to the above steps. In the context of combining the risk matrix with the human factor performance model, we can't ignore the consideration of multiple variables, including environmental factors, the variables that appear in the assessment of the physical and mental workload, and in the process of human capacity testing.

The major objective of this thesis is to guarantee that the risk assessment process is not affected by multiple variables and reduce accuracy. Therefore, it is necessary to continuously monitor and control these factors to ensure the feasibility, reliability, and effectiveness of the assessment results, so the measures are effectively implemented to solve these risk problems, thereby avoiding or mitigating the emergence of safety problems, and further optimizing product quality.

In the next section, we will consider the technologies that exist under Industry 4.0, through the monitoring and controlling of observable variables, data collection, and analysis, to achieve efficient, reliable, and rapid risk assessment.

4. Addressing method based on the Industry 4.0

4.1 The key techniques under Industry 4.0

This section reviews some of the major technologies used in intelligent manufacturing, which described in Table 2, including the IoT, Big Data, CPS, Cloud Computing, and other technologies as discussed in "Intelligent Manufacturing in the Context of Industry 4.0: A Review" by Zhong Ray et al. (2017). And more details of the widely applied technologies are shown below.

Technologies	Description
Cyber-physical systems	Defined as the connection and coordination between computing resources and physical resources
Internet of Things (IoT)	A network of physical devices and applications that connect and exchange information in real-time
Cloud computing	IT technology that allows universal access to system resources and data processing through the Internet
Edge Computing	Method of optimizing cloud computing systems, where data is processed at the edge of the network and as close to the source as possible.
Big data analytic	Processing large and various data sets
Artificial Intelligent (AI)	A concept that refers to a computer's ability to perform tasks and make decisions that would historically require some level of human intelligence.
Additive manufacturing	Rapid prototyping and 3D printing
Robotics (Co-bot)	Collaborative robots physically interact with workers in the production area
Human modelling and simulation	Simulate human behavior to improve ergonomics in mind and assess human factors for operations to help plan safer workplaces
IT / OT integration	To enhance the role of IT solutions in the field of operations
Augmented reality	A system that connects physical and real environments with computer-generated environments
Digital twin simulation model	Technology based on the digital model of the machine or production system, which can monitor and design new businesses in real-time

Table 2. The relevant technology under Industry 4.0

• Internet of Things

The concept of the Internet of things was formally introduced forward at the "information society summit" (WSIS) held in Tunis on November 17, 2005. However, as early as 1982, the technology has been taking shape. Researchers from Carnegie Mellon University applied networked devices to improved Coke machines to check inventory to confirm the number of drinks available. It is a new concept arising from the development of information technology. Also can be seen from the word meaning that the Internet of things is the Internet-connected with things. There are two meanings here. One is that the Internet is still the core and foundation of the IoT, and the physical network is the network derived from it; the other is that the user end of the physical network extends to any object for information exchange Exchange and communication. It allows all physical objects that may be individually addressed to form an associated interconnection network. And various electronic sensors, actuators, or other digital devices are embedded in these research objects, so they can be networked and connected to collect and exchange data. Generally, the Internet of things can provide the advanced connection between physical objects, systems, and services, to realize information exchange and data sharing between objects.

Internet of things technology has been widely used in industry, known as the industrial Internet of things technology. Industrial Internet of things (IIoT) covers the field of industrial communication technology for Machine to Machine (M2M) and automation applications. IIoT is integrated into the industrial production process through a variety of sensors and controllers with sensing and monitoring functions, mobile communication, intelligent analysis, and other technologies so that people can better understand the industrial production process, to achieve efficient and sustainable production. The purpose of the Industrial Internet is to realize the intelligent cooperation of massive industrial objects and change the future industrial infrastructure of industrial production form. It is necessary to use the new generation technology concept to model and control different kinds of industrial entities and even the entire industrial network, and efficiently integrate industrial and social resources, to realize the intelligent development of the industry entities.

• **Cyber-physical System**

A Cyber-physical system is a computer system whose mechanism is controlled or monitored by computer-based algorithms. In CPS, physical components and software can operate on different time and space scales, exhibit various behaviors, and interact with each other in a way that changes with the environment. It includes system engineering such as environment perception, embedded computing, network communication, and network control so that the physical system has the functions of computing, communication, precise control, remote collaboration, and autonomy. Its application is usually sensor-based autonomous systems that can communicate. For example, certain aspects of the environment are monitored by a wireless sensor network, and then the processed information is integrated into a central node. CPS covers a wide range of applications involving smart grids, autonomous vehicle systems, intelligent transportation systems, telemedicine, aerospace, and other fields. A large number of wireless sensor networks can monitor environmental aspects so that information from the environment can be centrally controlled and managed to make decisions. If the emergence of the Internet has brought enormous changes to human society, then the popularization of CPS will take a new industrial revolution to humans. At present, the research of CPS has just started, and opportunities and challenges coexist for researchers.

Many industries have begun to try different projects in the CPS field. For instance, the standardized platform taking Festo sports terminal as an example utilizes the intelligent fusion of technologies such as machinery, embedded sensors, electronic devices, and software/applications. The digital pneumatic device allows self-adapting and self-regulating subsystems. And the "distributed robot garden" developed by the Massachusetts Institute of Technology, which manages the tomato plant garden through a cyber-physical system that combines distributed sensing, wireless networking, navigation, and other technologies.

• **Cloud Computing**

Cloud computing is a kind of distributed computing technology. Its basic concept is to automatically split a massive computing processing program into numerous smaller sub-programs through the network, and then use a system composed of multiple servers to control it. After searching, processing, calculation, and analysis, the results are returned to the user. In a sense, cloud computing has become a fundamental resource as vital as water and electricity. By registering an account on the cloud service platform, enterprises and individual users can easily and quickly obtain the needed IT resources and technical capabilities through the Internet, which not only reduces costs but also meets the demands of flexible deployment and high-efficiency business. With the deepening of digital and intelligent transformation, cloud computing is playing an increasingly important role. Nowadays, cloud computing technology has been widely used in network services, such as search engines, Google Cloud, G-mail, etc., users only need to enter any request to obtain a large amount of information.

As the **National Institute of Standards and Technology (NIST)** defined, the ideal "cloud" has to include five fundamental characteristics:

• Self-service on-demand.
• Use any network device to access anytime, anywhere.
• Many people share the resource pool.
• Fast redeployment flexibility.
• Relevant services that can be monitored and measured.

This cloud model definition also involves four deployment models (Public,Private, Community, and Hybrid) and three service models (Software as a service, Platform as a service and Infrastructure as a service). Organizations of all types and sizes are using cloud computing to increase their capacity with a minimal budget, without the need to invest in licenses for new software, merge new infrastructure, or train new personnel.

Although cloud computing has significant advantages, severe challenges still influence the reliability of this concept of continuous development. As we all know, one of the service models of cloud computing is that consumers use services provided by cloud service providers, such as processing, storage, and transmission data in the cloud without control or managing the cloud computing infrastructure thus reducing costs. However, when the data shared on the network, privacy can not be prevented by physical isolation and other methods.

For example, with the development of the times, people use the internet for trading or shopping, online trading in the virtual environment of cloud computing, the two sides of the transaction will communicate and exchange information on the network platform. There are potential security risks in network transactions. Lawbreakers can steal information from users through cloud computing. They can also steal information from users and businesses when they conduct network transactions and will use some technical means to crack and analyze the information to discover more privacy information of users.

It should be also noted that a large number of users store data in cloud computing. When cloud computing is abnormal, some viruses will appear. The emergence of these viruses will lead to the phenomenon that the computer-based on cloud computing can not work correctly, which can also replicate and spread in some ways. Other challenges include data management, load balancing, data capping, and resource allocation, which will reduce the reliability and efficiency of cloud computing.

• **Edge Computing**

Edge computing is a distributed computing architecture that moves the large-scale services such as application analysis and data calculation that are processed by central nodes generally to the edge node on the network logic for processing. Edge computing decomposes the services and sends them to edge nodes closer to user terminal devices for processing, thereby speeding up data transmission and reducing delay. Under this structure, the data analysis and the generation of information are closer to the source of the data, so it is more suitable for processing big data. For example, with the increase in the number of IoT devices at the edge of the network, numerous data will be generated in the data center for calculation, thereby pushing the network bandwidth demand to the limit. Although network technology has improved, data centers still cannot guarantee acceptable transmission rates and response times.

As **Edge Computing Industry Consortium (ECC)** says about edge computing, it is an open platform that integrates network, computing, storage, and application core capabilities on the side close to the things or source of data and provides intelligent services in the edge. Its applications are initiated on the edge side to generate faster network service responses and meet the basic needs of the industry in real-time business, application intelligence, security, and privacy protection.

At the current stage, the development of edge computing is still in its infancy. As more and more devices connected to the Internet, edge computing has received extensive attention and unanimous recognition from industry and academia. In the industrial world, cloud giants such as Amazon, Google, and Microsoft are becoming leaders in the field of edge computing. Amazon's AWS Greengrass service has entered the edge computing field and leading the industry. They extend AWS to devices so that the locally generated data can be processed on local equipment. Moreover, Microsoft has also made vital initiatives in this area, which plans to invest US$5 billion in the Internet of Things in the next four years, including edge computing projects.

Although edge computing has been widespread concerned, there are still many problems to be considered in the practical application of edge computing. For example, in the edge computing architecture, different levels of edge servers have various computing capabilities, and load distribution is also crucial. From a security perspective, the distributed architecture of edge computing increases the dimension of attack vectors. The smarter is the computing client, the more vulnerable it is to malware infection and security breaches.

Compared with the traditional cloud computing model, the edge computing model computes some or all of the tasks that originally belong to the cloud computing center at the vicinity of the data source to achieve data processing and analysis in real-time, simultaneously take the advantages of low-traffic, privacy protection, robust security, and scalability.

• **Big Data Analytics**

With the development of science and technology and the promotion of technology under Industry 4.0, a large amount of data is being produced in many industries all the time, causing big data problems. Usually, these data sets are generated from different sources, such as industrial equipment, sensors, applications, video/audio, network, and social media. In this case, the "Big data environment" in the manufacturing industry has gradually formed. With the definition from IBM" Big data analytics means to use advanced analytic techniques against the huge and diverse data sets that include structured, semi-structured, and unstructured data, from different sources with different sizes." In recent years, big data analytics has become an indispensable tool in the operation of many enterprises. It can speed up the analysis and processing of information, thereby helping employees complete tasks effectively.

IT operation analysis is currently a relatively important department in an company. Its functionality is to solve the collection and analysis of large-scale data within the enterprise by using big data technology. Based on the principles of big data combined with concepts such as deep computing and machine intelligence, it can predict potential problems and take timely measures. The platform it provides brings together various data islands and gathers insights from the entire system rather than isolated data.

A growing number of facts prove that it takes more advantages to people. For example, research in the Industry shows that with the help of big data analysis technology, retailers' return on investment has risen to 20%. The analysis of customer relationship management (CRM) data is also considered an effective way to improve customer engagement and satisfaction. For retailers, collect and analyze inventory, questionnaires, demographic census, and other data, through these data (customer preferences, needs, experience) to establish excellent customer service. What is more prominent is the use of smart sensors to monitor and collect customers' movement paths and stay time. Besides, with the popularity of social media, retailers collect customer media data through the Internet to understand how customers feel about brands or services, thereby establishing a complete and satisfactory service and sales model.

The most remarkable benefit in the manufacturing industry is to improve the strategy of supply and quality of product according to the Global Trends study TCS. For instance, Some auto companies introduce the plan of "refurbished vehicle" by mining historical orders and feedback from users to meet the demands of customers than before. In addition, A more in-depth and detailed analysis of the data generated by the machine and its production process can help companies improve competitive -ness and productivity.

• **Human Modelling and Simulation**

Nowadays, digital modelling of human beings and their behaviors in a variety of ways has matured from research to industrial application. Nevertheless, there is still great potential for development. For human simulation, the digital human model has become a widely used tool in human-oriented products and virtual prototype design. By simulating anthropometry, movement, posture, force, and muscle strength, or discomfort during work, they will support the ergonomic evaluation of new product designs in human-in-the-loop at the early stages of product design.

Before many solutions are fully implemented, simulation has been widely used to test solutions in many different fields, including ergonomics. From the paper "Designing Work Systems to Support the Performance of the Best People" published by Berlin C. et al. (2017), we learned that the digital human body model is a professional term. Through specific digital simulation software tools(such as Jack 4.2 siemens 2016) the manikins and virtual workplace are simulated, interacted, and analyzed. In the virtual working environment, import the digital human modeling and take extensive tests to determine the ergonomic parameters related to the human body, and thus to assess further optimized for use in the workplace and tasks. At the same time, the database of anthropometric can be used to provide models with different scales in the same virtual working environment. DHM takes several benefits for the PE as follows:

• Convenient to take a forward-looking design method.
• Multiple solutions provide for comparison
• Access to the real environment is not always possible.
• Easy to test different measurement ranges (nation and gender)
• Visualization of industrial layout and ergonomic effects can provide designers or ergonomics with accurate and efficient analysis.
• Training assistance

Given the high cost and space required to build a complete model at the design and development stages, early identification of tasks that may involve clumsy postures or harmful body positions. And the relevant tests must be carried out when the assembly line is closed.

By using ergonomic simulation, intelligent design decisions can be made as early as possible. It is necessary not only to realize the existing problems after the system implementation and injury start but also to take a proactive approach and conduct comprehensive test and analysis of the test scheme as soon as possible through simulation, to reduce the risk of injury and save time and money in the later stage of implementation.

4.2 The methodologies and solutions

4.2.1 The variable monitor and control based on IIoT

There we list all the possible variables that presented and discussed in Section 2 and 3 shown in Table 3. In the context of Industry 4.0, we attempt to monitor and control those variables we have considered through the basic working principle of the technology proposed in Section 4.1.

Firstly we suppose these variables could be identified directly by the technology in IIoT or not, and if it's possible what kind of detailed technology can use; or otherwise, the other methodologies which are indirect we will implement to measure and assess these variables.

MODEL VARIABLES	IIoT MONITORING CAPABILITY
Noise and vibrations	Sound/Accelerometer Sensors
Temperature	Temperature Sensor
humidity	Humidity Sensors
Lighting conditions	Optical Sensors
Ventilation conditions	Gas Sensors
Dust sources	Particulate Matter Sensors
Hazardous sources	Proximity Sensors
Human biophysical parameters	Wearable Technology
Machine working condition	Condition monitoring
Tool condition	NO(Machine Vision)
Physical effort and Coping with pace	NO(Human Modeling and Simulation)
Handling	RFID tags
Task variability	NO
Task Complexity	NO
Selection	RFID tags
Manual skill	NO（Cloud Computing）
Physical skill	NO（Cloud Computing）
Memory skill	NO（Cloud Computing）

Table 3. Model variables and IIoT capability

According to the paper "Machining Process Monitoring" by Huaizhong Li et al. (2014), the techniques for the monitoring of machining have been categorized traditionally into two methods :

- Direct
- Indirect

Direct monitoring is a method that uses devices that can directly measure quantities of physics during production. In the industry 4.0 era, the smart sensor was the simplest way to monitoring and controlling tech parameters, as temperature, light, and ultrasonic sensors in the manufacturing process provide direct information about environmental variation. In the same way, to indirect monitoring, the quantities which can not be measure directly by numerous can apply the kind of sensors, such as using vibration, and current sensors. Relatively to say, the indirect measurement system is more economical. It can measure these auxiliary quantities, such as force, current, but requires more complex modeling for processing the signal.

As we described later, the environment variables identified previously can be measured by these sensors, then integrated by IIoT.

4.2.1.1 Installed smart sensors technology

A sensor is a device that can sense and detect certain information of the measured object and can transform this information into electrical signals or other forms of information output according to specific rules to meet the requirements of a transmission, processing, storage, record, and control, etc. The general composition of sensors included: sensitive components, conversion components, and measurement circuits and these sensors can directly contact the measured object or not. Among the many technical requirements for sensors, some are applicable to all types of sensors, and some are only applicable to specific types of sensors. Whatever, the basic requirements for the working principle and structure of the sensor on different occasions are high anti-interference ability, high sensitivity, easy adjustment, high precision, no hysteresis, high reliability, long working life, high response rate, etc.

There are two main functions of the sensor: one is the sensitive function, which senses the measured changes, and completes the collection of the signal; the second is the conversion function, which completes the conversion from non-electricity to electric quantity. Depending on the environment, the type of sensors that need to be applied is quite different. There are also many classification methods for sensors as follows:

1) Based on the information detected by the sensor, it can be divided into thermal, photosensitive, air-sensitive, force-sensitive, and radiation-sensitive sensors.

2) Based on the principle of sensor conversion, it can be divided into chemical sensors, bio-sensors and physical sensors.

3) Based on the output signal of the sensor, it can be divided into digital type sensors, analog-type sensors, and switch converter.

4) Based on the materials used in the sensor, it can be divided into semiconductors, nano-materials, polymer materials, and superconducting material sensors.

5) Based on the energy conversion of the sensor, it can be divided into energy conversion type and energy control type sensor.

6) Based on the sensor manufacturing process, it can be divided into integrated sensors, thick-film sensors, thin-film sensors, etc.

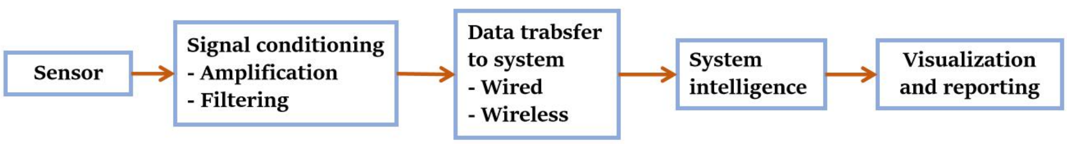

Figure 8. Typical sensing process

And the typical working mechanism of sensor (Mertens M. et al. 2011) shown in Figure 8.

As for the environment variables have mentioned in Table 3, here define the corresponding type of sensor according to the different detecting properties of observed variables, which intending to continuously monitor and collect the required data aggregated into the risk assessment. A brief description of the mainly used sensor in Table 4:

Sensor type	Description
Temperature Sensor	It enables to discover the state change in temperature and converts to information for a tool or user. It aims to monitor and manage the variation continuously and immediately to adjust the value into the required range for keeping the operating states
Proximity Sensor	A device that detects the presence or absence of a close-by object, or properties of that object, and converts it into a signal which may be simply collected by the user or other instrument while not stepping into contact with them. it's primarily placed around the dangerous sources to avoid inessential accidents
Gas Sensor	Depending on the gas concentration, a potential difference can be generated by changing the resistance of the material inside the sensor, which can be used as an output voltage measurement to detect the presence or concentration of gases in the atmosphere
Accelerometer Sensor	It is a kind of sensor used to measure the physical or measurable acceleration of an object due to inertial force, and convert mechanical motion into electronic output. It is defined as the changing rate of velocity relative to time
Sound Sensor	Sensor with a built-in capacitive electret microphone and with highly sensitive to sound. Sound waves will induce the thin film of the electret to vibrate, then the capacitance changes producing the corresponding changed voltage. It capable detect noise levels within decibels at 3 to 6 kHz
Humidity Sensor	A kind of device that defines the humidity by the quantity of water vapor in an environment of air or other kinds of gases. The term commonly measured is called Relative Humidity
Optical Sensor	A sensor that measures the physical amount of light rays according to optical principles and converts it into electrical signals, which can be easily decipherable and collected by users or electronic devices
Particulate Matter Sensor	A device based on laser detection, which can detect and count particles with a certain range in a given environment by the light scattering method. Recorded the particle that passes through the detection chamber on the image or light detector, then analyzes the light, converted into electrical signals, and calculate the concentration by provided particulate sizes and quantities in real-time

Table 4. The sensor related to environment variables

From the previous definition of the Internet of things, it is an information carrier based on the Internet and traditional telecommunication network. It enables all ordinary physical objects that can be independently addressed to form an interconnected network. Its main functionality is to connect various information sensors with industrial equipment and devices through the industrial network connected to the computer. In order to monitor in real-time anything that needs to control, connect, interact with objects or processes, collect required data, classify, and exchange information for subsequent analysis. To realize the ubiquitous connection between objects, objects and humans, and also the intelligent perception, identification, and management of components and processes. Industrial sensor technology is the cornerstone of the industrial Internet of things applications. The accuracy of the sensor directly determines the reliability of data collection and analysis. Therefore, the future development of the industrial Internet of things requires more accurate, more intelligent, more efficient, and more compatible sensor technology.

The connection between objects and systems is the most critical step for us to use sensors in the industry. It depends on whether the data can be collected in real-time and transmitted accurately. Generally, there are two ways of information transmission, wired transmission, and wireless transmission. Wired transmission usually connects the sensor directly to the device receiving the input, which means that the wired sensor is also the most durable system and does not need to be replaced frequently. Based on the broadband used, signal buffering, loss, and other issues need to be considered. Wireless sensor technology is becoming more and more popular in industrial applications, mainly because it is cheap to install and easy to maintain. Various wireless sensor networks also provide greater flexibility, such as LoRaWAN, cellular, Wi-Fi, etc., which makes the sensor system easier to adapt to the needs of users, but there are still some shortcomings. For example, they are usually limited by distance because the speed of data transmission depends on the position of the receiving device relative to the sensor. Compared with this, a wired sensor has a more predictable data transmission time.

4.2.1.2 Wearable Technology

When moving from the discussion of factors such as the environment and machinery to the health and safety of workers, it must realize the significance of continuously measuring physiological parameters of the human body and evaluating the health state of an individual during the production process. Therefore, wearable devices are proposed here for the detection of physiological parameters for humans.

Wearable technology refers to a series of electronic devices with micro-controller integrated into clothes, accessories, or can directly wear on the surface of human skin (smart watch, sports bracelet, etc.). The human body signal (heart rate, blood glucose concentration, etc.) can be recorded and fed back to the wearer in time.

As described in "Wearable Electronic Systems: Medical Diagnosis/Monitoring Applications" by Mc. Adams et al. (2011), the risk of chronic diseases increases with age. Therefore, it is essential to monitor some basic physiological parameters of the human body, such as blood pressure, blood glucose, heart rate, electrocardiograph, and other parameters. With the maturity of wearable technology, these parameters can be monitored by different intelligent devices in real-time. At present, the most widely recognized smart wearable device is the Holter monitor shown in Figure 9. Its principle is that one end of the sensor device is directly connected with the human body to record and measure the cardiac electrical signal of the human body. It also provides data storage (3-5days). Cardiologists can use this data to analyze physiological conditions such as arrhythmias.

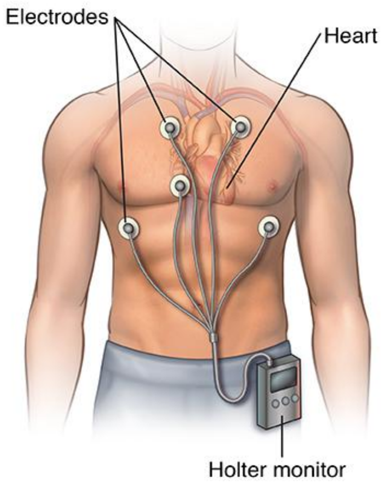

Figure 9. Holter monitor

From a case introduced in "IMU-based motion capture wearable system for ergonomic assessment in an industrial environment" by Caputo F. et al. (2019), a modular system based on capturing human motion was developed in the Department of Engineering of the University of Campania Luigi Vanvitelli, as shown in Figure 10. That system can predict the orientation of the segment for each body, the angles trend of postures, and recognize the gait during a working activity through the combination of inertial measurement unit (IMU) and sensor fusion algorithm. Finally, in order to prove the effectiveness of the system, the feasibility of the system is confirmed by the trial test held on the Fiat Chrysler automobile assembly line.

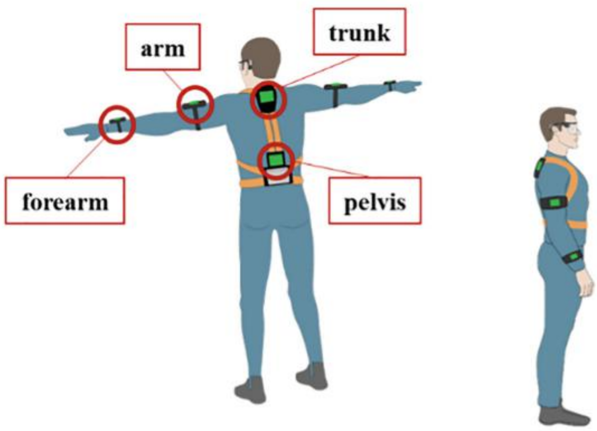

Figure 10. A motion tracking system with the different modules distributed in humans' body

4.2.1.3 RFID technology

In 1999, Radio-frequency identification (RFID) technology becomes essential for IoT in Auto-ID Center at MIT (Chopra and Sodhi, 2007; Liu and Chen, 2009; Zhang et al., 2011; Kuban et al., 2013). RFID as part of automatic identification (auto-ID) technology in the IoT, uses radio frequency for non-contact communication and combined with data access technology, which can be connected to the database system to realize contactless two-way communication. Then, the recording medium (electronic tag or radio frequency card) can be read and written through this technology to achieve the purpose of target identification and data exchange. In the identification process, the reading, writing, and communication of RFID tags were realized through waves of electromagnetic, according to the paper "Intelligent Library System Based on RFID Technology" by Zhou Donghua (2019). For the communication distance, it can be divided into Far-field and Near-field. And the data exchange method between the reader and the RFID tags can also be divided into back-scatter and load modulation.

There are two categories of RFID tags, battery-powered and passive tags. The former is powered by a board battery (also called an active RFID tag), while the latter is motivated by electromagnetic energy transmitted by an RFID reader. The use of passive RFID tags is mainly concentrated in three frequency bands: low-frequency band (120-150 kHz), High-frequency band (13.56 MHz), and Ultra-high frequency band (865-868 MHz). The use of these frequency bands has a different impact on the transmission range of RFID tags. There is no battery power supply in the passive RFID tag. When the reader scans this tag, after receiving the microwave signal sent by the reader, part of the energy is converted into DC power for its work, so that the product information stored in the tag is relayed back to the reader. The reader reads and decodes the information, and then sends it to the central information system for data processing. Embedded tags and hard tags are currently widely used in passive RFID tags. Embedded tags are usually thin enough to be attached to various materials. Hard tags are made of harder and more durable materials (such as metal or plastic).

Active RFID tags mainly use two frequency bands concentrated on 433MHz and 2.4GHz for information transmission. It consists of three parts that include the tag, antenna, and interrogator. The active RFID tag contains a battery with a limited life (3 to 5 years). The current technology does not support battery replacement, so the unit needs to be replaced. Two types of active RFID tags are beacons and transponders. The communication distance for the beacon can reach within several hundred meters, and specific information send periodically(3-5seconds), so battery consumption is relatively fast. The working principle of the transponders is similar to that of a passive one. When the RFID reader is close to the transponder, it will be activated and relay relevant specific information back to the reader. Therefore, the battery efficiency of the transponder is much higher than that of the beacon.

Normally, using electronic tags and radio frequency identification technology to collect equipment, various auxiliary tooling, tools (tool number, tool life, measurement parameters, etc.), fixtures, measuring tools, etc., manual experiment data, measurement data, material batch Secondary data, etc. Print the frequently used information on the electronic label. The workers in the workshop use a dedicated wired or wireless scanner to collect the information and transmit it to the database through the Ethernet network. This method can be used on old equipment without a CNC system or on the manual reporting station of the production execution system. This method reduces the workload of the operator’s information input and improves the amount of information collected and the accuracy of the information.

Figure 11. Bolts/screws with RFID tags

Similarly, according to the working principle of RFID technology, it can be applied to the identification of small parts as well as the classification and management of parts, so as to effectively assess the mental workload for the worker. For example, in the overall part management process, the selection of parts that are too similar to make the right choice. A customized RFID tag can help identify the number of these similar parts, such as UHF 915 MHz bolt and screw tags shown in Figure 11 made by RFID, Inc. (A company specializing in RFID custom development), it is capable of permanently immobilizing RFID tagged items or assets, tagging parts with different RFID information to facilitate the evaluation of part categories in the assembly process. In the same way, RFID tags can also efficiently and precisely record the related information on the production line. (Figure 12), and bring convenience to the quantity recording and inventory management of marked parts, so it's useful for assessing the number of parts has to manage during the task performing.

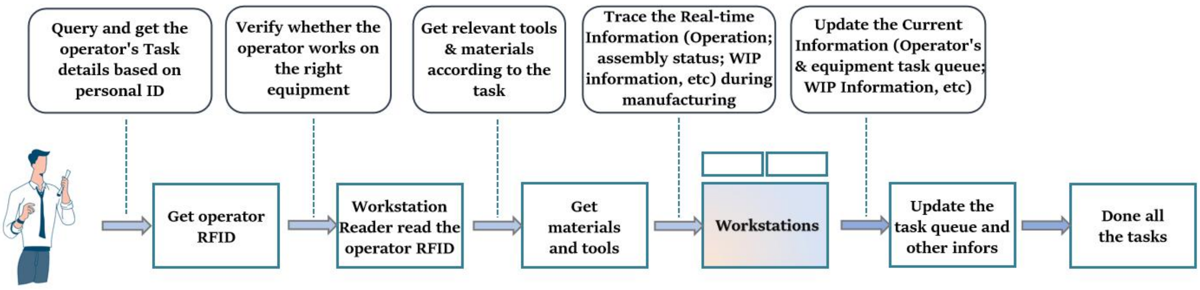

Figure 12. A RFID application in Industry

4.2.1.4 Condition Monitoring

As the paper "A review of machine vision sensors for tool condition monitoring" says, In order to avoid/minimize the impact due to the failure of production equipment and take timely measures and management processes to achieve robust production, it is essential to continuously monitor the machinery to analyze whether there is performance degradation or defect (K. Shahzad et al., 2018), that known as condition monitoring.

Condition monitoring is the process used to monitor the parameter of condition in machinery (temperature, vibration, saturated time, etc.) to identify the indications that failure may be developing. Condition monitoring is more efficient than passive maintenance since faults could be avoided in advance generally, then reducing machine downtime, cost-saving, and prolonging the life of the machines. Therefore, in order to detect the particular technical problems of different machines, relevant technicians must have accurate devices for measuring and powerful capability for data storing. With the formidable system of CM, it is more advantageous to gathering and analyzing massive amounts of data.

With to the definition as before mentioned for condition monitoring is a technical process, which is mainly aimed at controlling the specific parameters of the machine, and detecting whether there are potential technical failures, in order to repair it immediately before it is damaged or malfunctioning and the related data is transmitted through several devices which connection based on IoT technology. Under the Internet Of Things, it is generally applied to rotating equipment and other types of machinery, such as compressors, electric motors, pumps, etc. These components are typically key dynamic components with relatively concentrated stress and load, so they are easily worn down and aged faster, and will be damaged in the long term.

Condition Monitoring is an adaptable practice, utilized in various businesses for different kinds of machines. To fulfill the dynamic needs of industries, they need to apply various types of conditions monitoring. As the CM method has a variety of uses, the technology has been widely used in different industries. As the following list includes the most common condition monitoring techniques applied in the industrial and transportation sectors:

Vibration monitoring and analysis

This method is often used to monitor and analyze the working status of rotating machinery, by monitoring and analyzing the level and frequency of machine vibration. Generally, technicians will install the sensors for monitoring on the flat and clean surface of the machine, and connect the data to the IoT devices, and collect the data of acceleration, speed, displacement, or other data of the mechanical parts by analyzing the changes in the electronic signals. Use relevant software to analyze the collected vibration data and obtain specific conclusions. Or carry out a frequency analysis to compare the frequency data collected with the optimum machines' data.

Through the final comparative analysis, determine the vibration level that the mechanical equipment can tolerate, and then improve or made it (such as increase the strength of the material) to withstand the vibration. The threshold of vibration will be set, and if the vibration level is higher than the acceptable level, the device will automatically switch to a lower intensity operation mode or shut down.

Debris monitoring and analysis

Generally, the lubricating oil and other fluid substances in the mechanical production process will be repeatedly used, and the residual material debris will lead to irreversible system failure in the lubrication system (such as the failure of pumps, generators, blowers, and gearboxes), which will bring a high maintenance cost. Therefore, debris monitoring technology provides a guarantee for it. The oldest and simplest method is to use magnetic plugs to collect and retain ferromagnetic debris. After removing the plug, the collected particles can be checked externally as required. Also, electronic methods can be used to detect the presence of debris particles. Metallic particles act as a switch by bridging the gap between magnetized electrodes, attracting debris to the electrodes to indicate the number of particles present in the fluid. Then remove the electrode, analyze the collected debris, or analyze it directly through the filter and cartridge.

All of the methods mentioned above will be automated by using IoT sensor technology. Such as filters, magnets, electrodes that can be connected to IoT devices, and for real-time data transmission, to timely inform technicians to take out the detector for subsequent analysis.

Infrared thermography

Infrared thermal imaging is a kind of method, which is applied to detect the infrared energy emitted from the object and convert it into temperature, which is displayed as a temperature distribution image. The temperature distribution image detected here is called a thermogram, which can be viewed as the heating object invisible to the naked eye. At the same time, Through the monitoring of infrared radiation, the converted thermogram is analyzed to monitor the status and efficiency of the machine during production. For example, analysis shows that overheating areas may be failed more quickly, which could indicate abnormal heat distribution. Otherwise, cold areas may be affected by water and must be checked for leaks.

The major objective of infrared thermography is to confirm whether the machine is operating normally and detect the abnormal thermal mode inside the machinery, thus indicating inefficiency and defects. Therefore, it is necessary to measure the infrared energy of a healthy machine under normal working conditions, and then operate the device in the limited state to predict its abnormal behavior.

Most common industrial applications include power distribution systems for locating loose or deteriorated connections, overload, load imbalance, open circuit, equipment failure, and harmonic symptoms; mechanical systems to detect excessive friction, misalignment, improper lubrication, and belt tension, etc.

Acoustic emission (AE)

Due to changes in the internal structure of the material, the internal stress of the material will suddenly redistribute, such as aging，plastic deformation，etc. Through the analysis of moving parts, Mechanical energy will be converted into Acoustic energy (the stress waves generated converted into acoustic signals) to determine whether there is avoidable friction between components. If unnecessary contact occurs, there will be lead to loss of energy and wear of parts.

It is an on-line machine monitoring technology. During the detection process, the machine is in a fully operational state, and the real-time data generated will be transmitted to the relevant server. Its working principle is to install small sensors on the tested parts. The sensor converts the stress wave into an electrical signal and forwards it to the acquisition PC for processing. When the components are subjected to external stimuli, such as load, high pressure, or temperature, these stress waves are captured by the sensor. As the damage increases in the component, and the energy release will be greater. The detection rate, activity, intensity, and loudness of AE are monitored and used to assess structural integrity and for the health monitoring of components. By using multiple sensors, it is possible to locate the AE source (where the damage starts). Through signal analysis, the existence of different homologous mechanisms can also be determined.

Industry 4.0 technology has an indispensable impact on machine condition monitoring. In the process of condition monitoring, most monitoring technologies are based on smart transducers/sensors, the following data collection and transmission are through the Internet of things, as well as analysis of these data on PC terminals or mobile devices. Technicians conduct real-time monitoring of data and take measures immediately in case of crisis. For a large amount of data generated in the industrial process, the high cost of storing it on the hard drivers (most of the data will be stored in the physical server by default, which takes up a lot of available storage space, which will increase the extra cost). Cloud computing technology allows remote servers to store data on the cloud, and people can accessing and using data securely through personal accounts. When dealing with the data collected on the Internet of things platform, apply analytics and machine learning algorithms are usually used for understanding comprehensively. Furthermore, the more advanced condition monitoring and process control can be performed by mobile devices for determining when sensor data transmission. For example, employees can view, manage, and cancel the process through a PC terminal or smart-phone.

In short, condition monitoring avoids potential equipment damage by analyzing the weakest areas, enabling the technical team to address these issues in a timely manner. It takes a great impact both on productivity and the quality of the phase-out product. By the following aspects (Table 5) to describe the benefits of condition monitoring to industrial process :

PROS	DESCRIPTION
Reduce maintenance costs	The cost of system damage was expensive, may directly affect the productivity rate of the plant, or eventually suffered a loss. Detecting internal issues of the machine is a key part of preventing such damage. it eliminates the method of repairing problems when faults occur and shift the focus of work to predictive maintenance based on intelligent analysis. The team can deal with the damage as it demands, minimize the loss, and plan the repair work.
Prolong the useful life of the equipment	It must to noticed that machines are rarely damaged completely, and many parts work well. To replace all the components would be a waste where only a few of them need to be fixed. Condition monitoring allows to repair damaged machinery rather than replace it. Instead of buying an entirely new machine, they can identify the problematic areas inside the existing one and solve these problems one by one.
Planning intelligent maintenance	PM, Engineers, and Technicians can maximize productivity by synchronizing maintenance schedules. Instead of having to struggle to repair an emergency damaged machine, they can discover the damage in advance and distribute the work efficiently, without preventing the team from focusing on other priorities.
Maximize production output	Mechanical failures can reduce team productivity and prevent workers from completing tasks. They are not necessarily taking responsibility for these technical issues, but this delays production and requires companies to pay for non-production time. State monitoring based on the Internet of things helps to avoid these interruptions and increase production.
Preserving safety	Industrial accidents not only hurt worker who is related to the production, but also the residents in the nearby areas. Serious failures usually lead to critical environmental disasters. Through condition monitoring, these potential hazards can be detected before causing an Irreparable loss.

Table 5. The advantage of Condition monitoring for industry

4.2.1.5 The data collection and analysis in IoT

Although the data collection and analysis are not the major purposes and research direction of this work, the information communication system under the Internet of Things for these technologies used in the above variable monitoring is described briefly as below.

The traditional Internet of Things includes three communication network levels: the perception layer, network layer, and application layer. The IoT platform is the networked platform which is composed of physical objects embedded with electronic components, sensors, and software.

The IoT platform is shown in Figure 13. Different industrial equipment is equipped with various sensors to transform the required variables into specific parameters to realize the industrial data collection on the perception layer. At the same time, rely on the communication network of the network layer inside the industry to realize the data transmission between the perception layer and the application layer. The application layer realizes various specific applications of industrial data, intelligently analyzes the data, monitors the status of industrial equipment in real-time, and realizes advanced application functions such as automatic collection, intelligent analysis, and active maintenance of the comprehensive working conditions of the industrial site.

Perceptual layer: It simulates human perception features and is used to collect relevant data of the existing environment, such as sound, light, temperature, pressure, etc. The sensing tools used are sensor, identifier, Video Surveillance. Among them, the sensor is divided into physical, chemical, and biological, which can almost include all humans to see, hear, smell, and touch, even more-sophisticated detection of microbial enzymes; the identifier is mainly used for record, transfer, identification and verification of the identification of items, such as RFID, QR Code, bar codes, etc.; and audio and video monitoring is mainly through the interception of images and sound to detect the identity and movement of objects, For example, IP surveillance cameras, smart speakers, artificial intelligence and speech recognition, etc.

Network layer: The network layer uses the telecommunications network or Ethernet to set up transmission channels for the local data and remote data analysis centers so that data can be transmitted anytime, anywhere.

• Short-distance communication within 100 meters, including Bluetooth, WIFI, 4G, ZigBee, etc., are high-ownership, short-distance, high-cost transmission technologies.

• Long-distance communication, which is also divided into LoRawan (long-distance), is currently the industry's most supported LPWA, and narrow-band Internet of Things (Narrow Bad-IoT). Compared with LoRawan, the speed is lower and the coverage is promising in the future Industry standards.

Application Level: The application layer is mainly applications and controls, including browsers, various types of mobile terminal users (mobile phones, tablet etc.), information management centers (coding, authentication, authorization, quotation), information databases, and computing power sets. Independent spaces of various specialties and many types of projects are added according to the characteristics of the application, and their specialties and content are combined to be more precise, meticulous, and smarter at the level of information management. The application layer also includes user terminal devices of various devices or other operator interface devices.

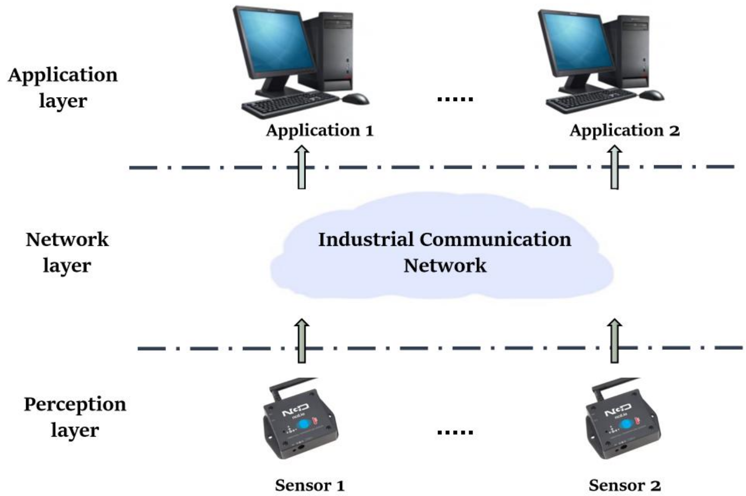

Figure 13. The communication layers of IoT

As appeared in Figure 13, the front-end incorporates different types of sensors with sensor perception and data collection capabilities; the back-end has massive data storage and big data analysis capabilities to achieve integration with application systems and support multiple applications in the industrial industry.

4.2.2 The solution with other technologies

4.2.2.1 Cloud Computing

Talking about Human Capability, its definition as mentioned in Straeter (2000), collects the total amount of resources that a worker has to perform a given task under environmental working conditions. This macro factor is given by the contribution of several human skills as said in the previous sections. In particular, the Human skills that have been considered in the case study have been defined (Comberti et al., 2018), after a detailed analysis of the working activity:

- Physical Resilience
- Handling Skills
- Memory

For example, according to the definition of these variables in section 3.2, during the evaluation of the Memory skill of workers, which has to show some simple sequence of geometric schemes to them and ask them to copy it on paper within a specified time. Then, the time to complete the task and accuracy will be recorded by the technicians. Also, we can see that the handling skills were defined by three related capability tests (Manual, Precision, and Coordination test). There is no doubt that when assessing the capability of workers, the number of errors and the time spent during the test must be retained and recorded, because each factor is associated with a specific variable that can be measured through the skill tests. Finally, integrate these related factors and variables to build a conceptual model of human capabilities (Comberti et al., 2019).

The relevant testing process of these three factors is coordinated and arranged by several experts and experts. More relevantly, In order to reduce the impact on the normal operation of the assembly line, the experts limit the average time of relevant tests (8-15min), and each test must provide a short break for workers to have a rest.

The whole tests are holding as a side process that does not interfere with the main manufacturing line, and which requires professional supervision and management, later relevant data is collected and recorded to provide accurate data on the assessment. As Sanders and McCormick, et al. mentioned in 1992, even if the system is currently fully automated, manpower is still required to program, install, repair, and maintain these systems in the process.

Therefore, cloud computing technology plays an indispensable role in massive data collection and storage, data sharing, remote control, and subsequent regular supervision and review of human capabilities, updating data, and comparing historical data. After the data is collected and uploaded, analysis and statistics are performed on the cloud platform, and various reports are automatically generated. Technicians can easily refer to the data and make precise decisions for the evaluation process.

According to the introduction of cloud computing from SIEMENS and the paper of "Industrial Automation Services as part of the Cloud" by Omid Givehchi et al. (2013), major acknowledge about cloud computing as follow:

Cloud Architecture

It refers to all the infrastructure, software, and systems that constitute cloud computing. And composed of various components and sub-components, and is typically divided into five layers shown in Table 6 :

Architecture Layer	Description
Hardware Layer	Includes data centers, servers, storage, and other physical components
Virtualization Layer	Comprised of virtual machines and networking resources that give customers accessibility to the of physical infrastructure's computing power
Platform Layer	Includes virtualized operating systems, middleware, and run-time systems
Application Layer	Contains network accessible software that's powered by the preceding layers of the cloud architecture
Client Layer	Consists of the network-connected desktop, mobile, or other devices customers use to access the cloud

Table 6. Cloud architecture layer

As we already mentioned in section 4.1, we know this cloud model has involved four deployment models and three service models.

Service Models

• Infrastructure as a Service (IaaS)

Through the network to provide the use of all facilities on demand, including processing, storage, network, and other fundamental computing resources, users can deploy and run any software, including operating systems and applications. In this model, the cloud service provider is only responsible for managing the hardware and virtualization layers.

With IaaS, peoples can select the operating system, deployed applications, and storage space as they want, as well as control restricted network components such as firewalls. And the management or control of the cloud computing infrastructure by the cloud service provider.

• Platform as a Service (PaaS)

In the PaaS model, the cloud service provider manages the components of the platform layer, as well as the hardware and virtualization layers. It provides a platform that allows customers to develop, run, and manage applications without needing to administer the complex construction and maintenance of infrastructure. Customers can't directly control these elements, but the CSP will customize these elements as part of the service agreement according to the customer's specifications. (usually related to developing and launching applications). The customer can't directly control these elements, but the CSP will customize these elements as part of the service agreement according to the customer's specifications.

• Software as a Service (SaaS)

SaaS is a software delivery model. In this delivery model, CSP hosts and manages software applications in the cloud, and the customer pay to access the software through a network (client layer) and without traditional installation steps (the software and related data set are hosted in the cloud). Therefore, customers do not need to maintain the software, and CPS will have complete responsibility to administer and maintain the software.

Deployment Models

• Public deployment model

Under this deployment model, the cloud environment is accessible over a network that is open to the public. Cloud service providers can provide users with storage, applications, resources, and other services. Most of them are free, and some are charged on-demand. This deployment model can only be accessed and used using the Internet.

• Private deployment model

This deployment model of infrastructure is exclusive to a single enterprise customer; it can be administered by a third-party cloud service provider, or owned and operated completely by the enterprise itself. In either arrangement, the enterprise is the sole user of the cloud computing resources, which must be accessed through an authorized client device or associated credentials. However, what this deployment model faces is that the enterprise bears the cost and responsibility of managing the private cloud. As the name of the deployment model also suggests, it provides customers the full advantage and flexibility in the allocation of data, information security, and computing resources.

• Hybrid deployment model

Enterprises prefer to store the most sensitive data and projects in private clouds, but at the same time want to have access to the computing resources of the public cloud. So the concept of a hybrid cloud deployment model is introduced, which combines the public and private clouds and operates as one infrastructure by allowing the sharing of data and applications among them. It can take advantage of the security of a private cloud to store critical internal data in a local data center, but can also use the computing resources of the public cloud to get work done more efficiently and quickly than either the private or public cloud.

• Community cloud deployment model

This deployment model is built between multiple companies with similar goals in a specific region. They share a set of computing cloud resources and infrastructure. These companies are "communities" from the same industry sector that use cloud computing to collaborate on business objectives, share data, and share the costs of cloud management. Because the number of users shared is smaller than in the public cloud, the cost savings realized are not as significant, but privacy, security, and policy compliance are all higher than in the public cloud. Members of the community cloud are allowed to log in and access information and applications in the cloud.

With the development of cloud computing and cloud platforms, it provides an alternative to building internal infrastructure for enterprises. Since this saves the companies from investment and the need to maintain expensive infrastructure, it has become a popular solution. Many companies offer cloud computing platforms for developing, managing, and deploying applications. Here we introduce several top Cloud Service Providers in short in Table 7:

CSP	Features
pCloud	• It will let you do the file management from the web, desktop, or mobiles • Multiple file-sharing options are available • It can save versions of the file for a specific period • It provides the facility to backup your photos from social media like Facebook, and Instagram • It provides data security through Transport Layer Security (TLS) encryption
Amazon Web Service	• It is the safest and protected platform of cloud service which offers a wide set of infrastructure services like database storage, computing power, networking • Using this AWS one can host static websites • By using such services, users are able to build complicated applications that are trustworthy, scalable, and flexible • One can have the hands-on experience of AWS for free
Microsoft Azure	• It is used for deploying, designing, and managing the applications through a worldwide network • Previously Microsoft Azure was known as Windows Azure • This Cloud computing service supports various operating systems, databases, tools, programming languages, and frameworks • A free trial version of Microsoft Azure is available for 30 days
Google Cloud	• It uses resources such as computers, virtual machines, hard disks, etc. located at Google data centers • It is integrated storage used by developers and enterprises for live data • Apart from the free trial, this service is available at various flexible payment plans based on Pay-As-You-Go (PAYG)
Red Hat	• It is an Open Cloud technology used by IT organizations to deliver agile and flexible solutions • Using Red Hat Cloud we can modernize the apps, update and manage them from a single place, and integrate all the desired parts into a single solution • It Cloud Infrastructure helps us to build and manage an open cum private cloud at a low cost • Red Hat Open Shift is an open and hybrid service used by developers to develop, deploy, host, and delivers the applications quickly

Table 7. Cloud Service Providers

4.2.2.2 Human Modelling and Simulation

Jack is a well-known human body modeling and simulation tool from Siemens. It can provide solutions for ergonomic evaluation as software and help organizations and workplaces in different industries improve the ergonomic factors. Users can design, analyze, and optimize the specific manual operation. Not only provides a variety of 3D virtual artificial models, which can realize the accurate simulation of manual work and analysis of ergonomics and assembly time. But also allows users to check the feasibility of relevant tasks, interactively improve the staff workshop, and evaluate the different design procedures.

It originated in the Human Modeling and Simulation Center of the University of Pennsylvania in the mid-1980s. The initial motivation for Jack's development was to support the design and development of the workspace, with the focus on optimizing the human-machine interface for specific groups of people. Jack's development funds come from multiple sources including NASA and the Army of U.S. As Jack's technology matures, it is becoming more and more commercialized and is currently being developed and sold by Siemens. Its application has also been extended to universities of related disciplines.

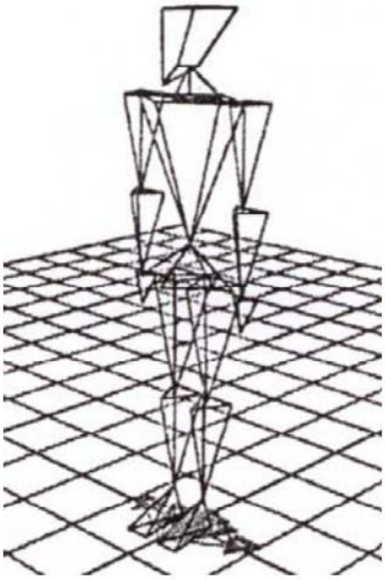

Figure 14. A sample Jack Model

Over time, Jack has gradually evolved from a simple and impractical tetrahedral arrangement (as Figure 14) to a highly realistic human model based on the anatomical, measurement, and bio-mechanical data of today's human body (Figure 15), which can also better analyze human factors. The human model created today can up to 26 individual dimensions (Blanchonette P. et al., 2010), including height, sitting height, and hip and knee lengths. Jack's human body model has a complex kinematic chain model, which is very similar to the human skeleton structure, the joints meet the physiological limits of motion, and the geometric shell is very similar to the shape of a human. Based on the inverse kinematics algorithm, the human body model has complex spine and shoulder models, which can ensure the human body to move realistically. You can use a wide range of pose libraries to pose.

Figure 15. Jack (male) and Jill (female)

Besides, a series of behavioral controls can be specified to allow the human activity to be restricted based on chosen behaviors. Such as, the driver's hand needs to keep in contact with the vehicle over the range of movement. Users create virtual work-spaces by using CAD modeling capabilities and object libraries (from basic cube to factory equipment and furniture) provided by Jack or use third-party converters to import work-spaces in multiple formats. And there are a variety of analysis tools that can use to evaluate ergonomic factors in the workplace. For instance, by setting the path of workers' actions, and using a collision detection algorithm to determine whether the task can be completed unimpeded.

As the discipline of ergonomics becomes more and more well-known, further which act as education programs introduced into Universities. The following are the several introductions of simulate guides or processes by using Jack 8.4 that was introduced by Divyaksh Chander from the Polytechnic University of Turin, Italy in the course of ergonomics for the manufacturing system.

Create a Mannequin Posture and force analysis

When a new human model was created in Jack, the manikin appears by default in a standing posture, as shown in Figure 16. At the same time, in order to provide an efficient and convenient simulation process, there is a posture library that contains a variety of postures such as running, standing_ straight, standing_overhead, seated_ typing, etc. You can also add your own created one to the library. Also, there is a series of hand shape libraries, which include hand shapes such as finger_press, finger_spread, and precision grips, etc.

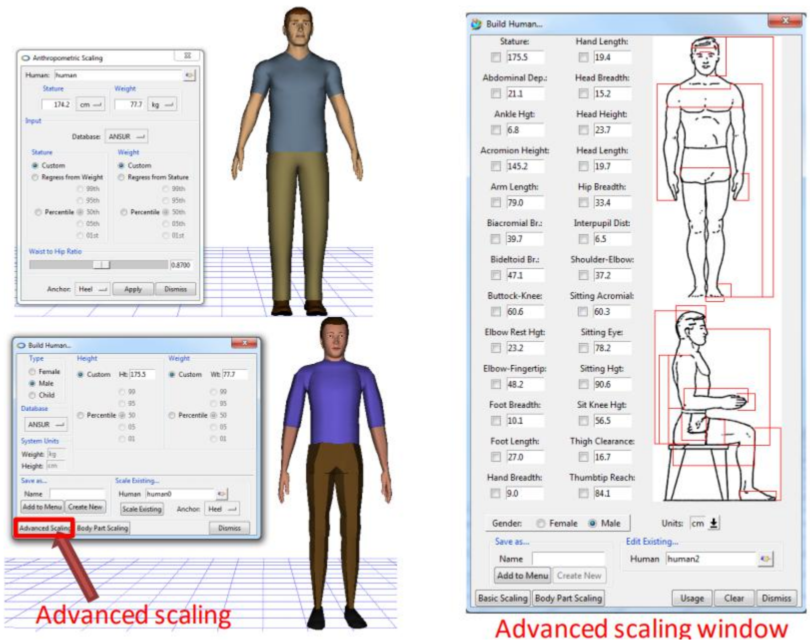

Figure 16. An example how to create a manikin male

An example of a "Default Female" who was standing by the desk is shown in Figure 17, here will assign a load (150 N) to the humans hand, to represent her pulling the box towards herself (the left-hand brace on the desk and right-hand grasp the edge of the box which on the desk).

The subsequent Force Solver offers a unique analysis approach shown in Figure 18, While determining the maximum acceptable hand force, both the posture and strength demands for the human updated interactively.

The specific operation is described briefly as follows:

- Define Environment
- Add Bracing
- Add Foot Placement Zone
- Add Load
- Add Grasp
- Additional Options

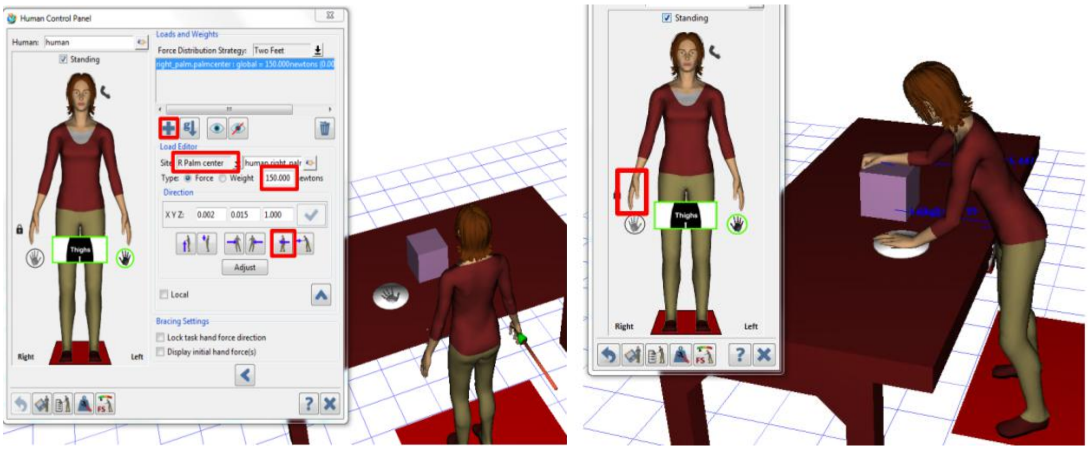

Figure 17. An example of default female

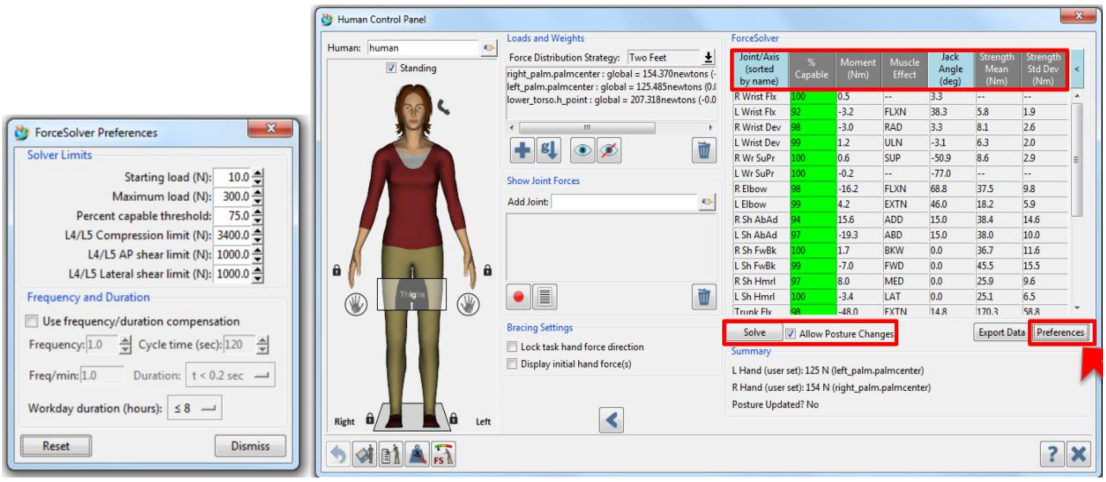

Figure 18. Force Solver analysis

Task simulation and Result analysis

Usually, the task simulation builder in Jack is used to create the simulation of the whole process, and high-level instructions are used to control and process people and objects. Users can navigate the TSB interface to select the activities to be executed, such as go, get, put, et. With a few user inputs, TSB will assign a series of actions or motions required to complete each task. A series of task motion is shown in Figure 19 with a timeline at the bottom.

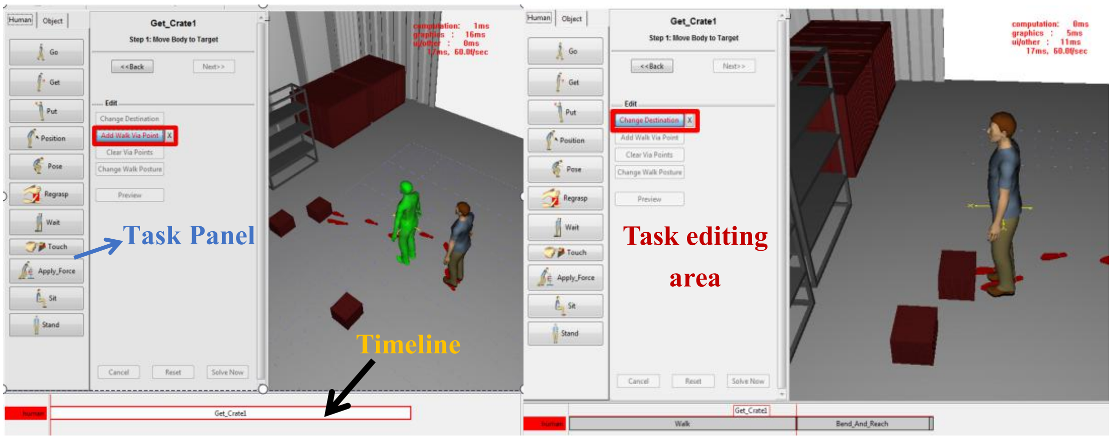

Figure 19. Task Simulation

TSB allows rapid, automated authoring of simulations while still providing user control over the level of detail of the final results.

• When all simulation processes run successfully, a time report can be generated immediately. In this report, each task decomposed into multiple actions, and the duration of them is estimated. Users can also select different prompt ergonomic analysis tools to view your simulation, which will be covered later.

• The results will be very flexible for use in " what-if " scenarios involving varying human models, changing environments, and even different number of people involved in a task.

The most vital tool applied here for analysis is the Task analysis toolkit. As a powerful ergonomic analysis toolkit, it contains a variety of analysis tools, such as fatigue analysis, force solver, manual handling limits, et. By using different analysis tools can help to design better workplaces and assess the physical workload of workers. It also further enhances the ability to evaluate industrial tasks.

TAT provides tools that can help.

- Analyse the risk of a low back injury.
- Evaluate lifting work.
- Determine whether the worker has the ability of the prescribed task.
- Determine the metabolic energy required during work.
- Compare alternative job designs based on the relative risk of fatiguing the worker.
- Assess whether the working posture is likely to expose workers to injury.
- Identify manual tasks that increase the risk of upper limb disease in workers.
- Manual handling tasks are evaluated based on the percentage of workers who are able to perform the task.
- According to the analysis, it can predict whether the worker can complete the work within the predefined cycle-time.

So It's much helpful to assess the variables of Physical effort and Coping with pace for humans by analyzing the ergonomic parameters of the task simulation for each worker in a fixed work position and this measurement with reference to the different safety standards analysis as following provided.

The following way must be noticed that mentioned in Figure 20:

- Lower Back Analysis, Static Strength Prediction, and OWAS tools work; With these indicators, it is can be used to evaluate the performance of manikins in real-time.
- All other tools implemented in Jack are simply based on the checklist, which prevents the analysis from running in real-time during the simulation.

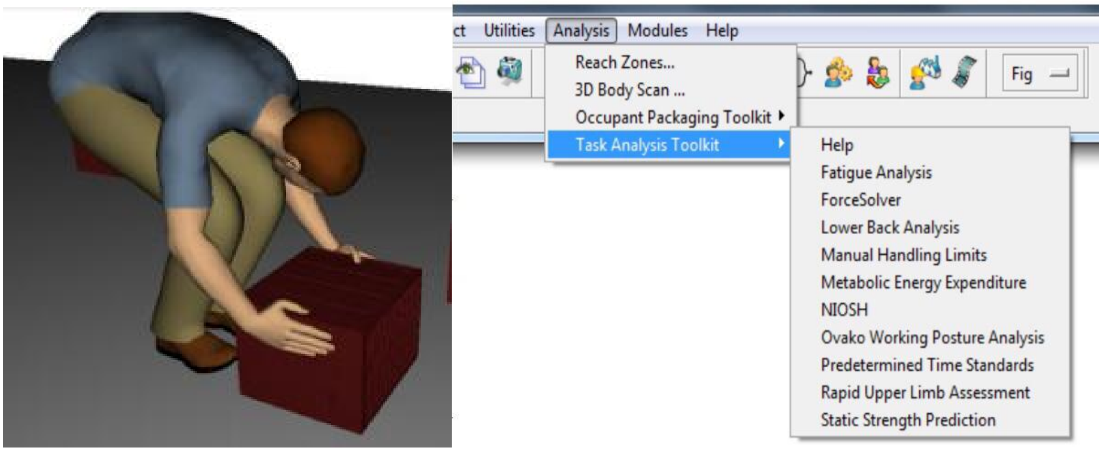

Figure 20. Task Analysis

Several common analysis as below:

• NIOSH Lifting Analysis Tool: its main purpose is to help workers evaluate the lifting task, including whether it is symmetrical, and the lifting task in the case of poor coupling between the part and the human's hands.

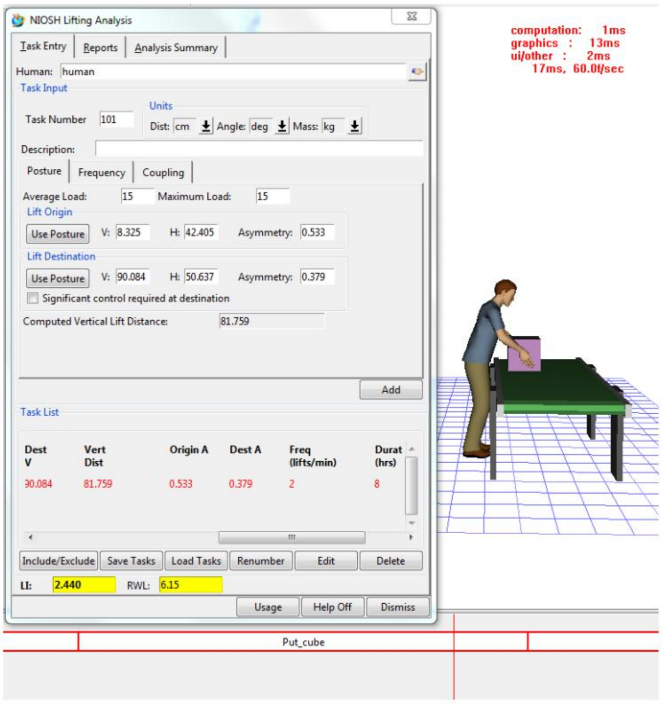

Figure 21. NIOSH Analysis

•OWAS tool: it offers a fast and simple method in order to check the worker's postural comfort during working and determine the emergency of taking recovery actions.

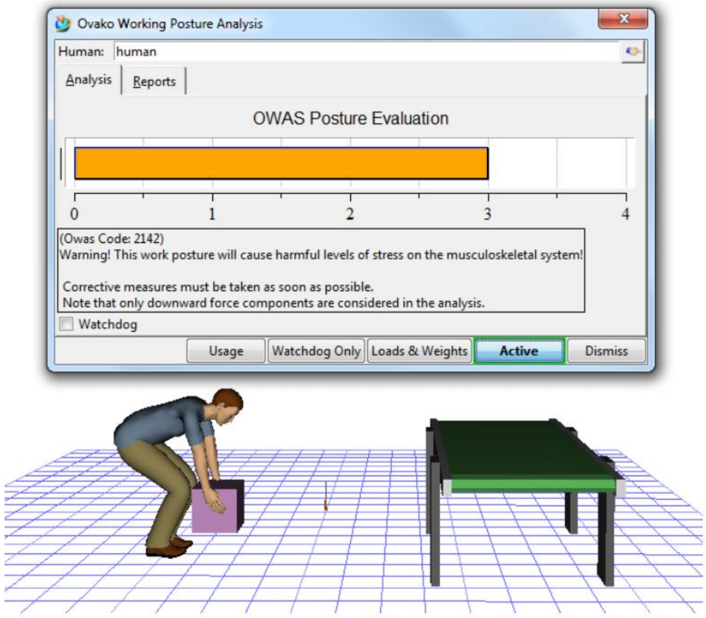

Figure 22. OWAS Analysis

• The Lower Back Analysis tool: through the use of complex bio-mechanical models to calculate the shear and compression forces at the vertebral joints of the lower back of the human body, and finally compared with the recommended limit value in NIOSH analysis.

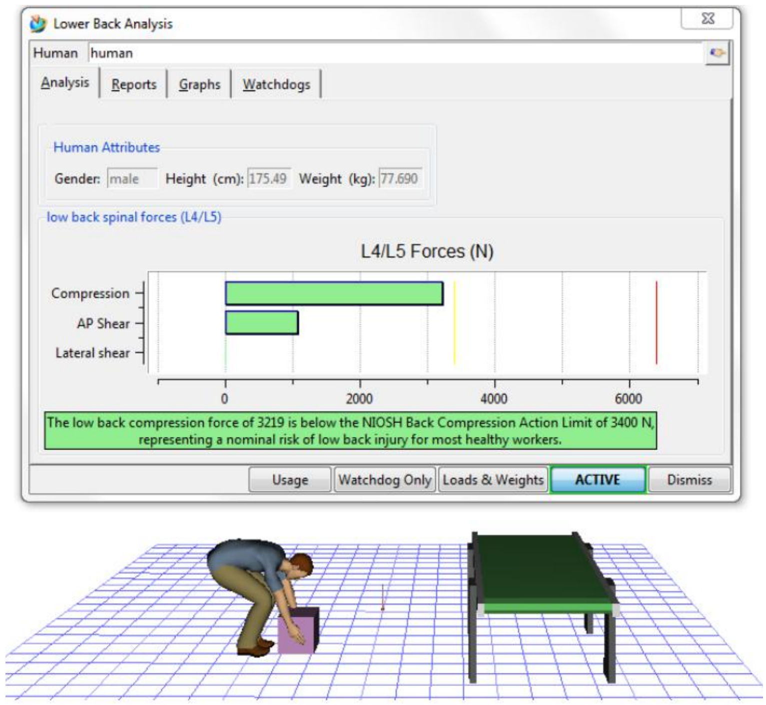

Figure 23. Lower Back Analysis

• Static Strength Prediction tool: according to the anthropometry, postures and exertion requirements to assess the percentage of workers that is capable of performing tasks.

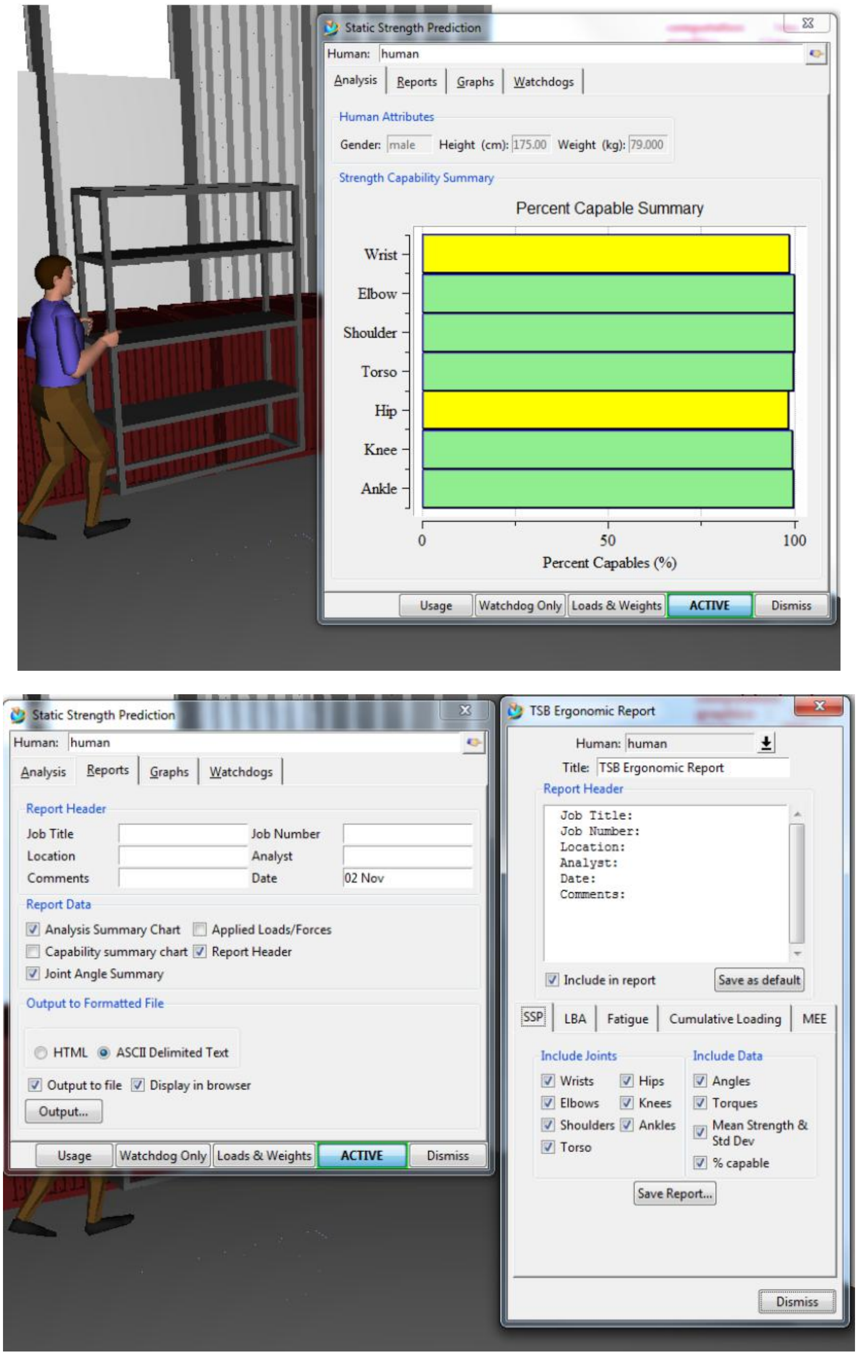

Figure 24. Static Strength Prediction

4.2.2.3 Machine Vision

The concept of tool condition monitoring has gained considerable importance in the manufacturing industry (Kurada S. et al., 1997). This is mainly due to the shift in the manufacturing environment from manually operated machines to CNC machines and highly automated CNC machining centers. It is a key issue in micro-machining for part quality control because the excessive tool wear and abnormal tool conditions will significantly decrease the size accuracy of part and shorten the tool durability as well, then further affect the machinery life cycle and also the product quality. Over the years, a configuration of a machine vision system for online tool condition monitoring is presented to improve the part quality and extend the micro tool life, the visual system is dedicated to automating machine vision inspection to monitor progressive wear and tear.

When processing with traditional machine tools, the machine tool operator mainly observes the change of tool surface morphology through a vision in order to make a judgment on the tool status. For modern machine tools, about 20% of the downtime is attributed to tool failure and the tool cost is accounted for 3 to 12% of the total processing cost (Zhang Chen et al., 2013), which leads to the decline of production efficiency and economic losses, so it is important to improve the monitoring level of tool wear and tear. Using machine vision instead of manual tool wear monitoring can realize the automation of tool status monitoring.

Machine vision is a method of automatically inspecting and analyzing objects, usually in industrial or production environments, using cameras or multiple cameras. The data obtained can then be used to control processes or manufacturing activities. A typical application may be on the assembly line. When an operation is performed on a part, the camera is triggered to capture and process the image. Cameras can be programmed to check the position of an object, its color, size or shape, or whether the object exists. It can also view and decrypt standard or two-dimensional matrix bar-codes and even read printed characters(Frank Lamb 2018). Another explanation from the Baidu Encyclopedia of China: Machine vision system refers to the machine vision equipment (i.e. image capture device, divided into CMOS and CCD) to convert the captured target into an image signal, which is transmitted to the dedicated image processing system. The system converts captured targets into digital signals based on pixel distribution, brightness, color, and other information; After the imaging system performs various operations on these signals and extracts their characteristics, and controls the operation of equipment on-site based on the judgment results.

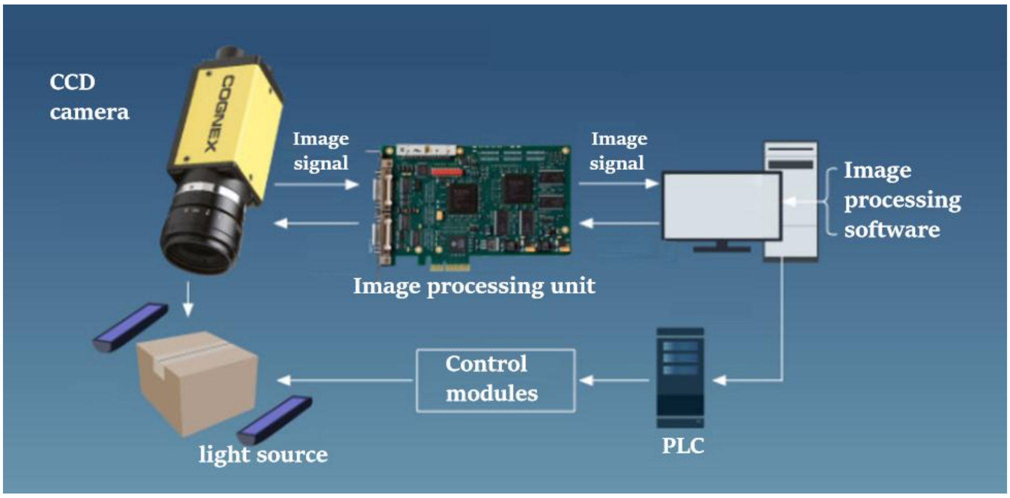

Figure 25. The inspection process of Machine Vision

A typical industrial machine vision application system (Figure 25) involves the following parts: lens, light source, CCD camera, image processing unit (or image capture card), image processing software, monitor, communication/Input & Output unit, etc. Firstly, the camera is used to obtain the image signal of the measured object, and then it is converted into a digital signal through A/D conversion and transmitted to the dedicated image processing system. According to information such as pixel distribution, brightness, and color, various operations are performed to extract the characteristics of the target, after the judgment result is output according to the preset judgment criterion, and control the driving actuator to perform corresponding processing.

There are three main types of application of machine vision methods in tool status monitoring introduced by Wang Zhongren et al. (2007): one is direct monitoring method based on tool surface image of observation point on the tool surface, the other is indirect monitoring method based on work piece surface image of two-star observation point on the surface of the processed work piece, and the third is quasi-direct monitoring method based on cutting network image of observation point on cutting edge.

- **Machine vision method based on tool surface image**

The surface of the tool is a direct reflection of the worn-out state of the tool, so the direct monitoring method based on the image of the tool surface has the advantages that other monitoring methods can't compare. The direct monitoring system based on the image of the tool surface generally consists of a lens, CCD, camera, light source, image capture card, computer, and so on. Since the chip is blocked on the surface of the tool during the cutting of the work-piece, the visual monitoring method based on the image of the tool surface generally cannot be performed during the cutting process, so it is only an intermittent quasi-on-line monitoring method. However, because this method directly detects the geometry of the worn-out part of the tool, it has the advantages of intuitiveness, accuracy, and reliability.

- **Machine vision method based on work-piece surface texture image**

The surface texture of the work-piece refers to the definition of parameters such as the surface morphology or geometric characteristics of the processed work-piece. It includes some features that appear in the surface contour, such as roughness, wave-forms, and defects. The surface texture of the work-piece is a negative image of the state of the cutting edge of the tool. When the blade is sharp, the texture of the work-piece is clear and the continuous part is good; when the blade is blunt, the texture of the T-piece is chaotic, discontinuous, and has broken marks. Different processing methods and shells have different texture characteristics. Since the surface of the work-piece is a negative image of the surface shape of the tool, it is directly affected by the shape of the cutting edge of the tool. Therefore, observing the texture of the surface of the work-piece to be processed can also determine the cutting edge state of the tool. The visual monitoring method based on the image of the work-piece surface is an indirect monitoring method that analyzes the surface texture of the processed work-piece through computer vision, thereby judging the state of the tool.

- **Machine vision method based on-chip image**

Since chip shape is an intuitive representation of chip deformation, if the basic conditions that affect chip deformation such as work-piece material, cutting amount, and tool geometric parameters remain unchanged during cutting, tool wear and tear is the main reason for the change in chip shape law. Therefore, the chip shape has been used as the main source of information for operators to judge the damage of the knife shell. The tool wear and tear status information contained in the changing law of chip shape can be used for online automatic monitoring of tool status. Figure 26 shows images of the most common types of wear in the general cutting process (Sun Wei heng et al., 2018).

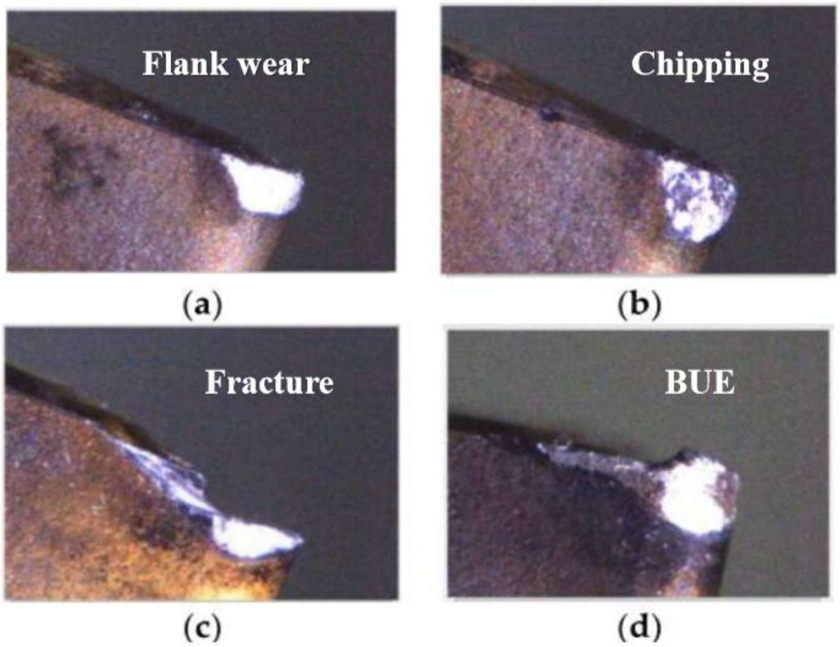

Figure 26. Four insert Status detected

5. Discussion

As discussed up to now, all the possible variables during the manufacturing process, and the relevant effective monitoring technology that supposed to use under the internet of things or not. There is no doubt that environment variables can easily apply the most common smart sensor technology and transmit the data collected by them through the IoT; Besides, the condition status for both human and machine must be guaranteed, Several popular wearable technologies provide sustained monitoring of human biophysical parameter, while the advanced condition monitoring (CM) and machine vision technology enable us better observe all the possible hazards due to the working of machines or damaged tools.

For these variables from the risk matrix and personalized risk assessment aims to focus on the impact of human performance, these factors are mainly divided into workload and human capacity, which can be obtained from the assessment process, such as variables related to mental workload: "TV(Task Variability)" and "TC(Task Complexity)", for these two parameters we do not account them into the variables that can be been continuously observed in this work. This is because we must realize that the work-flow or production line is defined and designed in advance, the severity and complexity of these two parameters must be judged in the previous design and installation phases. Meanwhile, the parameters of "Choice" and "Handling" (which is based on the evaluation of physical workload) can be applied through the same RFID technology and monitored through dedicated tags.

Another vital parameter for the physical aspects is "Physical effort and Coping with pace" the human modeling and simulation technology uses here to build the human manikin, to simulate the normal task scenario during the working condition, evaluate the impact of different postures or repetitive operations for human's body, then judge whether it meets the requirements of various ergonomic standards. The last significant aspect related to the human capacity, several special side tests required to be set by the experts to evaluate the HC and the results recorded one by one, since these tests are related to manual, memory, and accuracy, the relevant supervisors and recorders must be present. As is well-known that human performance varies with age, so the test has to be reviewed periodically, and all result related to worker's ability must be uploaded, analyzed, stored, and shared in the cloud, then latest data could compare with historical data to provide the managers with accurate, immediate, effective personal information for allocating of the workplace correctly.

6. Conclusion and further consideration

In summary, the central purpose of this thesis is to propose the risk factors defined under the existing risk analysis, through the emerging technologies derived from the industrial and social progress, to facilitate the risk assessment process in a faster and more effective way, to mitigate or avoid the possible risk events in the production process as far as possible. In the process of identifying the risk variables which analyzed around the human-machine -environment, define the potential safety hazards caused by environment variables, machine variables, and human factors, and point out the possible variables (in Table 3). Based on this analysis, introducing the technology under industry 4.0. Suppose whether the industrial Internet of things technology can directly monitor these variables firstly. We found through the relevant smart sensors technology and based on the data collection of the Internet of things platform, we use the relevant noise, temperature, and humidity, optical, gas, proximity, and particle matter sensors to monitor the variables that may affect the manufacturing process. For machine healthy monitoring, we have to mention condition monitoring technology based on a variety of specific monitoring technologies, we collect and analyze the condition parameters of machinery (such as temperature, vibration, etc.), and this process was implemented by integrating with several of industry 4.0 technologies, such as sensors, Internet of things, cloud computing or edge computing, etc. and the tool condition monitor by machine vision in order to guarantee the production with high-quality. Human factors in industrial production are often the most neglected aspect, and its primary purpose is to ensure the normal biophysical parameters of personnel. Therefore, wearable technology is widely used to monitor the heart rate, body surface temperature, and blood pressure of workers in real-time. Otherwise, several wearable technologies could be used to evaluate the ergonomic specification of humans to ensure normal working conditions without fatigue. Secondly, a series of variables in the process of risk assessment was defined according to the risk matrix combined with the human performance model, which is mainly based on the assessment of mental and physical workload and human capability process, as we said in this work, RFID technology, Human Model Simulation, and Cloud Computing technology plays a significant role for observing these variables.

As we proposed, these technologies enable us to monitor the variables in a specific way and to control them in advance to reduce the hidden threats to human safety also the product quality occurs in the manufacturing process. Unfortunately, they are still in the developing stage, and it will take some time before they are fully mature and widely used. Secondly, considering the economic aspect, when we integrate all the advanced technologies under Industry 4.0 into an integrated intelligent factory, It takes enough funding capital and time to replace traditional industries. Fortunately, the concept of Industry 4.0 has been paid attention to various countries around the world. More and more people are looking forward to the coming of the intelligent era in the future. With the effort of experts from all over the world, the advanced world is approaching step by step.

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