THE REAL BENEFITS OF PUBLIC INFRASTRUCTURE PROJECTS- COMPREHENSIVE COST-BENEFIT ANALYSIS OF PUBLIC PROJECTS BASED ON THE CASE OF THE A40 MOTORWAY RENOVATION

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Abstract

Infrastructure projects are in the public eye. The renovation of a chronically congested motorway in a densely populated region causes additional traffic jams, millions of hours of time wasted, additional fuel and CO_2 consumption and millions of Euros. Is it better to close the motorway completely for a few months, which has been a taboo, than to cause years of traffic congestion due to lane closures? The case of the A40 motorway renovation shows that the capital budgeting technique for public infrastructure projects of the European Union does not sufficiently consider all social, ecological and economic aspects and therefore needs a redesign.

We show that the holistic evaluation of all social, economic and environmental benefits can lay down the real impact of infrastructure investment in a comprehensive way. We conclude that the evaluation of all aspects of infrastructure projects is crucial to show the real cost and long-term benefits of infrastructure investments. We show that consistent, standardized indicators are needed for a comprehensive evaluation of public infrastructure projects.

Keywords: Benefits Management, Infrastructure Projects, Cost-Benefit Analysis

1. Introduction

Motorways are a key factor for private and commercial traffic in the infrastructure network of an economy. In this study we aim to demonstrate how the shortened construction time for the renovation of a motorway leads to great social, economic and environmental benefits for the society, however which could not be shown with the classic investment appraisal method proposed by the European Union. The A40 is one of the busiest motorways in Germany. The renovation of this motorway was an undertaking that, in the traditional approach, would have meant minimum 24 to 36 months of chronic traffic congestion in the Ruhr region, which is with more than 5 million inhabitants one of the most densely populated areas in Europe. The innovative idea of the project manager of closing the motorway completely and carrying out the construction work in parallel resulted in the reduction of the construction time of more than two years, which saved all stakeholders a lot of time, money and environmental impact. The two alternative project design approaches place different demands on the stakeholders. The following paper compares the two project designs using the holistic socio-economic-environmental cost-benefit analysis and shows that it is possible to quantify the impact of avoiding years of congestion. This comprehensive public infrastructure appraisal method is not used yet by the public infrastructure authorities.

2. Literature Review

The literature reviewed in this section encompasses the Cost Benefit Analysis for project evaluation and the socio-economic and environmental impacts of infrastructure investments.

2.1 Cost Benefit Analysis

The Cost Benefit Analysis (CBA) is a systematic, analytical method of comparing the benefits and costs of a project or program. It attempts to answer the question whether a proposed project is worthwhile, the optimal scale of a proposed project and the relevant constraints. CBA is fundamental to decision-making and is established as a formal technique for making informed decisions on the use of companies, societies and government scarce resources (Mishan and Quah, 2020). CBA is applied for project and program evaluation and appraisal.

One challenge of public infrastructure projects is to quantify their subsequent economic success, as there are usually no subsequent cost savings or profits compared to investment projects in industry. Assessing its contribution to societal benefits should be done for each public project. Standard valuation methods based on projected profits and capital expenditure cannot be applied due to the intangible nature of public infrastructure projects. Therefore, the method cost-benefit analysis (CBA) should be applied. Cost-benefit should be part of any business case for public investment projects.

The aim of CBA is to ensure that public administration allocates the scarce budgets among competing projects in the best interest of the society. The basic assumption of the CBA is to identify the benefits created by a project, whereby the benefits should exceed the costs.

CBA is particularly relevant for publicly financed projects, as they are evaluated from an economic-social perspective. However, measuring the benefits is not easy. Volden writes that the benefit is interpreted in terms of the citizens' willingness to pay, but he leaves open how to evaluate the benefits in the case of a public service provided for free, such as a public motorway (Volden, 2015).

2.2 Investment in public infrastructure

Research on the effects of infrastructure investment on regional growth and economic performance has a long history. During the 1970s and 1980s, the United States had undergone a dramatic slowdown in national productivity growth. Public infrastructure was not seen as an influencing factor for this slowdown, most studies focused on energy prices, social and economic regulation, and low levels of capital accumulation. Aschauer´s (1989) work enforced the research on the effects of public infrastructure when he found that public infrastructure was an important input into the national production, and argued for greater spending on public capital.

Cook & Munnell showed that public investment makes a significant contribution to national outputs like productivity, growth, and international competitiveness (Cook & Munnell, 1990). They state that investment in infrastructure tend to have greater output, more private investment, and employment growth. The World Development Report examined the link between infrastructure and development and explored ways in which developing countries can improve both the provision and the quality of infrastructure services (World Development Report, 1994). Palai examined how key infrastructure determines the national competitiveness, which in turn influences industrial policy (Palai, 2015). The results show that national competitiveness is influenced by the level of institutional development. He identified seven national competitiveness factors like infrastructure, determined mainly by the quality of roads, railroad infrastructure, air transport and electricity supply.

One of the weaknesses of CBA in infrastructure projects is that the traffic volumes are often overestimated, in average by 20-60% which distorts the results (EU, 2015). The construction costs are however are usually underestimated, leading to cost overruns of 50-100% (Andersen et al, 2016). The future interest rate is not predictable in the long term (EU, 2015). Higher interest rates favor smaller investments and short-term benefits. Another weakness of CBA is that the assumed residual value does not accurately reflect the true residual value (Jones et al., 2014). Assessing the value of lives saved through infrastructure interventions is even more difficult, as there is no agreement on the value for a human life. In Norway, where this form of project governance has been consistently applied to public infrastructure projects for years, the value of a human life is set at NOK 30 million (equivalent to EUR 3 million) (Volden, 2015). The same applies to the valuation of time savings: there is no consensus which variables are relevant for the valuation of time. The impact on the environment also carries great uncertainties. Life cycle assessment is usually not carried out and is thus not included in any CBA (Jones, et al 2014).

Despite its weaknesses, CBA is the most applied assessment method in the public transport sector (Volden, 2015). It is required for infrastructure projects funded by the EU. The EU's "Guide to Cost-Benefit Analysis of Investment Projects - Economic appraisal tool for Cohesion Policy 2014-2020" presents the CBA method and a case study on a motorway project which represents the basis for this CBA.

2.2.1 Economic Impacts

The most common method to directly relate economic development to growth is measured in the overall Gross Domestic Product (GDP), or the GDP per capita (Straub and Terada-Hagiwara, 2010). Regarding infrastructure investment it is common sense that infrastructure lowers the input costs while generating an overall increase in production, as shown in several studies (Aschauer, 1989, Montolia and Solé-Ollé, 2007, Macdonald, 2008, Calderón et al., 2015, Khanna and Sharma, 2020). Muvawala et al. (2020) find that initial high costs lead to negative impact on economic growth, however this overturns in the long-term with later significant economic growth. The authors argue that the negative short-term impact demonstrates that public spending needs to be rebalanced to better prioritize the social sector.

Leigh and Neill (2011) found that infrastructure investment on a national scale have spillover effects which contribute to reducing unemployment at a local level. While the results of the study were promising, they were unable to determine the effect on the national economic activity. However, the authors emphasize that there is evidence to suggest an indirect link between better national infrastructure bolstering local economic activity due to lower transportation cost for independent local business which consequently supports a substantial increase in job creation. Studies on the relation between unemployment and infrastructure investment show that efficient investment in infrastructure lead to an overall decrease of unemployment and an increase in job creation (Zhu et al. 2009, Hernandez et al., 2020, Edeme et al., 2020).

The studies that explore the socioeconomic impacts do so in the context of specific types of infrastructure, such as transport and ignore the potential effects of other types of infrastructure. In addition to these limitations, many studies do not differentiate the impact on a regional scale, and instead provide an overarching understanding on a national or global scale.

2.2.2 Social Impacts

Studies investigating the social impacts of infrastructure development show some commonalities. Zamojska and Próchniak (2017) describe the social economy as covering employment, social services and social cohesion. The fundamental purpose of infrastructure is to meet societal needs. The benefits of infrastructure should therefore not be limited to the provision of basic functional utilities.

Bristow and Nellthorp (2000) describe that social impacts also encompass the environmental and public welfare, and demonstrate how infrastructure directly improves social welfare. They illustrate that, for example, improving the quality of transportation infrastructure is linked with the reduction of road accidents and traffic disruption which consequently save travel time and costs. In this case cost are divided into direct costs as damages to vehicles, property, medical expenses etc. and indirect costs, as the loss of production through the loss of skilled or unskilled workers, thus cost to society as well as the economy.

The research corresponds with the study by Aschauer (1989) who argues that infrastructure enhances the quality of life with direct improvements to public safety, appearance of urban environments, health and wellbeing. Straub and Terada-Hagiwara (2010) demonstrate how infrastructure for utilities provide essential services. Additionally, improving existing infrastructure can reduce overall production and maintenance costs, resulting in reduced utility prices.

2.2.3 Environmental impacts

The assessment of the environmental impacts of infrastructure investments is the newest aspect of a comprehensive analysis. Only since about 40 years environmental impact assessment (EIA) exists, with emphasis on the last 15–20 years.

EIA is used as an umbrella term that captures the essential idea of assessing proposed actions from policies to projects for their likely implications for all aspects of the environment, from social to biophysical, before decisions are made to commit to those actions, and developing appropriate responses to the issues identified in that assessment (Morgan, 1998, Morgan, 2011).

Motor vehicles emit nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC) and particulate matter (PM), which constitute a major source of air pollution. Traffic generated air pollutants such as NO2 and PM are of health concern; traffic generated greenhouse gases such as carbon dioxide (CO_2) contribute to global warming (Xia & Shao, 2005).

In this paper we aim to show the economic, the social and the environmental impacts including the health impact of motorway renovation.

3.Methodology

The most commonly used method for valuing public infrastructure projects is the net present value (NPV) method. The NPV is calculated according to the formula:

$$NPV=\sum(B_t-C_t)/ (1+i)^t$$

where B is the social, economic and environmental benefits, C the social, economic and and environmental cost, i the interest rate and t the time period of the analysis. The decision rule states to implement a project if the NPV is positive, or to select the project with the highest NPV in case of multiple alternatives.

The challenge of the motorway renovation project which we use in this case study was to lay down the complete impacts of the two alternative construction methods. The official project closure report of the responsible public administration contains the project investment cost (CBA 1). They state that it is not possible to evaluate the comprehensive consequences of the alternative project scenario.

We take the recommendations of the European Union in their Guide to Cost-Benefit Analysis of Investment Projects and use their case study of a motorway project as model for the second Cost Benefit Analysis (CBA 2). However neither all social, economic nor environmental effects are considered sufficiently in the EU guide. Therefore the authors develop a third Cost Benefit Analysis (CBA 3) which aims to lay down the comprehensive, complete perspective on the public infrastructure project.

The aim is to compare the three CBAs for the two alternative project design methods and to demonstrate the feasibility of a holistic socio-environmental-economic project appraisal analysis for decision making.

4. The A 40 motorway renovation project

The A 40 motorway runs from the German-Dutch border to Dortmund, from West to East of the German federal state of North Rhine-Westphalia. Its planning began in 1926, making it one of the oldest motorways in the world. With 5 million inhabitants, the Ruhr region is one of the most densely populated areas in Germany, tens of thousands of commuters use the A 40 every day to get to work. Although only 95 km long, it is one of the busiest motorways in Germany with 115,000 vehicles per day (www.bast.de). The A 40 connects a total of 22 cities, hence its nickname "Ruhrschnellweg" (Ruhr express way). Due to the high traffic load and the density of junctions, there are many traffic jams at peak times. This is why the A 40 is popularly known as the "longest car park in the Ruhr area". In 2020, the German Statistics Office reported 6.470 traffic congestions for the motorway A 40, which corresponds to 17,7 congestions per day. Fig. 1 shows the dense motorway network in the Ruhr area and the forecast for the traffic volume for the year 2030:

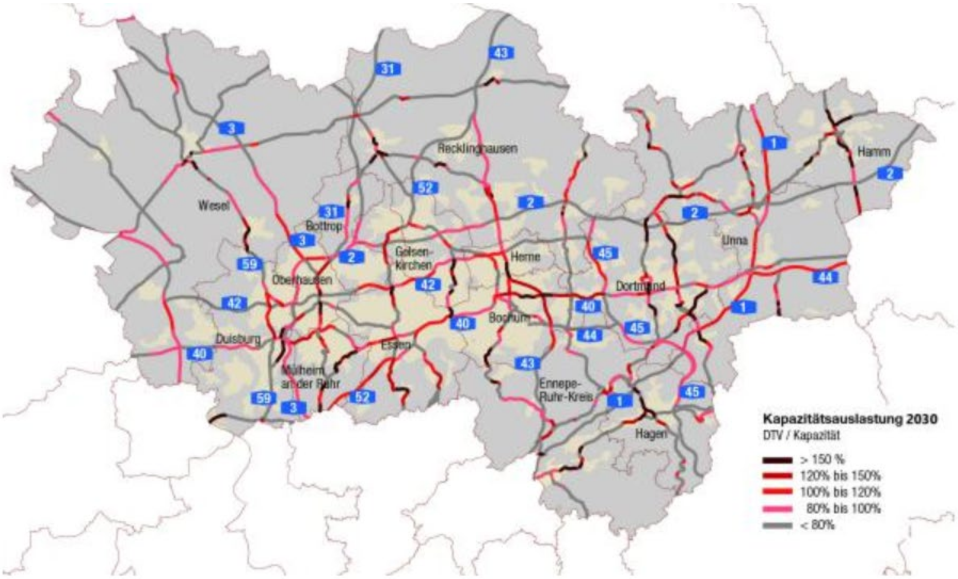

Fig.1: The motorways in the Ruhr region (Source: http://essenruhr.de/archive/category/verkehr/autoverkehr/Seite/9)

The motorway renovation project A 40 included the renovation of three bridges, the construction of a new bridge, the improvement of fire protection measures in a tunnel, the installation of whispering asphalt and new noise barriers.

The traditional approach of a motorway renovation is to carry out the construction measures during the continued use of the motorway. This means partial lane closures for two to three years and leads to traffic chaos in the region, which is already burdened by chronic traffic congestion on a daily basis.

The project manager's new project design consisted of closing the motorway completely for a few months so that the construction work can be carried out simultaneously. This reduced the duration of the renovation work from 24 to 3 months. In addition, the construction quality could be significantly improved by simultaneous execution. Furthermore, the full closure led to more safety for the construction personnel, as the risks due to construction under traffic were completely eliminated. In total, 2 million EUR construction cost could be saved through the parallel work.

However, the innovative parallel approach leads to a significantly greater complexity of the infrastructure project. The parallel planning of the processes and their coordination is significantly more demanding. There was no previous experience with this measure. If major technical problems occurred, the entire success of the project would have been jeopardized and the motorway completely closed not only for a few months but for years. In addition, three-shift operation causes higher personnel costs. If one of the special construction machines broke down, its replacement could take weeks. Thus professional project management including a profound risk management and good leadership of all parties involved was required. In addition, the public, public administration and also the politicians had to be convinced of the meaningfulness of this new procedure.

Table 1 compares the two project designs of 24 vs. 3 months construction time:

Criterion	Classic lane-wise renovation	Parallel construction
PM Approach	Sequential approach with lane closures in sections	Parallel approach with complete motorway closure
Experience	Common approach, much experience	New, no experience
Planning duration	6 weeks	6 months
Construction cost	25 million EUR	22 million EUR
Impact on traffic during renovation	24–36 months congestion, stop and go traffic	Risk of traffic chaos. Alternatives as bypasses and public transport were communicated 6 months in advance
Impact on construction	Lower construction quality, less safe for contruction workers	Higher construction quality, higher safety for construction workers
Social impact	Years of congestion;	Due to intense PR before start of construction, high acceptance among population

Table 1: Comparison of the two alternative project designs for a 24 vs. 3 months construction time

4.1 Cost Analysis of public roadwork authority (CB 1)

The original cost analysis of the public administration in the final project closure report (CB1) from 2019 consists of few figures: According to the public project executing administration StrassenNRW the total construction cost for the construction period of 3 months amount to EUR 22 million, and for the construction period of 24 months they amount EUR 25 million. The project team did not have to deliver a business case. The team assumed that the cost of both approaches would be almost the same. This is plausible at first, as in the 3 months approach the construction work was carried out in three shifts, which included night shift and weekend surcharges, as well as additional costs for hiring replacement specialist construction equipment. However, lane closures, diversions and sequential working also condemn additional costs, so that it can be assumed that the additional costs of the construction time reduction of 21 months are marginal.

In addition they assume cost savings for the new, parallel 3-months approach of 5.5 million EUR, which results from 2 million EUR for higher construction quality and 3.5 million EUR for avoiding 21 months of traffic congestion.

	24 months approach	**3 months approach**
Cost	25 million EUR	22 million EUR
Relative cost savings	none	5,5 million EUR

Table 2: Cost and savings for the two construction methods based on StrassenNRW

4.2 Cost-Benefit-Analysis based on EU Guideline for Investment Projects (CBA 2)
According to the EU Guide to Cost-Benefit Analysis of Investment Projects, the socio-economic objectives of transport projects are usually related to improving the conditions of movement of goods and people within, into and out of the area under study (accessibility), as well as to improving the quality of the environment and the well-being of the population covered (EU, 2015). The case study for a motorway construction in the guide is used as the basis for the cost-benefit calculation (CB2). The cost-benefit analysis is carried out for a 30-year reference period, which is common for road construction projects. A residual value is projected at the end of the period. The analysis uses constant prices. An interest rate of 4% is assumed in accordance with the framework set by the EU Commission. The periodic maintenance of the motorway in the reference period is calculated as an additional 10% of the construction costs.

The residual value of the motorway, the bridge and tunnel construction measures after 30 years is assumed to be EUR 8 million. Discounting for 30 years and an interest rate of 4% thus result in a current value of the investment of EUR 3 million.

After the renovation we assume the following benefits: transport infrastructure is a critical success factor for the prosperity of an economy, enabling companies and individuals to produce goods and services efficiently (Stupak, 2018). The improved condition of the road surface, the new and the three rehabilitated bridges, the safer tunnel and the noise abatement measures lead to the following social and economic benefits for stakeholders: The average speed of motorway users is slightly higher due to the renovation measures, which leads to the following - initially seemingly small - time savings:

An average speed of 85 km/h is assumed before, and 90 km/h after the construction work. The average length of use of the A40 is assumed to be 20 km due to the specific situation in the densely populated Ruhr area. Thus, the average usage time before the renovation is 14.2 min, and afterwards 13.3 min per vehicle. The time saved per day and vehicle is therefore 0.9 min, which results in 1,725 hours saved per day for 115,000 vehicles. Referring to the EU guideline we assume cost of EUR 12.90 per hour for work-related trips and EUR 4.30 per hour for non-work-related trips. This results in cost savings of EUR 11,610 per day for work-related trips, EUR 2,580 for private trips and EUR 4,218 for HGV trips, proving a cost advantage of EUR 18,408 per day and EUR 4.418 billion per year (based on 240 working days per year).

As the speed difference after the measure is only 5 km/h, the resulting higher fuel consumption and CO_2 consumption due to the higher speed is minimal and therefore neglected in this cost calculation.

Within the 30-year period, we assume cost savings due to the prevention of accidents. According to the statistics of the public road authorities in Germany, the accident rate with people injuries on motorways in Germany is 0.08 accidents/million car km (www.bast.de, 2021). Taken the average usage lengths of 20 km per car per day, and 115,000 cars makes 2,3 million km/day and 839,5 million km/ year on this motorway, thus an average 67 accidents per year. Due to the renovation measures we assume 9 prevented minor collisions per year, thus 261 prevented accidents in 30 years with costs of 10,000 EUR each, in total 2.61 million EUR.

According to the German public road authorities the mortal accident rate on motorways is 1.7 killed people/billion car km (www.bast.de, 2021). The usage of 839,5 million km/ year therefore cause 1.4 deadly injured people on this motorway per year. The renovation will not completely prevent fatal accidents, but we assume that the safer bridges and tunnels prevent 3 fatal accidents in 30 years. With a given value of a human life of 3 million EUR, the renovation saves additional cost of 9 million EUR. Thus, a total of 11.6 million EUR accident costs can be saved in the reference period of 30 years.

The Cost-Benefit analysis (CBA 2) based on the EU calculation standard shows the following result (for more details see appendix):

	24 months approach	**3 months approach**
Total cost	26 million EUR	21,5 million EUR
Total benefit	123 billion EUR	131 billion EUR
Net Present Value (NPV)	123 billion EUR	131 billion EUR
Benefit/ Cost Ratio (BCR)	4.814	6.098

Table 3: Calculation of NPV and BCR for the two construction methods based on EU calculation method

According to our calculation the 3 months renovation procedure seems to be more economic both regarding the NPV and the BCR. However Benefit-Cost Ratios for infrastructure measures in this height are not realistic for infrastructure measures and therefore indicate a default. The real cost of traffic congestions, the larger storage capacities of the companies in the neighborhood and the health aspects for the neighbors due to the noise reduction measures and the economic growth benefits for the region are not shown in this calculation. The authors therefore suggest to develop a complete holistic perspective for the infrastructure measure.

4.3 Real holisitic Cost-Benefit-Analysis (CBA 3)

The attempt to create a true holistic picture on the basis of a comprehensive cost-benefit-analysis shows several challenges: it is difficult to determine the economic cost of traffic congestions, as there are no official figures. We create the following conservative assumptions: traffic jams only occur on working days; we calculate 4 hours of congestion in the morning and 4 hours in the evening on the busy A 40, i.e. 8 hours per working day, or 20 days per month. The research of the economic cost of traffic congestion in Germany is difficult. A first indication is found in a study by Reed & Kidds who write "At the national level, Germans lost an average of 120 hours to all traffic jams in 2018, costing the country EUR 5.1 billion or EUR 1,052 per motorist" (Reed & Kidds, 2019). According to this study, the average cost per motorist due to traffic congestion is 8.76 EUR per hour. The study does not explicitly mention whether the total cost include petrol costs. We assume that they calculate the pure time loss. The report on infrastructure investments in the EU assumes similar values: congestion cost for work trips are assumed to be EUR 12.90 per hour and for non-work trips EUR 4.30 per hour throughout the EU (EU, 2015). A further distinction is to be made for lorry drivers. These are calculated with the average hourly wage of 18.75 EUR. Based on the data from the public road authority we know that 115,000 vehicles use the A 40 motorway daily, of which 15,000 are trucks. According to the EU case study, we assume that 60 % of the motorway is used for work-related trips and 40 % for non-work-related trips.

For the 24-month traditional project design with section-by-section lane closures we conservatively assume 4 hour of congestion per day. The congestion cost for the 60,000 car drivers on work-trips cause 3,096 EUR million per day, the cost of the 40,000 car drivers for private trips cause 688,000 EUR per day, and the costs of the 15,000 truck drivers cause 1,125 million EUR per day, therefore together the sum of 4,909 million EUR per day.

However the congestion cost do not yet include fuel cost. The 24 months construction time scenario leads to an additional fuel consumption of 27,6 million liters (at a fuel consumption of 1 liter/hr and a petrol price of 1.35 EUR/liter), which generates additional costs of 37,26 million EUR per month. Furthermore, congestion causes additional CO_2 emissions. We assume CO_2 emissions of 25 gram CO_2/hour/vehicle (basis: 1 l fuel consumption/hour) and a price of 80 EUR/ton CO_2 which adds annual environment cost of 9,6 million EUR.

Furthermore, we assume that the 24-months scenario with the single-lane traffic causes many rear-end collisions. Assuming only 2 accidents per day with repair costs of 10,000 EUR each (without personal injuries), these collisions cause additional cost of 14.4 million EUR in 24 months.

Many large multinational companies are located in the Ruhr area near the A 40 motorway. This is the reason for the high amount of 15,000 trucks per day. If we assume that the trucks spend only one extra hour per day in the traffic jam caused through the construction work and that the value of goods in each truck is 100,000 EUR, then the tied-up capital for 15,000 trucks per working day amounts to an additional 15 million EUR.

Months of continuous traffic jams or even a closed motorway cause great uncertainty in the supply chain of the production companies. North Rhine-Westphalia is one of the most industrialized regions in Europe with many medium-sized and large companies generating 22% of the German Gross Domestic Product (GDP). The authors could not get the figures on the GDP of the Ruhr region, we therefore make the following assumption: there are 1.75 million people employed in the Ruhr area, the GDP per employed person in the Ruhr area was 67,700 EUR in 2017, which in total corresponds to a GDP of the Ruhr area of 118 billion EUR (= 323 million EUR per day). This is plausible, as not only three DAX-listed companies RWE, EON and ThyssenKrupp have their headquarters in the Ruhr region, but also Schenker and Rhenus, two of Germany's largest logistics service providers, as well as the two grocery discounters ALDI and Tengelmann, but also Germany's largest construction group Hochtief, as well as many of their suppliers.

In order to reduce the capital commitment costs of the inventories of manufacturing and trading companies, logistics strategies such as just-in-time and just-in-sequence delivery have been used to drastically reduce the companies' inventories in recent decades. Closing one lane or the entire motorway carries the risk of no longer being able to produce or deliver on schedule due to supply bottlenecks. Therefore, companies have to increase their inventories for the time of the motorway construction work, which significantly increases the capital commitment costs. The average share of warehousing cost in total cost in manufacturing companies is 6.5 -11% (Sage Advice, 2020), in wholesale and retail trade the warehousing cost are even between 60 - 80% of the total assets (Logistik Know-how, 2020). The average inventory cost are therefore assumed with 15%. If the companies in the region generate a daily GDP of 323 million EUR, we estimate a 15% inventory value of 48,45 million EUR. As result of the motorway construction, the companies were forced to increase their safety stocks in the warehouses; according to Bauernhansl we assume a 30% increase in the warehouse safety stocks (Bauernhansl, 2014). This leads to a cost increase of 5%, or 16,15 million EUR per day. With an average inventory turnover of 3 days, this causes an additional 48,45 million EUR. We conservatively estimate that 50 % of the companies in the Ruhr area decide for this warehouse expansion measure. This leads to additional cost for the companies of 24,225 million EUR per day.

In addition, the lane-by-lane closure of the construction site leads to a higher accident risk for the construction workers. For the holistic benefit calculation, we assume one fatal accident during the 24-month construction period. The cost of one life saved is assumed with 3 million EUR according to Volden.

Furthermore, the new noise protection measures lead to better health for the residents. According to estimates about 160 million people in Europe are regularly exposed to road traffic noise of more than 55 dB(A). Above this limit, the World Health Organization (WHO) assumes a serious health risk. According to the German Federal Environment Agency, 13 million people in Germany have to work or live at this or even a higher noise levels. A study by VCD showed that 240,000 people in Europe suffer from traffic noise-related cardiovascular diseases and 50,000 people die prematurely from noise. Noise is the second highest health risk for the population (VCD, 2020). According to the Federal Environment Agency, about 30 % of the population in Germany is exposed to noise levels above the limit value. Sound barriers at motorways lead to a noise-reducing effect, a noise reduction of 5 to 15 dB(A) can be achieved with them. Since again no cost were available, the savings from the noise protection have to be estimated: 5 million people live in the Ruhr area. We assume that 1% of the population lives in the immediate vicinity of the motorway, i.e. 50,000 people. If 5% suffer from the noise that is 2,500 people. With conservatively estimated health costs per sick person of 10.000 EUR per year, the annual benefit of the noise protection is 25 million EUR.

Finally, it can be assumed that the motorway renovation creates economic benefits. Esser and Kurte analysed the impact of mobility on the economic growth in the EU and found that countries with high traffic volumes are generally more prosperous than countries with low traffic volumes. The relationship of prosperity and passenger transport is stronger than the one of prosperity and freight transport, showing the importance of personal mobility for the prosperity of an economy. For passenger transportation, road transportation dominates not only proportionally. There is a stronger correlation between road transportation and prosperity than between the other modes of transportation and prosperity. Furthermore, they found a strong correlation between the logistics volume and the productivity of an economy. They conclude that road transportation has strong productivity-enhancing effects (Esser and Kurte, 2009). The influence of road transportation on economic productivity is due to the associated mobility growth. A good infrastructure allows the production factor labor to be used more flexible at the production locations. This also applies to goods and commodities (Stupak, 2018). In their analysis of 24 European countries they confirm the hypothesis that a higher degree of individual mobility contributes to the transformation from a manufacturing to a high-tech industry. They show that the influence of road transportation is greater than of other modes of transportation. This applies both to passenger and freight transportation (Esser and Kurte, 2009).

A robust, reliable transportation infrastructure is an essential location factor and a prerequisite for companies to settle nearby. Formerly the numerous coal deposits and the good infrastructure are main reasons for the high density of people and companies in the Ruhr region. On the other hand it can be assumed that a decline in infrastructure leads to the economic decline of a region. Investments in new or upgraded roads increase productivity, which in turn frees up time and resources that can be used to generate additional economic output or more leisure time (Stupak, 2018).

Many researchers attempted to assess the complex impact of public infrastructure investments on economic performance. Hartwig and Armbrecht calculated the resulting employment effects. They conclude that a 1 billion EUR investment in infrastructure increases the output by 984 million EUR and creates 21.544 new jobs (Hartwig, Armbrecht, 2005). We apply this relation to the motorway A40. Then the investment of 22 million EUR leads to an annual increase in productivity of 21.6 million EUR plus 474 new created jobs. In 2013 the average income was 42.924 EUR in West Germany, causing an additional annual GDP of 20.34 million EUR. There are no figures on the effects of infrastructure renovation measures, therefore the authors assume similar effects.

	24 months approach	**3 months approach**
Total cost	15 billion EUR	10 billion EUR
Total benefit	125 billion EUR	133 billion EUR
Net Present Value (NPV)	117 billion EUR	133 billion EUR
Benefit/ Cost Ratio (BCR)	8	13

Table 4: Calculation of NPV and BCR for the two construction methods based on the holistic method

The analysis of the total cost for the motorway renovation project show that the construction cost only account for 0.2% of the total cost and are marginal. But 24 months congestion produce 21.3% of cost, with work trips making the largest part with 9.7%. Trucks account for 3.5% of the cost. However, it is surprising that the capital commitment cost of the neighbor companies amount to 76% of the total cost. We think that this cost factor was neglected in all cost-benefit calculations for public infrastructure projects so far, as these are not determined. Capital commitment cost are economic cost that a holistic cost-benefit analysis should include to draw a complete picture of all cost. Another surprise is the low fuel cost (5.8%) and especially how low the CO_2 costs (0.01%) are for 24 months traffic congestion. In times of climate debate, it can be stated that the price of CO_2 emissions is set clearly too low in relation to the other transport cost.

The analysis of the benefits of the motorway project shows that the time savings are the major benefit factor with 98,5% of all benefits, although we were cautious in our estimation with a speed increase of 5 km/h for the use of 20 km and time savings of 0,9 min per vehicle. However due to the intense use of the motorway the initially seeming small effect leads to annual time savings of 4.4 billion EUR, in total 123.7 billion EUR in 30 years. All other benefits such as economic growth, new created jobs, accident prevention and health savings are marginal.

The cost benefit analysis of 13 of the 3 months project design is much higher than the one of the 3 months design.

5. Analysis of the results

	3 mon construction time	**24 mon construction time**
Cost by StrassenNRW	22 million €	25 million €
CBA 2 NPV based on EU	131 billion €	123 billion €
CBA 3 NPV holstic method	133 billion €	117 billion €
Delta CBA 1	5,5 million €	
Delta CBA 2	7.7 billion €	
Delta CBA 3	15.8 billion €	

Table 5: Comparison of the Cost/ Benefit calculation results of the two alternative project designs

Although one might think that within a given timeframe of 30 years as laid down by the EU Commission Delegated Regulation 480/2014 makes no difference between 3 and 24 months construction time, the Cost Benefit Analysis shows a different result: the NPV is much higher with 131 billion EUR. The avoidance of 21 months of congestion in the Ruhr area based on the calculation of the EU guidelines generated an economic benefit of 7.7 billion EUR.

However the EU guideline does not show the complete socio-economic picture of the infrastructure measure. Neither all social, nor all economic and environmental cost are represented in the EU cost benefit analysis CBA 2. Therefore authors started to create a more holistic cost benefit analysis considering also those factors that were not covered so far in the cost analysis. This result CBA 3 shows that the holistic economic benefits of the innovative parallel 3 months renovation method is 15.8 billion EUR.

The comprehensive cost-benefit comparison of the two alternatives shows that the radical motorway closure with 3-month construction time project generates significant higher social, economic and environmental benefits. It is therefore proved that it was the right decision of the project manager to take the risk and to execute the project in only 3 months with a complete motorway closure.

The A40 project team considered that the social benefits of the parallel approach would be high, but they were not able to quantify these. The public road authority StrassenNRW did not require a comprehensive business case. The final project report estimated cost savings of 5.5 million EUR. However the social and economic benefits of public infrastructure project were not included in their project calculation.

A holistic Benefit-Cost-Analysis that covers all economic, environmental and social cost and benefits helps project managers and public decision makers to take the right decisions for the sake of society, the environment, and the taxpayers. The A 40 case study shows that they do not longer have to listen to their gut feeling.

6. Need for standardized comprehensive infrastructure project assessment criteria

This case study shows that it is very difficult and time-consuming to get all the criteria and the prices for the holistic analysis of the cost and benefits in order to create a comprehensive infrastructure project assessment. The authors therefore define the need for a standardized evaluation method, holistic project assessment criteria and equal unit prices if the approach taken with the A40 is adopted in similar infrastructure projects worldwide. Table 6 shows a first attempt of how the standardized evaluation criteria for public infrastructure projects could look like:

Assessment criteria	**Unit**	**Price**
Social cost		
Congestion time • Work-trips • Non-work trips • Freight trips	€/hour	 12,90 €/hr 4,30 €/hr 18,75 €/hr
Accidents caused through roadwork • Repair cost/ accident • Killed people	 €/ accident €/ accident	 10.000 € 3 million
Social benefits		
Accidents caused through roadwork • Repair cost/ accident • killed people	 €/ accident €/ accident	 10.000 € 3 million
Travel time savings • Work-trips • Non-work trips • Freight trips	€/hour	 12,90 €/hr 4,30 €/hr 18,75 €/hr
Health benefits through noise reduction measures (5-15dB(A))	€/person	10.000 €/person
Environmental cost		

Additional fuel consumption through congestion	l/hr	1 l/hr
Additional CO2 through congestion	€/ton	200 €/ton
Environmental benefits		
CO2 saved	€/ton	200 €/ton
Economic cost		
Capital tied-up in trucks e.g. value of goods	€/truck	100.000 €
Increase in safety stock in warehouses	% of cost	5%
Storage cost • Manufacturing companies • Wholesale/ retail	% of overall cost	 6,5-11% 60%-80%
Economic benefits		
Industrial/ logistics development		
Improved freight reliability (e.g. size of stock)	% of cost	5%
Employment change per 1 billion EUR investment in infrastructure	jobs	21.544 jobs
Changes in specific economic sectors through infrastructure (e.g. growth in tourism)	% and €	
GDP growth per 1 billion EUR investment in infrastructure	• Productivity increase in EUR • Creation of new jobs	984 million EUR 21.544 new jobs

Table 6: Example for consistent criteria and unit prices for standardized Cost/ Benefit Analyses of infrastructure projects

This example of standardized comprehensive cost-benefit analysis could help project managers to objectively quantify the social, economic and environmental benefits of alternative project designs.

6. Limitations

The present cost-benefit analysis is based on many assumptions, as most of the key figures were not available to the author despite intensive research. The real existing project data were included in the calculation. For all other data, the author carefully analysed the available information, but it might be incomplete or the assumptions might be wrong.

The case study of a motorway project in the European Union's "Guide to Cost-Benefit Analysis of Investment Projects - Economic Assessment Tool for Cohesion Policy" was helpful, but it is designed for the construction of a new motorway, not for the renovation of an existing one. The economic benefits of a motorway renovation are difficult to assess. On the other hand, the economic damage of decaying infrastructure could be estimated. The case of the A40 motorway shows that so far there are no methods to calculate the social and economic benefits for the renovation of existing infrastructure. However, this is increasingly the case in Europe where existing roads, bridges, railways, ports, waterways, airports, electricity grids, etc. need to be renewed and rehabilitated. The lack of tools to calculate the benefits of public infrastructure renovation projects could be one of the reasons for the investment backlog in the German economy.

7. Conclusion

The case of the A40 motorway renovation shows that it should become the norm that project managers design and evaluate alternative project design scenarios. The comprehensive socio-economic-environmental cost-benefit analysis could have significant impact and important societal implications, if the approach taken with this motorway is adopted in similar projects worldwide. This reworked methodology shall encourage to adopt CBA holistically as its focus still tends to be only on the financial aspects. The authors want to help encourage project manager in their CBA a more holistic view of benefit realization, since, generally, focus still tends to be on the financial aspects.

The approach of a motorway-closure for the renovation of the motorway increased the complexity, speed and uncertainty of the project and required significantly higher management and leadership skills from the project manager and the project team. However this could not be evaluated in classic Cost Analysis. Although the risks for eventual failure were high, the new project approach was successful. The project completion report shows that the road agency did not assess any economic, environmental and social benefits of the project. They suspected that the benefits for the region from avoiding years of congestion were high, but could not quantify them. The presented Cost Benefit Analysis shows that it is possible to assess the comprehensive benefits of infrastructure measures. Even in a lifespan of 30 years the difference between 3 and 24-month renovation are enormous. The full closure approach was 15.8 billion EUR more profitable for the society than the classic ongoing sequential approach.

The two alternative project design approaches place different demands on the stakeholders. The holistic socio-economic-environmental cost-benefit analysis shows that it is possible to quantify the impact of avoiding years of congestion. The A40 motorway renovation shows that the capital budgeting technique for public infrastructure projects of the European Union does not sufficiently consider all social, ecological and economic aspects and therefore needs a redesign. We show that the complete evaluation of comprehensive benefits can demonstrate the real impact of infrastructure investment for the society. This comprehensive public infrastructure appraisal method is not used yet by the public infrastructure authorities.

We conclude that the evaluation of all aspects of an infrastructure project is crucial to show the long-term benefits of infrastructure investments for the society. We also show that consistent, standardized indicators are needed for a comprehensive evaluation of public infrastructure projects.

The case study demonstrates how public infrastructure renovation projects should be accelerated by parallel processes and thus minimizing the negative consequences of traffic congestion both for the economy and the society.

Many motorways, bridges and tunnels need to be renewed in the next decades. The A40 case study should become a model for an innovative project design and the holistic assessment of public infrastructure projects.

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Appendix

A1: CB2 (EU Baseline) for 3 months measure

ERR for 3 months construction				3 Mo	9 Mo	5,00	10,00	15,00	20,00	25,00	30,00
				Constr		Operation					
Calculation of ERR	mEUR	**0,04**	%								
Project investment cost	mEUR	- 22,00	102,1	- 22,00		-	-	-	-	-	-
O&M cost	mEUR	- 2,06	9,5	-	0,06	0,07	0,07	0,07	0,07	0,07	0,07
Residual value of investment	mEUR	2,50		-		-	-	-	-	-	8,00
Total cost	mEUR	**- 21,56**		**- 22,00**	**0,06**	**0,07**	**0,07**	**0,07**	**0,07**	**0,07**	**8,07**
Time savings	mEUR	131.435,00	100,0	-	3.313,00	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00
VOC savings	mEUR	-									
Accidents savings	mEUR	13,79	0,0	-	0,05	3,06	3,06	0,06	0,06	3,06	3,06
CO2 saving	mEUR	-	-	-							
Total benefit	mEUR	**131.448,79**		**-**	**3.313,05**	**4.421,06**	**4.421,06**	**4.418,06**	**4.418,06**	**4.421,06**	**4.421,06**
Discounted benefit	mEUR	**75.533,00**		**4,00**	**3.188,00**	**3.631,00**	**2.987,00**	**2.452,00**	**2.016,00**	**1.658,00**	**1.362,00**
Net benefits (disc benefit - cost)	mEUR	**75.511,45**									
B/C ratio		**6.098**									
NPV	mEUR	**131.448,8**		**- 22,00**	**3.313,00**	**4.421,13**	**4.421,13**	**4.418,13**	**4.418,13**	**4.421,13**	**4.429,13**

A2: CB2 (EU Baseline) for 24 months measure

ERR 24 months				1,00	2,00	5,00	10,00	15,00	20,00	25,00	30,00
				construction		Usage					
Calculation of ERR	mEUR	**4,0%**	%								
Project investment cost	mEUR	- 25	- 97,3	- 12,50	- 12,50	-	-	-	-	-	-
O&M cost	mEUR	- 3	- 11,7	-	-	0,10	0,10	0,10	0,10	0,10	0,10
Residual value of investment	mEUR	2		-	-	-	-	-	-	-	8,00
Total cost	mEUR	**- 26**		**- 12,50**	**- 12,50**	**0,10**	**0,10**	**0,10**	**0,10**	**0,10**	**8,10**
Time savings	mEUR	123.704	100,0	-	-	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00
VOC savings	mEUR	-	-	-	-	-	-	-	-	-	-
Accidents savings	mEUR	12	0,0	-		3,06	3,06	3,06	3,06	3,06	3,06
CO2 saving	mEUR	-									
Total benefit	mEUR	**123.716**		**-**	**0,50**	**4.421,06**	**4.421,06**	**4.421,06**	**4.421,06**	**4.421,06**	**4.421,06**
Discounted benefit	mEUR	**68.255**		**0,48**	**0,46**	**3.631,00**	**2.987,00**	**2.016,00**	**2.016,00**	**3.779,00**	**1.362,00**
Net benefits (disc benefit - cost)	mEUR	**66.965**									
B/C ratio		**4.814**									
NPV	mEUR	**123.716**		**- 12,50**	**- 12,00**	**4.421,16**	**4.421,16**	**4.421,16**	**4.421,16**	**4.421,16**	**4.429,16**

A3: CB3 (comprehensive) for 3 months measure

IRR for 3 mon construction				3 Mo	9 Mo	5	10	15	20	25	30
				Constr	Usage						
IRR	mEUR	**0,04**	%								
Project investment cost	mEUR	- 22,00	0,2	- 22,00		-	-	-	-	-	-
Maintenance cost	mEUR	- 3,00	0,0	-	-	0,10	0,10	0,10	0,10	0,10	0,10
Project communication measures	mEUR	- 0,30	0,0	- 0,30							
Congestion cost for work travel	mEUR	- 30,96	0,3	- 30,96							
Congestion cost for private travel	mEUR	- 41,25	0,4	- 41,25							
Congestion cost lorries	mEUR	- 135,00	1,3	- 135,00							
Fuel cost	mEUR	- 111,78	1,1	- 111,76							
CO2 cost	mEUR	- 2,40	0,0	- 2,40							
Accident cost	mEUR	- 1,80	0,0	- 1,80							
Lorry capital commitment cost	mEUR	- 45,00	0,4	- 45,00							
Stock capital commitment cost	mEUR	- 9.712,00	96,1	- 8.712,00							
Residual value of investment	mEUR	2,50		-		-	-	-	-	-	8,00
Overall cost	mEUR	**- 10.102,99**		**- 9.102,47**	**-**	**0,10**	**0,10**	**0,10**	**0,10**	**0,10**	**8,10**
Benefits during the construction time											
Higher build quality	mEUR	1,00	0,0	1,00							
Prevented accidents during constru	mEUR	3,00	0,0	3,00							
Benefits after construction time											
Time saving	mEUR	131.435,00	98,5	-	3.313,00	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00
Prevented accidents	mEUR	19,79	0,0	-	0,05	0,06	3,06	3,06	3,06	3,06	3,06
Better health by noise reduction	mEUR	743,70	0,6	-	18,70	25,00	25,00	25,00	25,00	25,00	25,00
New jobs created	mEUR	610,20	0,5		20,34	20,34	20,34	20,34	20,34	20,34	20,34
Economic growth	mEUR	644,90	0,5	0,50	18,00	21,60	21,60	21,60	21,60	21,60	21,60
Overall benefits	mEUR	**133.457,59**		**4,50**	**3.370,09**	**4.485,00**	**4.488,00**	**4.421,06**	**4.488,00**	**4.421,06**	**4.488,00**
Discounted benefits	mEUR	**124.022,94**		**4,00**	**3.356,66**	**4.396,37**	**4.245,16**	**4.164,10**	**4.143,61**	**4.001,14**	**3.981,45**
B/C Ratio		**13,21**									

A4: CB3 (comprehensive) for 24 months measure

IRR for 24 mon construction				**1,00**	**2,00**	**3,00**	**5,00**	**10,00**	**15,00**	**20,00**	**25,00**	**30,00**
				Construction		**Usage**						
IRR	mEUR	**4,0%**	**%**									
Project investment cost	mEUR	- 25,00	0,2	- 12,50	- 12,50	-	-	-	-	-	-	-
Maintenance cost	mEUR	- 3,00	0,0	-	-	0,10	0,10	0,10	0,10	0,10	0,10	0,10
Congestion cost for work travel	mEUR	- 1.486,00	9,7	- 743,00	- 743,00							
Congestion cost for private travel	mEUR	- 330,00	2,2	- 165,00	- 165,00							
Congestion cost lorries	mEUR	- 540,00	3,5	- 270,00	- 270,00							
Fuel cost	mEUR	- 894,20	5,8	- 447,10	- 447,10							
CO2 cost	mEUR	- 19,20	0,1	- 9,60	- 9,60							
Accident cost	mEUR	- 14,40	0,1	- 7,20	- 7,20							
Lorry capital commitment cost	mEUR	- 360,00	2,4	- 180,00	- 180,00							
Stock capital commitment cost	mEUR	- 11.616,00	76,0	- 5.808,00	- 5.808,00							
Residual value of investment	mEUR	2,30				-	-	-	-	-	-	-
Overall cost	mEUR	**- 15.285,50**		**-7.642,40**	**-7.642,40**	**0,10**	**0,10**	**0,10**	**0,10**	**0,10**	**0,10**	**0,10**
Benefits during the construction time												
Higher build quality	mEUR	-	-	-	-							
Prevented accidents during constru	mEUR	-	-	-	-							
Benefits after construction time												
Time saving	mEUR	123.704,00	98,5	-	-	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00	4.418,00
Prevented accidents	mEUR	11,60	0,0	-	-	3,06	0,06	3,06	0,06	0,06	0,06	0,06
Better health by noise reduction	mEUR	700,00	0,6	-	-	25,00	25,00	25,00	25,00	25,00	25,00	25,00
New jobs created	mEUR	569,52	0,5			20,34	20,34	20,34	20,34	20,34	20,34	20,34
Economic growth	mEUR	604,80	0,5	0,50	0,50	21,60	21,60	21,60	21,60	21,60	21,60	21,60
Overall benefits	mEUR	**125.589,92**		**0,50**	**0,50**	**4.488,00**	**4.485,00**	**4.488,00**	**4.485,00**	**4.485,00**	**4.485,00**	**4.485,00**
Discounted benefits	mEUR	**117.642,77**		**0,50**	**0,50**	**4.434,57**	**4.396,37**	**4.312,37**	**4.224,32**	**4.140,84**	**4.059,01**	**3.978,79**
B/C Ratio		**8,22**										
NPV=∑(Bt-Ct)/ (1+i)t	mEUR	**117.642,77**		**- 129,00**	**- 129,00**	**885,00**	**884,00**	**884,00**	**884,00**	**884,00**	**884,00**	**884,00**