E-MOI
EUROPEAN MONITORING INITIATIVE

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Abstract

Our built environment is aging effecting structures as well as equipment and high-tech vehicles. **Health monitoring** is the measurement of the operating and loading environment in relation to the critical responses of a structure, a vehicle or a plant. It tracks and evaluates the symptoms of operational anomalies, incidents, and/or deterioration or damage indicators that may effect operation, service ability or safety reliability. Integrated health monitoring means to use this information for the assessment and management of structures or objects of the built environment. The twofold transition towards **knowledge based society** and sustainable development demands new paradigms of production and consumption. E-MOI shall help to move from resource based approaches towards more knowledge based ones, from quantity to quality (i.e. from sensors producing gigabytes of data to smart sensing solutions that automatically provide knowledge about the structural health) and from mass produced single use products to new concepts of higher added value. Ending in eco-efficient and sustainable products, processes and services (i.e. longer service lifetime of structures, plants and equipment by improved monitoring and management concepts).

Needs: Integrated health monitoring and **management systems are required** by owners of buildings to manage their facilities, public authorities to maintain the safety and operation of their structures, owners of plants to ensure service ability, HVAC engineers to check and maintain their millions of rotating machines, builders and operators of vehicles to permanently check and assess their structural integrity, users of innovative materials to demonstrate their abilities and durability, the energy sector to ensure sustainable power supply, the traffic managers to avoid breakdowns, the aircraft builders to increase safety and security the environment to make the new phenomena understandable and last but not least society which needs integrated knowledge based systems which will transform into a knowledge based society.

Breakthroughs: The link from singular to integrated systems shall be made by an **electronic decision support system** (DECIS, an intelligent integrated tool for plants, structures, equipment, vehicles and almost any other form of the built environment), based on neural computing technologies. The payoff in integrated operational and structural health monitoring is therefore significant. In this context, health monitoring is analogues to human health management, serving as the backbone of an integrated asset management program at the systems levels from civil infrastructures to automotive and aeronautic bodies as well as complex plants like an offshore wind energy park. Health monitoring and risk

assessment of structures and equipment has gained importance considerably world wide. In our vision ten years from now the world should look different in this field.

Partnership: The project shall consist of a **Consortium** which comprises of 5 lead partners (VCE, LMS, BRE, JRC, KUL) and 27 core partners, from all over Europe and strong participation of Candidate Countries. For the work the best party shall be looked for by means of **competitive calls**. Typical project management tools will be used as applied in major engineering projects. A professional management, supported by appropriate tools, will be established for that purpose. The core group has long standing cooperation experience and are the European leaders in health monitoring. Professional project management is exercised by the coordinator in his commercial activities since long time. A concept of a consortial agreement for proper project steering is proposed.

INTRODUCTION

Breakthrough/radical innovations expected

Our vision in health monitoring and asset management is:

- § The synthesis of different methodologies from different countries and engineering areas
- § Synergy effects and efficiency progress of health monitoring in plant control
- § Improved safety assessment and lifetime prediction by decision support systems
- § Increasing of EU competitive capacity in plant engineering
- § Increase of safety availability and economy of European engineering structures

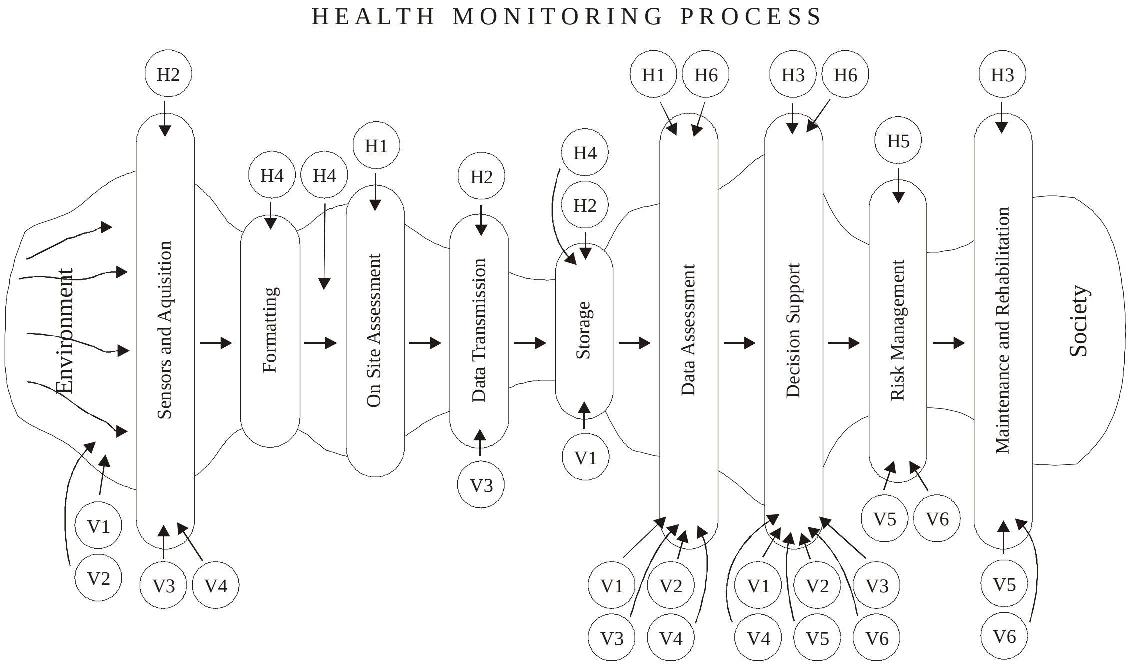

Fig. 1: Management and assessment process of the built environment

Structural health monitoring is to become **standard industrial technology** within the next 10 years. It is expected to be widely applied in the aeronautics, mechanical, civil and other sectors. Future structures will be integrated systems, equipped with embedded sensors, computers, software, as well as actuators for control and adaptation. These systems will be capable of continuously gathering behavioural and environmental data, analysing them, determine the current condition and status (intelligent diagnostics), their life expectancy (residual life prediction), and their required maintenance actions and periods. Their behaviour will be optimised and controlled and the structures will be capable of continuously adapting to new situations and conditions (reconfiguration). These structures will thus be economical to be maintained, very reliable and extremely save.

Our vision is a **substantial improvement of diagnostic methodologies**, tools and assessment processes. Large increase of quality and quantity of recorded and accumulated data require more effective organisation of databases, easier access and sorted information. Lifetime and actual stage identification will be carried out through extensive macro and local micro investigation and verification performed by a neural network.

Our major vision might be that **intelligent integrated health monitoring systems**, sometimes in combination with active control systems will be installed everywhere on every structure and complex system. A lot of damage detection techniques will cope with the characteristics of material behaviour and operating conditions. Complex neural networks will provide real time analysis of health conditions and will offer comprehensive decision support to the owners. The circle of maintenance, safety, risk, performance and related costs are the major drivers in the subject. The joint competence of engineers cooperating in different areas will lead to new ideas and concepts utilising the existing know how and jointly developing prospective solutions.

A typical vision of the owner of a freeway is the development implementation and application of a fully tested health monitoring system of **automated damage detection**, reliability and safety assessment of bridge structures. It shall be incorporated as a valuable component in existing bridge management systems to support decision making regarding cost effective strategies for system maintenance, inspection, repair and safety.

Structure of E-MOI

The points of contact between **vertical activities** and **horizontal approach** shall be determined by the management. The internal architecture of the project is demonstrated in the figure below. 6 vertical main objectives, encompassing the value chain from knowledge production and technology development to their transfer are implemented comparable to traditional R & D projects. They include all principal stake holders like end users, authorities and practicing engineers to make sure that the expected impact is achieved. They are supported by 6 horizontal initiatives covering the multidisciplinary nature of the project avoiding parallel development and providing the necessary scientific and technological components. The vertical and horizontal activities shall be integrated generating first of all a common approach strong enough to become a **world standard**. To support this integration training, demonstration, protection and dissemination of knowledge as well as take up activities are designed. They are expressed in a demonstration shell covering all activities and for distinct support tools.

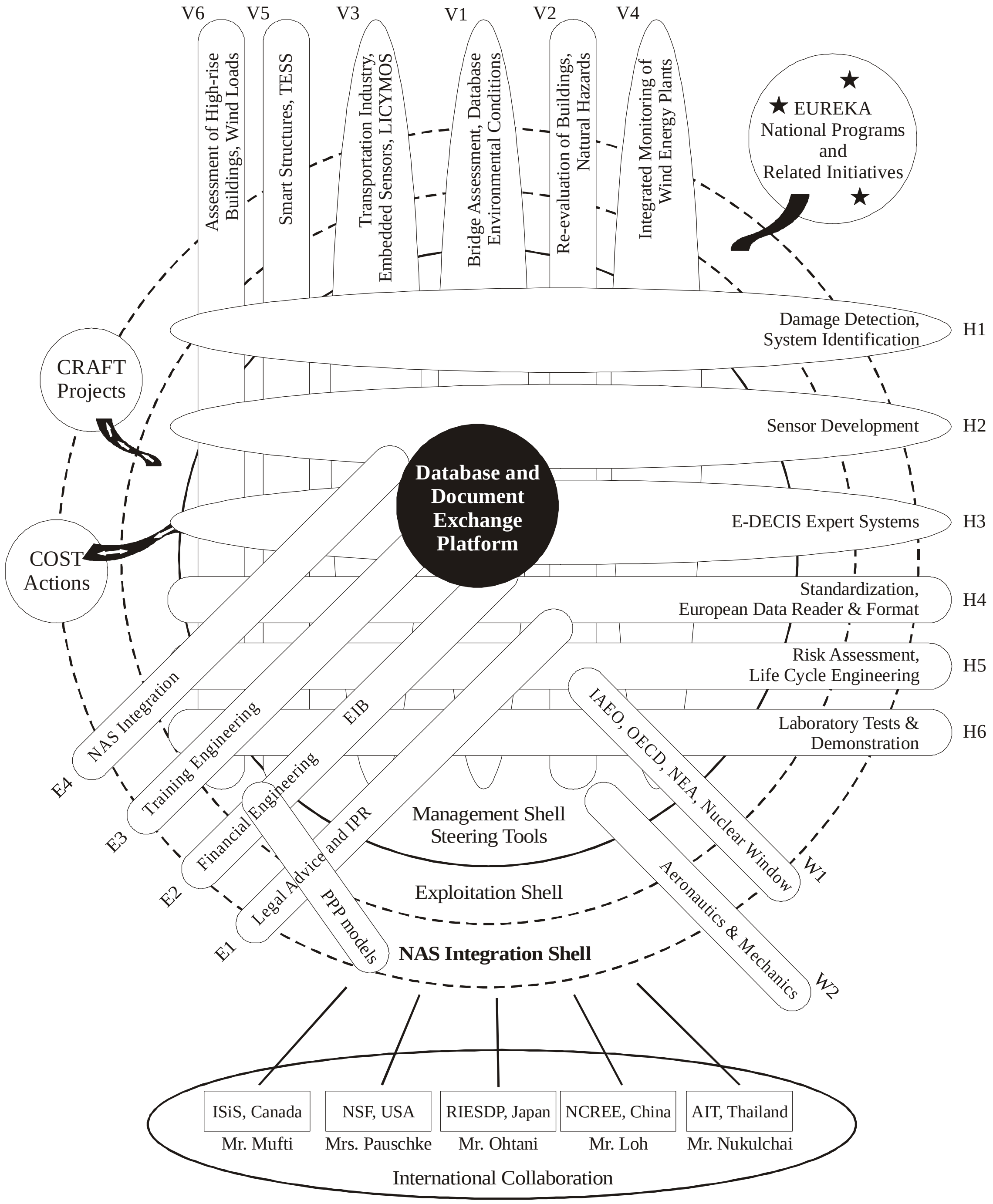

Fig. 2: Structure of the Project

POTENTIAL IMPACT

Economic impact

The estimated total **value of the built environment** that could be effected by the methodology has been estimated to **be € 300,000 billion** (current value). Another estimate is that annually 1.5% of this sum is invested in maintenance and rehabilitation, which amounts to € 4500 billion annually.

The problem is further characterised by the fact that due to the change from new investment into maintenance costs either more money or better assessment methods are necessary to keep the safety level at the current standard. Recent catastrophes (refer to the space shuttle Columbia and the tanker Prestige disaster) show us that the time has come where the age of a built investment becomes the critical factor for the assessment.

For example: The German Federal Ministry for regional policy, civil engineering and urban development as well as market analysis estimate annual costs of **10 billion €** resulting from building deficiency in Germany only. Although extensive codes and standards as well as related laws exist, several new structures are faced with design and construction defects. In addition there is an enormous amount of failures which are not cost-effective, yet resulting from the last years and decades. In particular concerning construction defects and problems advanced monitoring technologies could help to identify minor problems within a construction and thus preventing considerable costs which are required to improve serious damage or failure of a structure.

The optimisation of lifecycles of high reliability structures in industry will be managed and such increase the quality of the built environment. Due to the circumstance that the average age of structures and bridges in particular is increasing, rapid and accurate assessment is of growing importance. The peak period for assessment in Europe will be between 2005 and 2015. Then the number of structures to be assessed will be more than tripled compared to present values. Different studies show figures for the maintenance costs between **1.5% and 4%** of the value of the structure. The bridge maintenance budget evolution in Europe is estimated at:

1996: 1,844 million €/year
2005: 2,000 million €/year
2015: 3,320 million €/year
2030: 2,000 million €/year

Thus, the costs for assessment are estimated at about 150 million €/year. It is estimated that **only 15% of the maintenance costs are really justified**, the rest covering the risks of not knowing the real health status. To improve these figures it is essential to make the assessment process more effective and more efficient. Advanced monitoring technologies are a key factor for this improvement. The **economic implications** of deploying monitoring systems to improve the maintenance process are:

§ **Reducing the costs of inspection**. It is expected that the use of (continuous) monitoring systems can reduce these costs by 20% to 50% for each structure.
§ **Keep the infrastructure maintenance budget stable** at around 2,000 million €/year after 2005. This would lead to huge annual savings (500 million €/year). Early detection of damage, the possibility of adopting an optimum repair strategy and avoiding detailed tests of safe bridges.
§ **Keeping the infrastructure in operation**. In all developed countries, infrastructure is the backbone for economic activities. Keeping this infrastructure in operation is a major priority. The quality of infrastructure is a competitive element of a region.

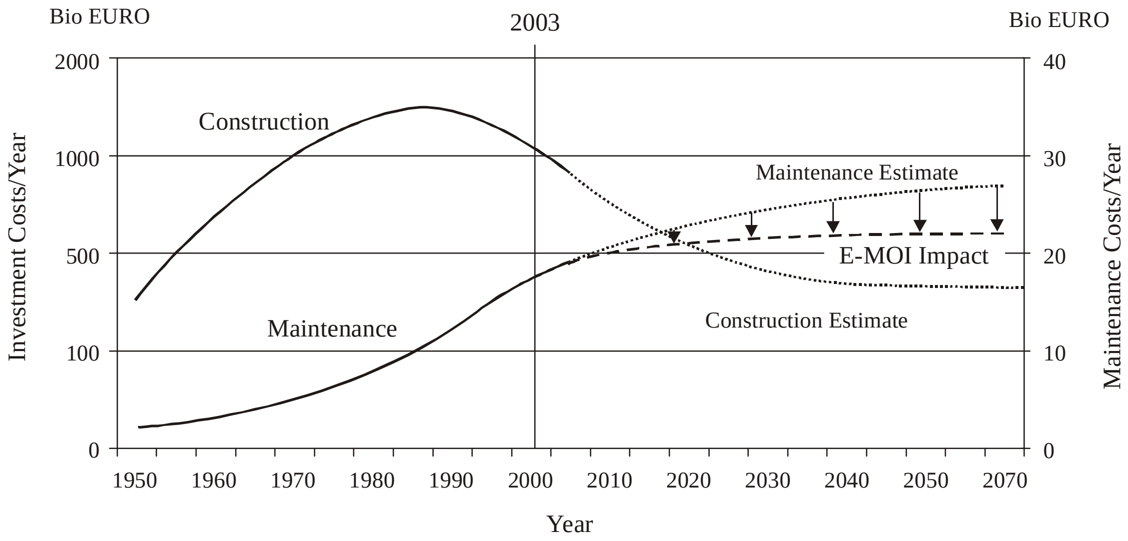

Fig. 3: Economic Impact of E-MOI on the Built Asset (Example: Construction Sector)

SCIENTIFIC AND TECHNOLOGICAL IMPLEMENTATION PLAN

S&T objectives

Several **issues** have been identified in order to implement meaningful and beneficial applications of **integrated health monitoring** and **management** (for graphic display refer to fig. 3):

- Issues related to **reliable, robust and economic sensors**
- Issues related to the **treatment of data** from acquisition till final storage management
- Issues related to **damage detection** and system identification technologies
- Issues related to neural networks, expert systems and **decision support systems** for application of the built asset management
- Issues related to **standardization**, data formats, data transmission and treatment tools
- Issues related to **risk assessment** and lifecycle engineering
- Issues related to **laboratory tests and demonstrations** carried out to prove technologies

These **horizontal integrating** activities shall be supporting **vertical research** and development activities, selected for their significance or current practice in the field:

- Issues related to **bridge assessment**, environmental conditions and all kinds of database aspects including the acquisition of Europe wide data
- Issues related to the **reevaluation of buildings** particularly focused on seismic issues and other natural hazards
- Issues related to the **transportation industries** covering cars, trains, ships or any other moving stock
- Issues related to the challenge of huge **offshore wind energy platforms**
- Issues related to **smart structures** covering all aspects of safety as well as environmentally friendly economy
- Issues related to **high rise buildings** from the not yet standardized wind loads to the assessment of aging facades and considering eventual terrorist impacts

These 6 horizontal integration activities and 6 vertical object oriented tasks shall lead to integrated approaches related to the following issues:

- § Issues related to the **nuclear industry** from **seismic re-evaluation** till save operation and maintenance aspects
- § Issues related to **aeronautics and mechanics** where these technologies partly derive from
- § Issues related to the **integration** of the candidate countries (CC)
- § Issues related to **knowledge transfer, training** and exchange of researchers
- § Issues related to **financial engineering**, company spin offs and investments
- § Issues related to legal questions and **IPR** subjects
- § Issues related to new forms of infrastructure models such as public private partnerships (PPP)
- § Issues related to the international collaboration to take advantage of the international practice
- § Issues related to the integration of **national projects**, EUREKA programs, CRAFT or COST initiatives into the integrated works

The **decision support system (DECIS)** shall be designed in a modular way allowing the implementation of any new development or new found methodologies. The database behind shall be structured in a way to allow at the same time the storage and transfer of basic knowledge as well as case studies.

State-of-the-art

Civil engineers have applied heuristic forms of health monitoring through visual inspection. So have mechanical and aeronautic engineers developed simple diagnosis systems based on the monitoring of singular phenomena such as the vibration characteristic. Further notable is the importance of information technologies in this fast growing field of operational monitoring. However, integrating the operational and structural health monitoring with decision support systems has been attempted only in narrow sectors. A wide and covering approach is desired. The issue is therefore to transform the current practice into a more integrating, rational and effective one. This new asset management approach will start with the accumulation of objective, accurate, and sufficiently comprehensive data to serve as a basis for reliable evaluation and forecasts by neural decision support systems. The ultimate goal that promises the maximum payoff and justifies the investment required for successful health monitoring and system integration research and development is the implementation of a generally applicable integrated asset management approach.

Knowledge based multifunctional materials are used in special cases in aeronautics nowadays and first research programs are made in the mechanical industry. The new materials and the related sensors / actuators are not known in the civil and plant engineering as well as nuclear industries. It would be a breakthrough to transfer existing knowledge between the industries and develop adapted systems for special purposes. A common support by an expert system or neural network is thinkable.

The **current trend** is that computers take over increasingly complex tasks which have to be controlled by decisions made based on monitored data. A key question is the treatment of eventually false and from time to time contradictive data, based on which decisions of most importance shall be made. These facts draw the attention of otherwise competing technologies such as telecommunication, fuzzy logic development and infrastructure management. Already Galileo Galilei said 400 years ago “We have to monitor what ever can be monitored and we have to develop monitoring wherever we are not able to do it.”

Radical innovation(s)

It seams clear that in 10 years powerful and very cheep **computers** will be **embedded** into almost every device. Therefore any concept of a single sensor will become obsolete. There will be only devices able to perform complex tasks, whether alone or cooperating with other devices. The challenge is to built huge distributed systems able to deal with the complexity and uncertainty existing and with sufficient adaptive and learning capabilities. The major vision therefore is in this decision support process promoted by this proposal.

Health monitoring systems will be equipped with homepage **nano server**, which can be accessed by the authorised users to browse the measured and stored data. Such solutions will be platform independent. Databases with operation history for critical structures will be available for users supported by a **decision support system** based on neural network solutions. The vision for health monitoring is that after 2010 thousands of structures are equipped with **smart sensors**, which communicate on a standard format with a database able to manage a million sensors at a time. An expert system based on neural network practice will care for the huge amount of data to enable selection, classification and decision making support. This fully **internet based system** will be operated remotely and support all registered users depending on their level of authorisation.

Our vision for 2010 would be a decision support system developed from an expert system and neural network basis to a tool near to **artificial intelligence**. This visionary objective means a tool that is able to recognize incoming signals, sort them accordingly and enable analysis for any kind of the built environment. The basic tool shall become a European standard used in all kind of industries.

Our major vision in **health monitoring** is:

- § The synthesis of different methodologies from different countries and engineering areas
- § Synergy effects and efficiency progress of health monitoring in plant control
- § Improved safety assessment and lifetime prediction by decision support systems
- § Increasing of EU competitive capacity in plant engineering
- § Increase of safety availability and economy of European engineering structures

Our vision is to develop inexpensive and precise enough technologies for **global structural monitoring** and **fault assessment**. The development of in-service monitoring devices that employ appropriate and precise monitoring methods for most structures like airplanes, nuclear containers, engines, plants, vehicles, etc. is a very important strategic direction.

Health monitoring should be foreseen already at the design stage and shall be **embedded** during construction. **Smart instrumentation** and expert systems for structural assessment that require minimal human intervention are desired. This technology shall be employed crossover all industries. Structures will be considered as intelligent or smart, able to make a **self-diagnosis** and reporting autonomously on its structural health. We will have better and more sensitive methods for the evaluation of the measured raw data and interpretation which enables the operator to make safe decision on further maintenance and operation. The under laying neural network will take care of methods to automatically detect sensor defaults, system failures or environmental exceptions. Better understanding of damage mechanisms and their effects on the behaviour will be understood by the expert systems. Within the next 8 years structural health monitoring should be able to demonstrate and convince operators and manufacturers of structures that the new methods are ready for application and that they can increase reliability of the structures and reduce maintenance costs by early detection of damage. The danger of heavy accidents due to overseen damage in structures should be widely reduced.

We expect that structural health monitoring is to become **standard industrial technology** within the next 10 years. It is expected to be widely applied in the aeronautics, mechanical, civil and other sectors. Future structures will be integrated systems, equipped with embedded sensors, computers, software, as well as actuators for control and adaptation. These systems will be capable of continuously gathering behavioural and environmental data, analysing them, determine the current condition and status (intelligent diagnostics), their life expectancy (residual life prediction), and their required maintenance actions and periods. Their behaviour will be optimised and controlled and the structures will be capable of continuously adapting to new situations and conditions (reconfiguration). These structures will thus be economical to be maintained, very reliable and extremely save.

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Another major vision relates to intelligent integrated health monitoring systems, sometimes in combination with **active control systems** will be installed everywhere on every structure and complex system. A lot of damage detection techniques will cope with the characteristics of material behaviour and operating conditions. Complex neural networks will provide real time analysis of health conditions and will offer comprehensive decision support to the owners. The circle of maintenance, safety, risk, performance and related costs are the major drivers in the subject. The joint competence of engineers cooperating in different areas will lead to new ideas and concepts utilising the existing know how and jointly developing prospective solutions.

New technologies require many years to become accepted by the general public. The innovative character of the proposed IP is that the basis for such an acceptance shall be provided. At present the parties involved in technology development (such as IASC, on the academic level) organise their meetings and conferences completely independently from those who should apply the technologies (such as IABSE, on the end users level). The overwhelming response to the offer of participation to such an IP from both scientific and the practical side shows that there is a large gap to be bridged. To make sure that it is the End Users requirement that counts, the IP is organised by a private SME.

DESCRIPTION OF THE CONSORTIUM

The project shall consist of a **Consortium** which comprises of **5 lead partners** (VCE, LMS, BRE, JRC, KUL) and **27 core partners** established at the beginning of the project. All steering functions for the vertical programs are with the leaders. For the work the best party shall be looked for by means of competitive calls. This allows a flexible management and a very effective work. Furthermore forces can be concentrated on specific items and no conflict of interest will arise. A key to success will be that the project is given enough freedom to select the necessary research topics, resources and players. Typical project management tools will be used as applied in major commercial projects. A professional management structure will be established for that purpose.
The Consortium has been selected based on the principle to have all effected groups represented and to

achieve a critical mass for success. The consortium is structured into several levels:

- The core group, those 5 partners leading the project
- The core partners, 27 important participants responsible for single activities
- The project participants, about 40 important entities allocated to the several work tasks
- Objective oriented partners, about 60 partners with specific limited objectives within the project
- The academic pool, a source of excellence, ready to bid for the work defined and called for tender
- Observers, an unlimited number with special access rights to the results
- International cooperation partners connected by a Memorandum of Understanding (MoU)

Fig. 4: Geographic spread of Partners

International Collaboration shall be established to coordinate activities with the United States, Japan and China. Looking at recent US activities it is expected that there will be a major competition with an US initiative in near future. Anyhow the current European advantage should be kept. Another objective here is to disseminate the results outside of Europe to open the way to business. The introduction of a virtual institute with other major laboratories or partners involved could be discussed. This concerns particularly the wish of Prof. Ohtani from Japan and Prof. Loh from Taiwan. A connection to the US NSF activities in this field is wanted by both sides. The level of these internationalization activities shall be decided later. There is a clear benefit for the Project through this cooperation because it opens doors and helps to disseminate results in the right place and at reasonable costs.

Fig. 5: Geographic spread of global cooperation

PROJECT MANAGEMENT

To manage such a complex undertaking it needs a combination of management experience and a drive for innovation. Strict management rules will be necessary nevertheless allowing the necessary freedom of research.

Organisational, management and governance structure

The proposed management structure represents the classical vertical hierarchy with a strong project manager, who is supported by an experienced team.

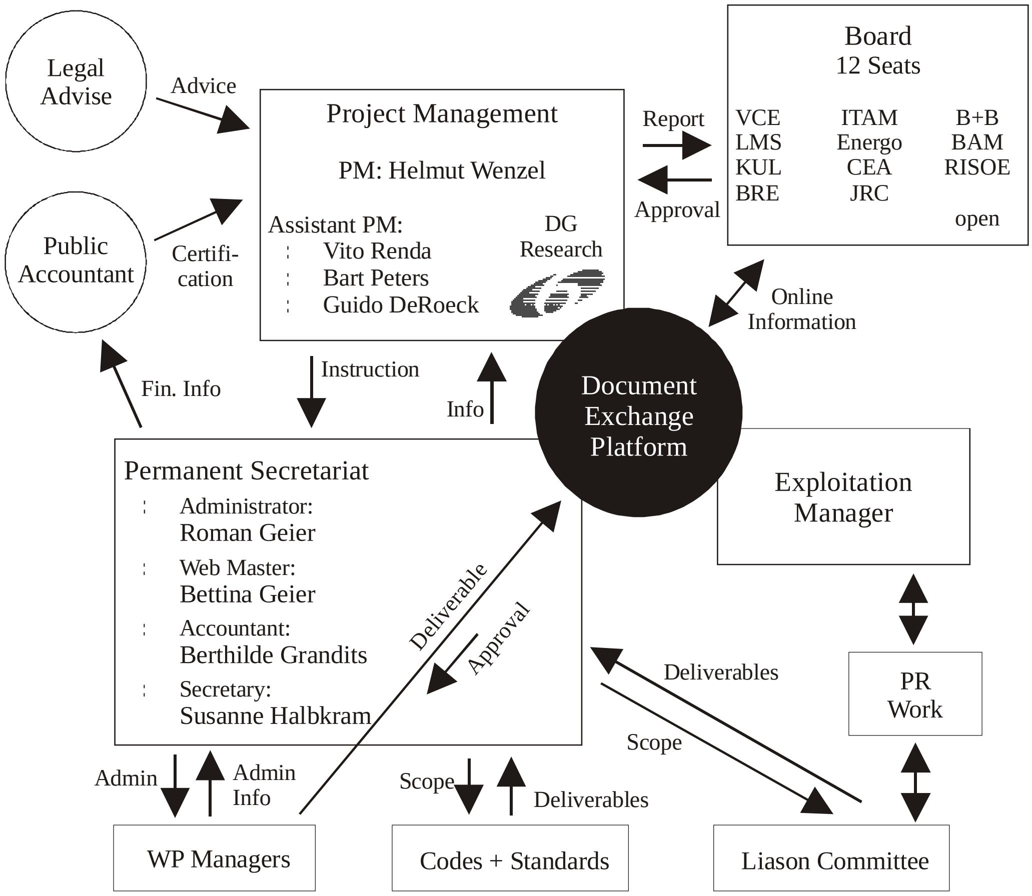

Fig. 6: Structure of the E-MOI management