DEVELOPMENT OF A LIFE CYCLE COST METHODOLOGY FOR RAILWAYS INFRASTRUCTURE, PROVISION AND USE

Dimitrios Tsamboulas, Angeliki Kopsacheili
National Technical University Of Athens
5, Polytechniou Street, Zografou Campus, Zografou-Athens, GR-15773 Greece
Tel. +301-7721367 Fax. +301-7722404 or +301-7721327
E-mail: dtsamb@central.ntua.gr; akops@central.ntua.gr

Abstract

The environment created by changing railway policy has an impact on the actual position of infrastructure management. Therefore, a systematic approach is needed for communication with the infrastructure manager and the rest of the ‘actors’ for guaranteeing pre-set levels of performance. Life Cycle Costing (LCC) can contribute to this. Review on the existing LCC practices in railways infrastructure management, proves that Life Cycle Cost applications by the management of the infrastructure is still in an early stages of development. This paper presents a harmonized LCC methodology for Railways Infrastructure Management, in terms of investment, maintenance and renewal costs, vehicle-infrastructure interaction, delay and scarcity costs, accident and environmental costs. This methodology is expected to assist the Infrastructure Managers in their duties, which is to develop a costing mechanism for the use of the infrastructure, so that they will be able to produce viable charging schemes.

Keywords: Life cycle cost analysis; Railways infrastructure management
Topic Area: C Planning, Operation, Management and Control

1. Introduction

The environment created by changing railway policy has an impact on the actual position of infrastructure management. The infrastructure manager has a clearly defined role and is confronted by increasing performance requirements of the other 'actors'. A systematic approach is needed for communication with the capacity manager and central government and for guaranteeing defined levels of performance. This approach is lacking in an organization where maintenance and renewal has long been planned and executed according to personal experience and skills (not to say that this is automatically a faulty way of working). Life Cycle Costing (LCC) can contribute to this.

Several definitions of LCC exist. As useful as any, and shorter than most, is: “The life cycle cost of an item is the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of the useful life” *(Woodward, 1997)*. Thus, the LCC of a physical asset begins when its acquisition is first considered, and ends when it is finally taken out of service for disposal or redeployment (when a new LCC begins).

In general the global objective of the use of the LCC methodology in railways infrastructure management, is the reduction of the maintenance cost and of the delay time but without reducing the safety level.

Review on the existing LCC practices in railways infrastructure management, proves that Life Cycle Cost based management of the infrastructure is still in an early phase of development *(IMPROVERAIL, 2002)*. Although (regional) maintenance managers probably used to consider the long-term impacts of costs and availability in their decision-making, this was at least not done explicitly and systematically. Mostly due to the high degree of technical specialization and the separate budgeting of construction, maintenance and renewal the focus in the design and maintenance processes remained on an operational level, ignoring possibilities to realize a better system performance and a reduced cost of ownership *(Zoeteman, 1999)*.

This paper presents the results of the IMPROVERAIL project, which contributes to the state of the art by developing –among other things- a harmonized LCC methodology for Railways Infrastructure Management, in terms of investment, maintenance and renewal costs, vehicle-infrastructure interaction, delay and scarcity costs, accident and environments costs. This will take place when the costs that fall under the responsibility of the Infrastructure Manager are identified. On the other hand he has to develop a costing mechanism for the use of the infrastructure, so that he/she will be able to produce viable charging schemes.

2. Life cycle cost analysis

LCC analysis has three components, namely inventory analysis, impact analysis and improvement analysis. Inventory analysis is a technical, data intensive process of quantifying requirements and releases for the entire life cycle of an asset, process, material, or activity. Qualitative aspects are best captured in impact analysis, although it could be useful during the inventory to identify these issues *(Woodward, 1997)*.

The impact analysis component is a technical, quantitative, and/or qualitative process to characterize and assess the effects identified in the inventory stage. This analysis addresses impacts; Life cycle impact analysis does not necessarily attempt to quantify any specific actual impacts associated with an asset or a process. Instead, it seeks to establish a linkage between the asset or process life cycle and potential impacts. The improvement analysis component of LCC Analysis is a systematic evaluation of the needs and opportunities to reduce the impacts occurring throughout the life cycle of an asset, process or activity. This analysis may include quantitative and qualitative measures of improvements. It has not undergone much research as compared with the other two components of LCC Analysis.

The general procedure for LCC analysis that it will be followed in this project will follow the general above stages but more specifically is based on one proposed originally by Harvey, and it is summarized in Figure 1

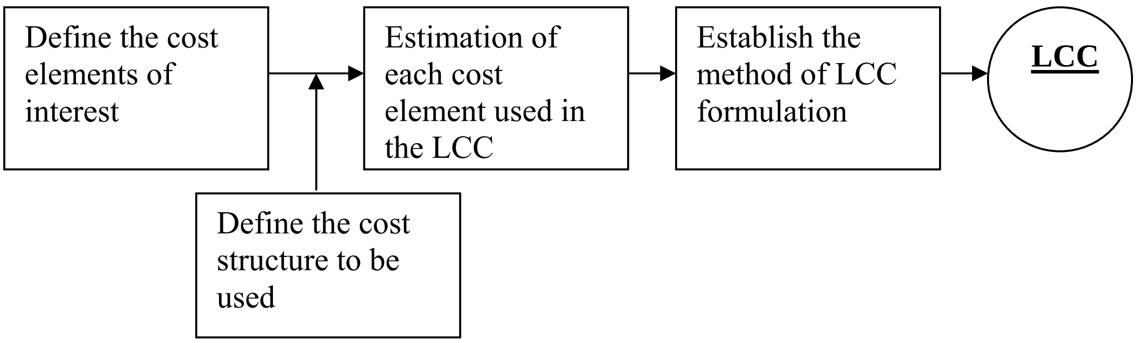

Figure 1. Harvey's life cycle costing procedure

Briefly, the four stages of the procedure are presented below and will be later analyzed.

The cost elements of interest are all the expenditures that occur during the life of the asset. From the definition of LCC previously provided it would be apparent that the LCC of an asset includes all expenditure incurred in respect of it, from acquisition until disposal at the end of its life. Whilst there is a general agreement that all costs should be included, opinion varies as to their precise identification.

Defining the cost structure involves grouping costs so as to identify potential trade-offs, thereby to achieve optimum LCC. The nature of the cost structure defined will depend on the required depth and breadth of the LCC study, and a number of alternative structures can be proposed.

A cost estimating relationship –or else measurement method - is a mathematical/quantitative expression that describes, for estimating purposes, the cost of an item or activity as a function of one or more independent variables. Historically collected costs will normally be the basis of such entities, utilizing linear, parabolic, hyperbolic, etc., relationships. The mathematical expression depends also on the costing approach; from the economists point of view there are two convenient approaches we can measure the railway infrastructure managers' costs:

- Average costs approach: the fully allocated method approach
- Marginal costs approach

Finally, establishing the method of LCC formulation involves choosing an appropriate methodological framework to evaluate the asset's LCC.

3. Cost elements of interest

From the review of existing practices in railways infrastructure management all the LCC elements were identified. All these LCC elements are relevant to the infrastructure management and dependent on vehicle-infrastructure interaction. They are:

A. Infrastructure costs

On a LCC (Life Cycle Cost) basis, rail infrastructure cost structure comprises the following cost categories:

- **Investment**: Acquisition of assets - *Land purchase*, New Construction (buildings and railway lines), Railway lines extensions
- **Renewal**: Track renewal, Building renewal, Major maintenance (Tracks, Switches, Ballast, Stations, Bridges, Tunnels, Catenaries, Signalling installations, Telecom installations etc.), Consultancy costs (external advisors)
- **Maintenance and Repairs**: Repairs (Tracks, Switches, Ballast, Stations, Bridges, Tunnels, Catenaries, Signalling installations, telecom installations etc.), Seasonal maintenance, Cleaning/ Cutting, Check conditions
- **Operations, Servicing**: Servicing of bridge beddings, Traffic lights, Operation of signalling, traction current, power consumption (electricity)
- **Management/ Administration**: Administrative costs, Wages, Security-Police, Scheduling & Planning, Training costs for staff
- **Disposal**: Disposal of used materials

B. Delay and Scarcity costs

- **Delay**: staff cost, energy consumption, vehicle capital cost, commercial costs – customer reaction
- **Scarcity**: Penalties for non-availability

C. Accident and Environmental costs

- **Accident**: Materials damage, Administration costs, Medical Costs, Production losses, Risk value
- **Environmental**: Air Pollution Cost, Noise Cost

D. Life of Infrastructure Components: The average operational life expectancy for railway infrastructure components

E. **The Discount Rate**: Choice of the appropriate discount rate, based on best practices, if not applied by the Infrastructure Manager.

The basic principle of the methodologies to be applied for each of the cost categories is the calculation of these costs over a pre-defined time period for each infrastructure component. An indicative infrastructure component decomposition is:

Linear Infrastructures and Equipments:

- Superstructure: track
- Substructure: ground, formation
- Structures: tunnels, bridges, noise barriers
- Equipment: catenary, signaling and telecom installations

Spot Fixed Equipment:

- Switches/turnouts, crossings
- Stations
- Service and light repair facilities
- Maintenance and heavy repair facilities
- Central facilities for the maintenance of fixed equipment

4. Defining the cost structure

Very careful thought must be devoted to the design of the management information system necessary to capture this wealth of information and make possible to identify potential trade-offs, thereby to achieve optimum LCC. In this section the time dimension as well as the interrelations between cost elements are taken into account.

4.1 Information/ data requirements

The data requirements to produce a LCC analysis are extensive, and will probably be an amalgam of information obtained both in-house and by forecasting the values. It is probably advisable to have a checklist of all aspects, which potentially contribute to the cost-effectiveness of a particular capital asset, and cost-effective trade-offs that can be performed among the parameters.

The information sought by LCC will involve financial, time related and quality data associated with reliability, capacity utilization and maintenance procedures, leading to an understanding of the relationship between the capital costs of specification, design, acquisition and disposal and the costs of operation, and maintenance as well as the external costs (accidents, environmental). These concepts are illustrated in Figure 2.

Depending on the importance and the cost of compiling LCC records, it may be worth developing and integrated database, shown in Figure 3.

4.2 Cost trade-offs and necessity for scenario development

Looking at new investments, as it is the case in most transport industries, railways suffer from the fact that a large proportion of costs incurred are related to the initial investments which tend to be considered as sunk costs and therefore are hardly related to the level of activity. In fact, the financial target for a transport system is usually to be able to keep up with operational costs, as infrastructure tends to be considered as a public entitlement and is not usually subject to consideration for charging purposes or even return on investment.

The importance of the previous remark lies on the need to adapt the trade off between High Initial Costs / Lower Running Costs to the expected demand for additional supply. If this aspect is overlooked, it may well result on a misleading low lifecycle cost while in fact it may be proved wrong the decision to invest, since e.g. the opportunity costs would become a dead weight.

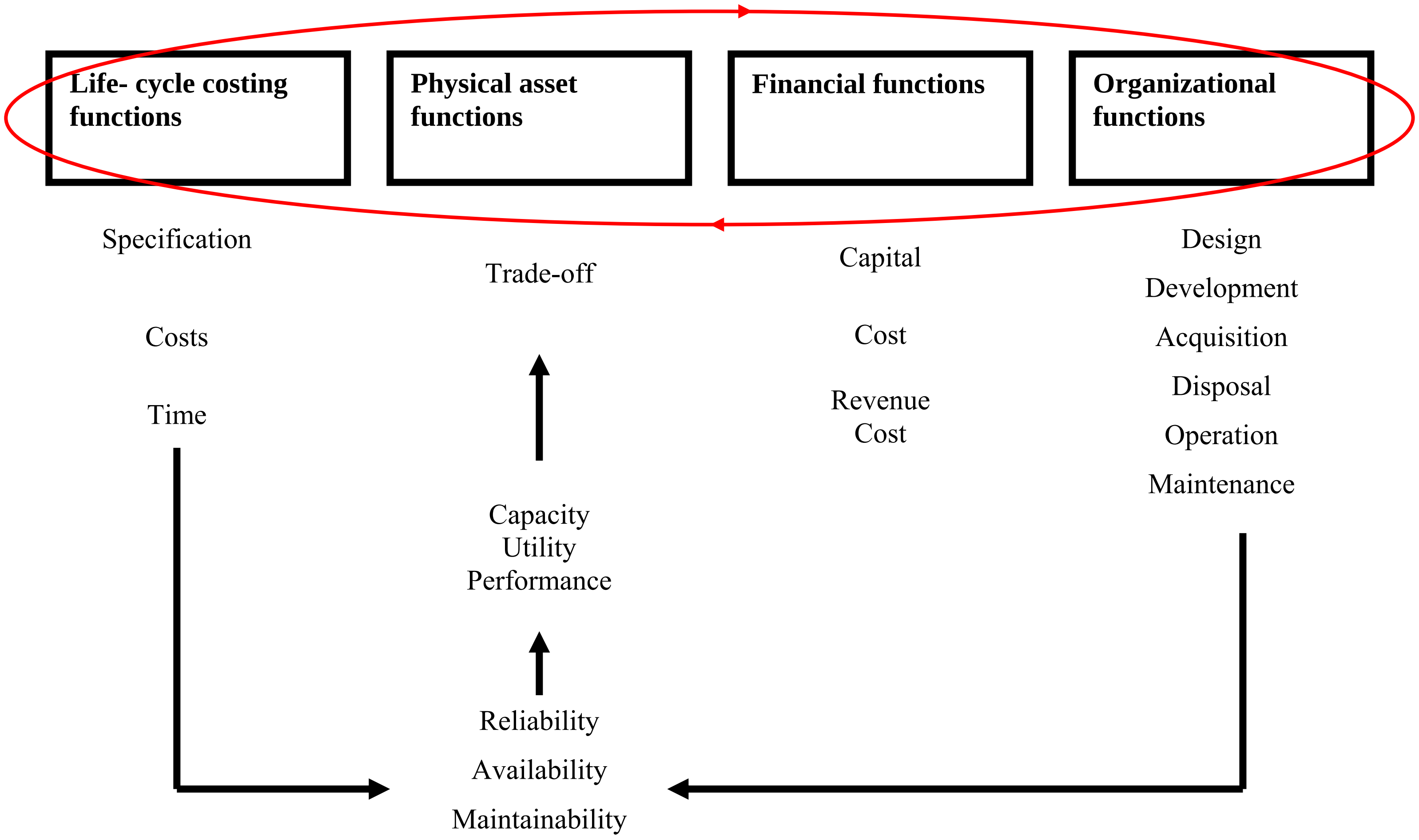

Figure 2. Cost elements integration in Life Cycle Costing (Source: IMPROVERAIL, 2002)

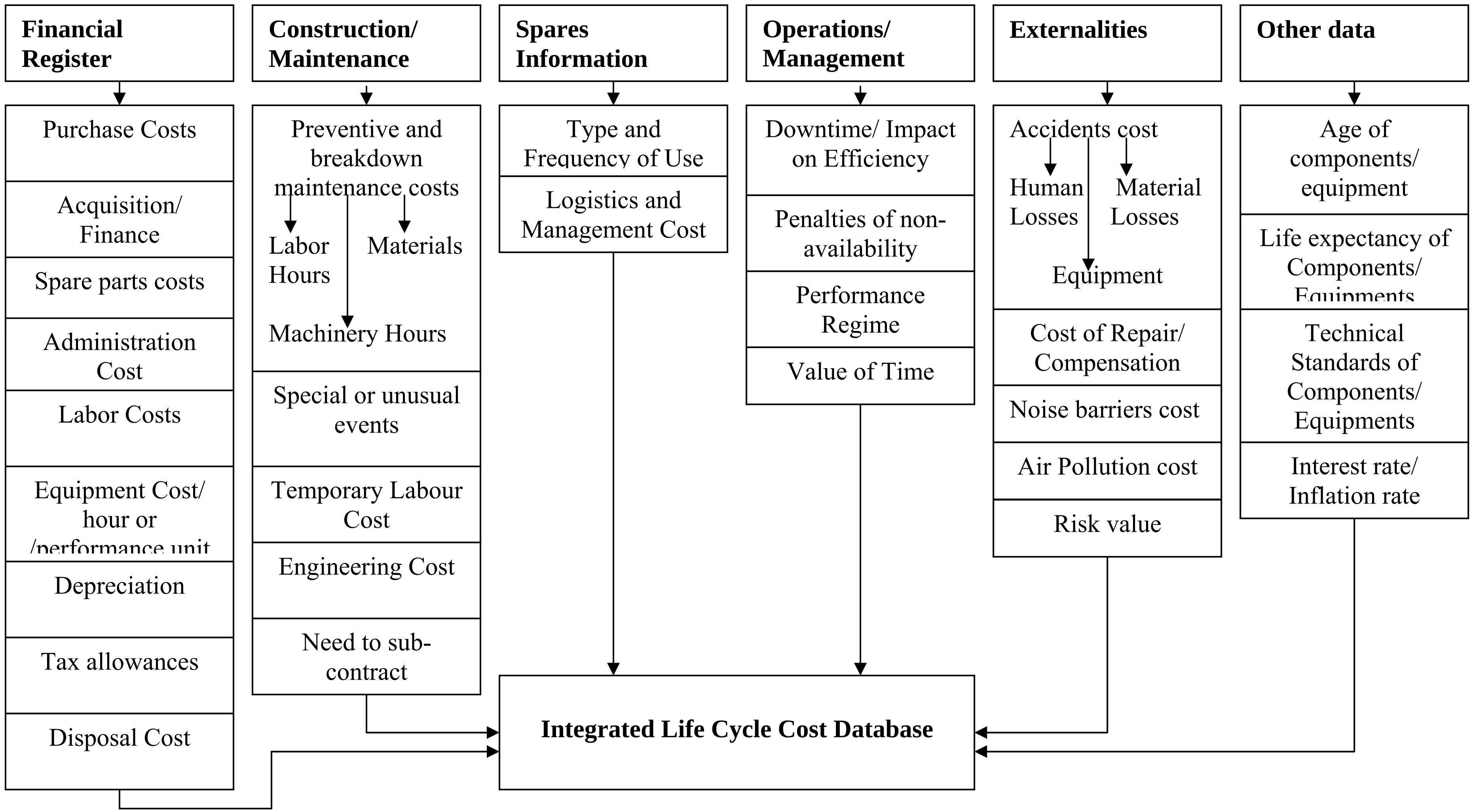

Figure 3. Design of an integrated LCC database (Source: IMPROVERAIL, 2002)

Resources are naturally scarce and should therefore be used in the best way possible. Therefore, considering the trade off between the decision to invest and to perform maintenance or renewal works is one of the underlying principles of a LCC analysis. The possibility of trading – off initial enhanced capital against subsequent maintenance savings is one of the underlying principles of a LCC analysis. This aspect may be illustrated by reference to Figure 4.

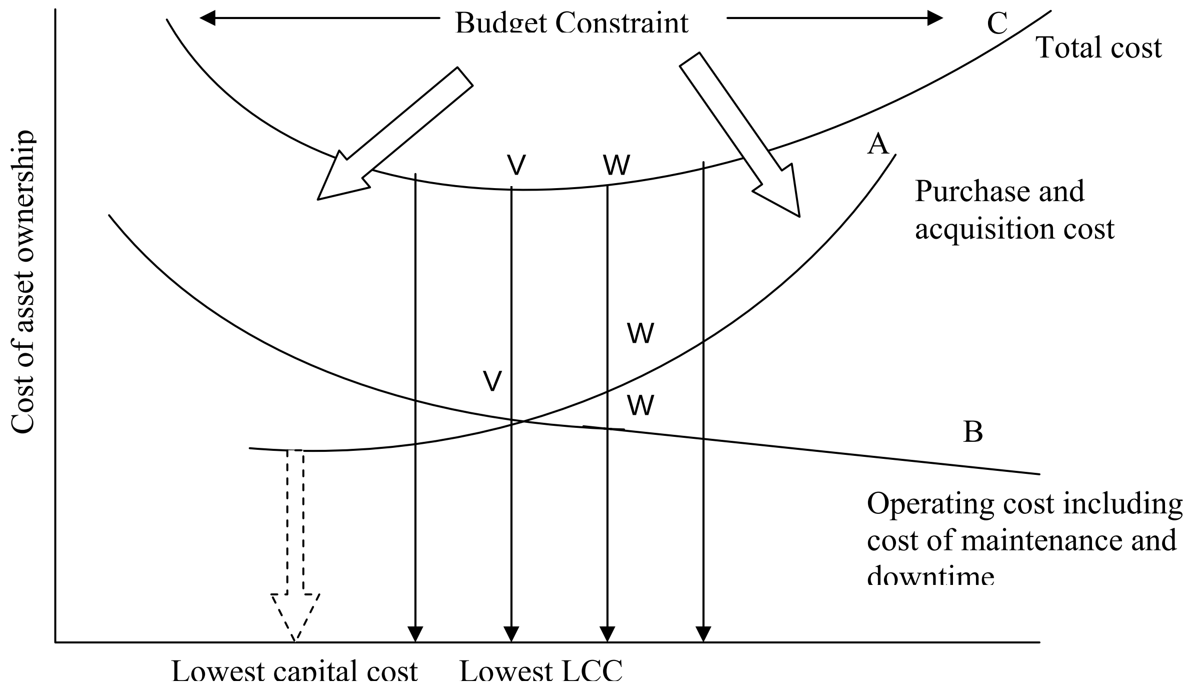

Figure 4. Cost trade-offs in asset ownership (Source: Woodward, 1997)

An increase in capital expenditure, as illustrated by *Curve A*, results in increased asset availability and reduced maintenance costs, measured by *Curve B*. Where total cost, *Curve C*, is at minimum. The optimum LCC of asset ownership is derived. The lowest capital cost alternative can, in contrast, be seen to have a very high LCC. In many cases, the optimum LCC is not critical, such that different combinations of capital and maintenance cost levels between points *V* and *W* will not significantly affect LCC.

A budget constraint is also shown, with the thick arrows indicating constraint on capital and maintenance expenditure, and the thin arrows a life cycle constraint for the asset LCC as a whole. As regards, specific examples of trade-offs, the following may be considered:

- Run the asset until it breaks down or replace it;
- Use the existing infrastructure with the existing capacity or proceed with capacity expansion; or else new vs. remanufactured;
- Devote more resources to the R & D stage to increase reliability and maintainability and thereby reduce maintenance cost;
- Increase asset efficiency (involving higher development/capital costs) to reduce scrap;
- Spend more on automation (higher initial costs) leading to lower manning costs;
- Buy more expensive equipment with a longer life.

These trade-offs are the basis for the investment scenarios, which the Railways Infrastructure manager must develop and examine. For example, within the life cycle frame, investment costs cannot be considered fixed. Different assets with different initial investment yield different returns and have different risks attached to them. Therefore an asset with high initial costs and probably high efficiency will result in the long run with lower LCC from an asset with low initial cost, due to low maintenance costs versus high maintenance costs.

Traditionally, railways replace components after they failed. Today, they are taking a more proactive approach such as take into account failure rates, and replace components in the mean time between failures instead of performing complete overhauls. When it comes to new vs. remanufactured components, whoever responds the quickest and offers the best quality and reliability wins, according to the practices followed by the railway supply community. Though initial cost is still a main factor in the purchasing process, the real challenge for suppliers is lowering the cost of ownership. Reliability and productivity over time, even at a higher initial cost, is becoming more important. The path to determining life-cycle cost of new vs. rebuilt components is not clearly defined. It is dependent upon the type of component and its application. Although prices are readily available, specific reliability data is not.

Therefore, macro-investment scenarios must be developed and examined - before the LCC formulation -, which must examine investment decisions as well as interrelation of investment costs and the other costs of railway infrastructure provision and use. The investment scenarios are mostly depended on Infrastructure Manager’s expertise, else there is no specific rule for choosing or constructing them, but according to past experience and expertise as well as the “desired” output, assumptions are made and scenarios are built. Next a suggested breakdown of steps for building alternative investment scenarios will be presented, as well as some default macro-investment scenarios are described next.

4.2.1 Steps for building scenarios

The necessary steps are five (5):

Identification of current status: it aims at establishing a complete view of the existing situation. This includes a coherent asset register that is able to link data of inspections, costs and operations (e.g. passengers, tonnes transported) with the asset age, location and any specificities of the asset, as well as the financial status of the Infrastructure Railways Company.

Configuration of the desired status: starting from the objectives, the Infrastructure manager must identify “where he wants to go” in terms of the infrastructure status. This includes setting clear targets/ threshold values for comparison with the final output.

- *Perform Key Considerations*: different issues should be addressed based on past performance as well as on research, knowledge and experience, such as:
  - → What is the impact of different interest rates?
  - → What happens with the costs and the availability for different designs or construction methods?
  - → What is the impact of the number of trains on costs and availability?
  - → What is the impact of the availability of other railway assets on the requirements for track design?
  - → What is the effect of different construction methods on safety and environment?
  - → What is the effect of longer maintenance slots?

These issues are necessary to identify those cost elements that will have a significant impact on the overall LCC of the asset(s) under consideration or those that will clearly vary between alternatives. These elements must be further analysed since they will probably be the variables of the alternative scenarios.

- *Planning and forecasting concepts*: as for planning and forecasting, the (average) renewal, maintenance and inspection needs per type of asset should be available (e.g. Mean Times To Restore Services and Mean Time Between Failures). The introduction of new designs of components and maintenance technologies, such as Condition Monitoring and advanced renewal trains, can influence these parameters. Traffic conditions as well as their impact must be taken into account and finally "sensitive" parameters such as accidents and environmental impacts should be considered.
- *Recognition of the "alternative paths":* the possible combinations of technological, policy and fiscal measures will be produced. Each combination will probably serve one or more of the following principles: availability, quality, longevity, safety, flexibility, performance, overtime and cost.

4.2.2 Proposed scenarios

The proposed default scenarios can form three categories, which are: Strong, Medium and Mild. The categorization is explained as follows:

Strong: for high initial investment, strict targets and threshold values that are more "accessible" to Infrastructure Managers, being financially healthy and without budget constraints.

Mild: for low initial investment, not so strict targets (enough to retain the level of service equal or somewhere above the existing situation), convenient (if there is a budget constraint).

Medium: for actions that lie between the mild and strong scenarios.

Mild Scenarios: Maintain Conditions

In the "Maintain Conditions" scenario, assets are replaced and rehabilitated over a pre-defined period with the target of reaching an average asset condition at the end of the period that is the same as the asset condition that existed at the beginning of the period. The model does not necessarily maintain the weighted-average condition of the assets in each year over the period because replacements and rehabilitations are only made when the condition of assets falls below industry standards. These minimum condition levels vary according to asset type. With this scenario, the average condition of the asset base improves during the initial year of investment and then fluctuates between this improved level and the initial condition level, which is reached at the end of the pre-defined period.

Medium Scenarios: Maintain Performance

The "Maintain Performance" scenario assumes that demand for capacity increases over time. Therefore, according to this scenario, assets are added at a rate necessary to accommodate the increase in capacity to achieve -at the end of the pre-defined period- the average utilization and average speed that existed in the base year.

Strong Scenarios: Improve conditions and performance

<u>(a) Improve Conditions</u>

In the Improve Conditions scenario, asset rehabilitation and replacement is accelerated in order to improve the average condition of each asset type in the existing asset base to at least "good" level. Assets are replaced to achieve a higher level of condition than under the Maintain Conditions scenario. This does not allow the assets to depreciate as much before they are replaced. This scenario eliminates any backlog of deferred investments that are needed to reach a "good" condition level. Asset conditions make their most significant improvement in the first year trending down gradually with year-to-year variations to a "good" condition level by the end of the pre-defined period.

(b) Improve Performance

The Improve Performance scenario simulates capital investments for construction and expansion that increase average network speeds, safety and lower scarcity and delay costs to threshold levels by the end of the chosen (pre-defined) period. This scenario assumes high initial costs, which eventually lead to lower maintenance and renewal costs as well as greater safety, reliability and liability of the infrastructure provided. This scenario is a long-term one.

The above-mentioned categories have different underlying principles:

- *Asset Rehabilitation and Replacement*: Reinvests in existing assets to improve their physical condition. The Asset Rehabilitation and Replacement case uses statistically determined decay curves to simulate the deterioration of track, sleepers, and other infrastructure components. As the assets deteriorate, their condition declines, requiring investments in rehabilitation and replacement. The main objectives behind are: flexibility, overtime and cost.
- *Asset Expansion:* Invests in new assets to maintain operating performance to meet projected increases in the demand for infrastructure use. The Asset Expansion case identifies the level of investment that will be required in each major asset category to continue to operate at the current level of service as demand for capacity (e.g. traffic) increases, i.e., to Maintain Performance. The main objectives behind are: availability, flexibility, performance, overtime and cost.
- *Performance Enhancement:* Invests in new assets to improve operating performance as measured by speed and capacity utilization. The Performance Enhancement case simulates investments that "Improve Performance" either by increasing the average operating standards or by reducing the average delay, scarcity and external costs. The objectives behind are: availability, quality, longevity, safety, flexibility, performance, overtime and cost.

4.3 Time dimension

Besides the measurement of the various elements of Life Cycle Costing, the time dimension must be examined. For instance, the following must be considered: the way in which maintenance costs and corresponding delay costs arise with the age of the infrastructure, and how the timing of renewals as well as the induced traffic influences these. Furthermore, the technical and technological changes over time as well as the issue of discounting must be taken into account.

Base maintenance –or renewal- task for track infrastructure is estimated including savings such as: getting the same work for less money by improving techniques and methods, or reducing waste; examining standards to ensure that too high a work input is not being demanded; using technical change to reduce maintenance or operating costs. Variations to the maintenance can be agreed because of changes in the nature or volume of the work caused by: asset replacement or renewal timing; asset age; vandalism & accidents; the accumulated rail traffic; a change in the nature or volume of rail traffic *(Lie-Fern Hsu, 1999).*

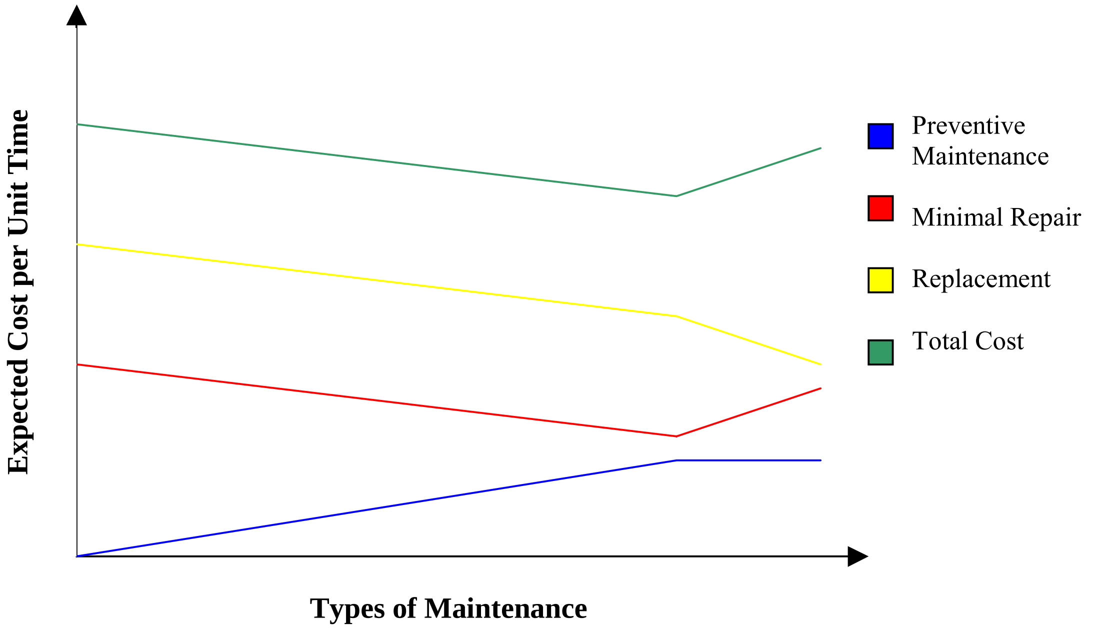

Figure 5. Comparative cost analysis (Source: Lie- Fern Hsu, 1999)

Since asset age and traffic volumes will probably increase over the period considered, then it is expected that, other things being unchanged, there would be an increase in maintenance activity. An indicative impact of maintenance activity on different kinds of costs – regarding railway infrastructure – per unit time is shown below in Figure 5. For other kind of infrastructure, like signalling for example, technological changes over time, determine the renewal timing.

Regarding the issue of discounting, a consensus must be found. It is well accepted that impacts occurring in the future should be given a different weight than impacts occurring today, so they should be discounted. This means for an asset the cost or benefit of X € appearing in the year T has a capital value of X/(1+r)T, when referred to the present year (t = 0). However, how to determine appropriate discount rates r for public and long-term decisions does not lead to an unequivocal solution.

Regarding discount rates as the expression of the rates of time preference, they can be separated into a component of pure rate of time preference (disregarding income or welfare effects from present to future) and the growth-related component of discounting. The latter consists (in the social perspective) of the per-capita growth rate of an economy, multiplied by the elasticity of the marginal utility of consumption (that is usually assumed as one).

For long-term cost impacts (or investments) extending to more than one generation, it is often argued that lower values should be used, as the individual time preference is influenced by the limited individual lifetime, so that the interests of future generations may not be fully reflected in the current discount rates. This argument is further strengthened if one accepts the assumption that the average long-term economic growth is lower than the growth observed in the last decades in Europe. Furthermore, it can be argued, that an increase of income in the future might lead to a shift in the relative utility of goods.

5. Cost calculation/ estimation

5.1 Investment costs

Investment costs or Capital costs consist of the economic depreciation of infrastructure capital and of interests expressed as the opportunity cost of capital. The weight of both components in total capital costs differs from country to country, depending also on the age structure of infrastructure assets. The main factors influencing costs identified for the value of the infrastructure capital stock hold also true for capital costs since these are derived from the asset values. Additional cost drivers result rather from methodological aspects such as the depreciation method chosen and the interest rates applied, as explained in the following section. This category comprises all the capital expenditures as presented below:

- Acquisition of assets - Land purchase
- New Construction (buildings and lines)
- Enlargement (Line extensions)

5.1.1 Perpetual inventory method

The depreciation is calculated within the perpetual inventory concept by applying – in most cases- a linear depreciation method. For the remaining value of assets, the interests are calculated. Depreciation and interests are contained in an annuity, which is calculated according to the known annuity formula:

$$a = u \bullet \frac{\frac{z}{100} \bullet \left(1 + \frac{z}{100}\right)^{d}}{\left(1 + \frac{z}{100}\right)^{d} - 1} \qquad (1)$$

Where:

a-annuity for the asset value
u-asset value
z-interest rate in percent
d-depreciation period (years) for the assets.

This formula gives the annual amount for refinancing investments. The advantage of using the perpetual inventory approach is that a distinction between depreciation and interest can be made, which gives transparency on the value and weight of these cost components. However, since it is based on the perpetual inventory method, the same comprehensive database previously mentioned becomes necessary. The advantage of the annuity method is the easy application, which does not require any long investment time series. However, a differentiation between the level of depreciation and interest cannot be made.

5.2 M & R functions

This category includes running infrastructure costs:

- Renewal
- Maintenance and Repairs
- Operations, Servicing
- Management/ Administration

In contrast to asset valuation and calculation of capital costs there is no sophisticated method to be applied for quantifying the running infrastructure costs. Since running costs

are monetary costs, valuation is rather straightforward. Hence running costs are usually taken from existing business accounts and therefore, no general methodological rules can be provided, depending mostly on the level of details in the business accounts.
These costs of the infrastructure depend heavily on the means of operation, in other words on vehicle-infrastructure interactions. Furthermore, it a problem might exist for collecting data for these costs. In fact, company can consider those data as commercially sensitive and thus they cannot be disclosed.

5.3 Delay and scarcity costs

Regarding the costs of delays the following cost categories can be differed:

- Staff costs
- Energy costs
- Vehicle capital cost
- Commercial costs – customer reaction

Staff cost: For the calculation of the increased staff costs due to delays, the number of staff per train (driver, attendants) with the corresponded unit costs [€/h] have to be ascertain. Normally the costs are calculated since the first delay minute, in cost / minutes of delay.

Energy cost: The costs for increased energy consumption depend on the line layout, train mass and the driving policy of the driver. Delays of freight trains – usually caused by the narrow length of the time slot at the final station- are critical when the arrival time is important. In general the driver is asked to reduce the delay with any means at his disposal, provided that safety standards are maintained. This results in more acceleration and deceleration actions than for the normal train run and therefore the energy consumption will increase. Up to now the energy consumption of trains is estimated, although in the future the electric locomotives will be equipped with an energy counting box.

Vehicle capital cost: The estimation of additional expenditure for vehicles is complex. The planning of operating reserves orient itself so far not at potential delays, but at the logistic availability of the vehicle fleet. In some related publications these costs are not calculated. Therefore for the calculation of additional rolling stock (e.g train vehicles, set of trains) costs, it is to be clarified whether an operating reserve is planned exclusively for the case by delays caused by maintenance / renewal, or by line overloading or due to accidents.

Commercial costs – customer reaction: Commercial costs are reduced revenues resulting on delays or planned extended travel times. Regarding passenger trains, these costs are caused by reduced sales of tickets, refunding of tickets. For freight trains they are caused by reduced cargo transport and conventional penalties for freight trains. The customer reaction, both for passenger and freight is almost not recorded, and thus it is difficult to include such parameter in the calculation of delay costs.

Regarding scarcity costs; the scarcity value of train paths could be estimated with the price paid, if paths were auctioned. However, in practice, there are difficulties with this approach, since it is not followed in a systematic way by the railways. A workable alternative is to permit negotiation of path allocation and observe the agreed prices between service providers and infrastructure managers. The complexities of rail systems are such that no simple formula can be found to estimate scarcity values of slots for a variety of typical circumstances. It is recommended that penalties for non-availability, is the best way to reveal scarcity values of rail slots.

5.4 Environmental and accident costs

The environmental costs can be evaluated with different means. Some costs are incurred in monetary terms (crop damage for acidification). For other costs, the willingness to pay method could be used to value health cost, disturbance of noise. As some environmental costs have long-term nature, it is recommended that the relevant discount rate (lower than the discount rate observed in capital market) should be that used in social cost benefit analysis. For the evaluation of environmental costs, three subcategories are proposed:

- Air pollution
- Global warming
- Noise

For quantifying the costs due to airborne pollutants the impact pathway approach (IPA) is used in several countries, e.g. Germany, Switzerland. It consists in an estimation of emissions, dispersion and chemical conversion modelling and calculation of physical impacts and monetary valuation of these impacts *(UNITE, 2001).* The method of calculating costs of global warming due to CO_2 emissions basically consists of multiplying the amount of CO_2 emitted by a cost factor. For the valuation of noise, health impacts caused by exposure to noise were estimated by IPA again or by hedonic pricing using values taken from the noise sensitivity depreciation index.

For the evaluation of accidents costs, different methods exist. The traffic accident risk depends on the volume of traffic and on the type of vehicle (rail accidents differ between rail track types, on high quality tracks the fatality risk is 30% lower than on the average track). It is also useful to consider risk in relation to vehicle kilometres for the same category of infrastructure. Having determined the risk of accidents, the costs themselves fall into two main categories: material and non-material costs. Material costs include: property damage, administrative costs, medical and hospital cost, net lost of production and congestion caused. The non-material costs are related to the emotional and social costs of casualties caused by the accident. Material costs are purely financial cost. For the "non material costs", it is recommended to estimate them by using the willingness to pay method.

5.5 General LCC elements

The following elements are also needed for the LCC evaluation:

- The discount rate
- Life Cycle of an asset

The life cycle of the infrastructure components or assets is known. Since asset component costs for differing options occur at varying times throughout the asset life cycle, converting them to values at a common base year, it is the only way that provides comparisons. The discount rate does that.

5.5.1 Calculation of discount rate

For the purposes of discounting, there are three relevant expressions of asset costs. These are:

Nominal Cost, C_N*:* The expected costs (ie. including inflation and price movements due to changes in efficiency, technology, etc.)

Real Cost, C_R: The cost expressed in values of the base date excluding inflation but including changes in efficiency, technology, etc.

Discounted Cost, CD: The Real Cost discounted by the Real Discount Rate which is equivalent to the Nominal Cost discounted by the Nominal Interest (or Discount) Rate. The Discounted Cost is thus often referred to as the *Net (or Discounted) Present Value.*

Therefore, for an asset component having a Nominal Cost, CN in Year *n*, then the Real Cost (or Present Value), CR at the base date (Year 0) is given by:

$$C_R = C_N * (1+f)^{-n} \qquad (2)$$

and the Discounted Cost (or Net Present Value), CD at the base date (Year 0) is thus:

$$\begin{aligned} C_D &= C_R * (1+d)^{-n} \\ &= C_N * (1+f)^{-n} * (1+d)^{-n} \\ &= C_N * (1+f)^{-n} * [(1+i)^{-n}/(1+f)^{-n} \qquad (3) \\ &= C_N * (1+i)^{-n} \end{aligned}$$

$$(1+d) = [(1+i)/(1+f)] \Rightarrow d = [(1+i)/(1+f)] - 1 \qquad (4)$$

Where:

d = (Real) Discount Rate
i = Nominal Interest (or Discount) Rate
f = Inflation Rate

6. Method of life cycle cost formulation

The three initial procedures were presented in Figure 1. Following these, the remaining procedure of Life Cycle Costing Formulation (else formulation of a comprehensive methodological framework for evaluation of the asset's LCC) takes place, which comprises seven steps that are described below, and it is summarized in Figure 6.

Step 1: The Management profile (MP) describes the periodic cycle of the assets, and indicates when asset will be, or alternatively will not, functional. It comprises the modes of start up, operating and shut down. The management profile is not unique since it includes all the assets of the infrastructure and their interrelation varies among the alternative macro-investment scenarios, which have been developed previously.

Step 2: Asset registration – technical data will be collected (to feed the LCC Database).

Step 3: Asset cost elements; every cost element or area of cost must be identified- cost data will be collected (to feed the LCC Database).

Step 4: All costs are first calculated at current rates according to Cost Calculation Functions developed, receiving input from Steps 2 and 3 (or else from the LCC Database) for each alternative management profile.

Step 5: All costs need to be projected in the future at appropriate rates of inflation. The difficulty in projecting such figures should not be underestimated, since lack of precision here can lead to inaccuracy in the final calculations. However, inflation rates, like interest rates, have something of the "self - fulfilling prophesy" to them, and if forecasts from "experts" are available, then some reliability must be placed upon them.

Step 6: It should be recognized that money has a time value and the costs occurring in different time periods should be discounted back to the base period to ensure comparability. How to establish the appropriate discount rate is, of course, the subject of much discussion.

Step 7: Summing all the costs involved will enable the LCC of the asset to be established, for each alternative management profile.

The output delivered by the Life Cycle Cost Formulation method is an *'Annual LCC'* over the period of analysis, for each alternative management profile. This is needed by the infrastructure provider to manage the infrastructure on a break-even basis. Hence, it is a flat amount needed to construct, finance and maintain railway infrastructure assets during their life cycle. Since the expenditures are not equally distributed over the years, the impact of interest costs is included in this amount. Moreover, the estimated penalty costs for non-availability are included. This annual LCC is one of the most decisive indicators for the decision-makers, in order to decide for the future strategy of railway infrastructure provision and use (the best management profile).

7. Summary and conclusions

Review on the existing LCC practices in railways infrastructure management, proved that Life Cycle Cost based management of the infrastructure is still at an early phase of development. Although the LCC methodology presented in this paper has some disadvantages, it is a first attempt to provide a comprehensive method for LCC calculation and it also presents advantages too.

The basic advantage is that it enables comparisons of different investments, the costs of which include all costs borne by society. Also, it enables ccomparisons between different infrastructure decisions varying in level of infrastructure type and use, maintenance conditions and techniques, vehicle characteristics, accident risk, pollution and time-horizon. All these cost elements can be compared with investment costs, which can provide aid for the best decision-making.

Some examples of the functions, which the LCC Methodology supports, are:

- Analysis the consequences of different track designs and investments on maintenance and renewal, safety and environmental implications.
- Analysis of consequences of different maintenance and renewal cycles and techniques on LCC
- Effects of vehicle-infrastructure interactions on delay and scarcity costs
- Effects of maintenance and renewal cycles and techniques on delay costs
- Analysis of consequences of different operational conditions
- Analysis of consequences of safer rolling stock to be implemented in the future
- Changes in system risk of accidents
- Changes in valuation of pollution
- Effects of changes in deflation rate

Furthermore, it is easy to understand and apply, and it gives results in a very simple form in order to make the analysis easier for the Infrastructure Manager. On the other hand, the LCC Methodology does not reduce the need for system-specific analysis of cost factors and the analysis of technical life cycle and failure risk of physical assets. With these values provided, the methodology will be helpful for further comparison of alternatives. Finally, it does not provide specific Alternative (macro-) Investment Scenarios; it just set breakdown steps for their formulation. Therefore the scenario's formulation is mostly based on the Infrastructure Manager's knowledge and expertise.

Acknowledgment

This paper is based on research carried out during the elaboration of the IMPROVERAIL research project, financed by the 5th Framework Programme on Research and Development of the European Commission

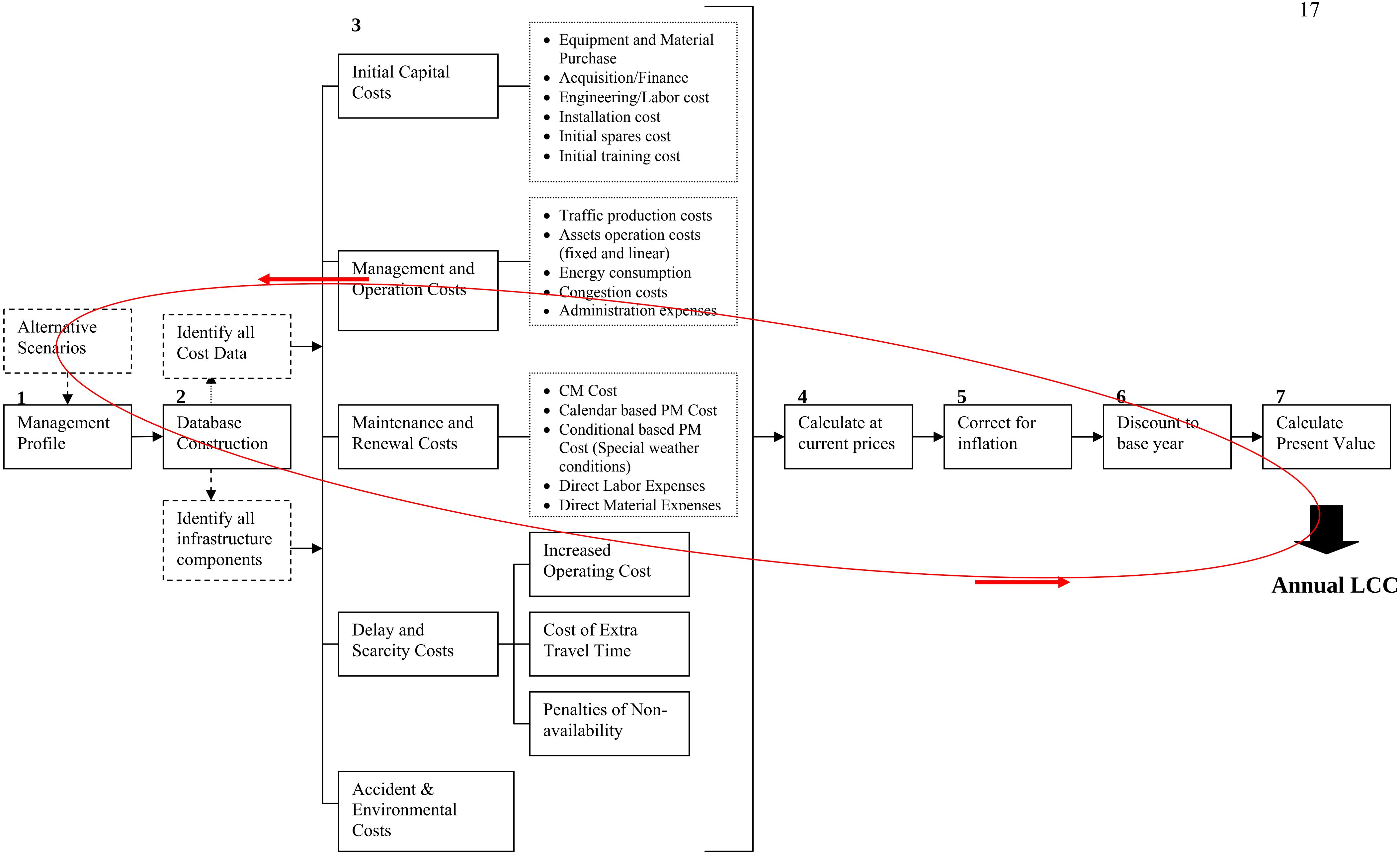

Figure 6. Life Cycle Costing Formulation (Source: IMPROVERAIL, 2002)

References

Harvey, G., 1976. Life cycle costing: a review of the technique, Management Accounting, pp.343-347

IMPROVERAIL Project, 2002. Deliverable 7 "Life Cycle Costs, Concepts and Definitions for Railway Infrastructure Provision and Use", Research project of the 5th Framework Programme on Research and Development, European Commission.

Lie – Fern, H., 1999. Simultaneous determination of preventive maintenance and replacement policies in a queue-like production system with minimal repair, Reliability Engineering and System safety, 63 161-167

U.N.I.T.E. project, 2001. UNIfication of accounts and marginal costs for Transport Efficiency, Research project of the 5th Framework Programme on Research and Development, European Commission.

Woodward, D.G., 1997. Life cycle costing – theory, information acquisition and application, International Journal of Project Management, 15 (6) 335

Zoeteman, A., Esveld, C., 1999. Evaluating track structures: life cycle cost analysis as a structured approach, World Congress on Railway Research, Tokyo.