TRANSPORT RESEARCH

FOURTH FRAMEWORK PROGRAMME

RAIL TRANSPORT

EUROPEAN COMMISSION

Remain

Modular system for reliability and maintainability management in European rail transport

RESEARCH FOR SUSTAINABLE MOBILITY

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Modular system for reliability and maintainability management in European rail transport

Fraunhofer Institut IITB — Deutsche Bahn AG — RENFE —
Ambit Ergo Systems — Sintef — ISAP — VAE

RESEARCH FOR SUSTAINABLE MOBILITY

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The research and development project

REMAIN

aimed at the design and promotion of an integrated system
for the management of reliability and maintainability
in European railway systems.

The project has been funded by the European Commission
under the Transport RTD Programme of the 4th Framework Programme

The consortium that carried out the project consisted of
two European railway companies, a public transportation operation,
a supplier of railway infrastructure equipment,
a software house, and two applied research organisations.

This document summarises methods and procedures
and describes the project results.

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CONTENTS

1 THE PARTNERSHIP

The REMAIN consortium consists of two of the major European railway companies, a public transportation operation, a manufacturer of infrastructure and signalling equipment, a software house, and two of the leading applied research organisations in Europe.

	Organisation	Role	Type	Country
IITB	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. Institut für Informations- und Datenverarbeitung	COO	ROR	DE
DB AG	Deutsche Bahn AG	CR	IND	DE
RENFE	Red Nacional de los Ferrocarriles Españoles	CR	IND	ES
Ambit	Ambit Ergo Systems A.E.	CR	IND	GR
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology	CR	ROR	NO
ISAP	Ilektriki Sidirodromi Athinon Pireos	CR	IND	GR
VAE	VAE Aktiengesellschaft	AC	IND	AT

1.1 FRAUNHOFER INSTITUT FÜR INFORMATIONS- UND DATENVERARBEITUNG IITB

Founded in 1949, Fraunhofer Gesellschaft today is the leading organisation for applied research in Germany with 47 institutes situated at 32 locations and an annual research volume of DEM 1,25 billion. 8300 employees apply their know-how in manifold research projects for clients from industry, SMEs and government.

Fraunhofer Institut für Informations- und Datenverarbeitung IITB is engaged in the transfer of methodology and techniques in the field of information technology into practicable solutions. It has about 250 employees and 10.000 square meters offices and modern laboratories.

IITB has a strong background in developing and providing automation equipment and systems for industrial process control. Further, IITB has extensive experience and supporting infrastructure in the area of software development and software engineering. IITB has been involved since 1986 in many CEC projects in the area of open systems for industrial automation.

IITB co-ordinated the project and provided knowledge and experience in particular in the fields of

- Signal analysis, pattern recognition and machine diagnosis
- Industrial process automation
- Computer architecture, distributed systems and communication

1.2 DEUTSCHE BAHN AG (DB AG)

Deutsche Bahn AG is the largest transport company in Germany. With a corporate turnover of DM 30.5 billion in 1997, it also achieved satisfactory results in its fourth business year as a privately structured joint stock company.

The aim of Deutsche Bahn is to develop into an integrated mobility, transport and services group. In this context, to an increasing extent it will act on the future market Europe, in order to be successful - also especially on this market - as an efficient transport company and competitive service provider.

In the endeavour to attract more traffic to rail, the quality feature "availability of the track infrastructure and of the trains" plays a major role.

DB AG intends to improve the reliability and maintainability of the technical system railway. They want to feed their experiences into a modular diagnosis management system to be developed. At present, there is no overall concept for the components to be diagnosed (points, signals, barrier systems, etc.). DB AG wants to participate in the knowledge of the European railways and the European industry.

Favourable results are to be anticipated from an introduced standardised concept within the framework of Europe-wide calls for tender.

1.3 RED NACIONAL DE LOS FERROCARRILES ESPANOLES (RENFE)

The Spanish Railway RENFE is now structured in two parts: the Infrastructure part and the Exploitation part. The Infrastructure has the duty to provide a safe and reliable network to the Exploitation in order to get a fluid rail traffic, avoid delays and improve the rail transport. These requirements are especially high in the High Speed Lines, where punctuality indexes should be near 100 %.

On the other hand, there is a pressure to reduce the overall costs, and that means maintenance costs should be lowered. To achieve these goals, it is necessary to pay special attention to the reliability and maintainability aspects of the infrastructure components and rolling stock material.

The High Speed Infrastructure Division of RENFE is now engaged in the maintenance of the Madrid - Sevilla high speed line infrastructure, including the track, switching points, signalling and telecommunication equipment and power supply installations. Most of the personnel has also a lot of experience in conventional lines of RENFE.

1.4 AMBIT ERGO SYSTEMS

Ambit Ltd was founded in 1989 and its main aim is systems integration and the generation of considerable local added value in state-of-the-art Information Technologies. Ambit is manned with scientists and engineers with considerable industrial and academic research experience, with post graduate degrees (M.Sc., PhD.)

in corresponding subjects. Ambit has connected its name and activity with sizeable projects in modern Technological & Industrial areas. In this sense Ambit has developed into a modern design and support centre serving the whole of the South-eastern Mediterranean basin. It is of some importance to report that although a new company, Ambit has already demonstrated considerable progress in exporting high technology products and services to the Middle Eastern countries.

The main activities of Ambit include the provision of services and technological solutions in the area of microelectronics where specialised engineers, design, simulate and guarantee production and delivery of VLSI Application Specific Integrated Circuits. Ambit also supports the development and integration of specialised applications and services in the areas of Executive Information Systems and Decision Support Systems using tools and technologies connected with Geographical Information Systems. At the same time Ambit has to show considerable research activity with participation in major EEC funded R&D projects such as ESPRIT III (MAXIMA) and STRIDE as well as in National funded projects.

1.5 SINTEF

SINTEF (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology) performs contract research and development for industry and the public sector in the fields of technology and the natural and social sciences.

With 1850 employees and an annual turnover of NOK 1.4 billion, SINTEF is one of Europe's largest independent research organisations. Contracts from the public and private sectors provide 90% of the operating revenue.

SINTEF operates in close collaboration with the Norwegian University of Science and Technology (NTNU). SINTEF's experts co-operate in projects and share laboratories and equipment. Together, the two institutions form a centre of expertise of high international standard. SINTEF also co-operates with the University of Oslo.

SINTEF Industrial Management, Safety and Reliability perform contract research within the safety, reliability, maintenance and quality disciplines. The division has extensive experience in supporting industry and the public sector with solving problems within its work areas. Practical problem-solving skills combined with scientific competence and analytical capabilities have resulted in several innovations in safety and reliability techniques.

1.6 ATHENS-PIRAEUS ELECTRIC RAILWAYS S.A (ISAP)

ISAP is a public transportation operation aiming at providing transportation services in the wider metropolitan area of Athens.

ISAP has been offering public transportation services to its patrons since 1869 initially as SAP (Athens-Piraeus Railways) and later on as EIS. In 1976 ISAP became part of the Government sector and received the present name.

Today ISAP operates a line of 25.60 Km, of which 3 Km are in tunnel, between Piraeus and Kiffissia. It employs about 1300 persons, plus 340 persons for bus lines under his responsibility. ISAP transports about 110 millions passengers every year.

1.7 VAE AKTIENGESELLSCHAFT

With its 14 subsidiaries and associated companies, VAE is the current global technology leader in the turnout and electronic turnout surveillance system sectors. One focus of activity is research and development, which matches product innovations to the rising demands of customers.

VAE turnout technology mirrors the new thinking among the railways, which on the one hand are looking for products with low life cycle costs and proven high levels of economy, and on the other hand, products that offer the advantages of efficient laying technology.

In addition, VAE has also branched out from the narrow sector of turnout manufacture and has turned its attention to the area around the turnout. The equipping of a complete section of German Railways track with the VAE Roadmaster 2000, has allowed the first scientific study of the subsequent costs of a turnout after laying. In other words, the maintenance requirement and costs could be analysed following examination using the VAE turnout diagnosis system. Thus, VAE Roadmaster has become one of the tools used by the railways to attain permanent way economy, thereby bringing the company into a new, downstream customer relations phase after turnout sales.

A further step is formed by drive technology, and in particular, drive technology for tram system turnouts. Successful testing at European tram operators in conjunction with our partner Siemens, has opened up new area of expanded turnout technology.

The future strategic product orientation of the Group will lie in the combination of the turnout and its peripherals. Such a strategy differentiates VAE from its competitors and provides new points of contact with customers. For the world market leader must also take great care to maintain and defend its position, a fact that makes close co-operation with all VAE Group company customers essential.

2 EXECUTIVE SUMMARY

It is a common objective of the European railway companies that their investments also in the RAMS area should pay off better than in the past.

Through a requirements analysis in the beginning of the project the general needs could be stated as follows:

- Cost reduction of maintenance by the introduction of condition monitoring where technically and economically feasible to decrease the number of necessary preventive maintenance (PM) actions
- Cost reduction of maintenance for a system by the application of some optimisation procedure, that takes into account the Life Cycle Costs of the whole equipment used and of the maintenance applied to the system and that helps in the selection of the correct maintenance type and the determination of the correct PM interval.
- Necessity of leaving the safety level unchanged and demand for a tool that helps to evaluate the safety level of a new system or maintenance strategy in the planning phase already.

These requirements set up the basic structure of the project, that comprised in addition to the requirements analysis work packages with the following objectives and results:

- *Management of the project, including demonstrator exploitation*

The demonstrator was used to deliver examples for the explanation and illustration of tools developed in the following work packages. For the demonstrator the three components turnouts, track circuits and axle counters have been equipped with condition monitoring devices because of their frequent contribution to delays and failures in infrastructure. Roughly these components contribute 30 % of all failures in signalling equipment as could be derived from statistical data collected in the requirements analysis. The line equipped is a conventional line type of DB AG between Dortmund and Hamm. The costs of the installation amounted to 2010 kECUs of investment and 214 kECUs for the installation. Of these costs 85% were used for the 68 turnouts being equipped.

- *Acquisition of data, its storage and retrieval for RAMS-management*

For the systematic storage and retrieval of data a structure has been proposed, in which data on failures, maintenance activities and costs are linked to an inventory database. The data also comprise condition monitoring information from sensors and human operators. The main principles are adopted to the ISO/DIS 14224 standards, with major enhancements concerning the inclusion of condition monitoring data, failure mode identification at maintainable item level, cost data related to failures and maintenance.

As a starting point it is recommended that each railway company develops its own database covering the following objectives:

- Retrieval of qualitative information (frequent problems)
- Provision of information on reliability parameters
- Provision of information regarding maintenance resources
- Provision of information on condition monitoring

- Provision of information on LCC

A common structure should be agreed upon among European Railways to exploit in a later phase the potential of merging data into one common REMAIN or global database offering the following advantages:

- Extension of the experience base
- Comparison of the reliability of various products
- Validation of LCC data during life time
- Feedback to equipment vendors.

It will not be a simple undertaking to realise this global database concerning e. g. necessary discussions and standardisation among railways, but the REMAIN information system (see later) provides tools allowing a stepwise technical implementation of the concepts.

- *Communication of data and information needed for RAMS management.*

The results in this area have been contributed by the railway partners, based on knowledge on their existing communication lines and on knowledge from related EC programmes. For the demonstrator a fieldbus corresponding to the Profibus standard is used successfully for the collection of data from measuring points. Pre-processing of sensor data in the field is not implemented. Pre-processing in general would be advisable for the concentration of data before delivery to a centre. Several systems are available and described for the realisation of such a system, but it has to be observed that they fulfil the railway requirements concerning necessary cable length and environmental conditions, which normally can be met but might require additional costly installation provisions.

Shortcomings in cable length can be overcome in future by the GSM-R radio-link that offers itself for circumstances where cabling is not feasible or too expensive. The transfer of data between the base station system and mobile trackside stations is well specified and under construction and testing at the moment. To keep transmission costs low, again data concentration and compression techniques should be used in decentralised intelligent measuring points.

- *Analysis of field data for condition monitoring of components.*

Continuous on-condition monitoring is a rather new field to railway companies. This monitoring is performed by sensors, which measure quantities being related to the state of the component. Normally sensors cannot measure an interesting state directly but they deliver results that are more or less correlated with the information wanted (e. g. detection of wear of the frog point by counting the number of knocks of wheels against it). For this reason the raw sensor data must be analysed to extract the information hidden in them. For this purpose in the areas of signal analysis and pattern recognition a lot of methods exist, on which an overview was given. In addition to that all failures possible for turnouts and the neighbouring track have been collected, also those not yet being detectable by Roadmaster 2000. Especially for these undetectable failures a proposal for their future measurement has been worked out, that will be discussed in a workshop in the beginning of March.

Because automated condition monitoring is such a new field and also because failure states are very rare for many components being designed to high reliability standards, condition monitoring often cannot be based on objective sensor measurements but must be based on subjective experience of human experts. Since this procedure should also be as reliable as possible, a structured process for the introduction of expert knowledge has been developed. It was illustrated using the component "turnout" of the demonstrator.

- *Strategic planning of maintenance, introducing condition monitoring under safety and cost restraints – REMAIN methodology.*

It has been outlined that investments made by railway companies and their maintenance strategies should obey the following requirements:

- Cost reduction by the introduction of condition monitoring methods
- Cost reduction by the optimisation of maintenance plans
- Guarantee of the safety level.

To check the fulfilment of these requirements in a formal way, specific methods have been devised for all three areas. To start with guaranteeing the safety level – a prerequisite that must not be changed through a new system or strategy – a change analysis method has been developed (RCAM – REMAIN Change Analysis Method). For a new system or strategy changes may be observed in the frequency of a maintenance task in its duration and in the time of the day it is carried out and in the probability of making a maintenance induced error. The effect of these changes on safety is evaluated in three categories for each related component and a summation of the individual values gives the total result on safety. This method is not complicated and can easily be applied by maintenance engineers as it was illustrated for an example of the turnout.

For the evaluation of costs an LCC model has been provided taking into account contributions from the four areas of investment, operation including maintenance, delay, and hazard. Its focus is on annual cost and therefore situations can easily be compared, where the number of years in operation for two options under consideration is different. The application of the LCC model to a turnout in a high-speed line without and with condition monitoring yielded annual LCC costs of 17.000 or 14.400 ECU resp. (assuming 40 years of lifetime).

This LCC model is an inherent part of the strategic maintenance planning which had been originally developed as a formal method for REMAIN purposes and therefore was called RESMAP - REMAIN Strategic Maintenance Planning. It comprises several methodological steps of which the most important are:

- Failure cause analysis,
- Extended FMECA analysis,
- Application of a decision logic for the selection of appropriate maintenance types
- Determination of necessary maintenance intervals
- LCC analysis

The application of the RESMAP method again to the turnout of the demonstrator which is a conventional line opposed to the high speed line analysed above, revealed that a reduction of costs by a factor of 2 is feasible with Roadmaster 2000. In addition a detailed analysis for the individual sensors shows that not all of them are necessary being a potential for further savings.

- *Proposal of a system architecture for the integration of the individual modules*

The proposed architecture combines three major functional components

- Monitoring based on
  - Acquisition of data, their storage and retrieval of information, and
  - Communication of data and information needed for RAMS management
- State Prediction, using
  - Signal analysis and pattern recognition for components
- Maintenance Management, relying on the REMAIN methodology, i.e.
  - Strategic planning of maintenance,
  - Introduction of condition monitoring,
  - Observation of safety and cost (LCC) restraints.

The system is based on standardised components allowing the use of existing tools previously developed for particular platforms and also allowing the distribution of modules over different locations.

For the integration of existing tools of legacy software and for co-ordination of activities in a distributed system the Common Object Broker Architecture (CORBA) is the most promising platform. CORBA is an internationally recognised standard, implementations are available for nearly all hardware platforms and operating systems, and through its interface definition language, CORBA offers a systematic approach for the integration of legacy applications.

The system comprises an information system to facilitate the exchange of the various kinds of information occurring in RAMS management. Access to information at various locations is facilitated through the recommended use of Internet and World Wide Web techniques, which offer basic mechanisms to link information and can be used independent of specific operating systems and hardware platforms. The system adds to the web functionality facilities to arrange information in a structured manner, includes efficient search mechanisms and provides flexible and configurable means for access control.

3 OBJECTIVES

3.1 STARTING POINTS

REMAIN started with the objectives in the description of Task 27 of the Rail Transport Programme. There the intention was to create practical realistic methods and tools (also called models) with application guidelines for all categories of railway systems.

The original approach was proposed to be in two parts:

- development of methods and application guidelines for application in specifications, contracts and service management
- identification of RAMS - data sources and development of a system for the continued extension, updating, analysis and interpretation of the data.

The methods developed should take into account all relevant factors like failure mechanisms, environmental (climate...) and operational (suburban, intercity, freight, infrastructure...) aspects, applied resources to the achievement of RAMS, degree of innovation and risk and others.

The deliverables of the task classified as a research action were theoretical: development of models and their description in a report. As such Task 27 represented a very broad approach which could not be followed in detail with the resources available.

3.2 OBJECTIVES OF THE REVISED PROJECT PLAN

Therefore in the first project phase a thorough definition of work to be accomplished was carried out that allowed to limit the scope of the task, to concentrate on important issues and to deliver not only a theoretical study but to work also in the realisation of a demonstrator as a test-bed for recommended methods. The criteria used in the definition phase were the following:

- Focus on infrastructure aspects
- Concentration on efforts already started by railway companies
- Weight on thorough definition of the database
- Strengthening of system aspects

3.3 MEANS USED TO ACHIEVE THE OBJECTIVES

During the active phase methods of conventional scientific work like exploitation of literature, knowledge transfer from similar projects in other areas, study of related European projects and discussions with experts in the field have been applied.

Also structured questionnaires have been prepared and thoroughly explained to partners and other experts to obtain results in specific areas of some workpackages. Several sessions have been held with experts from different railways, all preceded by intensive explanation and training. Partners themselves and other experts looked for inside and outside their respective organisations provided the necessary expertise to rely upon.

The exemplary application of methods to items of the demonstrator finally showed to be one of the most important means to achieve the objectives and especially to find out the specific attributes of a method, its range of applicability and its suitability for a given task.

4 SCIENTIFIC AND TECHNICAL DESCRIPTION

To integrate condition-monitoring procedures into the process of RAMS management, different functional levels had to be addressed:

- acquisition of necessary data, data storage and retrieval,
- communication of RAMS data and information,
- analysis of field data for condition monitoring of components,
- development of the REMAIN Methodology for application at system level,
- provision of an information system by integration of the individual modules.

These levels had determined the structure of the work programme. Before the results on these levels are described in the following sections, an overview is given on the future user requirements (section 4.1) and on the condition monitoring equipment installed for the infra-structure demonstrator (section 4.2) in this project. References for the major sections are listed in chapter 1.

4.1 FUTURE USER REQUIREMENTS

The objective of this section is to give a survey on future user requirements. It is based on an analysis of general problems and statistics for important failure classes. Concentration occurs on infrastructure components.

4.1.1 GENERAL PROBLEMS

Discussions in the project group have indicated that future needs primarily are the reduction of maintenance costs, but also the reduction in delay time, without reducing the safety level (to be verified by a formal safety analysis).

Two interrelated ways of achieving this reduction are:

1. Systematic analysis of maintenance needs and organisation, e.g. using Reliability Centred Maintenance (RCM)
2. Introduction of Condition monitoring methods (CON-methods)

Both of these actions are based on an optimisation of costs including e.g.:

- Investments costs
- Maintenance costs
- Delay-time costs
- Hazard costs

The user requirements should therefore be that the investments in either of the above two strategies pay off. For instance it may not prove wise to require a given availability figure (e.g. 98%), because an increase from say 95% to 98% may lead to a higher increase in maintenance costs than what is gained through reduced delay time. It is therefore difficult, and also not recommendable, for the railway companies to state any future requirements regarding availability without linking this to the maintenance costs.

Therefore the user requirements will be:

1. The maintenance costs should be minimised by the use of e.g. the concept of reliability centred maintenance (RCM).
2. The overall life cycle costs should be reduced by introducing condition-monitoring equipment (CON).

This is illustrated in Figure 4-1. The figure illustrates that RAMS enhancement (with the example of Roadmaster 2000) must run through the following steps:

1. Establishing the present situation by the use of life cycle cost analysis (LCC-analysis).
2. Predict the total costs (LCC) when using the Roadmaster 2000 as it is today.
3. Analyse the necessity and cost effectiveness of each measuring point of R2000 by the use of a systematic method (RCM), and then predict the total costs using an optimised version of Roadmaster 2000.
4. Analyse the turnout by performing an RCM-analysis on all maintenance tasks, not only condition monitoring, and establish a new maintenance plan. Then assessing the total costs (LCC) benefiting from both an optimal maintenance plan and also extensive (but cost effective) use of condition monitoring methods.

In addition to this "single component" optimisation, all components on a given track have to be analysed in terms of possible simultaneous maintenance execution, i.e. packaging of maintenance jobs.

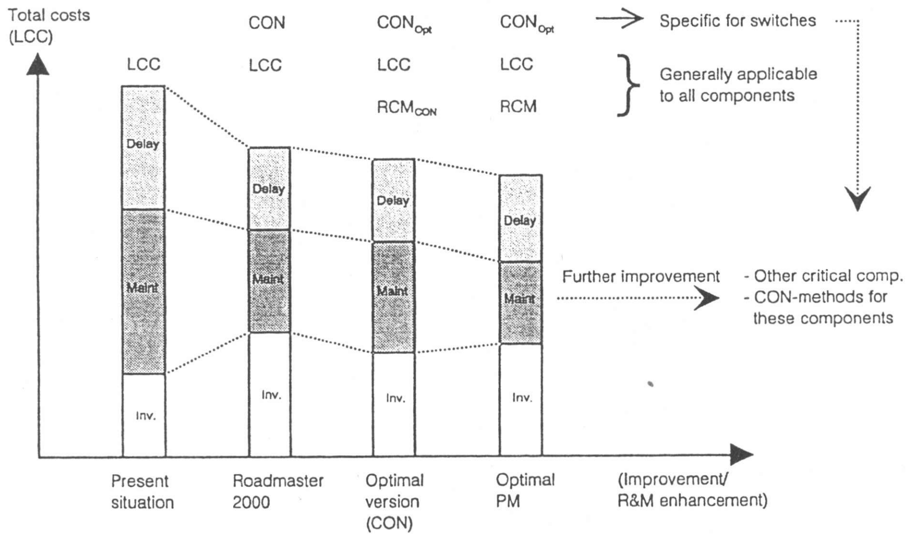

FIGURE 4-1: RAMS enhancement through condition monitoring and RCM

A complete maintenance plan therefore requires operational information as well, such as:

- Numbers of trains passing the track, and when
- Location of maintenance organisations
- Maintenance resources

4.1.2 STATISTICAL DISTRIBUTION OF FAILURES

A distribution of failures from turnouts and other infrastructure components provided by partners is presented in Figure 4-2 (conventional railway line) and Figure 4-3 (high speed railway line).

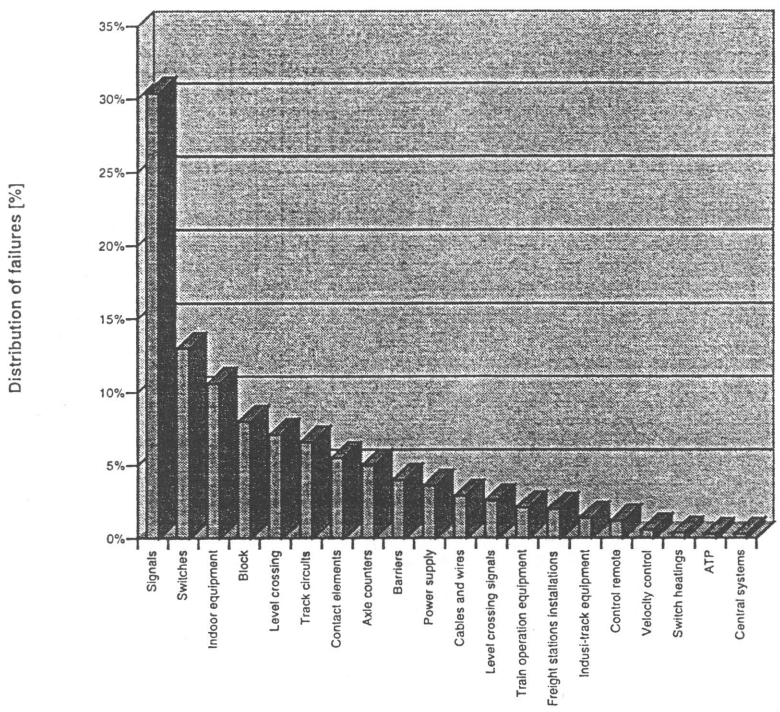

FIGURE 4-2: Distribution of failures from infrastructure components (conventional line)

The statistical data of the high speed railway line include all kinds of failures due to the equipment itself; failures due to external causes (i.e. damages produced by maintenance machinery) are excluded. As can be derived from Figure 4-3, most of the failures (ca. 55%) are due to signalling equipment and turnouts. ("Signalling equipment" here covers signals, track circuits, interlockings, ATP or LZB, and the traffic control centre.)

In Figure 4-3 the infrastructure components are grouped into the five categories used by the high speed line:

- Signalling equipment and turnouts
- Communication equipment
- Other equipment
- Substations
- Overhead line

Switches are an important component in the condition monitoring approach of the demonstrator, and they represent a frequent failure cause for conventional and high speed lines. These reasons led to the selection of the switch as the key element for exemplary applications of methods investigated in REMAIN.

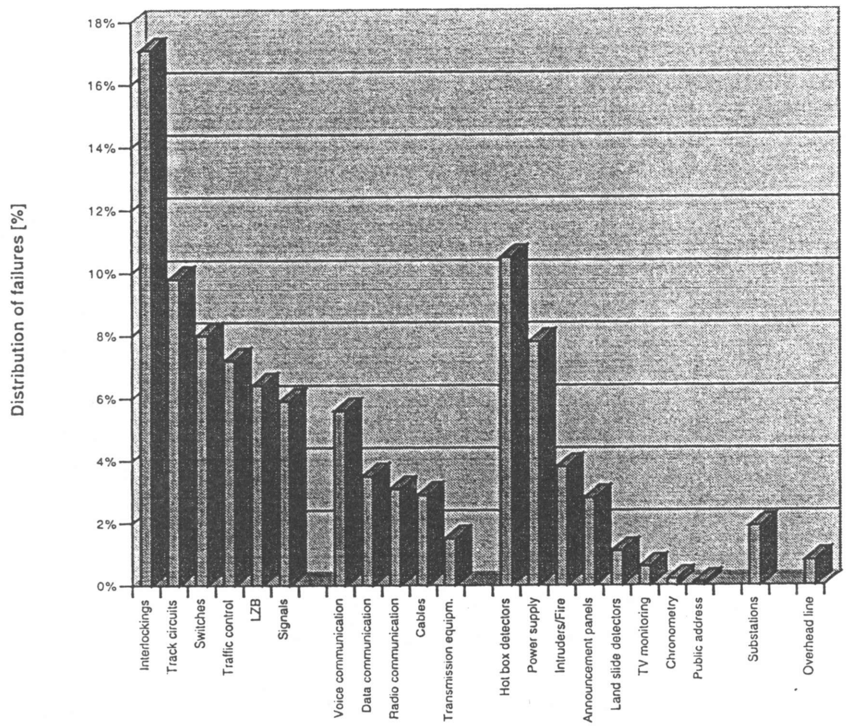

FIGURE 4-3: Distribution of failures from infrastructure components (high speed)

4.1.3 SUMMARY AND CONCLUSIONS

This section summarises the future needs (derived from the current problems), and methods to fulfil these needs (or solve the current problems), which have been identified in the project.

At a general level European *requirements* are:

Cost reduction, essentially achieved by:

- Reduction in maintenance costs
- Reduction in delay time

without reduction of safety level.

Main *means* required to achieve this (identified in the REMAIN-project) are:

- Systematic analysis of maintenance needs and organisation, e.g. using Reliability Centred Maintenance (RCM)

- Introduction of Condition monitoring methods (CON-methods)

The anticipated effect on costs and delays of utilising these methods, should be confirmed by use of life cycle cost (LCC) analysis. Safety analysis methods will be used to confirm that there has been no reduction in safety level.

The combination of RCM-analysis and introduction of CON methods with LCC and safety analysis will be referred to as "REMAIN methodology" that is explained in more detail in 4.6.

The RCM and LCC-analysis methods are generally applicable to all types of systems or components, while CON-methods are system or component specific. The procedure should be concentrated on those components contributing most to delay time and maintenance costs, and then to identify relevant CON-methods for these.

For the demonstration of the "REMAIN-methodology" turnouts have been chosen as one "critical" component. The condition monitoring techniques installed for this component are described in the following section 4.2, which covers the entire technical realisation of the demonstrator.

The work can be extended by the railway companies on other critical components, provided that the most critical components within the company are identified. Knowledge about CON-methods for these components is also required.

An important issue is the reduction of maintenance costs by co-ordination of various maintenance activities. DB AG, RENFE, and ISAP already realise this fact and try to combine different maintenance actions. E.g., instead of separate checks of infrastructure components by each maintenance department concerned, it should be possible to carry out common inspections. Also – as shown by ISAP – repair work should be performed by mixed teams consisting of specialists who belong to different sections.

The planning of preventive maintenance activity must be based on detailed failure and repair statistics to avoid unnecessary effort and, on the other hand grant safety and reliability. Thus, collection and evaluation of relevant data should be supported by computer-based equipment and tools.

4.2 TECHNICAL REALISATION OF THE DEMONSTRATOR

The specific methods, for improvement of reliability and maintenance that have been focused in the REMAIN project, are condition monitoring methods. These methods are specific for each type of railway system/component, and it was only possible to assess in detail a small number of different components in this project. The components chosen should, therefore, preferably be those contributing most to delay time and maintenance costs.

As mentioned before, one of these systems/components is turnouts, which at the same time is one of the central components in the demonstrator (on DB AG's track between Dortmund and Hamm), together with track circuits and axle counters. Therefore a brief description of the technical systems

- Turnouts
- Track Circuits
- Axle Counters

and their condition monitoring strategies is provided below.

4.2.1 TURNOUTS

The information given below is adapted from VAE information on Roadmaster 2000.

4.2.1.1 PRINCIPLE OF REMOTE SUPERVISION

The turnout monitoring system allows to continuously supply the responsible maintenance personnel with information on the actual operating condition of the connected turnouts and track components.

There is an electronic data processing system, together with a comparison of desired and actual measured values, plus a trend visualisation. This makes it possible to foresee faults well in advance, before the given limiting values are reached.

In this way changes in the operating conditions, which might lead to a fault or bring about damage, can be recognised at the earliest stage.

4.2.1.2 MEASUREMENT PRINCIPLE

The overall function of remote supervision is split into several levels and is achieved by means of the combined use of hardware and software.

An overview of VAE Roadmaster 2000 is given in Figure 4-4 below.

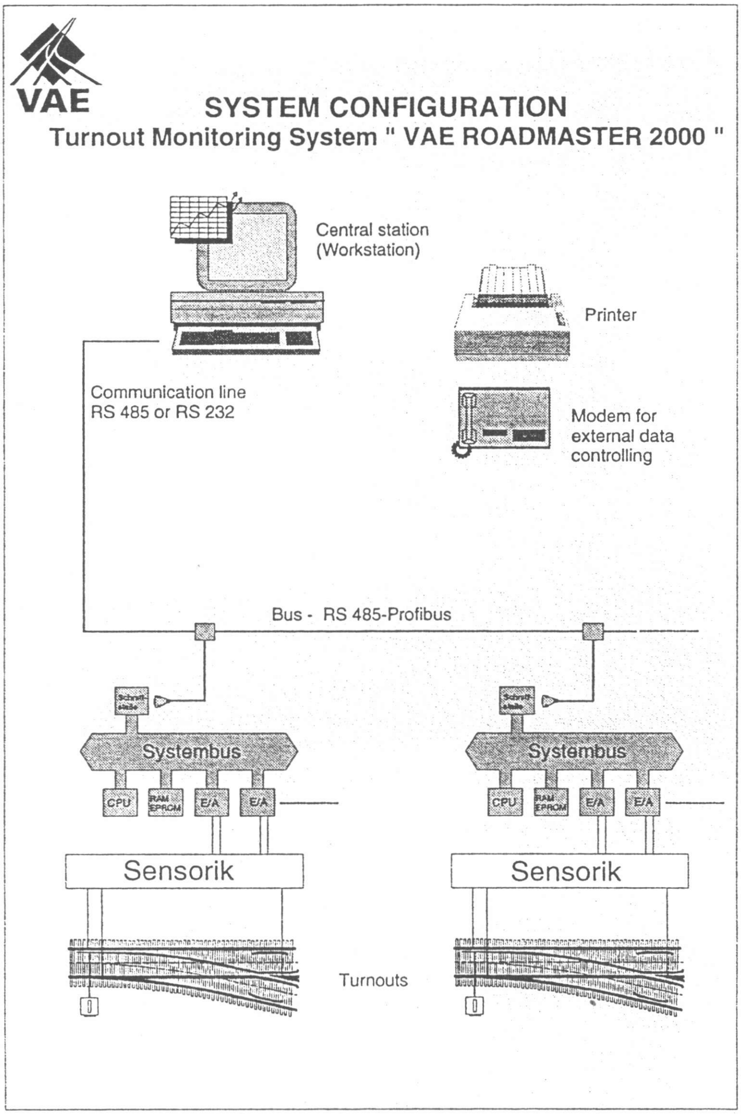

FIGURE 4-4: Overview of VAE Roadmaster 2000

On the acquisition level the measured data of those components which are to be monitored, that is, turnouts, axle counters, track circuits, are collected.

The measurement data are collected by appropriate sensors and analogue systems in a digital electronic collection system with bus modules. It is then pre-processed and prepared for transmission.

On the user level the measured data is visualised in the form of tables and graphs. The result is the output of such messages as required for the recognition of trends.

4.2.1.3 MEASURING POINTS IN THE TURNOUT

The location of measuring points is illustrated in Figure 4-5.

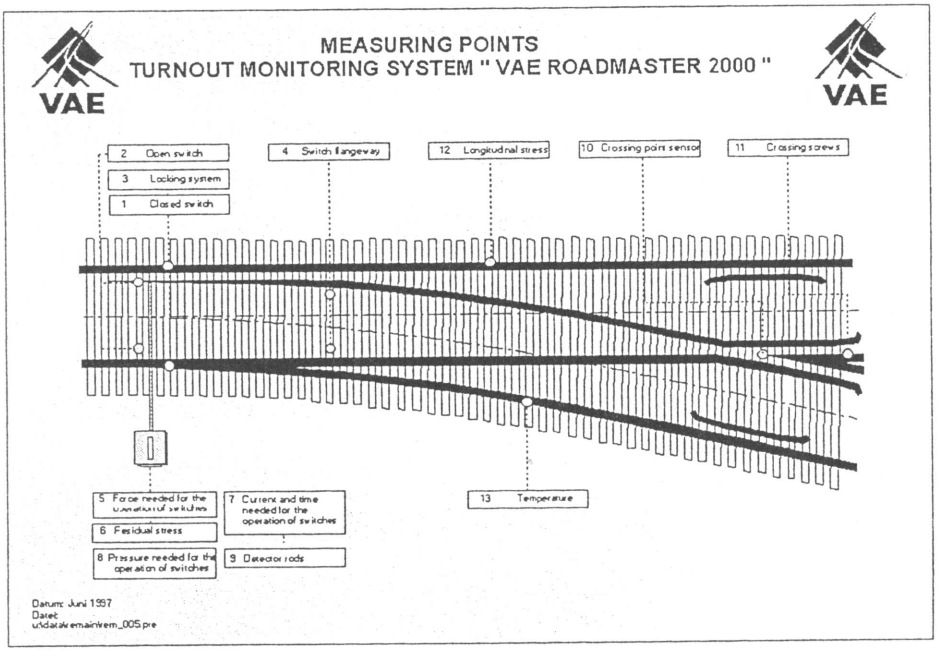

FIGURE 4-5: Location of measuring stations in the turnouts (switches)

The measuring points are:

1. Monitoring of switch-stock rail contact area
2. Monitoring of open switch
3. Monitoring of switch operating rods and/or switch locking system
4. Monitoring of minimum distance between open switch and stock rail (switch flangeway)
5. Direct measurement of the force needed for each single operation of switches
6. Residual stress in the switch and/or the rodding (retaining force)
7. Current and time needed for the operation of switches
8. Monitoring of the pressure needed in the switch machine for the operation of switches
9. Monitoring of the position of the detector rods
10. Monitoring of the strikes at the crossing point, indicating wear of the check rail and/or wing rail
11. Monitoring of screw preloading forces in bolted compound crossings
12. Longitudinal forces in the rail
13. Rail temperature and ambient temperature

A more detailed description of the measuring stations is given below.

1) Monitoring of the Switch-Stock Rail Contact Area

Inductive distance sensors are installed at several points of the right-hand and the left-hand stockrails, depending on the turnout radius and, consequently the length of the switch device.

The measuring method and the arrangement of the sensors make it possible that any "widening of the distance" between switch and stock rail (caused by heavy motion, insufficient lubrication, foreign particles ...) is discerned immediately and an appropriate message is triggered to the central station.

This measurement also enables selective lubrication (much longer lubrication intervals), because in combination with the force needed for the operation of switches trends are recognised.

2) Monitoring of the Open Switch

A specially developed inductive slot sensor measures the distance between the open switch and the stock rail at the switch tongue point each time the switches are operated.

3) Monitoring of the Switch Locking System

As these sensors are also located directly beside the switch operating rods, these rods are monitored for possible fractures. Similarly, any increased wear of bolts and bushes, and consequently any increase of tolerances will also be recorded.

4) Monitoring of the Switch Flangeway

The minimum distance between the open switch tongue and the stock rail is measured by a sensor of the same type as used for station 3. This sensor measures the switch flangeway each time the switches are operated.

Deficient minimum distance between switch tongue and stock rail might result in undesirable inner contact with passing wheel sets. This causes sinusoidal movements in the switch rail, which could lead to breakage.

5, 6, 7) Direct Measurement of the Force, Stress, Current and Time Needed for the Operation of Switches by Electric Switch Motors

A specially devised measuring bolt with a load cell is used for the continuous measurement of the force needed for the operation of switches. This electronic measuring bolt takes the place of the traditional bolt and thus additional mechanical machining is not necessary.

The average value of the switch operating force, stress, current, the time needed for the operation of switches, and the rail or ambient temperature are entered into a trend diagram for an overall evaluation.

8) Monitoring of the Pressure Needed in the Hydraulic Switch Machine for the Operation of Switches

By a pressure sensor in the hydraulic circuit and a current sensor in the feeder line of the hydraulic pump motor the same monitoring effects as in station 7 of an electric switch driving system can be realised. In this case stations 5 and 6 usually will not be provided.

The operation force (station 5) can be estimated from the hydraulic pressure value, the residual stress (station 6) is not recorded.

9) Monitoring of the Position of the Detector Rods

Inductive sensors are used for the contactless measurement of the position of the detector rods (position of the latch in relation to the control slide). These sensors are mounted directly at the housing of the switch machine. The sheet metal plate for the sensor is mounted on the detector rod (control slide).

Any change of the permissible clearance caused by

- length variations
- influence of temperature or
- wear (joints, bushes, pins)

is reported and thus the actual position of the latch is indicated.

A trend diagram shows any deviation from this set clearance instantly. Thus the actual position of the latch in the recesses of the control slides is always known.

If the amount of the clearance is equal on both sides, this will correspond to the zero line in the diagram. Thus the inspection can be carried out according to actual conditions only in the case of actual need.

10) Observation of the Strikes at the Crossing Area

In the area of the theoretical crossing point a special sensor is installed, which may be hit from above (by the wheel flange) or from the side (by the tread of the wheel) and then gives an electric signal. The pulses are counted and indicate the wear of the check rail and/or the wear of the wing rails. Thus necessary readjustments of the check rail can be carried out well before any damage of the crossing point by strikes of wheels occurs.

11) Monitoring of Screw Preloading Forces in Bolted Compound Crossings

In crossings of this type comprising several separate parts fixed by bolts and nuts, measuring rings can be included in any of these connecting devices. They measure the preloading forces applied to the bolts. Whenever the preloading forces of a bolt equipped in this way decrease or shearing of the bolt occurs, appropriate measures can be taken immediately.

12) Measurement of Longitudinal Forces in the Rail

The stresses which occur in a continuously welded track due to thermal expansion are measured by a special load cell and displayed together with the rail temperature value from station 13. This measuring method permits the display of the functional connection between rail temperature and longitudinal force. The actual force is displayed in a measured data chart which also indicates the positioning of the sensors in the track layout of the monitored area.

Again this chart is used for the establishment of a trend diagram for long term monitoring.

13) Rail Temperature and Ambient Temperature

Both temperatures are recorded by separate sensors, located under the foot of a stock rail and under the trackside collection system cabinet.

4.2.1.4 ELECTRONIC COLLECTION SYSTEM

The sensors and the computer system are connected by means of flexible cables, which are embedded in protective tubes. The measured values collected by the sensors are transmitted to the collection system via these cables and are read and processed via adequate input modules.

Special software programs combine the collected data and prepare these for subsequent transmission. The collection system is realised in a modular open microprocessor technology and consists of the appropriate bus components. The bus components are located in a common modular sub-rack (19"-technology) and consist of the interface module, the processor module, and the appropriate I/O modules. This pre-processed measured data are transmitted to the central station for subsequent processing and visualisation by means of bus protocol or serial data communication.

4.2.1.5 CENTRAL STATION - VISUALISATION

The hardware of the central station consists of a reliable high-speed work station or PC. The collected measurements are displayed on a 21" colour monitor.

The data communication is performed via interface cards, which enable the adaptation to different transmission systems. The measurements are visualised using a special software which retrieves the data from the main memory of the computer. Thus the complete collection and visualisation of all data stored in the computer is made possible.

The visualisation computer is operated by means of user-friendly dialogues via keyboard and mouse. Using the processing protocol it is possible to subsequently prepare any statistics (trends, service, maintenance ...) for any period of time.

4.2.2 TRACK CIRCUITS

4.2.2.1 FUNCTIONAL DESCRIPTION

In order to give a functional description, Figure 4-6 shows a strongly simplified set-up of the track circuit, which consists of the basic elements: a device feeding current into the section, the insulated track section and a receiving device (track or motor relay).

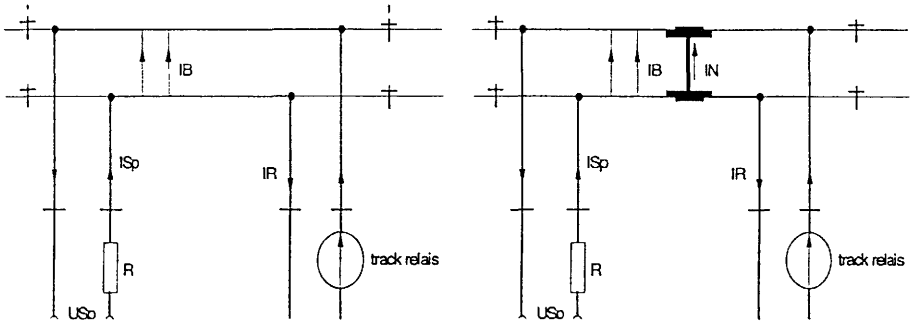

FIGURE 4-6: Principle of function for track circuits

The insulated section is provided with insulated joints at both ends which separate the insulated rails from the connecting track sections so as to prevent transfer of electricity. The feeding voltage U_{Sp} drives the supply current I_{Sp} in the "track clear" signalling circuit which consists of the damping resistor R, the insulated section and the track relay.

Since the two rails can only be insulated incompletely, a leakage current I_B spread continuously over the length of the insulated section flows - as undesired side effect - through sleepers and the ballast and reduces the quiescent current I_R as compared to I_{sp}.

Normally, I_R is large enough to keep the track relay energised (Figure 4-6, left side). As soon as a vehicle enters the section, however, the vehicle axles form an electric shunt of extremely low impedance to the track relay (Figure 4-6, right side); the shunt current I_N flows through the axles. The current I_R is reduced to a minimum I_{rest}. The track relay is de-energised and the section is signalled as being occupied.

The damping resistor in the feeding device has the task to reduce the supply current if the track is occupied and to keep the rest current which flows through the track relay as low as possible. The rest current's magnitude essentially affects the safety of relay operation.

The main characteristics of the track circuit are:

- The track relay is operated in a closed circuit system. Disruptions or resistance increased in the circuit, such as rail breakage, break of the connecting lines and faulty rail connectors as well as short-circuits lead to the de-energising of the relay. In the following it is signalled that the track is occupied, therefore railroad operation will not be endangered. The only disadvantage will be a reduced availability of the track section.
- The feeding device and the receiving device must each be connected to one end of the track section in order to ensure the above properties in the case of rail breakage.
- Excessive leakage current caused by inadequate rail insulation or faulty insulating joints prevents the track relay from getting energised ("track occupied" signalling).
- The insulated section must be longer than the largest possible wheel-base of rail vehicles in order to prevent any improper "track clear" signalling.
- The axle shunt resistor must be as small as possible. Insulating layers between wheel and rails or within the wheel set may under certain circumstances endanger proper operation.
- The more axles run over this section or the more frequently this section is overrun, the more reliable is the "track occupied" signalling.
- A mechanical restraint in the drive system of the track relay may endanger operation. Therefore relays with specific properties are used. Their functionality should be monitored, if possible, by means of the circuit technique.
- Excessive supply voltage may possibly prevent - on account of the increasing rest current - the de-energising of the relay in the case of "track occupied" signalling.
- The track relay must be protected against external current which may have entered into the "track clear" signalling circuit.

In almost all cases the track circuit is based on the principle explained above. In the circuit design, however, there may be some differences on account of different operational and technical conditions.

In the case of 100 Hz track circuits the two rails are operated as go-and-return line between a feeding 100 Hz voltage point and a motor relay.

If the section is clear, the input of the motor relay will get the full supply voltage. If the section is occupied, the axles of the vehicle will form a shunt to the motor relay.

Fault recognition

The consequences of possible faults in the system are indicated by:

- a change of voltage at the motor relay as a result of a change of the ballast resistance
- a change of the phase relation.

4.2.2.2 CONDITION MONITORING METHODS FOR TRACK CIRCUITS

Special modules (track circuit modules), which are accommodated in a special module frame, have been developed for the monitoring of the voltage and the phase relation of the track circuits.

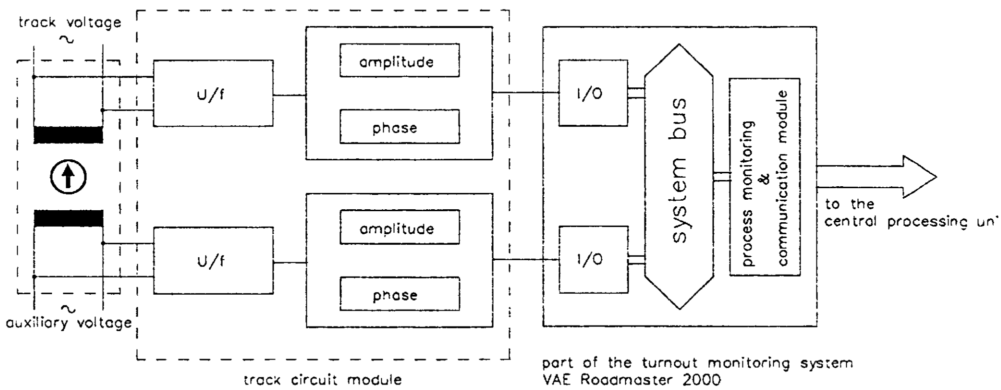

FIGURE 4-7: Condition monitoring of track circuits (track circuit modules)

The function of the track circuit modules is to measure the operational parameters of the track circuits, to process them and to pass on the prepared measured values to the input modules of the turnout monitoring system VAE Roadmaster 2000.

The following operational parameters are measured:

U_{GL} amplitude (peak value) of the track voltage

U_H amplitude (peak value) of the auxiliary voltage

φ_{PH} phase angle between these two voltages

These measured values are then transmitted to the central station, where they are entered into appropriate tables.

Again it is possible to call up a trend diagram for long-run observations for each monitored track circuit.

4.2.3 AXLE COUNTERS

4.2.3.1 FUNCTIONAL DESCRIPTION

An axle counter system which serves as safety device for the signalling of track clearance or occupation, consists of counting points which are positioned at the beginning or at the end of a section and a counter located in a signal box.

The counting points and the axle counter are connected via communication cables, and for the axle counter types ZP70M and ZP43M five leads for each counting point are needed.

A counting point consists of wheel sensors, the so-called rail contacts and the electronic connector box.

A rail contact consists of a transmitter and a receiver which are mounted on the rail web opposite to each other. In each device two coils are arranged in the longitudinal direction of the rail, which makes it possible to ascertain the direction.

In the connector box the signals of the two receiving coils are processed separately in two largely identical branches. The voltages are amplified, rectified and finally used for the control of a voltage/frequency transformer. If no overrunning of the coils occurs, the transformers will supply:

a frequency of f_1 = 3,85 kHz or f_2 = 6,73 kHz in the case of the ZP70M

a frequency of f_1 = 3,6 kHz or f_2 = 6,52 kHz in the case of the ZP43M

Then these two frequencies are processed in the electronic connector box by means of trigger and pulse shaper components. At the output there are two counting pulses available on separate count leads and one pulse on the monitoring lead for the activation of a motor counter.

The most important characteristics of the axle counters are:

- The function is not tied to an insulating superstructure (contrast to "track clear" signalling).
- The automatic "track clear" signalling method is also suitable for track sections with little traffic.
- The length of such a track section is essentially limited by the permissible length of the connecting lines, and may exceed the permissible length of track circuits by a multiple.
- Irregularities at the rolling stock (e.g. worn wheel flanges in certain traction unit types) lead to faulty counts.
- The axle counter also works in the case of very high traction currents. Thus, it is comparatively insensitive to the influence of any external voltage, provided that the counting pulses are transmitted adequately.
- Swinging axles may lead to disturbances under certain conditions.
- Superstructure devices mounted within a section with "track clear" signalling are not discovered.
- Compared to the track circuit much more equipment is needed.

- One counting station can be used for adjoining sections with "track clear" signalling.

If "clear" signalling is used for turnouts or turnout sections, more than two counting stations will be necessary.

The system has to fulfil the following tasks:

- Counting of the axles which enter and leave the section, without taking into account which counting station is passed and in which direction the section is entered or left. It must be possible to process input and output pulses simultaneously.
- "Track clear" signalling, if the numbers of the axles which have entered and left this section coincide.
- "Track occupied" signalling, if the counts do not coincide.
- "Track occupied" signalling for the section, if any pulse generator of the counting station starts working, but no counting of incoming or outgoing axles takes place or in the case of a line break in the connecting lines to the counting station.

The last task mentioned above is meant to ensure that the occupation of the track is also being signalled, if the counting station is partly faulty or the counting process is disturbed.

4.2.3.1.1 Fault recognition

The consequences of possible faults in the system are indicated by:

- Detuning in the frequency-selective circuits of the counting stations on the track and the counters in the signal box (drifting of frequencies).
- Changes of the electrical parameters of the counting stations on the track and the counters in the signal box.
- Temperature dependencies.

4.2.3.2 CONDITION MONITORING METHODS FOR AXLE COUNTERS

Special modules (axle count modules, Figure 4-8 have been developed for the control of voltages and frequencies of the axle counters.

The main functions of the axle count module are:

- acquisition of measured values
- calibration
- transmission of measurement results and errors to the turnout monitoring system

The function of the axle count module is to determine the measured values of two alternating voltages and one direct voltage as well as the calibration parameters of the test section and to transmit these values to the turnout monitoring system VAE Roadmaster 2000.

The axle count modules are accommodated in a housing beside the axle counting points. The measured values are transmitted to the central station at certain time intervals.

The display is in chart form and shows the following measured values:

U_0 direct supply voltage of the axle counting point

U_1	peaks/peak value of quiescent voltage with undamped coil system 1
U_2	peaks/peak value of quiescent voltage with undamped coil system 2
f_1	quiescent frequency with undamped coil system 1
f_2	quiescent frequency with undamped coil system 2

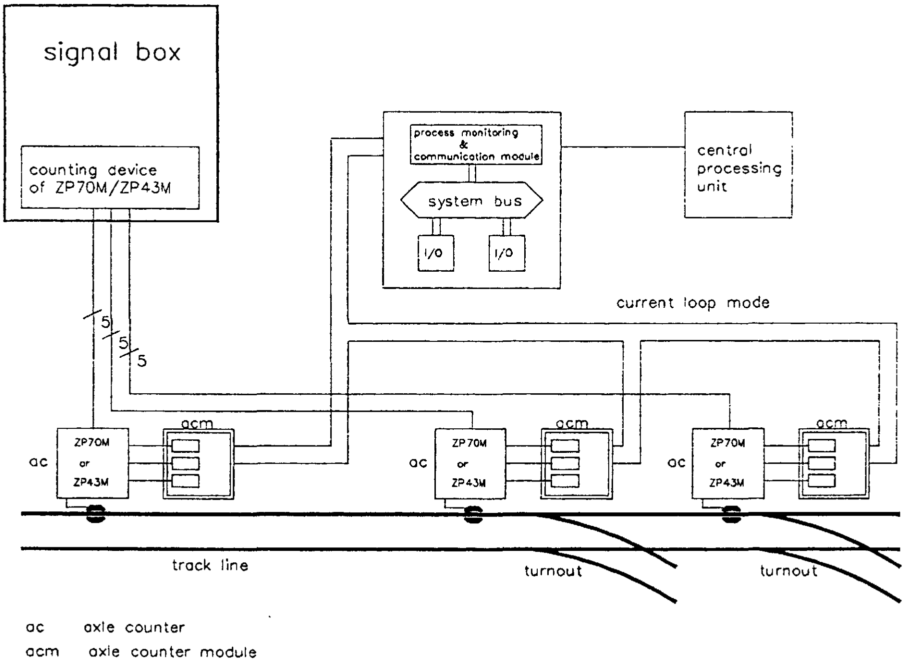

FIGURE 4-8: Condition monitoring of axle counters (axle count modules)

4.2.4 SUMMARY

In this section condition monitoring (CON) methods of the demonstrator applied to turnouts, track circuits, and axle counters have been described. For turnouts the most complicated system with 13 measuring points is used, which had to be realised by the additional installation of external sensors. For track circuits and axle counters, the condition monitoring procedure is somewhat more simple because it can rely on internal values of voltages and frequencies for which the measurement is straightforward and cheap. In general, the contribution of turnouts to failures (see Figure 4-2 and Figure 4-3) is as high as that of track circuits and axle counters.

Due to this fact and especially due to the circumstance that for turnouts 13 extra measuring points had to be installed, turnouts had been selected for the further exemplifications, which also took into account the cost effectiveness of the individual measuring point (see section).

4.3 ACQUISITION OF INFORMATION

This chapter is concerned with work done on the design and study of necessary tools for the collection, storage and retrieval of railway-specific status, reliability and maintenance data. The information can be used for condition monitoring, strategic planning of maintenance and for reliability evaluation of components.

Due to principal and economic reasons not all relevant information can be captured by sensors. Therefore a data format is needed that also allows the input of human inspection data and subjective evaluation of acoustical and vibrational data which often contain valuable information on the status of brakes, engines, gearboxes, track sections etc. Aspects related to the collection and storage of human operator and sensor data are described in section 4.3.1.

Data are collected and stored for several purposes. These may be

- learning from experience
- identification of frequent problems,
- estimation of reliability parameters.

These purposes direct the selection of methods for information retrieval contained in section 4.3.2. The final section 4.3.3 gives a short summary.

4.3.1 DATABASE STRUCTURE

The general purpose of a REMAIN database is to facilitate systematic storage and retrieval of data. Part of the data is needed locally (level of one railway company), but for the extension of experience also a global database (on European level) is proposed.

The proposed database structure is widely based on experience from the OREDA project [ISO98]. Failures and maintenance activities are linked to an inventory database. One inventory record corresponds to one physical equipment, for example one particular turnout. Inventories are classified into "classes"; "turnout" is such a class.

4.3.1.1 OBJECTIVES FOR A LOCAL REMAIN DATABASE

The local REMAIN databases are implemented and maintained by each participating railway company. Each company chooses its own platform for implementation. The main objectives for such a local REMAIN database are:

- Retrieval of qualitative information ("Upper ten lists")
  - List of items frequently failing
  - List of frequently occurring failure causes
- Provide information on reliability parameters
  - Failure rates and life time distributions
  - Repair times
- Provide information regarding maintenance resources
  - Spare part consumption
  - Man-hours required (PM and CM)
- Provide condition monitoring information

- Current state of condition monitoring (CON) variables
- Correlation between failure probability and values of the CON variables
- Evolution of CON values as a function of time (how fast)

- Provide LCC information
    - Current state of maintenance and operation costs.

4.3.1.2 OBJECTIVES FOR A GLOBAL RAILWAY COMPANY REMAIN DATABASE

A global common railway database is foreseen to be implemented at a later stage. Such a database will give each railway company access to (anonymous) data from other railway companies. The main objectives for such a database are:

- To extend the experience base, i.e. more data
- Comparing reliability of various products (installing new equipment for which one self does not have experience)
- Validation of LCC data during life time
- Feedback to equipment vendors. This will help the manufactures to improve the reliability of their equipment.

4.3.1.3 PROPOSAL OF THE LOGICAL DATABASE STRUCTURE

4.3.1.3.1 Data Categories

The Reliability and Maintainability data shall be collected in an organised and structured way. The major data categories for inventory, failure, maintenance and state information data are given below. Note that the OREDA concept (ISO/DIS 14224 [ISO98]) does not include state information data. In Figure 4-9 the inclusion of state information is explicitly demonstrated. The OREDA concept does neither include cost data. In the proposed REMAIN database structure of Figure 4-9 cost data are not shown explicitly. However, the inventory, failure and maintenance database have fields (variables) describing cost data.

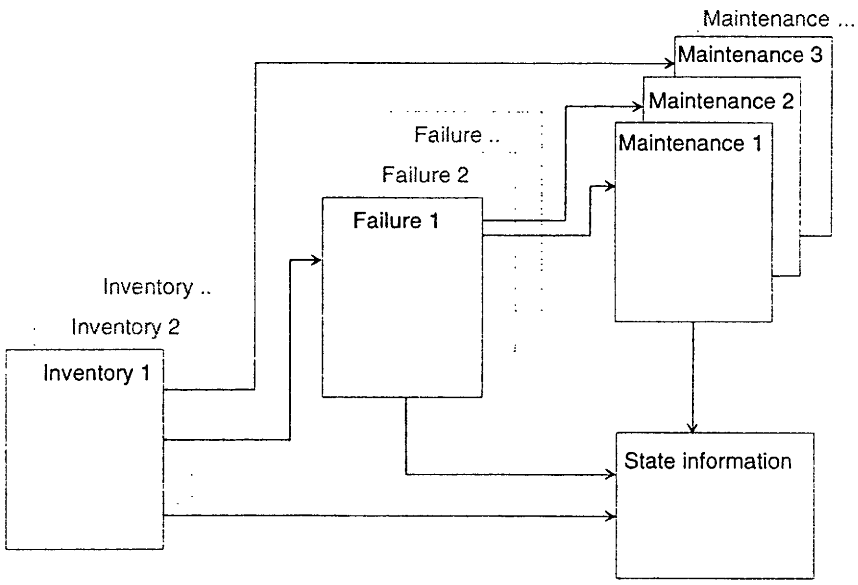

FIGURE 4-9: Logical REMAIN database structure

Inventory data: The description of an inventory is characterised by:

1. identification data; e.g. inventory location, classification , installation data, inventory class data;
2. design data; e.g. manufacturer's data, design characteristics;
3. application data; e.g. operation, environment.

These data categories shall in part be general for all inventory classes e.g. type classification and specific for each instance of an inventory e.g. radius for a turnout. This shall be reflected in the database structure.

Failure data are characterised by:

1. identification data, failure record and inventory location;
2. failure data for characterising a failure, e.g. failure date, maintainable items failed, severity class, failure mode, failure cause, method of observation.

Maintenance data are characterised by:

1. identification data; e.g. maintenance record, inventory location, failure record;
2. maintenance data; parameters characterising a maintenance, e.g. date of maintenance, maintenance category, maintenance activity, items maintained, maintenance man hours per discipline, active maintenance time, down time.

The type of failure and maintenance data shall normally be common for all inventory classes with exceptions where specific data types need to be collected.

Corrective maintenance events shall be recorded in order to describe the corrective action following a failure. Preventive maintenance records are required to get the complete lifetime history of an inventory.

State information (condition monitoring information) may be collected in the following manners:

- Readings and measurements during maintenance
- Observations during normal operation
- Continuos measurements by use of sensor technology

4.3.1.3.2 Data Format

Each record e.g. a failure event shall be identified in the database by a number of attributes. Each attribute describes one piece of information, e.g. the failure mode. It is recommended that each piece of information is coded where possible. The advantages of this approach versus free text are:

- queries and analysis of data are facilitated;
- ease of data input;
- consistency check undertaken at the input; by having pre-defined codes.

The range of pre-defined codes should be optimised. A short range of codes may be too general to be useful. A long range of codes may give a more precise description, but will slow the input process and may not be used fully by the data acquirer.

The disadvantage of a pre-defined list of codes versus free text is that some detailed information may be lost. It is recommended that free text is included to contain supplementary information. A free text field with additional information is also useful for quality control of data.

The values of data or attributes can be measured on several levels, which are often identified as nominal, ordinal, interval and ratio. All four levels shall be used in the REMAIN approach:

- Nominal-Level Measurement

The "lowest" level is the nominal level. No ordering between the values of the variable is assumed. This level is typically used for categorical data, which may e.g. be used by operators for describing the cause of a failure like wear, breakage, vandalism, etc.

- Ordinal-Level Measurement

The ordinal level is used when it is possible to rank-order all categories according to some criterion. Note that the ordinal level only rank-orders the values. It is not possible to say anything about *how much* the difference is between e.g. *moderate*, *medium* and *severe* wear.

- Interval-Level Measurement

In the interval level situation there is an ordering of the categories, in addition the distance between the categories is defined in terms of fixed and equal units. The temperature (measured in °C or °F) is a typical example. For the interval level there is no fixed zero point. Thus it does not make sense to claim that 20 °C is twice as hot as 10 °C. Interval-level measurements together with the following ratio-level are the area of sensors or gauges.

- Ratio-Level Measurement

The ratio level has the same properties as the interval level and has in addition a fixed zero point. For example temperature measured in °K satisfy the properties of a ratio level measurement. Also pressure measured in Bar will satisfy the ratio level measurement, i. e. it makes sense to compute ratios of measured values (Pressure of 1 bar is twice as high as that of 0,5 bar).

4.3.2 INFORMATION RETRIEVAL

Information is retrieved having some purpose in mind. REMAIN has focused on the following three topics:

- Learning from experience. That is, when a problem occurs the failure and maintenance databases can be searched for events which are similar to the current problem. If the database is properly updated, we might then find information about solutions that proved to be efficient, and also solutions that did not proved to be efficient in the past.
- Identification of common problems. By producing "Top ten"-lists (visualised by Pareto diagrams) the database can be used to identify common problems. For example which component contribute most to the total downtime (cost drivers), what are the dominate failure causes etc. "Top-ten" lists are used as a basis for deciding where to use resources for improvements.
- A basis for estimation of reliability parameters. Important parameters to use in RAMS analyses are the Mean Time To Failure (MTTF), ageing parameters and repair times. Please see section 4.6.

4.3.2.1 LEARNING FROM EXPERIENCE

The database may be used as a "case based" experience database, i.e. each failure and maintenance report represents a case from which experience might be gained. To utilise the information it is important that the failure and maintenance reports contain extensive information about the failure, the causes of the failures, what corrective actions were made, and also the results of any corrective action taken.

Since the database contains thousands of records it is also important that it is easy to search the database for relevant cases. The use of pre-defined lists in the database will make such search easier. In addition to such features built into the database, it is also important that the database can easily be searched. Most database systems have "search engines" for identification of relevant records. The search criteria can either be specified by a user friendly dialogue, or by some command statement such as a SQL statement.

In a practical situation when a problem is at hand, one will typically search for "similar" problems. It is however, not a straight forward task to define "similar" in this context. A problem is often characterised by a set of "attributes". However these attributes may be on different levels of measurements (see data format above) and the definition of "similarity" measures is therefore complicated. Several techniques for identification of similar events are described under the broad class of "data mining" techniques. Data mining is further one part of the more general problem of Knowledge Discovery in Databases (KDD) defined as: "the non-trivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data".

4.3.2.2 IDENTIFICATION OF COMMON PROBLEMS

A database is also a useful source for identification of common or frequent problems. The idea is to identify those problems which contribute most to the threat against safety, punctuality/availability, costs etc. This process is often carried out in two or more steps. First the database is searched for components contributing much to for example delay time. Thereafter these components/systems are further investigated to identify failure causes. A so-called Pareto diagram is often produced to visualise the result of the "Top ten list". An example is shown in Figure 4-10.

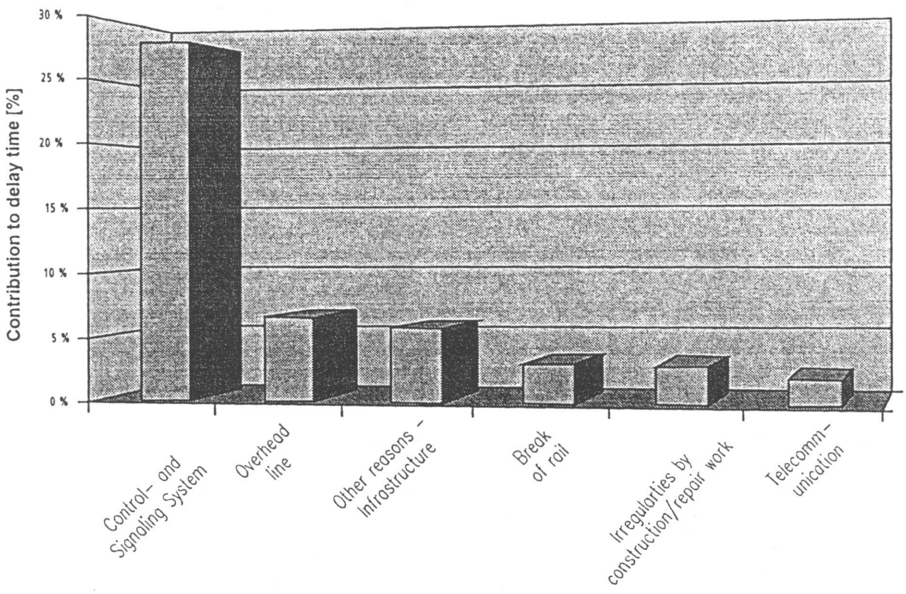

FIGURE 4-10: Pareto diagram showing contribution to delay time

Very often the two or three first "bars" account for a large amount of variable of interest. When constructing the Pareto diagram the following dimensions should be considered:

- What should be the "score"-variable?
- What is the "grouping" variable?

4.3.2.2.1 The "Score" Variable

The "score" variable represents the cost in some way or another. Various information from the failure and maintenance database can be used to produce a "score" variable, e.g.:

- Severity class
- Impact of failure on operation (number of trains affected, safety impact, material damages etc)
- Downtime
- Spare part consumption (costs)

- Maintenance man-hours

One or more of these variables should be combined into one quantitative measure representing the "score" for each event in the failure/maintenance database. This "score" variable is used when producing the Pareto diagram.

4.3.2.2.2 The "Grouping" Variable

The equipment class is usually the first variable to group on. In the discussion on future requirements (section 4.1) the inventory class was used as a grouping variable when the "turnouts" were chosen as a component of interest in the REMAIN project. Now several paths of breakdown exist. For example a breakdown into equipment types and/or application may be performed. Another breakdown is to group on sub-units and/or maintainable items.

4.3.2.3 A BASIS FOR ESTIMATION OF RELIABILITY PARAMETERS

Reliability parameters are important input to work strategic maintenance planning. In the RESMAP methodology the following parameters are of most importance:

- Parameters for "non-observable" failure progression
  - Mean time to failure (inverse of the failure rate)
  - Ageing parameter (α)
- Parameters for "observable" failure progression
  - Parameters in measurable quantity, e.g. failure progression $W(t)$
  - Parameters describing the "failure limit"
- Other parameters
  - Mean time to repair
  - Spare part consumption
  - mean down time when a failure has occurred.

In the first situation, we will take advantage of standard life time analysis. Regarding modelling of failure progression $W(t)$, refer to [RSAM].

4.3.2.4 OTHER TECHNIQUES

The borderline between information retrieval from a database and analysis of the data stored is not quite clear. In any case *plotting techniques* are provided with most databases. Such techniques comprise:

- Bar charts,
- Pie charts and
- Box-and-whiskers plots.

In order to control maintenance cost, it is important to identify the "*cost drivers*" by observing qualitatively one or more of the following variables:

- Severity class of failures,
- Impact of failure on operation,
- Downtime,
- Spare part consumption,
- Maintenance man-hours.

By means of qualitative *failure cause analysis* it is possible to identify failure causes that repeat. In the database failure causes may be found at two levels:

- Failure descriptor (general physical cause)
- Failure cause (Root causes related to design, specification, organisation).

Mathematical estimation procedures for failure rates, uncertainty, intervals, lifetime distributions and use of the data in *signal analysis tools* for condition monitoring usually cross the borderline between retrieval and analysis. These tools and examples of them are presented in sections 4.5 and 4.6.

4.3.3 SUMMARY

A database structure has been proposed in which data on failures, maintenance activities and costs are linked to an inventory database. The data also comprise condition monitoring information from sensors and human operators. The main principles are adapted to the ISO/DIS 14224 standards with the following major enhancements:

- Inclusion of condition monitoring data,
- Failure mode identification at maintainable item level,
- Cost data related to failures and maintenance arising during lifetime.

For the retrieval of relevant information methods have been collected to fulfil mainly three purposes:

- Learning from experience,
- Identification of frequent problems,
- Estimation of reliability problems.

More details on the database structure, together with illustrative examples for some components of the demonstrator, are described in [RDBR].

As a starting point, it is recommended that each railway company develops its own database. In order to ensure comparability between the databases of each company, a common structure should be agreed upon.

In a later phase one should evaluate the potential for merging data into one common REMAIN database. It should be noted that such a common REMAIN database need not be implemented as one physical database. It is possible to work with several distributed databases implemented on different platforms. However, the logical structure of the various databases should be compatible.

4.4 COMMUNICATION OF INFORMATION

In this chapter work is described that had to assess the suitability of existing and planned communication lines and protocols for the transmission of status information. As a starting point information by railway companies on existing structures, knowledge of partners on their own networks and results from related European programmes like EUROBALISE and EURORADIO was used, that is compiled in section 4.4.1.

For the demonstrator a fieldbus similar to INTERBUS-S is used and its reliability in the hostile environment of a railway infrastructure was observed during the project and has proven to be excellent. A comparison was made with other existing local area networks, see section 4.4.2.

In future radio links will gain growing importance and many existing radio channels will be given up by railways in favour of the GSM-R standard, that is described in section 4.4.3, followed by a short summary.

The proposals worked out in this chapter were based explicitly on results in other areas without spending time for own investigations and developments.

4.4.1 EXISTING INFRASTRUCTURE

The telecommunication infrastructure as it exists within railway companies today, mainly is used for voice communication and data transmission. To a relatively small extent they are also applied for real time transmission of video signals, e.g. for visual inspection and surveillance. Transfer media include twisted wire, coaxial cables, glass fibre, and wireless transmission. The importance of GSM-R in this field is steadily growing.

The following tables give an overview on telecommunication infrastructure and services being in use in the participating railway companies RENFE, ISAP and DB AG

Concerning the exchange of diagnostic data within railway companies and the development of common European communication facilities for diagnostic data, no clear preferences can be derived from the tables. However, the use of the GSM-R standard can be recommended for diagnostic data too, as it offers the flexibility required for border-crossing trains.

NR	Communication Infrastructure	Media	Protocol Access	Service	Safety/ Security	Reliability	Performance	Comment
1 1	Voice services	glass fiber	PCM, Voice	telephone communication, verbal announcement messages	redundant		4 x 2Mbps, duplex	
1 2	Voice services	glass fiber, radio	PCM, Voice	radio communication	redundant		4 x 64Kbps, duplex	
1.3	Voice services	glass fiber	PCM, Voice	music distribution to passenger stations			3 x 64Kbps	
1 4	Voice services	glass fiber	PCM Voice	other telephone communications			3 x 2 Mbps	
2.1	Data services	glass fiber	Data	communication between control centers and interlockings	redundant		2 x 64kbps	
2 2	Data services	glass fiber	data	selection of Tv camera	redundant		64 kbps	
2.3	Data services	glass fiber	X 25	(1) below	redundant		6 x 64kbps, duplex	
2 4	Data services	glass fiber	data	administrative traffic			6 x 64kbps	
2 5	Data services	glass fiber	data	other data communication			6 x 2Mbps	
3 1	video services	glass fiber	video data	image service			3 x 2Mbps	

TABLE 4-1: Telecommunication infrastructure - RENFE (high speed line)

NR	Communication Infrastructure	Media	Protocol/ Access	Service	Safety / Security	Reliability	Performance	Comment
1	Interior Telecommunication Network	wire, 2pair	voice	telephone				Telephone center ALCATEL 2600D Upgrade to glass fiber planned
2	City Line Telephones	wire	voice	telephone				
3	Radio Link	radio	voice	voice communication between trains, control center, walking stuff on the line, security group center, workshops				Installation of new Radio Link in progress

TABLE 4-2: Telecommunication infrastructure - ISAP

NR.	Communication Infrastructure	Media	Protocol/ Access	Service	Safety/ Security	Reliability	Performance	Comment
1 1	ARCOR-Voice-Services	wire	voice protocol analog access	telephone				only for voice communication
1 2	ARCOR-Voice-Services	wire	voice protocol digital access	ISDN				
2.1	ARCOR-Data-Services	wire	X 21 V 24 V 35 X 25 X 3/X.28 access	X 25 HDLC	greatest security of all systems provided by ARCOR X 25 operates also well on bad wires	97,5 % availability	9,6 -64 kbps	packet switched network international standardized data service Gateway to Hermes-Net Not suitable for real-time application
2 2	ARCOR-Data-Services	Wire	X 21 V.24 V.35/V 36 G.703 access	Frame Relay	transparent communication with only poor abilities for error detection and correction	97 5 % availability	64 kbps n x 64 kbps 2 Mbps	used for transmission of huge amounts of data ARCOR provides Frame Relay protocol only for long distance connections
2 3	ARCOR-Data-Services	wire	X.21 V.24 V.35/V 36 G.703 access	DECnet TCP/IP		97 5 % availability	64 kbps n x 64 kbps 2 Mbps	DECnet will not be improved; TCP/IP is used for BKU only
2 4	ARCOR-Data-Services	wire	X 21 V 24 V 35/V 36 access	pear to pear SNA Transdata		97 5 % availability	9 6 kbps kbps 64 kbps	transparent mode SNA and Transdata will be replaced by X 25 and Frame Relay Pear to Pear require modems for each point of connection
3 1	ARCOR Operational Communication Services	wire	voice protocol analog access	BFMA				will be replaced by GSM-R
3 2	ARCOR Operational Communication Services	wire, coax, glass fiber		Video Surveillance				
3.3	ARCOR Operational Communication Services	wire	X 25	Telex				will be replaced by BKU, RbMV or LeiBIT
3 4	ARCOR Operational Communication Services	radio		Rescue Trains				
4 1	Radio Service	radio	analog	Zugfunk				will be replaced by GSM-R
4 2	Radio Service	radio	analog	Rangierfunk Remote Control for brake check				replaced by GSM-R
4 3	Radio Service	radio	analog	BI-FU				replaced by GSM-R
4 4	Radio Service	radio	analog	KFZ-Funk				replaced by GSM-R
4 5	Radio Service	radio	analog	Bundelfunk				replaced by GSM-R
4 6	Radio Service	radio	analog	Remote Control				replaced by GSM-R
4.7	Radio Service	radio	analog	Grundstückfunk				replaced by GSM-R
4.8	Radio Service	radio	X 25	Diagnosevormeldedienst (ICE)				replaced by GSM-R
4 9	Radio Service	radio	C-Net	Ö-Kart				Migration to GSM
5.1	Special Service	wire	N/A	Zeitdienst				will be replaced by DCF77 technology
5.2	Special Service	wire		FUSTE	great security			replaced by GSM-R
5.3	Special Service	wire		Standard-Streckenfern-meldekabel				will be replaced by glass fiber

TABLE 4-3: Telecommunication infrastructure - DB AG

Note: Explanation of German terms used in the above tables

German Term:	Explanation:
Zugfunk	Ground-train radio link
Rangierfunk	Radio links for stations (shunting radio)
BFMA	Telephone switching centre for operational communication
Streckenfernmeldekabel	trackside wire
BI-FU	Operational communication and maintenance communication radio link
Zeitdienst	Time annunciation service
FÜSTE	Remote control of technical equipment
Ö-Kart	tunnel radio link for public telephone
Diagnosevormeldedienst	Diagnostic data exchange radio link for ICE
KFZ-Funk	Car radio link
Bündelfunk	special radio link

4.4.2 LOCAL AREA DATA NETWORKS

Local area data networks (LANs) are used to interconnect distributed communities of computer-based data terminal equipment (DTE) within a single building or a localised group of buildings.

LANs maybe classified into two types:

- wired LANs using twisted-pair or coaxial cable, and
- wireless LANs that utilise radio or light waves.

4.4.2.1 WIRED LANS

Wired LANs are mainly using one or more of the following topologies:

- star
- bus
- ring, and
- hub

in which bus and ring are the preferred topologies for LANs designed to function as data communication subnetworks for the interconnection of local computer-based equipment.

There have been adopted two techniques for the access control of LANs in the various standard documents, mainly IEEE 802, that are:

- carrier-sense multiple-access with collision detection (CSMA/CD) for bus network topologies and
- control token for either bus or ring networks.

An access method based on a slotted ring is also widely used with ring networks.

A CSMA/CD bus, also known as Ethernet, is normally implemented either as a 10 Mbps baseband coaxial cable network or as a 1 Mbps twisted-pair cable network. To overcome near-end crosstalk (NEXT) effects special integrated circuits known as adaptive crosstalk cancellation circuits are needed to ensure reliable operation at 10 Mbps with 100 m wire length. To detect errors in transmission a 32-bit cyclic redundancy check (CRC) value is used within the transmission frame, which allows a reliability in bit failure detection of 2e-10.

A typical token ring network, using a control token, where a screened twisted-pair cable is used as a cable medium, allows bit rates up to 16 Mbps. For this type of network also a 32-bit CRC is used to detect transmission failures.

4.4.2.2 WIRELESS LANS

A reason to use Wireless LANs are the costs associated with the installation of the physical wire cables, another reason is the advent of handheld terminals and portable computers. But the use of wireless media causes also some problems:

- radio-frequency waves are affected by path loss, adjacent channel interference and multipath propagation, and
- infrared light is interfered by background (ambient) light, like sunlight and light produced by filament and florescent light.

For radio wireless LANs there are four transmission schemes:

- direct sequence spread spectrum
- frequency-hopping spread spectrum
- single-carrier modulation, and
- multi-subcarrier modulation

and for infrared light based LANs

- direct modulation and
- carrier modulation techniques.

Both radio and infrared operate using a broadcast medium, that is, all transmitters are received by all receivers within the field of coverage of the transmitter. So a media access control (MAC) method is required with wireless LANs. The main schemes used are

- code-division multiple access (CDMA),
- carrier-sense multiple-access with collision detection (CSMA/CD),
- carrier-sense multiple-access with collision avoidance (CSMA/CA),
- time-division multiple access (TDMA) and
- frequency-division multiple access (FDMA)

There are two standards for wireless LANs under development, IEEE802.11 in the United States and HiperLAN in Europe, being developed by ETSI.

4.4.2.3 DATA COMMUNICATION VIA FIELDBUS

This text discusses some aspects of the data communication between sensors, related field devices and data processing devices over a fieldbus installation. The fieldbus is regarded as a special kind of LAN. The following requirements are assumed to hold for the data communication via a fieldbus system within the application addressed in REMAIN:

- Relatively low data transfer rates
- Moderate to low response times
- Defined environmental conditions
- Data transfer over long distances
- No power supply of bus devices over the data communication line

With respect to these requirements common features of all fieldbus systems are the following:

4.4.2.3.1 Transfer Rate:

The data transfer rates of all common fieldbus systems are sufficient for the intended purpose.

4.4.2.3.2 Response Times

Data Transmission in the intended application is mainly one-way: data of sensors are communicated to data collection and pre-processing devices and from there to some central processing station. In general, the total time needed for such a chain of data transmissions is not critical and can be allowed to take several seconds. All considered fieldbus systems are able to meet these low requirements.

4.4.2.3.3 Environmental conditions

There are specific requirements for electronic devices used with rail traffic concerning the environmental conditions, under which they must correctly operate. For example, the following requirements are listed in "ERTMS Environmental Requirements Specification (ERTMS Control/Command, Environmental Requirement)":

- Height between 0 m and 1800 m above M.S.L.
- Outside ambient temperature –40 °C to +55 °C
- Outside relative air humidity 5 to 100 %
- Operation under direct sunlight and UV
- Operation under mechanical stresses like shock or vibration.
- Operation at continuos deviations from rated voltages (+10% to –15% for a.c., +20% to –10% for d.c.)
- Operation in the electromagnetic environment (external electromagnetic fields, electromagnetic discharges or bursts, etc.)
- Operation under the most diverse environmental conditions such as wind, precipitation, splash or jet water, formation of ice and snow, pollution of ambient air by dust, smoke, aggressive gases and steams, salt spray mist, etc.
- Protection against the action of plants, mould and small animals.

Such requirements primarily do not concern the choice of a fieldbus system rather than the actual installation of its devices and communication media. (Depending on how strict the requirements are, the housings of nodes might be reinforced, made waterproof, air conditioned or buried underground, communication cables might be put into sealed tunnels, etc.)

A common requirement on fieldbus systems with respect to the operation under harsh environmental conditions is the existence of error detection and recovery procedures on the various data transmission protocol layers. All commonly used fieldbus systems include such provisions.

4.4.2.3.4 Distances between nodes:

Fieldbus systems are not designed for long distance data transmission. The maximum admissible cable lengths are typically a few kilometres.

For data transmissions over tens or even hundreds of kilometres a simple fieldbus architecture is not possible. An example of a suitable architecture could be a 'low level part' of several fieldbus installations (e.g. connecting sensors and data pre-processing units in the vicinity of a railway station) interconnected by some 'high level' wide area data communication system.

4.4.2.4 COMMONLY USED FIELDBUS SYSTEMS

The following widespread fieldbus systems are considered in the next sections:

- PROFIBUS
- FIP
- InterBus-S
- P-NET
- CAN
- DIN Meßbus
- LON

The following table gives an overview of some features of these fieldbus systems:

	PROFIBUS	FIP	InterBus-S	P-NET	CAN	DIN Meßbus	LON
Topology	Line	Line	Ring	Line, ring	Line	Line	Free topology possible
Max. No nodes	126	256	1 master, 256 slaves	125 per segment	128 (ISO 11898)	32	32385
Max. distance	About 10 km	2 km	12,8 km			Some km	
Max. distance between nodes		500 m	400 m	1200 m		500 m	320 m
Physical media	Twisted Pair, Fibre optics	Twisted Pair, Fibre optics	5 and 8 wire cable, Fibre optics	Twisted Pair, Fibre optics	Twisted Pair, Fibre optics	Twisted Pair	Twisted Pair, Infrared, Radio, Power Line
Physical data transmission	RS 485	RS 485	RS 485	RS 485	ISO 11898, RS 485	RS 485, FD	RS 485 (Twisted Pair)

TABLE 4-4: Features of selected fieldbus systems

4.4.2.4.1 PROFIBUS

The physical layer uses RS485 transmission at rates from 9.6 kbit/s up to 500 kbit/s on twisted pair cable of respective maximum segment lengths from 1200m (4800m with repeaters) down to 200m (800m with repeaters). The respective maximum drop cable lengths are 20m and 1m depending on cable type. At most 3 repeaters can be in sequence. Up to 32 devices can be on a segment, up to 127 on a network without gateways. The bus shape is a line (tree shapes are possible within electrical constraints). Power supply over the signal line not possible, but in the same bus cable. Fibre optic transmission is possible, although not defined in DIN 19245.

PROFIBUS distinguishes between master and slave devices. Media access is controlled by a token circulated between the masters. PROFIBUS provides services for variable access (cyclic and acyclic data transmissions, but not periodic transmission), program invocation, domain management (data down- and uploading) and event management. Time stamping of messages is not supported and there is no time consistency of data (but connections are aborted when confirmations are not received within a time out).

4.4.2.4.2 FIP

The maximum twisted pair segment length without repeaters (with repeaters) is 1500m (3500m) for transmission rate 31.25 kbit/s and 500m (1500m) for 1Mbit/s. The maximum admissible transmission delay between any two devices is limited. This yields the maximum number of repeaters and segment length. The transmission rate 2.5Mbit/s is also possible. Up to 32 devices can be on a segment, up to 256 on a network without gateways. The maximum drop cable length is 1m. The bus shape is a line (tree shapes are possible within electrical constraints). Fibre optic transmission is being defined. Power supply over the signal line or in the same bus cable is possible. A bus arbiter controls the bus access.

The services provided include periodic and acyclic data transmissions, program invocation, domain management (data down- and uploading) and event management. The fundamental feature is a distributed database of variables which are updated periodically. Time stamping of messages is not supported, but time consistency is.

4.4.2.4.3 InterBus-S

The topology is a ring realised in a single cable. The 2-wire ring comprises a chain of point to point connections. The maximum distance between two devices is 400m, the maximum total length is 13km with every device acting as a repeater. Fibre optics is also possible, although not defined in the DIN draft standard 19258. A system of connected subrings can be used to form a tree structure. Up to 64 devices can be on a segment, up to 256 in a network. The bit rate is 500kbit/s, but a special circulating message frame allows all devices to send and receive simultaneously. The frame contains the I/O data of all devices; data exchange is only with a central master. InterBus-S is optimised for the periodic exchange of user data (typically up to 4 bytes) between each of the field devices and the central master. Acyclic transfer of larger data units is also possible. A subset of the PROFIBUS application layer services can be optionally used over InterBus-S. Profiles for drives and encoders are defined.

4.4.2.4.4 P-NET

P-NET has a ring topology of maximum length 1200m with point to point connections of shielded twisted pair. The RS485 transmission is at bit rate 76.8 kbit/s. Up to 125 devices (32 masters) can be on a bus segment. P-NET distinguishes between master and slave devices. A virtual token circulated between the masters controls bus access. MMS (ISO 9506) services are provided in the application layer.

4.4.2.4.5 CAN

The bit rate depends on the bus length; the maximum rate of 1Mbit/s is only for cable lengths up to 40m whereas the rate 50kbit/s, for example, is for lengths up to 1000m. A 3-wire cable is used. Drop cables are possible, but not specified. The medium access is CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance). The transfer of variables with 8 bytes of user data is defined. No real-time services are provided.

4.4.2.4.6 DIN Meßbus

The length of a bus segment without repeaters can be up to 500m with drop cables up to 5m. The length is arbitrarily extendible with repeaters. A master (responsible for the centralised media access) and at most 31 slave devices can be connected to a segment. Various bit rates using RS485 up to a maximum rate of 1Mbit/s are possible. A 4-wire cable with full duplex transmission is used to increase the bus reliability. Fibre optic and infra red media are also possible. DIN Meßbus is designed for the reliable transfer of measurement data. Data is sent as 7 bit ASCII symbols. An application layer based on MMS and services for measurement applications are being defined.

4.4.2.4.7 LON

In a LON network, Neuron® protocol chips are interconnected via transceivers and physical media. Standard transceivers are available for twisted pair cable, radio transmission and power line transmission. Possible transmission rates range from 0.6 kbit/s up to 1250 kbit/s (commonly used bit rates are 1250 and 78 kbit/s). The architecture allows a variety of different bus topologies. For a single line doubly terminated twisted pair cable operated at 78 kbit/s and connected via a standard transceiver (FTT-10) the maximum cable length is 2700 m (without repeaters) and can be multiplied with repeaters. It is also possible for customers to build their own transceivers and use virtually any physical media with them. The addressing scheme allows up to 127 nodes (Neuron chips) in a logical segment. Up to 255 logical segments can coexist in one address domain.

The Neuron Chips implement the LonTalk protocol, which combines point to point and multicast/broadcast message transmissions with a model of a distributed database of "network variables" which are updated on demand.

4.4.3 RADIO COMMUNICATION VIA GSM-R

GSM-R is a digital mobile radio communication system based on the UIC standard 'EIRENE'.

4.4.3.1 COMPONENTS OF THE GSM-R TRANSMISSION SYSTEM

4.4.3.1.1 Base Station System (BSS) and Mobile Station (MS) trackside

The radio subsystem of GSM-R consists of the MS and the BSS.

The MS is defined as the complete physical equipment of the Public Land Mobile Network (PLMN) participant. It consists of the radio communication equipment and the user interface, that is needed for the access of the PLMN services by the participant.

The BSS connects the wired part of the GSM-R network to the radio part. Using the Um radio interface, there is the possibility to switch channels of the BSS to the MS, while the A interface is switched to the NSS. Each BSS supplies a defined geographical region called 'cell' the size of which is depending on the density of participants. The BSS consists of two or three of the following functions:

The Base Transceiver Station (BTS) is representing the radio equipment of a cell that is responsible for transmission and reception of radio signals, monitoring of the radio link, and transmission of switching and signalling signal via Abis interface to BSC. For reasons of redundancy, the connection between BTS and BSC must be set up as close loop connection. Additionally the BTS must have multi-drop capabilities.

The Base Station Controller (BSC) is organising several BTS, controlling the frequency changes and the hand over procedure between cells, controlling the radio channels and the waiting queue, monitoring the radio calls and the switching based transmission procedure.

The Transcoding and Rate Adaption Unit (TRAU) is transmitting switching related and signalling data from and to MSC via A-interface, and encoding the 64 kBps data from the MSC to 16 kBps in accordance to PCM procedure standardised in CCITT G.711. The TRAU is installed at location of MSC or integrated with BSC.

4.4.3.1.2 Network Subsystem (NSS)

The NSS is representing the interface between the radio network and the wired network, so the functions performed by the NSS are switching orientated and network orientated. The components of the NSS are

- the Mobile Service switching Center (MSC)
- the Home Location Register (HLR)
- the Visitor Location Register (VLR)
- the Authentification Center (AuC) and
- the Equipment Identify Register (EIR)

The resources of MSC and VLR must support approximately 30000 participants and the resources of HLR and AuC must allow sufficient growth potential for future network concepts of DB AG.

4.4.3.1.3 Operation Subsystem (OSS)

The OSS is represented by the Operation and Maintenance Centers (OMC), that is the central installation to control and monitor the other components of the network and to monitor the quality of network services. This installation is realised as hierarchical Telecommunication Management Network (TMN), that allows the remote control of network components by operator commands.

The OMC is connected to all network components via standardised O-interface, that is an X.25 interface.

The management function of the OMC is consisting in organisation of participants, data terminal equipment, payload and statistical data collection of maintenance condition and workload of network components.

4.4.3.2 INTERFACES

GSM-R is providing the following interfaces:

- MS user interface
- Radio interface at reference point Um
- BTS - MSC interface at reference point Abis
- BSS - MSC interface at reference point A
- BSC/MSC - OMC interface at reference point O

In addition there are the following connections:

- connection from MSC to ISDN utilising PCM systems using 2 MBps channels and signalling system CCITT Nr.7 in accordance to ETSI-ISUP
- connection from MSC to other single components of the application like movement inspector center using S2M interface and telephone voice communication using SO Interface and signalling system EDSS1

4.4.3.3 RELIABILITY

The system internal functions must be redundant. The system provider is responsible for verifiable Safety Assessment on component level.

4.4.3.4 TECHNOLOGY OF THE GSM-R TRANSMISSION SYSTEM

4.4.3.4.1 GSM-R Standard and Services

The network components are in accordance to specification of ETSI-Standard Phase 2 including actual change requests and amendment requests until 1995. GSM-R supports teleservices, bearer services and some supplementary services.

Service Name	Service Description	in accordance with	Comment
TS11	telephony	GSM Rec. 02.03	
TS12	emergency call	GSM Rec. 02.03	
TS21 SMS MT/PP	Short Message Service Mobile Terminated Point to Point	GSM Rec. 02.03	
TS22 SMS MO/PP	Short Message Service Mobile Originated Point to Point	GSM Rec. 02.03	
TS23 SMS CB	Short Message Service Cell Broadcast	GSM Rec. 02.03	
TS61	alternate Speech and Fax group 3	GSM Rec. 02.03	
TS62	Automatic Fax group 3	GSM Rec. 02.03	transparent to 03.45

TABLE 4-5: GSM-R Teleservices

Service Name	Service Description	in accordance with	Comment
BS21		GSM Rec. 02.02	optional
BS22		GSM Rec. 02.02	optional
BS23		GSM Rec. 02.02	optional
BS24	asynchronous 2.4 kBps transparent	GSM Rec. 02.02	non-transparent optional
BS25	asynchronous 4.8 kBps transparent	GSM Rec. 02.02	non-transparent optional
BS26	asynchronous 9.6 kBps transparent	GSM Rec. 02.02	non-transparent optional
BS32	synchronous 2.4 kBps transparent	GSM Rec. 02.02	
BS33	synchronous 4.8 kBps transparent	GSM Rec. 02.02	
BS34	synchronous 9.6 kBps transparent	GSM Rec. 02.02	optional

TABLE 4-6: GSM-R Bearer Service

The data service interface to ISDN or to any direct access participant is utilising a rate adaption (I.463) in MSC.

Service Name	Service Description	in accordance with
Number Identification SS:		
CLIP	Calling Line Identification Presentation	GSM Rec. 02.81
CLIR	Calling Line Identification Restriction	GSM Rec. 02.81
CoLP	Connected Line Identification Presentation	GSM Rec. 02.81
CoLR	Connected Line Identification Restriction	GSM Rec. 02.81
Call Offering SS:		
CFU	Call Forwarding Unconditional	GSM Rec. 02.82
CFB	Call Forwarding on mobile subscriber Busy	GSM Rec. 02.82
CFNRy	Call Forwarding on No Reply	GSM Rec. 02.82
CFNRc	Call Forwarding on mobile subscriber Not Reachable	GSM Rec. 02.82
Call Completion SS:		
CW	Call Waiting	GSM Rec. 02.83
HOLD	Call Hold	GSM Rec. 02.83
Multiparty SS	Multiparty SS	GSM Rec. 02.84
Community of Interest SS:		
CUG	Closed User Group	GSM Rec. 02.85
Call Restriction SS:		
BAOC	Barring of All Outgoing Calls	GSM Rec. 02.88
BOIC	Barring of all Outgoing International Calls	GSM Rec. 02.88
BOIC-exHC	Barring of all Outgoing International Calls except those directed to Home Country	GSM Rec. 02.88
BAIC	Barring of All Incoming Calls	GSM Rec. 02.88
BIC-roam	Barring Incoming Calls when roaming outside home PLMN	GSM Rec. 02.88

TABLE 4-7: GSM-R Supplementary Services

Service Name	Service Description	in accordance with	Comment
VBS	Voice Broadcast Service	GSM Rec. 02.69	
VGCS	Voice Group Call Service	GSM Rec. 02.68	
eMLPP	Enhanced Multi-Level Precedence and Pre-emption	GSM Rec. 02.67	
GPRS	General Packet Radio Service		not standardized yet

TABLE 4-8: GSM-Phase 2+/ Supplementary Features

4.4.3.4.2 Network Functions

There will be a flexible procedure for functions like communication connection, hand-over procedure, authentication, communication disconnection etc., to provide means for a future optimisation of the network under consideration of special railway addressing requirements as defined in project DIBMOF.

4.4.3.4.3 *Radio Features*

Frequencies

The uplink frequency band is defined from 876 MHz to 880 MHz, the downlink frequency band from 921 MHz to 925 MHz. These bands are divided into 19 channels of 200 kHz bandwidth each.

Transmission Power

The maximum transmission power of BTS shall be in the range from 20 W to 40 W in accordance with GSM TRX power class 5. The transmission power is related to the antenna terminal, e.g. combiner output of transmitter.

Antenna Diversity

Antenna diversity is a feature that may be required for special antenna locations. The diversity procedure shall consider the maximum ratio combining, this means that for a correlation coefficient of 0, there shall be realised a gain of 5dB in both reception trunks.

Frequency Hopping

Frequency hopping will not be realised in GSM-R

Discontinuous Transmission (DTX) / Discontinuous Reception (DRX)

The DTX/DRX feature is realised in GSM-R.

Low-Noise Amplifier for Receiver Antennas

Low-Noise Amplifier will be used at special locations to adjust additional cable losses between 2 dB and 8 dB without reducing the sensitivity.

4.4.4 RADIO COMMUNICATION VIA GSM-PUBLIC

Nowadays, GSM-Public coverage exists in some railway lines to provide voice communication services to passengers travelling in the trains. This radio infrastructure can be used also to transmit maintenance related information when GSM-R or cables are not available. Data can be transmitted in two ways:

- Setting up a call for the time the data transfer will take play. Data rates up to 9600 bauds are possible. This operating mode is similar to data transmission over conventional telephone lines.
- Using the GSM signalling channel. It is not necessary to set up a call and consequently is quite more cheaper. This Short Messages Service (SMS) facility allows the transmission of blocks of data up to 160 bytes; longer messages can be transmitted splitting them into smaller blocks. This operating mode could useful for sending warnings, alarms or rather simple diagnosis information.

Commercial equipment is available at present to work in both operating modes.

4.4.5 SUMMARY

With the exception of the requirements concerning environmental conditions and data transmission distances, all commonly used fieldbus systems meet the requirements for the transfer of sensor data for condition monitoring.

The requirements concerning environmental conditions can be met by the actual installation of a fieldbus system, e.g. by using protective housings, putting cables into cable tunnels etc.

Long distance data transmission can be a problem. Possible solutions may be:

1. Use a layered data transmission architecture with the fieldbus system at the lower and a wide area transmission line at the higher level.
2. Use a fieldbus system which allows customisable physical layer media and define and install your own physical data transmission line.

GSM-R is a radio link that will offer a powerful mean for a widespread field of railway applications. And of course for the transfer of RAMS-data, independent of the distance.

Automatic Train Control for example, which is in progress of standardisation by UIC, will be implemented as European Train Control System using GSM-R as transmission media. For this application, the data to be transmitted will be encrypted for reasons of safety, what is not necessary for maintenance applications.

Another application for GSM-R is Train Radio and Train Numbering which will be realised with the standard services of the GSM-R system defined by the Tele and Bearer services.

Applications like Group Communication will require the implementation of the GSM Phase 2+ Group Call Service. This kind of service includes also all variants of Broadcast Calls, Emergency Broadcast Calls and Group Calls.

Generally GSM-R allows Train Diagnostics by using Bearer Services and normal voice communication to maintenance workers.

4.5 CONDITION MONITORING OF COMPONENTS WITH DEMONSTRATION

To guarantee the high level of reliability and safety found today in railway operations, it is necessary to keep all relevant components of infrastructure and rolling stock operational at all times. Since many components are subject to wear, frequent inspection is required, resulting in maintenance actions if necessary. The prevalent maintenance strategy used today by most railway operators relies on inspections scheduled after fixed intervals, combined with preventive maintenance, e.g. replacement of parts, to make sure that the component can operate safely at least during the following interval.

On the other hand it seems to be agreed upon that this is not always the most cost effective maintenance strategy. The reason is that inspections must always be scheduled too early, because if they are scheduled to late, availability and safety cannot be guaranteed. Since inspections, as understood here, require a certain amount of human interaction, they are usually quite expensive. In addition, since parts are maintained or even replaced best during or shortly after the inspection, the lifetime of a part is not exploited optimally.

In the long run, a lot of money can be saved, if the time between inspections can be extended without loss of availability and safety. Currently there is often no up-to-date information available about the true state of components between inspections - which is the reason for the fixed interval between inspections. If however, for critical components, some information about actual wear would always be available, the time between complete inspections could be extended and adapted to actual demand as derived from the additional information. Deriving the necessary information from critical parts requires continuous *monitoring*.

To be able to monitor a device, one or more sensors must be applied. It is the task of maintenance experts to decide which parts are most critical and which sensors are most useful for monitoring, based on *Failure Mode Effects and Criticality Analysis* (FMECA).

Since it is usually not possible to use raw sensor readings to decide whether a part is (soon) worn out or needs maintenance, *signal analysis* methods are used to extract feature vectors, thereby eliciting in a compact form information on which maintenance decisions can be based. In some cases it may turn out that only one feature is necessary. Then a decision to initiate maintenance can be based on a simple threshold. If the maintenance decisions are based on several failure classes and in particular if classes are described by certain combinations of several features derived by *signal analysis, pattern recognition* and *classification algorithms* are necessary to sort a given feature vector into its corresponding class (section 4.5.1).

Based on a list of about 30 *switch and track failures* compiled by VAE, concepts for monitoring and diagnosis of the related components are discussed in the following section 4.5.2. Some of the failures can be detected already today by the Roadmaster 2000, while the automatic early detection of others is still an open problem that has to be investigated further. For this purpose, a workshop was held at MATISA in Switzerland to discuss possible solutions with experts working in the field (cf. also report [RSTF]).

The values of measurements at a component and the allowable intervals between inspections while maintaining the necessary level of safety and availability, can sometimes be derived from a mathematical model, but it is often necessary to base them on experience of a human expert. The section on *Expert Judgement* describes the possibilities to use expert knowledge in a formal way (section 4.5.3; [RXJH])).

4.5.1 SIGNAL ANALYSIS AND PATTERN RECOGNITION FOR MAINTENANCE DECISIONS

As already mentioned in the introduction to this section, scheduling maintenance on demand is usually more efficient than after fixed intervals. To be able to schedule on demand, the current state of a component must be known. In particular an estimation of the time until the component or a part thereof reaches its wear limit is of interest. For example at the switch, one wear limit is defined by the certain amount of grease on the switch rail chair which still allows proper functioning of the switch. With the *Roadmaster 2000*, VAE has shown that this particular wear limit can be estimated by comparing a sensor reading with a threshold. They use the force needed to move the switch rail as an indicator.

In general it is not always possible to find a sensor which measures a quantity identifying the wear limit directly. Even in the example above, non-linear effects as well as environmental effects as temperature changes or rain influence the measurement, so that the actual wear can only be approximated. Usually sensors can be found which deliver a useful indicator - somehow - but it is not the raw measured value itself. Rather the indicator must be extracted from the measured signal either in the *time-domain*, *frequency-domain* or *amplitude-domain*. If looking at the time-domain, one is interested in the development of the signal over time. If the frequency content of a signal is supposed to contain a useful indicator, the signal is transformed into the frequency domain usually by means of the Fourier Transform. If on the other hand mainly statistical features roughly independent of time are of interest, one is working in the amplitude-domain.

4.5.1.1 AMPLITUDE-DOMAIN ANALYSIS

Computation of extrema, average, standard deviation or higher order moments are the first methods that come to mind for the amplitude domain. They can be used either directly as indicators - in particular extrema and averages - but are also often used as one feature of a feature vector used for classification (see section 4.5.1.4).

More elaborate evaluations comprise counting methods like histograms or classification according to DIN 45667. The DIN-standard describes several counting methods which could be described as specialised histograms: zero crossing counting, peak counting, level crossing counting, range counting and range pair counting are some of them, to enumerate but a few. As the DIN-standard mentions, these methods are usually applied to random vibrations where methods of the frequency domain are often not applicable.

A modern extension of the amplitude classifications described in DIN 45667 is called *rainflow analysis* . It was developed to assess load-time histories. In particular it looks for the occurrence of specific "events" in a load-time trace. These events can be for example the exceedence of specific load levels, the occurrence of a load-change of certain magnitude, etc. The basis of these analysis techniques is to count the number of times, the specified events do occur.

Results of amplitude domain analysis are usually multidimensional vectors. They can be used as input to the methods described in section 4.5.1.4 to assign a (failure) class.

4.5.1.2 TIME-DOMAIN ANALYSIS

Time domain analysis looks at the signal variation over time and in contrast to amplitude domain analysis, the order in time of measured amplitudes is important.

Correlation techniques for example can be used to detect relations between two measured signals. One relation typically extracted with correlation is the shift between two signals. The shift can then be converted into a physical distance or speed. If correlation is used to compare a measured signal to a given signal, deviations from a predefined form can be detected, which is why this method could also be mentioned in section 4.5.1.4. Other examples of the application of correlation techniques include the extraction of root mean square and effective power of a signal independent of its form, and the discrimination of stochastic and periodic parts of a signal.

Instead of comparing a measured signal with a stored signal, it is often possible to come up with an analytical description with a few free parameters which describes the expected signal. The indicators used for diagnosis are then those values for the parameters which make the analytical description fit best to the measurements. Computing the parameters is called *parameter estimation*. The analytical form of the signal may either result from an elaborate model of the whole process to be observed, but in a more pragmatic approach only a signal-model is constructed, i.e. an analytical form of the signal is *made up* based on experience or example data (e.g. ARIMA-models).

If the signal of interest is actually modulated onto a carrier signal, demodulation and enveloping techniques must be used before the methods above can be applied.

4.5.1.3 FREQUENCY-DOMAIN ANALYSIS

Periodic or nearly periodic signals are best analysed in the frequency domain. In industrial applications, periodic signals accrue from rotating machines or vibrations. In general the methods described in sections 4.5.1.1 and 4.5.1.2 could also be applied in the frequency domain, but usually more specialised analysis, specifically geared towards the frequency domain is used.

Of interest in the frequency domain are for example features like height, position and/or width of peaks. If the measured signal is the result of an excitation of a linear system (either mechanic or electric) and if the excitation is known, then the transfer function can be estimated. The transfer function can be either compared with the expected transfer function, or can be used to derive features for classification.

If a system is not known to be linear, computation of coherence can be used to check whether it is or not.

Octave- and 1/3-octave-filters are defined in standard ISO R 266. They define band limits of a set of filters which are applied in situations were the filtered signal may also be recepted by humans, i.e. sound and vibrations, and where the impact on comfort is to be assessed.

Rotating machinery like combustion engines and electric motors can be monitored by measuring a signal synchronously to the rotation, i.e. instead of sampling the signal with a fixed frequency, it is sampled on a fixed angle of the rotation. If those signals are transformed into the frequency domain, peaks refer directly to parts of the rotating machinery, like e.g. cog-wheels.

In some cases, it might even be of interest to compute the Fourier transform of a spectrum, which leads to cepstral-analysis. It helps to find periodicity in a spectrum.

4.5.1.4 PATTERN RECOGNITION AND CLASSIFICATION

Pattern recognition and classification describes the methods used to recognise patterns in signals which are typical for certain states of a monitored component. Actually the comparison of a measured value with a threshold is the most simple form of classification. Depending on the comparison, the monitored component is either in state (or in class) *faultless* or in class *faulty*. In the general case, classification involves assignment of a class not based on a single value, but on a vector the components of which are any values derived by one or more of the methods in the previous sections. Typical methods for classification rely on a set of example vectors for which the class assignment is known. In a preceding step, the examples are examined by the methods to *learn* the class assignments. By comparing a new vector with the learned data, the methods are then able to recognise the correct class. Typical classes to be recognised are the failure free state and several failure states. For maintenance planning, the failure states are of course most important.

4.5.2 TRACK AND SWITCH FAILURES AND THEIR DETECTION

The list of about 30 failures on which this investigation was based, can be subdivided into 3 groups:

- Failures that cause looseness resulting in wrong geometry.
- Malfunctioning of moving parts, as the failure of a switch motor.
- Failures due to wear of rail or frog point.

The first group is basically covered already today by measuring trains. However, they cannot yet classify the particular reason for a wrong geometry, leaving the maintenance planning clueless as to what the actual cause is. Further research must show which causes of looseness can be classified either by making better use of the signals recorded by measuring trains, or by new sensors on measuring trains, or if it is necessary to use track mounted sensors.

Concerning sensors on measuring trains, an interesting development at DB AG (*Schwachstellenerkennung*) in co-operation with IITB as well as in Japan is the transfer of sensors from measuring trains over to regular trains. A control car equipped with accelerometers is coupled to commercial RENFE AVE trains running in the Spanish high speed line to carry out regular track inspections; the data obtained is used for subsequent track maintenance works. Compared to track mounted sensors, the approach will be cheaper for operators with a large infrastructure (like DB). Moreover, the frequency of inspection correlates nicely with the frequency of use.

The second group, malfunctioning moving parts, is probably no candidate for inspection by fast running measuring or regular trains. Sensors close to the place where the energy or force which moves the part is evident are most useful.

For the third group, further research is necessary in every single case to devise methods for wear detection. Image analysis methods as well as acoustic methods, either employed fixed near the track or on measuring trains are candidates.

It has been judged as a valuable input to further efforts to make at least a proposal for the detection of each of the failures (cf. [RSTF]). It has to be observed that in condition monitoring not a general methodology can be applied to all failures, but only case specific tools promise success.

4.5.3 USE OF EXPERT JUDGEMENT IN RAMS ANALYSES

4.5.3.1 THE NEED FOR EXPERT JUDGEMENT

Many of today systems are designed to such high reliability standards that failure data are difficult to obtain. Also, in the field of human reliability the human errors are rarely collected and registered in any error data bases. So in various fields like nuclear energy, process industry, railway and aerospace the reliability/maintenance/safety analysts often have to utilise expert judgements as input to quantitative analyses.

The expert judgements have been criticised for being used in a rather ad hoc/unsystematic manner. However, it should be kept in mind that RAMS analyses are undertaken because a decision has to be made. If the analysis cannot be based on field data then the knowledge have to be sought elsewhere, and the most obvious source is the people having experience within the relevant field. Further, during the last few years, a large amount of literature has appeared, providing a sound basis for the application of expert judgements. This literature has been worked through and a "Handbook on performing expert judgement" [RXJH] has bee compiled. In the next paragraph only the general methodology is outlined, but in the handbook an illustrative example and details may be studied.

4.5.3.2 MAIN STEPS OF THE EXPERT JUDGEMENT PROCESS

The three main steps for utilising expert judgements are

1. Preparation
    - i Choosing experts
    - ii Defining the questions
2. Elicitation
    - i Performing the interview
3. Calculation
    - i. Evaluation

      In the evaluation phase each experts answers are evaluated and usually they are given a weight depending on the goodness of their answers. This can then be used in the combination phase by letting the final estimate depend more on the judgements of the best experts.
    - ii. Combination (aggregation)

      Depending on the evaluation the estimates are combined (weighted) in order to achieve one single result; the overall estimate and confidence bounds.

4.5.3.3 OVERALL RECOMMENDATIONS ON UTILISING EXPERT JUDGEMENT

Overall requirements for the process of utilising expert judgements have been discussed in the literature. Such requirements should relate to the following five topics

1) Documentation

Thorough documentation is fundamental in order to make the analysis credible. All assumptions and decisions made by the analyst must be stated, including documentation of the elicitation process.

2) Objectivity

Objectivity should be a goal, and not something that can be guaranteed. Expert judgement is by nature subjective and the main criticism is directed toward this. Honesty of the expert is essential in order to achieve objectivity. Motivational bias can be difficult to reveal and control. The analyst must be aware of the danger of subjectivity, and objectivity is required when performing and documenting the expert judgement process.

3) Empirical Control

Empirical control (verification/checking) of the expert judgements may take a very long time. Thus, it could be a problem that some experts feel that exact knowledge will not become available within reasonable time, and thus he may be tempted to make precise statements, when actually he is rather uncertain about the issue.

4) Completeness

Requirements on completeness are demanding but necessary, in order to achieve credible results. The analyst should use experts with different professional background (operators, designers, maintenance personnel etc.) in order to cover all relevant aspects. This is particularly important if there is potential controversy involved.

5) Simplicity

The approach and the models should be simple in order to establish a competitive alternative to engineering judgement. This is also a question of costs.

Requirements on the topics 1) to 4) are needed for achieving scientific credibility. Simplicity (5) is needed for having a practicable approach that can gain widespread use.

There will be some obvious conflicts between various requirements of the topics 1)-5). For instance, simplicity could be in conflict to completeness and empirical control. The same is true for requirements on completeness and objectivity. Actually there could be a danger of overemphasising requirements of objectivity on the expense of completeness. After all, there is always an element of subjectivity in applied science (e.g. on model specification and result interpretation). When it comes to such conflicts, it is recommended to give top priority to completeness (*Get as much objective knowledge as possible out of the available experts*). Further, there is a fundamental need of documentation (*Document all steps of analysis*).

4.5.4 SUMMARY

In this section classes of tools and methods of information processing have been considered that are necessary to describe the current state of a component as accurately as possible. Based on selected sensor information, inspections and maintenance actions can be scheduled as late as possible, but early enough to guarantee the necessary level of safety and availability. Tools available for feature (or indicator) extraction belong to the amplitude-, time- or frequency-domain and consecutive methods of pattern recognition use these features for classification into states.

In favour of the collection of proposals for the detection of switch and track failures not detectable nowadays, methods for signal analysis and pattern recognition have not been described in detail, but should be studied in literature.

In practice it will often be necessary to base condition monitoring on data not derived from objective measurements but on subjective experience of human experts. To make this procedure as reliable as possible, a structured process for the introduction of expert knowledge has been developed, which is described in detail in [RXJH]. Data emerging from experts should not replace operational data, but its use according to the recommendations above will be a valuable supplement to data measured during operation and they will give essential information when operational data are not available.

4.6 REMAIN METHODOLOGY – BUILDING BLOCKS AND EXEMPLARY APPLICATIONS

As established in section 4.1, the user requirements for railway companies are:

- the introduction of condition monitoring methods (see section 4.5) and/or
- a systematic method for maintenance planning, called Reliability Centred Maintenance (RCM) (see below).

But before introducing anything new – even only a change in inspection – it has to be verified that this change infers "no reduction in safety level". Therefore the first step of the REMAIN methodology represents a safety analysis method based on change analysis, i. e. identification of changes in safety to be expected for a planned system. This methodology, described in section 4.6.1, should be applied before performing LCC analysis, which makes sense, if the outcomes of the safety analysis are positive.

LCC analysis (section 4.6.2) is used to verify the anticipated cost reductions of CON and/or RCM methods. It is described together with the underlying model assumptions and the result of an analysis for the turnouts in the demonstrator project. In this analysis a whole system (turnout) is evaluated that consists of several sensors and condition monitoring strategies.

The subsequent RCM analysis (section 4.6.3) might result in a recommendation to use specific CON-methods. However, in the RCM analysis, the decision on whether CON-methods shall be applied, will normally *not* include the considerations of new not yet tested technology. Only CON-methods that are tested and known (to the analysts) will be considered during an RCM-analysis. Thus, the development and testing of new condition monitoring methods is not a part of a standard RCM analysis, and so the cost benefits should be split between the two major means: introduction of promising CON-methods and use of RCM.

The effect of introducing CON methods and/or RCM for a given system/equipment is based on two main conditions. One is of "organisational" nature and concerns the appropriateness of the current preventive maintenance (PM) program. The second condition concerns the available technology of utilising CON-methods (or more CON-methods if some are already in use). A conceptual picture of these two factors is given in Figure 4-11. The achievements (i.e. cost reductions of *CON* and *RCM*) are here given *relative* to the cost of the *present* situation (which is here given as a fixed value for all four cases).

The application in the REMAIN-project (i.e., turnouts of DB AG) corresponds to the situation of the bottom right corner of Figure 4-11. Presently, rather little CON-equipment has been installed on turnouts, giving a high potential for cost reduction by introducing CON-methods. Contrary to this, the PM program of existing systems like turnouts has been "tuned" for decades, and in this situation the potential benefit of carrying out an RCM-analysis is relatively small compared to CON-methods. The benefits of performing an RCM-analysis are much higher for new systems and for new railway organisations.

It has been beneficial for the REMAIN-project that one of the partners possesses specific knowledge on CON-methods, in particular for turnouts (i.e. the VAE Roadmaster 2000 system), so that this knowledge was available prior to performing the RCM-analysis.

The LCC method is applied to turnouts of a high speed line (section 4.6.2), and the method for maintenance planning with integrated LCC analysis is applied to a conventional line (section 4.6.3). In particular, the contribution of the *delay time* to cost reduction is found to vary considerably in these two cases, due to differences in the companies' present situation (i.e. level of delay problems).

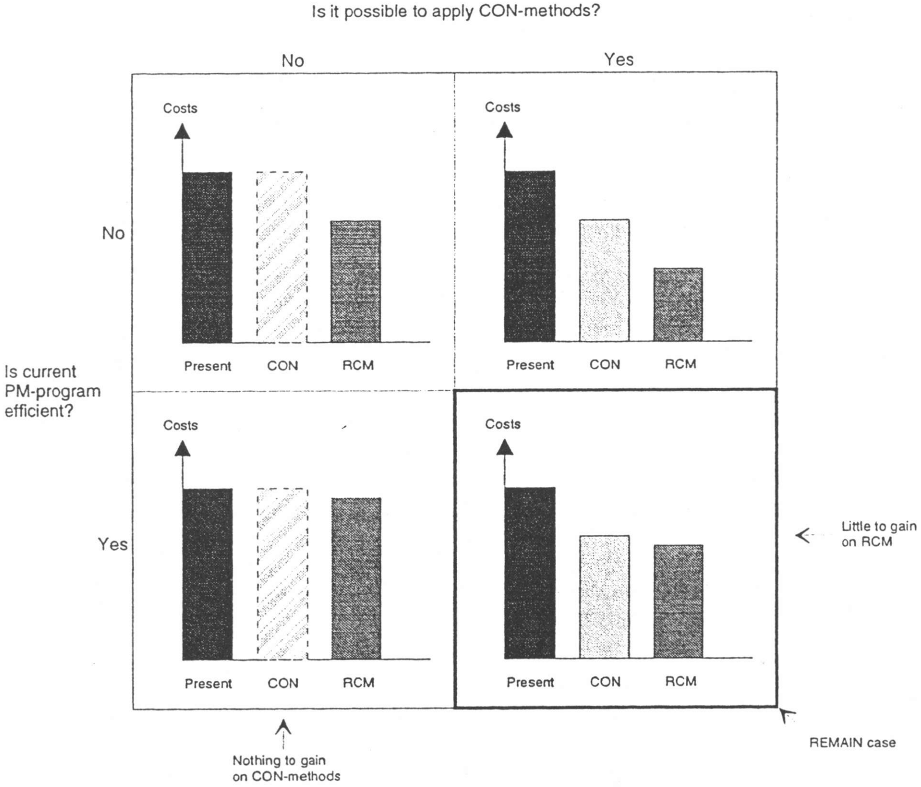

FIGURE 4-11: Effect on cost reduction of introducing CON-methods and RCM based on technical feasibility of CON-techniques and efficiency of current PM-program

4.6.1 SAFETY ANALYSIS FOR A PLANNED SYSTEM

The goal of the Remain project is to help the railway companies to meet the future demands regarding cost efficiency, without sacrificing safety. Thus, the main question regarding safety is formulated as follows:

> How will measures to reduce costs (both maintenance and delay time costs) affect the safety?

To be able to answer this question we have developed a *change analysis method*. This is a rough, qualitative method, used to evaluate any effect on safety by introducing condition monitoring equipment for railway components (and thereby changing the PM of the component).

This method will be an aid to assure that achievable cost reduction, e.g. by the use of condition monitoring equipment, has no (overall) negative effect on safety.

Why change is important to analyse may be emphasised by the following statement:

> *Change is the mother of twins: progress and trouble.*

Further, it is recognised that

> if a system has been operating in a stable manner, but now has troubles, change is the cause of the problem. This proposition almost amounts to a truism; that is, there are no problems if there are no changes.

The change analysis method developed here is especially adapted for use in the Remain project, and it is denoted the Remain Change Analysis Method (RCAM).

The method is illustrated in Figure 4-12, and its use is outlined below.

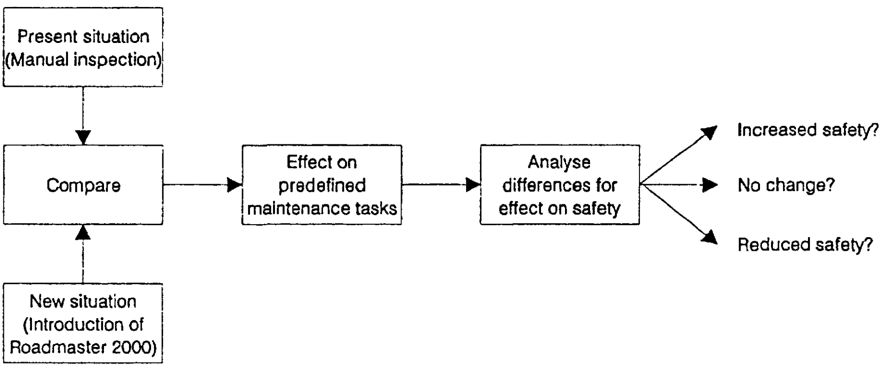

FIGURE 4-12: The Remain Change Analysis Method

For each component and each failure mode, which e.g. the Roadmaster 2000 system is intended to detect, we compare

- the "new situation", based on Roadmaster being implemented, and
- the present situation, based on manual inspection.

For each maintenance task an evaluation is performed with respect to the following possible *effects*

- change in the frequency of the task,
- change in the duration of the task,
- change in the time of the day the task is carried out, and

- change in the probability of introducing errors during this task (i.e. maintenance induced errors) is changed.

For each of these effects, there is also performed an evaluation on whether the safety is affected by the change. These effects are categorised into three classes: 'increased safety', 'reduced safety' or 'no changes in safety'. This evaluation is carried out for each task and each effect. Finally an overall evaluation of change in safety is given for the given component and failure mode. This change analysis method is described in [RSFA].

In addition to this change analysis method, [RSFA] presents a suite of methods for task analysis and human reliability analysis, to support the prevention of human errors. The following methods are covered:

- *Goals-Means Task Analysis*, which determines which subtasks are required to meet the overall objectives of a task.
- *Operations Sequence Diagramming*, which identifies the necessary sequencing of task steps and the allocation of the task steps to individuals.
- *Task Features Description*, which identifies cues, feedback and other characteristics of each task step.
- *Action Error Mode Analysis*, which identifies possible human errors, consequences, barriers and preventive measures connected to each task.

4.6.2 ECONOMIC EVALUATION USING THE LCC MODEL

It has been *one* objective of the REMAIN project to

- Provide a simple LCC model to be used in the overall economic evaluation of railway equipment, with focus on the possibility of making cost comparisons of different options.

In general, an LCC model provides a cost breakdown according to

- *Cost category* ("who"): The cost category of applicable resources such as labour, materials, fuel/energy, overhead, transportation/travel, etc.
- *Product/work* ("what"): Breakdown of the product to lower indenture levels.
- *Life cycle phase* ("when"): The time in the life cycle when the work/activity is to be performed.

In the LCC model developed in the REMAIN project there is a focus on *cost category* breakdown. The method is exemplified by evaluating the cost effectiveness of including condition monitoring equipment for turnouts. The sensitivity of the results with respect to various input parameters is discussed, also giving some guidelines for assessing the validity of the conclusions with respect to cost efficiency. The general LCC approach is outlined in the following, whereas details are to be found in [RLCC].

4.6.2.1 LCC MODEL

The LCC model for railway applications developed in REMAIN introduces the following *cost categories*

- Investment Cost
- Maintenance and Operating Cost
- Delay Cost (unavailability costs related to trains being delayed)

- Hazard Cost (costs related to hazardous/accidental events)

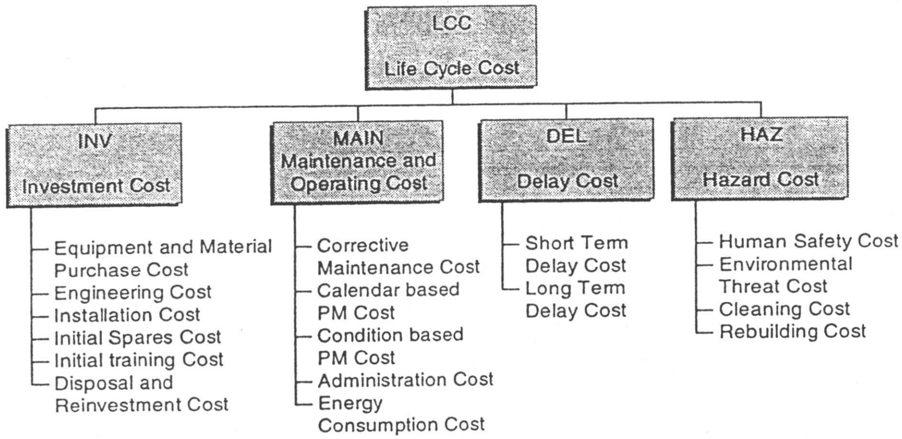

FIGURE 4-13: LCC breakdown into cost categories

Hence the total LCC equals

$$LCC = Cost_{INVESTMENT} + Cost_{MAINTENANCE} + Cost_{DELAY} + Cost_{HAZARD}$$

Or, in the notation of Figure 4-13:

$$LCC = INV + MAIN + DEL + HAZ$$

By introducing the notation

m = number of years in operation

k = annual rate of return = interest rate – rate of inflation

AIC = annual investment costs

AMC = annual maintenance and operation costs

ADC = annual delay costs

AHC = annual hazard costs

we obtain the following expression for the annual LCC

$$LCC_{ANNUAL} = INV \times k / [1 - (1+k)^{-m}] + [AMC + ADC + AHC]$$

This expression is applicable for comparison of two concepts, also when the two concepts have *different* lifetimes (i.e. different values of m). Observe that disposal and reinvestment costs are not incorporated in the above formulas.

Also DB AG is presently developing an LCC model, and based on comments from DB AG it is observed that

- The DB AG approach includes a data base for providing detailed data to the model. The REMAIN approach suggests a flexible method for data collection, applying a questionnaire that allows data to be provided at various levels of detail (i.e. adapting data collection to the resources available and to the requested accuracy of results).
- The REMAIN LCC model is simpler than the DB AG model, e.g. as
  - The discount factor can vary in the DB model, but is constant throughout the lifetime in the REMAIN model.
  - In the DB model maintenance plan might vary during the life cycle, and all yearly costs during operation might change from one year to another. In the REMAIN model yearly costs (maintenance, operation etc) are constant.
  - The REMAIN model is also somewhat simpler in its focus on *comparison* between two options. The main objective is rather to provide reasonable estimates of *cost difference* (for use as decision support), and is not aiming at obtaining very accurate total cost estimates.
  - The REMAIN approach focuses on *annual* LCC, and is also able to handle the possibility that the number of years in operation (*m*) might differ for the two options.
- Contrary to the DB AG model, the LCC model of REMAIN includes *Hazard costs*. The inclusion of hazard costs is somewhat untraditional. However, for a fair comparison of two options it is judged essential to have the safety in mind (also as costs are concerned).

The practical use/experience with LCC analysis for railway companies is rather sparse. However the Swedish State Railway has reported their experience with LCC in the acquisition of the high speed train X2000. They incorporated LCC analyses also in the contractual work, and follow up to verify reliability and availability. Main points of this experience are referred to in [RLCC] (The analysis of hazard costs cannot replace the safety analysis of the preceding chapter. Hazard costs cover some gross aspects of safety only. To take into account e.g. the risk of maintenance personnel, a dedicated method like the change analysis method has to be utilised).

4.6.2.2 APPLICATION OF THE LCC MODEL

The LCC model is applied to turnout data for an existing *high speed line* (these turnouts are denoted the reference system, *REFSYS*). Further, cost *differences* by the introduction of R2000 are estimated, resulting in predicted LCC for the same set of turnouts *with* condition monitoring equipment (denoted *CONSYS*). The main data are summarised in Table 4-9.

Cost element		Annual cost		
Code	Description	REFSYS	ΔSYS	CONSYS
AIC	Annual Investment Cost	8 000	+ 1 500	9 500
AMC	Annual Maintenance and Operating Cost	8 700	- 3 000	5 700
ADC	Annual Delay Cost	200	0	200
AHC	Annual Hazard Cost	100	0	100
LCC_{ANNUAL}	**Annual Life Cycle Cost**	**17 000**	**- 1 500**	**15 500**

TABLE 4-9: Annual Life Cycle Cost (ECU)

The cost data in Table 4-9 are based on the following inputs

m = number of years in operation for turnout = 30 (both for REFSYS and CONSYS)

k = annual rate of return = 4.5%

In addition, annual LCC is also calculated for CONSYS, assuming that the lifetime is extended to m = 40 years. In total this gives the following annual life cycle costs:

REFSYS (m= 30 years):

LCC_{ANNUAL} = 8 000 + 8 700 + 200 + 100 = **17 000 ECU**

CONSYS (m = 30 years):

LCC_{ANNUAL} = 9 500 + 5 700 + 200 + 100 = **15 500 ECU**

CONSYS (m = 40 years):

LCC_{ANNUAL} = 8 400 + 5 700 + 200 + 100 = **14 400 ECU**

This is also summarised in Figure 4-14. By comparing this with the general presentation of LCC in Figure 4-13, there is below *one* column giving the present costs, *two* alternative columns giving the annual LCC when condition monitoring is included, and *no* column giving the further reduction when an RCM analysis is carried out. The reduction in maintenance costs in this case makes it cost effective to invest in condition monitoring equipment. This true also when the lifetime, m, is not increased by introducing condition monitoring, but the reduction in annual LCC is of course larger if m increases to 40 years. Observe that according to the data presented here the annual delay and hazard costs (*ADC* and *AHC*) do not significantly affect the comparison, cf. also next section.

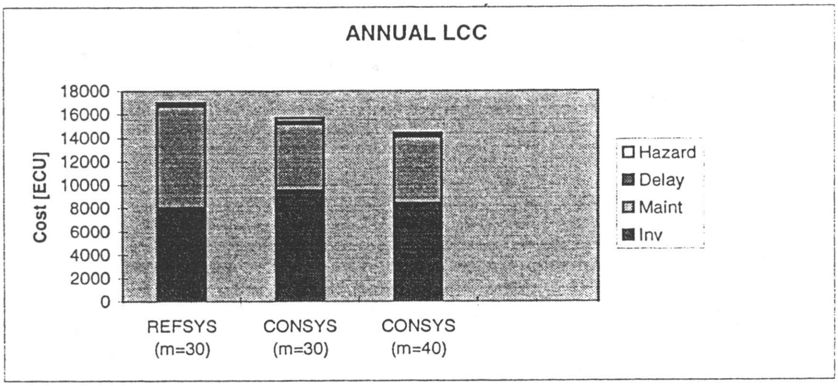

FIGURE 4-14: Annual LCC for reference system (turnout without R2000) and for turnout with R2000 (high speed line)

4.6.3 OPTIMISATION THROUGH STRATEGIC MAINTENANCE PLANNING

The main objectives of strategic maintenance planning are to identify relevant maintenance actions, evaluate the cost benefit of preventive maintenance (PM) actions, and to ensure that the PM actions are implemented as intended.

For the purpose of Reliability Centred Maintenance (RCM) a method for Strategic Maintenance Planning (RESMAP) has been developed in REMAIN. The decision logic of RCM represents a corner stone of this method (cf. section 4.6.3.3 below). Also note that the new method explicitly utilises Life Cycle Cost (LCC) analysis, which is not common in traditional RCM analyses.

The RESMAP method comprises the following main steps:

1. Study preparation
2. System selection and definition
3. Extended FMECA analysis
4. Preliminary LCC analysis
5. Systematic RCM decision logic
6. Determination of Maintenance Intervals and CON limits
7. Collecting maintenance tasks into maintenance packages
8. Updated LCC analysis
9. Implementation

Each step of the RESMAP method is described in [RSMP]. There some of the steps are further exemplified with data from the test line Dortmund-Hamm, where condition monitoring techniques have been implemented by the Roadmaster 2000 system. Note that this is a conventional line, giving LCC values that differs significantly from those of the high speed line, used as an example in section 4.6.3. Some "highlights" of the RESMAP method are presented below.

4.6.3.1 FAILURE CAUSE ANALYSIS

In order to identify relevant preventive maintenance actions it is crucial to have a good understanding of failure causes and mechanisms. Failure causes and mechanisms are revealed in a Failure Mode, Effect and Criticality Analysis (FMECA). To support this task we have defined four categories of failure progression as shown in Figure 4-15

1. The component is subject to gradual degradation, which might be observed (by suitable equipment).
2. The component is subject to gradual degradation, which can *not* be observed.
3. The component is subject to a rather "sudden" degradation, which can be observed by suitable equipment.
4. The component is subject to a sudden degradation ("shock"), immediately leading to a failure.

This classification serves as a tool for communication between the analyst and the PM experts, and has proven to be very helpful in order to arrive at a common understanding between the analyst ("theoretician") and the expert ("practitioner"). It is particularly useful when reliability parameters are assessed, as these parameters have different interpretations for the four categories of failure progression illustrated in Figure 4-15.

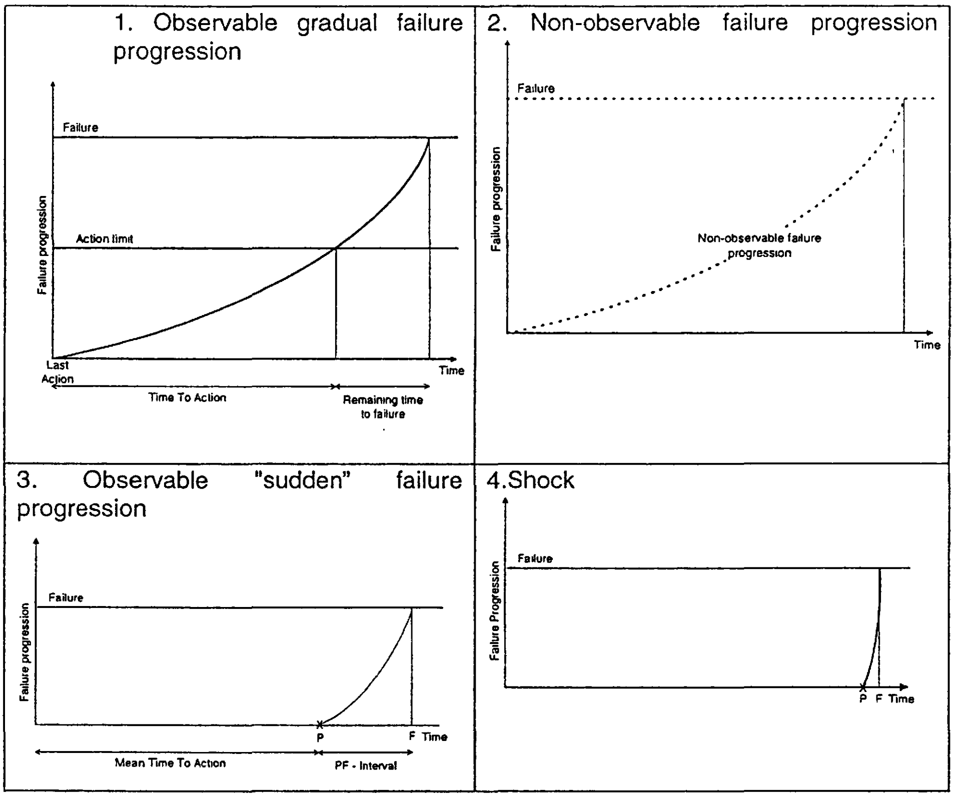

FIGURE 4-15: Types of failure progression

4.6.3.2 EXTENDED FMECA ANALYSIS

Failure modes, effects and criticality analysis (FMECA) is a widely used technique in most reliability and maintenance analyses. The strength of the technique is the systematic work to identify the failure modes, and the causes and effects of these. Each component of the system is analysed, and its failure modes are identified. In the current analysis we have extended the traditional FMECA, as there is also made an attempt to assess to what extent a specific Roadmaster 2000 sensor will reduce the failure rate of affected components ([RSMP]). This information is used to make a preliminary assessment of the cost efficiency of each sensor.

4.6.3.3 RELIABILITY CENTRED MAINTENANCE

The RCM methodology provides systematic considerations of system functions and the way functions can fail. It identifies applicable and effective PM tasks, based on considerations on safety and cost. The RCM decision logic (see Figure 4-16) is an essential element of the RCM analysis. This decision logic is also adopted in the RESMAP methodology.

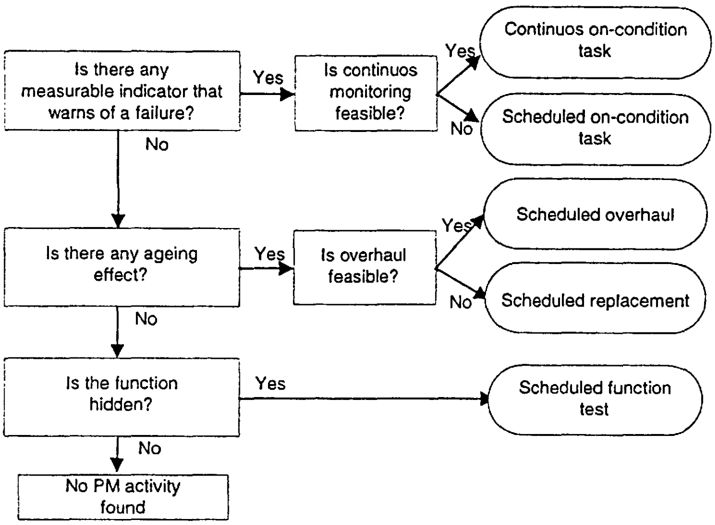

FIGURE 4-16: RCM decision logic

The decision logic is used to guide the analyst through a question–and–answer process, to arrive at the most appropriate *type* of maintenance for the component. The input to this RCM decision logic are the dominant failure modes, as obtained from the FMECA analysis of the component.

4.6.3.4 THE LENGTH OF INTERVALS BETWEEN PM

When the *type* of maintenance for a particular failure mode is determined by the RCM-decision logic, the next step is to determine the amount of maintenance to carry out. In [RSMP] some mathematical models for cost optimisation are presented, and examples from the demonstrator line are worked out.

4.6.3.5 RESULTS OF EXAMPLE ANALYSES

In general the RESMAP analyses show that the current maintenance program is rather well "tuned". The analyses recommend changing some inspection intervals, giving rather marginal reductions in cost. The analyses also show that some of the sensors in the Roadmaster 2000 system seem superfluous, i.e. they do not prove to be cost efficient.

In Figure 4-17 we have summarised the annual contribution to the LCC for various options with respect to inclusion of Roadmaster 2000 sensors. These data are obtained for a conventional line. In this figure the "Present" bar represents the annual LCC prior to installation of Roadmaster 2000. This is the "baseline" system, representing the period prior to the introduction of Roadmaster 2000 (in 1997).

The "R2000" bars represent the cost when Roadmaster 2000 is installed *as today*. The "Opt. R2000" bars represents an optimised version of Roadmaster 2000, where some of the sensors are omitted from the installation in order to minimise annual LCC. For each of these two options there have been performed two different LCC calculations (representing a sensitivity analysis). The calculation labelled "Disf" is based on assumptions (about service lifes etc) that are in disfavour of Roadmaster 2000, whereas the calculations labelled "Favour" are based on assumptions being more favourable for Roadmaster 2000.

So in the illustration of Figure 4-17 there are four columns that refer to the introduction of condition monitoring, and *one* column that illustrates the cost prior to introduction of R2000. Thus, the possible further reduction in LCC by using RCM analysis is not illustrated here (cf. [RSMP]).

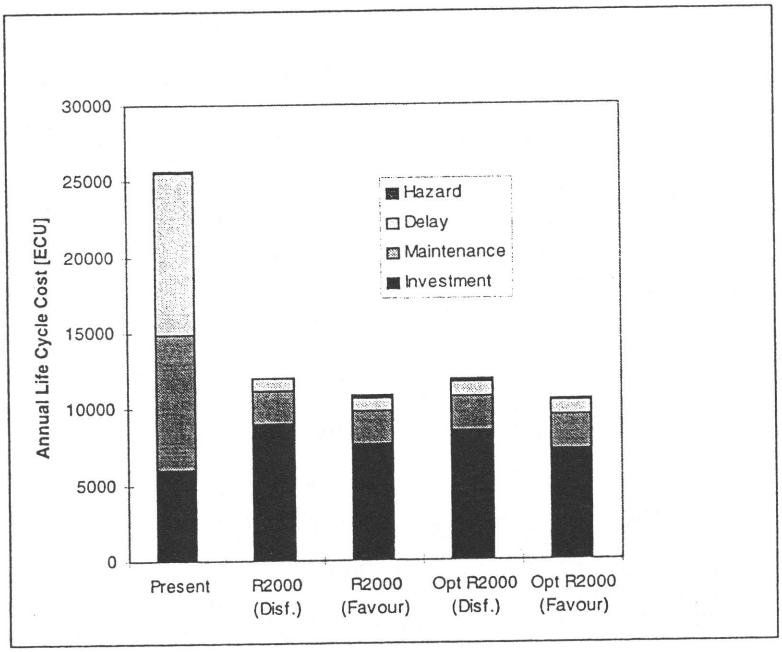

FIGURE 4-17: Summary of LCC results (conventional line)

List of Acronyms:

AIC	Annual Investment Cost (i.e. split on total life cycle)
ADC	Annual Delay costs
AHC	Annual Hazard Costs
AMC	Annual Maintenance and Operating Cost
CON	Condition Monitoring
DB AG	Deutsche Bahn AG
DEL	Delay Cost (over life cycle)
FMECA	Failure Modes, Effects and Criticality Analysis
HAZ	Hazard Cost (over life cycle)
INV	Investment cost of the system or equipment/product
k	Annual rate of return (*interest rate* minus *rate of inflation*)

LCC	Life Cycle Cost
m	The number of years in operation
PM	Preventive Maintenance
RAMS	Reliability, Availability, Maintainability and Safety
RCAM	Remain Change Analysis Method
RCM	Reliability Centred Maintenance
REMAIN	Modular System for Reliability and Maintainability Management in European Rail Transport
RESMAP	Remain method for Strategic Maintenance Planning
R2000	Roadmaster 2000

4.6.4 SUMMARY

In this section the building blocks of the REMAIN methodology have been explained. They mainly consist of three parts:

1) Safety analyses for a planned system

2) Economic evaluation of the system using the LCC model

3) Its optimisation through strategic maintenance planning

1) The *safety analysis* is based on the analysis on the effects on the safety of the new system, that demands changes in maintenance. Normally maintenance consists of several tasks and for each task an evaluation is performed with respect to the following changes

- change in the frequency of the task
- change in the duration of the task
- change in the time of the day the task is performed
- change in the probability of introducing maintenance induced errors

The effects of changes are classified into the three classes

- increased safety
- reduced safety
- unchanged safety.

By summation over all effects an overall estimation of the change in safety for the new system is derived. [RSFA] explains the procedure in more detail and gives several other approaches to safety analyses.

2) The developed LCC model for railway applications uses costs in the four categories

- investment
- maintenance and operation
- delay and
- hazard.

The somewhat untraditional inclusion of hazard costs is judged essential for a fair comparison of two options. The LCC model of REMAIN focuses on annual cost and therefore it can handle the situation that the number of years in operation for two options to be analysed is different.

Exemplary applications to data from a turnout installed in a high speed line without and with condition monitoring (Roadmaster 2000) gave annual LCC cost of 17.000 ECU without and 14.400 ECU with monitoring (assuming a lifetime of 40 years). Again, more information can be found in [RLCC].

3) For the purpose of Reliability Centred Maintenance (RCM), a method for strategic maintenance planning, called RESMAP, has been developed. It comprises 9 consecutive steps, which are outlined in [RSMP] with illustrating examples from demonstrator test line Dortmund - Hamm.

The most important steps in RESMAP are

- Failure cause analysis
- Extended FMECA analysis
- Application of the RCM decision logic for the selection of appropriate maintenance types
- Determination of necessary maintenance intervals
- LCC Analysis

The results for the demonstrator, which is a conventional line, show that the current maintenance programme (due to extensive experience) is rather well and only marginal changes can be recommended. But possible changes through the introduction of condition monitoring with Roadmaster 2000 result for the analysed conventional line type in a reduction of LCC costs by a factor of 2.

4.7 PROPOSAL OF A MODULAR SYSTEM ARCHITECTURE

The constituent building blocks of the REMAIN methodology have been described in the previous section. Here the architecture of a software system will be developed, that supports the co-operation and interaction between those modules and thus facilitates and promotes the introduction and implementation of the REMAIN methodology in railway organisations.

The functional blocks addressed

- data acquisition, storage, and retrieval,
- monitoring of components,
- state prediction for components,
- communication of data and information,
- safety analyses,
- economic evaluation and optimisation,

shall be integrated into a comprehensive software system for reliability and maintainability management. As organisational structures vary in European railway companies, a modular, distributable and configurable architecture shall be designed.

Figure 4-18 shows a basic outline of the functional components and their connection.

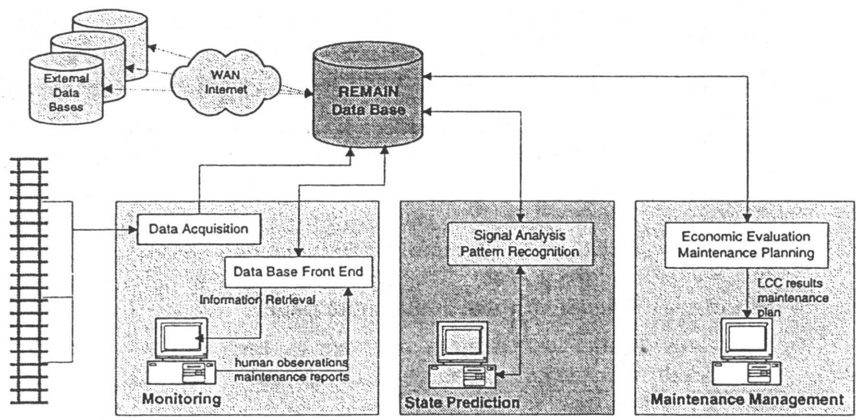

FIGURE 4-18: Functional components of the modular REMAIN system

4.7.1 ARCHITECTURAL FRAMEWORK

As starting point, a basic framework of the system architecture was elaborated.

The essential functional components have been identified, the expected needs for interaction have been described and basic solutions how to build up a system were developed:

The system must meet general requirements as

- *Openness*: Railway companies today already use a variety of software tools in different areas concerning maintenance. The system architecture therefore must support the integration of tools actually in use.
- *Extensibility*: The system shall allow to integrate hardware components as well as new software modules to guarantee future usability.
- *Adaptability and configurability*: European railway companies differ in many ways: size, equipment, organisational structures. Companies may want to use particular parts of the functions offered.
- *Modularity*: Only a system that is composed of neatly structured modules will be able to fulfil the above requirements.

The main functional system components were identified as follows:

Field data acquisition: To allow condition monitoring, the appropriate data describing the state of components must be available. Field data can be collected by human operators, or by sensors.

Component analysis: This module deals with the evaluation and interpretation of data referring to individual components of the equipment. To fulfil this task, a multitude of tools and methods is used, including signal analysis, pattern recognition, dependability prediction, etc.

System level analyses: On system level not only individual components are considered, but the enclosing system as a whole. Methods used concern cost analyses, as LCC analyses, maintenance planning, and safety analyses.

To implement this functionality, supporting functional modules are required:

Communication system: The integration of the system modules requires data exchange between particular components. Thus, the need for an appropriate communication infrastructure is obvious.

Databases: Databases are necessary to store the data produced and processed within the system. Databases can be used locally for storing proprietary or temporary data on the one hand, and shared by multiple users on the other hand. A central database may be physically distributed among different locations.

These components constitute a basic system model with the functional modules grouped around a central database. Local databases with the system modules may be included to keep local information.

4.7.2 SYSTEM DISTRIBUTION AND TOOL INTEGRATION

According to the organisational structures of railway companies, system modules may be distributed over different locations. Building such a distributed system can be significantly facilitated by an integration platform. The integration platform provides mechanisms to establish communication between the system modules, independent of underlying hardware platforms and operating systems

The implementation of the modules will involve many (software) tools, e.g. various numerical algorithms used for signal analysis and pattern recognition. Tools may either be available on the market or they have been previously developed by or for railways. Often those tools have been developed to run on particular platforms. In general, it is not an easy task to integrate such tools into a software system. Integration platforms therefore should support the integration of legacy software.

Integration platforms, widely known as middleware, which are available today, have been investigated. The Common Object Request Broker Architecture (CORBA) revealed to be the most promising system for implementation of distributed interactive systems as well as for the integration of legacy applications.

The main reasons for this judgement are: CORBA is an international standard; CORBA offers a wide range of features supporting development, integration, and execution of distributed applications; CORBA system implementations are available for nearly all hardware platforms and operating systems; CORBA supports the definition of interfaces through the interface definition language (IDL) and thus offers a systematic approach towards the integration of legacy software.

Integration of available evaluation tools, as signal analysis and pattern recognition algorithms, is necessary to implement efficient condition monitoring procedures at reasonable cost. Close interaction of distributed functions is required monitoring the equipment to assure prompt reaction on detected failures. The CORBA architecture provides suitable methods to achieve both tasks. A trial implementation performed in the project has confirmed the feasibility of this approach.

4.7.3 INTEGRATION OF THE REMAIN MODULES

In the architectural framework, the main functional components were identified and possible interactions were outlined. With further progress of the project, it became clear, that substantial interconnection between the functional modules is built on the data and information they operate on.

On monitoring level, raw field data are collected from sensors. These data may provide information relevant for maintenance that can be derived directly (e. g. by comparison to a threshold). However, often a broad basis of raw data, collected over a reasonable amount of time, is needed to derive relevant information on the status of a component. The status information then, collected over the lifetime of an equipment component, serves as a basis for reliability analyses and - together with information on executed maintenance actions - for cost calculations and long term maintenance planning.

Cost calculations, however, do not only rely on information provided by or derived from data generated within condition monitoring and maintenance procedures. They also need information from other sources, as investment costs, interest rates, man-hour costs or purchase costs and storage expenses of spare parts. These data in general are available in a railway organisation, but often are scattered over various organisational units and stored in different computer systems.

Thus the procurement of relevant information is crucial for the management of maintainability and reliability. Efficient methods to find and to access the information therefore are prerequisites for a successful implementation of the REMAIN methodology.

In the following, the architecture of an information system is proposed that forms a part of the reliability and maintainability management system. The information system will

- connect the functional modules providing a common view on the data basis

- assist to access information produced outside the RAMS domain
- provide mechanisms to expand the information base beyond the boundaries of a single organisation

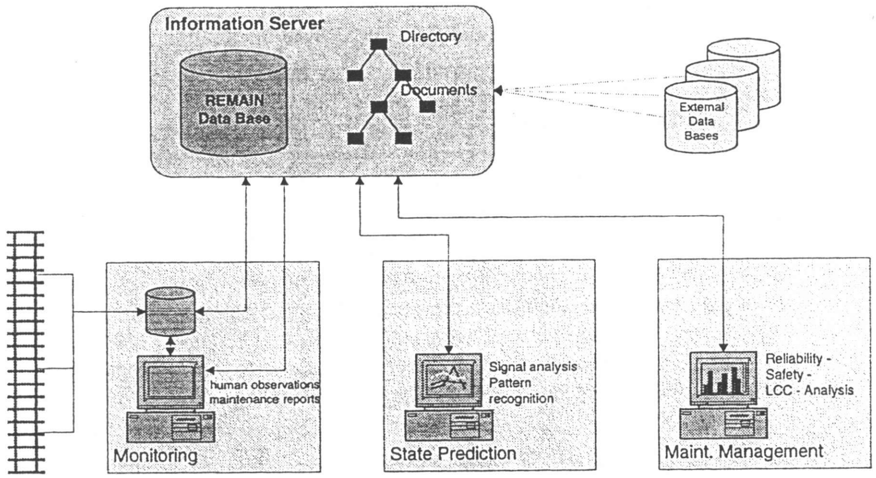

FIGURE 4-19: REMAIN INFORMATION SYSTEM

4.7.3.1 INFORMATION SYSTEM

4.7.3.1.1 Application Cases

The following examples demonstrate how the information system can be used to support tasks of reliability and maintainability management.

Component State Analyses

Signal analysis and pattern recognition methods may raise the need to store a great amount of data, raw sensor data as well as intermediate results. In normal operation, these data are not used for high - level evaluations, so that it is not efficient to store those data in a central database. But detailed analysis of raw data may be necessary in case of unexpected failures and development of enhanced or additional algorithms to cover new requirements is only possible with original data, typically raw sensor data.

The information system will allow storing raw data and intermediate results in separate databases close to the data acquisition and the basic evaluation. These local databases then will be linked to the information system, and the data may be accessed when required.

Thus the information system will support the enhancement of CON methods and, more general, allow development of procedures and tools based on real life data without interfering with daily operation. Moreover, it will enable provision of results for test and verification.

Global Database

A global common railway database will give each railway company access to (anonymous) data from other railway companies. The main objectives for such a database are:

- to extend the experience base,
- to compare reliability of various models
- to give feedback to equipment vendors.

In spite of the advantages of a global database, it must be expected that technical, organisational or legal obstacles as well as matters of competition will prevent the establishment of such a database in the next future.

The information system can be used to implement a practical step into this direction. The concept includes the possibility to provide information in such a manner that the data stay under control of the owner. The provider of the information shall be able to decide, which of the participants in the information system are entitled to access the information.

This concept will help to overcome reservations that are expected to exist with possible information providers against a real global database.

Access to the REMAIN Database

In general, to extract information from a database system, a user needs knowledge not only on the content, but also on the internal structure and organisation of the database. Integrating the database into the information system would provide to the user a unique interface. Frequently used queries and evaluation programs are stored in the information base and executed upon request.

Direct access to the REMAIN data base of course shall not be prevented and will be necessary to allow for more sophisticated evaluation.

Co-operation of Expert Groups

Various tasks of maintenance management may raise a need for co-operation. Ad-hoc groups may be useful to solve actual problems. The REMAIN methodology incorporates a systematic approach how to perform expert judgements in cases where sufficient statistical data to base a decision on are not available.

In general, costs arising in connection with co-operation of (expert) groups can be reduced if adequate means are available to support the process. In particular, the experts should be relieved from the necessity to perform their tasks at he same location and at the same time.

The information system provides such means. For example, to perform remote expert judgement sessions, the analyst would provide the questionnaire in the information system. The experts then, independent of each other, fill in the questionnaire and insert the answers in the appropriate subdivision of the information base, where the analyst can read and evaluate the answers.

By means of access control, the mode of co-operation can be controlled. If strictly independent answers are required, only the analyst will be allowed to see the answers. On the other hand, group members may be entitled to read and annotate the contributions of their colleagues, if a common voting of the group is desired.

4.7.3.1.2 System Requirements

Flexibility and Adaptability: The information system is based on an open concept, widely independent of special applications. Considering organisational structures of European railway companies, it is necessary that the information System can be accessed from numerous geographically distributed places. Adaptation to changes in geographical distribution as well as to restructuring of the organisation must be feasible with limited effort.

Modularity and Scalability: The various fields of application for information systems in reliability and maintainability management require different degrees of functionality. Each organisation may decide to implement specific functions individually or in any combination. Thus the system must be scaleable, not only with respect to size (number of users, amount of data to be handled) but also with respect to varying demands of functionality.

Management of Information

The system will have to handle very different kinds of information: raw sensor data, intermediate results of evaluation algorithms, inspection and failure reports as well as the results of condition monitoring and state prediction; descriptions of equipment and many other types of information used in the field of reliability management. The variety of information types can not be foreseen when the system is implemented, therefore the information management must be conceptually independent of particular information types.

In addition to information handled in the information system, a possibility is required to integrate heterogeneous and distributed data collections, which exist with the users. The integration shall be achieved without alteration of these 'local' data; the data management and the responsibility shall stay with the owner and shall not depend on the information system. This principle will be used to make available data from autonomous subsystems, that implement their own data management, as e.g. the Roadmaster 2000 monitoring system.

Each participant shall have the possibility to decide how he handles his data and which part of them he will make visible to which other participant. The autonomy of local data collections is a prerequisite for information providers outside the organisation to participate in the system and to provide useful information.

The variety of information types, local data collections and inclusion of external information sources raises the need for a description of the information that must be handled by the system in addition to the information itself. The description in general consists of a set of attributes, denoted as *metadata* (as opposed to data, which are constituent parts of the information).

Keywords are used to further describe the information content. Keywords are descriptive attributes that are assigned to the information by the originator.

Information Provision and Retrieval

The information system must support adequate mechanisms to enable a user to find desired information and to provide information to the system and its participants.

Two different approaches to retrieve information shall be considered. One will support an experienced user, which is acquainted to the system and has certain knowledge about the wanted information. Then a dedicated search can be performed, based on attributes associated with the information (e.g. originator, date) or based on keywords.

If the user is less experienced or has only rough knowledge about the information he is looking for, a structured approach will be more suitable. The user then will be guided through a structured register; thus moving from a global view on the information to increasingly detailed selections.

The latter approach requires an underlying structure of the information base. A hierarchical structure, comparable to the structure of a book or catalogue, or the directory structure in a file system, seems to be most adequate to support this procedure.

Consequently, when a user provides information to the system, he has to select the appropriate place in the catalogue structure. Provision of information may involve creation or change of sub-trees in the structure.

Access Control

The system will have to handle information intended to serve a variety of purposes. Certain information may be targeted to the public (all users), other to the employees in a department or to specialists within a technical domain. Access control shall assure that information in the system is visible only to the targeted users.

4.7.3.1.3 Realisation Approach

The requirements can be met best if the system is built from standardised components.

Considering this and taking into account the requirements in functionality and the technologies available today, the most promising approach is to base the information system on technologies used in Internet and World Wide Web.

Utilising Internet technology does not necessarily mean to use the Internet itself for communication and data transfer. Corporate networks also can rely on Internet communication protocols and provide the respective services within an enterprise.

Building an application on Web technologies in general offers a number of advantages: The basic technology has proven its reliability since decades of world-wide use. Standardised interfaces allow to add functionality. Web clients as well as web servers are available for the great majority of hardware platforms and operating systems. Client software, if required for special applications, can be kept and maintained at the server and downloaded to the client. Web browsers are commercially available at considerably low licence fees. In many cases today they are already installed in corporate networks, so no additional investments are necessary to install end user systems. Internet/intranet technologies are rapidly developing, users can benefit from new developments without considerable risks.

Web technologies offer a number of useful features to build information systems:

- The hypertext concept creates a basic mechanism to link information.
- HTML is a standardised language to describe documents that can be interpreted and viewed by browsers, independent of operating systems and hardware platforms.
- Standardised mechanisms are available to extend the functionality. In particular this is valid concerning access to databases.

Enhancements of the web functionality are necessary to arrive at an information system that combines the web principles with structured access to information and possibilities for a dedicated search. The catalogue structure, that changes dynamically during the lifetime of the system, must be maintained. Functions that support provision and retrieval of information are required. The combination of hyperlinks, structured arrangement of information and possibilities for dedicated searches are illustrated in Figure 4-20 below.

When implementing the additional functions, strict adherence to standard interfaces and extension methods is required. Otherwise, the resulting system no longer will be portable; further extensions and adaptation to advancements of the underlying technologies will become significantly more difficult.

Following the rapid development of the Web technology in the last few years, nowadays sufficient interfaces and programming methods are available.

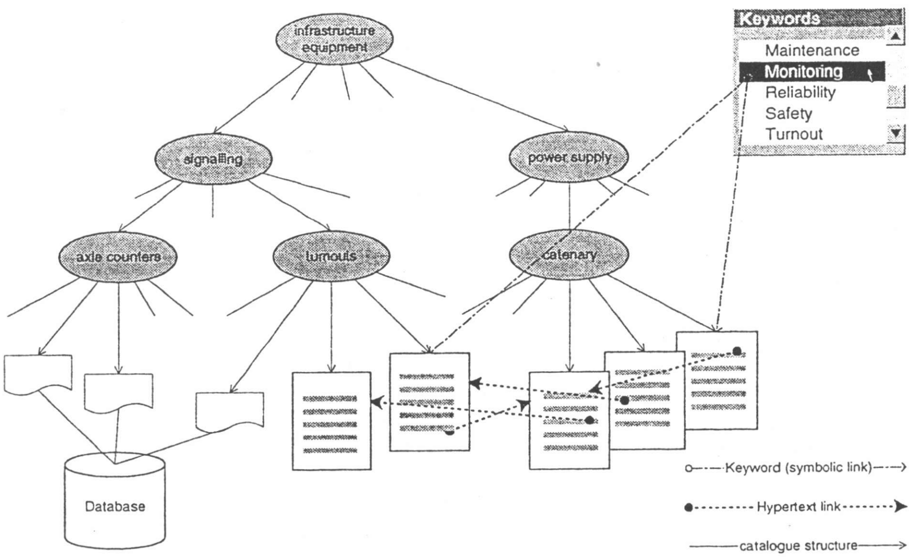

FIGURE 4-20 Structuring of information and access methods

4.7.3.2 SYSTEM ARCHITECTURE AND REALISATION CONCEPT

4.7.3.2.1 Functional Description

The information system is based on a client - server architecture.

Clients are the computer systems of the users, which they use to interact with the information system, i.e. to search for and to retrieve information and to feed information into the information system. The client communicates with the server, it sends a request. The server, receiving the request, performs the necessary actions and sends the results back to the client (responds to the request). The client then presents the results to the user.

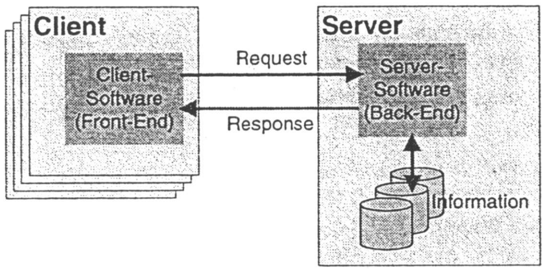

FIGURE 4-21: Client/Server Structure

There are two basic manners how a human user interacts with an information system:

- search and retrieve information
- provide information, i.e. add a leaf or a sub-tree to the catalogue (cf. Figure 4-20).

Automated devices contribute to the information content altering 'local' data collections.

Information handled in the system is characterised by a set of attributes, the metadata. These are stored in addition to the 'real' information. To each piece of information metadata are correlated. The metadata essentially represent a label associated with the real information and contain the data required to manage the information properly. The metadata only are interpreted by the information system software. Metadata are stored in a database at the server and handled by the server software.

In contrast to this, real informations are not interpreted by the system software. They are stored as a whole and communicated to and from a client upon request. Processing of the real information is left to external applications available at the client system (i.e. textprocessors, image viewers, or specific application programs as signal analysis algorithms or LCC calculation tools).

The functionality to be provided essentially is derived from the requirements (4.7.3.1.2).

The basic functions of the system therefore are

- to support a user to find the desired information
- to support a user to provide information
- user administration
- access control
- management of information
- system administration

The information system manages the data in a structured manner to support quick and direct access. Two approaches for information access will be available:

- Navigation through the information collection, following the paths defined by the tree - shaped structure
- dedicated searches on attributes and keywords.

The information system incorporates a central information catalogue, implemented by means of a (relational) database system. There the metadata are stored following the directory structure and linked to the real information.

The client software includes a user interface providing the necessary function to perform both ways of information access.

Information can be stored within the information system (under control of the server) or can be provided giving access to 'local' data collections that remain under control of the provider/owner.

In both cases, the adequate metadata have to be communicated to the server. The information provider's user interface therefore includes functions to assign attribute values, to send the set of attributes to the server, and to upload the information itself.

The users and their respective access rights are administered centrally. Potential users wishing to join the system are required to register. Then an account will be established and access rights are assigned according to the user's intended role. The system than will guarantee that each user may access and provide information according to the rights awarded.

In general, users may upload data to the information system. The server must provide the functionality to store and to handle these data, including the association with the respective metadata. The server's functionality basically does not include any functions that require interpreting the data, but corresponding functions can be added trough standardised interfaces.

4.7.3.2.2 System Components

The core system providing the general functionality of the information system essentially consists of

- Client application software (front-end)
- Server software (back-end)
- metadatabase
- access control
- external applications

Figure 4-22 below shows a model of the system illustrating the interaction of the components.

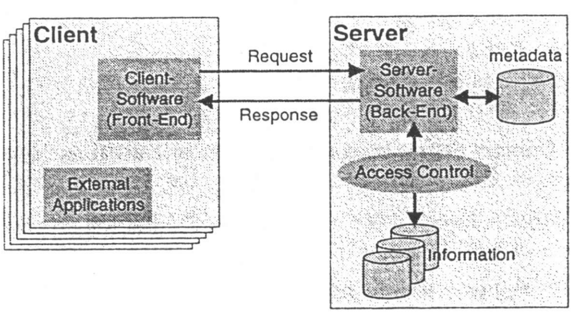

FIGURE 4-22: Components of the information system

A more detailed description of the components of the system architecture and a discussion of the technologies available for the implementation is included in [RSYA].

4.7.4 SUMMARY

The proposed architecture for a reliability and maintainability management system combines the major functional components

- data acquisition, storage, and retrieval,
- monitoring of components,
- state prediction for components,
- communication of data and information,
- safety and reliability analyses,
- economic evaluation and optimisation.

The system is based on standardised components allowing the use of existing tools previously developed for particular platforms and also allowing the distribution of modules over different locations.

Platforms facilitating the integration of existing tools of legacy software and the implementation and management of distributed systems have been assessed. The Common Object Broker Architecture (CORBA) is deemed to be the most promising platform: CORBA is an internationally recognised standard, implementations are available for nearly all hardware platforms and operating systems, and through its interface definition language offers a systematic approach for the integration of legacy applications.

Interconnection between the functional blocks is widely built on the data and information they operate on. The procurement of relevant information is crucial for the management of maintainability and reliability. The proposed system therefore comprises an information system.

Application scenarios illustrate how various tasks in the field of reliability and maintainability management benefit from an information system. Requirements the information system has to meet are derived from these application cases.

The information system allows arranging information in a structured manner. Searches may be based on this structure (the information catalogue), or on description of the information content that are kept in an integrated database system (metadata, keywords).

The system is built from standardised components. The basic technical approach is to utilise techniques that have proven their usefulness and reliability in Internet and World Wide Web. Standardised interfaces and platform independent programming tools are available to implement the functionality that is required in addition to the mechanisms already included in the Web technology. This approach promises reliability, extensibility, portability, and cost effectiveness of the information system and enables the users to benefit from a rapidly developing technology.

The system functionality includes that of a conventional Web server. The Web functionality is enhanced in that

- the catalogue structure enables a user to navigate through the information collection, following the defined hierarchy,

- sets of attributes that describe the information enable dedicated searches based on well-defined criteria,
- adaptable and configurable access control mechanisms, based on the concept of user *roles* , enable highly differentiated user rights

The procurement of relevant information is crucial for the management of maintainability and reliability. An information system that is based on the architecture developed will facilitate and promote the introduction and implementation of the REMAIN methodology in railway organisations.

5 CONCLUSIONS

5.1 CONCLUSIONS

The execution of this project the duration of which was limited to 15 months has shown that it is feasible to produce considerable results in such a short period. This was mainly due to the expertise of the partners in RAMS areas in other industries that could be transferred with necessary adaptations to the needs of railway companies. Unfortunately the project is finished now after the partners have worked into the specific area.

The REMAIN project, originally intended by the Commission as a mere research study on all imaginable aspects of RAMS management, took a lot of profit out of the following favourable circumstances:

- Revision of the original workplan in co-operation with CEC
- Concentration on RAMS aspects for infrastructure
- Incorporation of a demonstrator provided by DB AG with relevant infrastructure components
- Exemplary application of the theoretical methods to parts of the demonstrator

Without the demonstrator it is judged that a lot of work would not have been able to be concentrated on the key issues and the result would have been only theoretical and less convincing.

REMAIN has focussed on condition monitoring and RAMS management for turnouts. It has proven that in spite of very high installation costs for the Roadmaster 2000 monitoring system, the life cycle costs can be reduced by a factor of 2, depending on the specific cost contributions. From two workshops held by REMAIN the conclusion is justified, that promising new condition monitoring approaches can be made available also for interlockings, level crossings and the track.

5.2 RECOMMENDATIONS

The REMAIN project has provided a suitable set of tools for the technical selection of condition monitoring equipment and for decision support in the financial evaluation of new equipment and the planning/organisation of the maintenance.

Tools used for *condition monitoring* are rather component specific. Monitoring methods used for turnouts can normally not be transferred to other components. It is recommended, that the railway companies should extend this work to other components that contribute significantly to delay time and maintenance costs. The selection can be based on statistical data of contributions to delay and failures as they were compiled in the requirements analysis of REMAIN. For selected components sensors must be applied and specific signal analysis and pattern recognition methods have to be developed. To share in this work and to avoid parallel developments an agreement should be met among companies on which one concentrates on which component and corresponding CON-method. Later these methods can be exchanged and be used on different computer platforms. The REMAIN *system architecture* has devised means to integrate the tools and methods, so the implementation of the REMAIN system would remarkably facilitate this process.

All methods rely on data for which a *database structure* was defined. It is in accordance with ISO/DIS 14224 and as recommendation for the database it is stated that similar standardisation work should be started by railways, that would allow data exchange among European nations. These standardisation must comprise local and global database aspects. As a medium to access the global database also the Internet can be taken into account.

The methods for *decision support* and *strategic planning* provided by REMAIN are general and not component specific. They comprise:

- RESMAP, a method for strategic planning of Maintenance (to arrive at a correct type of maintenance and to choose correct PM intervals)
- An LCC model for comparing the annual LCC of various options (e. g. considering different types/amounts of PM or the possible use of condition monitoring equipment)
- RCAM, a change analysis method for comparing the safety of various options and to identify possible problems with respect to safety.

For the further elaboration of the decision and planning tools also in a combined effort among companies the following recommendations can be given:

- Developing computerised tools for performing LCC analyses, maintenance planning (RESMAP) and safety analyses (RCAM). The tools should e.g. perform numerical calculations, provide graphs for result presentation, and perform sensitivity analysis (e.g. as indicated in present report)
- An important issue is the reduction of maintenance costs by co-ordination of various maintenance activities. That is, instead of performing separate checks of infrastructure components by each maintenance department, one should try to carry out common inspections. Also, repair work should be performed by mixed teams, consisting of specialists from different sections. These questions are not addressed in the REMAIN project.
- Specific models for the failure progression of various equipment should be developed. This should result in a standard set of condition monitoring indicators and models.
- The LCC model could be extended to cover the more general concept of *Life Cycle Profit*. By this approach we will also model the *income* of the railway company, which seems particularly relevant for the owner of the railway infrastructure, renting the line to various traffic companies.
- In this context, the requirements on increased competitiveness/cost efficiency also make it very relevant to introduce higher level analyses, often referred to as *vulnerability* analyses. The increased complexity implied by serving different traffic companies, might easily result in a higher vulnerability (i.e. specific single events may have more dramatic effects than immediately foreseen). This could for instance be related to contract formulations and hazardous events (e.g. if an accident of one traffic company causes delays also of other companies). The ability to perform maintenance can also be affected.

A *system architecture* could be proposed, that allows to integrate existing software tools in the areas of data acquisition and retrieval, condition monitoring and state prediction, and in maintenance management and planning. The incorporated information system significantly contributes to the connection of the modules addressed, facilitating the provision of and the access to information, which is crucial for efficient execution of decision support and strategic planning methods. Thus the proposed system is a prerequisite for cost effective introduction of condition monitoring procedures and implementation of advanced planning techniques.

Consequently, it is recommended to implement the system in a relevant section of a railway organisation. As the system to a great extend can be build from standard components, there are no serious doubts about the feasibility. The modular structure will allow to proceed step by step, starting with the kernel functions of the information system and gradually extending the functionality and the range of use.

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