Development of Maintenance Engineering Training Programme – TMC-VET

1. Introduction

This report provides an overview of the activities undertaken in Work Package 3 during the period between September 2021 and March 2023. The report was prepared through collaborative efforts between Socomenin, the work package leader, and Plasmatrix, the co-leader, together with the partner in the TMS-VET cluster. Work Package 3 aimed to develop innovative training materials and guidelines for industrial staff and teachers in order to enhance their skills and competencies in using educational tools for VET purposes. The activities conducted during this period included a comprehensive review of existing training materials, an analysis of best practices, and development of new training materials. The report presents detailed information on each activity carried out by the team, along with their respective outcomes and impact. Overall, this report serves as a valuable resource for stakeholders interested in enhancing their industrial staff competence as well as teacher competencies in maintenance-based training methodologies.

2. Work package description

The outcomes of this WP will be based on the input from the industrial partners and other stakeholders. The courses have the purpose to boost the competence and skills of the maintenance personnel at all levels.

This WP will set the guidelines for the education, training, examination and qualification of maintenance personnel, and will prepare the training material. Industrial organizations will have an active role in the specification of the training programme and training of the staff.

Development of curricula for training for certification will be performed in the first part of this WP. There are three routes which could be implemented, standard route, self-going route and distance learning programs. The Standard Route requires attendance at approved Training Courses designed to meet the requirements specified in curricula. The Self-going Route allows those who have gained the knowledge and who can demonstrate it, to proceed to examination without compulsory attendance at an approved Training Course. In this deliverable will be decided the levels of maintenance qualification. At this are considered three levels:

- Level 1: Production managers
- Level 2: Maintenance engineers
- Level 3: Maintenance technicians

For each level, curricula identify the objectives and learning outcomes.

The activities in this work Package have been distributed in the following tasks:

3.1 Develop Curriculum for TMC-VET in maintenance engineering
3.2 Develop modular training material
3.3 Develop TMC-project scenarios for maintenance engineering
3.4 Organize Pilot course as well as evaluate and assess the Quality of the TMC-VET

4. Work Plan

The work package 3 activities are aligned with the initial proposal's work plan, which was developed to achieve the project's objectives effectively and efficiently. The work plan serves as a guide for the project team, outlining the tasks to be performed, their timelines, and the resources required to complete them. By adhering to the work plan developed in the proposal, the project team can ensure that they remain on track and that all deliverables are completed within specified timeframes. This approach allows for enhanced transparency and accountability throughout the project lifecycle, providing stakeholders with clear visibility into progress made towards achieving project goals. Ultimately, following the work plan developed in the initial proposal for work package 3 will help streamline processes and enable successful completion of project milestones.

Activities		Total duration (number of weeks)	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Ref.nr/ Sub-ref nr	Title													
WP3	Development of Maintenance Engineering training programme – TMC-VET	16=20X	0	0	0	0	0	0	0	1=1X	2=3X	2=3X	3=4X	6=7X
3.1	Develop Curriculum for TMC-VET in maintenance engineering (ME)	4=9X	0	0	0	0	0	0	0	1=1X	1=2X	1=2X	1=2X	1=2X
3.2	Develop modular training material	3=3X	0	0	0	0	0	0	0	0	0	0	0	3=3X
3.3	Develop TMC-project scenarios for ME	6=6X	0	0	0	0	0	0	0	0	1=1X	1=1X	2=2X	2=2X
3.4	Organize Pilot course and Evaluate and assess the Quality of the TMC-VET	0	0	0	0	0	0	0	0	0	0	0	0	0
WP3	Development of Maintenance Engineering training programme – TMC-VET	31=33X	2=2X	2=2X	2=2X	2=2X	2=2X	3=4X	3=4X	3=4X	3=4X	3=4X	3=4X	3=3X
3.1	Develop Curriculum for TMC-VET in maintenance engineering	0	0	0	0	0	0	0	0	0	0	0	0	0
3.2	Develop modular training material	24=26X	2=2X	2=2X	2=2X	2=2X	2=2X	2=3X	2=3X	2=3X	2=3X	2=3X	2=3X	2=2X
3.3	Develop TMC-project scenarios for maintenance engineering	7=7X	0	0	0	0	0	1=1X	1=1X	1=1X	1=1X	1=1X	1=1X	1=1X
3.4	Organize Pilot course and Evaluate and assess the Quality of the TMC-VET	0	0	0	0	0	0	0	0	0	0	0	0	0
WP3	Development of Maintenance Engineering training programme – TMC-VET	23=27X	3=4X	3=4X	2=2X	2=2X	1=1X	1=1X	1=1X	0	0	3=4X	5=6X	2=2X
3.1	Develop Curriculum for TMC-VET in maintenance engineering	0	0	0	0	0	0	0	0	0	0	0	0	0
3.2	Develop modular training material	9=13X	2=3X	2=3X	1=1X	0	0	0	0	0	0	2=3X	2=3X	0
3.3	Develop TMC-project scenarios for maintenance engineering	6=6X	1=1X	1=1X	1=1X	1=1X	0	0	0	0	0	1=1X	1=1X	0
3.4	Organize Pilot course and Evaluate and assess the Quality of the TMC-VET	8=8X	0	0	0	1=1X	1=1X	1=1X	1=1X	0	0	0	2=2X	2=2X

5. Description of the activities included in the tasks

5.1 Task 3.1: TMC-VET curriculum development (Task Leader Vigo University)

Task Leader: UVIGO

Due Date: 15-02-2022

Deliverable: TMC-VET curricula

Languages: English, French, Arabic

The development of curricula and syllabus for three levels of qualification is a critical aspect of any training program. This deliverable not only establishes the necessary forms and tools for effective training, but also specifies the required knowledge for trainers to effectively deliver the content. To ensure the quality of the training, test, examination, and evaluation mechanisms are formulated to assess the progress of trainees. The definition of training programs is essential in providing a structured approach to learning. One key element in creating effective curricula is outlining the learning outcomes for both theoretical and practical courses in a clear and comprehensible manner. Additionally, preparing trainees for qualification tests is an integral part of this process. Through careful consideration and planning, these elements come together to create a comprehensive and effective training program that produces qualified individuals ready to excel in their respective fields.

The proposed project includes the development of several training courses, which in total correspond to 60 ECTS. These courses have been carefully selected and designed to meet the specific needs and objectives of the project. Each course is designed to provide participants with a comprehensive understanding of a particular topic, as well as practical skills and knowledge that can be applied in their professional lives. The development of these courses represents a collaborative effort between subject matter experts, instructional designers, and project managers. Each course will undergo a rigorous review process to ensure that it meets high-quality standards and aligns with the overall goals of the project.

Upon completion of these courses, participants will have gained valuable knowledge and skills that will enhance their professional capabilities and contribute to their personal growth. The development of these courses is an important step towards achieving the objectives of the project, and we are confident that they will deliver significant value to all stakeholders involved.

Course Name	Type	L1, ECTS(1)	L2, ECTS(2)	L3, ECTS(3)
Statistical Analyses Tools	E-Handbook	6 ECTS	4 ECTS	2 ECTS
Maintenance of Mechanical Equipment	E-Handbook	10 ECTS	8 ECTS	6 ECTS
Lubrication course	E-Handbook, power point	2 ECTS	2 ECTS	2 ECTS
Vibration measurement and analysis	E-learning	2 ECTS	2 ECTS	1 ECTS
Bearing maintenance	E-learning, power point	2 ECTS	2 ECTS	2 ECTS
Flexible couplings for power transmission	E-Handbook	4 ECTS	2 ECTS	2 ECTS
Maintenance of Electrical Equipment	E-Handbook	8 ECTS	6 ECTS	4 ECTS
Corrosion	Power point	4 ECTS	2 ECTS	2 ECTS
Water Treatment	E-Learning	4 ECTS	2 ECTS	2 ECTS
Piping and Pumps	E-Handbook	4 ECTS	2 ECTS	2 ECTS

Root Cause Analysis	E-Handbook, power point	8 ECTS	6 ECTS	4 ECTS
Maintenance Economics	E-Handbook	6 ECTS	4 ECTS	2 ECTS
Requirements of Preventive Maintenance	E-Handbook, E-Learning	6 ECTS	4 ECTS	2 ECTS

(1) Level 1- Production managers
(2) Level 2 – Maintenance engineers
(3) Level 3 – Maintenance technicians

Following extensive discussions with partners in the TMS-VET cluster, as well as with our industrial partners, we have made some changes to our VET course offerings. These changes were driven by the characteristics of the equipment we have recently purchased, and are designed to ensure that our students receive the most comprehensive and up-to-date training possible.

As a result of these discussions, some existing courses have been extended to better reflect the needs of industry, while new courses have been added to cover emerging technologies and techniques. Our aim is to provide students with the skills and knowledge they need to succeed in their chosen fields, while also meeting the needs of employers who rely on highly skilled workers.

We believe that these changes will help us to maintain SMTMC Maintenance Centre as a leading provider of vocational education and training, and we look forward to continuing to work closely with our partners in order to deliver the best possible outcomes for our students.

Extended courses

Course Name	Type	L1,ECTS(1)	L2,ECTS(2)	L3,ECTS(3)
Statistical Analyses Tools + **Statistical Quality Control**	E-Handbook	**8 ECTS**	**6 ECTS**	**6 ECTS**
Lubrication course + **Tribology**	E-Handbook, power point	**4 ECTS**	**2 ECTS**	**2 ECTS**
Vibration measurement and analysis	E-learning	**6 ECTS**	**4 ECTS**	**2 ECTS**
Bearing maintenance + **Bearing Failures**	E-learning, power point	**4 ECTS**	**2 ECTS**	**2 ECTS**
Water Treatment + **Waste Water Treatment**	E-Learning	**6 ECTS**	**4 ECTS**	**2 ECTS**
Maintenance Economics + **Maintenance Engineer's Toolbox**	E-Handbook	**8 ECTS**	**6 ECTS**	**4 ECTS**
Requirements of Preventive Maintenance	E-Handbook, E-Learning	**6 ECTS**	**4 ECTS**	**2ECTS**

(1) Level 1- Production managers
(2) Level 2 – Maintenance engineers
(3) Level 3 – Maintenance technicians

New VET - Courses

Course Name	Type	L1,ECTS(1)	L2,ECTS(2)	L3,ECTS(3)
IR Thermography	E-Learning	4 ECTS	4 ECTS	2 ECTS
Introduction to System Dynamics	Stella Modelling, power point	2 ECTS	2 ECTS	X
System dynamics modelling and simulation of WATER-ENERGY-LAND-FOOD NEXUS	Model	4 ECTS	4 ECTS	X

(1) Level 1- Production managers

(2) Level 2 – Maintenance engineers
(3) Level 3 – Maintenance technicians

5.2 VET – Course Syllabus Template

All VET course were presented according to the following template.

- **VET-course Name**
- **Course code: TMC - XX**
- **Number of study points (ECTS): XX**
- **Course level: L1, L2, L3**
- **Prerequisites:**
- **Recommended prerequisites:**
- **Course description**
- **Method of work: Lectures, mandatory projects, seminars, demonstrations, laboratories**
- **Lecture language: English, French**
- **Learning outcome:**
- **Knowledge acquired**
- **Skills,**

  Examples:

  • Perform Failure mode effects and criticality analysis, Fault tree analysis, Event tree analysis, etc.
  • Perform a Life cycle cost analysis
  • Perform a simple Spare parts needs assessment as well as inventory and logistics considerations

- **General competence**

  Examples:

  • ability to identify, formulate, and solve operations and maintenance problems
  • understanding of common methods, tools and analysis
  • ability to design operations and maintenance management plan for a system, …

- **Requirements to sit for the exams/Required activities/courses:**
  - Example: The student needs to have a passing grade in the project

Forms of assessment: Assessment	**Weight**	**Duration**	**Tools**	**Grade**
Project report	40%		All	A-F
Written exam	60%	3 hours	All	A-F

The subject teacher decides the total grade

- **Literature:**
  - Compendium in Maintenance engineering
  - Rausand, M. and Høyland, A. (2004). ”System Reliability Theory: Models, Statistical Methods, and Applications” 2nd ed., Wiley InterScience, Chapter 3: Qualitative system analysis
  - Markeset, T., Kumar, U. (2001). R&M and risk-analysis tools in product design to reduce life cycle cost and improve attractiveness, In: Proceedings of the Annual Reliability and Maintainability Symposium, ISBN 0-7803-6615-8, ISSN 0149-144X, Jan 22-25, Philadelphia, USA: 116-122

5.3 VET-course presentation

The development and delivery of VET-courses employ a range of teaching methodologies to ensure optimal learning outcomes. These courses are designed to provide students with practical skills that they can apply in their chosen industry. Some of these courses have been developed as E-handbooks, which have been published by McGraw-Hill. These E-handbooks offer comprehensive guides that cover all aspects of the course, from theory to practical applications. The use of this teaching methodology ensures that students have access to reliable and up-to-date information that is relevant to their chosen field. Additionally, it allows for easy reference and review of course material, which can be particularly beneficial for students who need to revisit certain concepts or procedures. Overall, the use of various teaching methodologies ensures that VET-courses are effective in equipping students with the knowledge and skills required for success in their respective industries.

1. The VET-E-handbook set-up has proven to be particularly effective for theoretical courses, providing students with an accessible and interactive learning experience. This approach has been implemented in order to provide students with the most comprehensive and engaging educational content possible.

2. Some courses are offered as self-learning modules, which require an e-learning set-up to be effective. This approach allows learners to access course materials at their own pace and convenience, while also providing interactive features such as quizzes and assessments to enhance learning.

3. During an intermediate phase, some courses were developed in PowerPoint format; however, they will be converted to the e-learning format. These various teaching methodologies are employed with the aim of providing learners with a comprehensive and engaging learning experience that is tailored to their unique needs and preferences.

5.4 Task 3.2: Development of modular training courses (Task leader Socomenin)

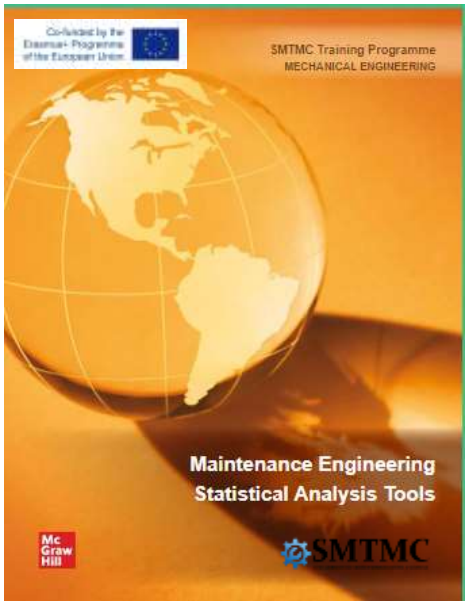
Due Date: 15-12-2024

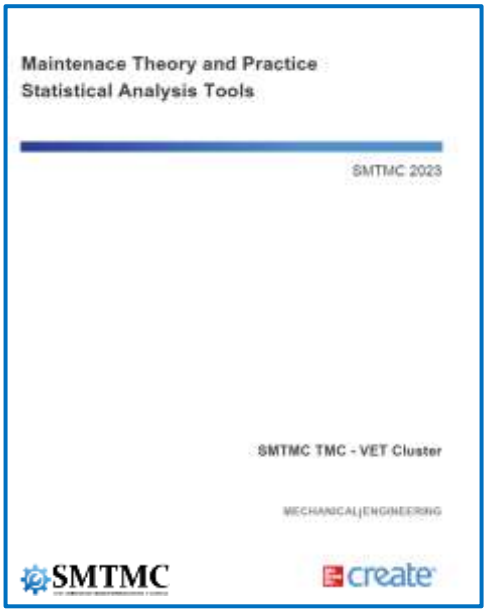
Language: English, French

The development of learning resources for theoretical education and fundamental practical skills is of paramount importance in ensuring the growth Tunisian industries. In this regard, we have undertaken a significant initiative to implement modern training forms and prepare a modular program that will meet the highest standards set by both European Union regulatory bodies and industrial organizations. The modules developed will correspond to the three levels mentioned above and will contain courses for 60 ECTS. To ensure the quality of these resources, we will be working closely with EU universities and industrial organizations to produce material under their close supervision. By doing so, we aim to provide top-notch learning resources that will enable individuals to acquire the knowledge and skills necessary to excel in their respective fields, thus contributing positively towards the growth of society as a whole.

VET courses developed

1. Statistical Analyses Tools + Statistical Quality Control. Format: E-handbook.





The E-handbook takes a practical approach to methods of statistical modelling and data analysis that are most often used in engineering work. This edition help motivate students and show direct connections to industry and research. While focusing on practical applications of statistics, the text makes extensive use of examples to motivate fundamental concepts and to develop intuition.

Contents

Chapter 1 covers sampling and descriptive statistics. The reason that statistical methods work is that samples, when properly drawn, are likely to resemble their populations. Therefore Chapter 1 begins by describing some ways to draw valid samples. The second part of the chapter discusses descriptive statistics.

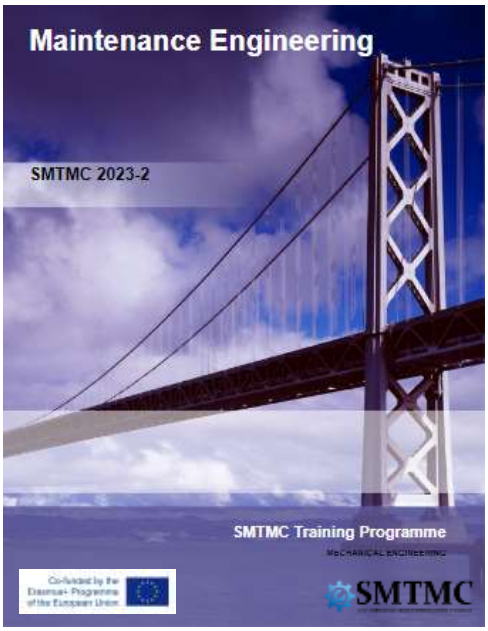
Chapter 2 is about probability. There is a wide divergence in preferences of instructors regarding how much and how deeply to cover this subject. Accordingly, I have tried to make this chapter as flexible as possible. The major results are derived from axioms, with proofs given for most of them. This should enable instructors to take a mathematically rigorous approach. On the other hand, I have attempted to illustrate each result with an example or two, in a scientific context where possible, that is designed to present the intuition behind the result.

Chapter 3 covers propagation of error, which is sometimes called "error analysis" or, by statisticians, "the delta method." The coverage is more extensive than in most texts, but because the topic is so important to many engineers. The presentation is designed to enable instructors to adjust the amount of coverage to fit the needs of the course.

Chapter 4 presents many of the probability distribution functions commonly used in practice. Point estimation, probability plots, and the Central Limit Theorem are also covered. The final section introduces simulation methods to assess normality assumptions, compute probabilities, and estimate bias.

Chapter 5 presents the topic of statistical quality control, discussing control charts, CUSUM charts, and process capability; and concluding with a brief discussion of six-sigma quality.

2. VET courses Lubrication, Maintenance Economics, Maintenance of Mechanical Equipment, Flexible couplings for power transmission, Maintenance of Electrical Equipment and Root Causes Analysis are available in the E-handbook Maintenance Engineering.



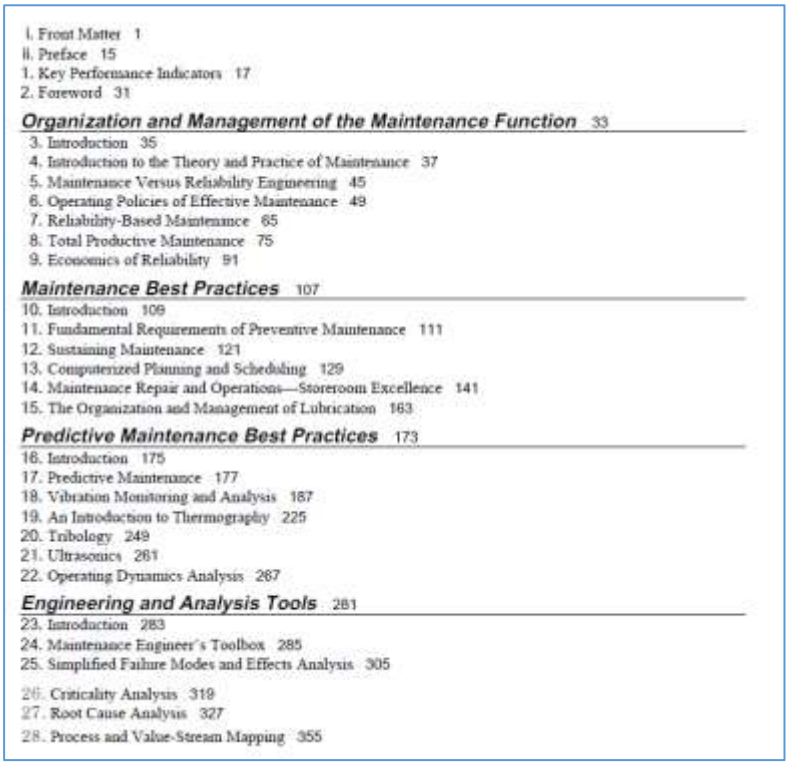
Contents

Maintenance of Mechanical Equipment is the work that keeps mechanical assets running with minimal downtime. Machine maintenance can include regularly scheduled service, routine checks, and both scheduled and emergency repairs. It also includes replacement or realignment of parts that are worn, damaged, or misaligned. Maintenance requirements have an impact on production scheduling and other functions performed by the production control department. Time lost due to maintenance may interfere with schedules from the production department. Therefore, maintenance requirements should be considered in choosing machines or equipment for replacement or increasing the capacity of installed machines and equipment.

3. Maintenance Management E-handbook

The E-handbook contains the VET – courses Organization and Management of the Maintenance Function, Maintenance Best Practices, Predictive Maintenance Best Practices and Engineering Analysis tools.

Contents



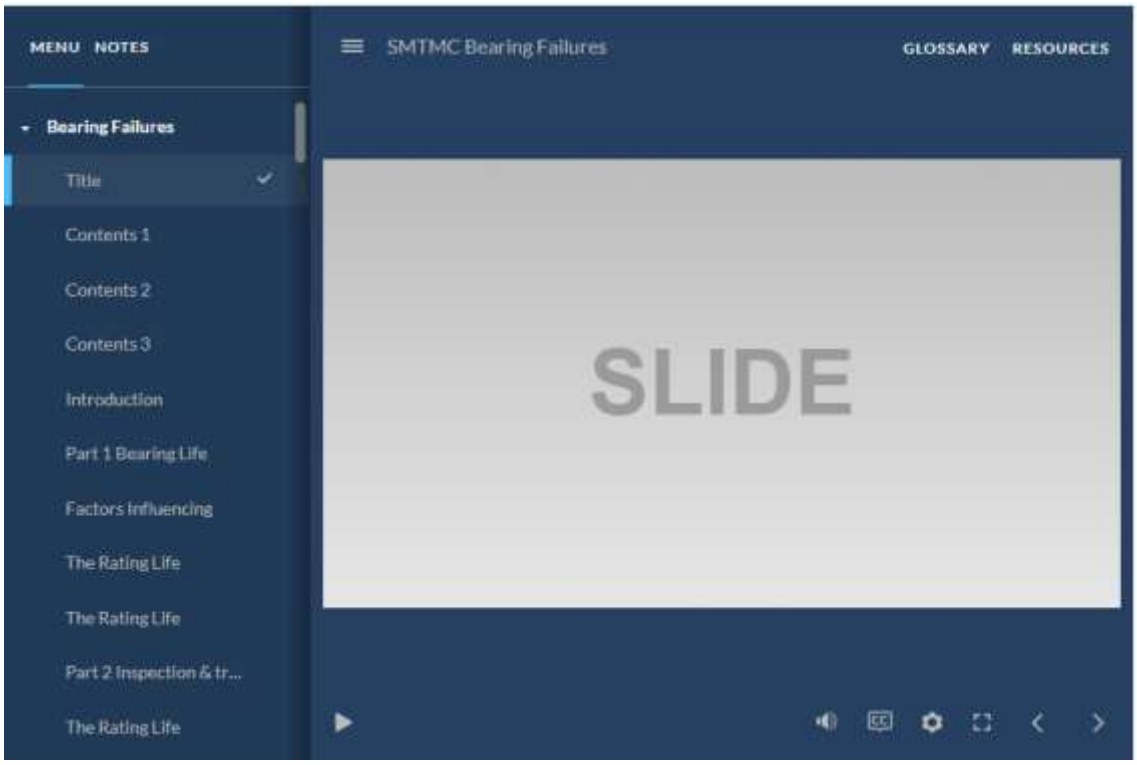
5.5 Self-Learning Modules

E-learning (sometimes called web-based training) is instruction delivered over the internet or a corporate Intranet to browser-equipped learners. Contrary to traditional learning methods, e-learning allows students, employees in training and casual learners to participate in an organized learning experience regardless of their physical location. E-learning has become an increasingly important tool in both the education and professional development spheres. With its flexibility and accessibility, e-learning methods and technology offer a range of benefits that traditional learning methods cannot match. For students, e-learning provides access to a wealth of information and resources that can be tailored to individual needs and learning styles. This helps to ensure that all students receive a high-quality education, regardless of their location or background.

5.5.1 Design of E-learning Modules

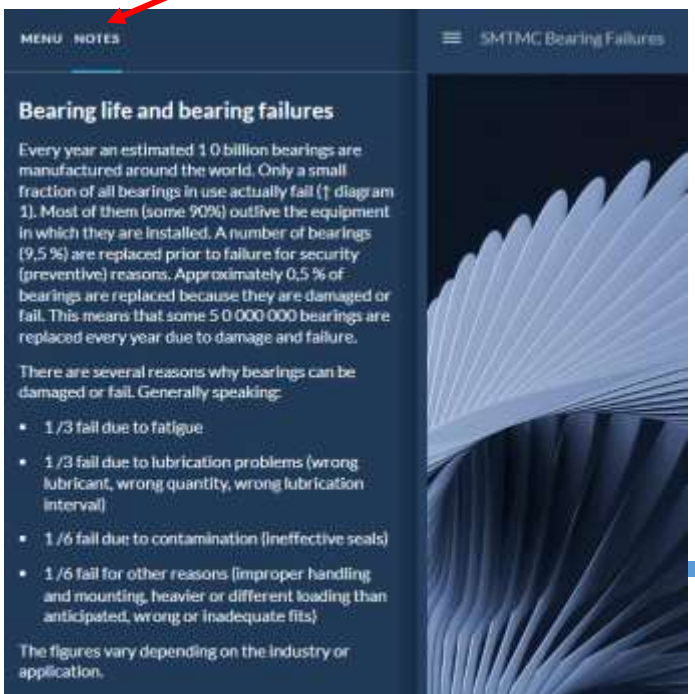
The E-learning modules are designed using the authoring tool “Articulate 360”. Articulate Storyline is software for creating interactive courses. It's designed to be simple enough, yet powerful enough for experts, enabling users to create virtually any imaginable interaction.

The Topbar of the interface comprises four tabs, namely Menu, Notes, Glossary, and Resources. The Sidebar allows users to select either the Menu tab or the Note tab. By selecting the Menu tab, users can easily navigate among the slides. Alternatively, they can also use the right or left arrows located on the bottom right of the screen to move between slides. Furthermore, by selecting the Notes tab, users can access a full text description of each slide. This feature provides users with additional context and information that may enhance their understanding of the content presented in each slide. Overall, these features make navigating and accessing information within the interface more efficient and intuitive for users. In the centre part of the screen, the slide holds text, picture or multimedia.



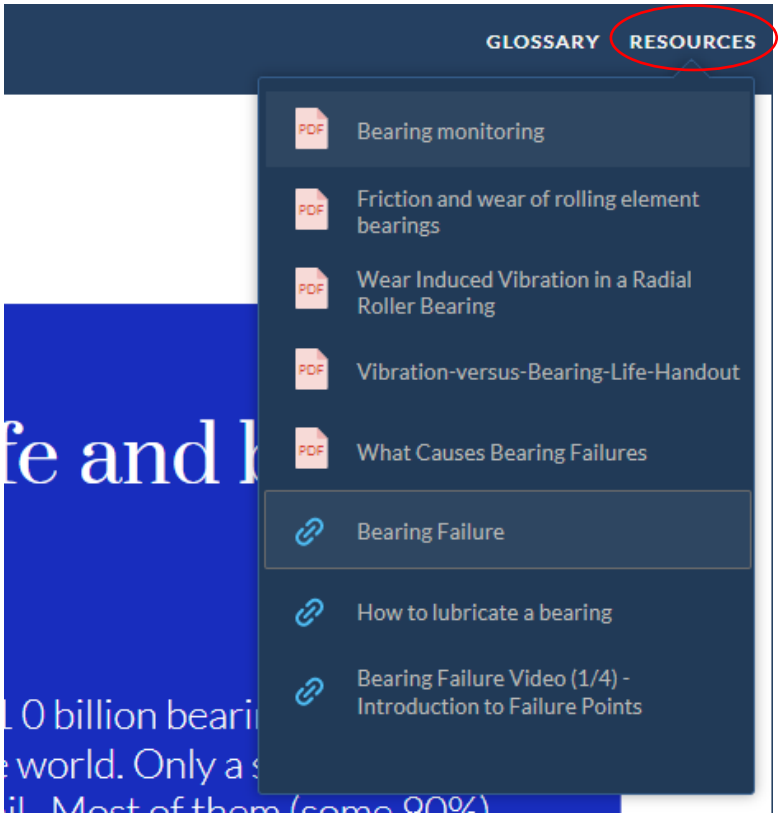
Selecting the Notes tab, the text describing the slide is presented.

Notes tab

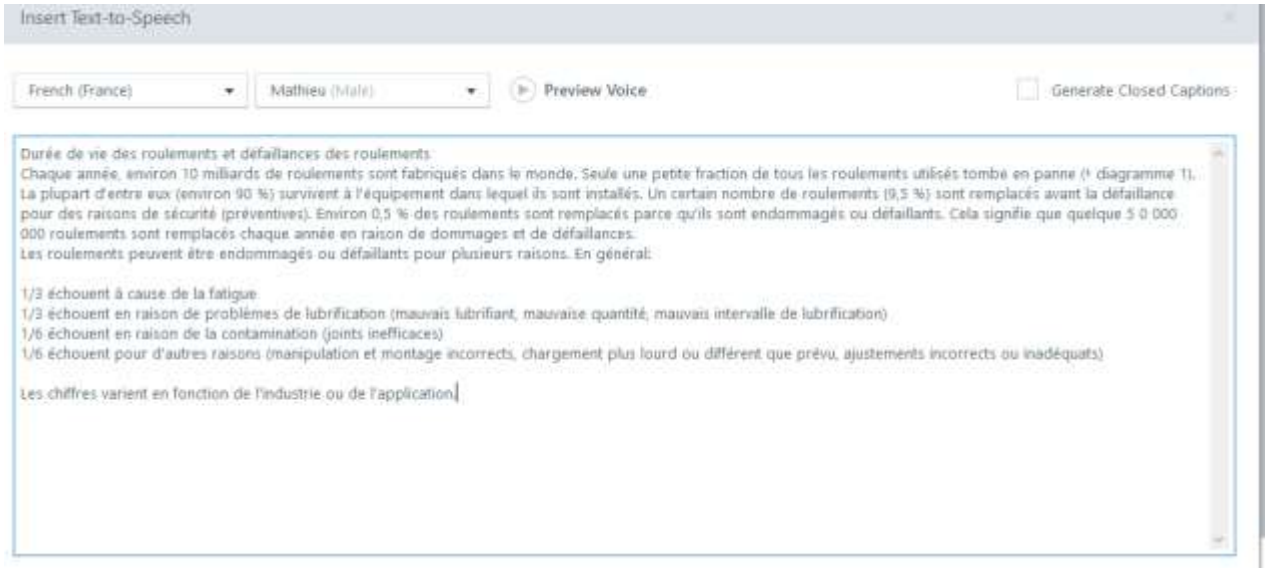


The Glossary is a repository for words pertaining to a specific topic.

In the Resource you can upload various documents such as text, photos or videos from your files or from the Internet.



The English text from the Notes is translated to French, and then the French text is converted to Speech. Therefore, in all E-learning courses, the text is in English while a voice read the corresponding French text.



The common structure of a E-learning module consists in slides and text describing the subject, question and problems at the end of each section, and examination.

5.5.2 E-learning Modules

1. **Bearing damage and failure analysis**
   Language: Text in English, Voice in French.

The E-learning course consists in 6 sections with theoretical description of the subject, a section containing case studies and 3 Appendixes.

Contents

Introduction

PART 1 Bearing life and bearing failures

- Factors influencing bearing service life
- When to replace a bearing?

PART 2 Inspection and troubleshooting

- Inspection during operation
- Monitoring noise and vibration
- Monitoring temperature
- Monitoring lubrication conditions
- Inspection during a machine shutdown
- Inspecting bearings
- Inspecting seal counterfaces
- Troubleshooting
- Common symptoms of bearing trouble
- Trouble conditions and their solutions

PART 3 Path patterns

- Normal raceway path patterns

- Radial bearings – radial load unidirectional and constant
- Radial bearings – radial load rotating in phase and constant
- Radial bearings – axial load unidirectional and constant
- Radial bearings – combination of radial and axial loads unidirectional and constant
- Thrust bearings – axial load unidirectional and constant
- Raceway path patterns from abnormal operating conditions
- Radial bearings – radial load unidirectional and constant
- Thrust bearings – axial load unidirectional and constant

PART 4 ISO failure modes classification

- Failure modes classification – ISO workgroup
- Failure modes
- Fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking

PART 5 Damage and actions

- Subsurface initiated fatigue
- Surface initiated fatigue
- Abrasive wear
- Adhesive wear
- Moisture corrosion
- Forced fracture
- Fatigue fracture
- Thermal cracking

PART 6 Other investigations

PART 7 Case studies

- Train derailment
- Variable speed electric motor problem
- Clay mill problem
- Jaw crusher problem

Appendix A: Factors influencing bearing selection

Appendix B: Bearing damage and failures – modes and causes

Appendix C: Collecting information

2. **Vibration Measurement and Analysis**
   Language: Text in English, Voice in French.

Vibration analysis is a crucial predictive maintenance technique that can help detect potential machine failures before they happen. By analysing the vibrations produced by machinery, maintenance teams can identify any inconsistencies or abnormalities that could indicate impending issues. This allows for proactive maintenance measures to be taken before a breakdown occurs, which can save both time and money in the long run. Our training course on vibration analysis covers the basics of how to conduct an effective analysis, including how to use specialized equipment and interpret the results. With this knowledge, maintenance professionals will be better equipped to keep their machinery running smoothly and avoid costly downtime.

Contents

Part 1 Theory

- Vibration Analysis (Detection Mode)
- Vibration Analysis (Diagnosis Mode)
- Vibration Basics
- Wave Fundamentals
- Vibration Terminology

Part 2 Detection

- Using Vibration Theory to Machinery Fault Detection
- Data Acquisition
- Collection of Vibration Signal
- Theory of Operation
- Vibration Analysis — Database Management Software
- Transmission Error

Part 3 Signal Processing, Applications and Representations

- Fourier Transform
- Sampling Rate

- Analog to Digital Converters
- Lines of Resolution, F-max, Bandwidth
- Time Waveform Analysis
- Operational Deflection Shapes Analysis
- Cross-Spectrum
- Coherence
- Enveloping and Demodulation
- Cepstrum Analysis

Part 4 Machinery Fault Diagnosis Using Vibration Analysis

- Commonly Witnessed Machinery Faults Diagnosed by Vibration Analysis
- Unbalance
- Unbalance — Overhung Rotors
- Misalignment
- Mechanical Looseness

Part 5 Case Studies

- Running Speed
- Rotor Rubs
- Journal Bearings
- Oil Whirl
- Rolling Element Bearings
- Gearing Defects
- Belt Defects
- Rotor Defects
- Stator Defects
- Flow-Related Vibrations
- Cavitation

Part 6 Correcting Faults that Cause Vibration

- Balancing
- Balancing Methods
- Balancing Machines
- Example
- Alignment
- Factors that Influence Alignment Procedure
- Types of Misalignment
- Laser Alignment
- Resonance Vibration Control with Dynamic Absorbers
- Applications of a Dynamic Absorber

Conclusions

Self-testing

Examination Questions

3. **Wastewater Treatment**
   <u>Language</u>: Text in English, Voice in French.

Wastewater is the polluted form of water generated from rainwater runoff and human activities. It is also called sewage. It is typically categorized by the manner in which it is generated—specifically, as domestic sewage, industrial sewage, or storm sewage (or stormwater).

Wastewater consists of water containing solids that are either dissolved or carried in suspension. The solids are usually less than 0.2 % of the wastewater composition by weight. This small number of solids is what treatment plants are designed to remove. The solids in wastewater are classified in a number of ways. For example, they can be divided into two general groups:

- Organic solids, and
- Inorganic solids.

Organic solids are the waste products of plants and animals. These solids will decay or decompose. Inorganic solids, on the other hand, usually will not decay or decompose. Inorganic solids include materials such as sand, gravel, silt, and salts. Organic and inorganic solids can be further classified as suspended solids and dissolved solids. The objectives of wastewater treatment are to reduce

(1) the level of solids,

(2) the level of biodegradable organic matter,

(3) the level of pathogens, and

(4) the level of toxic compounds in the wastewater, to meet regulatory limits that are protective of public health and the environment.

This online self-paced training course is designed to provide an overview of topics wastewater collection; pollutants; wastewater microbiology, physical, biological and chemical treatment; preliminary, primary and secondary treatment. The online course includes lessons, readings, and online knowledge testing for every module.

Contents

Module 1: Sustainable Wasterwater Treatment

Module 2: Preliminary and Primary Wastewater Treatment

Module 3: Wastewater Microbiology

Module 4: Secondary Wastewater Treatment

4. **IR Thermography**
   Language: Text in English, Voice in French.

This course follows the recommended training requirements of ISO 18436-7.
Temperature is one of the most common indicators of the structural health of equipment and components. Faulty machineries, corroded electrical connections, damaged material components, etc., can cause abnormal temperature distribution. By now, infrared thermography (IRT) has become a matured and widely accepted condition monitoring tool where the temperature is measured in real time in a non-contact manner. IRT enables early detection of equipment flaws and faulty industrial processes under operating condition thereby, reducing system down time, catastrophic breakdown and maintenance cost. Last three decades witnessed a steady growth in the use of IRT as a condition monitoring technique in civil structures, electrical installations, machineries and equipment, material deformation under various loading conditions, corrosion damages and welding processes. IRT has also found its application in nuclear, aerospace, food, paper, wood and plastic industries. With the advent of newer generations of infrared camera, IRT is becoming a more accurate, reliable and cost-effective technique. This review focuses on the advances of IRT as a non-contact and non-invasive condition monitoring tool for machineries, equipment and processes. Various conditions monitoring applications are discussed in details, along with some basics of IRT, experimental procedures and data analysis techniques. Sufficient background information is also provided for the beginners and non-experts for easy understanding of the subject.

Contents

Introduction
- General overview of the use of Infrared Thermography
- Course logistics and curriculum outline
- Trainer and student introductions

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- Energy - definition and basic principles

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- Basic relation of heat temperature and energy

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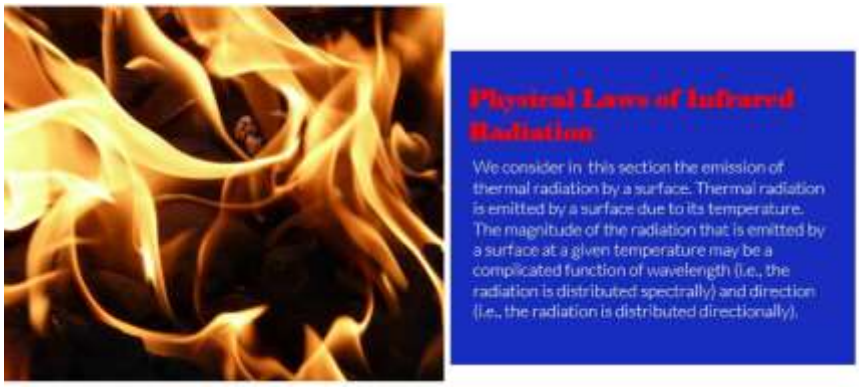
  *Conductivity/Resistance Basics
  *Practical application of conductivity in thermography
- Convection Fundamentals
  *Newton's Law of cooling
  *Practical application of convection in thermography

- Radiation Fundamentals



  *The Electromagnetic Spectrum
  *Plank's Law
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  *Stephan Boltzmann Law

Radiosity Concepts
- Reflection, Transmission, Emission
- Radiometry and Imaging
- Spatial Resolution Concepts

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Applications

Infrared Thermography Techniques

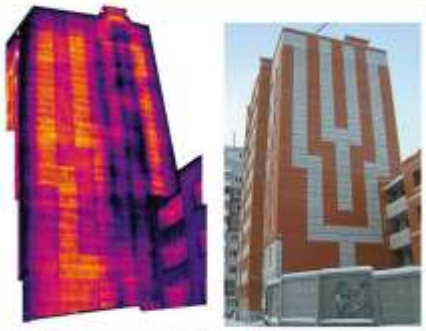
Thermal imagers make pictures from heat, not visible light. Heat (also called infrared or thermal energy) and light are both parts of the electromagnetic spectrum, but a camera that can detect visible light won't see thermal energy, and vice versa.

- Qualitative vs Quantitative Inspections
- Electrical Inspections
- Mechanical Inspections - Friction
- Thermal Resistance - insulation & refractory
- Thermal Capacitance - roof moisture surveys
- Physical State - Gas/Liquid, Liquid/Solid
- Process Inspections
  *Fluid Flow
  *Steam
  *Vessel levels
- Building Inspections

Practical Aspect of IR Building Thermography

The potential of IR monitoring compared to visual inspection are illustrated in Figure.

A reduced pressure in the ventilating shaft leads to air in-leaks along the total building height, producing temperature signals up to 5 °C.



Air leaks into a masonry building (dark blue areas) in the area of the ventilation shaft

- Energy Related Inspections

Examination

5. Predictive maintenance
Language: Text – English, Voice - French

Predictive maintenance (PdM) is maintenance that monitors the performance and condition of equipment during normal operation to reduce the likelihood of failures. Also known as condition-based maintenance, predictive maintenance has been utilized in the industrial world since the 1990s.

The goal of predictive maintenance is the ability to first predict when equipment failure could occur (based on certain factors), followed by preventing the failure through regularly scheduled and corrective maintenance.

The biggest application for predictive maintenance is in the manufacturing sector. As manufacturing plants continue to face demand to increase productivity, several maintenance strategies have been created and implemented. However, a majority of these have been reactive. Many facilities possess a mindset of “if it’s not broke, don’t fix it.” Unfortunately, this mindset contributes to unplanned maintenance and downtime.

Contents
Predictive maintenance definition and classification
Predictive maintenance techniques
Advantage of predictive maintenance
Disadvantages of predictive maintenance

PowerPoint Modules

Vibration & Bearing Condition Monitoring and Testing
Language: English
Sessions: 22

Contents

Session0 – Vibration & Bearings-Introduction
Session1 – Vibration & Bearings-Overview
Session2 – Vibration & Bearings – Condition Monitoring for Reliability
Session3 – Vibration & Bearings – Principal Cause of Machine Failure
Session4 – Vibration & Bearings - Vibration Analysis & Machine Faults
Session5 – Vibrations & Bearings – The Language of Machine Vibration
Session6 – Vibration & Bearings - Vibration Measurement Applied to Condition Monitoring
Session8 – Vibration & Bearings - Belt Driven Machines
Session9 – Vibration & Bearings – Rolling Bearing Vibration Monitoring and Testing
Session10 - Vibration & Bearings – Vertical Pump Alignment
Session12 – Vibration & Bearings – Other Machinery and Equipment Condition Monitoring Techniques
Session13 – Vibration & Bearings – Maintenance Planning-Based on Condition Monitoring
Session14 – Vibration & Bearings – The Justifycation for Machining Precision Maintenance
Session15 – Vibration & Bearings – Machine Failure Root Cause Analysis and Creative Dissambly
Session16 – Vibration & Bearings – Roller Bearing Care
Session17 – Vibration & Beasings – Accurate Machinery Assembly
Session18- Vibration & Bearings -Machine Shaft Alignment
Session19 - Vibration & Bearings – Phase in Vibration Analysis
Session20 - Vibration & Bearings - Vibration Signature Diagnostic Chart
Session21 - Vibration & Bearings – A quality System in the Workshop

Applications – Session 16

Condition-Based Maintenance

Contents

- Condition Based Maintenance Strategy
- Equipment Failure
- Equipment Condition Monitoring
- Equipment Degradation Process
- Condition Based Maintenance Strategy
- Defect Elimination Strategy
- Reliability Centered Maintenance
- Defect Management
- Maintenance Strategy
- Principles or Condition-Based Maintenance
- Principles of Predictive Maintenance
- Vibration Analysis — A Key Predictive Maintenance Technique

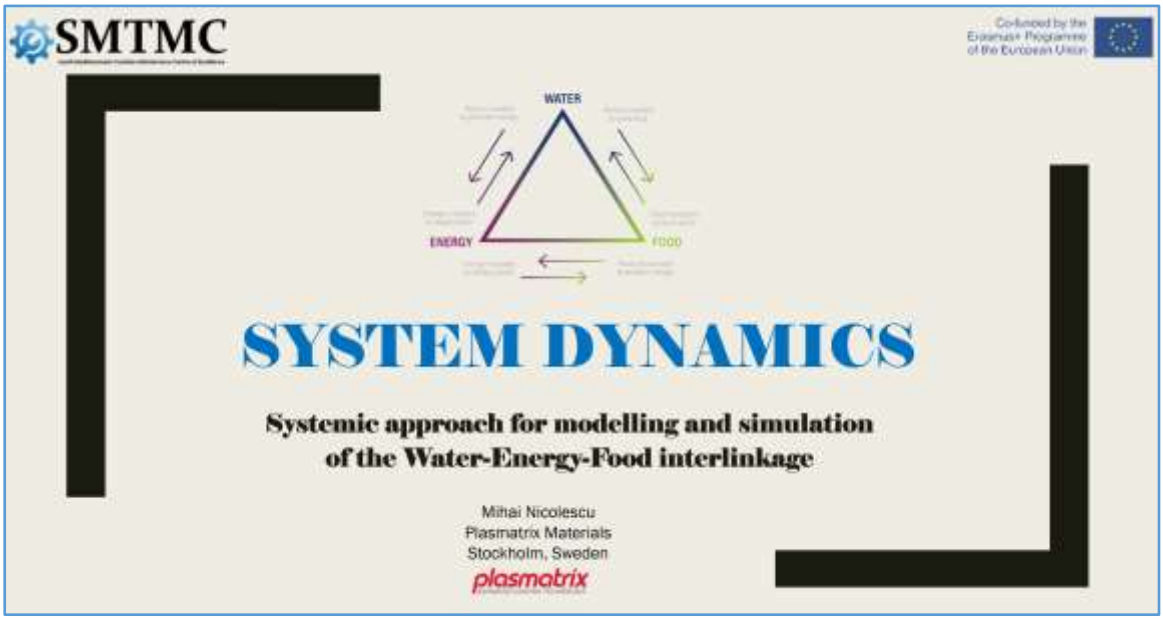
- Machinery Fault Diagnosis Using Vibration Analysis
- Commonly Witnessed Machinery Faults Diagnosed by Vibration Analysis
- Unbalance
- Misalignment and Other Radial Preloads (Orbit Representation)
- Rolling Element Bearings
- Gearing Defects
- Belt Defects
- Cavitation
- Correcting Faults that Cause Vibration
- Balancing
- Alignment
- Oil Fundamentals
- Condition-Based Maintenance and Oil Analysis
- Infrared Thermography

System Dynamics – Modelling and Simulation

Language: English

An introductive course in System Dynamics has been developed in order to demonstrate the potential of System Dynamics to analyse complex systems.

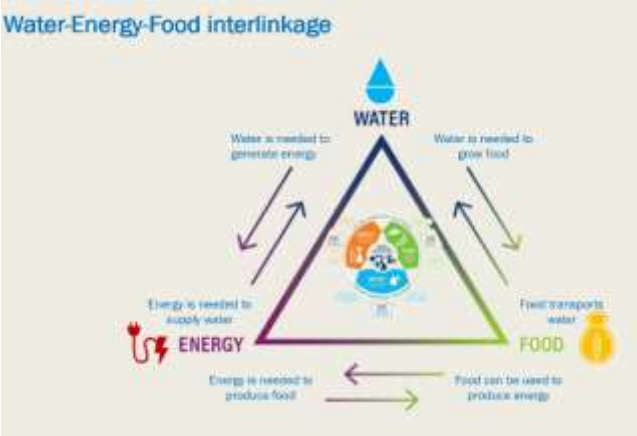
System dynamics is a relatively new branch of systems science that originated at MIT in the 1950s and 1960s. Within systems science, it is seen as a milestone in the overall evolution in the application of systems thinking and the development of tools to address complex issues in a wide range of disciplines such as engineering, ¬business and economics, health, planning, management, and so on.



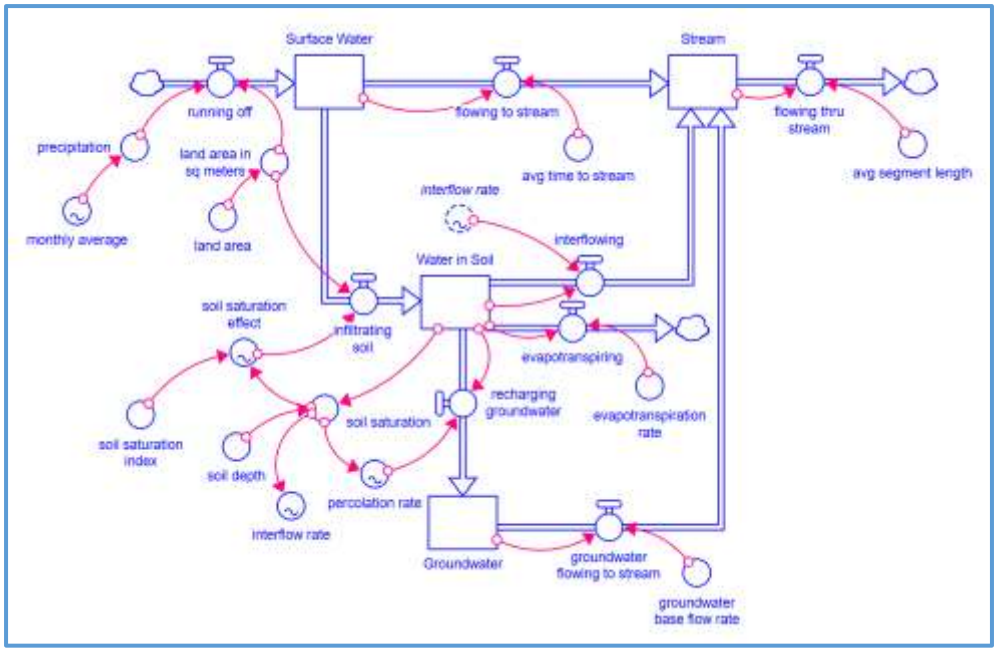
It is a method that can be used to study how systems continuously change over time due to possible changes in their components, relationships between components, and the overall direction of the systems. The method allows for both qualitative and quantitative modelling. Models of system

dynamics are defined by closed boundaries - (causally closed models) where endogenous components and factors (those originating from within) are assumed to form the system structure and predominantly dictate the behavior of the systems. Information feedback mechanisms in the system can be included in the form of interconnected closed feedback loops and circular causality, allowing trends in a system to be reinforced and balanced.

System Dynamics is a powerful tool for modelling and simulating complex systems, such as supply chains, production systems, maintenance systems, and business modelling. By breaking down these systems into their component parts and analysing the cause-and-effect relationships between them, System Dynamics allows us to gain a deeper understanding of how they work and how they can be improved. With its ability to model complex feedback loops and dynamic interactions between different elements of a system, System Dynamics is particularly well-suited to tackling real-world problems in industries such as manufacturing, logistics, and finance. By using System Dynamics to simulate different scenarios and test out potential solutions before implementing them in the real world, businesses can save time and resources while also improving their overall performance. Whether you're looking to optimize your supply chain or improve your business processes, System Dynamics is an indispensable tool for anyone working with complex systems.



The course includes 4 hours of lectures and 12 hours of hands-on modelling and simulation using Stella Architect. The modelling exercises are specifically designed to demonstrate the use of System Dynamics in modelling the Food-Energy-Water nexus. By the end of the course, students will have gained a deep understanding of how System Dynamics can be used to model and simulate complex systems, making it an essential tool for professionals working in a wide range of fields. Below it is representing a schematic model of the “Water” submodule.



Task 3.2 Remaining Activities

The remaining activities for the course development project include translating all E-handbooks into French, developing PowerPoint courses as E-learning courses, adding self-testing and examination questions to some courses, and performing improvements based on quality assessment and pilot testing.

It's worth noting that all courses will be available in both English and French to cater to a wider audience. The translation of E-handbooks into French is an important step in ensuring accessibility for French-speaking learners. Additionally, the incorporation of self-testing and examination questions will provide learners with a way to assess their understanding of the material covered in each course.

Finally, quality assessment and pilot testing will help identify areas where improvements can be made to ensure that the courses meet the needs of learners. Overall, these remaining activities are crucial to providing high-quality education through this course development project.

Task 3.3 TMC-Project Scenarios and Pilot course and TMC-VET programme evaluation

The task consists in 4 subtasks.

Subtask 3.3.1 Develop TMC - Project Scenarios and Train trainers and trainees

Likewise to academic teaching, innovative training methods will be implemented in vocational education and training (VET) programs. These new methods will help students learn practical skills that are relevant to the current job market. With the rise of technology, VET programs need to adapt and equip students with the necessary skills to succeed in their chosen fields. This means incorporating hands-on learning experiences, such as apprenticeships and internships, as well as using digital tools like virtual reality simulations and online learning platforms. By embracing these innovative approaches, VET programs can better prepare students for the workforce and ensure they have the skills needed to thrive in the modern economy.

Two innovative methods are introduced in VET-programme:

1) Project Scenarios and
2) Case Studies

Guidelines for Project Scenarios

For development of transversal skills of students, a practical project in an enterprise is introduced in the VET curriculum. The project scenarios follow the Guidelines described below

1. Representatives from universities contact several manufacturing companies
2. Companies interested in training their staff are selected
3. Each selected enterprise proposes in discussions with supervisors from university a list with project regarding problems to be solved in the company.
4. A description template is formulated to be filled for each project
5. Teams of 3-4 students are formed
6. Each student team is assigned a supervisor from university and one from the company
7. The list of projects is published on the project web page, and each student team select a project during a workshop organized by the university.
8. The students work together for solving the problem. Each team select a leader. A project plan is drafted for each project and discussed with the supervisor.
9. A period of 10 days is dedicated for studying the state-of-the art for each project theme
10. The experimental part of the project can be performed at the laboratories in university, at the company or at both.
11. A common template for all reports is prepared by supervisors.
12. A final report is written followed by a presentation for colleagues, teachers and representatives from companies
13. The TMC Prize rewards the best project presentation.

The project duration is 6 - 8 weeks.

Expected outcomes:

- Contributes to modernization of the Tunisian VET training system,
- Strengthen the cooperation between university and industry
- Improving practical and professional experience of trainees
- Creates the framework for the trainees to understand how to analyse and solve practical problems in their companies
- Contacts with company managers given possibility for students to show their skills while companies to meet and select potential employees.
- For female students, it is a great opportunity to come in contact with company managers, engineers for finding jobs.

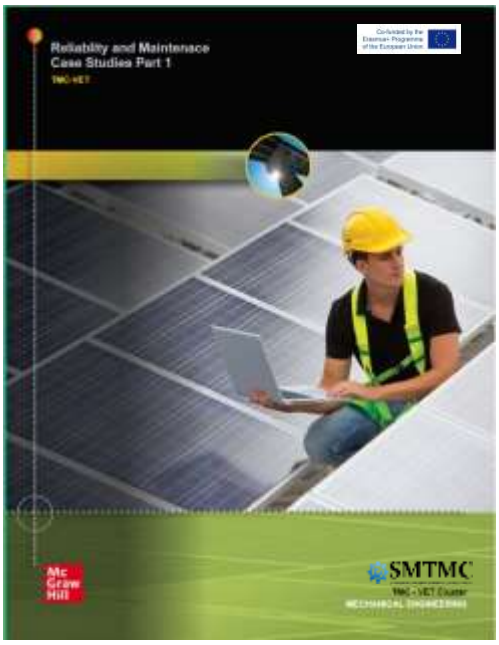
Subtask 3.3.2 Develop TMC - Project Cases and Train trainers and trainees

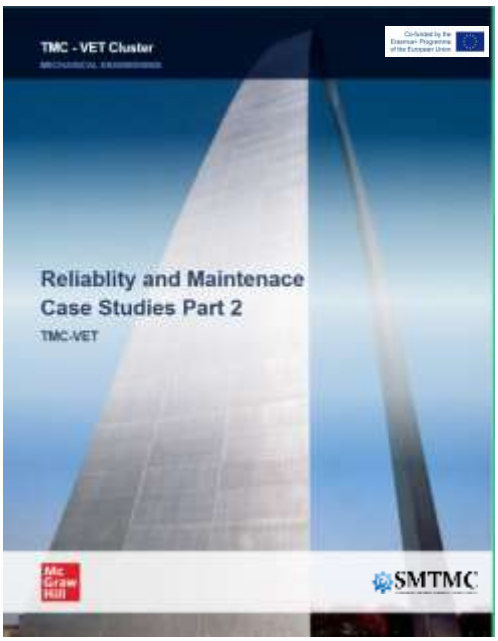
The traditional lecture-based training is no longer sufficient to meet the needs of modern technologies. To keep up with the changing times, new training forms need to be introduced in the curriculum. Trainees nowadays require more active and engaging forms of training that not only facilitate learning but also encourage participation and collaboration. Active training forms such as role-playing, case studies, and simulations can provide trainees with hands-on experience that will help them retain information better and apply it effectively in real-life situations. These forms of training are not only more effective but also more enjoyable for trainees, which can lead to a higher level of engagement

and motivation. By incorporating these active training forms into the curriculum, we can ensure that our trainees are well-equipped with the skills they need to succeed in their careers.
In the case studies likewise in the project scenarios students work in groups for analysing and discussing various cases.

In both case studies and project scenarios, students are encouraged to work collaboratively in order to analyse and discuss various cases. This approach allows for a deeper understanding of the subject matter as students can learn from each other's perspectives and experiences. By working in groups, students are also able to develop important communication and teamwork skills that will serve them well in their future careers. Through this process, they can gain a better understanding of how to apply theoretical concepts to real-world situations, which is essential for success in any field. Ultimately, the group work involved in case studies and project scenarios creates a dynamic learning environment that fosters innovation, critical thinking, and problem-solving skills – all of which are vital for success in today's rapidly evolving world.

In a case method classroom, the instructor and students have distinct roles to play in facilitating teaching and learning. Instructors are experts in their fields, but they don't simply deliver information to their students. Instead, they guide discussions by asking thought-provoking questions and providing feedback on answers. Their goal is to help students think critically about the material and draw connections between concepts. For their part, students must be active participants in the discussion, bringing their own insights and perspectives to the table. The result is a dynamic learning environment where everyone is engaged and working together to explore the meanings of the case at hand. The art of a case method lies in knowing how to create an environment where this kind of discussion can take place naturally and successfully.





A business case is a powerful tool that helps readers understand and analyse real-life situations. These cases are verbal representations of reality that enable the reader to participate in the situation, putting themselves in the shoes of the decision-makers. The unit of analysis in these cases varies significantly, from a single individual or organization to an entire nation or even the world. They can be short, concise one-pagers or extensive fifty-page documents. Regardless of length, their purpose remains the same: to convey a situation with all its complexities, nuances, and uncertainties, including irrelevant

information and misconceptions. When done well, business cases provide an accurate representation of reality that enables readers to make informed decisions based on facts and evidence.

A well-written case must have these characteristics in order to simulate reality. As a reader of cases, therefore, you must be able to:

- Construct conclusions from the information in the text
- Filter out irrelevant or low-value portions of the text
- Furnish missing information through inferences
- Associate evidence from different parts of the case and integrate it into a conclusion

Cases require active readers. The texts most of us regularly read encourage us to be passive readers. The journalism of newspapers, magazines, television, and the Internet, whether reporting or opinion, tells the reader what it means. If it doesn't, it has failed. A newspaper article, for example, states its subject clearly, often in the first paragraph, and carefully declares its main points, which are usually explained and amplified through specific examples.

Two packages with case studies have been published for using in the VET- programme. The fisrt pckage contains 8 cases selected from reliability and maintenance fields.

Reliability and Maintenance, Case Studies, Part 1

Contents

Reliability and Maintenance, Case Studies, Part 2

9. Warranty Data Analysis for Assessing Product Reliability, by Peter C. Sander, Luis M. Toscano, Steven Luitjens, Valia T. Petkova, Antoine Huijben, and Aarnout C. Brombacher
10. Reliability of Oil Seal forTransaxle—A Science SQCApproach at Toyota, by Kakuro Amasaka and Shunji Osaki
11. Ford's Reliability ImprovementProcess—A Case Study onAutomotive Wheel Bearings, by Karl D. Majeske, Mark D. Riches, and Hari P. Annadi
12. Optimization of Dragline Load, by Peter G. A. Townson, D. N. Prabhakar Murthy, and Hal Gurgenci
13. Mean Residual Life and Optimal Operating Conditions for Industrial Furnace Tubes, by Elsayed A. Elsayed
14. Case Experience Comparing the RCM Approach to PlantMaintenance with a Modeling Approach, by Xisheng Jia and Anthony H. Christer
15. RCM Approach to Maintaining a Nuclear Power Plant, by Gilles C. Zwingelstein
16. Reliability Model for Underground Gas Pipelines, by Roger M. Cooke, Eric Jager, and D. Lewandowski
17. Photocopier Reliability ModelingUsing Evolutionary Algorithms, by Michael Bulmer and John Eccleston
18. Maintainability and Maintenance—A Case Study on Mission CriticalAircraft and Engine Components, by U. Dinesh Kumar and John Crocker
19. Component Reliability,Replacement, and Cost Analysiswith Incomplete Failure Data, by Nicholas A. J. Hastings
20. Expert Judgment in the Uncertainty Analysis of Dike Ring Failure Frequency, by Roger M. Cooke and Karen A. Slijkhuis
21. Use of Extreme Values in ReliabilityAssessment of Composite Materials, by Linda C. Wolstenholme
22. Information Fusion for Damage Prediction, by Nozer D. Singpurwalla, Yuling Cui, and Chung Wai Kong
23. Modeling and Analysis of Software System Reliability, by Min Xie, Guan Yue Hong, and Claes Wohlin
24. Virtual Qualification of Electronic Hardware, by Michael Osterman, Abhijit Dasgupta, and Thomas Stadterman

Subtask 3.3.3 Pilot Course

Pilot courses organized by Sfax University and Plasmatrix in December 2022 provided valuable training opportunities for students interested in wastewater treatment and IR thermography. The course on wastewater treatment was offered at Sfax University, equipping students with the skills and knowledge necessary to manage and treat wastewater effectively. Meanwhile, the IR Thermography course at Cartage University (UCAR) in Tunis taught students how to use thermal imaging techniques to identify faults and weaknesses in various materials. These courses were a great success, providing students with practical experience in cutting-edge technologies that will be useful in their future careers. The organizers are already planning similar courses for next year, ensuring that aspiring professionals have access to the latest advancements in their fields.

Subtask 3.3.4 TMC-VET programme evaluation

In order to ensure the highest quality of VET-courses, a thorough evaluation process has been put in place. The first step involved gathering feedback from students who had participated in the VET activities. This feedback was used to make any necessary improvements and adjustments to the courses. However, the evaluation process doesn't stop there. In the second step, a deeper assessment will be conducted by the TMC Quality group as well as by industrial partners. This

comprehensive evaluation will help to ensure that the VET-courses meet the highest standards of quality and are optimized for success. By taking these steps to evaluate and improve VET-courses, we can provide students with the best possible education and training, setting them up for future success in their chosen careers.

Conclusion for the task performed in Work Package 3

The WP 3 activities are progressing smoothly and according to the work plan presented in the proposal. No delays have been encountered so far, and the team is looking forward to intensifying efforts in the pilot courses and VET-programme evaluation. To showcase project scenarios, a demonstration will be organized with collaborative participation from academic staff, students, and industrial organizations. The associated partners, UPMI, UTICA, and Chambre de Commerce et D'industrie De Tunis in Sfax, will also provide support for these activities. Also, a demonstration lecture will be organized for presenting the guidelines for Case Studies implementation. As part of the project's quality assessment, further improvements will be considered for the VET-courses. Overall, the team is optimistic about the remaining period and looks forward to achieving all project goals successfully.