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Presented by
Haroune AOUAIDJIA
Mohamed Rafik CHAABNA

INDUSTRY 4.0 IN THE CONTEXT OF COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM(CMMS): CASE OF STUDY SPA SAH ALGERIA

Supervised by
Dr. Saida GHERBI
ENSTI-ANNABA

Examination Board:

Dr. KARABADJI Nour Elislem	President	ENSTI-ANNABA
Dr. AISSAOUI Lamia	Examiner	ENSTI-ANNABA
Dr. KEBIR Salim	Examiner	ENSTI-ANNABA

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ABSTRACT

Abstract:

This dissertation presents the design and development of a web-based CMMS designed specifically for SAH SPA LILAS in El Bouni, Annaba. The CMMS was developed to address several significant problems related to the company's eight production lines. Problems in implementing paper-based maintenance which results in inefficient maintenance tracking, unsatisfactory team coordination, and little equipment traceability, are crippling processes and compliance for ISO 9001:2015 status for the company. In integrating new web technologies (HTML, CSS, Flask, MySQL) with machine learning algorithms (Pandas, NumPy, Scikit-learn) the maintenance department is able to analyze the equipment using predictive maintenance for machines using Multi-Layer Perceptron regression methods; the CMMS has sufficient features to allow for role- based access restriction, interventions as well as spare parts tracking, external work requests (work orders) processing, and KPI performance tracking using real-time dashboards. On the whole, the CMMS represents a considerable enhancement to SAH SPA LILAS's maintenance efficiency and processes in addition to advancing the process and practice from a reactive approach to a proactive maintenance strategy. Although it has not gone live at this time, user testing of the CMMS application has demonstrated its usefulness in minimizing downtime, making more efficient use of all operating assets and resources, and has the potential to also support SAH SPA LILAS's Digital transformation journey moving forward into the future. The research presented in this dissertation will contribute to the ongoing strategic roll-out of Industry 4.0 by local manufactures, especially as it is not common in Algeria. It is also a clear example of how a local enterprise may use new technologies and applications to further enhance their operational performance.

Keywords: CMMS; Industry 4.0; Predictive Maintenance; ISO 9001:2015; Digital Transformation; Machine Leaning; Algeria; Web Development.

Résumé:

Cette thèse présente la conception et le développement d'un système de gestion de la maintenance assistée par ordinateur en ligne, conçu spécifiquement pour SAH SPA LILAS à El Bouni, Annaba. Ce système a été développé pour résoudre plusieurs problèmes importants liés aux huit lignes de production de l'entreprise. Les difficultés de mise en œuvre de la maintenance papier, qui entraînent un suivi de maintenance inefficace, une coordination d'équipe insatisfaisante et une faible traçabilité des équipements, compromettent les processus et la conformité à la norme ISO 9001:2015 pour l'entreprise. En intégrant les nouvelles technologies web (HTML, CSS, Flask, MySQL) aux algorithmes d'apprentissage automatique (Pandas, NumPy, Scikit-learn), le service de maintenance est en mesure d'analyser les équipements grâce à la maintenance prédictive des machines à l'aide de méthodes de régression perceptron multicouche ; le système de GMAO dispose de fonctionnalités suffisantes pour permettre la restriction d'accès basée sur les rôles, les interventions ainsi que le suivi des pièces de rechange, le traitement des demandes de travail externes (bons de travail) et le suivi des performances des indicateurs clés de performance (KPI) à l'aide de tableaux de bord en temps réel. Globalement, la GMAO représente une amélioration considérable de l'efficacité et des processus de maintenance de SAH SPA LILAS, tout en faisant évoluer les processus et les pratiques d'une approche réactive vers une stratégie de maintenance proactive. Bien qu'elle ne soit pas encore opérationnelle, les tests utilisateurs de l'application de GMAO ont démontré son utilité pour minimiser les temps

ABSTRACT

d'arrêt et optimiser l'utilisation des actifs et des ressources d'exploitation. Elle pourrait également soutenir la transformation numérique de SAH SPA LILAS à l'avenir. Les recherches présentées dans cette thèse contribueront au déploiement stratégique de l'Industrie 4.0 par les fabricants locaux, d'autant plus que ce modèle est peu répandu en Algérie. Il s'agit également d'un exemple clair de la manière dont une entreprise locale peut utiliser les nouvelles technologies et applications pour améliorer ses performances opérationnelles.

Mots-clés : GMAO ; Industrie 4.0 ; Maintenance prédictive ; ISO 9001 :2015 ; Transformation numérique ; Apprentissage automatique ; Algérie ; Développement web.

ملخص:

قدمت هذه الأطروحة تصميم وتطوير نظام إدارة الصيانة المحوسبة (CMMS) القائم على الويب والمصمم خصيصًا لشركة SAH SPA LILAS في El Bouni، عنابة. تم تطوير CMMS لمعالجة العديد من المشكلات المهمة المتعلقة بخطوط الإنتاج الثمانية للشركة. إن المشكلات في تنفيذ الصيانة الورقية والتي تؤدي إلى تتبع غير فعال للصيانة وتنسيق غير مرضي للفريق وإمكانية تتبع ضئيلة للمعدات، تعوق العمليات والامتثال لحالة ISO 9001: 2015 للشركة. من خلال دمج تقنيات الويب الجديدة (HTML و CSS و Flask و MySQL) مع خوارزميات التعلم الآلي (Pandas و NumPy و Scikit-learn)، يتمكن قسم الصيانة من تحليل المعدات باستخدام الصيانة التنبؤية للآلات باستخدام أساليب الانحدار متعدد الطبقات Perceptron؛ يحتوي CMMS على ميزات كافية للسماح بتقييد الوصول القائم على الدور والتدخلات بالإضافة إلى تتبع قطع الغيار ومعالجة طلبات العمل الخارجية (أوامر العمل) وتتبع أداء مؤشرات الأداء الرئيسية باستخدام لوحات المعلومات في الوقت الفعلي.
بشكل عام، يُمثل نظام إدارة الصيانة المحوسبة (CMMS) تعزيزًا كبيرًا لكفاءة وعمليات الصيانة في شركة SAH SPA LILAS، بالإضافة إلى تطوير العملية والممارسة من نهج تفاعلي إلى استراتيجية صيانة استباقية. وعلى الرغم من أنه لم يُطلق بعد، فقد أثبت اختبار المستخدم لتطبيق CMMS فائدته في تقليل وقت التوقف عن العمل، مما يزيد من كفاءة استخدام جميع الأصول والموارد التشغيلية، ولديه القدرة أيضًا على دعم رحلة التحول الرقمي لشركة SAH SPA LILAS للمضي قدمًا نحو المستقبل. سيساهم البحث المقدم في هذه الأطروحة في الطرح الاستراتيجي المستمر للصناعة 4.0 من قبل المصنعين المحليين، خاصةً أنه ليس شائعًا في الجزائر. كما أنه مثال واضح على كيفية استخدام المؤسسة المحلية للتقنيات والتطبيقات الجديدة لتحسين أدائها التشغيلي بشكل أكبر.
الكلمات المفتاحية: CMMS؛ الصناعة 4.0؛ الصيانة التنبؤية؛ ISO 9001:2015؛ التحول الرقمي؛ التعلم الآلي؛ الجزائر؛ تطوير الويب

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
Sah	société article d'hygiène
Spa	société par actions
SAHD	SAH algérie
AI	artificial intelligence
API	Application programming interface
CMMS	computerized Maintenance management system
CSS	cascading style sheets
DRH	direction ressource humaine
ERP	enterprise resource planning
HTML	hypertext markup language
GMAO	gestion maintenance assistée par ordinateur
Lot	internet of things
Iso	international standardisation organisation
KPi	key performance indicator
MAE	Mean absolute error
ML	Machine learning
MLP	Multi-layer perceptron
R^2	coefficient of determination
SQL	structured query language
TND	tunisian Dinar
Ui	user interface
2Fa	two factor authentication

SUMMARY

Content:

SUMMARY

GENERAL INTRODUCTION

Now, more than ever, it is necessary for the rapidly changing industrial world of today to assimilate digital technologies with more traditional production methods to sustain competitive advantage and achieve sustainable development. The Fourth Industrial Revolution (or Industry 4.0) is a paradigm shift that utilizes networked systems, artificial intelligence, and data-based decision-making to change the way organizations operate. Maintenance management, within this changing context, presents an inherent challenge that impacts operating efficiency, product quality, and organizational sustainability.

SAH SPA LILAS, a leader in the North African hygiene and personal care sector, exemplifies the dilemma which industrial companies experience during rapid growth. Since its establishment in 1994, the company has evolved from what it was at the start as a specialist in women's hygiene products, into a diversified market leader, operating in 20 counties, with more than 4,500 employees. The Algerian subsidiary, created in 2007, has eight modern production lines manufacturing baby diapers, napkins, tissues, wet wipes, and other paper-based products. However, that growth has resulted in significant weaknesses in internal coordination and process-traceability, all this in addition to a systematic lack of quality management systems posing direct obstacles to the organization pursuing ISO 9001:2015 certification and operating at an excellent level.

In the past, Industry 4.0 technologies were not widely available, and good quality management standards have only recently become more widely accepted, providing us with unique prospects for solving operational underperformance. Computerized Maintenance Management Systems have also changed from basic scheduling applications to highly developed and sophisticated applications that can house IoT sensors, machine learning, and live analytics. All of this has opened the door for CMMS to be a strategic enabler of the process-based approach, the evidence-based decision-making, and continual improvement approach to developing the core concepts of ISO 9001:2015 certification.

This thesis documents the design, development, and deployment of a complete web-based CMMS for SAH SPA LILAS's operations in Algeria. This research analyzes the need for a merging of all maintenance operations into a consolidated digital application, which will drastically improve operational visibility, reduce durations of downtime, and provide predictive maintenance capabilities, and eliminates fragmented and paper-based operations. By using more modern web technologies with properly selected database systems and machine learning solutions, this research showcases how a company can successfully implement Industry 4.0 principles to solve real industry problems while supporting regulatory compliance and organizational growth.

This work will be structured in four main sections as follows:

In Chapter 1: we will introduce the company SAH SPA LILAS, its activities and choice of products, the issues it is presently encountering with coordination, traceability, and quality control to get ISO 9001:2015 certified, and we will discuss the driver for introducing the Computerized Maintenance Management System (CMMS) within an Industry 4.0 context.

In Chapter 2: we will examine the theoretical basis of the idea of Industry 4.0, provide a full description of CMMS, explain the ISO 9001:2015 standard, and assess how these three ideas relate to each other in today's industrial contexts.

In Chapter 3: we document the technical aspects of the methodology we used to develop a CMMS that is Web-based. We will report on the front-and back-end technologies that were adopted, the database structure, the data migration process, and the integration of artificial intelligence libraries for predictive maintenance, including outlining our process mapping to show the improvement in the process.

In Chapter 4: we will outline the functions of the CMMS developed, including user access and authentication, spare parts management, maintenance intervention management, key performance indicator (KPI) dashboards and organization of maintenance intervention, and the predictive maintenance module. We will also consider what is involved in the implementation, what we expect outcomes to bring in the short- and long-term, and the limitations and challenges that we encountered relate to the work we achieved in the development of the CMMS.

1.1 Introduction:

In a transformational manufacturing environment, internal quality and process performance can often be the main determinants of an enterprises long-term viability and competitive strength. In the current chapter, we first introduce the company SAH SPA LILAS, some of its activities, products and current issues. We then move on to the resolution of a packaging issue in one paper tissue production line, investigating internal processes to identify sources of inefficiency and compliance with the company's established standards.

1.2 Description:

Lilas Group SAH was established in 1994 by Mounir El Jaiez and Jalila Mezni starting with women's hygiene then expanding into diapers, tissue, incontinence products and cleaning products. The company has become the Market Leader in North Africa and Tunisia, expanded to 20 nations and has more than 4,500 staff. Milestones included investment from Emerging Capital Partners in 2008 and listing on the Tunis Stock Exchange in 2014. By 2024, the company has recorded more than 980 million TND in sales thanks to product diversification and sustainable production. [1,2,3]

Figure 1.1 logo of lilas

1.3 Algerian Branch Overview and History:

Overview of the Company

- Name: SAH Algeria
- Legal Status: Algerian law company
- Capital: 564 million Algerian Dinars (approximately 11.6 million TND)
- Establishment: Established in February 2007
- possessing 8 production lines:

  -2 baby diaper production lines: MBB1 and MBB2

  -2 napkin production lines:MST1 and MST2

  -1 tissue production line:MPM

  -1 wet wipes production line:MLG

  -1 industrial paper towel production line:MPRI

  -1 kitchen paper towel and toilet paper production line:MTKI1

1.3.1 Distribution Network:

SAHD Algeria: : Limited capital share company incorporated in February 2010 with share capital of 40 million Algerian Dinars (approximately 0.8 million Tunisia Dinars). tasked with marketing Lilas ranges of products produced out of SAH Algeria, which consist of adult hygiene and women's health products.

1.3.2 History:

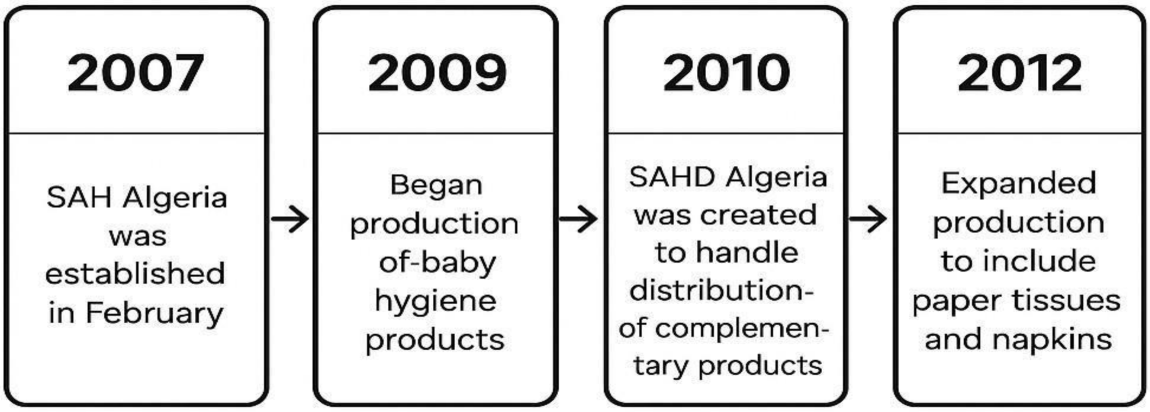


Figure 1.2 history of the company [4,5]

1.3.3 Location and address:

SAH Algeria's business linked to the Lilas brand's address is the Zone Industrielle MIN Lot 48 El Bouni, Annaba city Algerie1.as shown in the figure 1.3

Figure 1.3 Address of the company

1.4 Problem statement:

SPA SAH LILAS is rapidly expanding and needs a more effective organization and process management within itself. The company was able to penetrate and gain the market in personal care and hygiene, yet is experiencing difficulties with coordination, traceability, and quality management factors which are essential for obtaining ISO 9001:2015 certification. The goal of this project is to resolve these issues and provide recommendations on Industry 4.0 to help the company achieve quality objectives by purchasing and optimizing processes, improving traceability, and supporting data-driven decision making Industry 4.0, is based on connectivity, information transparency and Technical assistance to support and strengthen CMMS that comply with ISO 9001:2015.

1.5 Motivation:

The best way to maximize maintenance efficiency and control is through a Computerized Maintenance Management System (CMMS). We're going to show how this system can optimize workflow, improve coordination, and eliminate inefficiencies such as downtime and redundancy.

In the context of Industry 4.0 with a CMMS, SPA SAH LILAS will better be able to track equipment, schedule maintenance, and allocate resources. We will be providing you with a way to identify operational issues, make viable suggestions to help automate processes, minimize downtime, and improve product quality.

Lastly, we hope to help the company on the road to operational excellence and contribute to a good, lasting change with the proper implementation of a CMMS and AI prediction.

1.6 Conclusion:

In this chapter, we have presented SPA SAH LILAS, the organization's activities, and its concerns with internal coordination and quality management. We presented the implementation of a CMMS as a solution to these problems and in the following chapter, we will support the proposed implementation by discussing the theoretical foundations of CMMS to ensure it achieves a successful outcome.

2.1 Introduction:

In today's digital world, CMMS represent a key element to managing and automating maintenance processes. CMMS facilitate Industry 4.0 technologies for the effective execution of predictive maintenance and real-time asset monitoring, making CMMS a vital element of ensuring equipment reliability and efficiency in smart factories.

2.2 Industry 4.0:

Industry 4.0 is an evolution of utilizing digital technologies in manufacturing which includes aspects such as the IoT, AI, big data, robots, and cloud computing. Industry 4.0 builds on the prior industrial revolutions that have had mechanization, mass production, and automation at their foundation, and is possible due to machines, systems, and human beings having connectivity and communication in real-time with each other. Connected devices in smart factories can increase optimized production, improve quality, and eliminate waste. Machine learning, specifically Multi-Layer Perceptrons (MLPs), provides the technical function for this transformation by enabling predictive maintenance, quality monitoring, and demand forecasting by assessing historical data. The boundaries between the physical and virtual systems are being blurred in ways that dramatically alter the production and servicing of manufactured goods and with complex technological systems being a common and quotidian aspect of contemporary industrial practice.

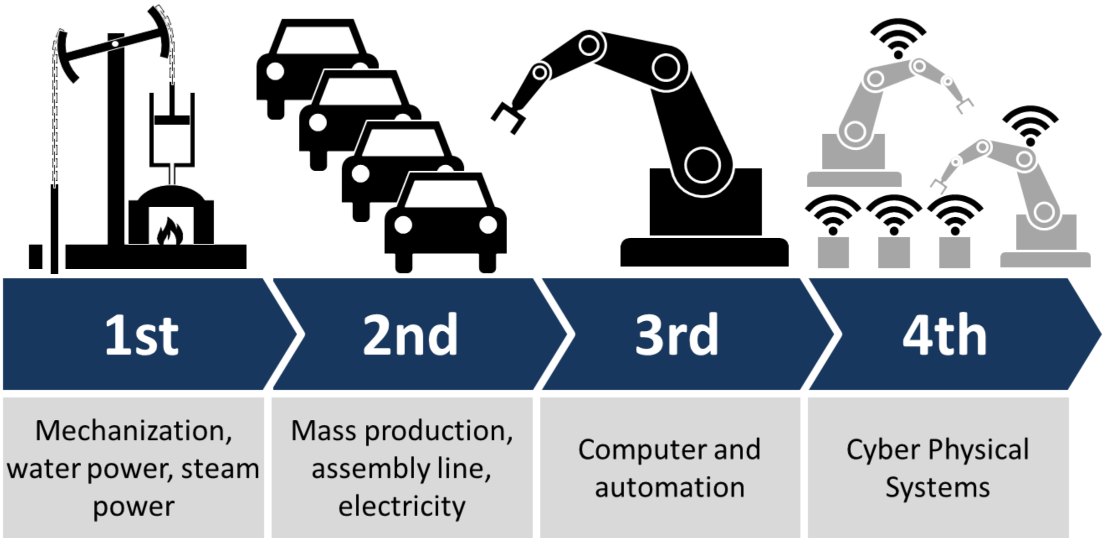


Figure 2.1 History of the industrial revolution [6]

2.3. Description of CMMS:

CMMS is a computer software system which allows organizations to plan, track, and manage maintenance activities. CMMS was created with the primary purpose to record simple maintenance, but with the advancement of more modern CMMS, they have emerged as critical components in the management of complex assets with industrial or manufacturing environments. A CMMS essentially puts maintenance data in one place allowing organizations to go from paper files and unreferenced spreadsheets to a fully represented view of all equipment condition, performance, and history related to all assets. Data is captured concerning everything from asset specifications, to warranties, to run charts, to failure analyses.

Work order management is the key component of CMMS to allow work to be created, dispatched, and closed. Real time schedules, procedures, and spare parts data allow technicians to perform their job faster, more accurately, and with accountability. Preventive maintenance is a means to lessen breakdowns by scheduling when maintenance will happen based on time, usage, or condition of the asset. CMMS systems track inventory as well, where vendors will engage with the CMMS to track availability of parts so the system can automate and trigger orders for replacement parts, which also lesson delays. CMMS systems also support regulatory compliance maintenance records and can maintain consistent records, which makes audits and report generation easier.

Organizations that use CMMS can expect to see around 65% efficiency improvement, downtime is reduced by over 50%, and equipment reliability improved by close to 60%. Ultimately, CMMS allows maintenance to be a strategic function that drives productivity and increases sustained business performance.[]

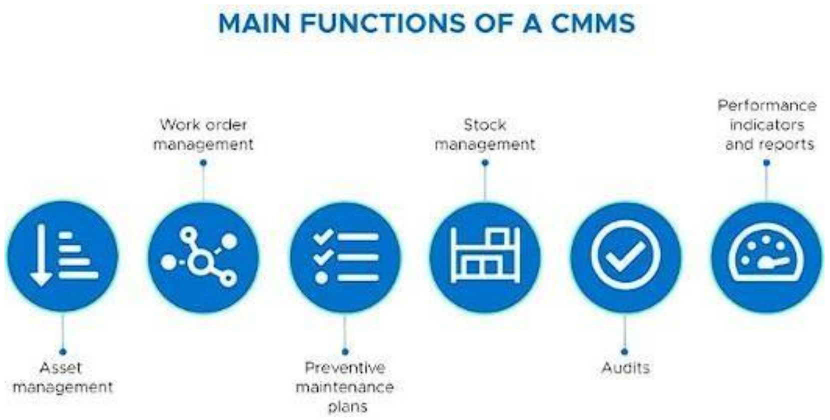


Figure 2.2 description of the functions of CMMS [7,8]

2.4. ISO 9001:2015:

ISO 9001:2015 is an international standard for Quality Management which provides organizations with a framework to ensure they consistently deliver quality products and/or services in a systematic way. It is based on process approach, risk management, leadership, and continual improvement. ISO 9001:2015 requires documented processes, performance measurement, and evidence-based decision making with an emphasis on the customer. While ISO 9001:2015 has less stringent requirements for documentation than the previous versions, it stresses organizational context and stakeholder needs.

2.5. Relation between ISO: 9001:2015 and Industry 4.0:

ISO 9001:2015 and Industry 4.0 are an impressive synergy that pairs quality management concepts with leading-edge digital technologies. Industry 4.0 offers data capture with IoT sensors, AI , ML that delivers the turn-key level data necessary for real-time evidence-based decision making as part of ISO 9001. Furthermore, ISO 9001's process-based model aligns well with Industry 4.0's systems integration, both of which are fundamentally about improvement in one way or another; ISO 9001 is about systemic formal quality management, and Industry 4.0 is about technology to enable quality management. Therefore, a combination of ISO 9001 and the industry 4.0 model allows organizations to obtain improved quality, improved efficiency, and improved outcomes for customer satisfaction through digitally enabled quality management systems that allow for rapid response to changes in an organization's context.[9]

2.6. CMMS in the context of Industry 4.0 and ISO 9001:2015:

In the framework of Industry 4.0, CMMS have moved from just simplistic scheduling tools to predictive systems, meaningful predictive platforms driven by real-time information from IoT sensors and machine learning algorithms. Current generation CMMS solutions can easily interface with other enterprise systems, providing complete and end-to-end visibility across the entire operations and supporting condition-based and predictive maintenance approaches that were, by nature, able to reduce downtime significantly. Mobile access allows maintenance personnel to see crucial information from anywhere while AI-based analytics simplify resource allocations and scheduling. These next-generation CMMS capabilities directly help quality management goals, through improved equipment reliability and availability; extending asset life; and meeting the documentation and traceability requirements to be ISO 9001:2015 certified. [10]

2.7. Conclusion:

This chapter presented the industry 4.0 themes and impacts on today's manufacturing and the role of CMMS in achieving predictive maintenance and proactive operation. The chapter also outlined the ISO 9001:2015 concepts and showed the compatibility of the quality standard with Industry 4.0 technologies. Here, CMMS is a strategic tool that not only assists with equipment reliability, but as shall be shown in the next chapter, will assist with some of the quality management standards. The next chapter will provide details, both theoretical and operational, regarding the CMMS to assist in the appropriate and effective implementation of the CMMS within an Industry 4.0 context.

3.1. Introduction:

This chapter describes the construction of a CMMS that will be web-based and help the SAH SPA LILAS manage maintenance activities. Using a CMMS to automate maintenance therefore has a minimum of three capabilities: tracking of work orders and workflow, spare parts management, and planning interventions. The front-end technologies used for this project include HTML, CSS, and Bootstrap which allowed for the creation of a responsive User Interface (UI). The back-end was set up using Flask and MySQL with phpMyAdmin in the background for the database operations.AI libraries including Pandas, NumPy, and Scikit-learn were incorporated into the code base to allow for data analysis and the maintenance prediction. This was included so that data from the Excel document would be migrated and some historic data could, take in working with the processes have been changed by using CMMS process modelling per ISO 9001:2015 the significant advancements made by the benefits to the capabilities from this system are endless.

3.2. Implementation Technologies and Methodology:

A combination of advanced web technologies was chosen very carefully in order to implement a successful and robust CMMS. Here is an explanation of the basic tools and frameworks that make everything work from the user interface to the server back end and database, and how they work together coherently to simplify maintenance management.

3.2.1. Frontend Development (HTML and CSS):

The frontend user interface was created using HTML and CSS, which are the building blocks of designing and structuring web pages. HTML was used to declare the different structures of the application such as forms, tables, buttons, and menu navigation. CSS was used to control the styles such as font, colors, spacing, and structuring. Using these technologies together allow the application to present the data accurately and structured so users have an easy experience interacting with the CMMS. In addition, responsive design and consistency across devices were further enhanced by also using a CSS framework such as Bootstrap.

Figure 3.1. HTML and CSS logos [11]

3.2.2. Database Design and Structure:

The database performs the functions of a CMMS, designed and created using MySQL, with phpMyAdmin as the graphical user interface to create and edit the database. The database schema, again with the only tables required for users, equipment, work_orders, interventions, spare_parts, maintenance_equipments, blocs, and production lines. The tables contain all the necessary information for the maintenance process, status of equipment, management of spare parts, and planning of intervention.

Figure 3.2.MYSQL[12]

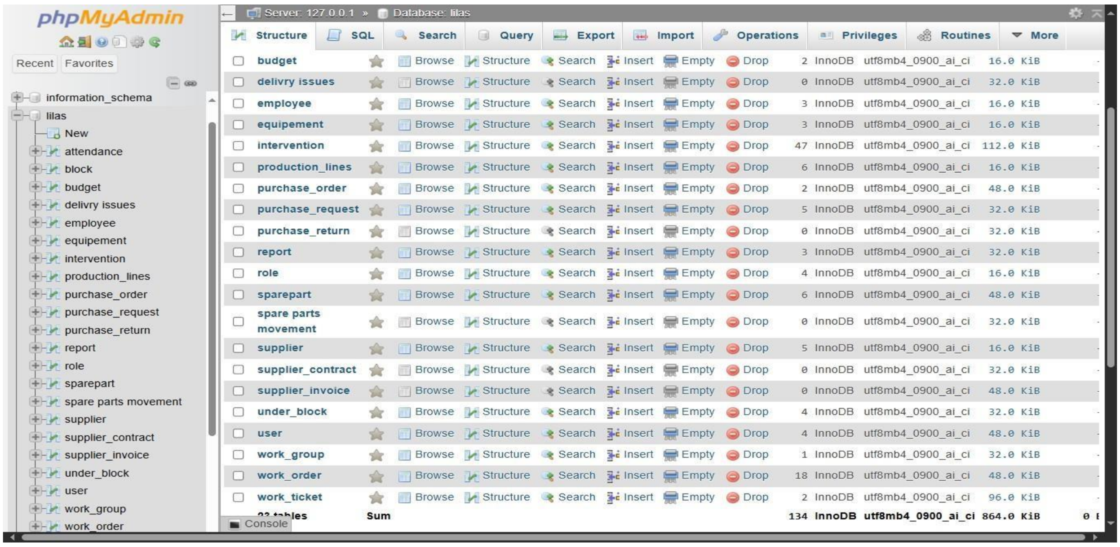


Figure 3.3. CMMS database in phpmyadmin[13]

The population of the initial CMMS database was achieved due to the planned migration of data from Excel spreadsheets to the CMMS data. The Excel spreadsheet data completely involved manipulating the structure of the data so they fit the normalized database. This involved normalizing the data formats, standardizing terms and descriptions and finally eliminating duplicate records. Apart from de-consolidating consolidated records key migration restructuring involved formatting dates to MySQL format, other key aspects included establishing proper foreign key relationships between the tables. Once the identified dataset had been cleaned up and migrated into a MySQL database, The migration project relied on Artificial Intelligence to engage in change monitoring of the datasets, before bulk loading into its MySQL database through phpMyAdmin. With this approach, the integrity of the data was preserved while maintaining historical maintenance data that would inform any future prediction, analytics and reporting functions in the system.

3.2.3. Backend Development (Flask & PyCharm):

The backend for the CMMS was created with Flask an efficient web-framework in Python, and used the PyCharm development environment. Flask was chosen for the ease of use, modular features, and support for MySQL databases. It allowed for the use of route-based logic to handle responses to user input such as form submission, data inputs, or updates to record entries. Each Route makes use of SQL commands to return the information using a MySQL connector directly from Flask. It handles the input, processes it, and serves an HTML page as a response or loads an HTML template page. PyCharm provides a conducive work environment for writing, testing, and maintaining the code which sped up the development process and improved efficiency as shown in table 3.1. Various libraries used to implement our proposed processes are listed below in Table 3.2.

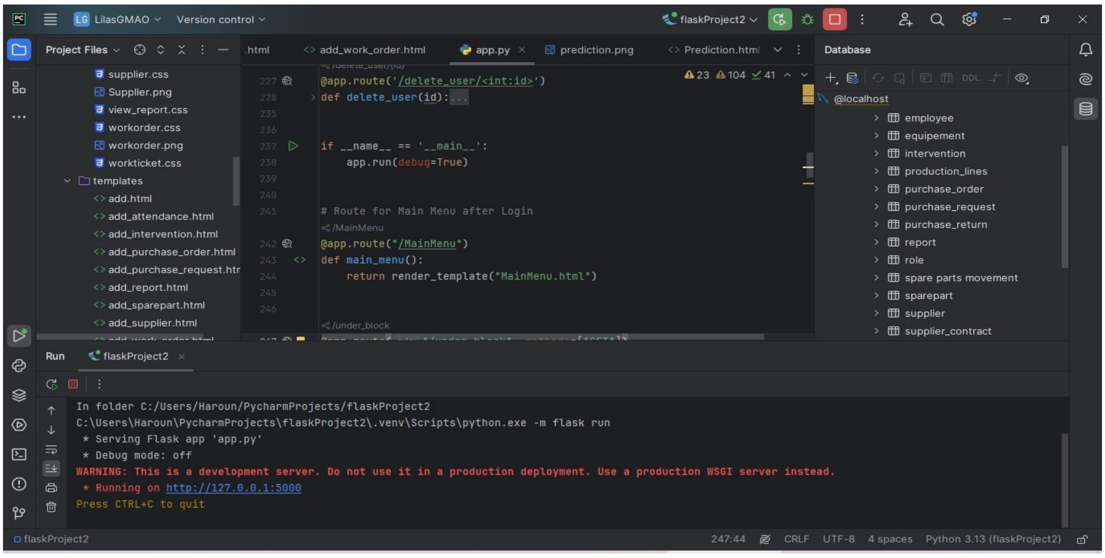


Figure3.4. PyCharm interface [14]

Advantage	Explanation
Scalable Architecture	start small and scale up as needed with minimal changes.
Built-in Development Server	Includes a server to test the app locally without extra setup.
Easy Integration with APIs	supports integration with RESTful APIs and third-party services.
Clear Separation of Concerns	Logic, templates, and static files are organized in separate folders.

Table 3.1. Pycharm advantages

library	purpose	application the code
mysql.connector	To connect Python to the MySQL database and execute SQL queries.	We utilized mysql.connector using a connection pool (cnxpool) for database access management efficiently. It enabled data fetching and update for user authentication, interventions, and maintenance records.
Flask	To create an interface with the web and handle HTTP routing	Flask powered the entire web application. We utilized it to define routes, render templates like Login.html and prediction.html, handle form data, and manage page navigation and user feedback in the form of flash() messages.
Pandas	To organize and manipulate tabular data.	Pandas translated SQL query outcomes into DataFrames for processing. We used it to calculate days between interventions and pull out features like day of the week and month to use in prediction.
NumPy	To allow numerical operations and array manipulation.	We used NumPy to form feature vectors (np.array) required for machine learning prediction and perform basic array manipulations.
Scikit-learn	To preprocess the data, train models, and measure performance.	LabelEncoder converted categorical columns to numerical values. MinMaxScaler normalized the target column (Days_Gap). DecisionTreeRegressor predicted the number of days for future maintenance. mean_absolute_error and r2_score computed model accuracy on a per-machine level.
datetime	To deal with dates and time deltas.	We used datetime.today() to start predictions from the date today, and timedelta to calculate future maintenance dates from predicted gaps.

Table3.2 Used libraries, purpose and application

3.3. CMMS Modeling:

In order to establish the added value of the CMMS that will be proposed as part of this project, a graphic representation using BPMN [15] have been developed to show the continuous improvement tool of the process mapping, ISO 9001:2015 [16] in figures 3.5 and 3.6. Figure 3.5 shows how the process is currently done within the company and figure 3.6 shows you how the process will be completed when the CMMS is implemented. Key improved processes:

Production Line Lane:

- Log fault directly via CMMS (phone/pc)
- Send Work request
- Resume work

Maintenance Planner Lane:

- automatic check on history
- Analyze frequency of previous failure
- Book necessary spare parts
- Check availability of technician

Technician Lane:

- Check equipment and tools
- Check asset docs directly via CMMS
- Log fault
- Generate reports via CMMS

Maintenance management (Reliability) Lane:

- Real time data analysis
- Reports and failure history analyses
- Maintenance staff productivity analysis
- Automatic KPIs calculate with CMMS
- Approving purchases order + quantity on spare parts
- Predict down time and line failure
- Creating a proper intervention plan
- Agreement of the prediction

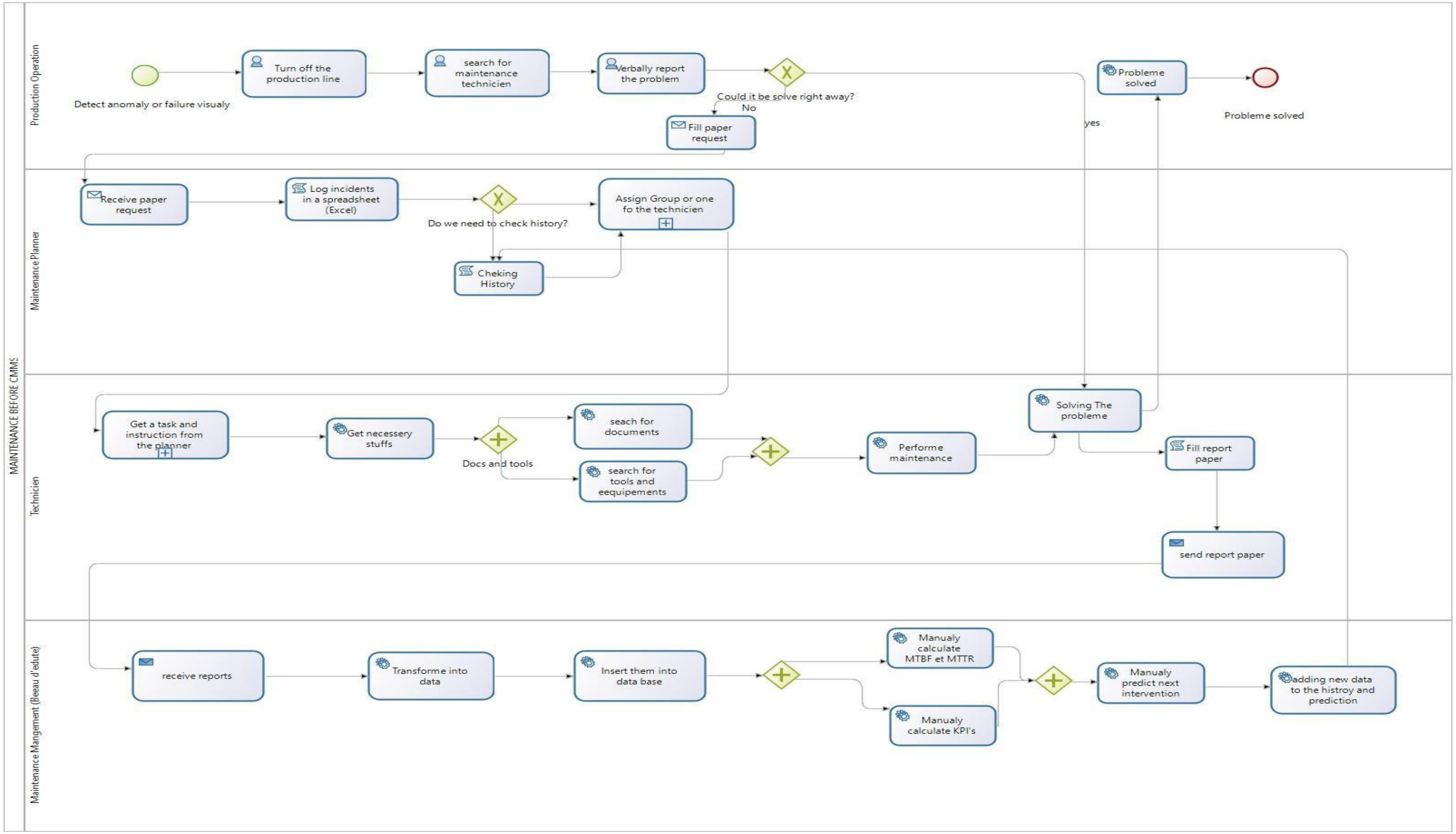


Figure 3.5 Company CMMS Modeling.

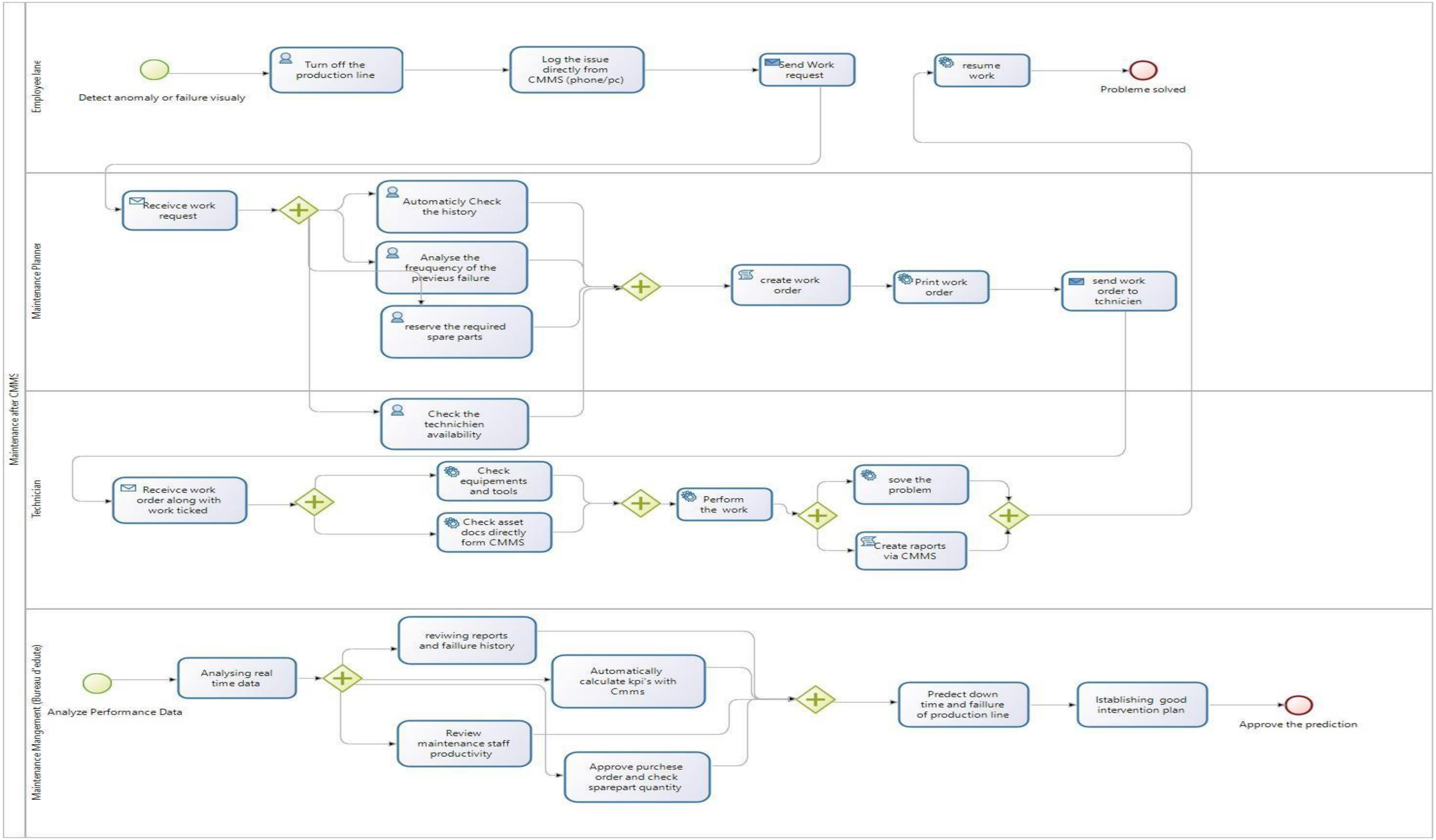


Figure 3.6 Proposed CMMS Modeling

3.4. Conclusion:

Throughout this chapter, we outlined the design of a web-based CMMS that was to address the distinct maintenance needs of its customer, SAH SPA LILAS. It contains critical modules to administer users, work orders, interventions, spare parts and predictive maintenance. It was built using HTML, CSS, Bootstrap, Python Flask and MySQL and libraries such as Pandas, NumPy and Scikit-learn, thus allowing for usable responsive design, efficient data handling and predictive accuracy. The CMMS successfully integrates an Excel-based representation of historical data and a process modeling approach that conforms with ISO 9001:2015, demonstrating the applicability of the system. This CMMS replaces unique isolated manual processes with an automated, centralized system that improves operational visibility, reliability and strategic planning.

4.1 Introduction:

The chapter highlights a CMMS designed for SAH SPA LILAS in Algeria, in web format. The system was designed to replace a paper tracking method, in a unique effort for a centralized electronic management of maintenance interventions, spare parts, work orders and user role management. The system was developed with HTML/CSS, Flask, and MySQL, and included a module for machine learning for predictive maintenance. The CMMS included recommendations for the design and production of key performance indicators dashboards and customizable user interface. Although it is not in a production environment within the company, the one single demonstration unit was tested in a simulated practice VIP program and showed great potential. The chapter addresses the systems functionality, technical architecture, potential benefits and limitations, as well as challenges encountered during development.

4.2 Implementation consideration:

The CMMS software generated from this project has not been put into practice in the Company. It is unclear how implementation could be possible, however, it is thought that if it could be done, the best way to implement/put it into practice, would be to run the system on a company server. That way, employees would have access both internally and through the company network, ensuring data security and functionality. The implementation would require the installation of the system, uploading the database, into the CMMS setup, with real working data, and setting up user access by predetermined roles, to then enable the Maintenance department and parties to begin automating and digitalizing their practices using the CMMS.

4.3. Functionalities of the Developed CMMS:

This section describes the major functionalities that have been delivered in the CMMS developed for LILAS. Each of the functionalities was designed to support a specific requirement of the maintenance workflow. The routines allow for end-to-end processes from ticketing and intervention management to spare parts tracking and purchase order approval. The user interface differed by user role, allowing for access control and different types of interactions. Data visualization (KPI dashboards) multi-language capabilities, and document printing are also part of the system. The following modules were implemented:

4.3.1. User Authentication & Role Management:

Role management is another key feature of the CMMS that as implemented for LILAS. The basic feature functions to allow each user to use only the functionalities concerning their job/topic. When logging in as shown in figure 4.1, the system will check the user role, and navigate to the particular dashboard related to that user role.

Figure 4.1 Log in window

The system has three main functions with direct access and duties as indicated below:

- DRH (Human Resource manager): handles employees roles and users of the app
- Director: manages overall system statistics, authorizes work orders and purchase orders and tracks Key Performance Indicators KPI'S.
- Technician: processes work orders, maintaining logs of maintenance and keeping track of stock for spare parts.
- spare part agent: Handles the spare parts management

4.3.2. Spare Parts Management:

The Spare Parts Management page is made to clearly show current stock levels of spare parts stored on LILAS. The Spare Parts Management page allows the Spare Parts Agent and the Director to display current stock level in almost real time. Users with the required access can also modify spare part details including adding and deleting parts to stock levels so that the stock detail is always accurate. With its visibility and control of spare parts, the module can prevent shortages and improve the ease of maintenance activity.


Spare Parts List

Search by name...

Add New Spare Part

ID	PART CODE	DESCRIPTION	UNIT	LOCATION	QUANTITY	REORDER LEVEL	SUPPLIER ID	ACTIONS
26	25	New	KG	ONE	23423	4324	5	Edit | Delete
32	234	OLd	L	One	4	5	8	Edit | Delete
39	50	new	KG	Three	4	5	8	Edit | Delete
40	80	used	Meter	One	4	5	8	Edit | Delete
47	90	Used	Kg	Four	12	12	5	Edit | Delete
52	100	New	Liter	One	12	12	5	Edit | Delete

Figure 4.2 Spare parts window

4.3.3. Intervention Management:

The Intervention Management page is a prominent area in the CMMS because it provides a complete listing of all the maintenance interventions performed in the company. The scope of the system is to allow for corrective and preventive types of intervention so users can categorize and track the nature of each activity. Each intervention record contains important information such as status, type, and the equipment concerned with the intervention. Users may add, edit, delete, print interventions, and update the progress status to indicate whether the intervention is pending, in process, or completed, these actions are depicted in the figures 4.3 and 4.4 for a better understanding. This enables a proper tracking system of maintenance procedures and allows a historical record for performance management and analysis.

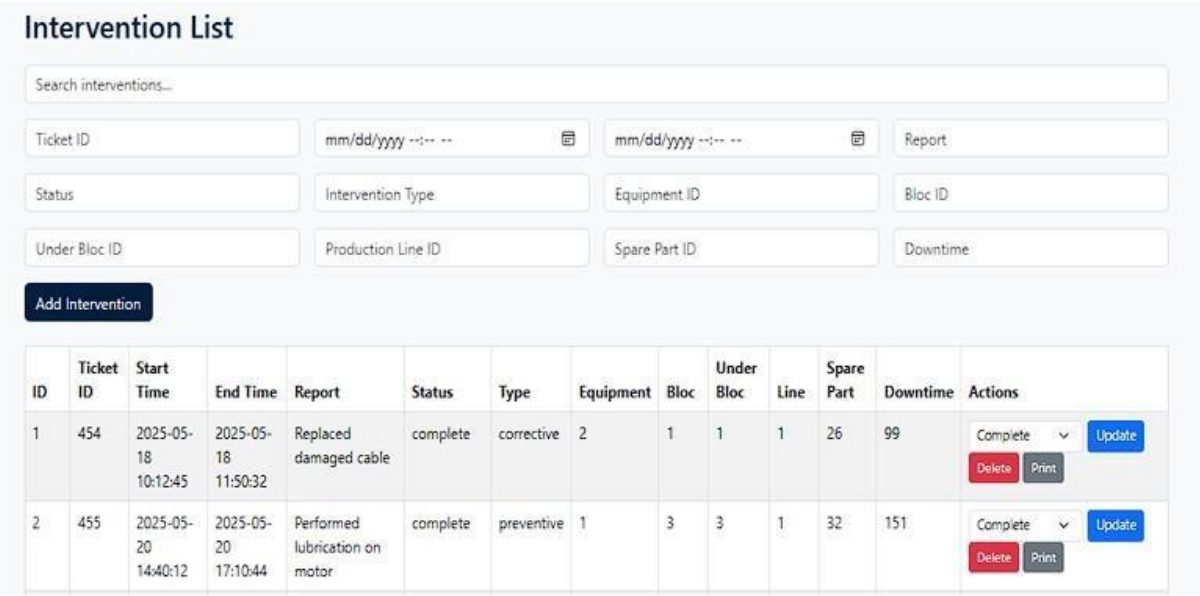
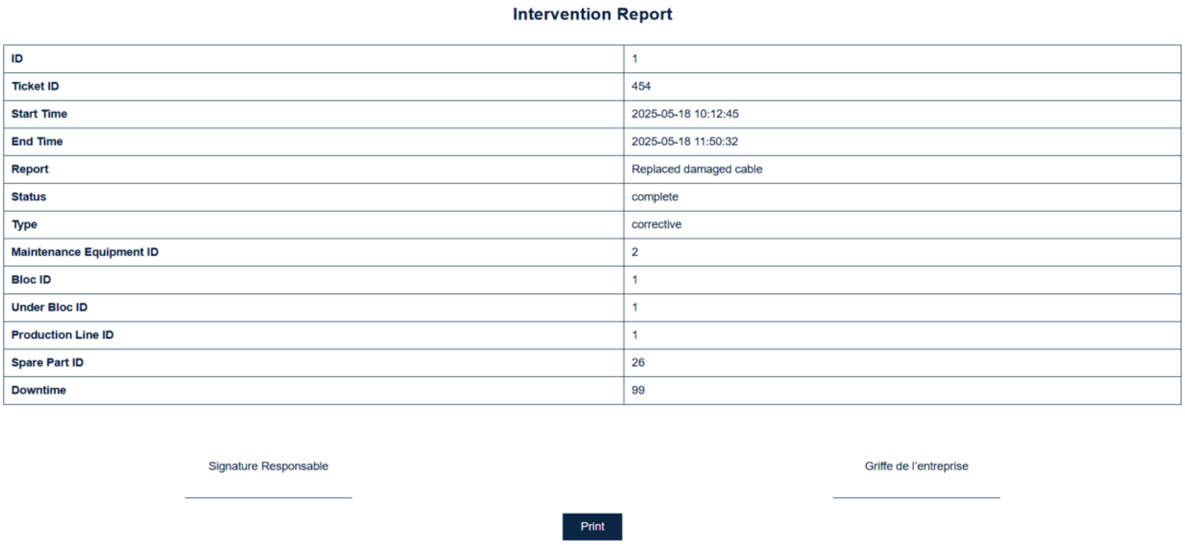


Figure 4.3 intervention list window



Intervention Report

ID	1
Ticket ID	454
Start Time	2025-05-18 10:12:45
End Time	2025-05-18 11:50:32
Report	Replaced damaged cable
Status	complete
Type	corrective
Maintenance Equipment ID	2
Bloc ID	1
Under Bloc ID	1
Production Line ID	1
Spare Part ID	26
Downtime	99

Signature Responsable

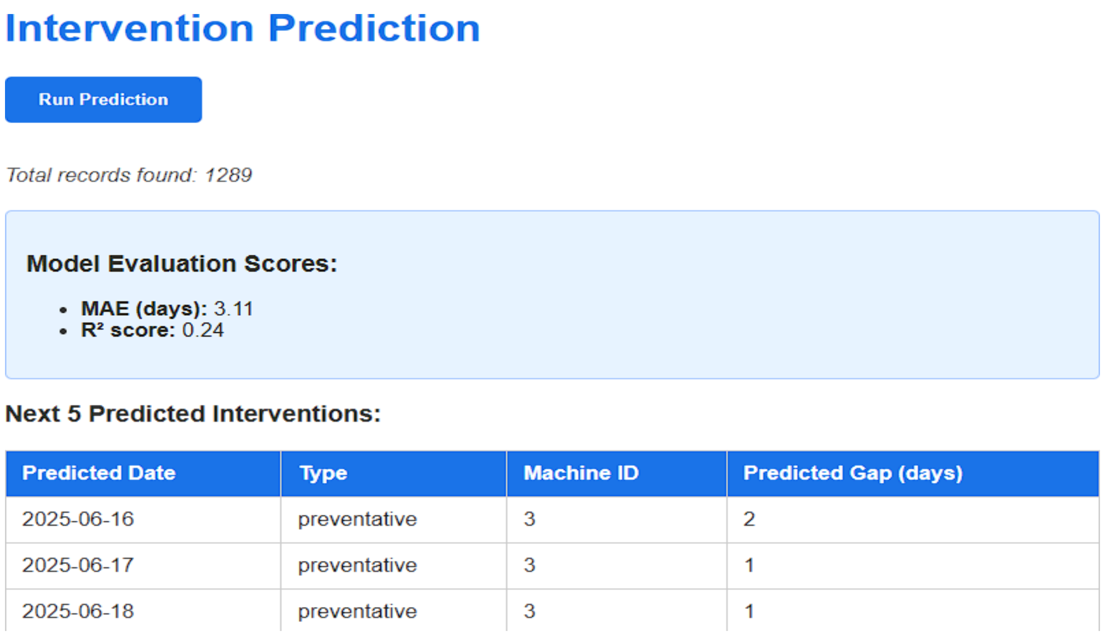
Griffe de l'entreprise

Print

Figure 4.4 Printing window

4.3.4. Predictive Maintenance Module:

To support the development of predictive maintenance, a machine learning prediction module was incorporated into CMMS. The module analyzes the historical intervention history to determine where patterns of maintenance may exist. A Multi-Layer Perceptron Regressor using label-encoded and normalized data is used to predict the future maintenance requirements. The accuracy of the model is defined by MAE and R^2 values. The system can predict the next five maintenance dates and intervals for every individual line of production and action to be able to do predictive scheduling to reduce downtime as shown in figure 4.5.



Predicted Date	Type	Machine ID	Predicted Gap (days)
2025-06-16	preventative	3	2
2025-06-17	preventative	3	1
2025-06-18	preventative	3	1

Figure 4.5 prediction results

4.3.4. Dashboard and KPI's:

The most important aspect of the CMMS is in the dashboard (figure4.6) and its ability to provide real time KPI's (figure4.7) so that upkeep of maintenance activities can be monitored effectively. The whole dashboard is made of cards that lead off to further pages that contain charts and reports. The dashboard was developed with the capability for management to make quick decisions based on trend data for things such as actions, work orders, stocks and personnel activities in visual and interactive format. The critical performance indicators that have already been incorporated into the dashboard are:

- ❖ Intervention Completion: This will tell if the intervention was completed, in progressor, not yet started.
- ❖ Work Order Stats: This will tell how many work orders and type of work orders were processed into the system.
- ❖ Attendance Dashboard: This will aggregate attendance forms from individual employees so that time in and out, as well as type of absence can be quickly found.
- ❖ Line Intervention Chart: This chart will show which production line had the greatest amount of activity for maintenance related intervention.
- ❖ Average Down time per Intervention: This will show average time of down time per intervention recorded.
- ❖ Spare Parts Stats: This will show what your spare parts on hand are, and compare to how much you used across all equipment.
- ❖ Maintenance budget: This will keep track and visually demonstrate budgeting regarding the cost of maintenance.
- ❖ Downtime rate : This will show the downtime or downtime rate of production or equipment downtime per selected time period

Figure 4.6 Dashboard window

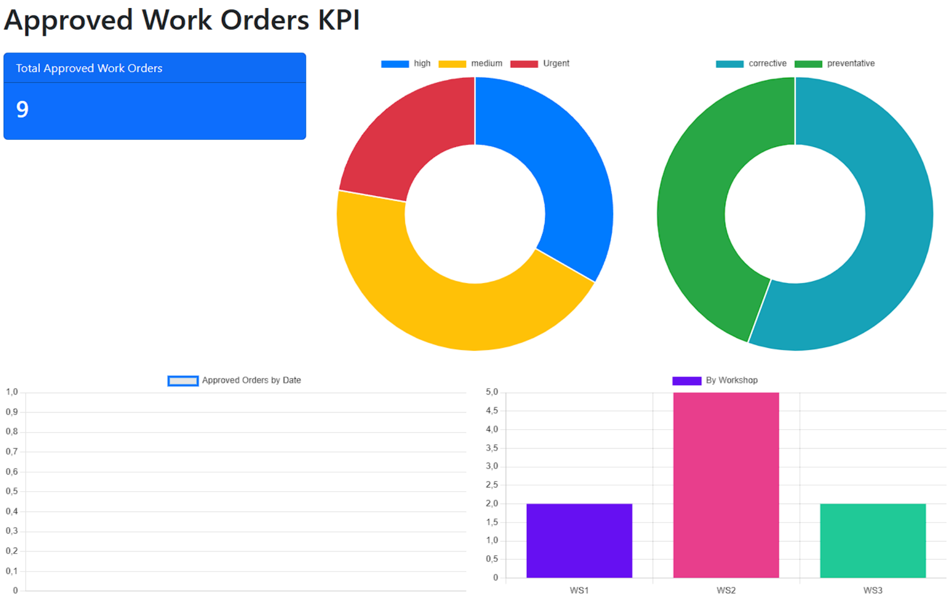


Figure 4.7 Kpis window

4.3. Expected Outcomes (Short-Term and Long-Term Effect):

While the CMMS developed for LILAS has not yet been implemented in a production manufacturing situation, the framework, capabilities, and technical specifications indicate a number of anticipated benefits. Regardless, these anticipated benefits are based on a combination of successful testing of the system, successful interface validation, and in some instances best-practice comparisons within the industry. The anticipated benefits can be viewed as two horizons, a short-term improvement immediately post installation, and long-term benefits from continued use and data accumulation.

4.4.1 Short-Term Expectations:

In the first cycle of implementation, the CMMS will converge maintenance activities through the entry, storage and retrieval of data into one user interface. This structured view will enable maintenance technicians, supervisors, and managers to view information relevant to them on equipment status, history of interventions and the inventory of spare parts without reliance on paper records or other non-system related paths of communication. In this transition to CMMS, we can expect:

- ❖ Decrease of human error and the loss of key maintenance information.
- ❖ Decreased response time to service requests to the maintenance team due to real-time access to data.
- ❖ Improvement of visibility to current workloads and inventory of spare parts.
- ❖ Ease of creating work order and intervention reports using electronic forms.

User role management will also allow that each user be provided access to only those modules or modules related to their role, thus improving both manner and security of use. The dashboards will provide simple access to key performance indicators, enabling supervisors to make short-term informed decisions regarding the deployment of staff resources and the prioritization of intervention requests.

4.4.2 Long-Term Expectations:

In the long term, we expect the CMMS to greatly enhance proactive and predictive maintenance practices. By continuously capturing history of intervention and equipment data, the CMMS will establish a reliable data set to be utilized in performance analysis and long-term planning. Employing a predictive maintenance module based on a Multi-Layer Perceptron (MLP) Regressor will enable maintenance staff to anticipate future breakdown patterns as a function of what we can learn from examining historical data sets and patterns. This process allows us to transition from purely reactive maintenance to a more proactive approach with a vision on upfront benefits including:

- ❖ Decreased unplanned downtime and the associated costs of production losses.
- ❖ Increased equipment life through consistent and timely maintenance.
- ❖ Improved management of spare parts inventory attributable to forecasting usage.
- ❖ Long term KPI trends and reporting for future strategy and decision making.

Finally, with dashboards, attendance logs and budget tracking combined, management will also be in a position to identify patterns of inefficiency, good spending and justification of costs associated with maintenance. Over time, these benefits will be expanded to form a culture of continuous improvement and data driven maintenance planning.

4.5 Discussion:

4.5.1 Limitations and Areas for Improvement:

While the designed CMMS for LILAS has a functional, modular and extendable architecture, during development, we encountered limitations that we know will be the basis of improved functionalities, as well as successful implementation in an industry setting.

- Absence of Real-World Deployment:

One obvious disadvantage is the absence of a real-world deployment and operation feedback. The system has been prototyped in a test environment, in a simulation or based on data available to us in a test environment that likely doesn't represent dynamic, real-time behavior of a real-world maintenance process. As such, there is a possibility that real usage by end-users or organizational integration will expose usability shortcomings or performance bottlenecks that we haven't revealed so far.

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- Narrow Scope of Predictive Models:

While we included a predictive maintenance module using an MLP Regressor, its dependability and accuracy is limited by the historical data quality, and quantity, that we can train it on, and again, in actual deployment would require fit for purpose periodical data collection in order to allow us to reload the model into our system, ultimately to improve predictive quality, and promote flexibility across equipment.

- Security and Authentication Enhancements:

There is basic role-based access control, but there are no advanced security features such as two-factor authentication (2FA) and logging of activities. If this system is going to be used in a production environment, these features are essential to safeguard sensitive operational and personnel information.

- No Integration with External Systems:

There are no integrations with external systems. Currently, the CMMS is a stand-alone application with no integrations with other enterprise solutions such as an ERP system, inventory management, or production planning packages. Future iterations could have APIs or webhooks that enable interoperability and data synchronization between departments.

- Language and Localization Constraints:

Although the system will prepare documents in multiple languages, there are localization capabilities (date formats, units of measure conventions, right-to-left interface operation etc) that have not been fully completed. These capabilities would make it possible for most employees who will deal with the software to accommodate it more easily.

4.5.2 Development Challenges:

The development of the web application for the CMMS occurred during different distinct technical and structural challenges in the integration of different parts into a cohesive and intuitive solution. The main challenges experienced are:

- Frontend-Backend Integration:

Meticulous routing and data formatting was needed for unhindered interaction between the HTML/CSS frontend and the Flask backend, especially in how user inputs were handled and used to create data output in the database.

- ❖ Role-Based Access Control:

Secure and efficient management of user roles was critical. This involved conditional content rendering, protection of routes, and maintenance of session content integrity for each role (Technician, Director, Spare Part Agent).

- ❖ Working with Interrelated Relational Data:

Working with information situated between disparate tables (interventions, equipment, orders, spare parts) involved an appropriate database schema, optimized SQL queries, and careful referential integrity.

- ❖ User Interface design without tools:

Due to our developing a responsive, interactive user interface only with HTML, CSS, Bootstrap (and no JavaScript libraries), layout, styles and flexibility were limiting factors

- ❖ Maintaining Usability vs. Complexity:

Developing a user experience that is uncluttered and easy to understand but simultaneously provides the complexity of maintenance activities (forms, dashboards, status updates) required progressive iterations and user design approaches.

In summary, although the CMMS developed for SAH SPA LILAS rests solid foundations with regard to architecture, functionality and prediction, its implementation in the real-world is necessary to confirm its strengths in practice. Addressing some of the currently weaker aspects of the system such as larger system integration, enhanced security, and greater localization will also correspond the platform to the needs of the Algerian industrial context and its use in operations. Learning from the development challenges will inform future development iterations, and offer a stronger, more scalable, and user-centered system that will evolve as LILAS's maintenance demands change.

4.6 Conclusion:

This chapter described the CMMS developed for SAH SPA LILAS's maintenance operations in detail. The CMMS was designed modularly, managed the role management aspect of the system, managed the interventions made, and spare parts, and provided a source for KPI, and even predictive maintenance. Along the way in development, there were problems to deal with e.g. issues due to functionality from frontend to backend, and a few more issues present such as a no deployment, no security policies, and as of now no system integration. This said, the CMMS delivered a sound digital platform for promoting efficiency, minimizing downtime, and furthering data-based decision making in the organization.

GENERAL CONCLUSION

In conclusion, this dissertation has provided a holistic approach to the operational challenges faced by SAH SPA LILAS through the design and development of a Computerized Maintenance Management System in an integrated way, allowing us to show how the intersection of Industry 4.0 technologies with quality management philosophies can provide transformational value propositions for modern industrial organizations.

The developed CMMS took a considerable leap forward from paper maintenance to an engaging digital system. By leveraging the capability implemented through web technologies (HTML, CSS), the rich foundational capabilities offered by established backend frameworks (Flask, MySQL) and the possibilities made capable by data analytics libraries (Pandas, NumPy, Scikit-learn), the system offers complete functionality for user authentication, role-based permissions, process intervention, spare parts stock management, work order management, and predictive maintenance modeling. The use of machine learning methods, specifically a Multi-Layer Perceptron (MLP) Regressor, allows for the transition from reactive maintenance approaches to proactive initiatives, thus enhancing the potential for unplanned downtime to be reduced, and equipment lifetime will be lengthened.

The ISO 9001:2015 process modeling based on analysis suggests some evolving influences affecting the target system. The identified gaps in the manual processes presently in use, and the targeted CMMS-supported workflows show significant improvements in coordination, traceability, and decision rights at every level of organization. The KPI dashboard function of the system provides up-to-the-minute operational visibility enabling management decisions through data, and promoting the potential for continuous improvement.

The work also identifies many limitations to be resolved for successful implementation in a real-world situation, for example: limited deployment / testing; limited predictive model capacity; evolving security capabilities; lack of external systems integration; and localization limitations. These are all noted limitations though they do not diminish the fundamental value of the designed system they represent opportunities for improvements.

PERSPECTIVE

As SAH SPA LILAS expands into the Maghreb region, this research is a practical roadmap for Algeria's industrial modernization. CMMS implementation at SAH SPA LILAS exemplifies a systematic problem-solving approach that is consistent with successful Algerian enterprises, and incorporates continuous improvement by establishing a recent implementation of new technology to improve the El Bouni manufacturing zone.

To lead the adoption of Industry 4.0 in Algeria, SAH SPA LILAS should provide a full digital transformation that includes smart sensors, real-time monitoring, and predictive analysis to mitigate downtime and enhance their competitiveness. Establishing a Digital Innovation and Quality Excellence Team would solidify this practice, promoting operational excellence in all eight production lines.

Human capital formation is important. A knowledge management center would also facilitate the preservation and transfer of knowledge across shifts to support Algeria's effort for self-sustaining industrial growth. The establishment of local supply chains and spare part production is consistent with the national objective of economic diversification and the reduction of dependencies on foreign markets.

CMMS would be expanded by adding mobile apps on tablets, which would also improve monitoring in real time and take advantage of the telecommunications infrastructure rapidly developing in Algeria. The addition of environmental monitoring to the system would support sustainability measures, and coordinate local and national eco-initiatives.

Lastly, collaboration agreements with universities and technical institutes would guarantee a steady supply of qualified engineers who are knowledgeable about cutting-edge maintenance systems.

In conjunction with the analytical precision that was demonstrated in this study, SAH SPA LILAS can set an example and a vision for other Algerian businesses and for sustainable, technology-oriented growth.

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