E-maintenance

Kenneth Holmberg · Adam Adgar · Aitor Arnaiz
Erkki Jantunen · Julien Mascolo · Samir Mekid
Editors

E-maintenance

Springer

Kenneth Holmberg, Prof.
VTT Technical Research Centre of Finland
Metallimiehenkuja 6–8
02044 VTT, Espoo
Finland
kenneth.holmberg@vtt.fi

Erkki Jantunen, Dr.
VTT Technical Research Centre of Finland
Metallimiehenkuja 6–8
02044 VTT, Espoo
Finland
erkki.jantunen@vtt.fi

Adam Adgar, Dr.
Teesside University
School of Science and Engineering
Borough Road
Middlesbrough, Tees Valley TS1 3BA
UK
a.adgar@tees.ac.uk

Julien Mascolo, Dr.
Centro Ricerche Fiat S.C.p.A
Strada Torino, 50
10043 Orbassano, Torino
Italy
julien.mascolo@crf.it

Aitor Arnaiz, Dr.
Fundación Tekniker
Avda. Otaola, 20
20600 Eibar, Guipúzcoa
Spain
aarnaiz@tekniker.es

Samir Mekid, Dr.
King Fahd University Petroleum & Minerals
Department of Mechanical Engineering
Dhahran 31261
KSA
smekid@kfupm.edu.sa

ISBN 978-1-84996-204-9
e-ISBN 978-1-84996-205-6
DOI 10.1007/978-1-84996-205-6
Springer London Dordrecht Heidelberg New York

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2010930014

Cover design: eStudioCalamar, Figueres/Berlin

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

This is the first book to present the topic of *e-maintenance*, which has appeared in the scientific and technological discussions at conferences and meetings during the last decade. E-maintenance is a synthesis of two large trends in our society: on the one hand the growing importance of maintenance as a key technology to keep machines running properly, efficiently and safely in industry and transportation, and on the other hand, the very rapid development of information and communication technology (ICT). This has opened the way to completely new concepts and solutions with more detailed equipment for health information and more effective diagnostic and prognostic tools and user interfaces to ensure good reliability and availability of plants and vehicles remotely worldwide.

The authors of the book are European top experts on ICT and maintenance technology both from academia and industry. They have worked very intensively together for the last four years, starting in 2005 within the European Commission funded research and development project DYNAMITE – Dynamic Decisions in Maintenance. The R&D group consisted of about 50 experts altogether from nine European countries: Estonia, Finland, France, Germany, Greece, Italy, Spain, Sweden and UK.

This book presents an overview of the subject of e-maintenance including trends, scenarios and needs in industry and advanced ICT technologies and future solutions to global and mobile industrial maintenance needs. The pioneering e-maintenance concept DynaWeb is presented, and the group of experts that were involved in its development describe the detailed technologies, their development and experiences gained with this R&D process, as well as future perspectives.

The book is divided into 16 chapters, which include the new integrated e-maintenance concept, intelligent, wireless, MEMS, and lubricating oil sensors, smart tags, mobile devices and services, semantic web services, strategies for e-maintenance and related cost effective decisions, industrial demonstrations as examples of e-maintenance, as well as related e-training.

The book is intended for engineers and qualified technicians working in the fields of maintenance, systems management, and shop floor production lines maintenance. It constitutes a good tool for the further development of e-maintenance in both current and new industrial sites.

It is the hope of the authors that this book will open new views and ideas to researchers and industry on how to proceed in the direction of a sustainable and environmentally stabile society.

Europe *The authors*
October 2009

Acknowledgements

The authors gratefully acknowledge the support of the European Commission Sixth Framework Programme for Research and Technological Development. This book summarises work performed as part of FP6 Integrated project IP017498 DYNAMITE “Dynamic Decisions in Maintenance”.

The authors are grateful for the support and encouragement received from the European Commission Scientific Officers Andrea Gentili, Philipp Dreiss and Barry Robertson. We also wish to thank the project reviewers appointed by the Commission, Flavio Testi and Christoph Hanisch, for their advice and guidance during the R&D work.

The excellent help and assistance from a great number of colleagues and staff members, as well as the encouragement and financial support from all organisations participating in DYNAMITE is gratefully acknowledged:

- VTT Technical Research Centre, Finland
- Fundación Tekniker, Spain
- University of Sunderland, UK
- University of Manchester, UK
- Université Henri Poincaré, France
- Linnaeus University, Sweden
- Zenon S.A. Robotics & Informatics, Greece
- FIAT Research Centre, Italy
- Volvo Technology, Sweden
- Goratu Maquinas Herramienta, Spain
- Wyselec, Finland
- Martechnic, Germany
- Engineering Statistical Solutions, UK
- Diagnostic Solutions, UK
- Prisma Electronics, Greece
- IB Krates, Estonia

The financial support from the following national funding agency is gratefully acknowledged:

- Spanish Ministry of Science and Innovation (grant no. DPI2007-29958-E)

The authors also wish to thank Ms Christina Vähävaara for the skilful and meticulous editing of the manuscript.

Contents

Contributors

Addison, Dale
University of Sunderland, UK
E-mail: dale.addison@sunderland.ac.uk
Web: www.sunderland.ac.uk

Adgar, Adam
University of Teesside, UK
E-mail: a.adgar@tees.ac.uk
Web: www.tees.ac.uk

Albarbar, Alhussein
Manchester Metropolitan University, UK
E-mail: a.albarbar@mmu.ac.uk
Web: www.mmu.ac.uk

Al-Najjar, Basim
Linnaeus University, Sweden
E-mail: basim.al-najjar@lnu.se
Web: www.lnu.se

Arnaiz, Aitor
Fundación Tekniker, Spain
E-mail: aarnaiz@tekniker.es
Web: www.tekniker.es

Baglee, David
University of Sunderland, UK
E-mail: david.baglee@sunderland.ac.uk
Web: www.sunderland.ac.uk

Bellew, Jim
Martechnic Gmbh, Germany
E-mail: jim.bellew@martechnic.com
Web: www.martechnic.com

Eberhagen, Niclas
Linnaeus University, Sweden
E-mail: niclas.eberhagen@lnu.se
Web: www.lnu.se

Emmanouilidis, Christos
CETI/Athena Research & Innovation Centre, Greece
E-mail: chrisem@ceti.gr
Web: www.ceti.gr

Garramiola, Fernando
Goratu Maquinas Herramienta S.A., Spain
E-mail: fgarramiola@goratu.com
Web: www.goratu.com

Gilabert, Eduardo
Fundación Tekniker, Spain
E-mail: egilabert@tekniker.es
Web: www.tekniker.es

Giordamlis, Christos
Prisma Electronics, Greece
E-mail: christos@prisma.gr
Web: www.prisma.gr

Gorritxategi, Eneko
Fundación Tekniker, Spain
E-mail: egorritxategi@tekniker.es
Web: www.tekniker.es

Halme, Jari
VTT Technical Research Centre, Finland
E-mail: jari.halme@vtt.fi
Web: www.vtt.fi

Holmberg, Kenneth
VTT Technical Research Centre, Finland
E-mail: kenneth.holmberg@vtt.fi
Web: www.vtt.fi

Iung, Benoit
Université Henri Poincaré, France
E-mail: Benoit.Iung@cran.uhp-nancy.fr
Web: www.cran.uhp-nancy.fr

Jantunen, Erkki
VTT Technical Research Centre, Finland
E-mail: erkki.jantunen@vtt.fi
Web: www.vtt.fi

Katsikas, Serafim
Prisma Electronics, Greece
E-mail: sekat2004@yahoo.gr
Web: www.prisma.gr

Krommenacker, Nicolas
Université Henri Poincaré, France
E-mail: nicolas.krommenacker@cran.uhp-nancy.fr
Web: www.cran.uhp-nancy.fr

Lecuire, Vincent
Université Henri Poincaré, France
E-mail: vincent.lecuire@cran.uhp-nancy.fr
Web: www.cran.uhp-nancy.fr

Levrat, Eric
Université Henri Poincaré, France
E-mail: eric.levrat@cran.uhp-nancy.fr
Web: www.cran.uhp-nancy.fr

Mascolo, Julien
FIAT Research Center, Italy
E-mail: julienetienne.mascolo@crf.it
Web: www.crf.it

Mekid, Samir
The University of Manchester, UK
King Fahd University Petroleum & Minerals, KSA
E-mail: smekid@kfupm.edu.sa
Web: www.manchester.ac.uk; www.kfupm.edu.sa

Naks, Tonu
IB Krates OÜ, Estonia
E-mail: tonu@krates.ee
Web: www.krates.ee

Nilsson, Per
Volvo Technology AB, Sweden
E-mail: Per.Henrik.Nilsson@volvo.com
Web: www.volvo.com

Pietruszkiewicz, Robert
The University of Manchester, UK
E-mail: rpietrus@gmail.com
Web: www.manchester.ac.uk

Salles, Nicolas
Université Henri Poincaré, France
E-mail: nicolas.salles@cran.uhp-nancy.fr
Web: www.cran.uhp-nancy.fr

Spais, Vasilis
Zenon S.A. Automation Technologies, Greece
E-mail: v_spa@zenon.gr
Web: www.zenon.gr

Starr, Andrew
The University of Hertfordshire, UK
E-mail: a.starr@herts.ac.uk
Web: www.herts.ac.uk/csc

Tohver, Avo
IB Krates OÜ, Estonia
E-mail: avo@krates.ee
Web: www.krates.ee

Tommingas, Toomas
IB Krates OÜ, Estonia
E-mail: toomas@krates.ee
Web: www.krates.ee

Voisin, Alexandre
Université Henri Poincaré, France
E-mail: alexandre.voisin@cran.uhp-nancy.fr
Web: www.cran.uhp-nancy.fr

Yau, Alan
University of Sunderland, UK
E-mail: alan.yau@sunderland.ac.uk
Web: www.sunderland.ac.uk

Zhu, Zhenhuan
The University of Manchester, UK
E-mail: Zhenhuan.Zhu@manchester.ac.uk
Web: www.manchester.ac.uk

Abbreviations

ACK	Acknowledgment
ACL	Asynchronous Connectionless Link
ADC	Analogue-to-digital Converter
AE	Acoustic Emission
AI	Artificial Intelligence
AmI	Ambient Intelligence
ANN	Artificial Neural Networks
AoA	Angle of Arrival
AP	Access Point
API	Application Programming Interface
AR	Augmented reality
ASIC	Application-Specific Integrated Circuit
BDM	Breakdown Maintenance
BN	Bayesian Networks
BN	Base Number
BP	Back Propagation
BSS	Basic Service Set
CAD	Computer-aided Design
CAM	Content Aggregation Model
CAP	Contention Access Period
CBM	Condition Based Maintenance
CBR	Case Based Reasoning
CCD	Charge Couple Device
CCK	Complementary Code Keying
CEO	Chief Executive Officer
CFP	Contention-Free Period
CNC	Computer Numerical Controlled
CM	Condition Monitoring
CMI	Computer Managed Instruction
CMMS	Computerised Maintenance Management Systems

CMOpS	Computer Maintenance Operational System
CMOS	Complementary Metal-oxide-semiconductor
COTS	Commercial off-the-shelf
CPT	Conditional Probability Table
CRC	Cyclic Redundancy Check
CRIS	Common Relation Interface Schema
CSMA	Carrier Sense Multiple Access
CUSUM	Cumulative Sum
DAG	Directed Acyclic Graph
DCF	Distributed Coordination Function
DIFS	Distributed Inter-Frame Spacing
DPSK	Differential Phase Shift Keying
DSP	Digital Signal Processing
DS	Distribution System
DSSS	Direct Spread Sequence Shifting
Dynamite	Dynamic Decisions in Maintenance
ECU	Electronic Control Units
EEPROM	Electrically Erasable Programmable Read-only Memory
EMC	Electromagnetic Compatibility
ESD	Electrostatic Discharge
ESS	Extended Service Set
EP	Extreme Pressure
ERP	Enterprise Resource Planning
ES	Expert System
FFD	Fully Functional Devices
FFT	Fast Fourier Transform
FMEA	Failure Mode and Effect Analysis
FSO	Full Scale Output
FTA	Fault Tree Analysis
GFSK	Gaussian Frequency Shift Keying
GPS	Global Positioning System
GTS	Guaranteed Time Slots
GTTT	Generalised Total Test on Time
HDD	Hard Disk Drive
HMD	Head Mounted Displays
HR/DSSS	High Rate/Direct Sequence Spread Spectrum
HSI	Human System Interface
HTML	Hyper Text Markup Language
HTTP	Hypertext Transfer Protocol
IBSS	Independent Basic Service Set
IC	Integrated Circuit
IP	Internet Protocol
ICP	Integrated Circuit Piezoelectric
ICT	Information and Communications Technologies

IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific and Medical
ISO	International Standards Organization
IT	Information Technology
ITS	Intelligent Tutoring Systems
ITU-T	International Telecommunication Union – Telecommunication
KBS	Knowledge Based System
KPI	Key Performance Indicators
LAN	Local Area Network
LCI	Life Cycle Income
LCP	Life Cycle Profit
LCC	Life Cycle Cost
LCMS	Learning Content Management Systems
LED	Light-emitting Diode
LIP	Learner Information Package
LMS	Learning Management Systems
LO	Learning Objects
LOM	Learning Object Metadata
LQI	Link Quality Indicators
LRD	Light Receiving Device
MAC	Medium Access Control
MDAQ	Machine Data Acquisition
MDSS	Maintenance Decision Support System
MEMS	Microelectromechanical Systems
MES	Maintenance Execution System
MIL	Matrox Imaging Library
MIMO	Multiple Input – Multiple Output
MIMOSA	Machinery Information Management Open Systems Alliance
MPDU	MAC Protocol Data Unit
MMME	Man Machine Maintenance Economy
MTBD	Mean Time Between Degradation
MTBF	Mean Time Between Failures
NC	Numerically Controlled
NIR	Near Infrared
NIRS	Near Infrared Spectroscopy
NDT	Non-destructive Testing
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplexing
O&M	Operations and Maintenance
OPD	Optical Particle Detector
OSA-CBM	Open Systems Architecture for Condition Based Maintenance
OSA-EAI	Open Systems Architecture for Enterprise Application Integration

OTAP	Over The Air Programming
OWL	Ontology Web Language
PAN	Private Area Network
PAPI	Personal and Private Information
PC	Personal Computer
PCF	Point Coordination Function
PDA	Personal Digital Assistant
PdM	Predictive Maintenance
PHM	Proportional Hazard Modelling
PHY	Physical Layer
PIFS	Priority Inter-Frame Spacing
PLC	Programmable Logic Controller
PLL	Phase Locked Loops
PM	Preventive Maintenance
PPDU	Physical Protocol Data Unit
PPM	Planned Preventive Maintenance
P2P	Person-to-Person
RCM	Reliability Centred Maintenance
RF	Radio Frequency
RFD	Radio Frequency Device
RFD	Reduced Functional Devices
RFID	Radio Frequency Identification
RISC	Reduced Instruction Set Computer
RMS	Root Mean Square
ROCOF	Rate of Occurrence of Failures
ROIIM	Return on Investment in Maintenance
RPC	Remote Procedure Call
RSSI	Received Signal Strength Indication
RTE	Run-Time Environment
RTLS	Real-Time Location System
RUL	Remaining Useful Life
SCADA	Supervisory Control and Data Acquisition
SCO	Synchronous Connection-Oriented
SCO	Sharable Content Objects
SCORM	Sharable Content Object Reference Model
SHM	Structural Health Monitoring
SIFS	Short Inter-Frame Spacing
SLED	Super Light-Emitting Diode
SME	Small-to-Medium sized Enterprise
SN	Sequencing and Navigation
SNR	Signal-to-Noise Ratio
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SoC	System on Chip

SQL	Structured Query Language
SSID	Service Set Identifier
SW	Semantic Web
TAN	Total Acid Number
TBN	Total Base Number
TCP	Transmission Control Protocol
TDIDT	Top Down Induction of Decision Trees
TDoA	Time Difference of Arrival
TDMA	Time Division Multiple Access
ToA	Time of Arrival
TPM	Total Productive Maintenance
TQM	Total Quality Maintenance
TQMain	Total Quality Maintenance
TTT	Total Time on Test
UART	Universal Asynchronous Receiver-Transmitter
UCD	Use Case Diagrams
UML	Unified Modelling Language
URI	Uniform Resource Identifier
USB	Universal Serial Bus
UWB	Ultra Wire Band
XML	Extensible Markup Language
XSD	XML Schema Definition
VBM	Vibration-Based Maintenance
VET	Vocational Education and Training
VR	Virtual Reality
WEP	Wired Equivalent Policy
WINS	Wireless Intelligent Network Sensors
WILE	Web-based Intelligent Learning Environments
WIP	Work-In-Progress
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WORM	Write–Once, Read–Many
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network
WWAN	Wireless Wide Area Network

Chapter 1
Introduction

Kenneth Holmberg

Maintenance is a field of technology that consists of technical skills, techniques, methods and theories that all aim at "keeping the wheels in our society rolling properly". The purpose is to find both technical and organisational solutions for large assets like factories, power plants, transportation vehicles and building technology equipment, as well as for smaller assets such as household machines, hobby devices and consumer products, to function properly, in a cost-effective way, with low energy consumption, without polluting the environment and in a safe, controlled and predictable way.

The huge costs and risks related to improper maintenance have been both observed and documented in the industry. Poorly functioning production machines and unreliable products are not good for a company's business. Maintenance is directly linked to competitiveness and profitability and thus to the future of a company (Pehrsson and Al-Najjar 2005).

In the last decades several organisational approaches to arrange the maintenance work as efficiently as possible have been developed. Such methods are, *e.g.*, total productive maintenance (TPM), reliability-centred maintenance (RCM) and condition-based maintenance (CBM) (Campbell and Jardine 2001, Márquez 2007). These methods have been implemented in the industry with mainly very good results.

At the same time people have realised that the strategy to wait to repair equipment until it fails is often not a good solution. The break down may come at an inconvenient time and the sudden and unexpected stoppage can be very expensive. The breakdown may even become a source of problem for nearby equipment (secondary damage), the environment (pollution) and may even pose health and safety problems to nearby personnel. One solution is to use scheduled maintenance, stopping the equipment regularly for checking and service. The problem with this approach is that the equipment is stopped also in unnecessary cases, and sometimes the stop and unnecessary service action may introduce new problems.

The optimal solution is to know continuously the condition of the asset and its components and take repair and service actions only when really needed. It is, of course, a big challenge to have complete control over the asset condition and also know what the optimal maintenance decisions are each time. However, current technological development offers new and advanced techniques and methods to support this approach.

Currently, there is an improved understanding of the physical, mechanical and electrical phenomena initiating and triggering disturbances and failures. There is the potential to develop low cost micro size integrated sensors for observing the behaviour of a device. There are high capacity and advanced methods for condition data collection, signal analysis, data mining, reasoning and decision making. There are methods for computer based diagnostics and prognostics of plant conditions. New wireless techniques and the internet offer the possibility of using mobile hand-held computers (PDA, personal digital assistant) to have access to large information globally and on line (Holmberg and Helle 2008).

This development opens a new possibility in asset maintenance. It is called *e-maintenance* and has been defined as "The network that integrates and synchronises the various maintenance and reliability applications to gather and deliver asset information *where it is needed*" (Baldwin 2001). The e-maintenance solutions typically offer answers to the following:

- What: which equipment needs maintenance?
- When: when is the maintenance needed?
- Who: computerised maintenance management systems.
- How: manuals, spare part availability.

The concept of e-maintenance integrates existing telemetric maintenance principles with web services and modern e-collaboration methods. Collaboration allows us to share and exchange not only information but also knowledge and e-intelligence (Han and Yang 2006, Muller *et al*. 2008).

In this book we present a flavour of advanced techniques and methods that form the basis of an integrated e-maintenance approach, including solutions such as advanced micro sensors, smart tags (RFID, radio frequency identification), online oil sensors, PDA maintenance applications, ontology based diagnostic and prognostic methods, wireless communication, semantic web service for distributed intelligence, dynamic cost effectiveness based decision making tools and a holistic e-maintenance concept.

In this book the development of such techniques and methods is reported and the state-of-the-art is reviewed. Moreover, experiences both from laboratory testing as well as the use of e-maintenance in industrial environments are reported. The reported cases are demonstrations on the global level, with milling machines, machine tools, foundry hydraulics, maritime lubrication systems and automatic stamping machines. An e-training package for implementing successful e-maintenance applications is presented.

The development work and industrial demonstrations were carried out in the European Commission 6th Framework Programme project “Dynamite” (Dynamic Decisions in Maintenance) by 17 academic and industrial partners in Europe. It is our hope that this book will help the reader to understand the different advanced techniques that e-maintenance is based on and how e-maintenance as a concept can offer new and optimal solutions for asset management in a modern net-based information environment for globally active enterprises.

References

Baldwin RC (2001) Enabling an e-Maintenance infrastructure. Maintenance Technology 12, available at www.mt-online.com/articles/1201_mimosa.cfm

Campbell JD, Jardine AKS (2001) Maintenance excellence – Optimizing equipment life-cycle decisions. Marcel Dekker, New York

Han T, Yang BS (2006) Development of an e-maintenance system integrating advanced techniques. Computers in Industry 57:569–580

Holmberg K, Helle A (2008) Tribology as basis for machinery condition diagnostics and prognostics. International Journal of Performability Engineering 4:255–269

Márquez AC (2007) The maintenance management framework. Springer, London

Muller A, Márquez AC, Iung B (2008) On the concept of e-maintenance: Review and current research. Reliability Engineering and System Safety 93:1165–1187

Pehrsson A, Al-Najjar B (eds) (2005) Creation of industrial competitiveness. Acta Wexionensia No 69/2005, Växjö University Press, Sweden, ISBN: 91-7636-467-4, ISSN: 1404-4307

Chapter 2
Maintenance Today and Future Trends

Andrew Starr, Basim Al-Najjar, Kenneth Holmberg, Erkki Jantunen, Jim Bellew and Alhussein Albarbar

Abstract. This chapter describes the state of the art in maintenance and its future trends. The key areas that have influenced maintenance in the last 40 years are *management* of people and assets, and *technological* capability. These areas are important because they aim to take the best advantage of expensive resources, whether that advantage be profit, or to provide the best possible service with limited resources. The chapter first sets out the current range of maintenance in industrial practice. It is recognised that many businesses do not undertake the full extent of the work reported here, but it is our purpose to survey the state of the art. The chapter then continues to survey the influences of nascent technologies and ideas, before making some predictions about the future. Indeed, some of the most advanced condition-based maintenance effectively aims to predict the future. However, here we do not offer a crystal ball calibrated to international standards; we will constrain ourselves to an informed, independent opinion.

2.1 State of the Art in Management

Maintenance today contributes to the aim of sustainable development in society, including environmental and energy saving aspects, safety aspects and economical aspects. Advanced maintenance has a critical role to play in improving companies' competitiveness. Technology will not be effective without excellent management. The reliability and availability of machines and instruments are crucial factors of competitiveness, particularly in applications where safety and availability are important. Automation and integrated production have resulted in larger technical systems, which are more difficult to control, and more sensitive and vulnerable to diverse consequential effects because of breakdowns.

Reliability, availability and lifetime planning first advanced in the nuclear energy industry. The aerospace industry quickly followed, developing methods to assure reliability by distributing and duplicating the crucial features. Safety and risk analyses have been developed and adapted not only in the chemical industry but to some extent in most industrial fields.

However, existing methods are not always so easily applicable to conventional power plants, or to the process and metal industries, where availability is often a more important criterion than reliability. In other words, the downtime is more important than a small probability of failure. A failure can be acceptable if the repair and restarting times are short. Maintainability and maintenance support performance are therefore most important in such cases.

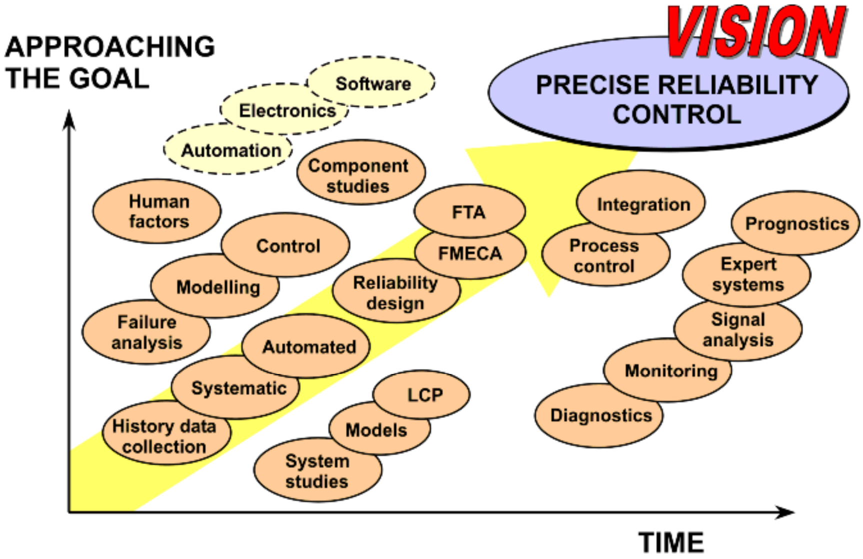

Figure 2.1 The fusion and advance of maintenance technologies

Traditionally, the manufacturer guaranteed the faultless action of a product for a certain warranty period. Nowadays, life cycle profit (LCP) planning is gaining popularity and it is based on the reliability of a product during its whole lifetime. Statistically-defined failure frequency, availability, and the lifetime of the product can now be used as a competitiveness argument. This will also give a reliable basis for recycling a product.

Higher reliability of industrial plants and machines means fewer risks, both personal and environmental, and better control, as well as energy conservation and lower expenses during the operating lifetime. The international competitiveness of the industry can be improved by developing new techniques and methods to specify and control the product reliability more precisely and convincingly. This is a very important sales argument in a situation where the gap between different products, in terms of performance and functional features, diminishes as a result of extremely advanced product development driven by competition.

Today's product design methods are mainly based on optimising the performance of the products and little attention is given to reliability and lifetime estimations. Few design tools emphasise reliability and availability.

This fusion of technologies is illustrated by Figure 2.1, in which the influence of a wide range of technological advances is considered over the last two decades. Because of the great variety of different techniques, based on expert knowledge in several fields of technology involved, there is a need to approach the reliability and maintainability problems from a general, holistic point of view, starting from the problem of the customer and ending with the satisfied user. The Technical Research Centre of Finland (VTT) has developed a systematic approach (Holmberg 2001, Holmberg and Helle. 2008). This is aimed at improving the synergistic interactions between the different fields of expertise by showing a logical and comprehensive structure, where each expert can find his place and see the connections to experts from other fields, all working with the same aim of a satisfied end user, as shown in Figure 2.2.

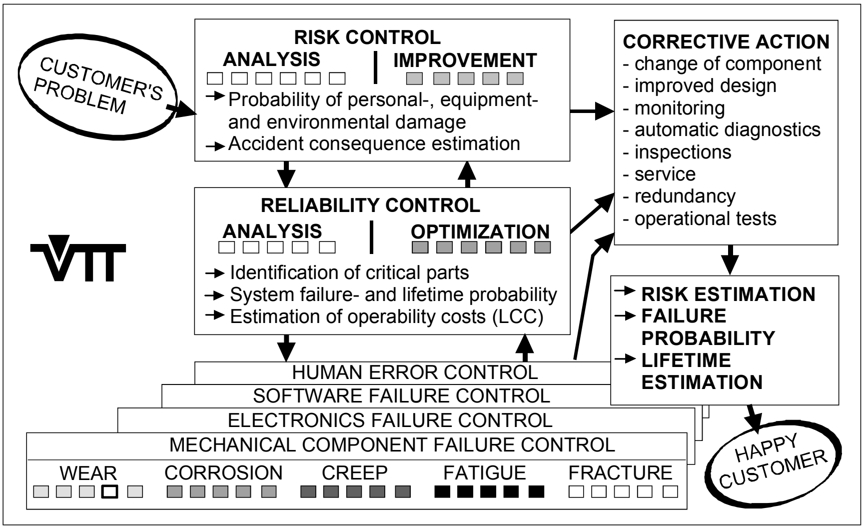

Figure 2.2 Holistic approach to maintenance integration

The probability of personnel, equipment and environmental damage can be analysed and the accident consequences estimated by systematic methods of risk control. The critical parts are identified, the probability of system failure and lifetime are calculated, and the operability costs are estimated by statistically based techniques of reliability control. When the critical parts of the production system