Evaluation of Pilot Courses in Maintenance Engineering Programmes

Achieved result of the SMTMC project

Developed and implemented in collaboration with the Universities of Sfax, Gabès, and Carthage
Focused on Virtual Reality, Predictive Maintenance, and Vibration-Based Diagnostics
Validated by academic teams and industrial experts
Used to test and improve competence-based pedagogical approaches

1. Introduction

This result presents the evaluation of pilot courses implemented within the SMTMC project in Tunisia. These pilot sessions were designed to test the effectiveness of newly developed Master's courses in industrial maintenance and assess their alignment with industry expectations and competence-based learning.

The pilots were conducted at the Universities of Sfax, Gabès, and Carthage, focusing respectively on Virtual Reality in Maintenance, Maintenance Engineering Technology, and Vibration-Based Fault Detection. This evaluation highlights the pedagogical value of the pilots, gathers feedback from students and instructors, and draws lessons for future programme deployment.

2. Objectives

The objectives of the pilot course evaluation were to:

• Assess the effectiveness and relevance of newly developed course content

• Collect structured feedback from students and instructors on course delivery and learning outcomes

• Identify challenges and improvement areas in teaching methods, digital tools, and student engagement

• Validate the alignment of the pilot courses with the competence framework defined under

the SMTMC project
• Provide transferable recommendations for other institutions seeking to modernise engineering education using similar pedagogical innovations

The pilot courses also aimed to:
• Provide hands-on learning experiences by integrating real-world industrial challenges
• Introduce advanced technologies such as Virtual Reality (VR), predictive maintenance, and data-driven diagnostics
• Bridge the gap between academic knowledge and industry expectations, ensuring graduates are job-ready
• Develop an evaluation framework to measure the effectiveness of these courses and improve future implementations

This document details the structure, methodologies, and evaluation process for each pilot course, ensuring they contribute to the broader objectives of the SMTMC project.

II. Sfax University Pilot Course

Virtual Reality in Maintenance using Oculus VR

An innovative pilot course in virtual reality for maintenance engineering was developed at the Higher Institute of Industrial Management of Sfax (ISGIS), University of Sfax. The course is open to all four Tunisian universities and was launched in September 2023 as part of the first-year programme of the professional Master's in Management and Maintenance of Industrial Systems.

The pilot course combines theoretical knowledge and practical application. Students are introduced to immersive learning environments using Oculus VR headsets. They explore virtual maintenance scenarios, simulate interventions, and analyse fault situations in 3D industrial spaces. The course is delivered through a blended approach, with classroom theory sessions followed by virtual simulations in the lab. Evaluation methods include project-based tasks and hands-on exercises conducted in virtual reality.

Student feedback highlighted the immersive quality of the course and its relevance to modern industrial contexts. Teachers observed increased student engagement and improved spatial reasoning skills. Some challenges were noted regarding adaptation time to the VR equipment and the need for more scenario diversity.

I.1. Overview of the Pilot Course

Virtual Reality for Maintenance is an introductory course that enables students to understand the principles of virtual and augmented reality. Virtual reality makes it possible to train technicians before on-site interventions, while augmented reality supports them during maintenance operations. Initial feedback has been highly positive. VR can be applied to tasks such as site inspection, quality control, and onboarding of new employees regarding safety policies and key procedures.

I.2. Objectives of the Pilot Course

The objectives of the pilot course “Virtual Reality with Oculus VR” are as follows:

1. Introduce core VR concepts: familiarise students with the foundational principles of virtual reality, including immersion, interaction, presence, and the supporting technologies.
2. Develop technical skills in VR development: train students to create VR environments using tools such as Unity and Oculus VR, including environment creation, 3D modelling basics, and interaction programming.
3. Enhance problem-solving and project-based learning: encourage students to develop interactive VR projects that address real-world applications.
4. Explore VR’s real-world applications: provide examples from various sectors (education, healthcare, engineering, entertainment) to broaden students' understanding of VR usage.
5. Promote teamwork and collaboration: enable students to work in teams on multidisciplinary VR projects, reflecting professional practice.
6. Foster communication and presentation skills: through presentations and demonstrations, students develop their ability to explain technical content clearly and justify design decisions.

The course aims to produce students who are proficient in both theoretical and practical aspects of VR, able to create and present functional VR projects, and equipped to develop further in this fast-evolving field.

I.3. Course Plan: Virtual Reality with Oculus VR

Technologies used: Oculus VR, Unity, SimLab, Blender
Teaching approach: Project-based learning using real-world case studies
Practical applications: Simulated maintenance of industrial equipment and remote training for technicians

Key learning outcomes:

- Understand the principles of VR and AR and their applications in industrial maintenance
- Develop VR-based training scenarios for industrial maintenance procedures
- Evaluate the impact of VR on technician training and safety

Programme details:

Part 1: Introduction to Virtual Reality
Objectives: Understand the basics of VR, its history, and applications
Theory: Definitions, immersion, interaction, applications across fields
Lab: Familiarisation with Oculus VR headsets and immersive experience

Part 2: Components and Technologies of VR
Objectives: Discover the hardware and software behind VR systems
Theory: Headsets, sensors, controllers, Unity and Unreal engines
Lab: Hands-on exploration in a 3D virtual environment

Part 3: Creating VR Content with Unity or SimLab
Objectives: Learn to design VR environments
Theory: Unity basics, 3D objects, lighting, interactions
Lab: Create a basic VR environment and deploy it using Oculus

Part 4: Interactions in VR – Controllers and Gestures

Objectives: Implement intuitive interactions in VR

Theory: Interaction types, ergonomic principles

Lab: Program basic movements and gestures with Oculus controllers

Part 5: Immersive Experiences and Educational Applications

Objectives: Explore educational use of VR

Theory: Examples of educational scenarios and engagement strategies

Lab: Develop an immersive educational scene using Unity

Part 6: VR and AR – Comparison and Use Cases

Objectives: Distinguish VR and AR and understand use cases

Theory: Introduction to AR, combined applications

Lab: Demonstration using hybrid VR/AR modules

Part 7: Team-Based Project

Objectives: Build a complete VR project

Theory: Project planning and evaluation strategies

Lab: Develop and test a fully functional VR environment addressing a real-world challenge

I.4. Evaluation Exam Overview

1. Theoretical Exam (40%)

Format: Written exam with multiple-choice questions, short answers, and one or two open-ended questions

Content:

- Core VR concepts: immersion, interaction, presence, applications
- Technical knowledge: VR system components, differences between VR and AR
- Design principles: user experience, ergonomic design

  Objective: Evaluate the students' understanding of VR and ability to apply it to practical or theoretical situations

2. Practical Project and Presentation (60%)

Format: Team project and individual evaluation

Content:

- Project development (30%): design and implement a complete VR scene with Unity and Oculus
- Presentation (15%): present project objectives, choices, and potential use cases
- Individual Q&A (15%): evaluate individual contributions and technical understanding

This evaluation structure ensures a balance between theoretical mastery and practical skill development. It also fosters teamwork, creativity, and communication, essential competences for professional practice in immersive technology fields.

II. Gabes university Pilot course

A Pilot course in ***Maintenance Engineering Technology for industrial systems and equipment*** has been created at The Higher Institute of Applied Sciences and Technology Gabes of the University of Gabes. This pilot course has started in September 2022 for the first year of the Professional Master Mechanics and Electronics of Automated Systems (MESA) (https://issatgb.rnu.tn/fra/pages/117/mecatronique). The pilot course offers both the theoretical as well as the practical contains of the program.

II.1 Overview of the pilot course

Understanding the parameters of different approaches to mechanical system repair and diagnostics is essential for a maintenance technician. Failure analysis, lubrication, and shaft alignment are critical components of a viable maintenance strategy for rotating machinery. Taken individually, each technique helps reduce unexpected machine failures, however when combined, they form the core of a proactive maintenance strategy that not only identifies emerging problems but also significantly extends machine life.

II.2. Objectives of the pilot course

These courses are composed of two main parts. The first part reviews the basics of maintenance, identifies the different types of maintenance documentation and covers failure analysis techniques. The second part focuses on specific techniques such as shafts alignment and lubrication systems. Therefore, at the end of this course, students should be able to:

- Choose the appropriate maintenance policy for a given situation using diagnostic support tools and understand various repair and diagnostic methods for mechanical systems.
- Control failure mechanisms.
- Develop technical skills in shaft alignment and lubrication to establish a viable maintenance strategy for rotating machines.

II.3. Course Plan

❖ **Part I: The different forms of Maintenance**

Objectives: This part presents methods and tools for organizing, evaluating, and analyzing the maintenance function. Basic concepts of maintenance will be introduced, followed by different methods and mechanisms. It covers:

- Maintenance concepts.

- Maintenance methods.

- Maintenance mechanisms.

❖ **Part II: Maintenance documentation**

Objectives: Discuss the various elements and components of maintenance documents and it covers :

- General documentation

- Strategic documentation

❖ **Part III: Failure analysis and diagnostic assistance**

-The characteristics of the failures.

-The failure mechanisms.

❖ **Part IV: Quantitative and qualitative analysis of failures**

Objectives: Select the appropriate maintenance policy for specific situations using diagnostic support tools, and master failure mechanisms through quantitative and qualitative analysis.

- **Part IV: Shaft alignment**

Objectives: Optimize shaft alignment choices through various alignment methods and practices. It covers:

-Alignment settings

- Alignment tolerances

-Alignment methods and practice

- **Part V**: **Lubrication of mechanical systems**

Objectives: Choose the optimal lubrication method for mechanical systems by understanding lubrication techniques and control tools. It covers:

-The characteristics of lubricants

-Lubricant control tools

-Lubrication techniques

II.4. Practical works

This course concludes with practical work on a **computerized maintenance management** system "CMMS" to reinforce the associated concepts. Students will familiarize themselves with CMMS software by configuring all the equipment of a company that is under the maintenance department's responsibility, managing various maintenance tasks (preventive and corrective) and the maintenance supplies in favor to finally monitoring and calculation of monthly performance indicators of equipment.

By the end of this course, students will understand the contribution of maintenance processes and maintenance management to high availability, safety, and profitability. They will grasp basic maintenance terms and know the methods and techniques for planning, scheduling, performing, and analyzing maintenance. Specifically, students will be able to develop maintenance documents, define indicators to measure maintenance performance, and analyze failures using quantitative methods. Students will also be able to manipulate maintenance management software and resolve any industrial problems.

II.5. Evaluation Exam Overview

This pilot course is evaluated through theoretical exam (75%) and practical project (25%).

1. Theoretical Exam (75%)

- **Format:** Written exam with multiple-choice questions, short answers, and a few in-depth open-ended questions.
- **Content:**
  - Fundamentals of maintenance concepts: definitions, concepts, methods, and key applications.
  - Technical knowledge: Students should be able to propose a technological solution to the maintenance problem posed.

2. Practical Project and Presentation (25%)

- **Format:** In the laboratory, students carry out exercises on maintenance work in a team. They solve problems and cases using the computer, analyze and interpret the results and writes a complete technical report. As personal work, students review theoretical concepts through study and homework, complete the exercises and work done in the laboratory. They prepare also the upcoming course by learning about the topics being studied.

This evaluation format balances theoretical knowledge with practical application, encouraging students to demonstrate both understanding and practical skills in maintenance management. The practical project also fosters teamwork and project management skills.

III. Cartage university Pilot course : Fault detection based on_vibration analysis

A recent course in Fault detection based on vibration analysis has been presented at The Ecole polytechnique de Tunisie (EPT) and the National Engineering school of Bizerte (ENIB), part of the university of Carthage. This pilot course has started since September 2022 and was presented for engineering students in different levels for their engineering programs (1st and 2nd year in EPT engineering program and 2nd and 3rd year at ENIB with both tracks Industrial and Mechanical engineers, Professional Master degree in Maintenance at ENIB). This course offers both theoretical and practical contents to handle industrial engineering applications such as rotating machineries.

I.1. Overview of the pilot course

The course is named "**Fault detection based on vibration analysis**" and it examines **problems and issues observed in some industrial applications** such as monitoring of rotating equipment like pumps, turbines and compressors.

The main objective behind this course is to familiarize engineering and master students on health monitoring techniques based on classical methods and new approaches to detect faults and/or damages before total failure of the equipment.

Example of a course handbook :

République Tunisienne
Ministère de l'Enseignement Supérieur, de la Recherche Scientifique

ENIB

Université de Carthage
-
Ecole Nationale d'Ingénieurs de Bizerte (ENIB)

Mastère professionnel : Ingénierie de la maintenance

Cours de

Maintenance – Niveau II

Code UE : 311

« Mieux vaut penser le changement que changer le pansement»

Préparé et enseigné par :

Dr. Ing. Mohamed Amin BEN HASSENA

Niveau d'étude : 2ème année Mastère Ingénierie de la maintenance

Année Universitaire – 2023/2024

Détail du cours

Objectifs de l'unité d'enseignement (UE) :

Cette unité permet d'identifier et de calculer les indicateurs de performance en production et maintenance afin d'évaluer les états réels des biens et des lignes de production par rapport aux objectives fixés. Ceci nous permet aussi de lancer des analyses prévisionnelles de défaillances : apport de la sûreté de fonctionnement (Sdf).

Plan du cours

I. Enjeux et métier de la maintenance

II. Sureté de fonctionnement et indicateurs de performances
   i. Sdf
   ii. Indicateur FMD (Fiabilité, maintenabilité, Disponibilité)
   iii. Durée de vie des biens

III. Méthodes et outils d'analyses
   i. Méthode ABC
   ii. Loi de Pareto
   iii. Diagramme Ishikawa
   iv. AMDEC

IV. Analyse et diagnostic des défaillances
   i. Analyse vibratoire
   ii. Exemple de défauts courants

Contribution du cours

Unité de l'enseignement : **Outils de la maintenance**

Éléments constitutifs	Volume des heures de formation Hybride (présentielles et à distance) sur 14 semaines				Crédits
	Cours	TD	TP	Autres	
Maintenance II	28			14	3
TPM et Tableau de bord de la maintenance	28			14	3
Total	56			28	6

Méthodes d'évaluation

ECUE	Contrôle continu				Examen final				Coef. de l'ECUE	Coef. de l'UE au sein du parcours
	EPREUVES			Pondéra-tion	EPREUVES			Pondéra tion		
	Ecrit	Oral	TP et Autres		Ecrit	Oral	TP et Autres			
UE311			X	50%	X			50%	1.5	3
UE312			X	50%	X			50%	1.5	

Activités pratiques

- Programmation des méthodes d'analyses sur Python
- Collecte de données sur mécanisme avec défauts : Banc d'essai de diagnostic à l'ENIB

Accès au cours en ligne

- Documents et travaux à rendre : https://classroom.google.com/c/NjM0OTgwMTU4ODY4

❖ Course Objectives

By the end of this course, the student should be able to:

CO1 - Solve analytical and numerical problems related to vibrations of non-complex systems

CO2 - Analize time and frequency responses of dynamic signals

CO3 - Develop and conduct appropriate experimentation based on vibration sensors

CO4 - Analyze and interpret data from signals based on experiments

CO5 - Use and develop AI based model for early detection purposes

❖ Course content

1. Basics and Fundamentals of vibration

a- Simple DOF systems

b- Multiple DOF systems

2. Rotating machinery dynamic behavior

a- shafts, bearings

b- motors, pumps, turbines

3. Classical methods for signal processing

a- time presentation

b- Frequency responses (FFT, envelope analysis, spectrum analysis)

c- time and frequency analysis (wavelet)

4. Artificial Intelligence and Machine Learning techniques

a- principles and classification methods

b- deep learning : CNN, DNN , RNN

c- autoencoders

❖ Course Evaluation

The final grade of the course will be based on industrial or laboratory projects in which we consider the technical findings and the proposed solutions.

❖ Course materials

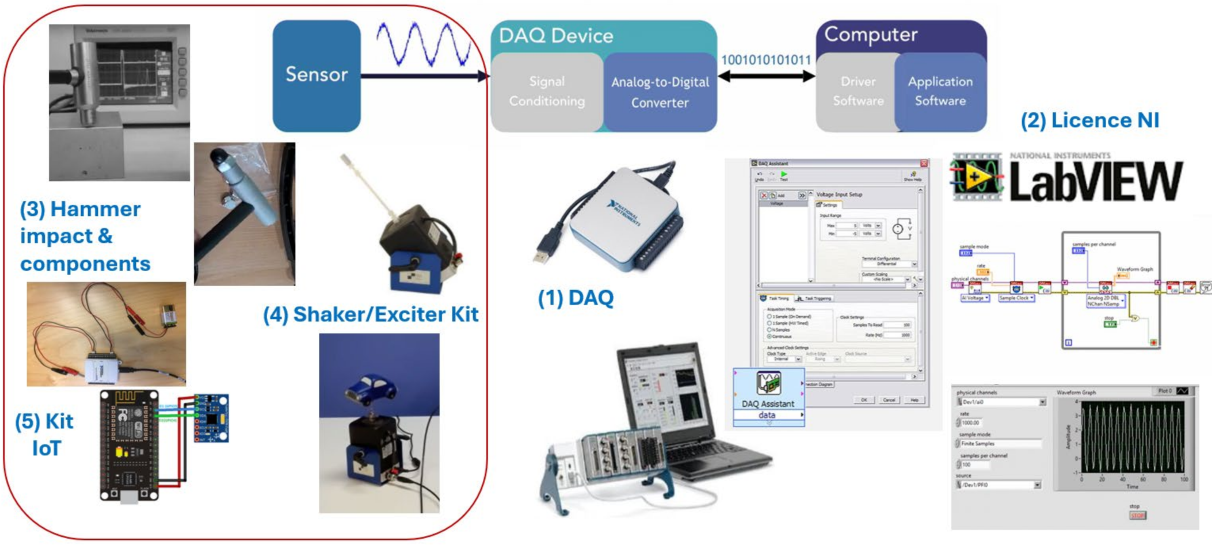
We need in this course, the following materials:

- Course notes : maintenance , basics of vibration , dynamic of structures
- Softwares: Matlab, Toolbox, google colab, Labview
- Hardware:

- Uniaxial Accelerometer 50g , NI-DAQ 9174, pcb-piezotronics-300A33, Miniature shaker with integrated amplifier
- Machinery diagnostic system base unit: PT 500 , Roller bearing faults kit PT 500.12
- Damage to gears kit PT 500.15 , Cavitation in pumps kit PT 500.17

- Data set (numerical and experimental)

The following figure presents the accessible materials to be used for this pilot course and.



I.2. Practical works and Course Progress

This course, combining theoretical, practical, and experimental approaches, enables students to acquire key skills related to practical machine diagnostics based on vibration concepts and signal analysis tools.

The application of theoretical concepts through the handling of real industrial equipment for vibration analysis and the use of software such as MATLAB and LabVIEW.

- **1st practical work: : Analysis of Vibrating Systems**

Based on a " Universal Educational Vibration Bench", to end up with a suitable analysis of vibration phenomena in simple mechanical systems (1D beams), this practical work aim to:

- Understand free and forced vibrations

- Analyze damping effects (underdamped, critically damped, overdamped)
- Explore resonance and its impact on structures

- **2nd practical work: Roller bearing fault detection**

Based on a " Educational Bench for Machine Vibration Diagnostic System" to end up with a suitable diagnostics in rotating machinery, this practical aim to enhance skills on Machine Condition Monitoring & Fault Diagnosis :

- Identify and diagnose common machine faults (unbalance, misalignment, bearing defects, looseness, etc.).
- Understand predictive maintenance techniques and condition-based monitoring.

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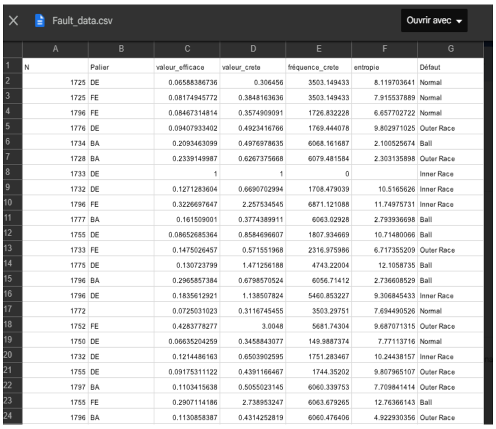
t aims basically to let student practice vibration Measurement & Signal Processing tools.

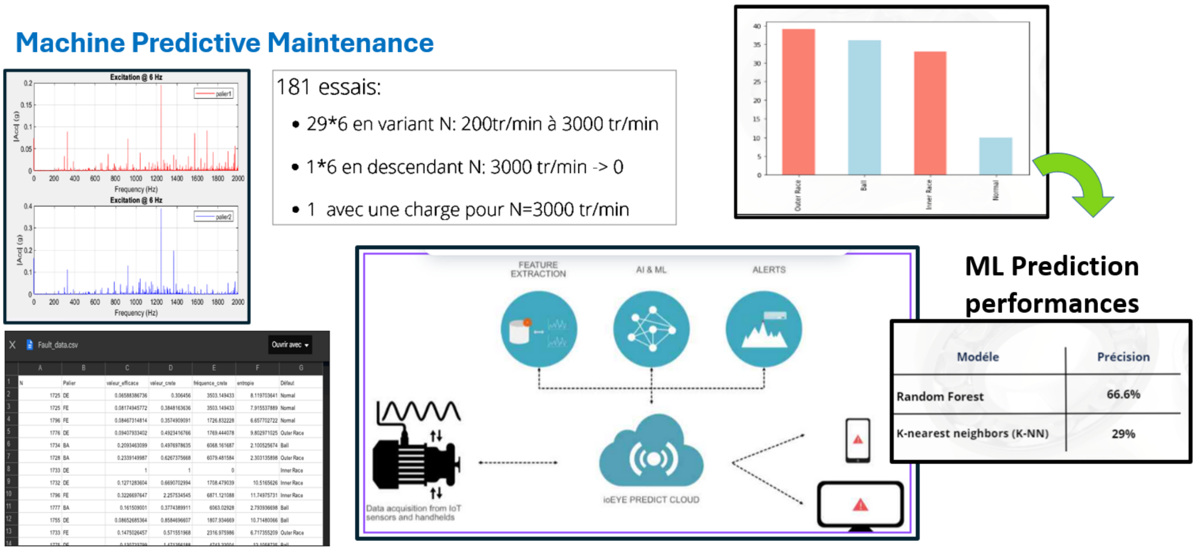
- What to measure (acceleration, displacement, etc.) ?
- How to analyze vibration signals using software like MATLAB (or LabVIEW)


Fault_data.csv

N	Palier	valeur_efficace	valeur_crete	fréquence_crete	entropie	Défaut
1725	DE	0.06588386736	0.306456	3503.149433	8.119703641	Normal
1725	FE	0.08174945772	0.3848163636	3503.149433	7.915537889	Normal
1796	FE	0.08467314814	0.3574909091	1726.832228	6.657702722	Normal
1776	DE	0.09407933402	0.4923416766	1769.444078	9.802971025	Outer Race
1734	BA	0.2093463099	0.4976978635	6068.161687	2.100525674	Ball
1728	BA	0.2339149987	0.6267375668	6079.481584	2.303135898	Outer Race
1733	DE	1	1	0		Inner Race
1732	DE	0.1271283604	0.6690702994	1708.479039	10.5165626	Inner Race
1796	FE	0.3226697647	2.257534545	6871.121088	11.74975731	Inner Race
1777	BA	0.161509001	0.3774389911	6063.02928	2.793936698	Ball
1755	DE	0.08652685364	0.8584696607	1807.934669	10.71480066	Ball
1733	FE	0.1475026457	0.571551968	2316.975986	6.717355209	Outer Race
1775	DE	0.130723799	1.471256188	4743.22004	12.1058735	Ball
1796	BA	0.2965857384	0.6798570524	6056.71412	2.736608529	Ball
1796	DE	0.1835612921	1.138507824	5460.853227	9.306845433	Inner Race
1772		0.0725031023	0.3116745455	3503.29751	7.694490526	Normal
1752	FE	0.4283778277	3.0048	5681.74304	9.687071315	Outer Race
1750	DE	0.06635204259	0.3458843077	149.9887374	7.77113716	Normal
1732	DE	0.1214486163	0.6503902595	1751.283467	10.24438157	Inner Race
1755	DE	0.09175311122	0.4391166467	1744.35202	9.807965107	Outer Race
1797	BA	0.1103415638	0.5055023145	6060.339753	7.709841414	Outer Race
1755	FE	0.2907114186	2.738953247	6063.679265	12.76366143	Ball
1796	BA	0.1130858387	0.4314252819	6060.476406	4.922930356	Outer Race

- **3rd practical work: Predictive Maintenance through ML**

Based on a collected dataset during the 2nd practical workshop, Studentes have to test ML algorithms to detect the default time in roller bearing systems



I.3. Course benefits and impact

For industrial partners, this course is beneficial and has a great impact mainly on:

- **Cost Reduction**: Minimizing production downtime, repair expenses, and costly replacements.
- **Quality Assurance**: Real-time and continuous monitoring and early fault detection to ensure maintaining consistent product quality standards

- **Decision-Making Support**: Providing valuable insights for process optimization, predictive maintenance, and resource allocations.
- **Safety**: minimize the risk of accidents and injuries for workers and operators.
- **Reliability (Maintenance & Production)**: Preventing unexpected failures, ensuring continuous operation, and improving production efficiency.

In sum, with existing equipment at **ENIB** and the devotion of the academic staff, engineering and master's programs centered on technologies such as **predictive maintenance and vibration analysis** have enhanced students' skills with practical works. Future prospects include the integration of **IoT technologies and artificial intelligence**, opening new opportunities to further enhance the **relevance and effectiveness** of the training.

IV. Evaluation Methodology of Pilot Courses

To ensure the **quality and effectiveness** of the pilot courses, a structured **evaluation framework** has been implemented, integrating **feedback from students, instructors, and industry professionals**.

The continuous improvement process is important to meet the needs of industries and student competencies. To gather feedbacks of students and instructors, a "Training Course - Evaluation Questionnaire" was developed in work package Quality (WP5.2). Additionally, individual feedbacks during training permit :

- **Instructor feedback**: Evaluation of **teaching effectiveness, challenges faced, and recommendations for improvements**.
- **Student satisfaction :** Identification of **strengths and areas for improvement**.

As perspectives, **Industry feedback** should be included to validate of the course's relevance to current and emerging industry trends**.**

Conclusion

The **pilot courses** enrolled in the Tunisian university, include in the **SMTMC project**, had combined theoretical, practical, and experimental approaches, to enhance training in

industrial maintenance engineering and acquire key skills essential for careers in maintenance.

Through these pilot courses have focused on **advanced technologies** such as **Virtual Reality (VR), predictive maintenance, and data-driven diagnostics, by using practical based innovative pedagogical approaches**.

The evaluation have proved the effectiveness of these courses for the student's motivation and provide some recommendations for future implementations.