International Journal of Engineering Trends and Technology Volume 71 Issue 8, 66-75, August 2023
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V71I8P206

Original Article

Study of the Impact of Industry 4.0 Tools in E-maintenance on the Performance of Industrial Companies

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Received: 26 May 2023 Revised: 29 June 2023 Accepted: 24 July 2023 Published: 15 August 2023

Abstract - *The emergence of Industry 4.0 has had a major impact on the industrial sector, introducing a range of new tools and technologies that transform how businesses operate. E-maintenance is one area that has undergone a major transformation with Industry 4.0 tools. Investigating the impact of Industry 4.0 tools in e-maintenance on industrial enterprise performance is critical to understanding how these technologies can be leveraged to improve operational efficiency and overall business performance. Organizations can streamline maintenance processes, improve equipment reliability, and reduce downtime by leveraging technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. This increases productivity, profitability and customer satisfaction. Consequently, the objective of this paper is to carry out a field study to gauge the impact of Industry 4.0 tools in e-maintenance over companies' industrial processes. The study has been launched in three countries with some common points but many different features.*

Keywords *- E-maintenance, Maintenance, Artificial intelligence, Industry 4.0, Industrial performance.*

1. Introduction

Digitization is a set of technologies that permeates almost all areas of business. In every company, digitizing parts of the business and managing the rest in traditional ways is complex. Business processes are interdependent and must move at the same speed. The maintenance department includes many processes that affect one of the most critical key metrics, which is cost. Maintenance activities can account for up to 70% of total production costs [1][2][3] and from 15% to 40% of manufacturing costs; they are actually considered as second largest cost after energy expenses [1][4][5][6][7].

In Europe, for example, it is estimated that about 150 billion Euros are spent on industrial maintenance per year [1][7], while in the United States, maintenance costs tripled within ten years, reaching US$ 600 billion in 1989 [1][7]. Another benchmark conducted by Wireman found that since 1979, maintenance costs for US industrial companies have increased by 10-15% per year. In financial analysis, average maintenance costs may reach 28% of the global product's cost. Maintenance is considered the most expensive operating expense (OPEX) to ensure equipment reliability. In other industries, unnecessary unplanned maintenance activities due to inappropriate maintenance planning account for a third of maintenance activities [1][8].

Every single product has a lifecycle step on which maintenance considerations are omnipresent. B. Iung et al. discuss maintenance objectives on each product's life cycle phase. For instance, during the design phase, engineers must ensure that characteristics such as maintainability, reliability, and durability are proven, also during the manufacturing phase, process engineers must consider product maintainability to optimize the likelihood of a failed component recovering or repairing to a specified condition within a given time frame.

Fig. 1 Product life cycle

Reliability, the quality of being trustworthy and consistently performing well, must be confirmed. The usage phase, considered the most important one since it represents the product/customer interaction phase, relies on reliability and availability as indicators to assess maintenance function.

Availability refers to the length of time a given device can perform its intended task. The final stage of every product cycle is disassembling and recycling. Durability and circularity must be respected.

Another aspect that enhances the maintenance position inside the business is regulations. Nowadays, almost all international standards have started giving more attention to the maintenance function. For instance, the French X60-000 series of standards define the standards and requirements for equipment maintainability. The European Standard NF EN 13306 gathers all technical and administrative actions required to maintain and keep a piece of equipment in good and appropriate condition to fulfill its main functions along its life cycle.

To give more examples, the NF EN 15341 standard integrates metrics into dynamic maintenance processes, and these metrics allow rigorous monitoring through dashboards. Finally, the appropriate corrective actions take place. The goal is clear: to enable users to evaluate and improve the performance of their machine park properly.

The NF EN 60300 series of standards describes the operational safety management framework. As such, it deals with the operational security of a product, process, system or service that integrates human, software or hardware aspects. The standard is important for planning and implementing reliability activities while integrating requirements related to safety or the environment.

The NF EN 16646 standard integrates maintenance activities into assets' management. It particularly affirms the importance of these operations in the assets' management process [21].

Another solid example of the interest given to maintenance function by standards is ISO 9001. The recent versions of this famous quality management system standard handle many maintenance issues, showing that maintenance becomes a focus point. The early versions handle maintenance, too, but with low intensity [20, 21].

The 21 CFR Part 11, this standard, has been first launched by US Food and Drug Administration to validate electronic documents and the authenticity and reliability of electronic signatures. This standard covers all aspects of the company's production activities. Therefore, all maintenance-related documentation, such as maintenance history, must comply with the requirements of 21 CFR 11.

ISO 55001 specifies requirements for asset management systems. Asset management coordinates financial, operational, maintenance, risk, and other activities related to an organization's assets to achieve optimal performance from them. It mainly deals with the management of physical assets. ISO 55001 management systems provide a framework for organizations to establish asset management policies, objectives and processes and enable organizations to achieve their strategic objectives. ISO 55001 uses a structured, effective and efficient process to achieve continual improvement and value creation by managing the costs, benefits and risks associated with its assets.

The aforementioned information highlights a key point: the significant importance of maintenance and its prominent role within businesses. However, maintenance has yet to be recognized and valued appropriately by many companies. They often view it as a necessary evil and remain unconvinced by the advancements in maintenance technologies. Just like in other fields, modern technological tools can be fully utilized in maintenance, transforming it into a more efficient system that tangibly contributes to a company's value proposition.

In various research articles, different authors have shown varying interest levels in specific regions or domains. Garambaki et al. proposed an intelligent functional test methodology based on data integration for e-maintenance, utilizing a cloud platform for the Swedish railway company [22].

Yousef et al.'s work emphasize the significance of establishing dedicated dry labs in the mineral industry to efficiently use and create data, especially considering its historically disaggregated nature [23].

Afef et al.'s article delves into the key factors contributing to the success of maintenance digital transformation initiatives and provides practical guidance to practitioners for its proper implementation [24].

On a separate note, Turner et al. explore integrating digital maintenance practices within the Circular Economy framework in the automotive sector. They discuss the role of maintenance in sustainable manufacturing and the potential benefits of leveraging Industry 4.0 technologies for digital maintenance. The paper also delves into concepts such as circular component design, remanufacturing, and the utilization of IoT, RFID, and blockchain technology for traceability and accountability in circular production. Furthermore, the authors propose frameworks and ontologies to support the automotive industry's circular maintenance, remanufacturing, and recycling systems [25].

Sri et al. highlight the importance of maintenance engineering in complex industries and the challenges associated with decision-making in maintenance activities. They explore the digitalization of maintenance through the application of natural language processing (NLP) and the design of a common degradation taxonomy. The paper presents a framework for automating knowledge extraction and relationship mapping in maintenance, with a specific focus on a use case involving the degradation of a safety-critical component in an aircraft engine. Additionally, the authors discuss developing a management system that employs a semantic approach to recognize, classify, and present data in real-time [26].

This article delves into a comprehensive investigation aimed at elucidating the impact of Industry 4.0 tools on companies' industrial and financial performance within the realm of maintenance processes.

By employing an empirical model, this study incorporates the valuable insights of numerous professionals, thereby yielding tangible outcomes that accurately reflect the realities of the field. The selection of participants for this study was carefully carried out, considering specific criteria which will be expounded upon in the subsequent sections.

2. Empirical Study: Methodology and Approach

2.1. Methodology

The primary aim of this empirical study is to gather field data from professionals through a detailed and comprehensive questionnaire conducted in two phases.

The first phase provides an overall picture of the collected data and a clear snapshot of the current situation in all interviewed companies.

The second phase is carried out 10 months later and provides insights into some key performance indicators related to maintenance performance, company financial performance, and qualitative aspects. These indicators will be discussed in detail in the section dedicated to the second phase.

Below is an overview of the questionnaire and information about the target population and methods used to reach them.

2.2. Questionnaire

As previously stated, the field data collection was conducted through a questionnaire consisting of 50 questions grouped into 5 blocks.

The first block consists of 10 questions aimed at shaping the profile of the respondents, which is crucial for obtaining rich and diverse data.

The second block contains 9 questions intended to identify the general organization of the company and the structure of its maintenance department.

The third block has 8 questions focusing on whether continuous improvement tools are used in the company and if maintenance staff are aware of them, as continuous improvement is a necessary factor in achieving excellence.

The fourth block comprises 11 questions designed to assess the interviewee's awareness of Industry 4.0 tools, which are essential as their integration with traditional maintenance leads to e-maintenance, according to Yassine et al. [1].

Finally, the fifth block includes 12 questions that measure Key Performance Indicators (KPIs) related to maintenance and operations, such as failure rate, maintenance cost, productivity, and quality rate, as well as other financial KPIs like gross margin percentage and return on sales (RoS). Some qualitative KPIs, such as employee, customer, and shareholder satisfaction, will also be processed. It is important to note that some companies have been asked to fill out the questionnaire for their customers and shareholders.

The homogeneity of these questions and the targeted population category ensure that the obtained data will be accurate and can be used to outline the survey results.

2.3. Targeted People

The survey aimed to gather responses from companies in three countries: Morocco, France, and Tunisia. These countries were selected to provide a homogeneous and trustworthy sample. France, being one of the most powerful industrial nations with a global GDP of approximately 2.791 billion USD in 2021 and a 7% registered growth as reported by INSEE, was included. Morocco and Tunisia, on the other hand, were selected as examples of emerging markets with young, skilled labor, developed infrastructures, and strategic geographic positions.

To ensure accurate and relevant responses for the study, individuals who work in maintenance, have worked in maintenance, or are closely associated with the maintenance department were consciously targeted. The selection has been based on the first questionnaire bloc.

2.4. Contact Channels

We have planned three approaches to answer the questionnaire, which include reaching out to people through phone or video conference by setting up appointments or conducting in-person meetings. The interviews have been limited to a one-hour time frame. In addition, some of the interlocutors have received the questionnaire via email or through their professional social media inboxes without any direct interaction.

3. Results and Discussion
3.1. Analyze the Impact of E-Maintenance Tools
E-maintenance encompasses different components and technologies; below are some of the most prominent elements.

Enterprise Resource Planning (ERP) is software that covers most of the needs related to managing a business. ERP computerizes all kinds of data for all company services: purchasing, accounting and administration, trade, sales, expenses, working hours, project management and the remaining functions of the company, according to Yassine et al. It has a moderate effect on industrial processes. [1]

MES (Manufacturing Execution System) is a software that mainly aims to pick up real-time production data in a factory or shop floor. The collected data can then be used to monitor the production system, to make sure everything is recorded, for quality control matters, and it is also used to set the preventive maintenance. Even more, the provided information helps to optimize production activities during the whole production process. The impact of MES on industrial processes is considered normal [1].

Cloud computing is defined as data or services on demand through the internet. It is actually billed based on usage. You can access your data everywhere and anytime rather than buying a physical hard disk, servers or data centers. Depending on the use, the IT (Information Technology) service provider proposes an appropriate solution. The most known solutions are SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service). In industry, most companies prefer to go on a SaaS solution which will allow them to outsource their IT solution entirely, which is definitely the contrast to local solutions. The following schematic explains a cloud computing system applied to industrial cases. E-maintenance engineers give more importance to Cloud Computing solutions as the use of software is a must. According to their previous research, Yassine et al. [1] have stated that Cloud Computing technology has a medium impact on industrial processes. [16]

Machine-to-Machine allows operators to get rid of redundant tasks; it also enables obtaining higher accuracy [9][10]. In fact, this communication between machines could be done between several terminals and could be used for smart cities development, Industry 4.0, or to reduce energy consumption. The technology is considered with a strong impact as it becomes common in most industrial processes.

The Internet of Things (IoT) is made of a set of systems or end-devices able to generate, transmit and receive data in order to create users' value [11] [29]. IoT has five main pillars; the first is the object, which is a sensor or actuator. The second one is the connectivity that represents the communication channel. The third one is data, which plays the role of row material and finally² last pillar is the interface of management. IoT terminals range from simple household appliances to highly complex industrial tools.

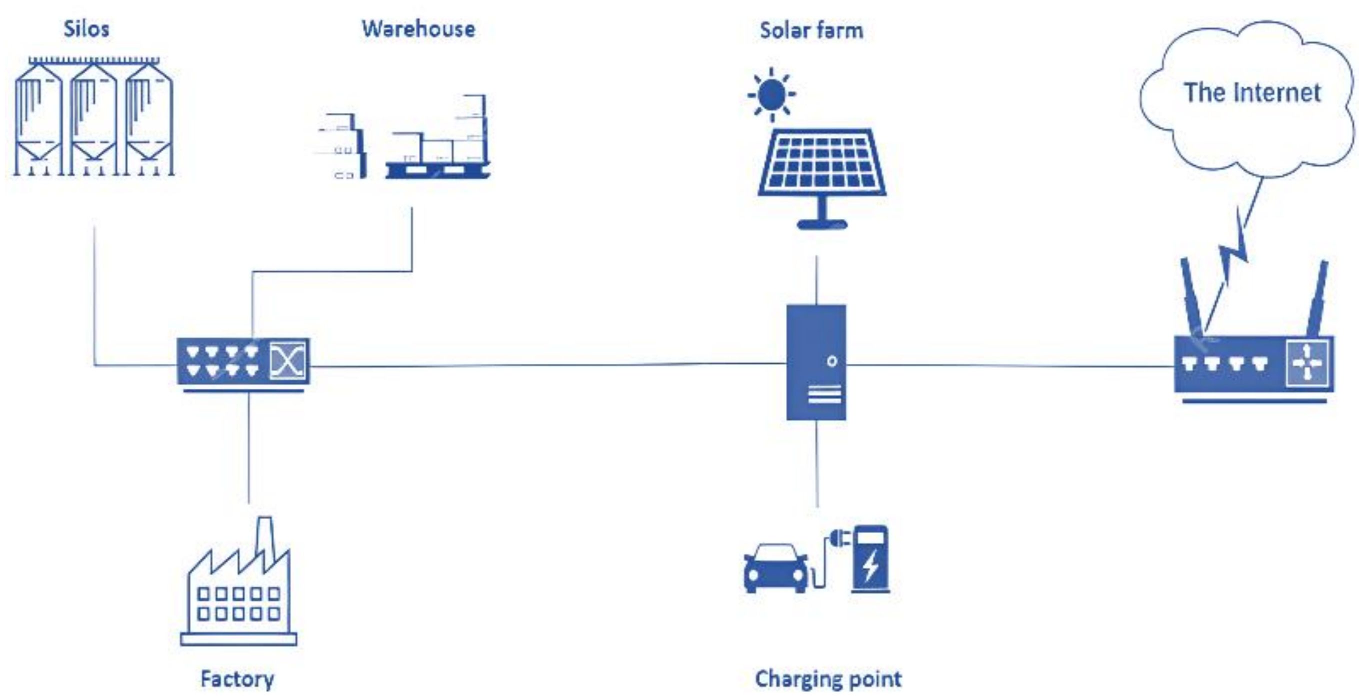

Fig. 2 Cloud computing

In the automotive sector, the implementation of IoT sensor networks and data acquisition holds the potential to enhance maintenance planning [25]. For instance, Cheng et al. have introduced a methodology for maintenance planning that relies on data acquisition facilitated by an IoT sensor network deployed in recently constructed buildings. To ensure effective data collection processes and quality assurance, they advocate using ontology for standardizing the acquired data [26].

Radio Frequency Identification (RFID) is a technology that uses radio waves to identify objects at considerable distances automatically. RFID is one of the most promising modern technologies that can be used to automatically identify, track and trace items in the supply chain management of a range of products. This system is amongst e-maintenance pillars. [1][19]

Virtual reality is a term for a device that allows a computer to create a digital simulation of an environment. Indeed, users could explore the virtual world based on their senses. Most technologies are based on sight, hearing and touch. Some other more advanced technologies also use smell. On the other hand, augmented reality relies on the association of virtual elements with real things. It combines the imagination of virtual reality and the facts of the real world. In other words, it is the addition of virtual objects to real situations. It is widely used in video games, training, culture, and maintenance. [1]

Smart sensors are capable of converting observed physical quantities into usable physical ones. The word "smart" was added to the elements to give them the ability to interpret autonomously. Smart sensors could collect, send and process information and orders through connectivity [5] [13]

Digital devices for mobile work: Devices that support maintenance teams in day-to-day business, such as when retrieving data from a production plant. [5][14]

A Computerized Maintenance Management System (CMMS) is an IT system specifically used to manage maintenance department operations. It is used by maintenance engineers, method engineers and also maintenance technicians. It enables engineers to upload maintenance programs for preventive maintenance and also the modus operandi for almost all maintenance tasks. Likewise, inventories and spare parts can also be managed in a CMMS. Other services collaborating closely with the maintenance department, like production, quality and planning, could also exploit maintenance information recorded in CMMS [5][15].

Signal and Data Processing Tools: All systems can perform integrated data acquisition and signal processing to provide useful information to maintenance technicians (e.g. SCADA, monitoring and data acquisition). [5]

Wireless infrastructure is one of the basic tools and means of electronic maintenance. They are mainly used to build communication networks to overcome limited space problems or long distances. [5]

Personal Digital Assistants (PDAs) facilitate the management of address books or appointment calendars and integrate increasingly complex functions. PDAs have evolved into true pocket computers. It has many features. The list is not exhaustive: processor, RAM, touch screen, compact body, office tools (viewer, calculator and spreadsheet) and GPS. It is a very practical tool in maintenance; it helps technicians properly do needed operations, monitor equipment and make the best decision. Moreover, it is absolutely possible to download data from machines through the PDA [5][16]. It has many advantages, such as; portability, accessibility, reachability, localization and recognition [5].

Other important tools that are not devices are lean manufacturing, six sigma and their toolbox. Maintenance-confirmed methodologies, such as Reliability Centered Maintenance (RCM) or Total Productive Maintenance TPM, are also considered prominent e-maintenance axis [17], as they are considered the basic stuff to have in place before going ahead.

3.2. Survey's Targets Insight

More than 50 people, with different hierarchical levels in maintenance and different experiences, answered the questions either by face-to-face interview, visio-conference interviews, and phone interviews or by email.

Here below is an insight into companies' sectors to whom belong the interlocutors in the three countries

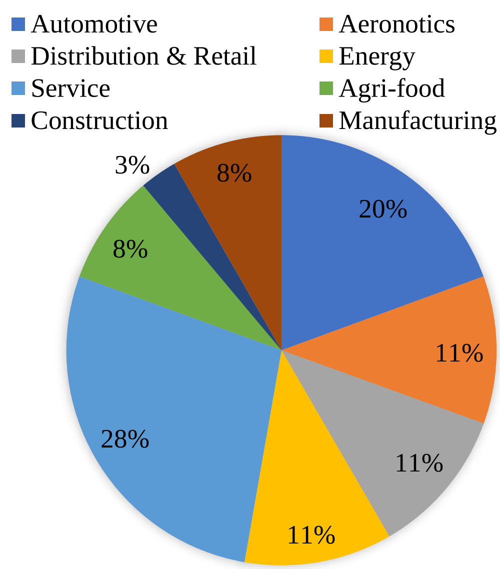

Fig. 3 Targeted companies' sectors

Over half of these companies are classified as large companies due to having more than 500 employees. Medium-sized companies, with a workforce ranging between 50 and 500 employees, make up 38,9% of the total, while small companies with fewer than 50 employees make up 11,1%.

3.3. Survey's General Results

Maintenance is an indispensable function for any company in today's business environment. With the growing demand for sophisticated products and the increasing expectations of customers, companies have had to improve their production systems and adopt complex machinery. As a result, there is a greater need for maintenance to ensure that these machines are operational for the majority of the time.

However, some companies have yet to prioritize the development of their maintenance function and still view it as a necessary evil, leading to its significant underestimation. The research indicates that merely 22.2% of companies have established a decision-making department specifically associated with overall management. Of the companies surveyed, 36.1% have a maintenance sub-department under the supervision of other departments. Meanwhile, 16.7% still regard maintenance as a sub-function and, as a result, place it at a level more than three tiers below the general direction.

On the other hand, nearly 14% of the interviewed individuals believe that the maintenance department within their organization is linked to the wrong department in terms of hierarchy. Additionally, it has also been observed that the significance of the maintenance department can be evaluated based on its hierarchical structure. The findings reveal that 22% of companies have more than three hierarchical levels within their maintenance department. Interestingly, 75% of these companies are categorized as large-scale enterprises with over 500 employees.

Another crucial aspect to consider is the size of the maintenance department. The survey revealed that more than 47% of companies have a maintenance department consisting of more than 30 employees, with a surprising 42% of these companies categorized as medium-sized enterprises.

Outsourcing activities can also shed light on the importance of the maintenance department. Approximately 14% of companies outsource more than 50% of their maintenance operations, while 39% carry out nearly all maintenance operations with their in-house teams, only outsourcing less than 10% for technological or staffing purposes during annual overhauls.

We also investigated data management systems and found that over 30% of companies consider their DMS to be outdated, with only 12% having modern DMS, 50% of which are located in France, 26% in Morocco, and 24% in Tunisia.

Budget is another significant factor that determines the importance of the maintenance department, as the larger the budget, the more crucial the department becomes. However, only 37% of companies have an annual budget exceeding 100,000 USD, based on the research.

3.4. Survey's Assessment of the Impact of Continuous Improvement (CI) Over Maintenance and Company Performance

This section of the survey focused on evaluating the degree to which companies have implemented best practices for continuous improvement, which is an essential tool for implementing e-maintenance practices and activities.

The results show that almost 89% of companies have incorporated continuous improvement practices into their processes, with over 75% of these companies located in Morocco and Tunisia.

In industrial companies, lean manufacturing and continuous improvement are frequently linked. Lean manufacturing is significantly influenced by Industry 4.0 in general and e-maintenance in particular [22]. The survey findings indicate that more than 61% of companies incorporate lean manufacturing into their maintenance processes and activities, which is essential before applying Preventive Maintenance (PM).

Preventive maintenance is another CI best practice [1]. Approximately 30% of companies carry out over 50% of their maintenance operations as preventive maintenance, while nearly 20% have less than 10% of their maintenance operations designated as preventive.

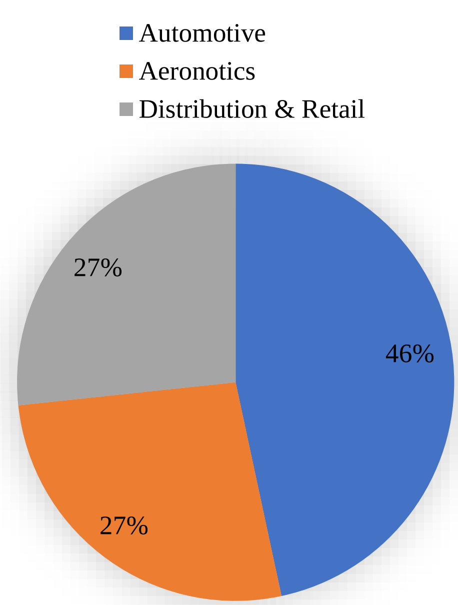

Fig. 4 Preventive maintenance deployment rate

The failure rate was selected as the primary metric to assess the influence of continuous improvement (CI) on maintenance and company effectiveness. The survey found that over 36% of the companies interviewed have a failure rate of less than 10%. Moreover, 93% of these companies have implemented CI's best practices in their maintenance processes, indicating the direct impact of CI on maintenance and, by extension, on company performance.

3.5. Survey's Assessment of the Impact of INDUSTRY 4.0 Tools on Maintenance

Out of all the professionals interviewed, 61% confirmed that their respective companies had implemented AI tools. Within this group, a range of AI tools was listed, and the professionals were asked to rank them from 1 (no impact) to 5 (highly impactful) based on their perceived impact on the company's performance, encompasses costs, benefits, User Experience (UX), Financial KPIs before and after deployment. The resulting rankings are presented in the table below:

Table 1. Table of AI tools impact

AI tools	Impact degree	Comment
ERP	5	Very Impactful
Cloud Technology	4	Impactful
RFID	3	Moderately Impactful
Big Data	4	Impactful
IoT (Internet of Things)	3	Moderately Impactful
Machine Learning	5	Very Impactful
Deep Learning	5	Very Impactful
Virtual Reality and Augmented Reality	3	Moderately Impactful

3.6. Second Phase of Data Collection

Ten months after the first phase of the questionnaire, the second phase was conducted, during which companies were divided into two categories based on their utilization of Industry 4.0 and CI tools. The first category comprised companies that had these tools in place, while the second category consisted of companies that had not deployed Industry 4.0 or CI tools.

During this phase, only the fifth block of questions was administered, which focused primarily on the evolution of maintenance, financial, and qualitative KPIs. Maintenance-related KPIs include the failure rate, which measures equipment downtime by dividing it by total working time, and the maintenance cost to operating expenses, encompassing all indirect costs associated with product or service realization, such as salaries, energy, and maintenance. In addition, relevant financial KPIs were also examined, such as the gross margin percentage, which compares the cost of goods sold (CoGS) to global revenues, and the net income percentage, which provides insight into global company expenses, including costs, salaries, quality, maintenance, bank interests, and depreciation.

Lastly, certain satisfaction KPIs were evaluated, with an emphasis on employee satisfaction, which was determined by a global employee vote concerning their basic working conditions in relation to their wages. Customer satisfaction was assessed through a brief satisfaction questionnaire distributed to some companies' customers, with questions centred on fundamental customer requirements. Shareholder satisfaction is also a crucial indicator since company executives must ensure that shareholders and investors are fully satisfied with the company's performance.

4. Results

4.1. Companies with Industry 4.0 and CI tools

Only industrial companies have answered maintenance and financial KPIs to assure statistical homogeneity. As for qualitative KPIs, even service companies have answered.

Table 2. KPIs table evolution 1

	1st Assessment	2nd Assessment
Maintenance KPIs		
Failure rate	22%	18%
Maintenance cost to expenses	17%	13%
Financial KPIs		
Gross margin percentage	17%	19%
Net income percentage	4%	6,5%
Qualitative KPIs		
Customer satisfaction	72%	79%
Employees' satisfaction	67%	76%
Shareholders' satisfaction	71%	79%

Table 3. KPIs table evolution 2

	1st Assessment	**2nd Assessment**
Maintenance KPIs		
Failure rate	37%	39%
Maintenance cost to expenses	27%	32%
Financial KPIs		
Gross margin percentage	11%	10%
Net income percentage	3,7%	3%
Qualitative KPIs		
Customer satisfaction	41%	39%
Employees' satisfaction	31%	29%
Shareholders' satisfaction	56%	54%

4.2. Companies without Industry 4.0 and CI tools

This empirical study was with great benefits as it helpedgather data directly from the field. It helped to understand how business KPIs could be impacted by using new technologies in the maintenance field. Findings will be then used to issue a new study based on statistical analysis. Likewise, this study has implied a causal inference as it has established a cause-and-effect relationship between variables, new technologies and companies' KPIs. These findings were previously unknown, and henceforth they could be evenly used by researchers to refine new theories. M.Ghouat et al. have already given a theoretical point of view related to the impact of Industry 4.0 technologies. The present paper has confirmed the work and will bridge the gap between theoretical knowledge and practical applications.

Overall, this empirical study has served as a crucial scientific method for generating knowledge, validating theories, and informing decision-making processes.

The empirical study conducted in this research has yielded significant benefits by directly collecting field data. It has provided valuable insights into how the utilization of new technologies in the maintenance field can impact business Key Performance Indicators (KPIs). These findings will serve as a foundation for future studies that involve statistical analysis. Moreover, the study has successfully established a cause-and-effect relationship between the variables of new technologies and companies' KPIs, enabling causal inference. Researchers can now utilize these previously unknown findings to refine existing theories. Notably, M. Ghouat et al.'s [22] theoretical perspective on the influence of Industry 4.0 technologies has been confirmed by this study, effectively bridging the gap between theoretical knowledge and practical applications.

Overall, this empirical study has played a crucial role as a scientific method, generating knowledge, validating theories, and informing decision-making processes.

5. Conclusion

After analyzing the results before and after a 10-month period, it is evident that companies that have not implemented CI tools or Industry 4.0 are facing significant challenges and are struggling to achieve satisfactory technical, financial, and qualitative outcomes. Moreover, the situation appears to be deteriorating progressively over time.

Companies equipped with Industry 4.0 tools and CI practices are making progress from good to excellent, and their customers are becoming increasingly satisfied. This suggests that these companies will continue to flourish in the future.

We are of the opinion that the effective implementation and utilization of new technologies are the key factors behind these remarkable outcomes. The deployment of CI tools allows for better organization, while industry 4.0 technologies introduce new tools that streamline processes, increase accuracy, and ultimately lead to more satisfied customers.

After verifying the significant impact of Industry 4.0 and CI tools on business performance, the next objective is to develop a maintenance 4.0 framework. The concept involves creating a maintenance 4.0 package that includes multiple warranties to achieve specific objectives.

Acknowledgments

We are very grateful to the team members for their valuable and constructive suggestions.

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