Project no. TIP5-CT-2006-031415O

INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D 6.2.1 Unique Boundary Conditions

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Glossary

AASHTO	American Association of State Highway and Transport Officials
CBS	Cost Brakedown Structure
DCF	Discounted Cash Flow
EAC	Equivalent Annual Cost
FHWA	Federal Highway Administration
IEC	International Electrotechnical Commission
IM	Infrastructure Manager
IRR	Internal Rate of Return
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PBS	Product Breakdown Structure
PI	Profitability Index
RAMS	Reliability, Availability, Maintainability and Safety
SP	Sub Project
TPV	Total Present Value
WACC	Weighted Average Cost of Capital
WBS	Work Breakdown Structure
WP	Work Package

1. Executive Summary

INNOTRACK addresses mainly the objective of reducing Life Cycle Costs (LCC), while improving the RAMS characteristics of a conventional line with a mixed traffic duty. In the field of railways, RAMS technology and LCC are widely implemented and will provide a definite advantage to the IM:s (Infrastructure Manager) in helping calculate costs for the implementation of innovative technologies. In the frame of INNOTRACK these methods will be defined at a European level and used to identify cost drivers and assess the track components. The sub-project SP6 deals with RAMS and LCC. Task 6.2 deals with Life Cycle Cost Methodology and a first step within this task is to address the required economical boundary conditions.

Life cycle cost analysis can be more or less detailed or ingenuous but it cannot deliver a fair decision support process without coherent rules. This deliverable addresses the need to agree on unique economical boundary conditions, specifically the capital budgeting techniques, the choice of proper discount rate and the choice of time horizon for LCC analysis.

Concerning capital budgeting techniques it was shown that Net Present Value (NPV i.e. Total Present Value in Life Cycle Costing) is the most accurate procedure for decision support. A combination of techniques and indicators can also be advisable as a complement to NPV results: particularly estimation of Annuity factor, break-even or in some cases Internal Rate of Return (IRR) can bring useful indications.

Economical boundary conditions are key factors on the results provided through LCCA. An in-depth evaluation of current practices concerning the discount rate and the time horizon on infrastructure project appraisal was performed. Most recent bibliography on the subject shows that, among the diversity of criteria and values adopted, there is a tendency to use reduced values for discounting combined with large periods of consideration.

A detailed theoretic analysis performed towards the definition of an unique criterion for discounting and the time horizon of LCCA has driven to the following first suggestions:

- To consider a variation of 3% to 5% for the discount rate, with a reference value of 4%
- To consider a range of 30 to 40 years as time horizon, with 40 years as recommended upper bound for large investments on ballasted tracks assessed through LCCA (closely linked with an accurate estimation of the alternatives residual value as discussed)

Both results are in accordance with most recent research and guidelines in project appraisal and life cycle costing practices.

These first findings will need to be further analysed and agreed within WP6.2 before adopting a final criterion for the on-going work within SP6.

2. Introduction

The Project INNOTRACK aims to develop a cost-effective high performance track infrastructure for heavy rail systems. INNOTRACK addresses mainly the objective of reducing Life Cycle Costs (LCC) while improving the RAMS characteristics of a conventional line with a mixed traffic duty.

INNOTRACK project brings IM (infrastructure managers) and railway supply industry together, to investigate and evaluate leading edge track system technologies, adopting a controlled methodology to assess life cycle cost benefits of “track-technology solutions” and of a set of emerging railway hardware solutions. It will also support the overall sustainability of the railway sector, meeting needs such as the increase of track availability and network capacity. The results of this project will build on a standardised LCC formulation developed within the project, based on best LCC practices at EU level and independently assessed.

Optimisation of track constructions or track components regarding technical and economic requirements is essential for railway companies to fit the market and to compete against other means of transport. Due to the long lifetime of the track and track components – ranging between 20 to 60 years – pre installation technical and economic assessments are necessary to optimize the track construction and get the return on investment (ROI) in a manageable timeframe. LCC and RAMS technology are two acknowledged methods for assisting the optimisation process.

LCC is an appropriate method to identify cost drivers and to gather the costs of a system, module or component over its whole lifetime including design and development, manufacturing, installation, operation, maintenance and disposal costs. Different views and evaluations allow the comparison of different systems and deliver necessary information for technical and economic decision.

In the field of railways, LCC methods are starting to be implemented and will provide a definite advantage to the IMs in helping calculate costs for the implementation of innovative technologies. In the frame of INNOTRACK these methods will be defined at a European level and used to identify cost drivers and assess the track components. The project is divided in 7 Sub-projects:

1. Duty
2. Track support structure
3. Switches and crossings
4. Rails
5. Logistics
6. LCC
7. Dissemination and Training

This report is included in Sub-project 6 LCC and covers an estimated analysis of the economical boundary conditions to be applied on LCC methodology.

2.1 Objective

The purpose of this deliverable is to analyze the economical boundary conditions for life cycle costing together with the capital budgeting techniques.

More specifically, the objectives are:

- To evaluate the different capital budgeting techniques and assess the most suitable methods for LCCA
- To assess the most relevant economical boundary conditions
- To gather common practices and experience on the consideration of the discount rate and time horizon of the project
- To appraise the most recent theoretical findings on the definition of those boundary conditions
- To discuss the interest of establishing an agreed criteria for discounting and time horizon
- To suggest a first range of values to adopt in the later stages of the project

2.1.1 Activities

- Synthesis of LCC general procedure
- Evaluation of the capital budgeting techniques
- Definition of key boundary conditions for LCCA
- Current state of the practice of the key boundary conditions: evaluation of the experience in transport infrastructure projects
- Definition of Unique Boundary conditions for Life Cycle Costing
    - Discount rate
    - Period of consideration and criteria to calculate residual values

2.1.2 Time schedule

The time to furnish the report (D6.2.1) was 9 months from the start of the project. The status of the report will be “public”.

2.2 Organisation and resources

Organisation and resources for this work package are given Table 1. ADIF is responsible for delivery of WP 6.2 which includes the current deliverable D6.2.1. WP6.2 ends in Month 18.

Organisation and resources

Workpackage	6.2 – Life Cycle Cost Methodology		Start date or starting event:				M1
Participant id	UIC	VAS	BV	ADIF	Alstom	NR	OBB
Person-months per participant	2.0	3.0	3.0	5.5	1.0	2.0	3.0
Participant id	DB	Corus					
Person-months per participant	6.0	1.0					

Another partner in the working group is ProRail.

2.3 Information acquisition

Information on LCC was obtained from the following sources:

- Previous Deliverables D.61.1 and D.6.1.2
- International Standards (IEC)
- Published papers, project reports and theses
- Internet research

3. Main section

3.1 LCC calculation

3.1.1 LCC general procedure

According to the IEC 60300-3-3, life cycle costing is the process of economic analysis to assess the total cost of acquisition, ownership and disposal of a product and its primary goal is to provide input to decision making in any or all phases of a product's life cycle. As defined in the same International Standard there are six major phases in a product's life cycle:

- Concept and definition;
- Design and development;
- Manufacturing;
- Installation;
- Operation and maintenance;
- Disposal.

In line with these definitions, a LCC model is basically an accounting structure that contains mathematical expressions for the estimation of each cost element (see fig.1) constituting the life cycle cost of a product. This usually includes:

- Ground rules and Assumptions
- Cost breakdown structure (CBS);
- Product/Work breakdown structure (PBS/WBS);
- Selection of cost categories;
- Selection of cost elements;
- Estimation of costs;
- Presentation of results (including a sensitivity analysis).

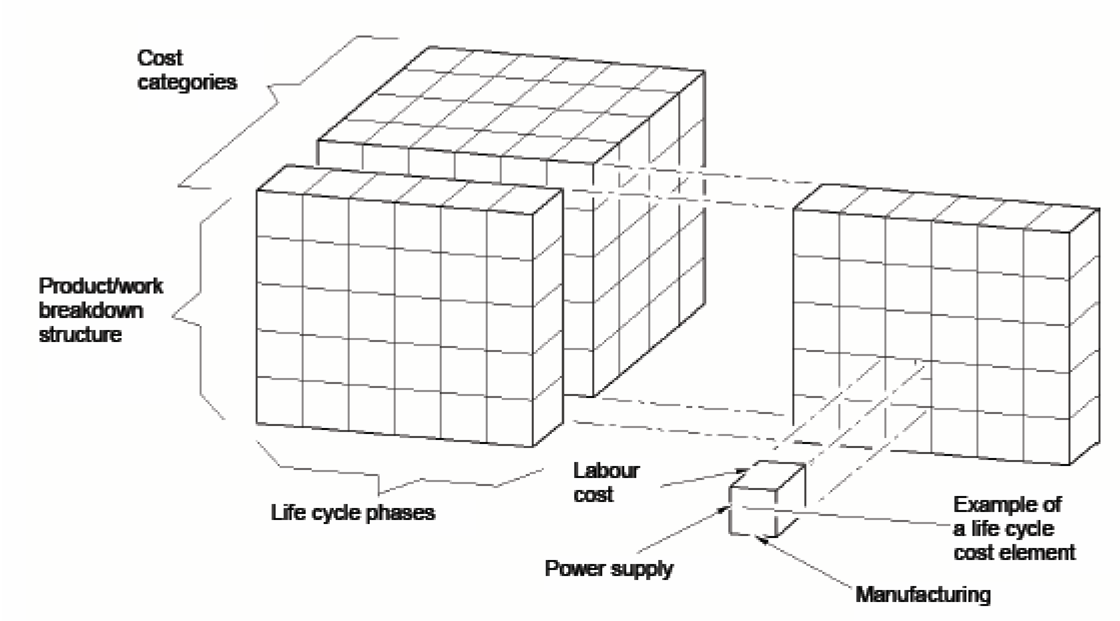

Fig.1: Cost element concept. Source: IEC (2005)

The CBS is a tree structure of the duty and costs that occur along the entire life cycle of a product. The PBS is a hierarchical tree structure of components that make up a product that can help clarify what is to be delivered by the project and can help build a work breakdown structure (WBS). These two structures, the PBS and the CBS, are connected through cost equations, since each cost element depends on the used material, the parameters of the material, etc., until the lowest indenture level (Fig. 2) The PBS might include product characteristics and variables that can be used as input for those cost equations.

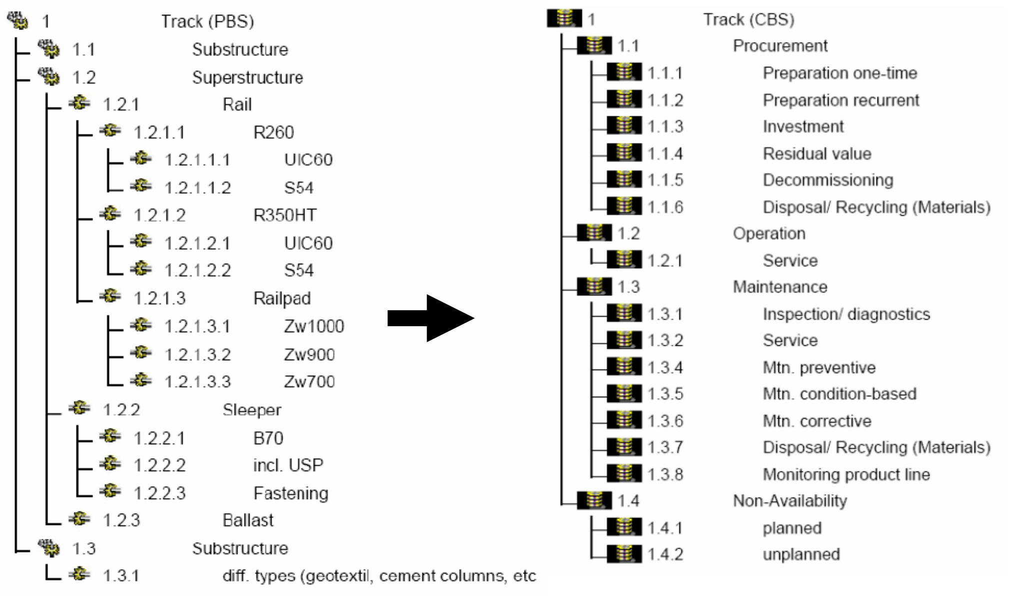

Fig. 2– Examples of a Product Breakdown Structure (PBS) and a Cost Breakdown Structure (CBS) from Deutsche Bahn AG (using D-LCC software application). Source: Kumpfmüller (2006)

Depending on the situation different cost calculation methods can be used to estimate cost elements required. Most common methods are (IEC, 2005):

- Analogous cost method - draws on historical data from components of other products having analogous size, technology, use patterns and operational characteristics;
- Parametric cost methods - develops mathematical cost equations between parameters and variables and general characteristics of the product or process. This method is employed when actual or historical detailed product component data is limited to few parameters
- Engineering cost method - involves the direct estimation of a particular cost element by examining the product component-by-component and uses standard established cost factors to develop the cost of each element. This method is used when there are detailed and accurate capital and operational cost data;

Besides, when data on the ongoing process is available, Cost Accounting methods can be applied. It is based on the collection and storage on the accounting system of data during the system life cycle (relying on concepts of Activity-Based-Costing) and used in some cases as a method to track and improve initial estimations (Zoeteman, 2004).

Detailed costs are sometimes difficult to obtain, especially on the long run time frame where costs can be assumed to vary due, for example, to technology improvement. Throughout the process, experts' analysis is always required to improve, calibrate and validate the cost estimation relationships.

To obtain the results and estimate the total costs of a given investment solution or strategy and compare it with an alternative (including "do nothing" hypothesis), the LCC calculation involves the application of capital budgeting techniques, where the net present value (NPV) is the most popular one. However, other techniques like accounting for the Annuity, IRR or the break-even point can also be applied.

At the end of the process sensitivity analysis is always required in order to make out the major cost drivers, to calibrate (with historical data for example) and improve the model, involving all the way experts' opinion.

Finally since LCC outputs should be as much reliable as possible the inclusion of an uncertainty and risk analysis should become mandatory in LCCA for large investment projects. Applying probabilistic analysis such as Monte-carlo simulation are among the recommendations of most LCCA standards. Also, the consideration of external factors such as environmental costs should be taken into consideration, particularly when those costs differ among different alternatives (including "do nothing").

3.1.2 Capital budgeting techniques

One of the basic concepts of LCCA is the time value of money, i.e, the value of money changes with time and as a result, expenditures made at different times are not equal.

A number of different techniques can be used to equate costs that are expended at various points in time. All have been in use in many different sectors. Three of the most commonly used methods in the building sector are the following: *simple payback*, *net present value* and *internal rate of return*.

1. The *simple payback* is a method defined as the time taken for the return on an investment to repay the investment.

   Simple payback can be expressed by the following formula:

   $$P = \frac{I}{R} \qquad (1)$$

   Where ***P*** is the *payback period (in years)*, ***I*** is the *capital sum invest*, and ***R*** is the *money return or saved* as a result of the investment. In a simple manner, it consists of adding cash flows from each year until the cumulative sum equals the initial investment. The decision process has to decide if ***P*** years is an acceptable period for a return of an investment, i.e. the decision maker should accept projects when the payback period is below a maximum desired payback period. Simple payback period is relatively easy to calculate and results are easily understandable.

   Some basic limitations of this technique are that it ignores the time value of money and ignores the cash flows after the payback period (misleading to think that all cash flows after this period represent profit). To overcome the first limitation, a *discounted payback period* technique can be used, where the cash flow from each period is discounted reflecting appropriately the cost of capital of the investor. *Discounted payback* technique gives useful information on how long funds will be attached to a project, i.e. the liquidity of the project.

   Nevertheless, it still has particular limitations such as ignoring cash flows after the initial investment has been recovered. Furthermore it doesn´t bring useful and easily understandable information to decision-makers when comparing different project alternatives: for example the ranking of alternatives can change if some investments are considered together.

2. The *net present value* (NPV) determines the added value that a given investment will bring. It is the difference between the sums of the discounted cash flows (present value of cash flows) expected from the investment minus the amount initially invested.

   It can be expressed as:

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \qquad (2)$$

   where C_t is the *cash-flow in year **t*** (including costs, incomes and initial investment), ***r*** is the *discount rate,* ***T*** is the *period of analysis in year*s.

   The discount rate represents the time value of money: it should reflect the opportunity cost of capital or what it can be expected to earn if the capital is placed on other investments of equivalent risk.

   Since it represents the sum of discounted costs and benefits, the usual decision rule is to accept investments with positive NPV (since all projects with a positive NPV are profitable). When comparing different investments or strategies, the highest positive NPV is chosen[1].

3. The *internal rate of return* (IRR) is a method defined as the percentage earned on the amount of capital invested in each year of the life of the project after allowing for the repayment of the sum originally invested.

   IRR is the discount rate from formula (2) for which an NPV of zero is obtained. This implies a “break-even” where the discounted cash-flows balance each other out. The calculation of the IRR can be based on a trial and error procedure: it consists of calculating and plotting the NPV for different discount rates (increasing from low to high discount rates) until the NPV has a negative value: the discount rate for NPV=0 can then be deduced.

   When calculated properly, IRR gives the same results as NPV for projects with normal cash-flows (i.e. negative cash-flows at the beginning followed by positive cash-flows). The decision rule when evaluating an investment is to accept that investment if the IRR is greater than the opportunity cost of capital. IRR can be interpreted as the effective rate of return for the investment made if considering a one-period-only analysis. However, if the project has positive cash-flows at the beginning and negative cash-flows after, instead of landing money the project is borrowing money, and therefore in this case the decision rule is inverted: accept the project if IRR is lower than the opportunity cost of capital.

   IRR is considered an unreliable technique in two specific situations:
   - When cash-flows change sign more than once along the project life cycle: in this case there will be more than one IRR and the interpretation of whether a high IRR is good or bad is not obvious. To overcome this problem, a *modified IRR technique* can be applied: in this case, cash-flows that change signs during the life cycle are discounted at the opportunity cost of capital and added to the cash-flow of other years
   - When comparing different investments (mutually exclusive alternatives) the use of IRR can lead to an incorrect evaluation of the best decisions: a project with higher IRR doesn’t necessarily mean it

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[1] Other definitions might be used using this budgeting technique. Zoeteman (2004) refer that since for Life Cycle Costing the analysis is focused only on costs, instead of NPV one should preferentially use the term Total Present Value (TPV). In this case, the lowest the TPV the more attractive will be the alternative.

is the best solution. In these cases the IRR evaluation should be done with the differences between the cash-flows of the alternatives, thus defining the discount rate for which the NPV of a project becomes higher than the NPV of the other (i.e. calculating the so-called NPV crossover rate). If NPV's of the projects don't cross then the highest IRR is the best solution.

Besides the abovementioned solutions, IRR technique presents some problems when applied to life cycle costing of infrastructures, since it assumes that an investment will generate an income (the IRR is usually used where investment produces a return on capital employed) and there is a rate where NPV becomes zero. When TPV technique is used instead of NPV, the calculation of IRR is not applicable. Only when comparing different alternatives it can be useful to know the discount rate for which a solution becomes more profitable (lower TPV) than the other: i.e. IRR as the TPV crossover rate.

Finally other limitations of IRR when compared to NPV method are that the ranking of different projects can be changed when packaging some projects together and it doesn't take into account the scale of the project (a more reduced IRR on an high investment can bring much more income to the firm than an high IRR over a reduced investment).

The use of NPV technique for life cycle costing is therefore considered the best solution to evaluate investment decisions. NPV represents directly the value added (to the company or stakeholders) of a given investment or strategy: by accepting to perform a given project with a positive NPV will bring an added-value precisely equal to the amount of the NPV calculated. Therefore, if the goal is to increase owner's wealth, NPV is a direct measure of how well this goal is achieved. This is the reason why many analysts agree to consider that the use of NPV leads to better investment decisions than any other criteria: it expresses exactly the amount of money earned by the firm through a given investment.

However, when applying NPV to compare different projects the following aspects should be taken into consideration:

- Only the part of costs and revenues that changes with a given investment should be considered.
- Optimal timing of the investment must also be evaluated: The fact that a project has a positive NPV doesn't mean it has to be fulfilled immediately, since carrying out the investment in a later date can be more profitable. Optimal timing of investment should be the one hat maximizes NPV.
- The cost of excess capacity should be considered in the analysis: the use of currently available capacity of a given asset can not be considered as free, since it will anticipate its replacement need.
- Restrictions on the availability of resources (such as capital to invest) must be considered. For this purpose another criterion that can be found in the analysis in investments is the *profitability index* (PI) measure. PI is defined as the NPV divided by the investment performed (thus a complement of the NPV method). This measure is particularly useful when there is limitation of capital and not all profitable investments can be carried out: the investments with higher PI should be chosen (or the lower PI if TPV is applied). However, as in the case of IRR, particular attention should be paid when comparing mutually exclusive investments, since PI is scale dependent and may therefore lead to incorrect decisions.
- As *PI*, a great variety of indicators can be used to complement the analysis based on NPV, depending on the resource that is scarce or the variable to be assessed (for example traffic volume)
- Some choices might involve replacing old assets which ha still some useful life left or choosing between assets with two different useful lives. In such case solutions must be evaluated on an equal-life basis, taking into account all future replacement decisions, otherwise the application of simple NPV rules may lead to a wrong decision. Since using NPV requires considering a fixed study period, one possibility is to include in the analysis an appropriate estimate of the residual (or salvage) value of the investment once the study period is over.

Another possibility of considering equal-life basis when comparing investment options is to use the Equivalent Annuity Technique. The Present Value of an annuity is obtained by multiplying cash-flow with the following Annuity Factor (a):

$$a = \left(\frac{1}{r} - \frac{1}{r \cdot (1+r)^n} \right) \qquad (3)$$

Where *n* is the number of annuity payments. The Equivalent Annual Cost (EAC) or Annuity (A) of an entire investment or project is then obtained by dividing its NPV by the Annuity Factor (a), i.e.:

$$A = \frac{TPV}{\frac{1}{r} - \frac{1}{r \cdot (1+r)^n}} = TPV \cdot \frac{r \cdot (1+r)^n}{(1+r)^n - 1} \qquad (4)$$

An Annuity (A) is an investment that pays a fixed amount of money at equal intervals of time. For replacement decision a possibility offered by this technique is to compare the costs of each year (including the loss of residual value during the year) with the EAC of a new asset. Optimal life of an asset is the one that maximizes its EAC. However, when applying this technique one should bear in mind that some factors such as uncertainties on technological changes can disturb the use of Annuity for decision making purpose (see chapter devoted to period of consideration).

Lastly, financial techniques such as depreciation and amortization[2] should not be considered on LCCA, since they refer to accounting conventions that can be far from reality, masking the sensitivity of the comparisons of a company's operating cash flow (IEC 60300-3-3).

As a synthesis, when performing an LCCA, the NET Present Value (NPV) technique is the most recommendable and can be complemented with the calculation of the Annuity (A). In particular, when LCCA aims to compare different alternatives, it is advisable to:

- Assess the difference of the Net Present Value (NPV) of the different alternatives
- Assess as well the difference of Annuity (A) of the different alternatives

3.2 Key boundary conditions for LCCA: current state of the practice

In order to obtain a robust LCC model and consequently, to conduct a reliable Life Cycle Cost Analysis (LCCA) to competing investment options, it is necessary to bear in mind that most of its input parameters are inherently uncertain. A thorough understanding of the theoretical engineering and economics background within each parameter value is critical to conduct a trustworthy LCCA. Among those, the correct choice of economical boundary conditions such as the discount rates, the period of consideration and the criteria for calculating residual values are known to be some of the most critical issues on the LCC results. This chapter will revue the usual assumptions and values considered for these factors.

3.2.1 Economical boundary conditions for project appraisal

The accuracy of an economical evaluation is of course extremely bound up with the accuracy of the cost estimation techniques (for both investment and operational costs): the improvement and homogenization of those techniques (e.g. at a European level) would bring further confidence on the results obtained. However

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[2] Accounting techniques used to allocate tangible (depreciation) and intangible (amortization) asset's costs over its estimated useful life.

those are not the only aspects where attention should be focused when preparing an economical analysis. Current experience in European infrastructure projects appraisal has shown that there are three other important key issues requiring particular attention, given that they strongly affect the results obtained. Those are (EC, 2002):

- The selection of appropriate discount rate (financial and social)
- The definition of time horizon for the project
- The evaluation of the residual value of the investment

The discount rate is roughly the opportunity cost of capital: it is the cost of using the capital in one project renouncing to earn a return in another project. Its value is defined mostly empirically for a given project, in a given country or region, for a given firm and at a given time. As it can be deduced from previous formula (2), the value of the discount rate can have a very serious impact on the decision making process of a cost-benefit or life cycle cost analysis. Adopting either a 3% discount rate against an 8% or 10% rate (all common values) can suppose a drastic change on: The profitability of a given project (move from negative to positive NPV) and/or the choice of an investment over an alternative one (move from inferior to superior NPV of a project over the other).

In Life Cycle Cost Analysis, theoretically applying a high discount rate will tend to favour investment alternatives with low capital costs, short life cycle and high recurring costs. On the other hand, low discount rates will tend to favour high capital costs, long life cycle and low recurring costs. Therefore, an appropriate selection of discount rate is critical: among different approaches for estimating this parameter, many authors and governmental authorities suggest applying a standard criterion, taking accounts of some benchmarks. Next sections will address the current state of the practice in this subject.

In the same way as for the rate of return, the choice of a correct period of consideration also highly affects the results of NPV calculation: depending on the cash-flows distribution, a project can move from negative to positive NPV just by changing the project time horizon. On the same way, a project can become inferior or superior to another alternative simply by adjusting a different period of consideration. Also in the case of this factor, important differences can be found over similar infrastructural projects.

Accordingly, suggestions from many authors tend to favour the use of internationally accepted practices for the selection of time horizon, depending on the sector. Next sections will revue current state of the practice.

The consideration of the residual value of the investments is a key issue to avoid distortions due to different time horizon criteria. According to cost-benefit guidelines, residual value is considered as a liquidation value of the project and should include the discounted value of all expected net revenues after time horizon. Therefore it should be calculated in two ways (Florio et al., 2003):

- Considering the residual market value of fixed assets (capital), as if it were to be sold at the end of the time horizon considered – includes future net incomes generated by the project
- Considering the residual value of any other current assets and liabilities

Proper application of the residual value calculation to the life cycle costing process in railway infrastructure will be discussed within this workpackage.

3.2.2 Experience in transport infrastructure projects

Trends on the values of the Discount Rate

The discount rate factor is known to be highly variable depending on the country and the project that is considered. Some recent studies performed with the aim of defining new and homogeneous criteria for this factor have tried to synthesize the current practices worldwide. An example can be found in a report of the French government which gathered the different discount rates and the time horizon usually considered on project appraisal (fig. 3). Most of the data comes from projects within the road infrastructure sector.

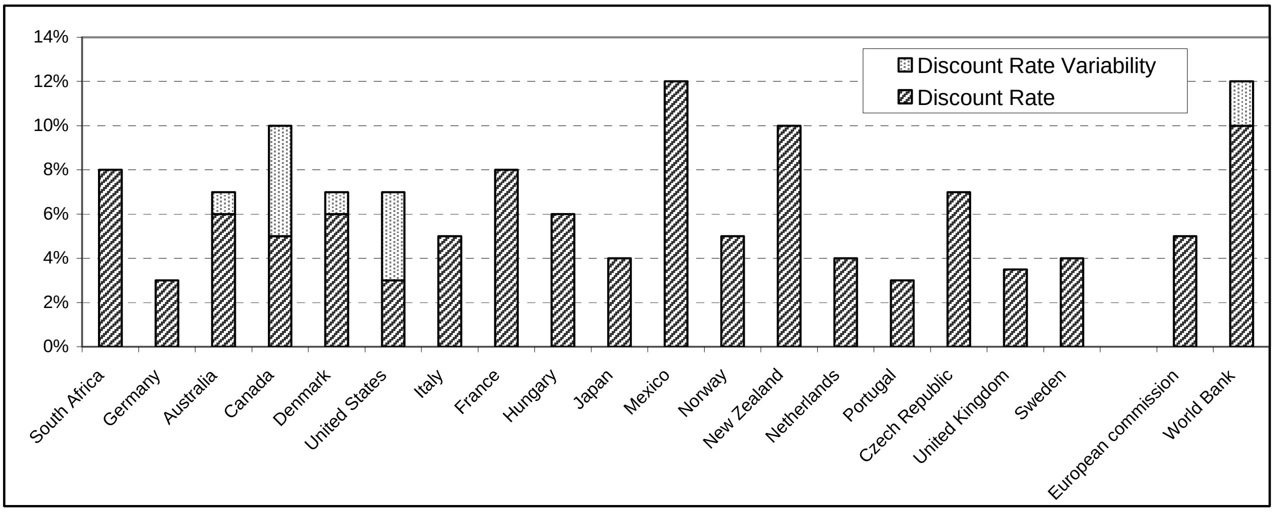

Fig. 3: Usual practices concerning discount rates. Source: based on the results of the survey performed by the Commissariat Général du Plan (2005)[3]

It can be seen that discount rates applied vary generally from 3%-4% to 6%-8%, with maximum values of up to 10% to 12%.

At European scale these variations are confirmed on an analysis performed by the European Commission over a sample of 400 major investment projects (financed with Cohesion Funds): the results showed that a wide variation from 3% to 11% can be found on the discount rates adopted on projects appraisals achieved until the end of the last decade. Table 1 shows some examples of discount rates considered into specific project appraisals for different sectors.

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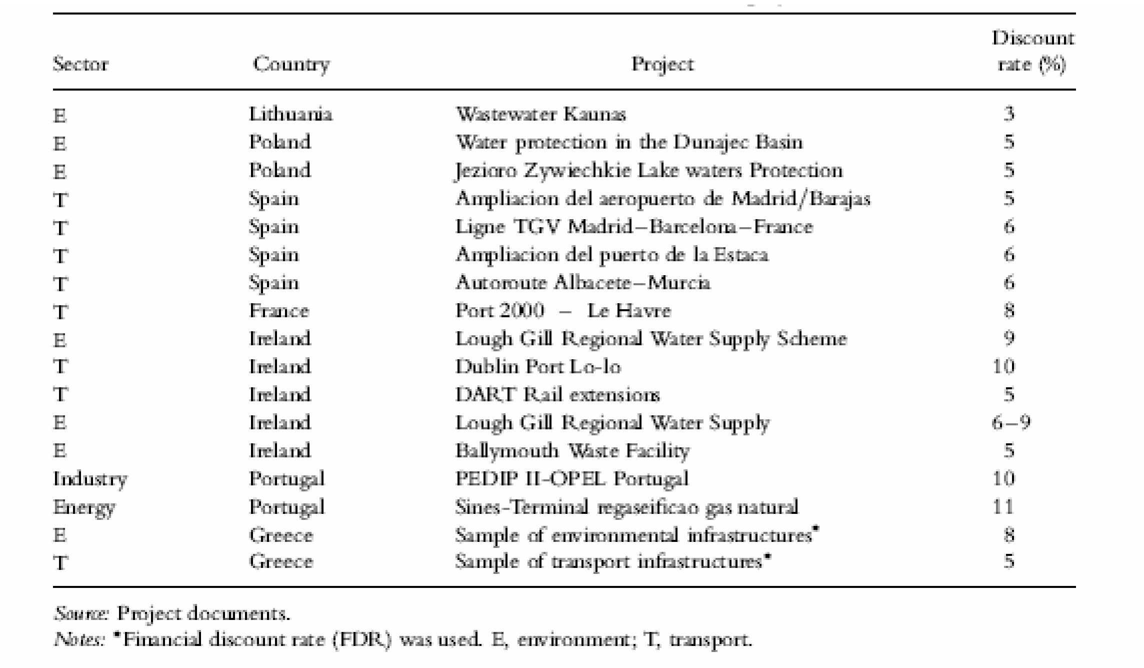
[3] Based on internal data and information from the study “Economic Evaluation Methods for Road Projects in PIARC Member countries, Summary and Comparison of Frameworks, PIARC Committee C9”. August 2003.



Sector	Country	Project	Discount rate (%)
E	Lithuania	Wastewater Kaunas	3
E	Poland	Water protection in the Dunajec Basin	5
E	Poland	Jezioro Zywiechkie Lake waters Protection	5
T	Spain	Ampliacion del aeropuerto de Madrid/Barajas	5
T	Spain	Ligne TGV Madrid–Barcelona–France	6
T	Spain	Ampliacion del puerto de la Estaca	6
T	Spain	Autoroute Albacete–Murcia	6
T	France	Port 2000 – Le Havre	8
E	Ireland	Lough Gill Regional Water Supply Scheme	9
T	Ireland	Dublin Port Lo-lo	10
T	Ireland	DART Rail extensions	5
E	Ireland	Lough Gill Regional Water Supply	6–9
E	Ireland	Ballymouth Waste Facility	5
Industry	Portugal	PEDIP II-OPEL Portugal	10
Energy	Portugal	Sines-Terminal regaseificao gas natural	11
E	Greece	Sample of environmental infrastructures*	8
T	Greece	Sample of transport infrastructures*	5

Source: Project documents.
Notes: *Financial discount rate (FDR) was used. E, environment; T, transport.

Table 1: Discount rates considered in selected European projects. *Source: M. Florio (2006)*

Concerning railway projects appraisal, both microeconomics perspective and the non-transport related significance of a railway project have traditionally required lower discount rates than those required of other transport facilities. Current discount rates in the railway sector fall within the range 2.5%-8% for most of the projects in developed countries (RAILPAG, 2006; CENIT, 2003).

On the attempt to adopt a consensus criterion for infrastructure projects, in the last decade the European Commission (EC, 1997) suggested the use of a financial real discount rate of 6% (and 5% social discount rate) as benchmark values for real opportunity cost of capital in the long term. On a revision of the guidelines for cost-benefits analysis (EC, 2002) the same criterion was adopted. Since then some national practices have been upgraded. An evaluation of the most recent trends can be found in a survey recently published by the OECD: answers from OECD members which participated on the study are shown in table 2.

Country	**Summary of Guidance on Discounting**
Australia	Varies across the Australian States and depends on the type of project
Austria	No standardised discount rate[4]
Canada	TBS: 10% (sensitivity at 8% and 12%); Environment Canada: 7% (5% and 9%)
Czech Republic	Ministry of Environment 1% (real, risk-free government borrowing rate)
Denmark	3% discount rate (SRTP), but ministry of finance employs 6%
Finland	Discounting not widely used; 5% (Ministry of transport and communications)
France	4% for t < 30 years, 2% for t > 30 years since Jan 05 (reviewed on 5 year cycle)
Hungary	Depends upon the shape of the HUF and Euro zero coupon yield curves
Ireland	5% for all public projects, as set by Department of Finance. Reviewed regularly.
Luxembourg	Cost benefit analysis is not employed by the Ministry of Environment
New Zealand	10% discount rate, with sensitivity analysis. Lower rates in some cases
Slovak Republic	5% discount rate based on EU guidance
Spain	5% discount rate, except for water infrastructure (4%), based on EU guidance
Sweden	4% discount rate, to be reviewed in May 2006
Switzerland	No standardised discount rate.
Turkey	The discount rate is the interest rate on debt finance for the specific project
United Kingdom	3.5% rate (SRTP) for first 30 years, then declining schedule
United States	3.0% or 7.0% depending upon type of cash flow, lower rates for longer-term

Table 2: Information on discount rate practices gathered by a survey among OECD countries. *Source: OECD (2007)*

As it will be discussed later, a tendency to reduce the discount rates can be observed, as it is the case for practices in Denmark or France: in the later case since 2005 rates were reduced from 8% to 4%, based on results from studies performed by Evans (2004). Additionally reduced discount rates are applied when the time horizon considered for the project is larger than 30 years (e.g. France and UK).

The tendency to reduce and homogenise the use of discount rates around 3% to 5% or 6% of discount rates was also found in surveys performed in the different states DOTs[5] of the US regarding life cycle cost practices for investments in road infrastructures. While in a study performed in 1984 the discount rates chosen for LCCA ranged between 0% and 10% with an important dispersion, in 2001 the results obtained by Ozbay et al. showed that the applied discount rate ranged between 3% and 5%, much more clustered around a mean of 3.9% (Table 3). The responses of 1984 were more dispersed over a wider range, whereas in 2001 these were more clustered. Some answers introduced the choice of the annually published Office of Management and Budget rates as the discount rate in LCCA.

Discount Rate	**0%**	**1%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
1984 Survey	27%	3%	0%	16%	10%	7%	3%	7%	7%	7%
2001 Survey	0%	0%	14%	43%	7%	0%	0%	0%	0%	0%

Table 3: Discount rates as employed by state DOTs in 1984 and 2001. Source: *Ozbay et al, 2004*

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[4] However, according to P. Veit, a 5% net value (without inflation) was used as standardized value at ÖBB.
[5] Departments of Transportation

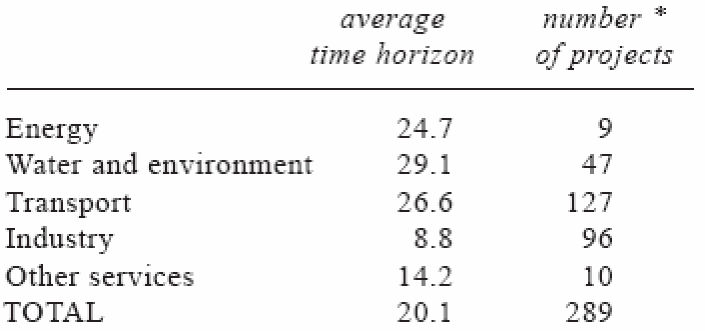
In the European case when considering Life Cycle Cost Analysis no specific discount rate values can be found on current practices in most recent surveys in road infrastructure (PAV-ECO and RIMES projects): usual practices tend to consider discount rates as a variable to evaluate through sensitive analysis.

This last practice is also recurrent in railway administrations: if we except for Germany where DB consider a fixed 8% discount rate, a large majority of LCCA performed in Europe doesn't refer to a fixed criteria for discounting, it is rather considered a variable factor. When evaluating the bibliography on recent LCCA studies on the specific railway infrastructure sector, some few examples can be found: 5% discount rate was used by Zoeteman (2004), while 4% interest rate is used by Vatn (2002) in Norway.

Trends on the values for period of consideration

The period of consideration highly depends on the nature of the project: It can move from low values (until 10 years) for industry related projects to higher values for large infrastructure investments (up to 50 or even 60 years).

Current practice on project appraisal reflects this wide variety. Table 4 presents average time horizon values in use per sector, based in the analysis of a set of 400 major European projects. Results show that the average period of consideration for transport infrastructure investments is around 27 years.



	average time horizon	*number * of projects*
Energy	24.7	9
Water and environment	29.1	47
Transport	26.6	127
Industry	8.8	96
Other services	14.2	10
TOTAL	20.1	289

Table 4: Average time horizon (in years) obtained from the appraisal of a sample of 400 major projects on the period 1989-93 and 1994-99. *Source: EC (1997)*

Accordingly, information gathered in the last years on the practices among different countries (mostly European) showed a range of variability in the analysis period considered that goes mostly from 25 years to 40 years for transport (mainly road) infrastructure projects, with some maximum values of up to 50 or even 60 years (fig.4).

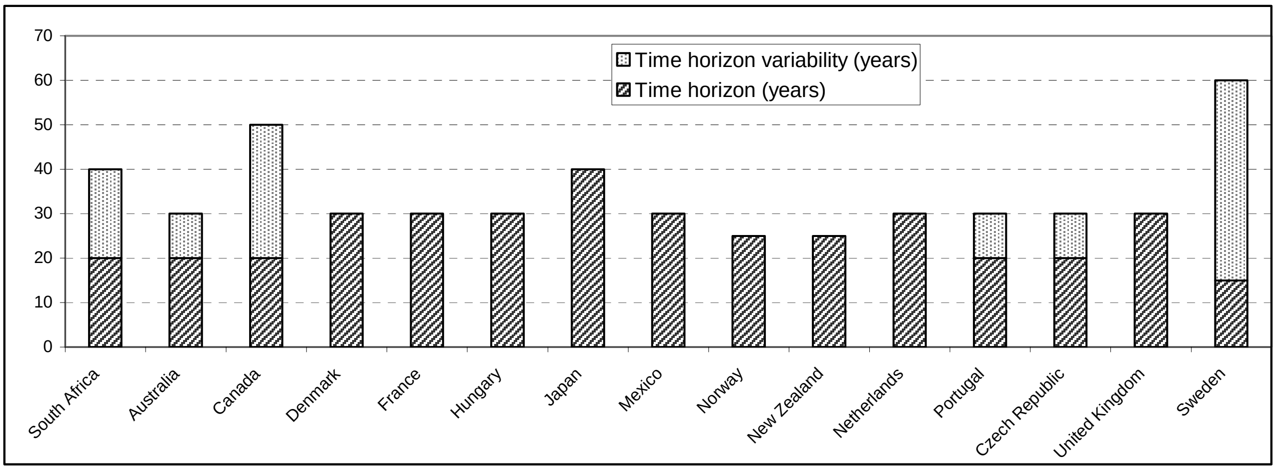


Fig. 4: Usual practices concerning time horizon for transport infrastructures in different countries. Source: based on the results of the survey performed by the Commissariat Général du Plan (2005)[6]

In United States and specifically for Life Cycle Cost Analysis projects in road infrastructures, surveys performed in 1984 and 2001 showed a tendency to enlarge the project analysis period. As showed by Ozbay (2004) in 2001 the analysis period ranged from 30 to 50 years, with 44% of the agencies indicating that this period varied between projects, while in 1984 this period ranged between 20 to 40 years (table 5). The higher analysis period results is justified in this case based on the tendency for a longer lifetime of pavements thanks to the continuous introduction of improved materials and construction techniques.

Analysis Period	**20 Years**	**25 Years**	**30 Years**	**35 Years**	**40 Years**	**50 Years**
1984 Survey	45%	17%	14%	3%	21%	0%
2001 Survey	0%	0%	7%	14%	29%	7%

Table 5: Analysis periods considered by state DOTs (Department of transportation) in 1984 and 2001. *Source: Ozbay et al, 2004*

Still in the field of roadways, FHWA's Technical Bulletin states that an analysis period of at least 35 years is recommended for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration and resurfacing projects. A shorter analysis period may be considered when alternatives are designed to buy time until more permanent solutions can be constructed.

On the other hand, more specifically the AASHTO Guide for Design of Pavements Structures also provides some guidelines for the selection of the analysis period, as shown in table 6. In this criterion a differentiation is made according to the traffic volume. Generally low traffic volume could indicate a longer life-span and thus a longer time period of analysis: this is not the case. In this criterion traffic volume is understand as an indicator of the degree of importance of the project: higher traffic will mean higher design requirements to meet a given life-span (as a result, low importance roadways have thin layer with shorter life-span than for important roads with thick layers).

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[6] Based on internal data and information from the study "Economic Evaluation Methods for Road Projects in PIARC Member countries, Summary and Comparison of Frameworks, PIARC Committee C9". August 2003.

Highway conditions	Analysis period (years)
High volume urban	30 to 50
High volume rural	20 to 50
Low volume paved	15 to 25
Low volume aggregate surface	10 to 20

Table 6: Recommended analysis period by the AASHTO.

When looking at recent and future trends and recommendations for transport infrastructures projects in Europe, the European Commission establishes a minimum (indicative) of 20 years for this type of projects, while for productivity investments the minimum indicative value can be only 10 years. The EC recommends the time horizon not to be so long as to exceed the economically useful life of a given project and it should be chosen based on internationally accepted practices, for each sector. Based on former data from OECD, the EC proposes table 7 values as a possible example of application (EC, 2002).

Project by sector	Average Time horizon recommended for the 2000-2006 period
Telecommunications	15 years
Industry	10 years
Water and Environment	30 years
Energy	25 years
Transport infrastructure	
- Roads	25 years
- Ports and Airports	25 years
- **Railways**	**30 years**

Table 7: Average time horizon (years) recommended for the period 2001-2006. *Source: EC (2002)*

On the case of railways, it can be confirmed that a longer time period (30 years or even higher) is suggested when compared with other transport infrastructures. This tendency is confirmed in some LCCA for railway infrastructure published in the technical literature (if we accept some specific cases)[7]. However differences found still vary widely from 30 years up to 40 to 50 years (Zoeteman, 2004; Vatn, 2002) and no specific pattern can be identified.

To define a proper time period for different types of railway infrastructure investments, some important factors should be taken into consideration, such as:

- The life-cycle of the project or of the main components to be analyzed
- The technology changes and macroeconomic scenarios
- The residual value calculation of the project

Accordingly, the time period considered is directly linked with the discounting rates to be used, as it will be addressed on the next sections.

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[7] Lower values can be found for example is some projects where PPP-contracts are defined (like in the case of the Dutch High Speed Line project, where a PPP-contract covers the provision of the infrastructure)

3.3 Definition of Unique Boundary conditions for Life Cycle Costing

3.3.1 Discount rate

The aim of this section is to discuss the possibility to adopt a “consensual” discount rate at European level to be used on the life cycle cost analysis. But before addressing the different theories and practices for the selection of this factor, to fully understand the value to adopt for project analysis one should be careful differentiating between financial discount rate (FDR) and economical or social discount rate (SDR).

Financial discount rate (FDR) is the opportunity cost for the investor (or firm), i.e. the return he could have from an available alternative safe investment (Campbell and Brown, 2003). It should represent the preference for the present compared to future financial flows. If the investor has access to different project alternatives or to financial markets, it is the marginal return of the best alternative (Florio, 2004).

Social discount rate (SDR) may differ from financial discount rate (FDR) due to market failures in the financial markets, such as the existence of taxes (both on the savings and on the benefits of the firms), limitations of capital (capital rationing) and information asymmetries, among others.

Focusing firstly on the FDR, the proper value to use depends on whether the benefits and costs are measured in real or nominal terms, depending if it is necessary to eliminate (real discount rate) or reflect (nominal discount rate) the effect of expected inflation. A real discount rate can be approximated by subtracting expected inflation from a nominal interest rate (market interest rates are nominal interest rates in this sense).Therefore, to evaluate the changes in money value through time, the best option is considering real discount rate, which takes into account those two indicators: inflation[8] and market interest rate[9].

Over the years many sophisticated techniques have been developed to assist with this particular problem of choosing the appropriate value of the discount rate. For private firms, the weighted average cost of capital (WACC) is the most widely used method (although some practitioners prefer a risk free rate plus an equity risk premium as it will be discussed). As a company’s assets are financed either by debt or equity, WACC is calculated by multiplying the cost of each capital component by its proportional weight and then summing:

$$\mathrm{WACC} = \frac{E}{V} \times \mathrm{Re} + \frac{D}{V} \times \mathrm{Rd} \times (1 - \mathrm{Tc}) \qquad (6)$$

Where:

Re = cost of equity
Rd = cost of debt
E = market value of the firm's equity
D = market value of the firm's debt
V = company’s total value (E+D)
Tc = corporate tax rate
E/V = % of financing that is equity
D/V = % of financing that is debt

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[8] *Inflation* is the proportionate rate of change in the general price level, as opposed to the proportionate increase in a specific price. Inflation is usually measured by a broad-based price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index.

[9] *Market interest rates* represent the annual yield of the principal if invested in some form, such as bonds, treasury bills, or a bank savings account

Cost of equity is basically the annual rate of return expected by an investor for owning the asset and for bearing risk. The cost of equity reflects the opportunity cost of investment for individual shareholders and consists both of dividend and capital gains. In finance, it is calculated by the dividend capitalization model:

$$Cost\ of\ Equity = \frac{Dividends\ per\ share_{\ (for\ next\ year)}}{Current\ Market\ Values\ of\ Stock} + Growth\ Rate\ of\ Dividends \qquad (7)$$

However, the most widely used method to calculate the cost of debt is the Capital Asset Pricing Model (CAPM), which requires some estimate of the firm's equity market beta that measures the risk of the company relative to the risk of the stock market in general. Since the historical beta may bear little relevance for the future, analysts are granted the flexibility to modify their estimates to allow for what they view as realistic assumptions of relative share price volatility going forward. The CAPM cost of debt is usually the yield at which outstanding debt trades or the risk free rate plus an appropriate credit spread. On this basis, the cost of equity is represented by the following formula:

$$\mathrm{Re} = \mathrm{Rf} + \beta\,(\mathrm{Rm} - \mathrm{Rf}) \qquad (8)$$

Where:

Re = cost of equity

Rf = risk-free rate

β = the sensitivity to market risk for the security

(Rm-Rf) = equity market risk premium

Risk-free rate (Rf) is the amount obtained from investing in securities considered free from credit risk, such as government bonds from developed countries.

Beta (ß) measures the risk of the company against the market as a whole. The beta of an average risk firm in the stock market is one. If the beta is above one it is a sign that the share is exaggerating the market's movements and less than one means the share is more stable. Occasionally, a company may have a negative beta (e.g. a gold-mining company), which means the share price moves in the opposite direction to the broader market.

Equity Market Risk Premium (Rm – Rf) represents the returns investors expect to compensate them for taking extra risk by investing in the stock market over and above the risk-free rate i.e. it is the difference between the risk-free rate and the market rate. Usually, the Equity Market Risk Premium (EMRP) average may either be calculated using the geometric or the arithmetic method, the most commonly used. As the geometric mean provides an annually compounded rate of excess return it will, in most cases, be lower than the arithmetic mean.

Once the cost of equity is calculated, adjustments can be made to take account of risk factors (including the size of the company, pending lawsuits, concentration of customer base and dependence on key employees) specific to the company, which may increase or decrease company's risk profile of the company. These adjustments are entirely a matter of investor judgment and they vary from company to company. For example, a typically riskier investment has a high discount rate and consequently, a lower present value of future cash flows, whilst a low discount rate will have the opposite effect.

Cost of Debt (Rd) is the interest rate a company is paying on all of its debt, such as loans and bonds. This rate should be the current market rate the company is paying on its debt or if the company is not paying market rates, an appropriate market rate payable by the company should be estimated. As companies benefit from the tax deductions available on interest paid, the net cost of the debt is actually the interest paid less the tax savings resulting from the tax-deductible interest payment. Therefore, the after-tax cost of debt is Rd (1 - corporate tax rate).

In the WACC formula, the proportion of debt is represented by D/V, a ratio comparing the company's debt to the company's total value and the proportion of equity is represented by E/V, a ratio comparing the company's equity to the company's total value. An example of application (purely theoretic) can be: considering that the rail investment to study has a capital structure of 50% debt and 50% equity, with a tax rate of 27,5%; assuming that the risk-free rate (RF) is 4,1%, a beta parameter for transport rail industry is 0,51 (Damodaran, 2004) and a risk premium (RP) of 6%, the result using the WACC formula would be a discount rate for the investment of 6,3%.

Nevertheless, investors need to determine the company's cost of equity and cost of debt to calculate the WACC. This technique main advantage is taking into account the firm’s cost of capital for common equity, preferred equity, and debt financing, as well as the capital structure of the balance sheet. However, there is little consensus on what value is appropriate in any given circumstance, and it often makes a significant difference.

Therefore even if this procedure is widely applied, it is difficult to establish a common “best practice” on the calculation of the discount rate trough this technique on the one hand, and on the other it would inevitably lead to different rates for different companies.

When looking at important public investments in infrastructure performed by public administrations, it can be consistent to have different discount rates for different regions or countries, given that it reflects different opportunity cost of capital in different financial markets. The standard procedure is then to consider the return of government bonds as the minimum value of reference. For public sector investments, some authors recommend using the real interest of each government public bonds (for a given horizon similar to project horizon), or to consider a unique official government’s discount rate as suggested by Saerbeck (1990). This approach would bring a consistent and “consensual” procedure for the calculation of discount rates, but once again it will lead to different discount rates in different countries.

It is true that when considering only Europe, these differences should be minimal since the financial markets are supposedly well integrated. However, evidence and practical experience (see previous sections) shows heterogeneities among interest rates and discount rates that seem difficult to justify.

To overcome these heterogeneities, as previously mentioned, the European Commission proposes a unique benchmark value (6% or 8% for FDR for old and new members respectively, 5% SDR). Still this value is hard to justify since there is no systematic study at European level to support it: the proposed values are rather considered to be based on an average value of the current practices in Europe.

An alternative to look for a “consensual” value for public investment (rather than consensual criteria) is proposed by Florio et al. (2003): the author proposes to consider the real interest rate of a prime lender such as the European Investment Bank (EIB). In this case the opportunity cost can effectively be considered the same in the public sector within the European Union. The author stresses that the real interest in this case would be as low as about 3,2% (value of 2004 for an horizon of 15 years) or even lower in the close future. This criterion can be justified assuming that EIB bonds can be considered a risk-free benchmark for financial investments among Europe.

Of course an European wide reference value of FDR requires an empirical estimate of average marginal cost of public funds. While this study is not performed Florio (2004; 2006) considers that the range of estimates would not be too different from the real interest rate of EIB plus a premium for tax distortion that could be around 30%. In these conditions the FDR would be situated between 3,5% to 4%. These values seem to correspond to recent values in use as well for life cycle costing of infrastructure, as discussed previously.

Now the discussion should address the specific case of considering public sector investments: in such investments we should refer rather to a social discount rate (SDR) and this rate can have values that might differ from actual financial rate.

According to the guidelines of the European Commission for project appraisal (EC, 2002) there are three alternatives to estimate the social discount rate:

- Use a formula based on the social time preference and the growth of the economy
- Use the real financial rate of return
- Use a standard benchmark value (suggesting 5% as a first approach)

The starting point to estimate the social discount rate is in fact the so-called *social rate of time preference*. In a simplest way, the social rate of preference is the value that reflects the way the community values the cost of renouncing present consumption against future consumption. Many complex approaches can be found on the literature to determine the most suitable value for the social rate of time preference. One of the most used and a recommended approach is given by Ramsey (1928) equation:

$$Stpr = \rho + \mu \cdot g \qquad (8)$$

where:

Stpr is the *social time of preference*

ρ is the inter-temporal preference rate, i.e. rate at which individuals discount future consumption over present consumption (considering that there is no change in per capita consumption)

μ is the elasticity of marginal utility of consumption or the elasticity of social welfare to public expenditures

g is the real growth rate per capita real consumption or public expenditures

In this formula the social rate of return is then the sum of two components: the rate at which individuals discount their future utility and the social value of increasing public investment or consumption.

There is an extensive literature concerning the different values of each parameter, see Evans (2004) or Florio (2006). However there is a general conformity on the results obtained through this method in Western Europe, with results of around 3% to 4% as it can be deduced from table 8.

Country	**Social Discount Rate**	**Method of determination**	**Year**
France	4 %	Social rate of time preference	2004
Germany	3 %	Social rate of time preference	End of the 1980s
Portugal	4 %	Social rate of time preference	2003
Italy	4 %	Economic literature	2001
Netherlands	4 %	Social rate of return of private investment	1994 / 2003
Ireland	5 %	Social rate of return of private investment	1995
Spain	4% to 6 % (transports)	Depends on the sector	

Table 8: Social discount rate obtained in some European countries. *Source: based on results from OECD(2007), Florio (2006 – referring to Spackman, 2002 and Booij, 2004)*

Therefore the referred approach typically drives to low values of discount rate(except for countries where the expected economic growth is higher that average EU-15 countries where social discount rate would be in this case higher, about 5,5% suggested by Florio, 2006). For projects with higher periods (beyond 30 years) some author's found that very low discount rates should be used (2% or less).

However, the capital could be alternatively invested on the private sector, which in this case would lead to an higher return (Rose, 2006). This causes a dilemma on which rate should be chosen: as stated by Mendelsohn (1981) if the social rate of time preference is used as the public discount rate, the opportunity cost of public investment would be understated, while conversely, the market rate of interest tends to overstate the opportunity cost of funds taken from the private sector. To overcome this question some authors (De Rus, 2001) refer that one should clearly differentiate the cases where public investment competes with the private sector (where it is more understandable to adopt a real interest rate) and those where competing projects are evaluated within the public sector (where social discount rate should be precisely estimated). In these later cases, an approach often referred to estimate the social discount rate value can also be the one proposed by Harberger (1972): to estimate an weighted average value between the social rate of time preference and the marginal return rate of capital. However this technique requires among other factor knowing the origin of funds: besides its difficulty it would be impossible, once again, to reach a consensus value at European level.

The second approach suggested by the EC (2002) is to simply consider the financial discount rate as social discount rate value. This assumption would be justified by the fact that the increase of state savings due to long term economic growth is approximately equivalent to the reduction of the investment on the other sectors (that have not been performed because savings were applied in this project). Even if it is conceptually difficult to understand (since finance analysis has different interests from economic analysis), this assumption has the advantage to simplify the reasoning of looking for an agreed value, especially if we bear in mind that the FDR values abovementioned are similar to the common benchmark on social discount rate based on the social rate of time preference method.

Finally the last proposal of the EC (2002) is to simply adopt a current benchmark value, which is maybe the most attractive solution when seeking for a consensus discount rate. In this case the analysis performed by EC in 1997 and 2002 have proposed a 5% social discount rate. However, looking at current practice and most recent publications it is more likely to consider a slightly lower value: most authors recommend a 3% to 4%; discount rate as European benchmark; recent European research projects (HEATCO and UNITE for instance)[10] indicate as well lower values close to 3%.

In synthesis, if one looks for a consensus and updated value for discounting as a reference at European level, either based on the FDR or the SDR, it can be deduced from the abovementioned (and in accordance with all the most recent literature) that this value would fall into the 3% to 5% range

As a result a possible approach for LCCA analysis of railway infrastructure within INNOTRACK project could be:

- To adopt a **4% reference value for calculation**
- To consider a **range of variation from 3% to 5% in sensitivity analysis**
    - As an alternative 2% instead of 3% as lower bound for very long period of consideration
    - As an alternative consider 6% instead of 5% as upper bound (for example Eastern European countries)

To consider 4% as reference value agrees with common practices for LCCA in the United States (see previous table 3).

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[10] HEATCO - Developing Harmonised European Approaches for Transport Costing and Project Assessment
UNITE - UNIfication of accounts and marginal costs for Transport Efficiency

3.3.2 Period of consideration

This section addresses the definition of criteria for estimating the time horizon of a project, with the aim of reaching a consensual methodology and ranges to consider on the LCCA for railway infrastructure.

The first step is to clearly identify the starting point of the project, i.e. the beginning of the project analysis (year 0). Should we consider the time horizon starting from the year operation begins? Or from the year each component is effectively installed (since it will begin its deterioration)? IEC (2005) standards clearly defines that a complete LCC should address all phases of a project (as referred in the example of fig.5), so should we consider as starting point the year the project conception is started? Or on the year LCC is being performed, e.g. at an early stage of design or development? How to include costs of former research and development?

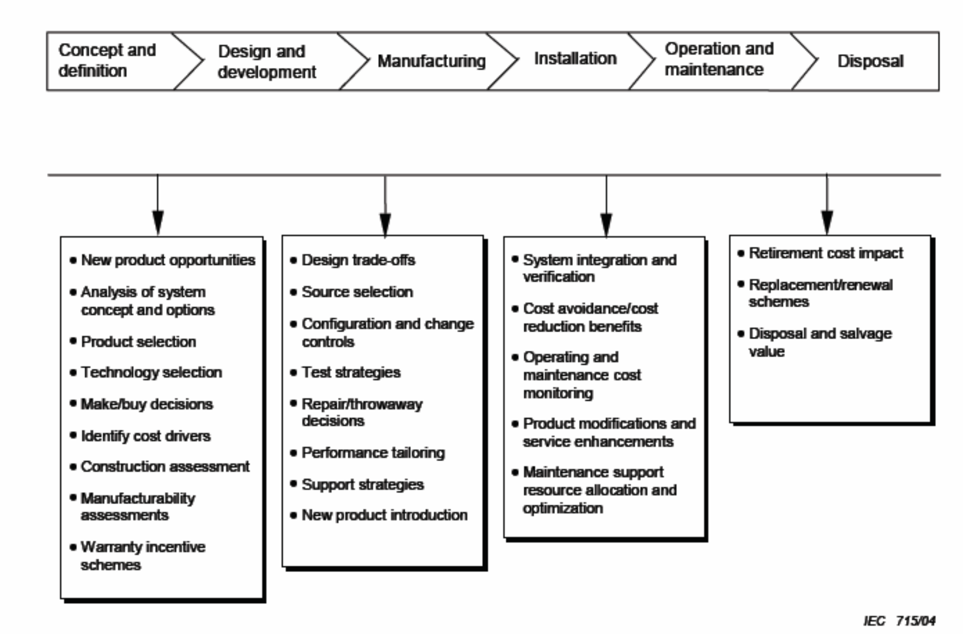

Fig.5: Life cycle phases and topics that should be addressed by life cycle costing study.
Source: IEC (2005)

Looking at common practices, the most logical assumption is to consider the beginning of commercial operation as a starting point. In such a case all costs incurred *before* the start-up of the project should be merged into year zero[11] and it is important to take into consideration the following aspects:

- Costs incurred prior the base year should be duly escalated (to be sure to meet the same reference base for all prices and costs –material, labour, etc.). This is the case for example for costs of research and development
- If degradation or life-span of a component has started before the beginning of commercial operation, it should be taken into consideration either by shortening its life-time on the project or including an equivalent cost at year zero (e.g. in some occasions some components can be build, acquired and in use far before the beginning of operation - case of testing periods, long-time between infrastructure and superstructure, etc.)

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[11] If a year-by-year project cost over time is chosen (year granularity is the most common assumption, however smaller or larger time period segments can be considered as well -e.g. month, week, day or multiples of years). If a different segment is adopted, instead of year-to-year, those costs incurred before the start-up would always be included on the first time segment.

Looking now at time horizon or period of consideration of a given investment, from a theoretical view point it can be considered virtually indefinite: indeed, it is a matter of convenience that a final year is defined as the year where assets are theoretically liquidated (Florio et al., 2003). However the assumption of given period is required in order to have a fair decision support process based on NPV technique: since this factor might have an important impact on the results and consequent decisions (as discussed previously) coherent rules must be defined.

Getting into detail on the definition of the time horizon for an LCC analysis, the following aspects should be taken into judgement:

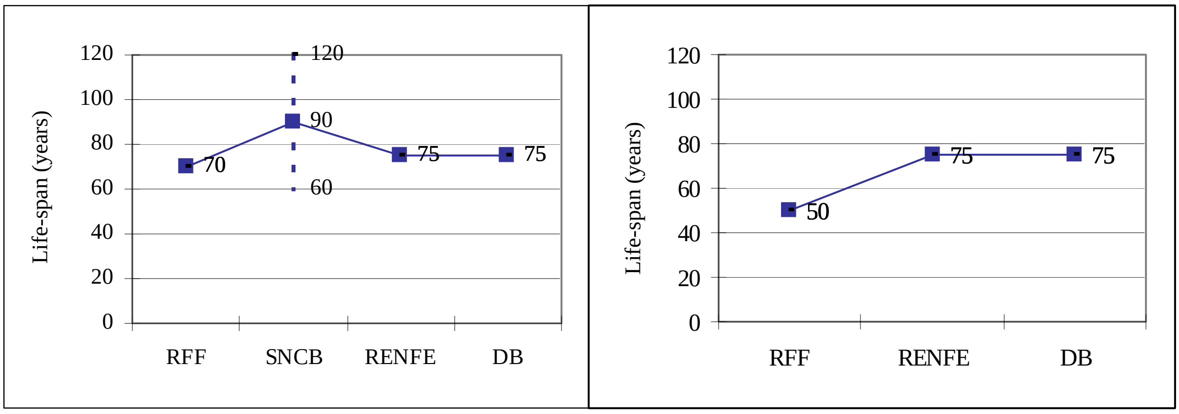
1. Time horizon should be at least equivalent to the life-span of a great part of the components, i.e. including at least one entire life-span of the majority of the replaceable components
2. When comparing alternatives where the majority of components have different life-cycles, the time horizon should be long enough to avoid distortions (in theory consider at least one cycle of the most long-lasting component)
3. Too long time periods will increase the uncertainties and risks on the project appraisal
4. The range of values to adopt for time horizon on LCCA in railways should be in clear consensus with most recent guidelines and practices on the project appraisal standards
5. Finally the definition of any time horizon for comparison of solutions with very different life-span should address an homogeneous and consensus criteria to estimate the salvage / residual values

The first and second aspects are related to the life-span of the alternative considered: since such definition is not proper for a project where different life-spans can be found among the different components, it is rather easier to refer to the life-span of the most relevant (lifelong) components. These life-spans should give a first indication on the required length for the time horizon of the alternative.

The first difficulty when assessing a custom life-span of, for example, railway infrastructure components (as in any other case) is that they are highly dependent on external parameters, such as traffic volume. In a certain way it would be more correct to refer to parameters such as traffic horizon rather than time horizon. But the difficulty arises on the fact that not only traffic but also other critical parameters should be taken into consideration and thus the analysis would become excessively complex. The alternative to estimate is then to consider “reference” time horizons under certain circumstances of traffic volume and other relevant technical boundary conditions (line type, traffic type, etc.).

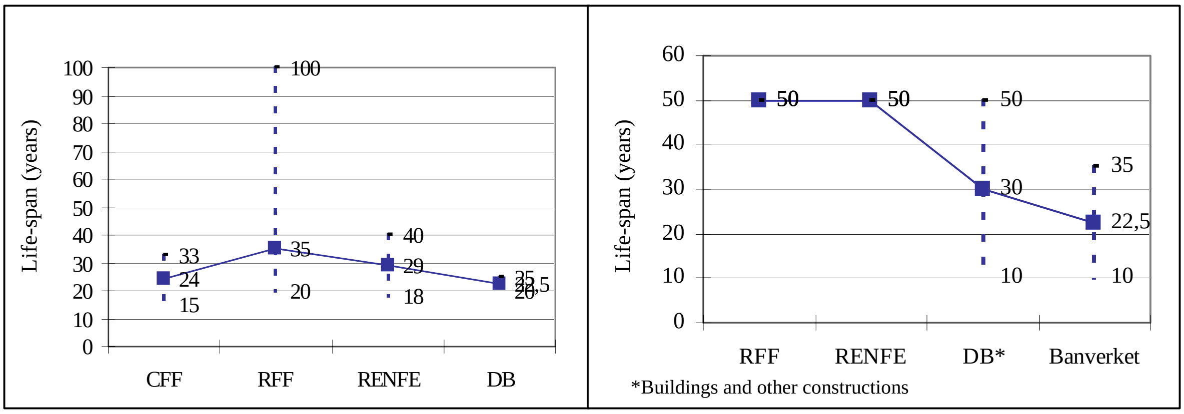
In this case, focusing on railway infrastructure, one possible way to have a first insight on the life-span of components is to look at their economical life, i.e. accounting standards adopted in each country for depreciation purposes (which means accepting that those standards were defined based on an accurate technical appreciation and not purely financial).

Fig.6 shows a synthesis of different accounting time periods considered by different railway administrations in their annual reports. Considering important civil engineering works, the life-span is usually close to 60 to 75 years, while for track superstructure components a range of between 25 years to 40 years is usually found.



Bridges and Tunnels

Track earthworks



Track superstructure

Buildings

Fig.6: Life-span of track superstructure, track earthworks, buildings, bridges and tunnels considered for accounting purpose by different railway administrations[12]

Based on experience in main tracks, reference values for the technical life-span of main components of the track superstructure can be found on different bibliographic references: usually the reference values will not fall far from the ones shown in table 9.

Component	**Operating Period in million gross tons**	**Operating Period in years for an average traffic line**
Rail UIC-60 in ballasted track	500	40
Concrete sleepers	500	40
Ballast	250	20

Table 9: Indicative Operating Period of elements in track superstructure (high-speed). Source: CENIT (2003)

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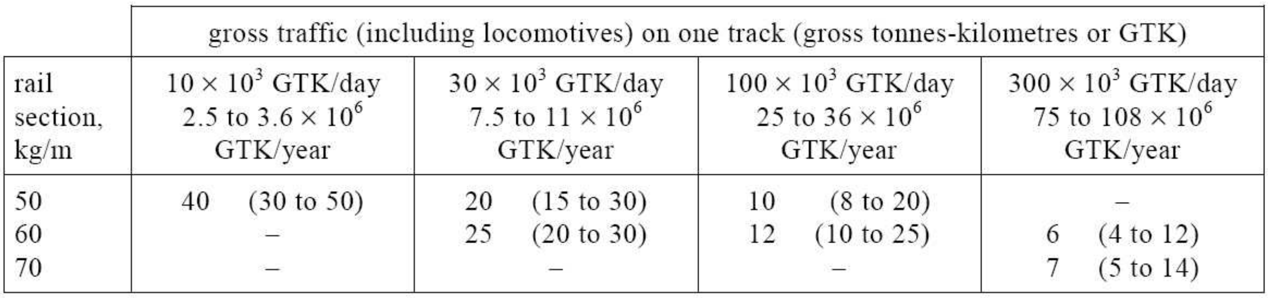
[12] Based on information published in each European Railway Company annual reports (year 2005)

Concerning the complete renewal of track superstructure, an example with some reference values for different types of lines (rail types) and traffic volume can be found in table 10.



	gross traffic (including locomotives) on one track (gross tonnes-kilometres or GTK)			
rail section, kg/m	10×10^3 GTK/day 2.5 to 3.6×10^6 GTK/year	30×10^3 GTK/day 7.5 to 11×10^6 GTK/year	100×10^3 GTK/day 25 to 36×10^6 GTK/year	300×10^3 GTK/day 75 to 108×10^6 GTK/year
50	40 (30 to 50)	20 (15 to 30)	10 (8 to 20)	–
60	–	25 (20 to 30)	12 (10 to 25)	6 (4 to 12)
70	–	–	–	7 (5 to 14)

Table 10: Reference values for time intervals, in years, between two full renewals.
Source: Baumgartner, 2001

Another possible way, more straightforward is to look into current technical considerations adopted for LCCA, bearing in mind that those are generally fully validated through expert analysis. From the questionnaires performed within WP6.1 (see report D.6.1.2) it is seen that DB adopts the following time horizons:

- Ballast track: 40 years
- Slab track: 60 years
- Switches: 20 years
- Bridges: 75 years

Those values refer to one life cycle (from complete renewal to next complete renewal) and are usually taken as reference for the time horizon (Kumpfmüller, 2006). Those values agree with the abovementioned ranges.

Thus, based on this criterion, the choice of the proper time horizon will depend on which components are affected by different solutions considered on the LCCA: the maximum time horizon is therefore derived from the most critical component or system in terms of calculated life-span.

The problem to establish the time horizon will arise when the infrastructure behaviour and costs (e.g. earthworks structure) are considered to differ among the different solutions studied. In those cases, according to the abovementioned values, two possibilities arise:

- To consider as reference the life-span of the long-lasting major component, which is related to track infrastructure and would suppose time horizons as long as 60 at 75 years
- To consider as reference the life-span of track superstructure; this would suppose values of between 25 years to 40 years. In this case, the effect in the infrastructure should be considered on the evaluation of the residual value, as discussed later

The first hypothesis supposes horizon periods that will be in conflict with the third aspect referred at the beginning, i.e. the largest the time horizon, the highest will be the uncertainties and risks taken.

Those uncertainties are of many kinds:

- Within the real discount rate adopted: economy trends and social welfare issues are difficult to forecast at very long time periods. Besides, very large time horizon will make almost indiscernible any investment close to the end period (even considering variable discount rates, the criteria for its definition makes little sense for very large periods).
- Within the cost estimations - cost estimation methods are generally based on past knowledge and anticipated trends. Since in most cases a deterministic analysis is performed, there is already an element

of uncertainty with most LCCA parameters: the longer the time horizon the higher is the uncertainty within this cost estimation function

- Within the technological assumptions: beyond a certain period it no longer coherent to forecast on maintenance needs, processes and re-investments since the whole technological scenario might have completely change

Therefore it seems more reasonable to consider a time horizon that would *not* be far beyond the usual life-span of track superstructure components. This is precisely what is mentioned on the guidelines of the European Structural Instrument for Pre-Accession countries, which refers that "*infrastructure projects are generally appraised over a period of 20-30 years, which represents a rough estimate of their economic life span. Although the physical assets may last significantly longer than this – e.g. a bridge may last for 100 years - it is not generally worthwhile trying to forecast over longer periods. In the case of assets with a very long life, a residual value may be added at the end of the appraisal period to reflect their potential resale value or continuing use value*".

Turning then to the fourth question, the alignment with current standards, the previous guidelines are also in accordance with the guidelines from the EC for Cost Benefit Analysis (CBA) studies, where the following references can be found (EC, 2001): "*The lifetime varies according to the nature of the investments: it is longer for civil engineering works (30-40 years) than for technical installations (10-15 years). In the case of a mixed investment comprising civil engineering works and installations, the lifetime of the investment may be fixed on the basis of the lifetime of the principal infrastructure (in this case investment in the renewal of infrastructure with a shorter lifetime must be included in the analysis). The lifetime may also be determined by considerations of a legal or administrative nature: for example the duration of the concession where a concession has been granted*".

Therefore 30 to 40 years is suggested as benchmark (upper) value for main linear infrastructures such as railways. Since some LCCA are performed for projects that will apply for State or European budget under the development of CBAs, it does not seem coherent to adopt different cost estimation strategies (rates, time horizon) for LCCA and CBA.

The assumption of a given fixed time horizon stresses the need to properly account for the residual value of the assets. An adequate and accepted criterion for the estimation of the residual value would simplify the choice of time horizon.

Residual value is in theory the discounted sum of future forecasted flows over time horizon to infinity. However, in practice the estimation of such residual value considering theoretic infinite life time is unpredictable and unrealistic. The solution is to consider only the remaining lifetime of components after time horizon is reached. This remaining life is computed as a negative or "positive" costs (i.e. a benefit), at the last year of the analysis. For that, two approaches can be used:

- An appraisal of the net revenues of the project generated beyond time horizon (i.e. before any substantial renewal)
- Consider the market value of fixed assets - case of positive residual value
- Consider the cost for the disposal of the infrastructure assets (removal of all assets and re-establishment of initial conditions, according to national environmental standards)

The first option would mean to account for costs and benefits of having the infrastructure for longer life times: even if it is probably the most realistic and truthful option, it is clearly beyond the boundaries of an LCCA. Indeed, it is a conceptual limitation for LCCA: the question is to define whether LCCA should turn into a CBA to correctly address the residual value estimation (thus involving expertise that usually is not covered by LCC experts). In general, the residual value estimation in the case of LCCA should avoid the inclusion of future net incomes generated by the assets (especially because most incomes can be related to external effects).

The solution is then to consider the market value of fixed assets beyond the fixed time horizon. The most common method (perpetual) accounts for the remaining economical life-time applying a depreciation method (linear in most cases in railway administrations, according to a recent study -RAILCALC, 2007). An alternative is to evaluate the liquidation value or what it would cost to replace the asset (different techniques can be applied[13]). Even if this last option is conceptually more correct, the difficulty to gather proper and reliable information makes it difficult to apply it, especially bearing in mind that the estimation is for a rather long time horizon. Linear depreciation is an acceptable approach since residual value appears in the last year of consideration and thus it is highly discounted when the time horizon is long. Therefore a pragmatic approach for estimating the residual value of infrastructures which includes determining the fixed lifetime of the infrastructure (or its sub-components) and using a linear depreciation profile is mostly recommended (HEATCO).

The last mentioned item on the residual value estimation is the complete disposal of the infrastructure. This cost is very difficult to estimate and is highly dependent on local environmental legislation, in many occasions not precise on this issue. Moreover, even if that legislation is already consistent, it is difficult to estimate the environmental requirements when reaching time horizon of the project: environmental requirements are likely to be improving in periods of time like 30 to 40 years from now. Therefore, when comparing different options, the most reasonable practice is to only focus on major difference in these costs between alternatives: the difficulty still exists on the confidence of the calculations (for example on the cost differences between removing a slab track and a ballasted track: any assumption would be made based on current technological outline, thus limited -equipments are now very different from 40 years ago…-)

Therefore, as a **synthesis** the following considerations can be drawn regarding the adoption of a **unique criterion for time horizon of LCCA**:

- When evaluating important investment solutions, if a multiple of the life-spans of major components/renewal (e.g. rails, sleepers) falls into the 30 to 40 years range, then a choice should be made to **fix a time horizon value among this range**.
- It **should not be reasonable** to account for **larger periods than 40 years** due to the limitations in terms of forecasting (technological changes) and the equilibrium that should be kept with parallel economic appraisals (such as CBA, etc.). In fact, adopting this criterion goes in accordance with:
  - EC directives that established a 30 to 40 years as benchmark for investment in major civil engineering works
  - Recent European projects HEATCO which recommends the use of a 40 year appraisal evaluation period for all European TEN-T projects. It also refer that when potential projects are compared starting at different times, a common final year should be used, determined by adding 40 years to the opening year of the last project to be started

- Besides, adopting a **40 years as maximum reference** base time horizon for ballasted track options corresponds to the most common technical criteria found in bibliography
- Accordingly, as described previously, the use of a 40 years time horizon as maximum reference base corresponds to the average value adopted in the US for LCCA of main road infrastructures (where there is a large experience)
- All these assumptions are based on a proper calculation of each alternative residual value, as discussed previously

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[13] Fair market value: Fair market value is the amount for which an asset could be exchanged between knowledgeable, willing parties in an arm's length transaction.
Replacement value: The replacement value is the amount that it would cost to replace an asset with another of equivalent quality.
Value in use: The value in use is the present value of the cash flows generated by the asset over the rest of its service life.

Further developments and discussion within WP6.2 will contribute to define better whether this (or other) criterion should be adopted for the analysis to be performed within WP6.5

4. Conclusions

Life cycle cost analysis can be more or less detailed or ingenuous but it cannot deliver a fair decision support process without coherent rules. This deliverable has addressed the need to agree on unique economical boundary conditions, specifically the capital budgeting techniques, the choice of proper discount rate and the choice of time horizon for LCC analysis.

Concerning capital budgeting techniques it was shown that Net Present Value (NPV i.e. Total Present Value in Life Cycle Costing) is the most accurate procedure for decision support. A combination of techniques and indicators can also be advisable as a complement to NPV results: particularly estimation of Annuity factor, break-even or in some cases Internal Rate of Return (IRR) can bring useful indications.

Economical boundary conditions are key factors on the results provided through LCCA. An in-depth evaluation of current practices concerning the discount rate and the time horizon on infrastructure project appraisal was performed. Most recent bibliography on the subject shows that, among the diversity of criteria and values adopted, there is a tendency to use reduced values for discounting combined with large periods of consideration.

A detailed theoretic analysis performed towards the definition of an unique criterion for discounting and the time horizon of LCCA has driven to the following first suggestions:

- For the discount rate: to consider a reference value of 4%, with a variation of 3% to 5% in sensitive analysis (lower bound can be reduced to 2% if time horizon is very long; higher bound can be increased to 6% for countries with high economical growth –like Eastern Europe)
- For the time horizon: to consider a range of 30 to 40 years, with 40 years as recommended upper bound for large investments on ballasted tracks assessed through LCCA (closely linked with an accurate estimation of the alternatives residual value as discussed)

Both results are in accordance with most recent research and guidelines in project appraisal and life cycle costing practices. Naturally, for the application of discount rates, one should always have to take into consideration already fixed rates in the different Infrastructure Managers.

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6. Annexes

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