Final Report for Publication

CRMA

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Project Co-ordinator: **European Rail Research Institute**

Partners: **European Rail Research Institute**
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Siemens Transportation Systems
Technicatome

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1 EXECUTIVE SUMMARY

The project contributes to Task 29 of the European Commission Research, Technology and Demonstration programme in the field of Transport and has a time span of 12 months.

CRMA is a vehicles based project that is seeking to provide a common basis of understanding on which life cycle costing techniques can be applied.

The experience gained with life cycle costing in the railway industry was reviewed as was the experience in other business sectors where the techniques are used to assist with strategic decision making, for instance aviation, defence and nuclear which also have strong safety requirements.

It was not the intention of CRMA to review the calculation methodology, but to concentrate on identifying all the costs that should be included, the boundaries of the cost elements and the links to other cost elements. Although this is a vehicle based project, discussions immediately highlighted the need for a system approach which included environmental costs, amongst others, to be considered. In practice it became clear that most companies have their own calculation methods and that the real problems relate to the consistency of the requirement specifications, the ambiguity of RAMS terminology and the quality of the historical data. For prestige national projects introduced since the theme of LCC was just applied data is not a problem since these trains are maintained in purpose built facilities with the data generally collected in a consistent and effective manner.

Finally the project examined the effect of different management, operation and strategic decisions on maintenance and interoperability. Since the project time span was limited to one year it was necessary to take a major system which is common to all vehicles e.g. braking system and determine the type of effects which might occur.

In order to obtain a common opinion from all parts of the railway industry it was intended that the work of the project would be accomplished through a series of expert groups and workshops that would be drawn from UIC members and UNIFE experts.

The CRMA project resulted from a merging of two projects that were presented to the 3rd Call for Proposals to the 4th Framework Programme for Transport Research programme. The original CRMA project was recommended for acceptance whilst MOST was not. However, the Most Project included some elements which the commission thought could be beneficially added to the CRMA programme.

The revised project had a significantly smaller number of partners, and shorter timeframe. Although the budget was increased a large proportion of the budget had to be directed to a single partner who was 100% funded. It was also agreed between the partners and the commission that the proposed work programme would be re-considered in the early months of the project to ensure that the Work Packages properly reflected industry needs.

The kick off meeting for the merged project was held in February 1998.

At about the same time a number of discussions took place with the UIC and other interested parties where it became clear that LCC considerations were much more complex. For example, decisions to reduce vehicle costs could adversely effect track maintenance costs and similarly decisions made on infrastructure could affect the rolling stock and the operation of the railway. It follows that cost optimisation of vehicles or infrastructure could result in sub-optimisation of the railway. Thus a total system approach is required if a cohesive result is to be achieved.

The discussions with partners and other interested groups have illustrated a need for harmonising definitions and methodology used for LCC calculations, using the same terminology, definitions and financial assessment criteria. There is no reason why this cannot be achieved based on current experience. On the other hand it appears that the way LCC is evaluated and used internally by individual companies varies considerably. Much of the harmonising work is actively being pursued within trade groups with UIC participation. ERRI has subsequently produced a LCC handbook on behalf of the UIC.

Different ownership structures and financial responsibilities within the railway administrations further complicate the issue. Together with a clear definition of LCC it would be beneficial to introduce a standard LCC method to give consistency in a similar way to that achieved by quality assurance programs, i.e. ISO 9000. If this is not done then the results will be confusing and misleading

A considerable amount of time has been spent in considering and discussing these new factors and trying to rationalise the requirements. This has introduced delays into the project planning.

A priority was to establish the basic information, which is required for successful and consistent application of the techniques. Critical amongst these items identified are the RAMS terminology and equipment requirement specification or “mission statement”, and quality of data.

Results from the Railway Industry show that there was limited application of LCC techniques. Generally the use of LCC techniques is to ensure that equipment meets the RAMS and cost performance requirements agreed by the contract.

In addition LCC procedures are used to develop the maintenance plan and procedures in order to minimise the total cost of the operation.

Variable interpretations of RAMS terminology can lead to confusing and variable results being obtained. This can lead to inappropriate conclusions when comparing offers

Work is in progress within several groups working groups, for instance UNIFE and VDB to resolve these difficulties

The actual methods of performing the calculations vary between companies but most have developed sophisticated models that are able to perform the calculations once the data is available.

Investigations into the activities of non-railway industry have revealed some interesting results and conclusions. A comparative analysis of the collected results indicates that the application of LCC procedures is a lengthy and costly process. Most thought that it provided worthwhile benefits.

Strong mutual links between supplier and user especially with regard to data exchange, the need for cultural change within the company, strong and skilful top management involvement and the measurement of progress were cited as key requirement for success.

The clear perception of a competitive threat and the onset of LCC implementation proved to be clearly linked. The implementation is clearly more mature and advanced in civilian aviation severe where competitive pressures were experienced very early than in the nuclear energy, weapon systems and helicopter industries where competition was of lower priority than other issues.

As a result of the work of WP1 the objectives of WP2 were revised to look more closely at the overall implications of LCC rather than the details of calculations. By that means it was hoped to demonstrate the benefits of a system approach to LCC and so expand the breadth of consideration.

In WP3 it was decided that freight vehicle braking system will be studied as the productivity and competitiveness of freight systems is currently a major issue for the railways. The braking system has implications on interoperability, safety, the environment (noise issues) and improvements in productivity.

2 OBJECTIVES OF THE PROJECT

This project contributes to Task 29 of the European Commission Research, Technology and Demonstration programme in the Field of Transport.

The objective of the research task is to develop a Life Cycle Cost (LCC) methodology where the information required to perform calculations, i.e. availability/reliability details, operational requirement specifications, cost contributors, are clearly identified in a manner which is accepted by all parts of the railway business. The methodology will be used to examine maintenance and suggest strategies for the management of maintenance which will assist with the introduction of harmonised rules for maintenance and reliability to ensure economic and safe maintenance of rolling stock outside their home network.

2.1 Identification of sector and global objectives

The development of efficient rail transit calls for the use of advanced methods to achieve a full understanding of the influence of the cost contributors to the LCC of the total operation. This project considers railway and mass transit transportation systems and has the following global objectives:

1. To extend the scope of current Life Cycle Costs procedures, to include all factors directly influenced by rolling stock. Amongst the factors to be included will be specification, design, production, reliability, maintenance, interaction with track, current collection and disposal.
2. To determine which information is critical to a top down approach to LCC prediction and to provide a definition of these items, which is acceptable to the railway industry.
3. To identify the major cost elements.
4. To propose strategies for maintenance and operation to suit different operations and vehicle types that contribute to the formulation of harmonised rules for efficient European operations.
5. To formulate proposals for further extension of LCC activities

3 MEANS USED TO ACHIEVE THE OBJECTIVES

The means used achieve the project objectives:

1. Workshops.
2. Interviews with external contributors.
3. Working groups of the project partners with external contribution.

4 SCIENTIFIC & TECHNICAL DESCRIPTION OF THE PROJECT

Introduction

CRMA has concentrated on trying to understand how LCC methodology is applied in railways and other safety conscious industries and so identifying the difficulties and pitfalls in applying the methodology. Then a particular system, the freight braking system, was examined to identify the decisions that are required to influence to cost structure and interoperability of the vehicles.

The Global Objectives for the project were identified Technical Annex of the project proposal and restated and restated in Section 2 of this report.

Three technical work packages were identified as the means to meet the global objectives. These are briefly described below with the objectives for each work package.

Work package 1 - State-of-the-art

Work package leader: Powell Duffryn

Life Cycle Cost models are currently used within the rail industry to mainly monitor contractual situations and predict maintenance costs. This work package seeks to consolidate the knowledge of LCC techniques as applied and to identify the benefits which they bring, the problems which are experienced and the deficiencies in current knowledge. We also seek to extend the knowledge of the strategic uses of the procedures by other industry sectors such as aviation, defence and nuclear businesses so that the breadth of experience can used to benefit the rail industry.

Objectives:

- to determine the current usage of LCC techniques within the rail industry and obtain a better understanding of the limitations and the difficulties of applying the techniques, including critical terminology, interpretation of requirement specifications etc.,
- to determine the strategic uses of LCC methodology in other business sectors such as aviation, defence and nuclear industries.
- to understand the benefits which might be obtained and the difficulties which have been experienced in other business sectors.
- to determine the suitability of the methods used in other sectors for use or development to railway applications.

Work package 2 - LCC Procedures

Work package leader: Siemens

To provide a “top down” methodology for rolling stock Life Cycle Cost investigations including clarification of the critical terminology and other information required for the techniques to be applied satisfactorily. Whilst this research is directed to rolling stock, links will be defined to the infrastructure and environmental issues.

To identify all of the cost areas influenced by or directly associated with rolling stock and to produce a framework with all the cost areas identified together with the elements which form the cost area. This will include links to infrastructure and environmental costs.

Objectives:

- to clarify critical terminology.
- to define the information required to perform a "top down" life cycle cost calculation.
- to define a life cycle cost framework.

Work Package 3 - Strategies for Interoperability

Work package leader: Technicatome.

This work package will develop alternative operating scenarios which will achieve the same business objectives. The scenarios developed will be examined qualitatively to determine the effects on the LCC. Some sensitivity analysis to determine the effect of variations to the mission and considerations such as the failure to complete a mission, lateness etc. will be considered. The results will be used to develop management, operating and maintenance strategies for interoperability. The process will also be used to identify the data which will need to be stored.

Technicatome were selected as the task leader for the exercise because of their wide experience in industries other than the railways. This provided the opportunity to obtain an view of railways not constrained by extensive experience of the railways.

Objectives:

- To provide a strategy, organisation and management policy for international interoperability which includes:
    - A complete pattern of actions to service or maintain equipment in order for it to perform its intended function at maximum benefit to the operator.
    - A definition of the required data type and how it should be collected, stored and retrieved bearing in mind the commercial implications of data sharing.
    - An investigation on a concrete example (braking system).

The methodology adopted, the findings are discussed and the results and conclusions presented in parts 4.1,4.2 and 4.3 of this section of the report. The global conclusions are presented in Section 6.

4.1 Work Package 1

Within Work Package 1 two tasks were identified:

- Task 1.1 to review the use of Life Cycle Cost (LCC) techniques in the railways.
- Task 2.2 to review how LCC techniques are used in other safety conscious industries.

4.1.1 Task 1.1

This task had the objective of determining of the experience of the railways and specifically to determine:

- The benefits that have emerged

- The drawbacks that have been discovered
- The conditions for further successful development.

The project plan identified that a workshop would be organised to elicit the information required completing the task. and the information available within the project group led to a change of plan with ERRI leading

However, in early discussions within the project partnership it became apparent that in the preparation of the original CRMA project ERRI had undertaken extensive discussions with manufacturers and operators which had identified most of the information required to conclude this task.

The original partnership group with which ERRI had discussed and formulated the original proposal is listed in Annex 1 this report.

Many of the discussions held were quite intensive and revealing and ERRI would like to acknowledge the help given by this group.

It is generally recognised that LCC procedures were introduced to the railway sector as a result of greater commercial awareness.

This should not be taken to mean that all parties of the industry were not cost conscious previously. Cost has always been an important aspect for the industry but the means to measure cost effectiveness was missing. However, condition were changing and there was even greater need in the increasingly competitive transport market to ensure that first and maintenance costs were minimised. It was also necessary to demonstrate that equipment purchased was performing to the contract conditions, as the effects of failures, i.e. reliability/availability was a significant cost in the operation of a fleet of vehicles.

Hence, a formalised method was required which considered all of the factors affecting cost during the build and operation of the rolling stock and a method of establishing whether the equipment actually complied with the contract requirements against which the equipment was purchased. LCC procedures provided a means of doing this.

The historical separation between suppliers and railways had certain knowledge implications whilst suppliers had knowledge of the manufacturing process they had little knowledge of how equipment was actually operated and often less on the cost of maintaining the rolling stock.

Initially this created a difficulty, a lack of reliable data on which to forecast reliability/availability of the rolling stock and predict with any accuracy the maintenance trends. Data had been collected in the past but its recording was variable, the data collected could often be different depending on where it was collected and what was deemed to be important to the different workshops or organisations, and the analysis of the data was inconsistent. Thus reliable and consistent data recording and processing data was recognised very early in the introduction of LCC procedure as an important requirement.

From this position it was it was clear that with the data collected it was possible to monitor and forecast trends to determine whether maintenance/repairs procedures should be modified to improve reliability and/or reduce costs.

In practice this meant that the procedures previously used were more formalised, quantified more fully, and results used to adapt maintenance procedures. In effect build, maintenance and operation were considered as one process.

With the increasing commercialism of the railways, suppliers have to consider the design/build process in a different way. With specific requirements for reliability and maintenance cost, suppliers have to think about quantifying the difference between stating “best quality” and consider how to achieve “fitness for purpose” at a cost.

This requires a significant change in attitude to design and manufacture. As expressed

With reliability and maintenance figures to be quoted considerably more information about the design is required to be able to justify the figures asked for in the tender documents.

As a consequence most suppliers have developed comprehensive tools and the methodology of using them. Incurring significant costs in the process.

LCC procedures are widely recognised as being time consuming, costly and requiring changes in company culture to be successfully implemented.

Other difficulties experienced in the introduction of LCC largely relative to interpretation of terminology and the results of calculations. These problems effect both the start and the end of the process in that they affect one of the basic input parameters, reliability and the financial output and its method of analysis.

The specification of reliability data can be ambiguous with the user taking different meanings to the terminology and yet apparently producing answers that satisfy the requirements. A comparison of different company offers can be inconclusive and misleading. The problems are magnified when a second potential customer means something different with the same specification.

Development of unambiguous specifications for terminology is seen as a prerequisite for successful calculation. There have been and are several working groups attempting to remove these variations and to develop acceptable standards amongst these are CEN. However, experts still express the view that even within newly agreed CEN standards there are ambiguities.

The method of handling the financial output can also provide contradicting results.

For instance using a “Discounted Cash Flow” method, which relates to the time value of money will place a different emphasis on the first cost maintenance, residual value and disposal costs of equipment from one which uses a current cost methodology.

Again this can lead to confusion in the comparison of results and to different emphasises being placed on the cost phases for the equipment.

The calculation of LCC requires that data from suppliers of components, sub - assemble and major equipment items have to also supply cost and reliability data to prime contractors. As such there is a need for an interchange format for data.

It is also recognised that the application of LCC procedures allows greater understanding of option for controlling cost though it will not of itself reduce cost.

For cost to be reduced the specification of the equipment must be to the real requirements, its operation has to be to agreed specification and the maximum benefit account has to be taken of the effects of the system interfaces. For rolling stock these are track, signal and overhead category and supply in the case of electric traction.

Other aspects, which have to be considered, are:

- operational modes,

- the requirements for interoperability,
- the disposal of the asset,
- environmental implications in terms of Noise and Vibration and Pollution in operation and at the disposal point also need to be considered.

4.1.2 Conclusions for Task 1.1

The key points to emerge are:

- LCC experience approx. 20 years.
- LCC is an expensive and time-consuming process.
- LCC means changing company culture.
- LCC means changing preparation for quotation work to give more design and component information so that LCC can be calculated.
- Many LCC models are available generally tailored to particular activities.

The major difficulties to emerge:

- DATA – A lack of reliable information is generally seen as a problem. This is not true for specific projects (ICE, X2000, and TGV) where information is available to a selected audience.
- DATA – Confidentiality of data is seen as an issue, it is of value to a competitor if generally available.
- Terminology – Interpretation and use is variable.
- Cost and time are significant for preparing bid offers. An agreed requirement would help reduce total industry costs.
- Consistent preparation and evaluation of results is required to give a meaningful basis for comparison.
- An agreed interchange format required for data to be exchanged between contractors.

4.1.3 Task 1.2

Objectiv is to survey of present practices business sectors, other than rail transport, with emphasis on:

- use of LCC in strategic decision making and realisation follow-up,
- benefits obtained and difficulties experienced,
- understanding how feedback might be best applied by the rail industry to influence, for example, financial planning, operations, maintenance, etc.

Consideration was to be given to relevant aspects of the question such as standardisation and interoperability.

In the name of the EC, TECHNICATOME withstands to thank the following experts for their essential contribution and their kindness:

Mr LONGERE EUROCOPTER

Mr SERIDJI	Bureau VERITAS
Mr MEUWISSE	EDF
Mr DE MAISTRE	DESCO

Based on previous relevant experience of the subject, the study group undertook the following tasks:

- to collect general pieces of open information on LCC implementation strategies,
- to outline precisely the scope of the survey in connection with the overall objectives of the project,
- to define a significant panel of industrial branches to be included in the survey,
- to structure it with respect to kinds of use, kinds of products, main product operation related activities (purchase, supply, operation, maintenance, logistics),
- to identify pertinent companies and competent representatives to be interviewed,
- to set up a questionnaire as a guide for the interviews.

From the beginning, it was assumed that LCC implementation in various sectors was quite unequal depending on specific environment and strategic priorities of the actors.

Anticipated differences could possibly concern for instance:

- lacks in the encompassed costs with respect to total costs, or
- unequal progress towards expected complete implementation.

So, in order to extend the results of the survey to the rail transport sector, it seemed most important to get ability, not only to identify those differences, but also to introduce in the scope of the survey some reflections about correlation between those differences and significant environment features.

It was anticipated that significant criteria could be found among the following:

- costs structure (possible preponderance of a small number of costs items, etc.),
- ability of actors to directly control important costs items,
- competitive pressure (equipment user’s side or supplier’s side),
- whole business branch structure,
- structure of the equipment related network of actors,
- quality and relevance of cost data,
- quality of costs data exchanges between the main actors.

The above reflections were used in developing and structuring a questionnaire and in selecting a panel of representative companies and activities.

Main criteria for this last selection were:

- involved equipment were mobile ones as in transport application; however, specific EDF (Electricité de France) experience was considered useful and unavoidable,
- both civil and military,
- in various physical environments: ground, sea, air,

- surveyed activities covered almost the entire scope related to the equipment life cycle: specification, procurement, operations, maintenance, and logistic support.

The survey concerns the following companies, activities and branches:

- weapons systems branch, (procurement, operations and maintenance sides),
- helicopter production and maintenance (civilian and military),
- civilian air transport,
- sea transport,
- nuclear power stations (EDF: building up and operations/maintenance).

On such bases, a questionnaire has been developed and provided before each interview.

Some parts of this questionnaire were intended to specific activities: design, production, operations, maintenance, etc., so it could be tailored to the effective conditions of each interview.

As one could anticipate very different levels in LCC concept understandings, the questionnaire was intentionally very detailed (more than 40 items!), and the people interviewed could answer according to their specific experience.

4.1.4 Conclusions to Task 1.2

A comparative analysis of the collected results suggests that:

- in any case, up to ***no return point***, and even more ***to positive ROI***, LCC implementation is considered as an expansive and rather long term process,
- presently, in many sectors, LCC has not gone beyond preliminary reflections and it is not quite sure that a strong involvement in LCC will always prove to be necessary or even convenient,
- where it was considered possible and relevant, even partial LCC implementation shows significant opportunities of overall efficiency improvements,
- while some sectors or companies have decades of successful works on LCC, almost all of them thinks that present achieved status could or should be improved.

Most of the anticipated significant criteria for a successful LCC implementation and other important key points were pointed out:

- Mutual links and strong exchange of data between partners,
- deep changes of culture, both in internal organisation and in mutual links between the involved companies,
- top management involvement and management skill maturity,
- setting of short term and comprehensive measures of progress.

As anticipated, the above factors influenced the launch and the progress of LCC implementation and should be considered in extending the approach to a new area, say rail rolling stock management. The essential need for communication (not only exchange of information) between the set of actors into an area has to be highlighted.

This communication set-up, which is a rather long term process implying a progressive build up of trustful relationships, needs as a driving force an external pressure (i.e.: competition).

- **Competition context**

  The perception of a competitive threat and the start of LCC implementation proved to be clearly correlated.

  Civilian air transport experienced very soon such a severe competitive context and LCC implementation is older and probably more advanced than in other studied branches.

  In nuclear energy, weapons systems and helicopters branches, for years, competition was superseded by other priorities and LCC history is more recent and perhaps less advanced.

- **Structure of costs**

  In sea transport branch, almost all costs are concentrated in acquisition costs and fuel costs. Opportunities for balanced design did not appear clearly and the need for a LCC structured approach is not obvious. Present LCC implementation in this branch seems embryonic.

  Other branches exhibit more balanced cost structure, opening a larger range to design balance opportunities, mainly between acquisition costs and maintenance costs.

- **Direct control on important cost items and cost related features**

  Identification of cost related features that govern the costs are obviously an important step of the studied processes. This resulted in defining specific concepts whose content and structure were considered most suitable for the purpose of collective (multidisciplinary) management: DOC in civilian air transport, DMC in Eurocopter approach. Even very close to the full LCC concept, each of them reflected branch specific approach and priorities, and such collective reflection is considered a prerequisite to the LCC approach. Collective analyses result also in defining ***cost drivers***, important features to control and measure during design and realisation.

- **Structure of the industry and of the missions**

  Complexity of the branch panorama seems to broadly influence LCC implementation.

  EDF case is the most simple one: at the same time the power station designer, builder and operator, single kind of mission and of operating conditions. Even relatively late, LCC implementation is considered effective. Cost simulation was not a major issue.

  Civilian air transport actors are much more numerous, but is structured by a small but powerful nucleus of manufacturers and transport companies. Corresponding operating environment was rather homogeneous and simulations of the differences were manageable. The context favoured some level of convergent motivation.

Bilateral negotiations readily resulted in minimum industry standards for cases that proved to be efficient.

Clearly, the complex sea transport panorama does not favour discerning probable needs for LCC implementation.

At industry level, collective motivation, co-operative multidisciplinary studies, agreement on costs definitions and structures, seem to be important factors of success.

- **Data collection and models**

  LCC approach requires funding cost estimates on models that use lots of cost and cost related databases.

  Data measurements, quality and confidentiality are often difficult issues depending on bilateral motivation and competition context.

  Obviously, this favoured EDF process as there was no internal competition between the power stations builder and operator.

  DOC approach resulted in defining driving features as well as related measurements and figures that were just necessary and could avoid most confidentiality problems.

  Eurocopter stated that cost drivers type analyses permitted to drastically reduce the number of significant figures to be managed under DMC (mainly reliability figures).

- **Organisation and processes**

  Each time LCC implementation is claimed, it is always related to a ***Design To LCC*** concept under which LCC is considered a design induced measurable performance to be integrated in the design concurrent engineering general process and liable to all the performance management processes (specifying, allocating, measuring and checking during life operations).

- **Systems complexity**

  Any one of the studied examples of positive LCC implementation was **rather complex systems** whose design process was ***concurrent engineering*** type.

  Opportunity of a full LCC implementation for less complex products is **questionable** and obviously subject to **specific process adjustments**.

  Top management involvement, level of management skills and of accounting systems

  Due to the rather long, costly and sometimes disappointing LCC approach, the process shall be based on resolute involvement of the companies top management. Strong priorities shall be defined and supported by appropriate allocated means.

  Most often, a high level of management methodology and of accounting systems will be closely correlated to such top management involvement.

4.2 Work Package 2

Within Work Package 2 two tasks were identified:

- Task 2.1: Terminology and Information requirements
- Task 2.2: Life Cycle Cost Framework

The original research task was "to develop a Life Cycle Cost (LCC) methodology where the information required to perform calculations, i.e. availability/reliability details, operational requirement specifications, cost contributors, are clearly identified in a manner which is accepted by all parts of the railway business. The objective is to use this methodology to examine maintenance and suggest strategies for the management of maintenance which will assist with the introduction of harmonised rules for maintenance and reliability to ensure economic and safe maintenance of rolling stock outside their home network. This should cover passenger transportation systems as well as freight railways".

In the course of the project the objectives have been adapted and the scope of supply shortened. Above all the depth of investigations is concerned.

There is not only a big challenge to railways in Europe but also a request from the European Commission to minimise costs in all areas of a railways systems life. It seems to be „simply" a question of railways survival.

Cost reduction cannot be reduced to investment costs only, it is mainly to do with the application of Life Cycle Costing (LCC). This means to find out, to describe and to optimise the relationship between reliability & availability in safe operation, maintainability, maintenance and disposal of a train in its railways and non-railways environment, reflected in the design as well as in the investment.

It should be said that there exist two main areas of LCC improvement. One is the further improvement of systems, which are already at an acceptable level of Life Cycle Costs. The other area is the removal of those obstacles on the way to low costs, which are very obvious cost drivers. Sometimes they are already known but from several reasons they are not removed. The latter is not subject of this brief paper but there is no question that it should be treated with the same effort.

The existence of these two areas (certainly there are all gradations between) reflects the situation in Europe: High Speed Trains like e.g. ICE or TGV are under constant monitoring to improve performance and to reduce operational and maintenance costs. Experiences gained are used for improvement of the next train generations.

An example of the other area or end of scale general spoken seems to be freight traffic.

4.2.1 Task 2.1

The basics of an entire system necessary to apply Life Cycle Costing will be subject of consideration and are under focus below.

Life Cycle Cost are very clear linked to Reliability, Availability, Maintainability and Safety (RAMS). Therefore, a RAMS/LCC – system will be described. There is a focus to the need to use an *entire* approach. Information logistics are discussed as well as modelling, parameters (figures of merit) and analysis strategies. The requirements for generation and installation of such a system are briefly discussed.

RAMS/LCC – Systems

Definitions are taken for granted are of interest to the supplier as well as to the operator and maintainer. All parties wish to:

- get transparency in the development of costs
- get knowledge about contributors, influences and their relationship
- be able to reproduce predicted values in given scenarios
- to influence life cycle costs.

This requires a system of

- information logistics,
- description of costs dependent from influencing parameters and
- a system which enables the engineers and the management to take decisions with regard to cost reduction.

The top-level targets of an RAMS/LCC – system are:

- reduction of costs,
- improvement of quality, reliability, availability, maintainability,
- safe transport,
- to meet environmental requirements,
- to contribute to competitive railways.

It seems to be very necessary to the authors to emphasise that it is very vital for success to follow a **process, which** has to be implemented ***as a whole***.

Unfortunately it does not go without saying that the sequence of implementation should be: set a goal, develop a strategy, choose and apply the appropriate method.

♦ First identify the targets then develop the strategy and the methods.

More and more we are faced with *permanent changes* in all areas of organisations involved which is true not only for railways and railway industries. This comprises content, volume and complexity of data, organisational structures, share of management responsibilities, in short all elements of the RAMS/LCC-process.

Thus it makes it more difficult to describe the relationships in the process, get transparency and to control it. It is not investigated up to now whether this situation adversely affects the efficiency or if it could even create new approaches for the optimisation of LCC.

With regard to the supporting conditions it should not be underestimated that politics can play a very important role to establish the conditions for successful application of Life Cycle Costing.

System basics and architecture

Reliability, Availability, Maintainability and *Life Cycle Costs* are bound up each other. Additionally *Safety* and related costs are mostly involved in indirect or direct manner. To assess a system it is necessary to settle and agree parameters.

Parameter:

Characteristics of RAMS/LCC properties that can be quantified. Examples: cost rate, failure rate, cost gradient, inherent availability, etc.

Parameter Value:

Value of the parameter defined above. The parameter value embodies quantified information. It is an aid for entrepreneurial decisions (plan, decide, control). In this paper based on realisations with regard to RAMS/LCC.

Parameters and parameter values are vital basics and prerequisites for the analysis and the description of a certain status of the equipment in its operational environment. Based on this knowledge the targets can be set and the parameter values have to be used for controlling the changes.

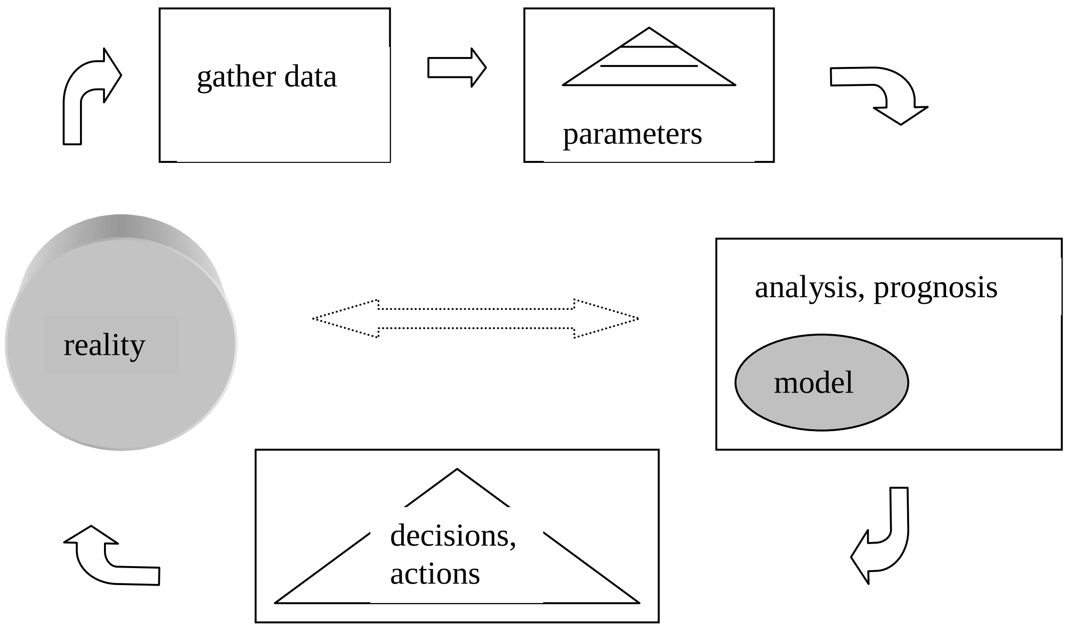
This means that fully descriptive parameters are very important. These parameters are clearly linked to the quality of the LCC model used and its supporting RAMS structure. The model has to reflect the technical and economic reality as well as necessary.

The other two basic columns beside

- the adequate LCC model and its supporting RAMS structure are the
- application of the Entirety Approach and
- the information logistics.

The basics named form the substructure for the workflow:

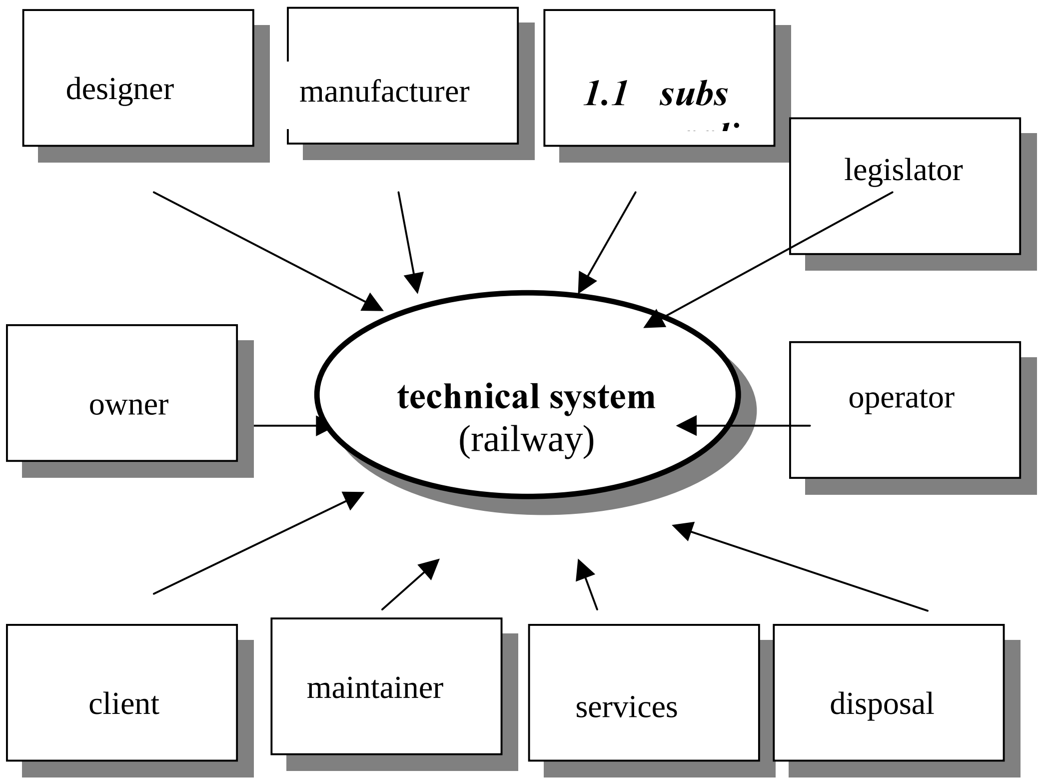
- gathering of data, modelling, analysis, prediction, decision & action and (closing the loop) monitoring of results by gathering data.



This brief description has to be considered and explained in further detailed reports.

Data exchange

Information handling plays a very important role in a RAMS/LCC system. General logistics of information and data has to be seen as a precondition for successful modelling. The number of parties involved in any way should not be underestimated and increases the demands on quality of information logistics. This is illustrated by the scheme below.



It is very obvious that an efficient information logistics system only can be based on use of computer. Unfortunately the use of paper currently is not an exception in wide areas of railways.

The implementation of an information logistics system that has to cross boundaries between the parties involved is a big challenge in every case. Wherever interfaces between different information systems have to be overcome special effort has to be paid to the interface.

Use of Internet technology for data exchange often is the first idea that comes into consideration. This has to be treated very carefully. First of all it is a for sure that under the given circumstances of competition free access and exchange of data is inconceivable. In many cases there are also legal restrictions with regard to confidentiality. Maybe the Internet will be used as an aid for transport only and combined with advanced encoder technologies. This kind of investigation needs further development.

Information logistics should be performed via computers as much as possible. Nevertheless there is no success without human beings. Therefore, selection of qualified staff and appropriate training has to be emphasised as a key issue. In reality field data collection, analyses or parameter value assessment never can be fully automated and are dependent from actions and decisions of skilled persons. Due to practical experience this kind of skill as a combination of mathematics, reliability & safety engineering, life cycle costing know-how and technical railway knowledge is not very widespread. As a consequence an education will be started in Germany at the end of 1999 where engineers will be qualified for RAMS under consideration of Life Cycle Costing.

Structure of data

Information exchange in any case needs a structure and rules of handling. This structure can be seen as a skeleton to be used from gain of data via analysis and LCC prediction up to validation.

Information with different structure sometimes can not be processed together. In the worst case data are useless if they do not match the structure of existing data or of the model structure.

The parameter values to be extracted from raw data give us a further request: under consideration of mathematical basics a minimum level of number and quality of data has to be reached. The existence of some single high quality data does not necessarily lead to high quality results of calculated parameter values. There has to be support by an adequate structure of information.

It is known that due to this realisation endeavour has been made to determine adequate structures. Working groups, e.g. at UNIFE or the German Railway Supplier Association (VDB), are dealing with that subject. The experience from that activities confirms the statement made before: the more the “entirety” approach is ignored the more difficulties inhibit the successful solution. Experiences made by German railway supplier industries could contribute to further investigations.

Siemens Transportation Systems operates with a set of data, which is in use for a very long time. This data set represents a minimum of data needed for RAMS/LCC calculations. Siemens could contribute with their experience.

4.2.2 Task 2.2

It is agreed for the CRMA project neither to develop a LCC model nor to describe one. Concerning this a lot of work already has been done and experiences have been made. This subject was also dealt with e.g. in the German Railway Supplier Association (VDB). During this work it became obvious that it seems to be very difficult and may be arguable to create a kind of “Standard LCC Model”.

The two main reasons should be mentioned. First of all every company has their own system of processes, software and hardware. The LCC model has to fit with that environment. The second thing is to do with the special accent every user of a model emphasises. There is wide range from the simplified approach with low accuracy up to models which satisfy high demands.

For that reasons the VDB working group came to the solution to describe indispensable basics, to focus on mistakes to be avoided in case of creating a model and to articulate recommendations. The main point is commonly agreed terms and definitions to be able to communicate and to be able to define clear interfaces. The results are available.

Currently models for Life Cycle Costing in the railway sector obviously are mostly used for Rolling Stock. Applications which really can be named "LCC-model" for railway systems including signalling, fixed installations, power supply and other parts of an entire system are not known but there is a real need. It has to be said, that a "Railway System LCC Model" can not be created by simply linking LCC models of the separate parts. For such complicated systems where the kind of information about the process and its data is much more fuzzy as it is for the system parts another approach has to be made under consideration of mathematical systems theory.

RAMS/LCC parameters

It has already been said that parameters play a key role. The better Parameters reflect the modelled reality the better Parameter Values can be used for process control and decision taking (a certain quality of data provided). Four stages of parameters can be called:

I. primary parameters (mostly empirical)

II. RAMS/LCC parameters (mathematical-statistical)

III. descriptive process parameters (decision orientated)

IV. management parameters (decision orientated)

This range represents a status of data aggregation. Every level of parameter is dedicated to a certain level of the RAMS/LCC process.

It is very clear that high demands have to be made on a model that is able to create these levels of parameters.

Especially the levels III and IV are highly dependent on use of sophisticated methods. In this context it should be said that often such parameters and their value are used which are calculated disregard calculation methods restrictions, e.g. the development of maintenance strategies on basis of calculated parameter values is not possible in a correct way without application of the method of *Renewal Process.* This method has to be paid more attention in future.

In general it would be a great progress if mathematical and statistical rules were applied as they should be. The authors are available for further details.

Management requirements

Life Cycle Costing supported by RAMS engineering is an aid for the management to optimise the system with regard to cost and performance. It has to be used on the way to profitable railways in competition with other transport systems.

It should be repeated again: if use of LCC techniques is intended, efficiency only can be reached if the "Entirety Approach" is applied. That means full support from the management and full understanding of target, process and methods.

Moreover, there has to be the ability for interpretation of results as a basis for decisions. This concerns the level of decision-makers which has to set the stage for efficient work of the level below which is responsible for information gathering and processing as well as analysis.

4.2.3 *Summary and Conclusions*

As far as known such a RAMS/LCC system does already not exist as a whole. There are some companies, maintainers or operators, which already have implemented parts of such a system. Considering RAMS orientated Life Cycle Costing with regard to Railway some thesis are advanced for discussion:

- The processes to be modelled and to be controlled can not be monitored in all areas. Improvement is necessary as well as development of methods to cope with that fact.
- Information and data available are often incomplete and sometimes contradictory. This mainly concerns verbal information, which can be just as important as numerical information. This increases the required skill level of staff.
- RAMS/LCC parameters are sometimes not descriptive. There is a need of more descriptive parameters. They have to be amended and to be composed in the sense of a hierarchy.
- Currently analysis is too large-scale. There is a need of standardised analyses based on well-established accepted mathematical rules.
- Use of stochastic basics seems to be a problem but is very important for credibility of results.
- Current RAMS/LCC solutions regarding structuring and access to aggregated information are unsatisfactory. There is a lot of effort to gain and retain data wasted since databases have been structured and initiated under neglect of the view to the whole system of processing.
- Information logistics often is underestimated or there is a lack of.
- Co-operation between all participants in the process needs to be improved. Every part (especially supplier and customer) wants to benefit but often are not aware of their duties to contribute. If operators more and more increase contractual demands to the supplier it becomes very clear that industries have to get knowledge on performance and failures of the equipment concerned.
- Even on national level it is difficult to clarify fundamental issues. It is a big challenge to undertake it European-wide and needs much support from administration. On the other hand it could be a new chance.
- CEN RAMS (e.g. Standard EN50126 etc.) are being developed to give uniformity on the definitions and terminology in use. However, since different Working Groups are involved with allied areas there is a risk there will be inconsistency within the Standards UNIFE as representatives of the Railway Industry Suppliers are aware of there potential difficulties.

4.3 *Work Package 3*

Within Work Package 3 two tasks were identified:

- Task 3.1: Framework Analysis
- Task 3.2: LCC Investigation and Benefits

The aim of this work package was to propose new ways of thinking for alternative strategies for managing and assessing the Life Cycle Cost (LCC) of railways rolling stock or at least to highlight some patterns for policy management. Alternative strategies for LCC, through a more global vision, help to avoid wasting European Railway resources and then inevitably lead to an integrated set-up for interoperability.

To illustrate the topics of the report, work package 3 is built around the example of the braking system for freight rolling stock. There are a lot of interactions with the braking system. There is the primary function of stopping the vehicle and how this function is controlled relates closely to the operation of vehicles, the maintenance of rolling stock and the rolling noise generated by the wheelset.

The finding of Task 1.2 during which other industry sectors were investigated prompted many conclusions and recommendations stated within this section.

Technicatome were selected as the task leader for the exercise because of their wide experience in industries other than the railways. This provided the opportunity to obtain an view of railways not constrained by extensive experience of the railways.

Environmental Issues

Noise generated by freight trains is seen as a major threat to the operation of freight trains. The dominant cause of noise is the roughness of the rolling contact surface between wheel and rail. For freight vehicles using cast iron shoes braking on the wheel rim is the cause of the wheel roughness. Trains, which are disc braked, have much smoother wheels and are therefore quieter. Passenger trains using composite block materials and braking on the treads are also quieter.

There is a major initiative by the railways to try to control the noise generated by freight wagons at source by changing to composite clasp brakes rather than installing noise barriers, etc. between the source and the receiver. Composite blocks also have lower maintenance costs.

The use of composite materials as wheel temperature are raised as temperatures on the wheel are higher using composite materials which can cause damage to the wheel, friction levels are different etc., which could affect safety. There is interaction between environment, cost, operating conditions and safety.

References for Work Package 3

<1> Review of strategic uses of LCC in other business sectors listing benefits and drawbacks.
TA-91142 Ind. A du 14/01/99

<2> International Railway Journal
January 1999 and February 1999

<3> La vie du Rail et des Transports
N° 2679 - 13 janvier 1999

<4> Technica - Revue des ingénieurs de l'école centrale de Lyon
N° 466 - Octobre-Novembre-Décembre 1989

<5> 2 websites
www.brakebeam.com
www.sabwabco.com

<6> UIC Leaflet 544-1

<7> Minutes of meeting
TA-056935, du 21/04/98

The goal of this section is to state the present situation on the railways networks, the different freight rolling stocks, and the principal activities of such a train. After that, particular attention will be given to the operations, that is to say how a train is constructed, coupled, and how it is used. Finally, the last section will deal with the maintenance of the rolling stock, and give general information about the way it is performed in the European Community.

The railways network and rolling stock

It seems important to highlight some situations about railways traffics and networks in the European Community, which have an influence on the subject.

Freight transport by train represented around 32% of the total freight transportation in 1970, this part decreased to 14% in 1996. This reflects a modal shift to road transport that increased from 49% in 1970 to 73.6% in 1996.

During this period industrial changes also significantly changed the type of goods being transported away from heavy raw products, iron ore, coal, chemicals etc., to less dense finished products.

Expressed in ton-kilometres, the performances of the freight transportation decreased of 14.6% between 1970 and 1996. During the same period the road transportation increased of 23% (cf. Ref. **<2>** & **<3>**).

There are some significant differences from one network to another in Europe, for example, signals, maximum admissible load, railway gauge (Spain), etc. These create some difficulties for border crossing. At border crossings, the change of voltage (and/or frequency, a.c./d.c. etc.) requires also a change of locomotive and various checks, notwithstanding national or network rules requiring driving by national or network crew; this can result in large losses of time (one hour or more). Multi-voltage locomotives, but their exploitation costs are very high, and due to this, they are dedicated in priority to passenger transportation.

Freight and passenger traffic run together on the same tracks, with priority given to the passenger traffic in the global management. Freight trains run in the time slots left by passenger trains; and as a consequence freight trains spend a lot of time stationary. Consequently, it appears that the average speed of a freight train, in the European Community, is around 20 km/h. By comparison the average speed of the road transportation is estimated at around 60 km/h.

Experts agree that a freight wagon runs between 20 days per year in worst case and 200 days per year in best case. This poor rate of use explains, in the first case the operation cost and the difficulties in recovering the cost of the wagon in a reasonably short time period. A wagon is designed for theoretical life duration of 25 years, but practically, a wagon generally runs 35 or 40 years. That can introduce some reliability problems and generally increases the operating cost.

The number of wagon manufacturers has decreased dramatically from 100, 25 years ago, to around 10 nowadays. The most important ones are:

- ALSTOM
- POP
- BOMBARDIER
- ARBEL

- COSTAMASNAGA
- BREDA
- ANF
- POWELL DUFFRYN
- ADTRANZ
- SIEMENS

There are wagons dedicated to carry every kind of goods; this leads to a large number of different wagon types.

Dedicated wagons are built for specific goods for a market in which demand can change rapidly leaving the fleet poorly utilised.

Distances travelled by freight vehicles vary considerably and are generally low by comparison with road vehicles. Typically a road vehicle will travel between 100 000 and 200 000 km/year, whilst rail freight vehicle travel between 20 000 and 100 000 with the vast majority at the lower end of this range.

Running only in the time slots left by passenger trains make it difficult to have a high average speed. It is important to keep in mind that the average speed is much more depend of the waiting time than on the top speed.

Freight trains have to accelerate and brake strongly to fit in the slots left by passenger operations. This surely adds to the brake maintenance bill. More constant speed operation would obviously reduce brake maintenance and maybe reduce the requirement for strong brakes.

Trains are generally marshalled in one of two ways:

Two options exist at the present time:

- The first one consists in coupling empty wagons, checking all the systems and loading the train with the goods. This is particularly well adapted for Intermodal Transport Units (ITU) and block train operators. In this case, it’s also possible to run the train with some wagons empty and to fill them along the way.
- The second case consists of loading wagons separately, and to coupling them to form a train.

Note: a (functional) check of the braking system of the train, visual checking by an operator walking along the train, is made before every departure.

In some conditions it is difficult to notice a non-functioning brake. Track side detectors are used to identify hot axle-boxes and wheels.

If the brake capacity of the train is inadequate (due to too many wagon braking systems being out of order), it will be necessary to uncouple the train, uncouple defective wagons and make again the train before checking once more all the systems. On top of this arrangements have to be made to repair the wagons and take the cargo to the final destination.

Safety is a prime issue in the operation of a train. The train must stop under all normal and emergency operating conditions. If the stopping distance is 1000 metres, the effective braking distance will be around 650 m ±100m. The first 350 m represents an interval period of 8s to 20s. This period is the propagation time of the pressure drop, to go from the locomotive to the last wagon. In the case of the use of an electronic command to control the action of the pressure on each wagon, the braking action will be immediate and, for the same braking distance of 1000 m, the wear of the material will be less.

The constructor must certify that the wagon will comply with requirements, generally UIC and RIV regulations. Sometimes, waivers are granted by the national operator (SNCF, DB, FS, etc.) for specific needs concerning transportation on the home network. However, this can lead to problems if subsequently the wagon is used for international traffic.

Sometimes the constructor has to comply with RAMS (Reliability, Availability, Maintainability, Safety) requirements asked for by the owner or the operator (sometimes, the operator and the owner is the same person or company). Then, the owner and operator have to provide the "safety case" to the infrastructure manager.

It seems that there are three basic requirements (cf. ref. **<7>**):

- α: number of faults or of shortcoming by millions of km. These faults can cause railway track unavailability. α goes from 12 in the past, to 3 now, and probably 1.5 in the next future;
- μ: the cost to maintain the equipment for 1 000 km. It goes for passengers application from 550 Euro to 275 Euro now, and probably 140 in the next future;
- γ: the availability in percent of the rolling stock. It means the probability to be judged able to perform a 18 hours mission. A typical figure is 95%, however, some ask for 99%.

It is clear that all these figures have a strong impact on the acquisition cost, and that railway companies have to optimise the RAM requirements according to the cost.

Maintenance is a major cost in the operation of most freight vehicles. The maintenance cost of a wagon is generally stated at around 50 Euro for 1000 km. Nevertheless, this figure is difficult to use. It comes from a computation taking into account the total maintenance cost of all the wagons and the total running distance (km) of the trains, but not the real running distance of every individual wagon.

Today much of the maintenance of the rolling stock is based on systematic maintenance performed at fixed date and on repair of the failures occurring in regular operation.

Private companies operating transportation on railway networks are subject to the same rules.

These rules are rigid, established on bureaucracy and have not been modified for a long time.

The maintenance operations (wagons and sub-assemblies) are largely performed by the railway networks without any industrial integration. So the networks operators need to have all the skills for running repair and maintenance shops: mechanical, electrical, pneumatic. They use very few external shops or services. The catch is poor schedule and problems to plan tasks in advance.

The maintenance is made at several levels:

- minor repairs and inspections of vehicles at the track side or in freight yards;

♦ systematic maintenance operations in large network workshops.

For the major repairs and scheduled maintenance, network operators have workshops dedicated to a type of vehicle (types of wagons, types of passenger cars, dedicated diesel locomotives, electric locomotives, etc.).

As a result, often to reach its workshop, the vehicle has to go a long way and then the vehicle may have to wait for its turn. Moreover, the sequence of operations, in the workshop, is very long.

Generally freight trains are braked using a single well-developed terminology. Today, for freight trains, there is almost only one technology, one century old:

♦ **Cast iron tread brakes (clasp brakes):** cast iron shoes, directly pressed on the rim of the wheel, activated by compressed air, on loss of control time pressure. A master cylinder takes its pressure from a pipe running all along the train. A linkage presses the shoes on the wheel when the master cylinder loses pressure; this pressure is 5 bars. The principle of reducing the pressure in a very long pipe (a freight train may be 750 m long, today, up to 2 km, to-morrow), makes this kind of brakes slow to gain power when activated (tens of seconds). It may be enhanced by some kind of electronic control, at the risk of some loss of compatibility with old rolling stock. The cast iron brakes induce rolling noise through the wear of the wheels. A variant uses composite shoes, with the benefit of reduction of noise.

Some others technologies are available and used in railway transport (cf. ref. **<5>**). The main ones are:

♦ **Disk brakes:** large disks (two to four) are fastened to the axles; theses disks are of large diameter (500 to 800 mm), very thick (~10 cm) and with air-cooling canals inside. The friction material is pressed on the sides of the disks by callipers with hydraulic cylinders. These brakes are used on fast passenger trains (TGV, ICE, etc.). This is a very mature technology (it is used on most road cars and trucks and for the landing gears of planes). Disks brakes may have a long life between overhauls (> 10^6 km on fast passenger train). It is easy to change of friction materials. They are able to brake instantly, powerfully and progressively. A wagon so equipped may not get these advantages fully, when mixed with wagons equipped with cast iron brakes in a train. On fast passenger trains, the disk brakes are electronically tested, activated and controlled.

♦ **Dynamic braking:** locomotive motors make electricity from decelerating the train; electricity is converted to heat in the motor, or in dedicated resistors. The electricity may be also taken back to the catenary (recuperation brakes), but this is only possible in electrical locomotives specially designed for this possibility. Dynamic braking is, in principle, a no-wear braking. <u>It can slow, but not totally stop the train</u> (in case of need, the train may be stopped by its friction brakes, or the friction brakes of the locomotive). The dynamic braking reduces the use of the friction materials, so the wear, of the friction brakes (disks or cast iron), but cannot be the only brake system. It is mainly used for taking trains (including freight trains) down long grades (Alpine crossing). It is also quiet.

They are significant differences between these technologies:

♦ Cast iron tread brakes:

  - are less expensive (ownership cost - this is to be discussed later),
  - are already installed on almost all the stock,
  - wear the wheel (even when the wheels do not lock),
  - dependent on control system can be prone to locking,
  - induce rolling noise through the wear of the wheels causing roughness,
  - the life of the shoes is short,
  - the long pipe makes the activation of brakes long to get its full power, and difficult to brake progressively (if not enhanced by electronic or other means), but this could be overcome by the adoption of ECP braking.
- Disk brakes:
  - are more expensive (ownership cost),
  - have a long life between overhaul,
  - have higher life between change of friction pads,
  - are able to be serviced easily,
  - are able to brake progressively,
  - do not act on the wheel tread and so induce much less wear on the wheels (if no locking!), so do not induce rolling noise,
  - are of a known and mature technology and used in other industries,
  - are (today almost) never installed on existing stock,
  - can create problems when mixed with other braking forms due to unequal wear.
- Dynamic braking:
  - is only possible on locomotives,
  - necessitates dedicated electrical locomotive,
  - is a no-wear and quiet braking,
  - has long life and almost no servicing,
  - is progressive,
  - ignores largely the nature and weight of the wagons,
  - cannot induce wheel locking on the freight vehicle,
  - cannot stop completely the train.

The cast iron tread brakes design is very conservative (cf. ref. **<6>**), very constrained by the regulation and norms (UIC norms) and very unsophisticated, so of a rather low cost.

In the UIC Leaflet 544-1, there are the conditions of uses of a wagon and the method to achieve the good braking pressure. This allows computing the brake weight of a wagon. This figure is used to allow the train to run, according to its loading and even taking into account some wagons with inoperative brakes.

For example, consider a train of 20 cars, with a required brake weight of 70 t.

If the wagons are a capacity of 4 t, then the train can run even if the braking systems of two wagons are off. ($18 \times 4 = 72 > 70$). If three or more braking systems are off the train cannot run, because the brake weight capacity will be lower than the required one.

To run a train at a given speed requires a minimum braking performance (=braking percentage) of the whole train (e.g. 65% to run at 100 km/h).

The braking performance of each vehicle is indicated as a braked mass on the outside of each vehicle. The sum of the braked masses of the vehicles consisting a train gives the braked mass of the train. This “braked mass” divided by the mass of the train gives the braking percentage of the train.

If this braking percentage is equal or higher than the minimum braking percentage of the train (depending on signalling distances and gradients of the track) the train can run at the speed mentioned in the driver’s timetable. If it is lower because the brakes of some vehicles are not working, or if there are some vehicles in the train that have a lower braking performance than necessary for that type of train the driver will receive an information by the operator where (e.g. from km 65.2 to 66.1) and how much (e.g. maximum speed 92 km/h) the speed has to be lowered. This speed reduction is depending how much braking percentage is missing. But there is minimum braking performance depending on the line (gradients) under which a train cannot be operated not even at a very low speed! (There are other additional specifications in case that some brakes, or parts of the braking equipment of some vehicles are shut off.)

A lower or even missing braked mass of one or more vehicles can, within certain limits, specified by the operating railway, be compensated by higher braked mass of other vehicles.

Noise emitted by the trains is a parameter of growing importance.

Even if constructors comply with the UIC leaflets, there remain some differences between the systems built in every country, due to technical interfaces etc. That induces some difficulties:

- some wagons are not allowed to cross some borders,
- even if the basic brake components are the same, and so, in theory, the maintenance can be done everywhere in the European Community, it appears that each operator or car constructor adds some specific parts that impose to maintain the system in the home area.

Due to the very long life of freight wagons (design life ~25 y. - practical useful life ~30 y), on any individual wagon, the whole braking system may be changed from the initial one; the wagon has his brake weight to be computed again, and the wagon has to be certified again. The brakes may be only tested after that, before the first journey of the wagon.

Control of the brake effort required for wagons which can vary in weight due to varying cargo density is often very crude and involves simple change over which caters for tare and gross loading conditions only. Thus a wagon weight is above the changeover level but only by a small margin significant over braking and wheel sliding with consequent damage to wheel and track can occur.

More sophisticated systems are available which can continuously vary the brake effort between the tare and gross loading condition.

The braking verification and certification of the braking system of a new wagon is done on a section of a railway occupied only by the test train. The braking system is a safe system, that is to say that in case of loss of pressure, the brakes must stop the wagon. To test a new wagon, they fasten this wagon behind a locomotive and at a particular time t, the wagon is released and the stopping distance measured. The system is deemed acceptable provided the vehicle stops within the minimum and maximum stepping distance.

Much wagon maintenance is done at fixed dates, often without any regard to the kilometres run by the wagon. So it is for the brake system, too. The interval between these fixed dates is on the order of 3,5 years.

Most maintenance is done in the home network, in the shops of this home network, manned by people from the network.

If the wagon is abroad at the time of scheduled maintenance, it can be maintained abroad, following agreement between networks (IC conventions); these agreements are not contractual agreements, but compulsory ones; the network who does the maintenance supports the cost.

There may be failures requiring maintenance. If a failure occurs abroad, the car may be maintained abroad, depending of the failure, or taken back empty to the shop. Some minor maintenance may be done by yard staff (lubricating, changing shoes).

Brakes constructors

There are at least four brake constructors in Europe and US:

- Knorr Bremse (Germany)
- SAB Wabco (Europe)
- Buffalo Brake Beam (US)
- Westinghouse (US)

Brake construction is deemed a profitable activity.

Cost of ownership for the procurement of a freight wagon, we have the following ratios against some ownership cost for a typical freight wagon:

Ownership cost of brake system

	Technology of brakes	
Fraction of ownership cost	Cast iron	Disks
% Wagon	10%	16%
% Bogie	8%	20%
% Bogie vs. Wagon	30%	50%

Note: *Part of the braking system is on the bogie, and part on the rest of the wagon; this explains the apparent discrepancies in this table.*

The cost of a brake system designed for a maximum speed increases steeply with that speed. 120 km/h is a threshold for a significant increase of cost; this is interesting, as speed higher than that is required by the insertion of freight trains into passenger traffic.

For brake maintenance and operation costs the following costs can be identified:

- maintenance costs, containing:
  - costs of scheduled maintenance,
  - costs of unavailability of the wagon during the maintenance,
- operation costs, containing:
  - costs of minor unscheduled maintenance, done at track side, such as changing brake blocks,
  - costs of unscheduled repairs due to failures, containing unavailability costs,
  - costs of other unscheduled actions.

Theses costs have to be related to the work done (example: km with load, tons x km) to make significant comparisons with other ways of working.

The costs of the maintenance of the brake system, and the relation to work done is not very obvious: the network, who implements the maintenance in its shops, does not take into account the quantity of use of the wagon, before making a scheduled maintenance. The wagon may have made anything from 300 km up to 150 000 km since last brake schedule maintenance. So, the net has no incentive to minimise the cost (direct or other) of a given maintenance operation. Moreover, the network may think that, as his people have to be paid, the salary costs have nothing to do with, for instance, the cost of maintenance.

The network that does not think about availability of the wagons has no incentive to put them back quickly on operation.

To create an incentive to return the wagon quickly to service the cost breakdown must include costs for out of service time i.e. increase availability.

For the scheduled maintenance, it may show the time to get the wagon, empty, to the shop, plus the repair time proper.

For an unscheduled failure induced maintenance operation, the cost should include the unavailability costs, that may include, for instance, the costs of:

- not using the wagon because the brakes are inoperative;
- stopping the train, uncoupling the wagon, unloading the wagon and putting the goods in another wagon, coupling that new wagon to this train, of a latter one, (as the brakes, not being tested individually, the train is formed when you know the failure);
- having the wagon stay idle till it may be brought back to the shop;
- bringing back the wagon to the (unique) shop.

This requires gathering and sharing of information on traffic, and failures. This may show the interest of having many less dedicated shops, and/or a stock of spare parts.

That eventually may more than balance for a different (more available but more expensive) braking system (given the organisation changes suggested by the above).

We may put the exchange of worn shoes into the operating costs of the braking system; usually the shoes are changed on a yard, at the trackside, when visually worn out.

Contractual relationships vary, the main partners to the agreements are:

- the manufacturer: he builds the wagon,
- the owner: he buys the wagon,
- the operator: he uses the wagon,
- the maintainer: he maintains the wagon,
- the customer: he asks for a specific need relative to good transportation,
- the infrastructure owner: he rents the railways.

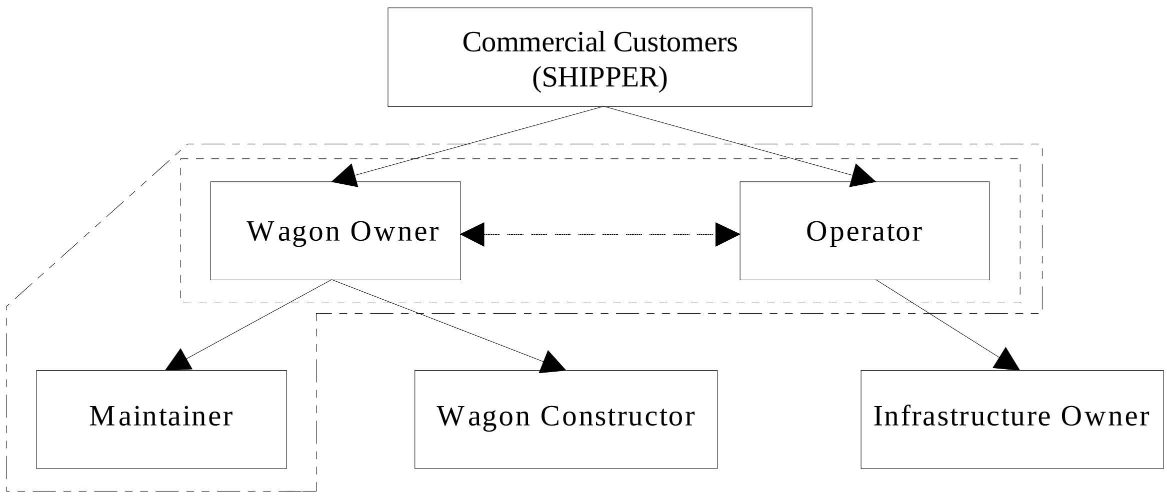
In some countries, railways companies (including subsidiaries) represent all the actors, or the main part of them, as for example, SNCF in France or FS in Italy.

There is also another actor, not a physical one i.e. the legislation:

- The legislation is the texts that describe the exploitation rules: safety, noise, pollution, etc.

It is an important point to take into consideration, because it sets limitations.

The relationship that exist between all the actors can be depicted by the following graph.



It does appear that the main actor is the customer as he has to evaluate the commercial benefits of using road, rail or sea. He will contact the wagon owner and give his specifications. The wagon owner will contact the maintainer and the wagon builder. This last one will contact the different part constructors in order to build the desired wagon.

The customer is also in relation with the operator, who deals with the infrastructure owner to determine the running conditions and specifications. The operator is also in relation with the wagon owner, in order to give him information about the infrastructure rules.

Different situations exist:

- each actor is a physically different actor, only in relation with the other ones;
- the wagon owner and the operator is the same actor;
- the wagon owner, the operator and the maintainer is the same actor.

Often there is a very poor exchange of data between the actors, largely because of the commercial competition between them. This seems to be true no matter the type of actor. This creates a lack of communication and partnership within the industry, penalties of the commercial nature of the business.

The relationships between the set of actors are only commercial ones.

Nowadays with regard to maintenance, data gathering concerns only that data involved in systematic maintenance operations and in corrective maintenance operations. Systematic maintenance operations are performed largely at predefined times. The date of the next maintenance operation is written on the rolling stock.

Such maintenance is expensive since it is performed even when the rolling stock is working well. Some parts are systematically changed while they could stay in operation longer. However this maintenance does not need any kind of data from operation and this explains the very poor exchange of data between operation and maintenance.

At present time, we can see that collaboration between actors is limited to exchanges of information. There is no actual communication. Whatever the solution for improving railway transport and the new approach proposed, communication between actors and partnerships is a key factor of success.

Staff qualification and skills vary significantly according to the type of activity performed, especially between operation and maintenance. However, staff are educated and trained to the necessary level to carry out task properly.

As a train driver has to have specific route knowledge where signalling equipment is located, train drivers are only qualified for a limited zone. That tends to increase the number of changes of crew and of correlated verifications; this impairs the global use of the European Railways Network.

The driver has a complementary maintenance task in the reporting of faults, performing some functional checks and in the checking of train after assembly.

With respect to maintenance, production of repairable and maintainable vehicles has laid on the adoption of general criteria specific to:

- freight wagons;
- passenger wagons;
- high speed trains.

Maintenance procedures and skills follow this breakdown, without consideration of possible commonalties.

4.3.1 Summary

Improving the competitivity of railway is clearly an important issue.

A lever to improve the competitive edge of the railway may be to improve the return on investment (ROI) of the rolling stock. Many remarks can be made in the light of ROI considerations.

The average use rate of wagons is very low: from 20 days/year to 200 days/year. This is correlated to the fact that their lifetime is 50% more than what they are designed for, in normal use. The ROI for freight wagons may be drastically improved by using them more often.

Another point is that many of freight wagons are dedicated to a single traffic and not easily adapted to other users after the market changes and the opportunity to future is no longer available. One way to improve that may be to rationalise the design of freight wagons. This is not so easy, as wagons have to carry many kinds of goods. Perhaps the evolution of freight ships, and container transports could offer some guidance. The wagon design should use some partnership between users and builders to define a range of need, and design accordingly, taking into account the requirements to run on an integrated European network: benefits in maintaining, compliance with rules, etc. This opens the way to block trains, loaded and unloaded without uncoupling wagons, so making large gains in time, and schedule.

Changes to maintenance schedules to a distance basis rather than a time-based system has simplification for the RIV regulations, which govern international traffic. Basing maintenance on distance criteria means that distances have to be recorded and the variation which occur due to operation over different types of route have to be evaluated and understood.

For networks the following two points are worth considering.

Firstly, having freight trains sharing the same network with passenger trains is questionable for the following reasons:

- It induces low use of the wagons because freight trains use only slots left available by passenger trains;
- Due to these slots, freight trains have to accelerate and brake heavily, and this induces more maintenance costs;
- Freight wagons have to be qualified for high speeds.

Secondly, we understood that freight trains pathways are static: they stay unmodified, as they have been planned whatever will be the situation of the traffic at hand. For instance, if there is a heavy traffic in Paris, a freight train going from south of France to north can get tied up a long time around Paris. This effect exists for long distance as for local journeys. In the contrary, trucks can use alternative pathways; they are informed by many means of the traffic situation: other drivers, their company, radio traffic information.

Though it is less easy to manage for freight trains, it is worth examining, since the position of all the trains is known at all times, and freight train traffic can be anticipated. The global strategy of pathway definition could be worth examining.

From the previous chapters it seems that the relations existing between the numerous actors (national/international) are not precisely defined. This implies difficulties for the customer to manage the interface to carry goods from door to door. This number of partners induces a loss of time and effort.

Another point is the number of operations needed to make a train run between two places: number of time the locomotive is changed, the change of crew, number of train checks due to coupling and uncoupling... Moreover, these operations are more numerous and lengthy when a train must cross a border. The operational procedures have to be simplified, particularly between different networks.

Moreover, there is no total service, as for example in the road industry, where there is door-to-door servicing. For competitive freight transportation, time schedules are too imprecise and irregular. Transport duration, and generally quality of service, is hardly guaranteed.

Waiting time is an important problem of the rail transportation. This acceptable in the future, if railway are to compete with road transport. The organisational and operational forms have to be adapted to reach a quality of service competitive with road.

Wagon uses and return on investment (ROI)

Some points that can make railways economically questionable for customers use:

- Railways are organised around the passenger market to give the priority to public service. As passenger transportation has priority, freight trains use slots left available by passenger trains. If all the slots may be used, the ROI increases. A first point will be to use all the available slots; in any case, freight market does not use enough slots to provide attractive services to customers at an acceptable price.
- Having tracks dedicated to freight (additional tracks, or at night, for instance) appears to be a worthy way of investigations. Other alternatives are to increase the capacity of the whole network, or to reconsider track priority according to the potential market associated.
- Increasing the annual ROI rate for wagon will allow investing into new techniques, like disk brakes or dynamic braking for example. These techniques could become cost-effective and the investment to buy a wagon will be amortised in a shorter period. The techniques exists they have to be applied economically. . All the techniques are already existing, mature and proven. They just have to be adapted to the desired applications.

Maintenance issues

Another way to improve the ROI of wagons is to lower the cost of maintenance (for a given use), and the time it takes, in order to increase the use (availability) of the wagons.

The way rolling stocks are maintained can be reconsidered. Several goals can be outcome:

- being able to perform maintenance locally, by having many shops able to carry the maintenance operations, in much of the places where that kind of wagon may usually run;
- modify wagons exploitation plans to bring them, in normal operation, close to its maintenance workshop in time;

- improve mean time to failures, in order to have less maintenance actions to perform;
- improve useful life before first failure;
- improve availability.

An interesting approach is to consider additional maintenance strategies:

- preventive maintenance: performed in accordance to predefined criteria to reduce the failure probability of a system, or the deterioration of a service provided (servicing);
- conditional maintenance: performed in accordance to criteria related to the state of a product, material, or application (wear information and pre-failure symptoms provided by sensors);
- predictive maintenance: performed on the observation of a pertinent symptom (rapid deterioration of a state of a product, material, or application).

All maintenance improvements need to take into account the use of the wagon. This is easier to do if there is gathering of information about wagon activity. To have a good insight in what we should do, we could collect data on:

- usage and failure rates;
- costs, duration, periodicity, type, of every maintenance operation.

Such data have to be updated.

This data then will allow Reliability Centred Maintenance techniques (pinpointing the faulty equipment, knowing critical failure mode and exact cause of failure, defining and using criticality index as decision help, and consequently adopting the best course of action for preventive maintenance). The notions of "small" interventions and "important" interventions, five-year servicing, ten-year servicing, updating, revamping, etc, may then be reconsidered. Indices can be selected to characterise staffing levels, training effort, spare part requirements, balance between preventive and corrective maintenance, and search for the best cost combination.

Data use can make it possible to manage stocks, spare parts, and procurement logistics, particularly outside of the domestic network.

Several possible actions have been indicated. A case by case study have to be performed to select the most appropriate and to outcome a coherent and complete strategy.

The technical actors should be less and less obliged to intervene during the journey by conventional visits in marshalling yards or station platforms (broken springs, worn out brake blocks, hot bearings, failed brake air pipes, should not result in loss of "slots".

The maintenance intervention would be either planned or unexpected, but in the latter case, the actors can receive maximum information related to the problem in order to facilitate their action (working conditions, reduced immobilisation time, reduced costs, etc.).

In any case, if there are many shops able to, and qualified to do the maintenance over the networks (home network and abroad), any unscheduled repair will not take the wagon out of service for long.

Operator/Wagon owner relationship issues

If it seems possible to a wagon owner, to know his wagon is in his home country, it is much more difficult to know where that the wagon is in a foreign country. This impairs the good management of a fleet of wagons. The fleet management system should optimise the running time of the rolling stock.

In the same order of idea, there are customers who rent a number of trains to use during the year, but there is no guaranty covering the quality of service. And if this is not acceptable, there is no sanctions or measures taken. A contractual relationship has to be used.

4.3.2 Recommendations and conclusion

Remember that the main objective is to put interoperability as a standard of working, and to improve the Return On Investment (ROI) in the frame of the European Railway Network. In the previous chapter, we pointed out a number of issues that have to be revisited and investigated to implement new and coherent approaches favouring interoperability and improvements for global efficiency.

However and whatever, solutions and approaches are selected, it must be remembered that the goodwill of the of actors and their staff is mandatory. This implies that a lot of conditions and precautions are fulfilled and a cautious way of managing the transition is adopted.

First, it is important to mention that in the issues discussed, problems are not technical ones. Technical solutions for new approaches already exist and only require (if needed) adjustment to the selected approach. Undoubtedly, a new strategy will have an impact on the technical aspects of rolling stock, above all care must be exercised: the technique must not become the motor in this evolution. On the contrary, the technique must remain the means for efficiently meeting the changing demands of the organisations and individuals concerned.

It's clear that nothing can be done without involving the whole set of actors. That is a mandatory condition. The actors will have to clearly negotiate and define the rules. The limits of the services and responsibility of each actor should be clearly stated to ensure and guarantee good relationships between them. Better structured contractual agreements can do this. **However, it must not be forgotten that exchanging information is a good thing, but communicating is a better thing.**

Relationships between the actors should be established before maintenance costs and other indicators are re-calculated.

A good and pertinent assessment of costs and especially of maintenance costs must been seen as a result of a good interoperability strategy and not the contrary.

However, it could be interesting to implement quality indicators like number of locomotives going from A to B, time, etc.

Whatever the new scenarios proposed, specific attention will be given to the following points:

- acceptability of the philosophy by rail culture (operators and constructors of different countries),
- impact on actors (qualification, training, personnel requirements, organisation),

- international interactions (interconnections, interoperability, logistics),
- cohabitation of currently employed and future methods during transition periods (integration of philosophy),
- handling and management of the transition period
- integration of the new concepts (time period, costs, progress, modularity, etc.),
- impact on the design of materials, standards, operating regulations and material life cycles ,
- impact on operating costs: material and human investments, surveillance, management, maintenance.
- RIV ruler to reflect need for mileage based on well as time based requirements.

5 COMPARISON OF INITIALLY PLANNED ACTIVITIES AND WORK ACCOMPLISHED

The following tables illustrate the time planned to be spent on each work package and the time actually spent.

CRMA - PLANNED TOTAL MAN-MONTHS

WP	Partners				Total
	ERRI	TA	SIE	PDS	
1		1,5		2,5	4
2			6		6
3		10			10
4	7	0,5	0,5	0,5	8,5
Total/partner (man-months)	7	12	6,5	3	28,5

CRMA - ACTUAL TOTAL MAN-MONTHS

WP	Period covered 01-01-1998 to 31-12-1999				Total
	Partners				
	ERRI	TA	SIE	PDS	
1	0,7	1,5		0,3	2,5
2			1,3		1,3
3		4,14			4,14
4	2,91	0,5	0,5	0,5	4,41
Total/partner (man-months)	3,61	6,14	1,8	0,8	12,35

With one exception CRMA achieved the technical objectives set out in the original planning.

One of the objectives of Work Package 2 was to define a grid of elements for vehicle life cycle cost techniques and the interfaces between the various elements.

During discussions between the project partners and the proposed partners for the original CRMA project it was plain that most suppliers have an implementation of Life Cycle Cost techniques for which this objective of this project is defined.

Two of the models that were discussed, those of Adtranz and Alstom were advance developments on to which significant investments of time and money had been made.

The detailed structure of the models was different but they performed the same functions and would give similar results when used with the same data and interpretation of the terminology.

One of the models could calculate the size of fleet required to provide a service based on the RAMS data, likely failure situations and the placement of maintenance facilities and the replacement rolling stock.

There is reason to believe that other suppliers have models capable of performing similar calculations and are able to fulfil there commercial needs for LCC calculations.

As a consequence Technical Annex deliverable D 2.2 was not delivered.

The other objectives were largely met in a very economical way though not always by the means originally proposed. For example to meet objective of Task 1.1 the results of the proposed partners of the original CRMA project and discussion within interested groups from the UIC and UNIFE were used rather than a workshop as envisaged.

The short timeframe of the project and the decision amongst the partners to use simple report layouts dispensed with the need for complex procedures hence Technical Annex deliverable D 4.1 was not deliverable.

List of Deliverables

Deliverable	Description	Status of delivery
D1.1	High lighting current deficiencies	Accepted on 10 December 1999.
D1.2	Review of strategic uses of LCC in other business sectors listing benefits and drawbacks	Accepted on 10 June 1999.
D2.1	Clarifying terminology and defining information required.	Accepted on 10 June 1999.
D2.2	Defining the framework with element contents, boundaries and links fully defined	Not delivered, see comments in text above
D3.1	Identifying possible patterns and associated pitfalls for contract agreement strategies	Accepted on 10 June 1999.
D3.2	Detailing beneficial strategies with recommendations for actions	Accepted on 10 June 1999.
D4.1	Detailing quality, financial control and communications procedures	Not delivered
D4.2	Monitoring the progress of the project	PR 1 and PR 2 accepted on 10 June 1999.
D4.3	A proposal for exploiting and disseminating the results	This is part of the Final Report.
D4.4	Preparation of the final report	This is part of the Final Report.
D4.4	Final consolidated progress report	Final version sent 28 January 2000
D4.4	Dissemination and exploitation report.	Final version sent 28 January 2000
D4.4	Summary report	Final version sent 28 January 2000
D4.4	Final report for publication	Final version sent 28 January 2000

6 PROJECT CONCLUSIONS

Remembering that CRMA was a vehicle based project the following conclusions can be drawn:

- Railways use of LCC techniques is not new having been initiated approx. 20 years ago.
- Some experiences of the railway industry and other industrial sectors show a great similarity. The motivation for introducing the techniques for both was commercial. Both industry groups were faced with ever increasing pressure to reduce costs. In the case of the railways growth of the road transport and competition between rival companies whilst in the other sectors government or social pressures to control costs and the competition between rival companies.
- Both industrial groupings recognise that the introduction of LCC is a long-term process that is costly and requires changes within company structures and cultures to be effective.
- Both groups recognise that LCC is a development of older cost control processes that aim to give value against known specification parameters rather than a "best at a cost" approach.
- Both groups see the quality of the data on which designs and judgements have to be based as a critical issue. The free exchange of data between competing companies is viewed as being commercially unacceptable. The commercial value of the data is recognised by the fact that in the other business sectors there is payment of some kind when data is exchanged between user and supplier.
- The initial uses of LCC techniques in the railways were to mainly to check availability and maintenance costs met the requirements of the contract. The use also allowed monitoring of maintenance costs and the modification of maintenance schedules and methodology to minimise maintenance costs. For new prestige project with well controlled maintenance confined to few locations the collection of data, its recording and process is not a major problem providing it is made available to suppliers.
- The initial uses identified some problems that relate largely to the RAMS terminology and the financial analysis of the results. The deficiencies in the terminology definitions is being addressed through the development of CEN standards though care must be taken to ensure that there is consistency between the various groups working on the standards.
- The examination of freight vehicle braking system shows very well the need to take a total system approach to many railway problems. This example shows interesting links between vehicle costs, operational issues, safety, infrastructure costs and environmental issues.
  - ♦ To have the majority of freight vehicle designed to meet the worst braking conditions when the majority of these vehicles will not see the conditions lead, may lead to excessive costs and or operational restrictions
  - ♦ Management of the braking requirements to meet the safety requirements may allow the lower cost solution for the majority of the fleet but would introduce route restrictions.

RIV regulations which govern the international interoperability of vehicles need to be reviewed to ensure that they provide for the lowest cost maintenance of vehicle and greater utilisation is achieved so that the performance of the public sector fleets more closely meets the privately owned fleets.

7 ANNEXES

Annex 1: Industrial partners

Annex 2: SYNTHESIS of the interviews