Life-Cycle Cost-Benefit Analysis

present and in the future

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Life-Cycle Cost-Benefit analysis. Present and in the future.

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ABSTRACT: The future use of Life-Cycle Cost-Benefit (LCCB) analysis is discussed in this paper. A more complete analysis including not only the traditional factors and user costs, but also factors which are difficult to include in the analysis is needed in the future.

1 INTRODUCTION

In a very interesting research report "Ethics and cost-benefit analysis" by Arler (2006), a short history of cost-benefit analysis as a tool is presented. As early as in 1708 the French Abbé de Saint Pierre studied in details the utility of public road improvement. More methodical procedures were investigated by a group of engineers at the École Nationale des Ponts et Chaussées in France in the first half of the 19th century, see Ekelund & Hébert (1999). A result of this study was a series of books on use of cost-benefit in the second half of the 19th century.

The U.S. Flood Control Act required in 1936 that the expected benefits from planned flood control projects should exceed their presumed costs. Various public committees used in the following years cost-benefit assessments. In 1950 the so-called "green book" entitled "Proposed Practices for Economic Analysis of River Basin Projects" was published. This book set the standard for application of cost-benefit analysis in assessment of public investments; see e.g. Hufsmith (2000).

Since then cost-benefit methods have been used extensively in connection with public regulation. A major progress was made when health and environmental issues became included in the cost benefit analysis. Contingent valuation based on willingness –to-pay was suggested already in 1947, but was not really accepted until the 1980's; see Hanemann (1994).

A number of literature surveys on life cycle cost have been published in the last 30-40 years. Gupta & Chow (1985) published in 1985 a survey of literature on life cycle cost in 25 years. The paper contains 667 references. Other interesting surveys have been presented by Dhillon (1981), (1989), Asiedu & Gu (1998), and several others.

2 NEW LCCB MODELS IN THE FUTURE?

Extract from a text by Hans Scherfig: "The year 2061"; see Scherfig (1961).

In the museum of my village there is one of these hideous machines with rubber wheels and a horn. Such a vehicle had much more engine power than necessary and drove faster than it was safe to do. It was run by petrol explosions, had a nasty smell and made a lot of noise. It was deadly dangerous to those who drove it and to those walking next to it. Accordingly to historians just as many people were killed in automobile accidents as in wars and epidemics in these days.

The automobile was a lunacy which can only be compared to the hysteric epidemics in the Middle Ages. It gave people a pleasurable sense of power to rush along at an unreasonable speed and be in control of unnecessary engine power. In the capitalistic age people were allured to buy automobiles on hire-purchase by depraved manufacturers using psychological advertising. People were working hard to pay the instalments on their useless driving machines. There was vanity and snobbery, not hard to understand. The automobiles changed the looks of the countries and made the cities uninhabitable. Trees were cut down, fertile soil was covered with asphalt and special hospitals were built to take care of the casualties. People's legs withered since they were not used. People had circulation disturbances and fat bellies because they were sitting in their cars instead of walking.

We have come closer to nature. We have not gone back to nature as the development does not

go backwards. But we have gone forward to nature. Life has become simpler. Technology is not a burden and does not make life troublesome and complicated. Technology has become so perfect that it does not bother us anymore. We do not see it. It is not noisy and obstructive. It works for us secretly as an invisible, silent slave."

The present financial crisis has had the effect that most countries worldwide have shown an increased interest in improving their infrastructures especially making new motorways, fast train connections between cities etc.

The main reason for this fact is a belief that the difficult financial situation will be recovered faster with a better infrastructure and that this is a good way to reduce the unemployment. A second reason is based on the fact that the infrastructures in many countries are in a bad condition.

The governments are eager to initiate this kind of activities as fast as possible. Therefore, there is a major risk that the investments are not optimal from an economic point of view. To obtain an optimal investment use of LCCB analysis seems to be a natural solution. However, the present classical LCCB models are in most cases not sufficient since a number of factors that are difficult to include in the analysis are left out.

3   THE HISTORICAL BACKGRUND

LC-CB analysis is based on a engineering knowledge, economic understanding and mathematical experience. These three disciplines are baser on fundamental work by three famous scientists Jules Dupuit (1804-1866), Alfred Marshall (1842-1924), and Vilfredo Pareto (1848 – 1923).

Figure 1. Jules Dupuit (1804-1866).

The first serious application of LC-CB analysis seems to be performed more than 150 years by Jules Dupuit (1804-1866). He was born in Fossano, Italy then under the rule of Napoleon Bonaparte. At the age of ten he immigrated to France with his family where he studied in Versailles - winning a Physics prize at graduation. He then studied in the Ecole Polytechnic as a civil engineer. He gradually took on more responsibility in various regional posts. He received a L ́ǵion d'honneur in 1843 for his work on

the French road system, and shortly after moved to Paris. He also studied flood management in 1848 and supervised the construction of the Paris sewer system.
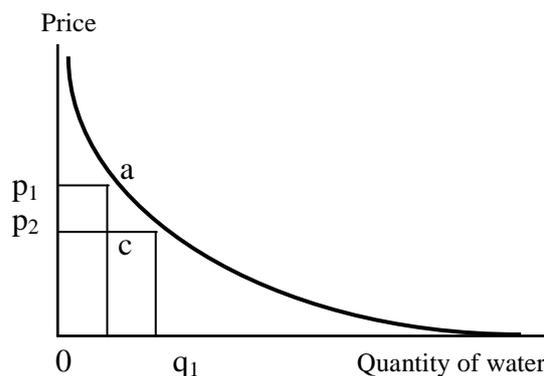

Figure 2. Demand curve by Dupuit.

Dupuit introduced in 1844 the so-called demand curve, see figure 2. Assume that the consumer is originally in equilibrium when the price of water is at p_1 and the quantity taken is q_1. Then assume with Dupuit that the price of water falls to p_2. At the lower price for water the individual is in disequilibrium at point c. The marginal utility of the last unit of the consumer's existing stock is greater than the now-lower marginal utility of water represented by the lower price. In terms of price, what the consumer would pay for q_1 of water is greater than the price he or she must pay for quantity q_1. The same quantity of water (q_1) could be bought at a lower total expenditure, but Dupuit assumed that the consumer would not do this; see [Dupuit].

Alfred Marshall's magnum opus, the Principles of Economics, was published in 1890 and went through eight editions in his lifetime. It was the most influential treatise of its era and was for many years the Bible of British economics, introducing many still-familiar concepts. Marshall was born in London was professor of Political Economy at the University of Cambridge from 1885 to 1908.He was the founder of the Cambridge School of Economics which rose to great eminence in the 1920s and 1930s. Arthur Cecil Pigou and John Maynard Keynes, the most important figures in this development, were among his pupils.

Figure 3. Alfred Marshall (1842-1924).

Marshall's specialty was Microeconomics - the study of individual markets and industries, as opposed to the study of the whole economy. In his most important book, Principles of Economics, Marshall emphasized that the price and output of a good are determined by both supply and demand: the two curves are like scissor blades that intersect at equilibrium. Modern economists trying to understand why the price of a good changes still start by looking for factors that may have shifted demand or supply, an approach they owe to Marshall; see [Marshall].

Figure 4. Vilfredo Pareto (1848 – 1923).

Vilfredo Pareto was an Italian industrialist, sociologist, economist, and philosopher. He made several important particularly in the study of income distribution contributions to economics, and in the analysis of individuals' choices. His legacy as an economist was profound. Partly because of him, the field evolved from a branch of social philosophy as practiced by Adam Smith into a data intensive field of scientific research and mathematical equations.
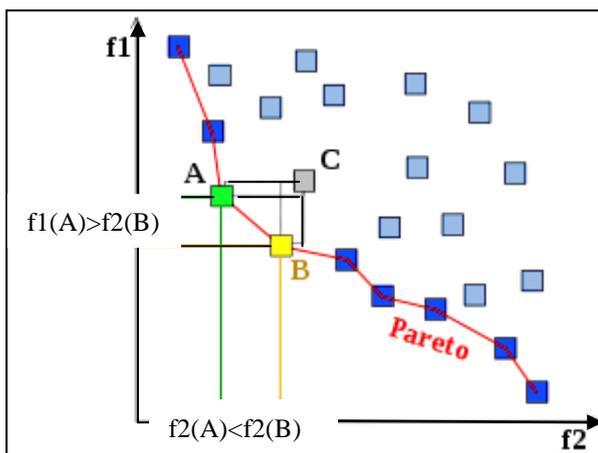

Figure 5. Pareto optimization.

A Pareto-optimal allocation of resources is achieved when it is not possible to make anyone better off without making someone else worse off. Given a set of choices and a way of valuing them, the Pareto frontier or Pareto set is the set of choices that are Pareto efficient. The Pareto frontier is particularly useful in engineering: by restricting attention to the set of choices that are Pareto-efficient, a designer can make tradeoffs within this set, rather than considering the full range of every parameter. Example of a Pareto frontier is shown in figure 5. The boxed points represent feasible choices, and smaller values are preferred to larger ones. Point C is not on the Pareto Frontier because it is dominated by both point A and point B. Points *A* and *B* are not strictly dominated by any other, and hence do lie on the frontier; see [Pareto].

4 PRESENT LCCB ANALYSIS

4.1 *Introduction*

Life-Cycle Cost-benefit analysis is a term that is used in a number of different connections. However, it refers in general to a tool, which

• may help to appraise, or assess, the case for a project or proposal, or
• is an informal approach to making decisions of any kind.

Under both definitions the process involves, whether explicitly or implicitly, weighing the total expected costs against the total expected benefits of one or more actions in order to choose the best or most profitable option. Benefits and costs are often expressed in money terms, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their "present value.

The traditional formulation of LCCB is:

Expected Advantage =
    Expected Benefits - Expected Costs   (1)

where the estimated expected advantage is used as a decision tool.

The traditional formulation may be used in a number of relatively simple cases like:

• Comparing a small number of bridges proposals,
• Deciding whether e.g. a bridge should be repaired or replaced,
• Planning a maintenance strategy for a group of bridges,
• Reliable data are not available.

However, there are a number of serious limitations. There most import limitation is that a number important factor especially related to non-cost terms are left out. Therefore the traditional formulation cannot be used for a major infrastructure.

Modelling of an LCCB analysis may be performed by a number of different approaches. In most cases, these approaches can be divided into three levels:

♦   Level 3 - scientific level,
♦   Level 2 - engineering level,
♦   Level 1 - technical level.

Level 3 is the most advanced level. Models on this level are "exact models" in the sense that the modeling of LCCB analysis is based on a sound and consistent scientific basis. Advanced information on the deterioration and maintenance of the infrastructure is used and detailed information on the environmental loading is taken into account. A level 3 model is typically used in the design of a new infrastructure system such as a long suspension bridge or a new motorway. It is a very expensive model, and it is not easy to formulate a level 3 method based on existing information. An important application of level 3 models is to supply information to be used in a level 2 model.

Level 2 is from a sophistication point of view an average level. Level 2 models are based on the semi-physical or average material deterioration parameters and the average effects of maintenance. They are also based on a number of engineering simplifications regarding the modeling of the average quantities used. A level 2 model will often limit the deterioration of the infrastructure to a few types of deterioration. Level 2 models may be used for the design of new infrastructure systems and for the estimation of deterioration of existing infrastructures.

Level 1 is the most simplified level. It is based on direct observations and expert experience regarding deterioration, repair types, repair intervals and repair costs. A level 1 model is usually based on a limited number of parameters, e.g. those obtained from level 2 models.

4.2 *EU research project*

The first major research on combining stochastic models, expert systems and optimal strategies for maintenance of reinforced concrete structures in a prototype LCCB bridge management system was sponsored by the EU from 1990 to 1993; see Thoft-Christensen (1995) and de Brito *et al.* (1997). The research project is entitled "*Assessment of Performance and Optimal Strategies for Inspection and Maintenance of Concrete Structures using Reliability Based Expert Systems*". The methodology used in the project was analytic, using traditional numerical analysis and rather advanced stochastic modeling. This EU sponsored LCCB bridge management system is a typical level 2 model, but is based on some elements of a level 3 model.

4.3 *User costs*

The importance of including user costs in estimating the economic consequences of maintaining bridges has been studied by Thoft-Christensen (2008), (2009). It is concluded that a cost-benefit analysis is needed when life-cycle analysis of maintenance (including inspection cost, repair cost, and user cost) of

bridges is performed. This conclusion is based on an extensive study of documents on maintenance costs. From five of these documents a limited number of excerpts are shown. They are related to estimation of the importance of estimating user costs when repair of bridges are planned, and when optimized strategies are formulated. Further reference to three other documents is made. These excerpts clearly show that user costs in most cases completely dominate the total costs. In some cases, the user costs are even more than ten times higher than the repair costs.

The main conclusion is that an LCCB based bridge management system without including user costs in most cases is insufficient. User costs will, in general, dominate the cost of inspection and repair. There is an enormous amount of work on user costs in bridge engineering in the literature. However, much more research is needed before an LCCB analysis in the bridge area can be made in a satisfactory manner. Much of the work done until now is limited to narrow models without a wide area of application. A reliable life-cycle based tool must include direct as well as indirect cost. The bridge owners must learn to listen to the public when decisions regarding repair or replacement of structures are taken.

4.4 *The Future Transport Infrastructure in Denmark*

A Danish Infrastructure Commission was in 2006 appointed with the overall objective to maintain and develop Denmark's position as one of the countries in the world with the best transport systems.

• To analyze and assess the key challenges and development potential for the infrastructure and national traffic investments until 2030.
• To identify and assess the strategic options and priorities and to put forward suggestions to strengthen the basis for the national investment decisions in the transport area.

The final goal of the project was to make a systematic and economic prioritization of the governmental investments in the transport infrastructure.

The background for the investigation was a number of statements: The opportunities and the welfare of the individual citizen depend of a modern and efficient infrastructure. The growing globalization and development in EU will result in a significant increase in international goods transport. It will require profitable investments in a new and modern infrastructure to establish the best settings for high mobility and effective logistics. However, it is at the same time important to take into account the consequences, the increasing traffic may result in, for the environment, the noise, and safety. Mobility is important to us as individuals to be able to do the things we want – and the individual has mobility as a high priority. Almost everybody is in contact with

the transport system on a daily basis – in our way to work, to visit family, to leisure activities or to travel to the countryside. The average Dane spends more time on transport than on completing their primary education. Danish households spend an average 15 % of their income on transport. That is more than they spend on food.

Three different LCCB alternatives are used in the Commission report to present the results of a LCCB analysis:

♦ Net Present Value: The total value for the society of the advantages and disadvantages in the expected lifetime discounted back to the present.
♦ Benefit–Cost Relation: The present value for the society of 1 $ invested by the society.
♦ The internal rate: The internal rate is the corresponding to a project net present value equal to zero.

A proposed enlargement of an existing motorway through a city is used as an example of the LCCB analysis used by the Commission. The enlargement is compared with building a new motorway to bypass the city, see figure 6. The result of the LCCB analysis is shown in table 1.
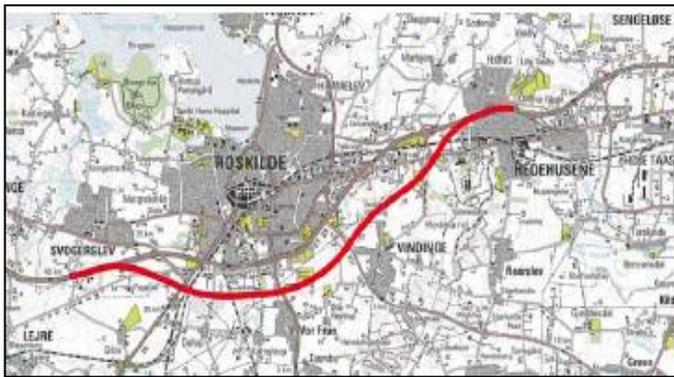

Figure 6. LCCB analysis.

Table 1. Result of the LCCB analysis.

2005 DKr Millions	Enlarge motorway	New motorway
Financial expenses Construction, maintenance	- 1,376	- 2,009
Traffic advances Time reduction, driving exp., inconveniences	2,108	1,978
External expenses Accidents, noise, air pollution, CO2	305	101
Other consequences	-235	-190
Net present time value	877	-120
Internal rate of interest	7.8 %	5.8%
Net profit per public invested 1DKr	0.64	-0.06

It follows from table 1 that enlargement of the motorway will give a positive present time value of 877 million DKr, and building a new motorway will give a loss of 120 million DKr for the society.

Effects included in a LCCB analysis in Denmark are:
♦ Construction costs
♦ Inconveniences during the construction
♦ Working expenses
♦ Travel time reductions
♦ Traffic safety
♦ Noise
♦ Local and global air pollution
♦ Polluted soil and ground water
♦ Area application
♦ Indirect effects

Effects not included in LCCB analysis in Denmark are:
♦ Influence on the surroundings
♦ Vibrations
♦ Loss of landscape values
♦ Loss of cultural artifacts values

5 SOCIAL AND FINANCIAL CONSIDERATIONS

5.1 *Introduction*

This section is based on a report published by the Danish Ministry of Transportation in 2002; see Transportministeriet (2002). In the last 20 years, the environmental impact of the growing traffic has been in focus when major decisions regarding the infrastructure are taken. Therefore, it is of great interest to derive consistent methods by which the environmental impact may be evaluated.

The purpose of a socioeconomic evaluation of a product is to give a total evaluation of the projects societal profitability. However, there will always be a great uncertainty related to such an analysis. It is therefore important not only to focus on single numbers, the present net value or the internal rate of interest. The analysis must also identify the critical factors in the societal profitability. The evaluation must also give a systematic and transparent presentation of the projects advantages and costs so that an open decision process can be performed.

The following three central questions are formulated in Transportministeriet (2002):

1 How is the socioeconomic analysis used in the political decision process?
2 What kind of principles are use to weight the different types of costs and advantages in a project?
3 What kinds of effects are included in the analysis?

With regard to the second question three formalized evaluation principles exist:

♦ Multi Dimensional Comparison MDC, where each involved effects are evaluated by monetary, quan-

titative or qualitative well-defined systematic principles.

♦ Multi Criteria Analysis MCA, where in some way the different effects are combined in a single criteria by weighting so that all projects can be ranked.

♦ Cost-Benefit Analysis CBA, where all effects are assigned a monetary value, so that they can be added to a single value of the project.

Most LCCB analysis is based on a pure Cost - Benefit Analysis CBA. As mentioned earlier this is in some cases justified. However in most cases it is insufficient. Multi Criteria Analysis MCA is already used in several cases and seems to be the way forward towards a comprehensive and satisfactory LCCB analysis. An example of a MCA decision support system is briefly presented in the next chapter.

5.2 *The* EURET *report*

In the European Commission EURET (1996) report an appraisal spectrum is suggested; see also the ECMT (2001) report. The MCA (multi-criteria approach) employs weights to results derived from a variety of techniques, with a large degree of subjective assessment and expert judgments likely to be involved.

It is for large, medium-sized, and small interurban road infra structure projects proposed that the two main evaluation approaches CBA (cost-benefit analysis) and MCA are used for Core Impacts and Non-core impacts, respectively.

The Core Impacts are:

♦ Investment costs
♦ System operating and maintenance costs
♦ Vehicle operation costs
♦ Travel time savings
♦ Safety
♦ Local environment (air pollution, noise, severance).

The Non-core Impacts are divided in nonstrategic and strategic impacts. The Non-core, nonstrategic impacts (where MCA approaches are proposed independent of size) are:

♦ Driver convenience (comfort, stress)
♦ Landscape and urban quality.

The Non-core, strategic impacts (where MCA approaches are proposed for large (and mediumsized impacts) only) are:

♦ Strategic mobility (accessibility and networks)
♦ Strategic environment (greenhouse gases, ecological damage)
♦ Strategic economic development (regional effects)
♦ Other strategic policy and planning impacts.

A number of interesting data and conclusions are presented in the ECMT (2001) report. The evaluation time and the rate of discount for some EU-countries are shown in table 2. In the report is stated that discount rates should not be so high as to conceal longer term, especially environmental, impacts.

Table 2. Evaluation time and discount rate. ECMT (2001).

Country	Evaluation period	Rate of discount
Belgium	Infinite	4%
Germany	Project time	3%
France	Infinite	8%
Sweden	Trunk roads 60 years Other roads 40 years	4%
UK	30 years	6%

Traffic forecasts are a very important input to CBA. Expected high traffic growth is often one argument when capacity improvements are argued for. Scenarios are a very useful tool for analyzing effects of different traffic forecasts. Time saving is in general the main benefit in a CBA when e.g. a new road or a new bridge is built. VoT (Value of Time) for 17 countries is shown in table 3. The spread in values in table 3 may be due to different income level, the infrastructure, macroeconomic factors etc.

Table 3.Value of travel time. ECMT (2001).

Country	Euro/hour for passenger car	Euro/hour for Goods vehicle
Belgium	7.8	29.7
Canada	4.5	n.a.
Denmark	7.2	20.9
Finland	4.6	16.9
France	9.5	25.2
Germany	4.6	28.3
Greece	3.8	5.9
Ireland	11.3	14.1
Luxembourg	13.5	16.5
Netherlands	7.8	9.5
Norway	7.8	n.a.
Portugal	4.3	5.2
Spain	10.0	16.5
Sweden	5.4	21.5
Switzerland	27.3	61.7
Turkey	4.8	n.a.
UK	9.9	12.2

The multi-criteria effects discussed in the ECMT (2001) are presented in chapter 7.

6 FUTURE LCCB ANALYSES

The main drawback with most existing LCCB systems is that a number of factors cannot be including in a satisfactory way. It is clearly not an easy job to make a fully satisfactory format for future LCCB analysis. However, it may be useful to remember the

following quotations by Albert Einstein and Winston Churchill respectively:

"The significant problems we face cannot be solved at the same level of thinking we were at when we created them."

"A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty."

The Danish Centre for Logistics and Freight Transport has developed a decision support system based on Life-cycle Cost-Benefit Analysis LCBA embedded in a Multi Criteria Analysis MCA; see Salling e. al. (2007). The LCCB model presented in this chapter is based on the decision support system described in Salling et al. (2007). The format of the decision support system is shown in figure 7.

The proposed decision model is used to compare the life cycle costs for a number of alternative projects p_i, $i=1,\ldots,P$. The model is based on a Multi Criteria Analysis as defined in section 5.1. Let C_{total} be the total life cycle cost of a given project a_i

$$C_{total}(p_i) = C_{trad}(p_i) + \alpha_i C_{extra}(p_i)$$
(2)

where $C_{trad}(p_i)$ is the traditional costs for the project included in the present LCCB analysis, and where $C_{extra}(p_i)$ is the costs which cannot be included directly in the present LCCB format. α_i is a project specific calibration factor that expresses the costs between the traditional part and the extra part.

The "extra" costs $C_{extra}(p_i)$ in a project will in general include several different effects. If these effects are independent then $C_{extra}(p_i)$ is a sum of the single "extra" effects

$$C_{extra}(p_i) = \sum_{j=1}^{J} w_j C_{extra,j}(p_i)$$
(3)

where w_j is a weight factor expressing the importance of the costs $C_{extra,j}(p_i)$ from the effect j to the "extra" costs. By inserting (3) in (2), the total "extra" costs can be written

$$C_{total}(p_i) = C_{trad}(p_i) + \alpha \sum_{j=1}^{J} w_j C_{extra,j}(p_i)$$
(4)

The LCCB analysis is in this formulation (4) extended to a more general format. However, for each project i the factors α_i and w_j and the costs $C_{extra,j}(p_i)$ from effect j to the project i must be estimated.

The extra life cycle costs for effect j in project i in the life time T can e.g. be modelled in a format like the traditional LCCB analysis

$$\alpha w_j C_{extra,j}(p_i) = \sum_{t=o}^{T} \frac{1}{(1+r)^t} C_{extra,j}^w(t)$$
(5)

where r is the discount rate, and $C_{extra,j}^w(t)$ is the weighted cost in year t.

In this format the analysis is reduced to evaluate the weighted costs for all effects in every year within the lifetime. With P projects and I effects and a life time T the maximal number of evaluation of effects is $P \cdot I \cdot T$.

It is important to notice that using the format described above and illustrated in Figure 7 makes it possible to make individual weights not only on the projects but also on the effects. It is e.g. possible to put more weight on e.g. the noise effect than on environmental effects and vice versa. The multi-criteria effects are discussed in chapter 7.
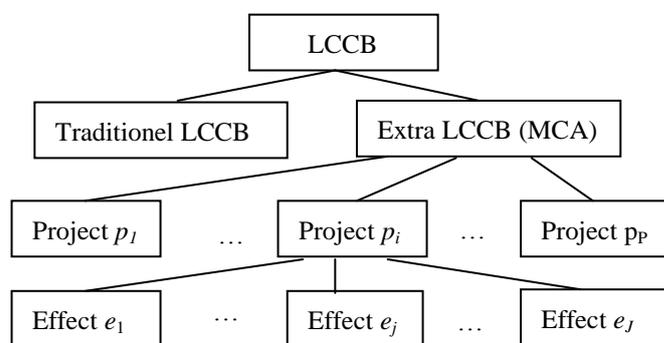

Figure 7. LCCB format.

7 MULTI-CRITERIA EFFECTS

7.1 *Introduction*

In the traditional LCCB only effects which can monetize are included. This is in general not possible for multi-criteria effects which to a certain degree are based on subjective information from decision makers.

To illustrate the situation it is useful to consider an example presented in ECMT (2001). The project is a bypass in the state of North Rhine-Westfalia, Germany. The bypass investment is thought to improve the environmental conditions. In table 4 the benefits of this road investment is shown.

Table 4. Benefits of a bypass road investment. ECMT (2001).

Effects	Benefit (million DM)	Benefit share (%)
Savings in transport costs	0.464	17.4
Road maintenance costs	-0.067	-2.5
Safety contributions	0.189	7.1
Improvement of accessibility	0.405	15.2
Regional effect	0.089	3.3
Environmental benefits	1.581	59.5

Total benefits	2.661	100

It is interesting to observe that 59.5% of the bene-fits are attributed to environmental improvement.

7.2 *A case study*

The Danish Ministry of Transport has published a manual for socioeconomic analysis within the area of transportation; see Trafikministeriet (2003). Two case studies illustrating the application of the manual are published in a report by the Danish Ministry of Transport; see Trafikministeriet (2004). The first case study is described in this section.

The case study is a typical socioeconomic analy-sis where traffic and effect models can be used. The problem treated by a LCCB analysis is whether a new 4-lane motorway should replace an existing road. The expected life-time of the new motorway is 50 years starting with year 2008. All costs are dis-counted back to year 2001. The discount rate is 6%.

Tabel 5. Air pollution effects 2008. Trafikministeriet (2004).

Pollution					
	Number		Unit price		Effect
	Country	City	Country	City	1.000 DKr
	tons		tons		
SO$_2$	5		-13		-26
	-1		-39		
NOx	100		-24		-960
	-20		-72		
HC	0.2		-13		
	-0.1		-40		1.4
CO	1.200		-0.2		-
	200		-0.6		120
Particles	1		-44		-17.4
	-0.2		-133		
Total					-1.122
Climate					
	Number		Price		Effect
	tons		DKr/kg		1.000 DKr
CO$_2$	6.000		-0.3		-1.800
Total					**-2.922**

The traffic is assumed to increase with 1.5% in the first 20 years after the opening of the new mo-torway and is the constant in the remaining 30 years. All the traditional effects are included in the LCCB analysis. However, a number of other external ef-fects are also included such as improved safety and the air pollution.

The air pollution has a direct negative effect on the health of people but has also some other effects for the society. The proposed motorway has a posi-tive effect since it will transfer the traffic from the city to the country. The total effect of the pollution is shown in table 5. The total effect of the pollution is 1.1 million DKr in 2006. The increased traffic will increase the CO_2 emission with an expected cost of 1.8 million DKr.

The total socioeconomic analysis is shown in ta-ble 6. The effects are divided in three groups:

♦ Effects for the Government
♦ Distortion loads
♦ Effects for the road users
♦ External effects

Tabel 6. LCCB discounted 2008. Trafikministeriet (2004).

Effects	Discounted to 2008
	million DKr
Government	
Construction	-1.985
Rest value	86
Operation	-196
Tax yield	626
Total	-1.442
Distortion loss	-261
Road users	
Cars	1.089
Vans	304
Trucks	171
Total	1.567
External effects	
Accidents	496
Noise	124
Air pollution	-17
Climate	-30
Total	573
Total NNV	**433**

The calculations results in an estimated net present value in 2008 of 433 million DKr. The bene-fit-cost relation that is the net benefit per used public DKr is 0.28. The internal rate is 6.8% that is a little higher than the discount rate 6.9%.

The estimated relatively low net present value is sensitive to the estimated cost and especially to the non-monetary effects. Only small changes in the used assumptions can result in a negative net present value and thereby make the project not profitable.
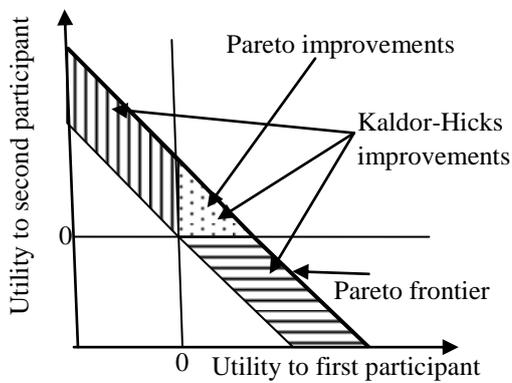
7.3 *Kaldor-Hicks efficiency*

Figure 8. Pareto and Kaldor-Hicks improvements. Stringham (2000).

As mentioned in chapter 3, a Pareto-optimal allocation of resources is achieved when it is not possible to make anyone better off without making someone else worse off. Given a set of choices and a way of valuing them, the Pareto frontier or Pareto set is the set of choices that are Pareto efficient. However, it is almost impossible to take any social action without making at least one person worse off; see e.g. Stringham (2000). Modern economics is based on pioneered work by Kaldor (1939) and Hicks (1939).

Modern economics is based on pioneered work by Kaldor (1939) and Hicks (1939). An alternative to Pareto is the so-called Kaldor-Hicks efficiency. Kaldor-Hicks is a measure of economic efficiency where an outcome is considered more efficient if a Pareto optimal outcome can be reached be reached by rearranging sufficient compensation from those that are made better off to those that are made worse off.

In figure 8 is shown a 2-dimensional case with a first and a second participant in a decision problem. The utility is as starting point assumed to be 0 for both participants. With the shown linear Pareto frontier a Pareto improvement is obtained in the shown triangular area. All three market areas contain Kaldor-Hicks improvements. Every Pareto improvement is also a Kaldor-Hicks improvement. But most Kaldor-Hicks improvements are not Pareto improvements.

As an example assume that a new project results in a positive effect to a person A equal to 10000 units and a negative effect to a person B equal to -8000 units. Then this project is not Pareto efficient because B is worse off with this project. However, the project is Kaldor-Hicks efficient as person A theoretically could pay anywhere between 8000 and 10000 units to accept the project. The key difference between the two types of efficiency is therefore the question of compensation.

In a typical cost-benefit analysis of e.g. a planned new bridge the total costs (building and environmental costs etc.) is compared with the benefits (travel time savings etc.). The project will in general be accepted if the benefits exceed the costs. This is an application of the Kaldor-Hicks criterion because the benefits in principle could compensate those who have made a loss.

8 SOME CRITICAL COMMENTS

Critical objections to using LCCB analysis can be found in numerous papers published in journals or presented at conferences. Most of the criticism is concentrated on missing effects included in the analysis and on the uncertainties in estimating the effects.

The use of case-study research has been criticized by Flyvbjerg (2006) in a paper entitled "Five Misunderstandings about Case-Study Research". The five misunderstandings are (extract from Flyvbjerg (2006)):

1. *General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge.*
2. *One cannot generalize on the basis of an individual case; therefore, the case study cannot contribute to scientific development.*
3. *The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypotheses testing and theory building.*
4. *The case study contains a bias toward verification, that is, a tendency to confirm the researcher's preconceived notions.*
5. *It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies.*

These misunderstandings are aimed at case studies but are also to some extend existing for LCCB analysis in general.

9 CONCLUSIONS

The traditional LCCB format is only acceptable for small situations e.g. in some simple cases where a small number of alternatives are compared. But even in such cases at least user costs should be included. User costs are in most cases the dominating factor in a life cycle analysis of infrastructures like bridges. It is well-known that maintenance of a bridge stock may be up till 10 times the original construction costs. The main reason for this limited type of LCCB format seems to be that decision makers are reluctant to include effects if they are difficult to monetize.

In this paper it is argued that the traditional LCCB formats are incomplete. More sophisticated formats are now standard for major infrastructure projects. Multi-criteria effects are already now included in several governmental standards especially in the transport area. It is shown by examples in this paper how the multi-criteria effects like accidents, noise

air pollution, and climate may be included in future LCCB formats.

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