SHEng
SMART HEALTHCARE ENGINEERING
2023-1-RO01-KA220-HED-000159985

Co-funded by
the European Union

HOSPITAL ENGINEERING

Class content material

This document is part of a training materials collection developed within the Erasmus+ project “Smart healthcare engineering”, SHEng, project No. 2023-1-RO01-KA220-HED-000159985.

The collection is intended for engineering students and professionals working in the healthcare sector. It covers technical subjects relevant to hospital infrastructure, equipment, materials and support services, helping readers understand how engineering contributes to safe patient care and the reliable operation of healthcare facilities.

These materials support classroom teaching and independent study. They should be used alongside the project handbook and the presentations, courses and other learning resources available on the project website. Each document addresses a specific subject, while the collection provides a broader understanding of the responsibilities and practical challenges of healthcare engineering.

The content is educational. Its application in practice requires consideration of the conditions of each healthcare facility, the applicable standards and the instructions provided by equipment manufacturers.

Project website: www.smarthealtheng.com

SHEng
SMART HEALTHCARE ENGINEERING

Transilvania University of Brasov
ULPGC Universidad de Las Palmas de Gran Canaria
MANISA CELAL BAYAR ÜNİVERSİTESİ
Servicio Canario de Salud
SPITALUL MUNICIPAL SĂCELE
Co-funded by the European Union

HOSPITAL ENGINEERING

This course supports the contents of the four sessions devoted to Maintenance Management. The course outline establishes four blocks: introduction to maintenance, management tools, maintenance team, and the organizational and management model for a hospital maintenance service.

The synthesis follows the sequence and terminology of the presentations. It emphasizes the relationships between maintenance, asset availability, safety, information management, work organization and hospital service delivery.

Structure

Block	Main content
1. Introduction to maintenance	Concept, evolution, maintenance types, physical asset management, regulation, facilities and good practices.
2. Management tools	"SCADA", "CMMS", "BIM, BAM, BOOM", procedures, work orders, inventory and energy records.
3. Maintenance team	Professional profiles, training, preventive culture, electrical risk, metrics and KPIs.
4. Hospital organization	Service objectives, physical assets, organizational structure, work orders, response times and HUGCDN activity.

Across the four sessions, maintenance is presented as a technical and organizational activity requiring trained people, appropriate resources, planning, information, procedures and performance monitoring. In the hospital context, these elements are connected with safety, reliability, comfort and profitability.

1. INTRODUCTION TO MAINTENANCE

1.1 Introduction

Concept and scope

The first presentation places maintenance as an essential activity for preserving the availability of equipment and facilities under defined conditions of quality, cost and time, while complying with safety, regulatory and environmental requirements. The central idea is not limited to repairing failures. Maintenance is presented as a system involving human resources, technical means, documentation, spare parts, planning, training, cost control and interaction with other organizational areas.

The management framework shown connects maintenance with human resources, spare-parts logistics, equipment documentation, production time, new projects, safety, regulation, cost control, energy optimization, quality, reliability, customer orientation, waste management and decision-making. These elements are connected with plans, objectives, measurements and reports.

Historical evolution

The evolution of maintenance is presented, from a situation dominated by repair after failure towards planned maintenance models supported by information and analysis. During the Industrial Revolution, machines were relatively simple, production stoppages occurred and maintenance was largely reactive and unstructured. During the First World War, maintenance teams emerged in response to the need for rapid and continuous production, with corrective maintenance predominating.

During the Second World War, machines and systems became more complex and reliability became increasingly important. Preventive maintenance and scheduled maintenance developed to reduce unexpected failures. Later, from the 1950s to the 1990s, the presentation introduces quality, competitiveness, electronic components, condition-based predictive maintenance, risk assessment and decision-making.

The historical overview concludes with maintenance and engineering concepts associated with TPM, TQM, CMMS, BIM, Internet of Things, Big Data, prescriptive maintenance and artificial intelligence. The material therefore shows a shift from repair as the main response towards more planned, measured and information-based maintenance.

TPM and 5S

The historical block introduces TPM and presents a structure based on five foundations, eight pillars and four objectives. It also presents the five S principles: Seiri, classify and remove what is unnecessary, Seiton, organize, Seiso, clean and inspect, Seiketsu, standardize, and Shitsuke, maintain the application of standards.

1.2. Types of Maintenance

Maintenance strategies are presented according to the timing of intervention and the information available about equipment condition. The diagram of Maintenance shows the main branches as preventive maintenance, corrective maintenance and improvement, while preventive maintenance is divided into predetermined maintenance and condition-based maintenance.

Corrective maintenance

Corrective maintenance takes place after a failure has appeared or when a damaged component has to be repaired or replaced. The presentation indicates that corrective interventions are an unavoidable part of maintenance activity, but highlights the risk of allowing all maintenance to become repair work. Effects associated with a predominantly corrective approach include unexpected stoppages, possible major damage, higher repair costs, the need to hold spare parts because of uncertainty, increased accident risk, limited knowledge of machine condition and persistent chronic failures whose causes have not been identified.

Preventive or scheduled maintenance

Preventive maintenance is based on intervention according to a schedule, for example by replacing components or performing lubrication at intervals associated with theoretical service life or manufacturer recommendations. Its purpose is to act before failure occurs. The presentation also identifies limitations. An intervention may be carried out on a machine that is operating correctly, components may be replaced while still in good condition, hidden damage may remain undetected, and costs may increase when frequent interventions provide limited value.

Predictive maintenance

Predictive maintenance is based on studying variables or parameters related to equipment condition while the installation remains in operation. The presentation lists techniques such as vibration analysis, infrared thermography, visual inspection, oil analysis, ultrasound, laser alignment, dissolved gas analysis, motor current analysis and insulation testing.

This approach makes it possible to determine equipment condition, identify component problems or even design and installation problems, and schedule an intervention when available information indicates that it is necessary. The presentation recognizes a high initial investment in technology and training, together with profitability considered over the medium and long term.

Improvement and root-cause analysis

The material introduces Root Cause Analysis, Reliability-centered Maintenance, Total Productive Maintenance and Total Quality Management applied to the Maintenance-and-Engineering department. The bearing example shows that investigating the cause may lead to questioning component sizing or suitability rather than simply replacing the failed component.

1.3. Physical Asset Management, Regulation and Facilities

Physical asset management

The presentation introduces physical asset management through references to EN 16646 and the relationship between maintenance and asset management. A physical asset is presented as an item that has or can have value for an organization, with examples including components, machines, plants, constructions and buildings. Physical asset management is described as a set of coordinated activities for obtaining value from physical assets and is related to the life cycle and achievement of objectives.

European regulation and standardization

The regulatory section describes the development of European maintenance standardization. The presentation places an early attempt to unify maintenance activities within the OECD in 1963, mentions the creation of EFNMS in 1970, the project to unify maintenance terminology in 1972, and the development of standardization in France during the 1980s. It also refers to the Euroguidelines project initiated by EFNMS in 1993 and the creation of the CEN/TC 319 Maintenance technical committee in 1994.

The presentation also lists standards and references associated with maintenance and asset management. Visible references include EN 13306, EN 16646 and standards in the ISO 55000 family, together with documents concerning terminology, processes, indicators and asset management.

Building services and regulation

The material relates hospital and building services to several regulatory references. Among those shown are RITE 2007, DB-HS3 and DB-HS4 of the CTE, REBT 2002, RD 552/2019, RSCIEI, DB-SI, DB-HS5, REP, RIP and RAPQ. This summary records the references as presented in the teaching material without extending their legal scope beyond what is shown.

1.4. Good practices

The final section of the first session connects good practices with professional training, spare-parts management, cooperation with other departments, investigation of accident and failure causes, and orderly facilities. The presentation uses visual examples to reinforce the importance of an organized workplace and attention to causes rather than symptoms alone.

2. Maintenance Management Tools

2.1. SCADA

The second presentation introduces SCADA, Supervisory Control and Data Acquisition, as a system intended for process supervision, control and optimization. The material highlights its use in industrial and infrastructure processes and presents four main components: Remote Terminal Units (RTU), Programmable Logic Controllers (PLC), Human-Machine Interface (HMI) and Master Terminal Unit (MTU), connected through a communications network.

Components

Component	Function described in the presentation
RTU	Collects data from sensors and transmits it to the central system. It can also receive commands and act on field equipment.
PLC	Performs local control and data processing. It can execute algorithms, sequences, PID control and safety interlocks.
HMI	Graphical interface used to visualize the process, consult data and alarms, modify setpoints and initiate control actions.
MTU	Central station that gathers data from RTUs and PLCs, processes information, stores and analyzes data, and issues control commands.
Communications network	Transfers data among system components and must meet requirements for reliability, security, data volume and latency.

Reliability, communications and security

The presentation identifies protocols such as Modbus, DNP3 and IEC 60870-5-104 and highlights functions including error checking, retransmission and time synchronization. It also shows redundancy mechanisms, alternative communication paths and redundant equipment. Security

measures mentioned include firewalls, encryption techniques, network segmentation into zones and activity logging.

Communications architecture may use wired networks, wireless networks or a combination of both. According to the material, selection depends on geographical distribution, transmission requirements, latency and cybersecurity considerations. Modularity and scalability allow new RTUs, PLCs and other devices to be incorporated.

SCADA in maintenance management

Within the maintenance management toolset, SCADA provides operational and supervisory information that can be connected with technical facility management. Its role in the presentations is part of a broader system in which operational data can be related to planning, work orders, inventory and performance indicators.

2.2. CMMS and Building Information Management

CMMS

CMMS, Computerized Maintenance Management System, is defined in the presentation as software intended to manage and optimize maintenance operations. It provides a centralized platform for planning, scheduling and tracking activities, as well as managing maintenance-related data and resources.

Function	Application described
Asset management	Database containing equipment, specifications, maintenance history and spare parts.
Work orders	Creation, assignment and tracking of preventive, predictive and reactive work.
Preventive scheduling	Automation of tasks according to time, use or other triggers.
Inventory	Tracking parts, supplies and tools and supporting purchasing.
Reporting and analysis	Reports and dashboards concerning performance, costs and trends.

The presentation connects CMMS with improved asset reliability, work efficiency, cost control, documentary tracking of activities and decision-making. It also states that analysis of availability, costs, preventive maintenance compliance, MTBF, MTTR, inventory accuracy and user satisfaction can reveal improvement opportunities.

BIM, BAM, BOOM

BIM is presented as a collaborative digital working methodology for creating a virtual representation of a construction containing graphical and non-graphical information. The material

describes a paradigm shift from analogue to digital and relates building information to the different stages of the life cycle.

Acronym	Definition in the presentation	Associated phase
BIM	Building Information Model	Concept and design
BAM	Building Assembly Model	Construction
BOOM	Building Operation Optimization Model	Users and operation

The illustrations in this section show the building life cycle and collaboration among the owner, architects, engineers, contractor, manufacturers, installers, facility managers and users. The maintenance contribution is placed in the continuity of information from design and construction through to operation.

2.3. Procedures, Work Orders, Inventory and Energy Records

Department procedures

The presentation identifies a broad set of maintenance department activities. These include routine maintenance and small repairs, preventive maintenance, supplies and spare-parts management, energy records, small rehabilitation works, department administration, safety and surveillance control, control of subcontracted work, investment decisions, internal training programs, emergency management and evacuation drills, as well as budget comparison and activity reports.

Work-order system

A work order is presented as a request to carry out a job. The system makes it possible to establish priorities, record corrective maintenance and evaluate response times and quality. Preventive tasks associated with assets can be scheduled and assigned to internal personnel or external companies.

The work order also helps organize individual workloads. Analysis of work orders can be used to justify staffing levels and department budgets and to assess outsourced work against contractual conditions. The material recommends recording spare parts, time, dates, work status and worker comments, while taking into account the time required to enter this information.

In the hospital model presented in the fourth session, the workflow runs from projects, preventive maintenance or a failure to tasks and requests, then to the work order, materials and time, work-order closure, costs and invoices, and finally the database. System customers can consult their requests and monitor their status.

Equipment inventory

The inventory introduces the equipment list into the system and creates an asset tree. Each physical item receives a reference code and can be organized by groups, families or sections. The record can

contain drawings, manufacturer manuals, certificates, inspections and audits. Preventive tasks and checklists can also be associated with large equipment families.

Energy records

Energy records are intended to check the consumption reported by utility companies through periodic measurements and meter readings. The presentation indicates the value of measuring critical points and selected equipment during different periods in order to assess operating efficiency and record results in the equipment history.

3. Maintenance Team, Training and Prevention

3.1. Multidisciplinary team

The third block starts from the idea that the maintenance team consists of professionals from different trades and levels of responsibility. The large-team structure distinguishes senior management, management positions and field workers. Technical roles include facilities maintenance, planning, engineering, supervision and coordination, while trades shown include electrician, plumber, refrigeration technician, mechanic, builder, carpenter and painter.

The structure presented links responsibility levels with required training. Positions associated with engineering degrees, positions requiring higher education and positions related to vocational training or equivalent studies are shown. The material therefore places emphasis on the relationship between professional competence, function and responsibility.

3.2. Occupational risk prevention culture

The presentation distinguishes hazard and occupational risk. A hazard is described as a characteristic of a situation, material or piece of equipment capable of causing harm to people, the environment or property. Occupational risk is related to the possibility that a worker suffers harm arising from work. Risk severity is presented as requiring consideration of both the probability of harm and the severity of its consequences.

A work accident is presented as bodily injury suffered by a worker because of or as a consequence of work. Risk assessment is connected with industrial and occupational safety and with references such as REBT, RAPQ, RSCIEI and other provisions identified in the presentation.

From identification to prevention culture

The presentation organizes prevention culture around four elements. First, planning and design of measures after risks have been identified. Second, training and awareness so that measures are correctly applied. Third, communication and participation to support understanding and organizational involvement. Fourth, implementation and monitoring to check application and make adjustments.

The material emphasizes that prevention is not only a matter of having safety measures. It is presented as a philosophy in which safety and health are integrated into activities and organizational levels.

Electrical risk

Electrical-risk is one of the most important field any maintenance worker must pay attention. Therefore, there´s a specific point in the contents dedicated to this question. The electrical-risk section shows short-circuit, overload and electrocution situations together with protective elements and technical measures. It includes aM, gF and gT fuses, magnetic and thermal parts of circuit breakers, thermal relays and residual-current devices, insulation monitoring relays, earthing, circuit separation, safety extra-low voltages, insulation between live parts and metal parts, simultaneous inaccessibility and equipotential connections.

3.3. Maintenance Service Evaluation

Service evaluation is based on metrics and KPIs. Maintenance metrics are defined as any data recorded by an organization to monitor elements related to employees, machines, operations and inventory. KPIs are used to evaluate factors critical to success and measure performance against objectives concerning failures, repair times, outstanding work and costs.

Maintenance KPIs are specific targets, like “decrease downtime by 25%,” for tracking progress in accomplishing bigger goals like preventing downtime, reducing costs, or strengthening machine reliability. A KPI is the combination of a metric, like downtime, and a benchmark, like a decrease of 25%, that quantifies success for a goal, like preventing downtime. A good KPI is true to the SMART acronym of Specific, Measurable, Achievable, Realistic, and Timely.

Some common examples of maintenance goals around which metrics and KPIs focus include:

- Reduce costs.
- Reduce failures.
- Reduce downtime.
- Increase work identification.
- Improve work planning.
- Improve scheduling.
- Improve execution.

The information that matters for maintenance goals is different for every company, so it’s important to understand how every aspect of the business affects reaching the goals set.

It is also important to distinguish between a leading indicator and a lagging indicator. A leading indicator signals future events and includes metrics like Preventative Maintenance Compliance or Estimate vs. Actual Performance. A lagging indicators values results of past events and include maintenance metrics like Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR)

Main indicators

Indicator	Meaning in the presentation

Availability	Percentage of time during which equipment is operational and available for use.
Reliability	Probability that a machine or system performs its function adequately for a specified period under normal conditions.
Maintenance backlog	Identified maintenance work that has not yet been completed.
Downtime	Time during which equipment is not operational because of failures or maintenance.
MC/ERV	Relationship between annual maintenance cost and estimated replacement value of the asset.
MTBF	Time elapsed between failures of a system during operation.
MTTR	Average time required to repair a failed component or item of equipment.
OEE	Assessment of how effectively equipment is used, considering availability, performance and quality.

Combined interpretation

The indicators should not be considered in isolation. The contents presented states that a low MTBF together with a high MTTR may indicate opportunities to improve reliability and repair efficiency. It also relates maintenance information to decisions about staffing, inventory and repair versus replacement.

For OEE, the presentation expresses OEE = Availability × Performance × Quality. It breaks down losses in availability, performance and quality and defines concepts such as planned production time, operating time, total count, good-unit count and ideal cycle time.

4. Organizational and Management Model for Hospital Maintenance

4.1. Characteristics of the hospital environment

The fourth presentation places maintenance within buildings and equipment of high complexity. The objective is to establish planned and systematic processes capable of preserving buildings in appropriate conditions of safety, use, comfort and aesthetics throughout their useful life. The service is organized around four objectives: safety, reliability, comfort and profitability.

The example used is Hospital Universitario de Gran Canaria Dr. Negrín. Data shown during the presentation states that the infrastructure was inaugurated in 1999, with 220,000 m², 800 beds, 22 operating rooms, 6 linear accelerators, more than 85% conditioned surface, 9,000 kWt of installed refrigeration and a building technical management system with 32,000 control points. These data are used to illustrate the scale and complexity of hospital maintenance.

4.2. Hospital physical assets

Assets are grouped into physical and technological resources. The diagram distinguishes building facilities, general equipment and electromedical equipment. Hospital areas shown include operating rooms, intensive surveillance units, technical rooms, X-ray areas, heliport, laboratories,

guest rooms, industrial laundry, industrial kitchen, restaurants, shops, conference rooms, parking, administration offices and storage rooms.

Facilities listed include HVAC, hot water, electrical systems, water supply, refrigeration, fire protection, sanitation, thermal generation boilers, fuel storage, compressed air, pneumatic systems, steam, medical gases, cryogenic facilities, telecommunications and transport systems and elevators.

4.3. Service organization

The organizational model is multidisciplinary. It includes sections oriented towards facilities or equipment of similar nature and administrative and technical departments operating across the service. The model includes management autonomy, budget and analytical accounting, capacity to subcontract, a department head and section managers. Execution is described through a professional team permanently present in the hospital, 24x7.

The organizational chart includes service management, department management, area managers, external services and workshop managers. It also shows a safety and prevention department and an administrative and technical department with management, technical office, IT, inventory and technical management, and logistics and purchasing units. Operational areas include thermal and mechanical facilities, building conservation, electrical and electronic systems, general equipment and electromedicine.

4.4. Work orders and response times

The work-order system connects requests from customer departments with tasks, materials, time, closure, costs and the database. Actions whose effectiveness depends on immediate intervention are classified as emergent. Critical failures are those that compromise the safety of people, continuity of functional units, the useful life of building elements or high-value equipment, or essential functions. The presentation gives, as an example, starting urgent actions within 30 minutes and resolving them within 60 minutes, while ordinary actions are proposed to start or have a proposed start within 60 minutes and be resolved within 24 hours.

CONCLUSION

The four sessions present maintenance as an integrated function. It begins with a strategy for preservation and availability, incorporates preventive and predictive methods, uses digital tools and records, requires competent teams and a prevention culture, and culminates in an organizational model capable of managing hospital assets, priorities, response times, costs and quality.

The HUGCDN case illustrates this management scale through an organization that, according to the presentation, manages more than 240 people, more than 110,000 work orders per year, more than 300,000 preventive operations per year and more than 40 million euros associated with activity, projects, renewals and new implementations. The material concludes by presenting technical capability as a means of achieving broader objectives of service to citizens.

Documentary bibliography

Garg, A., & Deshmukh, S. G. (2006). Maintenance management: Literature review and directions. Journal of Quality in Maintenance Engineering, 12(3), 205–238. https://doi.org/10.1108/13552510610685075. ResearchGate

Pintelon, L., & Parodi-Herz, A. (2008). Maintenance: An evolutionary perspective. In K. A. H. Kobbacy & D. N. P. Murthy (Eds.), Complex System Maintenance Handbook (pp. 21–48). Springer. https://doi.org/10.1007/978-1-84800-011-7_2. DOI

Ahuja, I. P. S., & Khamba, J. S. (2008). Total productive maintenance: Literature review and directions. International Journal of Quality & Reliability Management, 25(7), 709–756. https://doi.org/10.1108/02656710810890890. Emerald Publishing

Parida, A., & Kumar, U. (2006). Maintenance performance measurement (MPM): Issues and challenges. Journal of Quality in Maintenance Engineering, 12(3), 239–251. https://doi.org/10.1108/13552510610685084. Emerald Publishing

Saraph, J. V., Benson, P. G., & Schroeder, R. G. (1989). An instrument for measuring the critical factors of quality management. Decision Sciences, 20(4), 810–829. https://doi.org/10.1111/j.1540-5915.1989.tb01421.x. Wiley Online Library

Schonberger, R. J. (2006). Japanese production management: An evolution—with mixed success. Journal of Operations Management. https://doi.org/10.1016/j.jom.2006.04.003. Metascience Observatory

Pliatsios, D., Sarigiannidis, P., Lagkas, T., & Sarigiannidis, A. (2020). A survey on SCADA systems: Secure protocols, incidents, threats and tactics. IEEE Communications Surveys & Tutorials, 22(3), 1942–1976. https://doi.org/10.1109/COMST.2020.2987688. mendeley.com

Gao, X., & Pishdad-Bozorgi, P. (2019). BIM-enabled facilities operation and maintenance: A review. Advanced Engineering Informatics, 39, 227–247. https://doi.org/10.1016/j.aei.2019.01.005. ScienceDirect

Dhillon, B. S., & Liu, Y. (2006). Human error in maintenance: A review. Journal of Quality in Maintenance Engineering, 12(1), 21–36. https://doi.org/10.1108/13552510610654510.

Ministerio de Industria y Turismo. Subdirección General de Calidad y Seguridad Industrial. (2024). Reglamentación de seguridad industrial: Instalaciones industriales. Boletín Oficial del Estado.

Asociación Técnica Española de Climatización y Refrigeración. (2007). Guía técnica de contabilización de consumos. Instituto para la Diversificación y Ahorro de la Energía.

Instituto para la Diversificación y Ahorro de la Energía, & Comité Español de la Iluminación. (2020). Guía técnica de eficiencia energética en iluminación: Hospitales y centros de atención primaria. IDAE.

Junta de Castilla y León. (s. f.). Guía para inspección y mantenimiento en instalaciones de la Administración de la Comunidad de Castilla y León y sus Organismos Autónomos.

Smart Buildings Alliance for Smart Cities. (2022). Le BIS & le BOS: Les outils de la gouvernance des données du bâtiment [Livre blanc].

https://www3.gobiernodecanarias.org/sanidad/scs/organica.jsp?idCarpeta=887001ae-541d-11de-9665-998e1388f7ed

UNE_151001-2011

UNE-EN_13269=2016(EN)

UNE-EN_13306=2018(EN)

UNE-EN_13460=2009(EN)

UNE-EN_15331=2012(EN)

UNE-EN_15341=2020+A1=2023(EN)

UNE-EN_15628=2015(EN)

UNE-EN_16646=2015(EN)

UNE-EN_16991=2018(EN)

UNE-EN_17007=2018(EN)

UNE-EN_17485=2023(EN)

UNE-EN_17666=2024(EN)

UNE-EN_17840=2024(EN)

UNE-EN_60300-3-1=2005(EN)

UNE-EN_60300-3-11=2013(EN)

UNE-EN_60300-3-12=2014(EN)

Acknowledgments
The content was supported by the project “Smart Healthcare Engineering (SHEng)”, Grant Agreement No. 2023-1-RO01-KA220-HED-000159985, co-funded by the Erasmus+ programme of the European Union. Results, views and opinions expressed are however those of the project team and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor the granting authority can be held responsible for them.