HÁSKÓLINN Í REYKJAVÍK
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An Ex-Post Analysis on Traffic Demand Data for Four Icelandic Road Tunnel Projects

Guttormur Guttormsson

Thesis of 30 ECTS credits
Master of Science in Construction Management

January 2013

TÆKNI- OG VERKFRÆÐIDEILD
SCHOOL OF SCIENCE AND ENGINEERING

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Abstract

Recently there has been an increased international interest in evaluating accuracy of traffic demand forecasts by conducting an ex-post analysis on transportation projects. The role of traffic demand forecasting and accuracy of traffic forecasts made in support of these projects have been of particular interest. The financial viability of transportation projects is often heavily dependent on the traffic demand forecasts, and traffic forecasts often form the basis for socio-economic appraisals. This research follows the international research interest, and compares traffic demand forecasts of four selected Icelandic road tunnel projects with their actual traffic counts. The research method applied is a multiple-case design and the four selected case studies consist of three non-tolled projects and one toll-road project. The data collected contain traffic demand data from the time of decision making (primary data), and actual traffic counts (secondary data) from the Icelandic Road Administration (ICERA). The results of the three non-toll road projects are consistent with the results of comparable leading foreign studies, regarding accuracy in travel demand forecasting, thereby supporting those findings, which all give evidence of inaccuracy by underestimation. The toll-road project studied does, however, not reconcile with comparable foreign studies, as it shows a drastically underestimated traffic forecast. A possible explanation of the observed inaccuracy in travel demand forecasting could be: (1) Planners may have ignored the existence of, or underestimated, generated traffic. (2) Standard national traffic growth forecasts do not incorporate local variations based on population trends. The author’s concluding recommendation is that future Icelandic road tunnel projects should be appraised by a socio-economic analysis, and their traffic forecasts scrutinized and peer-reviewed before the final approval of projects.

Keywords: Traffic demand accuracy, Travel demand forecasting, Socio-economic analysis, Transportation appraisal, Road tunnel projects.

Samanburðargreining á umferðarspám: Fern íslensk jarðgöng

Guttormur Guttormsson

Útdráttur

Í nýlegum erlendum rannsóknum fyrir umferðarmannvirki, hefur verið aukin áhugi á að meta nákvæmni á umferðarspám með samanburðargreiningu. Sérstök áhersla er lögð á nákvæmi þeirra, þar sem umferðarspár hafa verið notaðar við ákvörðunartöku slíkra verkefna. Fjárhagsleg hagkvæmni samgöngu verkefnisins er mjög háð umferðarspánni, jafnframt myndar umferðarspáin grunn að félagshagfræðilegri greiningu og kvarðar einnig umhverfisþætti slíks mats. Þessi rannsókn fylgir eftir þessum erlendu rannsóknum og ber saman umferðarspár fyrir fern íslensk jarðgöng með raun umferðartölum um jarðgöngin. Aðferðafræði rannsóknar er svokölluð „multiple-case design“ og verkefnin sem til skoðunar eru þrenn jarðgöng án vegtolla og ein með vegtollum. Gagnaöflum samanstöð af (1) upplýsum um umferð við ákvörðunartöku viðkomandi jarðgangna mannvirkis, (2) rauntölum umferðar eftir að jarðgöngin voru tekið í notkun. Rauntölum þessum er safnað saman af Vegagerðinni. Niðurstöður samanburðarrannsókna sýna að þrennu jarðgangnaverkefni sem eru án vegtolla eru samhljóma erlendu niðurstöðunum, þ.e leiða líkur að ónákvæmni og vanmati á umferðarspám. Jarðgangnaverkefnið með veggjöldunum sýnir sömu niðurstöðu og hin þrjú, en það er ekki í samræmi samanborið við erlendu niðurstöðurnar, þar sem verkefni með veggjöldum eru oftar en ekki ofmetin m.t.t umferðarspár. Hugsanlegar skýringar á þessu ósamræmi milli umferðarspánna og raunumferðar eru: (1) Við áætlunargerðina hefur vægi nýrrar- og viðbótarumferðar með tilkomu samgöngubótar (generated traffic) verið hunsað eða vanmetið. (2) Að almenn umferðarspá tekur ekki tillit til staðbundinna áhrifa sem byggja m.a. á byggðaþróun. Að lokum leggur höfundur til að fyrirhugaðar jarðgangna framkvæmdir á Íslandi verði metnar með félagshagfræðilegri greiningu og að umferðapár fyrir þau verkefni verði sérstaklega yfirfarin og ritrýnd af fagaðilum áður en viðkomandi jarðgangna verkefni er endanlega samþykkt.

Leitarorð: Umferðarspá, samgöngur, félagshagfræðileg greining, forgangsröðun samgangna, jarðgöng.

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Table of Contents

Acronyms

AACE, Association for the Advancement of Cost Engineering International

AADT, Annual Average Daily Traffic

B/C, Benefit/Cost Ratio

CBA, Cost-Benefit Analysis

EUG, The European Commission and the CBA Guide team

ICERA, Icelandic Road Administration

IKR, Icelandic Krona (currency)

INTP, Icelandic National Transport Plan

IRR, Internal Rate of Return

MCA, Multi-Criteria Analysis

NPV, Net Present Value

QRA, Quantitative Risk Assessment

Icelandic names and letters:

ð/Ð (pronounced like th in English, as in this).

þ/Þ (pronounced like th in English, as in think).

In this thesis, ð is transliterated as d and þ as th in personal names, for consistency with international references, but otherwise the Icelandic letters are retained.

List of Figures

List of Tables

List of Equations

Chapter 1. Introduction

Following the financial crash in Iceland in 2008, the Icelandic government tightened the controls over public investment. The Icelandic National Transport Plan (INTP) for the period 2011 - 2022 is subject to the approval of the Icelandic Parliament. The INTP involves an evaluation of new transportation infrastructure by applying socio-economic analysis, i.e. for transportation projects that exceed the value of IKR 500 million at 2012 prices, in total project costs, as proposed in a recent parliamentary resolution [1]. Socio-economic analysis is supposed to support a more cost-effective approach, increase transparency in project selection, efficiently allocate resources among projects and reduce political pressure on decisions regarding transportation projects (ibid). In this regard, the Icelandic Road Administration (ICERA) shall commence work to adopt a data model from the Danish Ministry of Transportation, applied for socio-economic analysis in the transportation sector, and adjust it to Icelandic conditions.

1.1 Background and motivation

"One of the arguments often advanced for committing public funds to infrastructure investments is that it will generate economic growth. There are good theoretical and empirical reasons for treating such claims with caution." Flyvbjerg et al. [2]

Public transportation projects, like road tunnel projects, utilize a vast amount of resources in terms of money, material, labor, equipment and time. Their main characteristic is that they require large initial capital investment and are usually operated over a long period of time. Hyari and Kandil [3].

The appraisal of the proposed transportation projects and their subsequent economic viability depends heavily on traffic demand forecasts made in support of these projects, prior to project implementation. Such forecasts also form the basis for socio-economic and environmental impact assessments. The high cost of such projects, limited availability of resources, irreversibility of decisions and associated inefficiencies makes it essential to focus on accuracy of traffic demand forecasts. Parthasarathi and Levison [4], Flyvbjerg et al. [5].

A recently published paper by Nicolaisen et al. [6] presents the results of an on-going research project on uncertainties in transportation project evaluation (UNITE). They found forecasts of traffic demand to be not only uncertain, but at times also highly inaccurate and often displaying a concerning degree of bias. Their paper and other recent studies on the subject were a major impetus for this research project, evoking the question of how their finding would fit in an Icelandic context.

1.2 Problem statement

As stated above, recent studies on accuracy of traffic demand forecasts have found empirical evidence of the fact, that too often traffic forecasts are not only uncertain, but also highly inaccurate and often displaying a concerning degree of bias. Some of the most comprehensive studies on this subject, i.e. both for tolled and none-tolled road projects were conducted by Flyvbjerg et al. [5], Bain, [7], Parthasarathi and Levinson. [4], Welde and Odeck [8].

According to the INTP, a considerable amount of money will be spent on Icelandic road tunnel projects within the next 10 years, with a value of approx. IKR 30 to 35 billion at 2012 prices (approx. US$ 260 million) for the proposed projects. No previous research effort has been done in Iceland to compare ex-post traffic data with forecasted value of completed road tunnel projects. Such comparison could help answering the question of whether these projects have had the intended effect of generating economic growth.

This thesis will follow the path of a previous research by Flyvbjerg et al. [5] by using ex-post traffic data from the ICERA for selected Icelandic road tunnel projects and examine how these projects have performed compared with their forecasted traffic demand.

1.3 Overview of socio-economic analysis

Socio-economic analysis is derived from traditional cost-benefit analysis (CBA) which is the most common method for appraising public infrastructure projects. Salling and Banister [9], Brzozowska [10], Nicolaisen et al. [6], Leleur [11], Beria et al. [12]. “The general question that a CBA is set out to answer is whether investment projects A, B, C, etc., should be undertaken and, if funds are limited, which one, two, or more among these projects that would otherwise qualify for admission, should be selected.” Mishan and Euston [13]. The basic principle underlying the CBA is that the decision objective is to maximize the net socio-economic benefit of the project. P. Richard et al. [14].

CBA measures the total economic return of a project by comparing cost and benefits of given projects. Such appraisal is typically condensed into a set of performance criteria in the form of net present value (NPV), internal rate of return (IRR), or the most widely used benefit-cost ratio (BCR). Nicolaisen et al. [6], [Brzozowska [10], Hyari and Kandil [3].

In public transportation projects, costs include project costs, users and non-users costs, operation and maintenance costs. The benefits include monetized values of: savings in travel time, vehicle operating cost (VOC), reduced cost of accidents, injuries and fatalities (safety factors). Traffic forecast forms the basis for these impact factors, and are therefore crucial to the validity of any subsequent impact assessment, whether it is in the form of CBA appraisal or any other technique. Næss et al. [15].

Nicolaisen et al. [6] conclude that the two dominant factors in most CBA appraisals of transportation infrastructure, are the estimated construction costs and expected benefits from travel time savings. These two factors can make up three fourths or more of the total costs and benefits, and in trivial road projects they will be closer to nine tenths of the total budget.

1.3.1 Current state of Icelandic transportation funding

Taxes on fossil fuels are the main source of income for the Icelandic ICERA. Some transportation projects are also directly funded, like bridges, motorways and road tunnel projects. Total annual funding to the ICERA amounts to IKR 20 billion at 2012 prices (approx. US$ 160 million), until the end of the planning period in 2022. This includes service and maintenance for the total road network which is approximately IKR 10 billion annually. According to the ICERA this funding is too low to sustain the current road network, and if nothing is done, the road network will soon start to deteriorate. Figure 1-1 shows the total budget for the Icelandic transportation sector for the period 1998 to 2012.

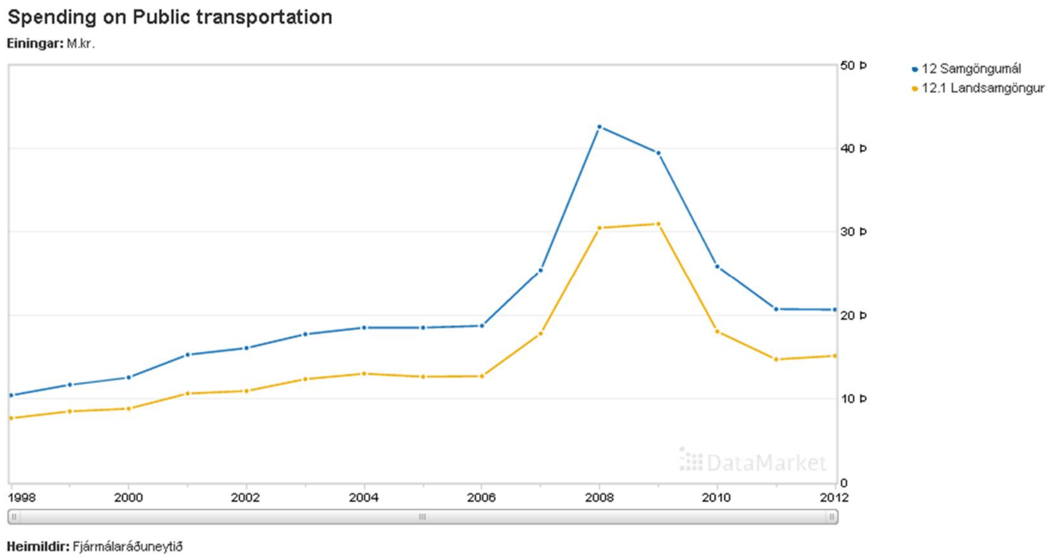


Figure 1-1 Icelandic transportation funding 1998 -2012

Where the top line (legend, 12 *samgöngumál*) shows the total budget for public transportation projects, drawn in blue, and the line below (legend, 12.1 *landssamgöngur*) shows the portion that goes to ICERA, drawn in yellow. The data was obtained from the Icelandic Ministry of Finance and Economic Affairs (*Fjármála- og efnahagsráðuneytið*), and graph generated by *DataMarket* [16].

In order to reach the aims and objectives set forth in the INTP[1], and to be fully achieved in the next 20 years (2030). ICERA has estimated the total financial cost to be approximately IKR 400 billion, excluding service and maintenance of the total road network. In ICERA opinion, this amount is based on the cheaper variant of proposed infrastructure by the plan. This means an average annual funding of IKR 20 billion and approximately IKR 80 billion for every four year planning period. Table 1-1 shows the difference between the ICERA estimate for financial funding needs (shown in column A), and the scheduled budget until 2022, which is now awaiting approval from the Icelandic parliament [1]. The allocated funding for the time period 2015 -2018 is then only 36% of what is needed according to ICERA.

[1] See further a list of aims and objectives in Appendix A.3

Table 1-1 INTP Budget plan 2011 - 2022

	(A)	**INTP budget plan 2011 - 2022**			
	ICERA est. until (2030)	1st period 2011 – 2014	2nd period 2015 – 2018	3rd period 2019 – 2022	Total 2011-2022
Pri. roads	254.0	13.2	15.2	24.3	**52.7**
Sec. roads	38.0	4.1	3.2	2.5	**9.8**
Tunnels	108.0		10.8	12.7	**23.5**
Total	**400.0**	**17.3**	**29.2**	**39.5**	**86.0**

Currently, there are 10 road tunnels in operation on the road network, and three new road tunnel projects are scheduled in the INTP for the period 2011 – 2022, (1) Norðfjarðargöng, (2) Dýrafjarðargöng, and (3) Hjallahálsgöng. Figure 1-2 shows the location of existing road tunnels in Iceland [17] and the location of the next three ones, marked with the subsequent number. Beside these three, a toll road project (4) Vaðlaheiðargöng is now in a start-up phase for project execution.

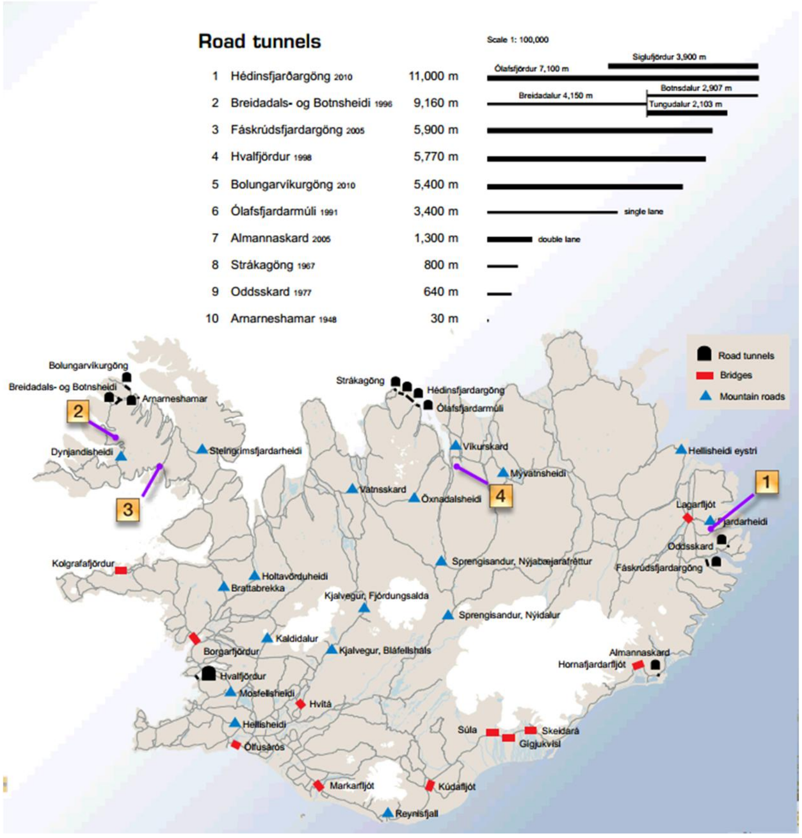


Figure 1-2 Overview of road tunnels in Iceland 2012

1.4 Aim and objectives

The aim of this research is to conduct an ex-post analysis on four Icelandic road tunnel projects to estimate their accuracy of traffic demand forecasts. This is done by comparing their actual traffic numbers, i.e. traffic volume from first year of operation with their forecasted values, and examining the potential causes of discrepancies between the forecast and actual numbers by answering the following research questions:

1. What is the difference between forecasted traffic demand and the actual figures in the selected cases?
2. Can the occurring difference, if any, be explained?

1.5 Limitations

1.5.1 Time and resources available

This research will only include Icelandic case studies. Relevant literature will be used to gain knowledge and understanding of the concept accuracy in traffic demand forecasting for the selected cases. Academic literature, peer-reviewed journals and research papers will be used to determine the important variables for accuracy in travel demand forecasting.

1.5.2 Data availability

The study is limited to data available from ICERA sources and its website. It does only consider traffic forecasts from four preselected Icelandic road tunnel projects.

1.6 Outline of thesis

This document will be divided into six chapters, starting with an introduction and motivation for the thesis project. In chapter 2, a literature review is presented with a summary of previous research. Chapter 3 discusses research methodology and approach taken. Chapter 4 presents the four Icelandic case studies followed by a summary. Chapter 5 discusses the results and in chapter 6 some conclusions are drawn, based on the case studies.

Chapter 2. Literature Review

2.1 Cost-benefit analysis (CBA)-A brief history

The origin of CBA can be tracked back to the French Engineer Jules Dupit (1844). Jules pointed out that the users of roads and bridges enjoyed benefits in excess of the toll that they paid for the usage. This concept later became known as the consumer's surplus (willingness to pay). In the 1920's, Pigou introduced the concept of externality by arguing that there is a difference between a private economic production and a public economic production. These two concepts are now included in standard introductory microeconomics. Mishan [18], The European Commission and the CBA Guide team (EUG) [19].

The US Flood Control Act of 1936, stating that any flood control project should be deemed desirable if the benefits to whomsoever they may accrue are in excess of the estimated costs. The Act paved the way for the assessment of projects on the basis of calculating their net benefits and the entire social assessment, instead of basing it only on financial appraisal. Due to lack of specific and concrete guidelines, and inconsistent sets of standards and procedures, an inter-agency group was formed in 1946 which published the Proposed Practice for Economic analysis of River basin Projects in 1950. This publication attempted to standardize the practice and bring it in line with economic theories which in turn encouraged academic interest. Mishan and Quah [13].

A firm theoretical framework for CBA was established in 1958 by the three economists (Eckstein, Krutilla and Mckean), which methodically utilized neoclassical welfare economics in relation with CBA. From that point on, the use became more widespread as governments in the US, Canada and the UK required CBA as a commencement of certain policies and projects. This was then followed by numerous books and papers on the subject. In the 1970's, international organizations like the OECD, UN, and the World Bank adopted the practice (ibid).

In the 1980's, due to rapid developments in the use of computer aided calculations, the development of the so called multi-criteria analysis (MCA) emerged, among other alternatives to CBA. In the 1990´s, the transportation planning appraisal has been characterized by major EU research programs like the Fourth and Fifth EU Framework program conducted from 1995 to 2002 e.g., TENASSES, EUNET/SASI, CODE-TEN and TRANS-TALK. Leleur [11].

The Nordic countries have published their own guidelines for making socio-economic analysis regarding the use of CBA in public project appraisal. Norway, (Vegvesen, handbok 140, Konsekvensanalyser, divers publications 2006 - 2008); Denmark, Manual for samfunds-okonomiske analyser, 2003 (Expected revision in 2012-2103); Sweden, (Översyn av samhällesokonomiska metoder och kalkylvärden på transportområdet, SIKA rapport 2002:4).

The latest development is the ongoing UNITE (Uncertainties in Transport Project Evaluation) research effort, which is a leading ex-post evaluation of transportation infrastructure projects in Denmark, Norway, Sweden and the UK. Nicolaisen et al [6].

2.2 Traffic forecast modeling

2.2.1 Transport planning

Following is a summary from the textbook Transport Planning and Engineering, edited by C A O'Flaherty [20], which suggests a proposed methodology for traffic forecast modeling.

Traffic data is required for economic and environmental assessments in relation to the justification, scale and location of project alternative under appraisal. This collection and analysis of data can be a complicated process, particularly in urban areas.

Traffic volumes for a future design year can be derived from measurements of current traffic and estimates of future traffic, and the actual design period may be some 30 to 40 years in the future. It should be noted that the longer the design period is, prediction reliability declines. Basic components of the design volume for an individual road are current traffic, generated traffic and normal traffic growth (ibid). This is illustrated in figure 2-1.

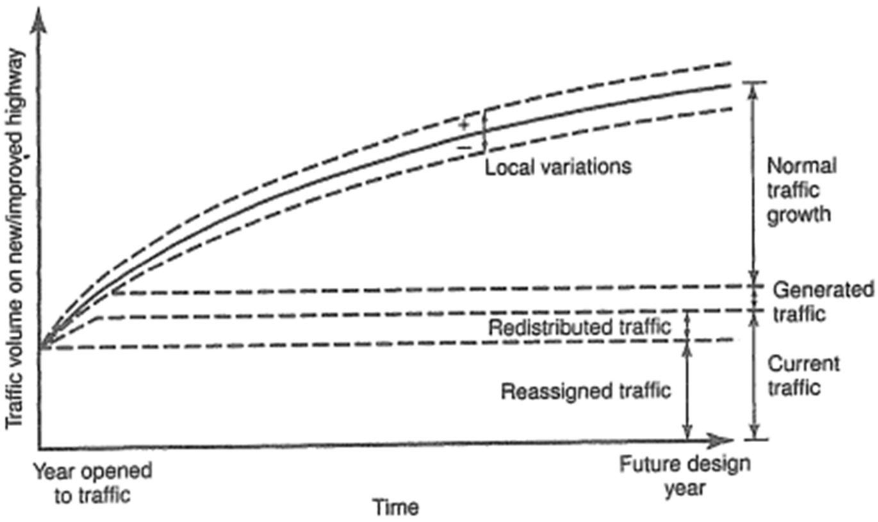


Figure 2-1 Components of a road's design traffic volume

Current traffic is the number of vehicles that would use the new road if it were open for traffic at the time the current measurements are taken. This traffic consists of reassigned traffic and redistributed traffic. Reassigned traffic is the amount of existing same-destination traffic that will immediately transfer from the existing road(s), redistributed traffic is traffic that already exists on other roads in the region, but will transfer to the new road because of changes in trip destination brought about by the new road (ibid).

Generated traffic represents new generated vehicle trips that are directly attributable to the new road, and consists of three constituent components: induced, converted and developed traffic. Induced traffic is traffic that did not exist previously in any form and results only from the new road or facility, and of extra journeys by existing vehicles as a result of the convenience and reduced travel time via the new road. Converted traffic comes from changes in mode of travel, i.e. transit from bus or rail to car traffic. Developed traffic is the future traffic volume component that comes from land development adjacent to the new road. Experience with highly improved or new roads suggests that adjacent land with ready access tends to be more rapidly developed than can be explained by normal traffic growth. Developed traffic is highly dependent upon how planning authorities encourage/allow land use (ibid).

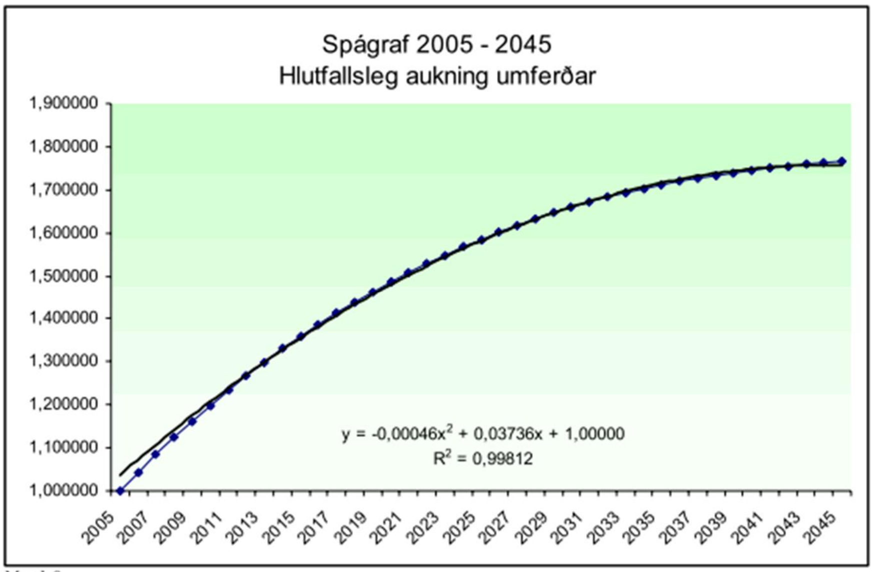
If the journey time, .i.e. the travel time ratio between the new road divided by the quickest alternative, is high, then it can be expected that the amount of induced traffic will be low. The amount of converted traffic is mainly dependent upon relative travel cost, convenience and journey times (ibid).

Normal traffic growth is the increase in traffic volume due to the cumulative annual increases in the numbers and usage of motor vehicles. In this respect, care needs to be taken when deciding the extent to which national projections figures should be applied to particular situations, to ensure that the figures finally selected reflect the local growth rates (ibid).

Parthasarathi and Levison [4] summarize recent efforts of what has been done to identify and reduce errors/uncertainties in the traditional traffic forecast modeling. Their analysis of 273 US roadway links were compared with direct comparison, i.e. the traffic forecast and an actual traffic count. Further analysis indicated that traffic forecasts on 61.5% of the links were underestimated, compared to the actual traffic counts, and the forecast were more accurate for higher volume roadways. They conclude with an emphasis on the benefits gained for agencies when record keeping and data archiving are consistent and up-to-date. They also point to a lack of proper understanding of travel behavior and trip distribution as a possible cause of traffic forecast modeling errors.

2.2.2 Current Icelandic traffic forecast model

In 2006, ICERA published a revised traffic forecast for the time period 2005-2045 [21]. The growth trend for the model has an annual factor of approx. 1.4%. ICERA notes that the forecast is primarily thought of as a long-term forecast and should only be used on a general bases, and is not suitable to predict traffic data 1 - 3 years ahead. For such circumstances, it is preferred to use real counting data from a nearby road network to predict the traffic development. Figure 2-2 shows the proportional growth of traffic for the period 2005 - 2045 [21].



Mynd. 8

Figure 2-2 National traffic forecast 2005 - 2045

In a recent Icelandic document by Kristinsson [22], the current Icelandic traffic forecast model is being debated; a special concern of the author is the new tunnel toll road project (*Vaðlaheiðargöng*) and the traffic forecast for that project. In the author's opinion Iceland is possibly entering an era, where a certain correction of the "traffic bubble" that has accumulated in the past 10-15 years is taking place. This correction of total traffic volume could lead to a considerable decline in traffic on the national road network for the next 3-5 years, which could sum up to about -20% at the end of the period.

The author predicts that when the bottom will be reached in the years 2014/2015, the total traffic will be similar to what it was during the years 2003/2004. From 2015, the total traffic will start to increase again for the years thereafter at an annual rate of 1.5 to 2.5% on average. The expected forecast for the total traffic volume on the national road network will be similar in 2020/2021 as it was during the years 2005/2006. It will not be until around the year 2026/2027 that the traffic volume on the national road network will be similar to what it was when it peaked in 2008.

2.3 Previous studies on forecasting inaccuracy

2.3.1 Forecasts: uncertain, inaccurate and biased?

Nicolaisen et al. [6] recently presented a Proceeding paper at the Annual Transport Conference at Aalborg University 2012, on the topic “Forecast: uncertain, inaccurate and biased”. Their paper presents results from an on-going research project on uncertainties in transportation project evaluation (UNITE) that finds forecasts of demand to be not only uncertain, but at times also highly inaccurate and often displaying a concerning degree of bias. Demands for road projects appear to be systematically underestimated.

The paper summarizes some past leading studies on the topic accuracy in travel demand forecasting. These are shown in table 2-1, and are categorized into: (1) non-toll roads, (2) toll roads, and (3) rail projects. Inaccuracy was measured by percent as shown by Equation 2-1.

$$I = \frac{(O - P)}{P} \times 100 \qquad \text{Equation 2-1}$$

Where (I) indicates the relative difference between expected and actual traffic volumes counts, .i.e. a mean inaccuracy of +10% indicates that 10% additional traffic materialized compared with the forecasted value. O = indicates the observed value or actual traffic counts, and P = indicates the predicted value or forecasted travel demand.

Table 2-1 Results from previous ex-post studies on forecasting accuracy

Study	Sample	Mean	Std. dev.
Mackinder & Evans (1981)	Road: 44	-7%	N/A
National Audit Office (1988)	Road: 161	+8%	43
Pickrell (1990)	Rail: 10	-65%	17
Fouracre et al. (1990)	Rail: 13	-44%	26
Flyvbjerg et al. (2005)	Road: 183 / Rail: 27	+10% / -40%	44 / 52
Bain (2009)	Road (toll): 104	-23%	26
Parthasarathi & Levinson (2010)	Road: 108	+6%	41
Welde & Odeck (2011)	Road: 25 / Road (toll): 25	+19% / -3%	22 / 21

The results of those studies indicate a tendency in forecasts for non-toll road projects to be underestimated, and road toll projects tend to be overestimated. This can be considered as an expression of forecasting bias and an observed degree of deviation in most studies, which can be considered as an expression of forecasting imprecision. Bias and imprecision are both problematic for the validity of subsequent decision support based on such demand forecasts.

Due to lack of project specific data in many of those studies a joint research program was launched to study an ex-post evaluation of transportation infrastructure projects in Denmark, Norway, Sweden, and the UK, i.e. the. UNITE program, which consist of 146 road projects and 31 rail projects. Its purpose is twofold, to investigate whether the results from previous projects (see table 2-1) hold true for more recent projects completed in these case areas, and identify characteristics of projects that are prone to bias or imprecision in their demand forecasts. Data included in their study, where available, contain data with regard to the forecasted traveling demand (P), as well as the observed value (O) after the project´s completion. There are both theoretical and practical problems in obtaining validated (O) and (P) values[2]. The main obstacle seems to be that project documentation neglects to provide a year of reference for the traffic counts / forecasts, thus it is assumed that the reference year is the opening year of the project, and in many cases traffic counts do not exist for the opening year.

The authors argue that it is not uncommon for separate ex-post evaluations for the same project to reach different conclusions, as there is methodological difference in how a delay in the project delivery will influence the traffic volume for the first year of operation, given that the delay in the project delivery is greater than one year. In the UNITE program, the observed values / actual traffic counts (O) were adjusted with the following formula, given in Equation 2-2.

$$A = O \times (1 + r)^{(Y-T+1)} \qquad \text{Equation 2-2}$$

Where (A) indicates adjusted value for the observed value or actual traffic counts, r= calculated growth trend, Y = opening year for traffic, and T = the scheduled opening

[2] Refer to Nicolaisen et al., for a detailed discussion on this issue

year. Whether Equation 2-2 gives a more valid value, rather than those calculated by, Equation 2-1 remains a debate for interpretation of how accuracy of travel demand forecasting is treated with the methodological differences in mind.

Some of the findings of the UNITE program are shown in Figure 2-3 and display the observed inaccuracy of demand forecasts for road projects. There seems to be a tendency of underestimating demand in the appraisal of the road projects, as more than one third of the projects experience traffic volumes that deviate more than +-20% from the forecast.

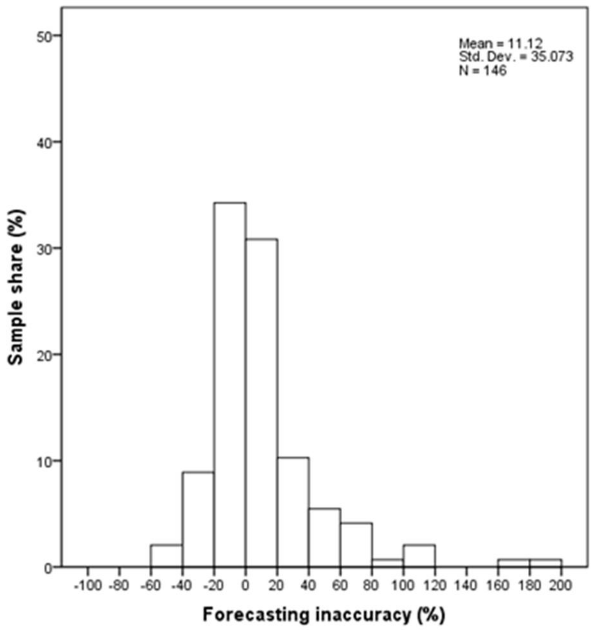


Figure 2-3 Forecasting inaccuracy for road projects, UNITE program

The same data for the road projects are then disaggregated according to project type and are illustrated in Table 2-2. This suggests that fixed link projects (tunnels and bridges) are quite problematic (28% mean and 66 Std. dev), i.e. such projects are prone to bias and inaccuracy in forecasting travel demand.

Table 2-2 Road projects disaggregated into different project types

Project type	Sample	Mean	Std. dev.
Fixed link	19	28%	66
Bypass	39	17%	32
Motorway (new link)	38	9%	29
Motorway (upgrade)	50	2%	20

Inaccuracy in forecasting travel demand can lead to distorted prioritization of project selection and investment, thus providing a weak base for appraisal methods, such as CBA. A treatment of those uncertainties is presented which propose a supplement to cost-benefit analysis with quantitative risk assessment (QRA) and Monte Carlo simulation by applying relevant probability distributions to these impacts. By applying the QRA and Monte Carlo simulations risk analysis techniques it is possible to get a more nuanced perspective on the uncertainties related to the socio-economic feasibility. In practice, this is achieved by transforming the so called single point estimate values, .i.e. the calculated net present value (NPV), internal rate of return (IRR) and benefit cost ratio (BCR) values, also known as performance indicators into an interval by comparing them with the forecasting accuracy observed in the ex-post evaluations from previously completed projects. The indicator is represented in terms of a certainty graph depicting the likely outcomes of an investment by the use of probability estimates for the different value[3]. In this way policy makers are informed about how the feasibility of an investment can change in relation to the variability of forecasted cost and benefits.

Finally, the authors conclude that a necessity for improved uncertainty management by structured archiving of relevant project data, i.e. the projects benefits and costs in needed. It is also recommended that more attention should be given to monitoring completed projects so future forecasts can benefit from better data availability through systematic ex-post evaluation like the one which is now under development by the UNITE research project.

[3] Refer to Salling, K.B (2008). Assessment of Transport projects: Risk Analysis and Decision Support, DTU, Ph.D. thesis. Probability distributions and reference class forecasting

2.3.2 Error and optimism bias in toll road traffic forecasts.

In the paper Error and optimism bias in toll road traffic forecasts, Bain [7] continues his previous toll road study from 2005, i.e. on 104 international toll road, bridge and tunnel case studies. The research findings had been presented as a ratio of actual traffic/forecasted traffic, with actual traffic based on first year traffic. Projects that out-performed their forecasts therefore had ratios above 1.0, and ratios <1.0 reflected a trend of over-forecasting. The research results are summarized in Figure 2-4.

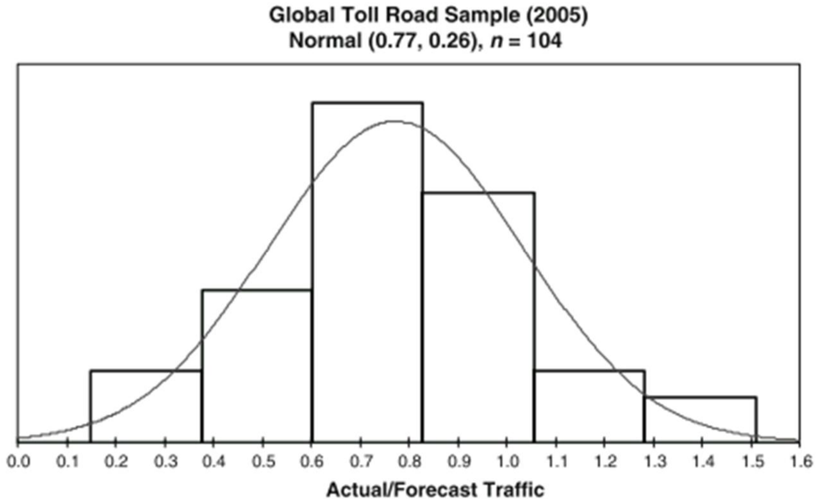


Figure 2-4 Toll road sample, Bain 2005

The mean of 0.77 suggests that on average the respective forecasts were optimistic by some 23%. Bain’s findings demonstrate a large range of error and systematic optimism bias. Most reported sources of errors relate to uncertain or dubious assumptions including, time savings that often turn out to be lower than expected, and the willingness to pay road tolls is overestimated. Bain tested a hypothesis stating that predictive performance of traffic forecasts would reach their forecasted traffic values after a few years and to be more reliable. This is also known as ramp-up traffic. Multi-year traffic data was available for a subset of the case studies from 2005, and that data contained sufficient data for the hypothesis to be tested through year 5. The means and standard deviations of the time series from Bain’s study are illustrated in Table 2-3.

Table 2-3 Time series distribution analysis, Bain 2005

Years from opening	Mean	Standard deviation
Year 1	0.77	0.26
Year 2	0.78	0.23
Year 3	0.79	0.22
Year 4	0.80	0.24
Year 5	0.79	0.25

From this data, the conclusion was drawn that there is no evidence to support the above hypothesis, that there is any systematic improvement in toll road traffic forecasting accuracy after year 1.

In the second part of the study, Bain compares these toll road projects with a study from Flyvbjerg et al., 2005, "How (in)accurate are demand forecasts in public projects works?" The Flyvbjerg study consists of 183 toll-free road projects compiled from 14 countries. His findings are presented in Figure 2-5 as a ratio value to be comparable with data from Bain (-20% inaccuracy is 0.8 in the ratio of actual traffic /forecasted traffic value).

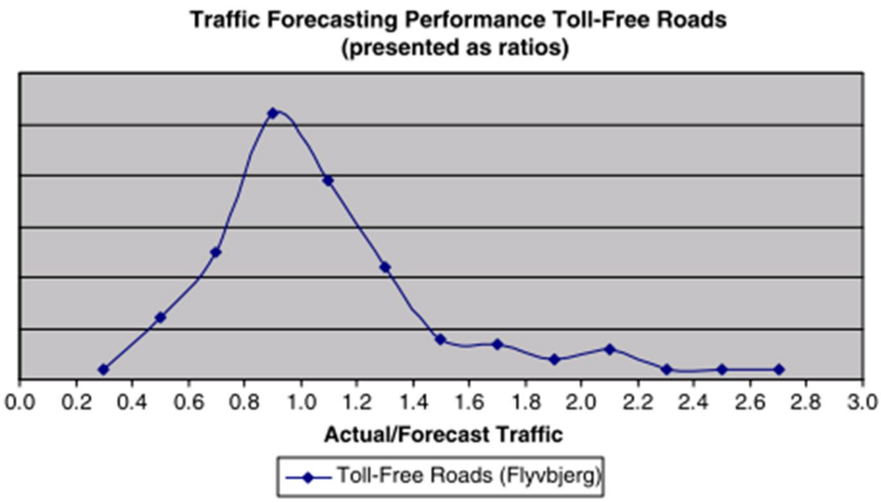


Figure 2-5 Toll free road forecasts as ratio, Flyvbjerg et al. 2005

The mean of the bell-shaped portion of the distribution is close to 1.0, which suggests that forecasts for toll-free roads do not display the strong systematic tendency toward optimism bias identified earlier for the toll projects. The long right- hand tail represents actual traffic that exceeded its respective forecasts. A possible explanation for this could be that toll-road forecasts are subject to more rigorous, multi-party scrutiny than traditional public sector toll-free road forecasts. Therefore, toll-road forecasters are less likely to fail to capture the possibility of high traffic usage, and the focus on upside traffic potential undoubtedly contributes to the optimism bias findings. Figure 2-6 shows a comparison of the two data sets from Flyvbjerg, 2005, and Bain, 2009.

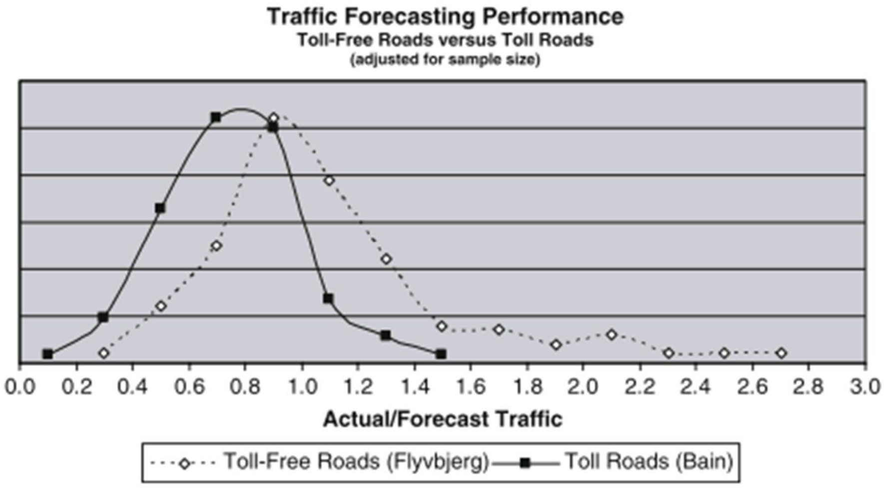


Figure 2-6 Comparison of Flyvbjerg et al., 2005 and Bain, 2009

The substance of the two distributions looks very similar (toll roads distribution to the left), and the presence of systematic optimism bias appears to be a characteristic that differentiates the two data sets. Optimism bias does not appear to be a defining attribute of toll-free road traffic forecasts. By adding +20% to the actual toll road traffic volumes, as a measure of correction for optimism bias in the toll road forecasts, the spreads of the two distributions appear to be broadly comparable. This is illustrated in Figure 2-7.

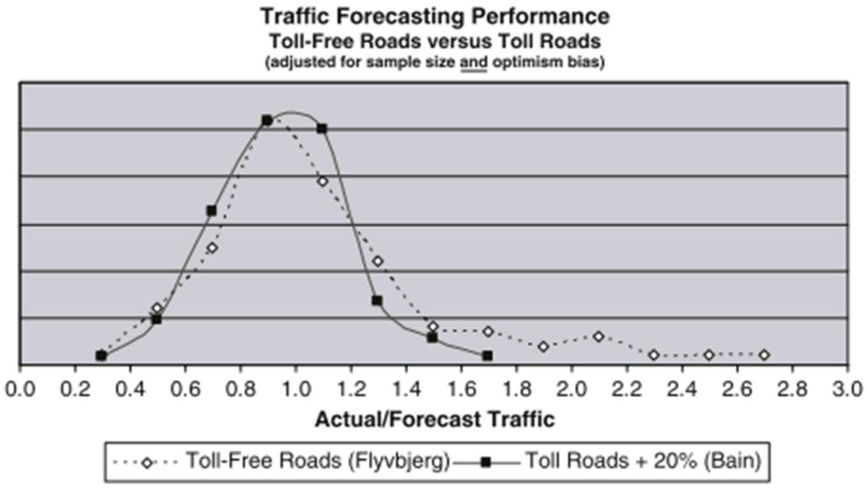


Figure 2-7 Adjusted comparison of Flyvbjerg et al., 2005 and Bain, 2009

The key lesson from this analysis can by summarized as follows, (i) toll and toll-free road traffic forecasting appears to differ in terms of optimism bias, (ii) toll and toll-free road traffic forecasting accuracy appears similar in terms of absolute error. These findings are important in the context of privately financed shadow toll road projects[4]. Project sponsors have strived to introduce (promote) toll roads as less risky prospects for private investors than user-paid toll roads. The argument for the road toll-projects points to the fact that, (i) getting feedback from the consumers regarding user fees is a major challenge, (ii) in the case of shadow toll where this challenge is removed then the forecast reliability is enhanced. This argument does not appear to be supported by the data presented above. There is no evidence to support the notion that predictive error is reduced in situation where drivers are not required to pay tolls. The principal conclusion to be drawn from the research reported in this paper is that toll road investors need to be aware of the considerable potential for error and bias to influence future projects of asset usage.

[4] Shadow tolls are payments made by the government to the operator of the road, based on the number of vehicles using the road.

2.3.3 How accurate are demand forecasts in public work projects?

In 2005 Flyvbjerg et al. [5] published a comprehensive research on the concept of optimism bias or risk denial. At that time most existing studies concluded that there was a strong tendency for traffic forecasts to be overestimated. The research measured inaccuracy of traffic forecasts in a sample of 210 transportation projects with comparable data for forecasted and actual traffic. The sample comprised a project portfolio worth approximately US$ 59 billion at 2004 prices. The project portfolio included 27 rail projects and 183 road projects from 14 different countries. These transportation projects consist of urban rail, high-speed rail, conventional rail, bridges, tunnels, highways and freeways.

Measuring inaccuracy follows a common practice and is defined as actual minus forecasted traffic in percentage of forecasted traffic. Forecasted traffic is the traffic estimate for the first year of operations (or the opening year), while the forecasted demand was obtained from the demand estimation produced at the time of decision to go ahead with the project.

For road projects, they found with 95% confidence level that there was no significant difference in terms of forecast inaccuracy between vehicle traffic on highways, bridges and tunnels. Therefore, they considered the 183 road projects as an aggregate (a single entity!). 50% of the road projects showed a ±20% difference between actual and forecasted traffic, and if the threshold was doubled to ±40%, then 25% of the road projects were above that level.

Road traffic forecasts were underestimated by an average of 8.7%, resulting in actual traffic that was on average 9.5% higher than forecasted traffic. Accuracy of traffic forecasts did not improve over time, with road forecasts showing greater inaccuracies towards the end of the 30-year study period. Against this background, planners and decision makers are well advised to take with a grain of salt any traffic forecast that does not explicitly take into account the uncertainty of predicting future traffic. Figure 2-8 shows the distribution of inaccuracy of traffic forecasts for the 183 road projects.

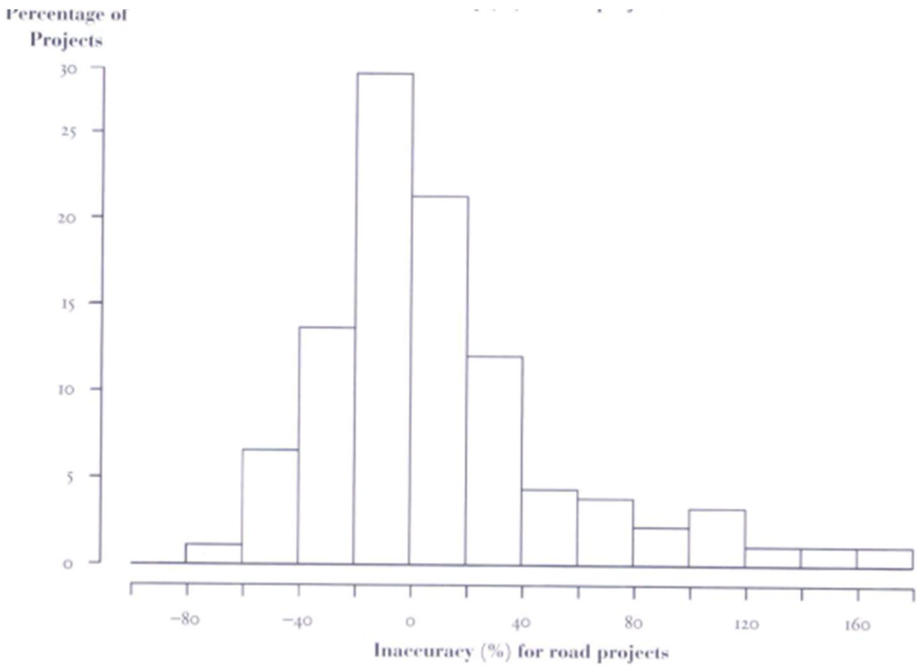


Figure 2-8 Inaccuracy precentage for road projects, Flyvbjerg et al., 2005

2.3.4 The accuracy of travel demand forecasting in Norway

Welde and Odeck [8] studied 25 toll road projects and 25 non-toll projects in Norway. The data sets for the toll road projects included 12 fixed-link crossing (bridge and tunnel), 11 highway projects and two toll cordons. All toll projects in Norway require a specific approval from the Norwegian parliament, and as they are being presented, the toll projects have to include all financial assumptions, including traffic forecasts. The critical test for the traffic forecast accuracy is thus how the actual traffic will relate to what was presented at the time of the decision to build. The toll free projects are also approved by the parliament, but with less data containing NPV single point estimate from a CBA that relies heavily on the traffic forecast. The data for the 25 toll free projects were from the years 2001 to 2007, consisting of projects outside the major urban areas.

The forecasted traffic on the toll road projects was higher than the actual traffic, being 2.5% less than forecasted on average. In their opinion actual traffic compared to forecasted traffic was well within an acceptable range of ±10%. A closer look at the data revealed that the majority of the projects experienced traffic overestimation. 24% of the projects had 20% less traffic than expected and an overestimation of 35% for the first year of operation could have severe financial implications for the viability of toll road projects. The consequences for such a drastic shortfall could lead to difficulties in loan refinancing, prolonged payment period, increased toll and thus less traffic. The standard deviation for this data set was 22%, indicating a rather large variation between projects. Figure 2-9 illustrates traffic forecast accuracy distribution of the 25 toll road projects.

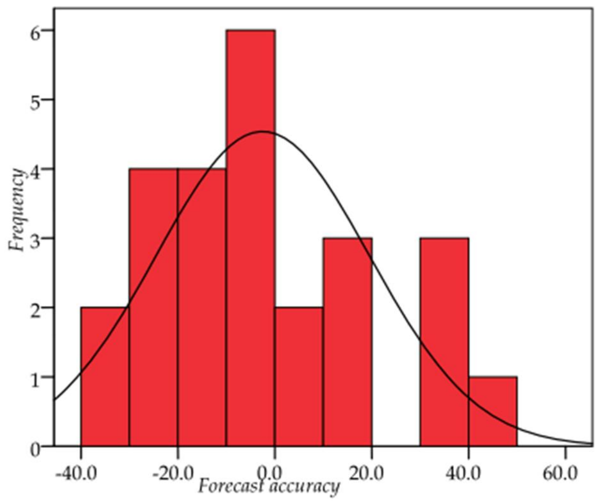


Figure 2-9 Accuracy of the 25 toll road traffic forecasts, Welde and Odeck, 2011

For the road toll projects, it is concluded that these projects often struggle to reach their full potential in the first whole year after opening, but can catch up the loss of traffic in subsequent years. This is called the ramp-up effect. International evidence of ramp-up effect has been inconclusive as different studies have shown different results. In this sample of toll road projects, there were signs of ramp-up effects.

The 25 toll free projects showed that actual traffic was on average higher than forecasted. The mean underestimation was 19%, but with a large range (-14.6% to +76.1%). These findings are consistent with the observations of Flyvbjerg et.al. Six projects had traffic levels below the forecast, and 13 projects showed overestimation above the sample mean. In seven projects, actual traffic was over 30% higher than forecasted. It was expected that the traffic forecast accuracy for toll free road projects would be higher, and concluding with an indication that these 25 Norwegian traffic forecasts have been underestimated. The spread in the distribution was alarmingly high, which indicated a high level of general error. Figure 2-10 illustrates traffic forecast accuracy distribution for the 25 toll free road projects.

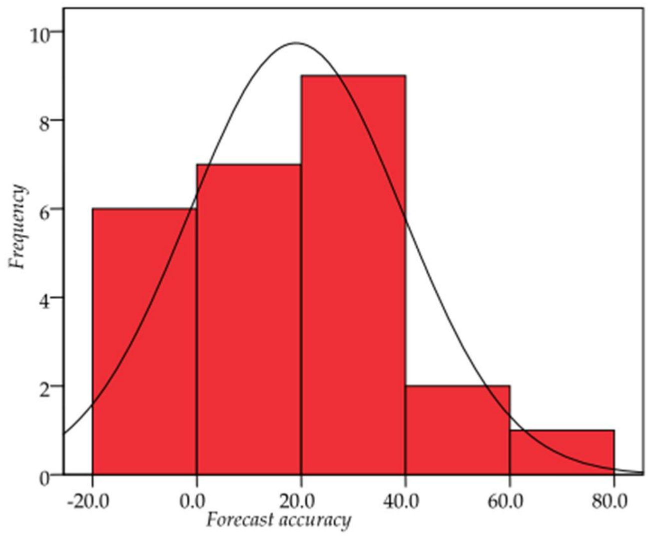


Figure 2-10 Accuracy of the 25 toll free road traffic forecasts, Welde and Odek, 2011

For the projects with the large underestimation, there is a reason to suspect that planners have failed to account for induced traffic. This underestimation may have lead to inefficient resource allocation, and that beneficial projects were foregone in favour of less beneficial ones. The Norwegian model for traffic forecasts does not consider induced traffic explicitly. Finally, the high uncertainty revealed by inaccuracy in the traffic forecast, can present a misleading single point estimates, i.e. NPV, IRR and BCR for decision makers.

2.4 Summary

This chapter presented a review of some existing literature on accuracy in traffic demand forecasting. The peer-reviewed journals articles point out that there seems to be a tendency to underestimate traffic demands in the appraisal of the observed road projects, and demonstrate a large range of error and systematic optimism bias. The critical test for the traffic forecast accuracy is how the actual traffic will relate to proposed traffic that was used in the decision to build the road infrastructure. It is also concluded that more attention should be given to recording and archiving of relevant project data, i.e. benefits and costs, and monitoring completed projects so future traffic forecasts can benefit from better data availability through systematic ex-post evaluation.

Therefore, the intent of this research is to compare actual traffic of four Icelandic road tunnel projects with their proposed values. These findings will then be compared to findings of Flyvbjerg et al. [5].

Chapter 3. Research methodology

3.1 Introduction

In order to achieve the objectives stated in chapter one, the research work in this study is organized into four main research tasks that are designed to: (1) conduct a comprehensive literature review of the latest research on the topic “accuracy of traffic demand forecasting”; (2) gather data from four preselected Icelandic road tunnel projects for their forecasted and actual traffic, and (3) compare these observations with those of Flyvbjerg et al. (2005) [5]; (4) to discuss the occurring difference if any is discovered.

3.2 Nature of research

The purpose of research is to expand knowledge, thus adding to one´s own knowledge and understanding of a phenomenon, circumstances or scenario in the chosen subject area. “Research can be considered to be a ‘voyage of discovery’, whether anything is discovered or not. What is discovered depends on the pattern and techniques of searching, the location and subject material investigated and the analysis carried out.” Fellows and Liu, [23]. Prior to research one has to consider which research methodology best suits the purpose of the study, and the research design must take into account the research question(s). Choosing the right strategy is a crucial step when pursuing a desired goal, this necessity applies to companies, organizations, and individuals as well as research projects. The strategy then defines the direction and steps required to reach a certain goal (ibid).

According to Yin [24] there are five common research strategies in the social science: (1) experiments, (2) surveys, (3) archival analysis, (4) histories, and (5) case studies. These and other choices represent different research methods. Each is a different way of collecting and analysing empirical evidence, i.e. following its own logic, and each method has its own advantages and disadvantages. Yin suggests that determining the most appropriate style to adopt depends on: (1) the type of research question posed, (2) the degree of control that the researcher has over the variables involved, and (3) whether the focus of the research is on contemporary or historical events. Figure 3-1 show these three conditions in relation to the five research strategies.

METHOD	(1) Form of Research Question	(2) Requires Control of Behavioral Events?	(3) Focuses on Contemporary Events?
Experiment	how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Archival Analysis	who, what, where, how many, how much?	no	yes/no
History	how, why?	no	no
Case Study	how, why?	no	yes

Figure 3-1 Different research methods, Yin 2009

The different approaches focus on collection of data rather than examination of theory and literature. The methods of collecting data impact upon the analysis which may be executed, i.e. the results, conclusion, and validity of the study. Fellows and Liu, [23].

3.3 Traditions in research

Quantitative approaches seek to gather factual data and to study relationship between facts and how such facts and relationships accord with theories and findings of previous research on the topic. Scientific methods are used to obtain measurements – quantified data. Qualitative approach, on the other hand, seeks to gain insight and understand people´s perceptions of the world, whether as individuals or groups. Thus their beliefs, understanding, opinions or views are investigated. This is the preferred method of most social scientists seeking insight into a particular situation or phenomenon, through close observation (ibid).

A triangulated study employs two or more research techniques, quantitative and qualitative approaches may be employed to reduce or eliminate disadvantages of each individual approach whilst gaining the advantages of each, and the combination giving a multi-dimensional view of the subject, gained through synergy. The essence of triangulation is that is provides some measure of comfort for the researcher when he can see that results from two or more methods seem to lead to the same overall finding (ibid).

Validity will be maintained by using multiple sources of evidence that will be used in triangulation to establish a chain of evidence. These sources will include: (1) published reports, documents and feasibility studies, etc., (2) real traffic count data obtained from ICERA; and (3) review recent evidence from peer-reviewed journals on the topic. In order to produce reliability, a consistent case study protocol must be used. In this research, all cases are treated in an identical manner for a consistency of results, so that if the study would be done by another academic, similar results would probably be obtained.

3.4 Research approach

This research is mainly concerned with: (1) conducting a document analysis of primary sources, looking for estimated traffic volume at the time of decision making; (2) obtaining traffic data (real count data) during the first year of operation as the basis for measurement; (3) comparing the findings with previous research efforts.

The research questions are in the form of what and how questions, there is no control over the variables and the event is a past/contemporary one. According to the methods in Figure 3-1, experiments, history and case study seems to be the most appropriate ones. The research is not asking the questions in the context of “how much or “how many”, which favours survey methods or archival analysis. How questions are more explanatory, thus seeking an explanation of a situation or problem and they are more likely to lead to the use of case studies, histories and experiments, because such questions deal with operational links needing to be traced over time and both qualitative and quantitative data can be used. Yin [24].

Experiments are ruled out, because the researcher has to have control over the variables, i.e. he must be able to manipulate their behavior directly, precisely and systematically. History research is also disregarded as it relies only on past documentary data. A case study seems to be the best fit, as it has the ability to deal with a variety of evidence, i.e. documents, observations and interviews. According to Yin [24] a case study is appropriate when a “how” or “why” question is being asked about a contemporary set of events, over which the investigator has little or no control.

A survey and archival analysis were also considered. A survey is usually based on tools such as questionnaires and interviews, and relies on the basis of statistical sampling, where a small amount of information is collected from each source and then repeated many times over (large population). Surveys are usually appropriate for descriptive studies Fellows and Liu [23]. Archival analysis was not found feasible, because the variables of interest have not been systematically collected by public authorities, agencies or private partners, nor are they based on a uniform data collection protocol.

3.5 Research methods

The research uses a case study as its research strategy. According to Yin [24] a case study research has an advantage when "how or why questions are asked about a contemporary set of events, over which the investigator has little or no control." There are two variables in measuring accuracy in travel demand forecasting, and two sources of data were used: (1) (document analysis) obtaining forecasted travel demand from the project's planning and decision phase as the first variable (Tf) in measuring accuracy. (2) Using traffic data (real count data) from the first year of operation as actual travel demand (Ta) for the second variable in measuring accuracy. The document analysis focuses on getting data from public documents and reports on forecasted traffic demand at the time of the project's approval.

Validity will be maintained by using multiple sources of evidence that will be used in triangulation to establish a chain of evidence. These sources will include: (1) published reports, documents and feasibility studies, etc.; (2) real traffic count data obtained from ICERA and; (3) review recent evidence from peer-reviewed journals on the topic. In order to produce reliability, a consistent case study protocol must be used. In this research, all cases are treated in an identical manner for a consistency of results, so that if the study would be done by another academic, similar results would probably be obtained.

3.6 Definitions

In order to estimate the accuracy in traffic demand forecasts it is necessary to compare forecasted with actual demand. It is common practice to define the inaccuracy of a demand forecast as actual minus forecasted demand in percentage of forecasted demand, as shown in Equation 3-1, Flyvbjerg et al. [25].

$$I = \frac{(Ta - Tf)}{Tf} \times 100 \qquad \text{Equation 3-1}$$

Where I = inaccuracy in percent (%); (Ta) = actual travel demand; (Tf) = forecasted travel demand. Actual demand (Ta) is typically counted for the first year of operation (or the opening year). Forecasted demand (Tf) is typically the estimate for the first year of operation (or the opening year) as estimated at the time of decision to build the project. With this definition of inaccuracy, a value of zero means no variance, a value of - 20% indicates that actual traffic is lower than forecasted traffic, and a value of +20% means higher than forecasted traffic, Skamris and Flyvbjerg [26]. Equation 3-1 will be used to answer research question 1: What is the difference between forecasted traffic demand and the actual figures in the selected cases? This is the same equation which is given in section 2.3.1.

3.7 Summary of research methods

The case study methodology will be applied to the extent possible. Several constrains may lead to slight variations from the ideal case study methodology. For instance time available for research will be a limiting factor regarding the level of detail provided in the case studies. But every effort will be made to keep the entire process as unbiased and scientifically rigorous as possible.

Generally, the research procedure follows the guidelines presented by Yin [24]. The cases were selected based on the replication logic, and had sufficiently distinct characteristics to examine if similar results could be found in different contexts. Data were collected from each case study using the data collection protocol, then individual case results and conclusions were drawn, and finally the case study conclusions were compared to find out how well the findings matched each other. Triangulation was used to confirm the findings from multiple data sources in the same project in all cases, where possible.

Chapter 4. Case study

4.1 Introduction

The national road tunnel plan, approved by the Icelandic parliament in 2000, 21 road tunnel projects were considered as feasible investments [27]. The parliament decided that the first two road tunnel projects to be build according to the plan should be Héðinsfjarðargöng, between Ólafsfjörður and Siglufjörður, and Fáskrúðsfjarðargöng, between Reyðarfjörður and Fáskrúðsfjörður. In 2012, four of the originally considered tunnel projects have been completed and three more are scheduled in the next 10 years.

The following four road tunnel case studies are selected because they are rich in data and contain information about the forecasted travel demand and real count data for the first year of operation. Most of the data is available directly from ICERA website. Figure 4-1 shows the location of the case study tunnel projects, marked with a red ellipse.

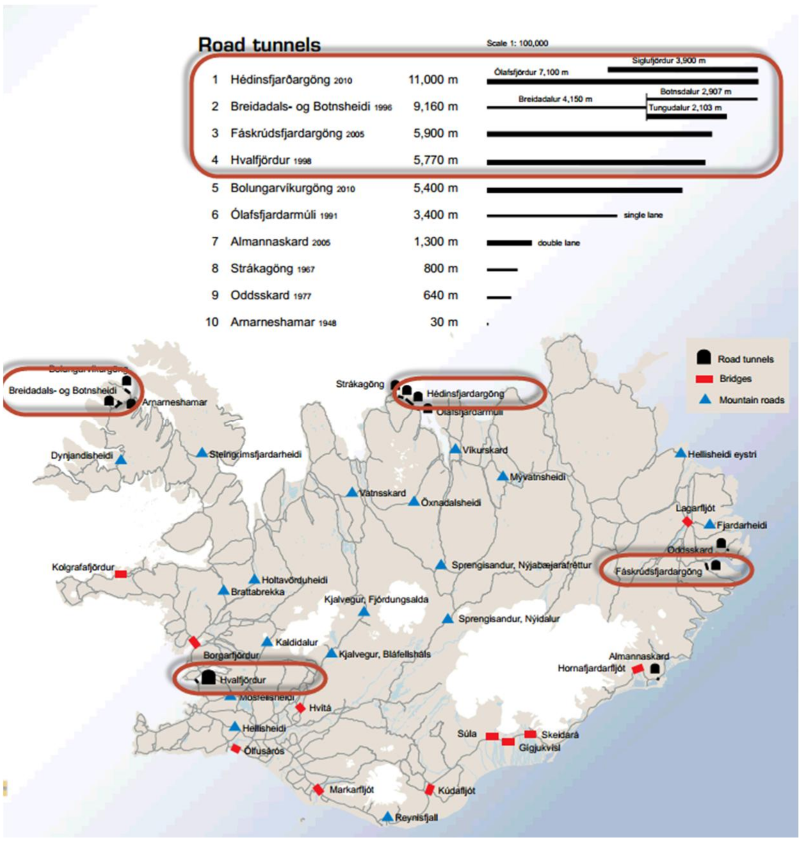


Figure 4-1 Road tunnel case study projects illustrated

4.2 Case study 1, Breiðadals- and Botnsheiði, 1996

4.2.1 Description

A decision was taken by the Icelandic parliament in 1989 to build Vestfjarðargöng, later named tunnel under Breiðadals- and Botnsheiði. Total project cost was estimated to be IKR 3.2 billion at 1991 prices, *Vegagerðin* [28]. The total length of the road tunnel is approximately 9100m with an intersection. 2.2km of the tunnel is a two lane section, 7.5m wide with a cross-section of 48.5m². The rest of the tunnel is a single lane section, 5m wide and 29.5m² in cross-section, with recesses approximately every 160m. Annual average daily traffic (AADT) is expected to be 533 vehicles in the opening year. The estimated increase in AADT traffic was expected to be 25% after the opening of the tunnel. The main argument for the tunnel project was to contribute to a positive sustainable rural development of the local municipalities, and to replace a mountain road (+600 m.a.s.l.) where winter conditions could be very harsh. In the time period 1991 to 1994, the mountain road was closed for approximately 50 days each winter, *Jarðgangnaáætlun* [27]. Figure 4-2 shows the road tunnel location in the northwest part of Iceland. Map, National land survey of Iceland [29].

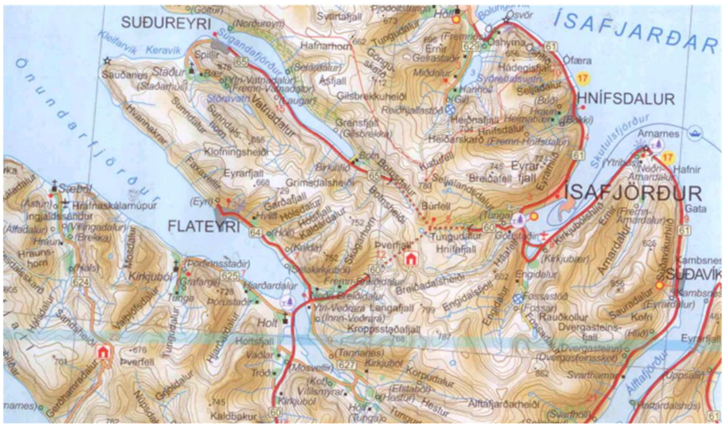


Figure 4-2 Breiðadals- and Botnsheiði, 1996

The project faced severe problems with freshwater leakage in one of the tunnel arms (*Tungudalur*), with a total water flow of 250 l/s. It caused a considerable delay and was finally solved with a special concrete channel for the water flow. The tunnel opened for traffic in late autumn 1995 and was formally opened in September 1996. The total project cost amounted to IKR 5.5 billion at 2002 prices. Source, *Kostnaður við jarðgöng 1981-2002* [30].

There were no reliable methods for predicting increased AADT traffic when opening new road communications like the road tunnel project in question. In Norway, the rule of thumb, based on decades of experience, is to expect a 25% increase in addition to normal traffic growth. There are no examples of an increase exceeding 50%. The tunnels referred to have replaced both mountain roads and car ferries. Figure 4-3 shows the traffic forecast made for this road tunnel project. Source, *Vegamál* [31].

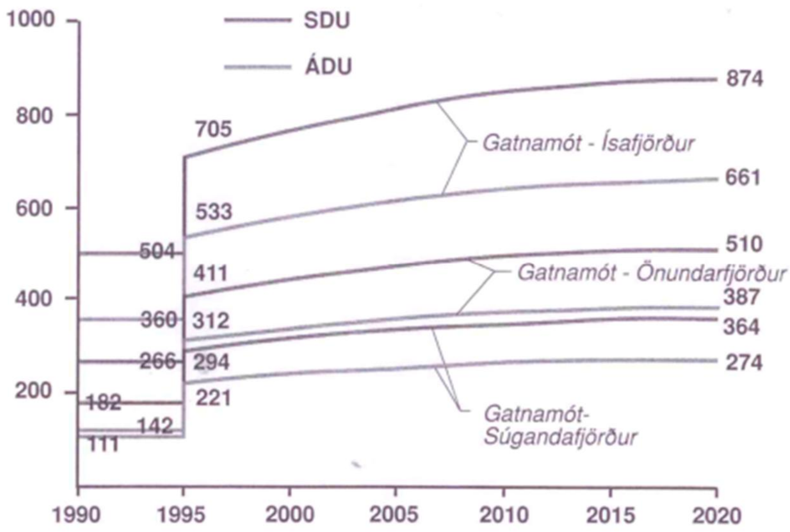


Figure 4-3 Breiðadals- and Botnsheiði, traffic forecast

4.2.2 Data analysis

Table 4-1 shows: (1) the actual demand (AADT), or measured value, (2) the forecasted value, or predicted value, and (3) the calculated inaccuracy. Table rows two through six shows the values for the five following years. These values are shown to follow up on so called “ramp-up” traffic and provide a comparison for the findings of Bain [7], and Welde et al. [8]. 1997, is the first whole year of operation for the tunnel. Icelandic data source, ICERA website [32] and [33].

Table 4-1 Breiðadals- og Botnsheiði, Actual demand vs forecasted

Year	Actual demand	Forecasted demand[5]	Inaccuracy in %
1997	547	533	2.6
2000	670	554	20.9
2001	690	561	23.0
2002	681	568	19.9
2003	743	575	29.2
2004	704	582	21.0

Forecasted demand is based on normal traffic growth, and approximately 25% generated traffic, which was expected with the opening of the road tunnel. A copy of traffic count data table from ICERA is shown in appendix A.1. The whole data set, i.e. from 1997 to 2011 for actual and forecasted demand is shown in a line chart in Figure 4-4.

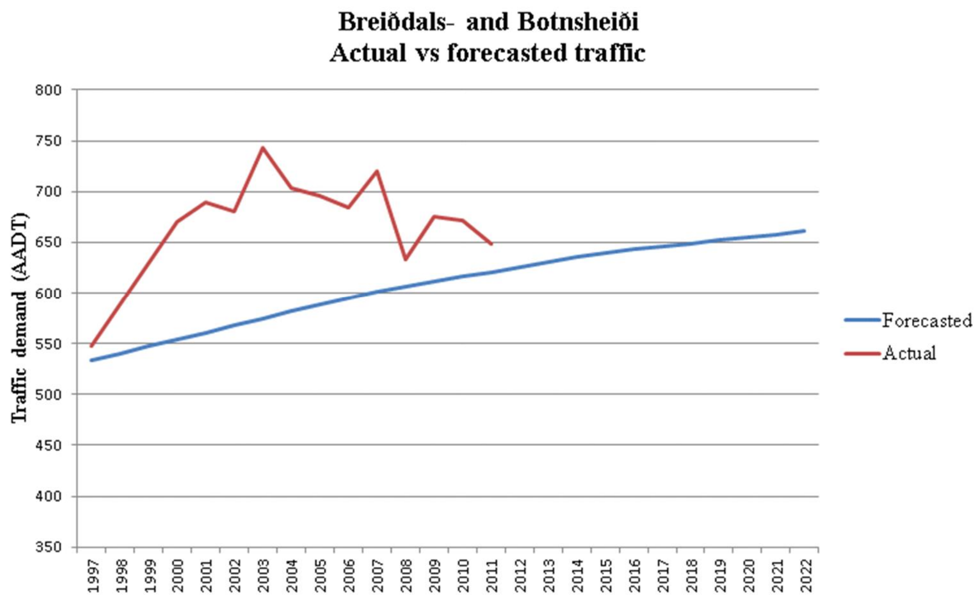


Figure 4-4 Breiðadals- and Botnsheið, data set

Figure 4-5 shows the calculated percentage inaccuracy value, from first year of operation, i.e. 1997, for Breiðadals- og Botnsheiði. This inaccuracy value is presented here on a chart from the findings of Flyvbjerg et al.

[5] Author calculated values from traffic forecast in Figure 4-3

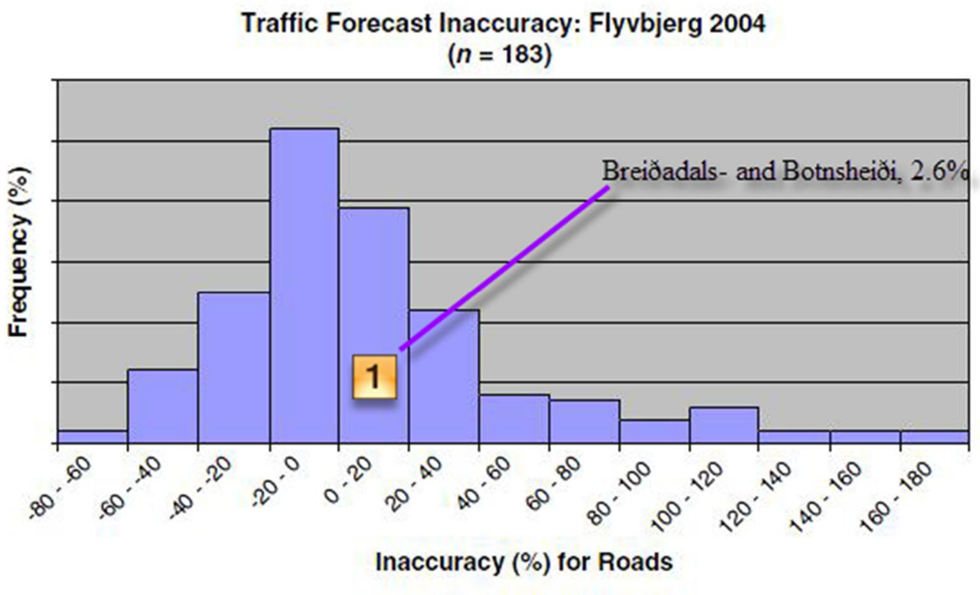


Figure 4-5 Breiðadals- and Botnsheiði, inaccuracy plot

4.2.3 Summary

When plotting the inaccuracy value of the first year of operation for Breiðadals- and Botnsheiði on the distribution chart by Flyvbjerg et al., then it fits in the range +0-20% as shown by the marker (1) on Figure 4-5. This positioning indicates that the traffic forecast is fairly accurate for the first year of operation. For the year 2000 through 2004 it exceeds the ±10% tolerance, presented by Welde and Odeck [8] as an acceptable range for traffic demand forecasting accuracy. See Table 4-1 for values.

The project itself was a success, even though it falls outside the acceptable range of accuracy for travel demand forecasting. Project cost escalated due to severe water leakage in the tunnel during excavation, and the weakening of the Icelandic krona, IKR. However, the main argument, to contribute to a positive sustainable rural development of the local municipalities did not come true, as population in the area has declined since the opening of the tunnel by approximately (-1.0%) per year on average. Source, *DataMarket* and *Samband íslenskra sveitarfélaga* [34]. (See Appendix A.4 for graph and data table from Datamarket).

4.3 Case study 2, Hvalfjarðargöng, 1998, road toll

4.3.1 Description

The Hvalfjörður tunnel is a 5.8 km long sub-sea tunnel with two different cross sections: (1) a two lane tunnel (T8.5), 3.6 km long; gradients of 7% and 4.4%; (2) a three lane tunnel (T11), 2.2 km long; gradient of 8%. The tunnel safety installations were designed according to Norwegian requirements for a tunnel with a safety class B (AADT less than 3500 vehicles within 20 years). It also complies with many of the clauses in EU regulation 16215/03. The tunnel shortens the distance from Reykjavik to Borgarnes by 42 km, and travel time by some 30 minutes. Expected total project cost was IKR 4.6 billion at 1996 prices, of which IKR 3.3 billion were financed by foreign banks. Source Spölur website [35]. The project is the first private partnership road toll project in Iceland. Expected traffic volume at project approval (financing approved by all parties) in 1994 is 1500 to 1700 AADT, whereas AADT of 1700 vehicles were considered as “high expectations”. The road tunnel project has a payback period of 20 years, and will then be handed over to ICERA as an asset at no charge. This is will probably happen in the years 2018-2020.

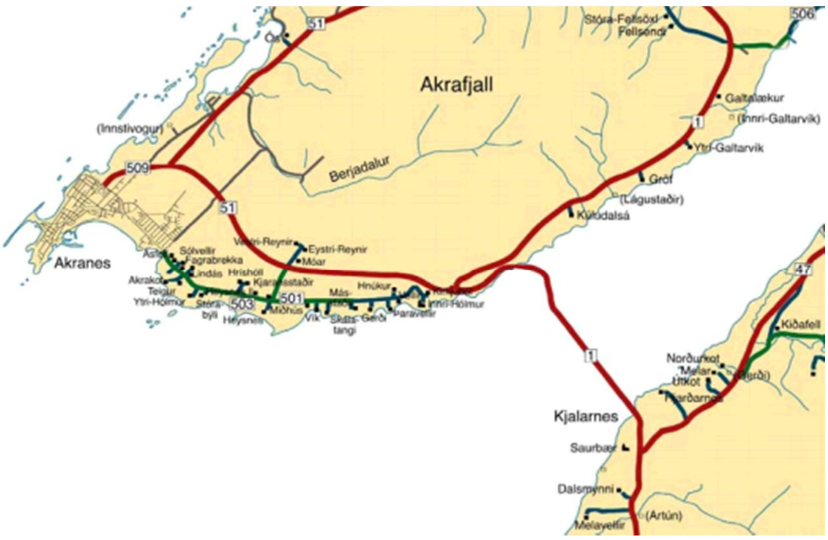


Figure 4-6 Hvalfjarðargöng, 1998

The tunnel formally opened for traffic on July 11th 1998. The annual traffic through the tunnel was much higher than initially forecasted. In 1999 (first year of operation), AADT was 2824 vehicles, and in 2002 traffic had reached an AADT of 3540 vehicles, which was the expected value for the years 2018-2020. In 2011, AADT had reached +5500 vehicles, and the road tunnels design capacity will soon be met. In 2008, a discussion started on building a new road tunnel parallel to the existing one, estimated to cost IKR 7.5 billion at 2008 prices. Source Spölur website [36].

ICERA estimated that the national traffic volume would have an average annual increase of 1.7% for the time period 1996-2000; and 0.95% per annum in 2001 – 2009. This forecast was used as a basis for the project feasibility study. In an ICERA report, a comparison is given for a traffic measurement point at Fossá in Hvalfjördur, between 1991 and 1992, measuring 6.6% annual increase, which was a much higher growth rate compared with Suðurlandsvegur for the same time period.

4.3.2 Data analysis

Table 4-2 shows: (1) the actual demand (AADT), or measured value, (2) the forecasted value, or predicted value, and (3) the calculated inaccuracy. Table rows two through six shows the values for the five following years. These values are shown to follow up on so called “ramp-up” traffic, to provide a comparison like in the previous case study. 1999, is the first whole year of operation for the tunnel. Source, ICERA and Spölur website (ibid).

Table 4-2 Hvalfjardargöng, Actual demand vs forecasted

Year	Actual demand	Forecasted demand[6]	Inaccuracy in %
1999	2824	1700	66.1
2000	3241	1729	87.5
2001	3557	1745	103.8
2002	3540	1762	107.7
2003	3846	1779	116.2
2004	4103	1796	128.5
2011	5070	1920	164.6

[6] Author calculated values, based on data from ICERA in text

The whole data set, i.e. from 1999 to 2011 for actual and forecasted demand is shown in a line chart in Figure 4-7.

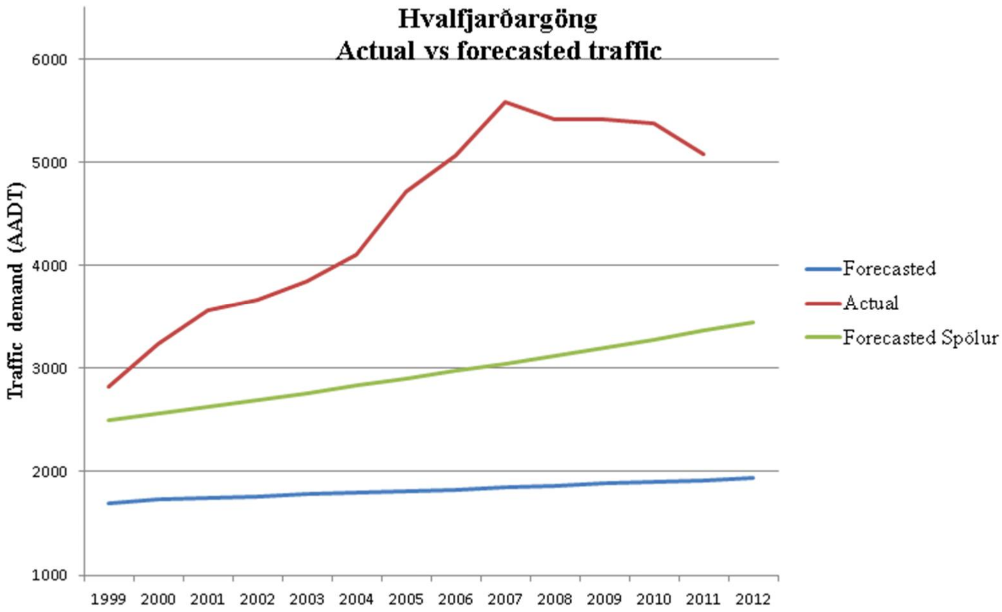


Figure 4-7 Hvalfjarðargöng, data set

Figure 4-8 shows the calculated percentage inaccuracy value from first year of operation, in 1999, for Hvalfjarðargöng. This inaccuracy value is presented here on a chart from the findings of Flyvbjerg et al.

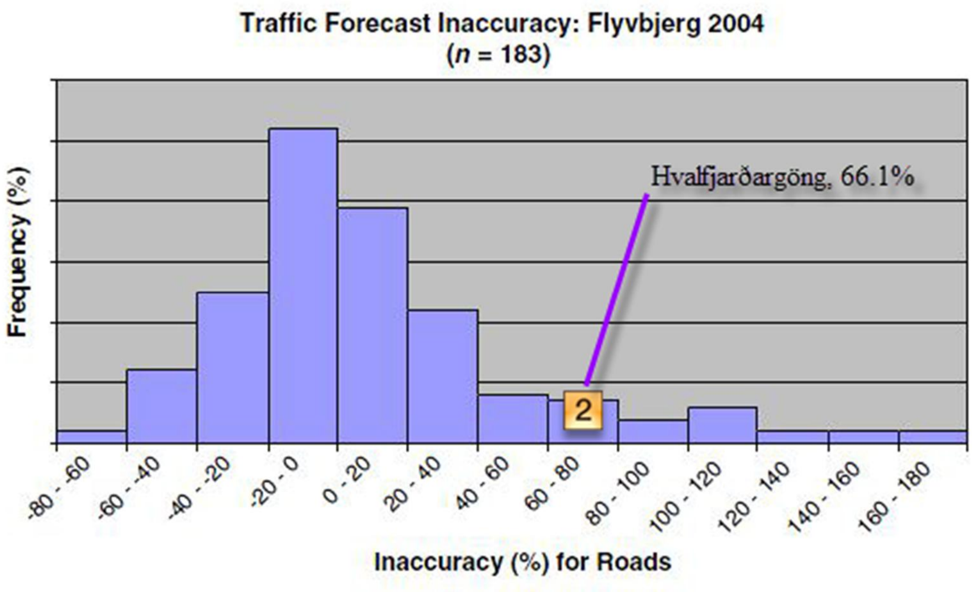


Figure 4-8 Hvalfjarðargöng, inaccuracy plot

4.3.3 Summary

When plotting the inaccuracy value of the first year of operation for Hvalfjarðargöng on the distribution chart by Flyvbjerg et al., then it fits in the range +60-80% as shows by the marker (2) on Figure 4-8. This positioning indicates that the traffic forecast is rather inaccurate for the first year of operation. One of possible reasons for this inaccuracy is an underestimation of generated traffic and lack of proper understanding of travel behavior and trip distribution. The average annual increase in traffic volume from 2000 to 2004 is approximately ~7%. See Table 4-2 for annual traffic data.

The project itself can be considered as a great success and the tunnel has had a very positive impact on the local municipality, Akranes and the heavy industries located in Grundartangi. According to the projects owner, Spölur, the project costs were within margins. However, one can safely assume that a more realistic traffic forecast for the toll road project would have given an entirely different picture regarding the projects feasibility and socio-economic analysis, .i.e. regarding benefits, costs and environmental impacts.

4.4 Case study 3, Fáskrúðsfjarðargöng, 2005

4.4.1 Description

In the national road tunnel plan from 2000 (*Jarðgangnaáætlun*), a decision to build a road tunnel between Reyðarfjörður and Fáskrúðsfjörður was taken. In 1998, the AADT on the road between Reyðarfjörður and Stöðvarfjörður was about 200 cars per day, and summer traffic some 270 cars. The road tunnel project will shorten the distance between Reyðarfjörður and Stöðvarfjörður by 34 km. With the advent of a road tunnel in this region, traffic was bound to increase, as it would contribute to a larger commercial and service area. It was expected that some of the traffic that passed through Breiðdalsheiði on the national road nr.1 (ring road) would choose this new route, as it would shorten the distance to Egilsstaðir by 13 km and would have a special advantage during the winter time, *Jarðgangnaáætlun* [27], *Vegagerðin* [37]. Figure 4-9 shows the road tunnel location on the east coast of Iceland.

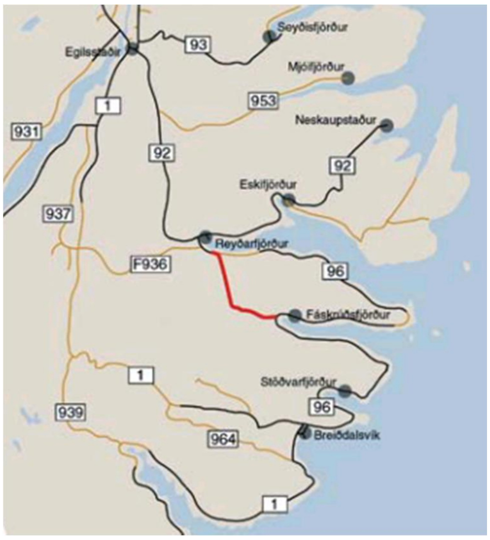


Figure 4-9 Fáskrúðsfjarðargöng, 2005

The total project cost was estimated to be approximately IKR 2.5 billion at 1999 prices. It is a 5.3 km long, single lane road tunnel with meeting points, and 7.5 km of new roads outside the tunnel (daylight zone) to connect to existing road network. A two lane tunnel (T 8.5), was estimated to cost approximately IKR 3.5 billion at 1999 prices, *Jarðgangnaáætlun* [27].

A pre-feasibility study was conducted for the project, where the cost of the tunnel variant was compared to the cost of rebuilding part of the existing ring road in the area with a paved road deck. It turned out that the road tunnel project was the more feasible alternative, measuring approximately 5% in internal rate of return (IRR), assuming that total traffic would increase to about 300 AADT, (ibid). It is assumed by ICERA that AADT could reach a value of 1000 AADT in 20 to 30 years after opening, meaning approximately 6.0% annual growth rate in traffic volume until 2025.

In 2002, the Minister of transportation decided to bypass the pre-defined tunnel project order decided in *Jarðgangnaáœtlun* from 2000. The project started in 2003, with the two lane variant (T 8.5), and was completed in spring 2005. The tunnel was formally opened for traffic on September 9th that same year. Final project cost amounted to IKR 3.9 billion at 2005 prices. Source, ICERA website [38]

4.4.2 Data analysis

Table 4-3 shows :(1) the actual demand (AADT), or measured value, (2) the forecasted value, or predicted value, and (3) the calculated inaccuracy. Table rows two through six show the values for the five following years the. 2006 is the first whole year of operations. No traffic forecast for the following years is available. The forecasted demand for the years 2007 through 2011 are based on the national traffic forecast presented in Figure 2-2, with approximately 1.4% annual traffic growth rate. Source, ICERA website (ibid).

Table 4-3 Fáskrúðsfjarðargöng, Actual demand vs forecasted

Year	Actual demand	Forecasted demand[7]	Inaccuracy in %
2006	**594**	**300**	**98.0**
2007	**622**	**304**	**104.5**
2008	**588**	**308**	**90.6**
2009	**590**	**313**	**88.6**
2010	**561**	**317**	**76.9**

[7] Author calculated values, based on ICERA data in text

2011	**527**	**322**	**63.9**

The whole data set, i.e. from 2006 to 2011 for actual and forecasted demand is shown in a line chart in Figure 4-10

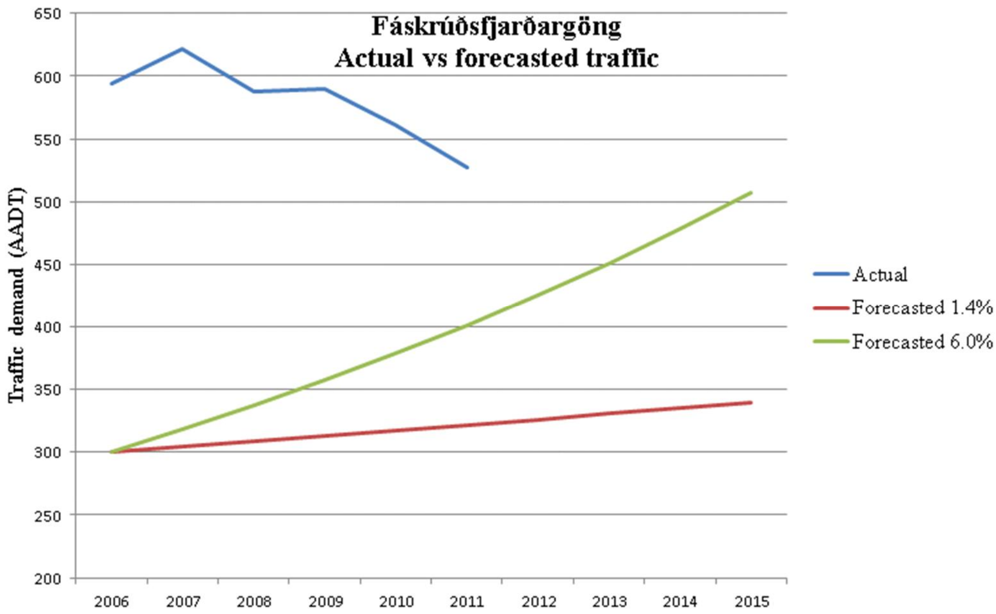


Figure 4-10 Fáskrúðsfjarðargöng, data set

Figure 4-11 shows the calculated percentage inaccuracy value, from first year of operation, 2006, for Fáskrúðsfjarðargöng. This inaccuracy value is presented here on a chart from the findings of Flyvbjerg et al.

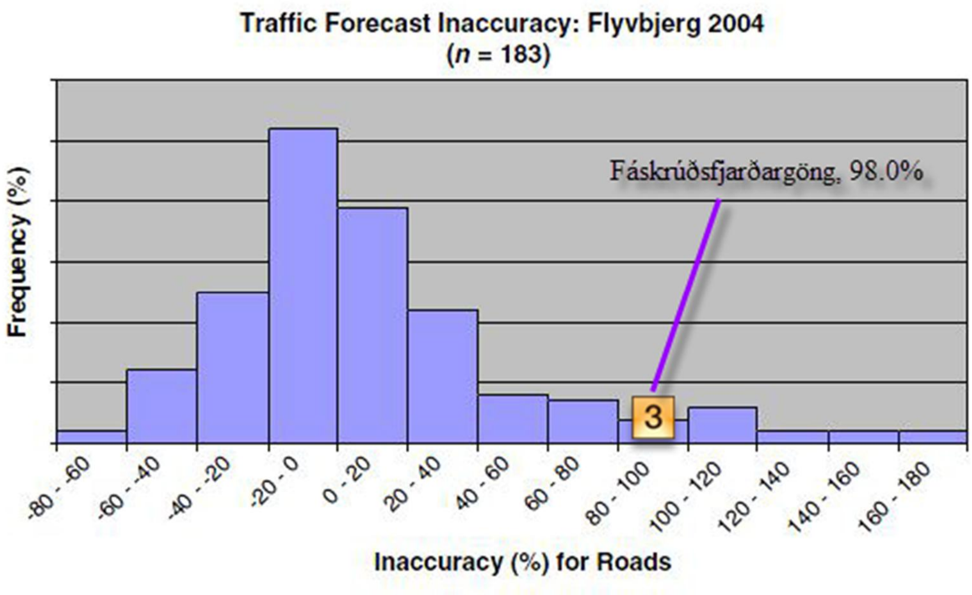


Figure 4-11 Fáskrúðsfjarðargöng, inaccuracy plot

4.4.3 Summary

When plotting the inaccuracy value of the first year of operation for Fáskrúðsfjarðargöng on the distribution chart by Flyvbjerg et al., then it fits in the range +80-100% as shown by the marker (3) on Figure 4-11. This positioning indicates that the traffic forecast is extremely inaccurate for the first year of operation. One of possible reasons for this inaccuracy is underestimation of generated traffic and lack of proper understanding of travel behavior and trip distribution. The average annual increase in traffic volume from 2007 to 2011 is negative by approximately (-2.3%). See Table 4-3 Actual demand vs forecasted.

The project itself is a success, although project cost escalated to some extent due to the weakening of the IKR. One can, however, question the argument of contributing to a positive sustainable rural development of the local municipalities, as there has been a negative average annual growth rate in traffic for the years 2007 to 2011.

4.5 Case study 4, Héðinsfjarðargöng, 2010

4.5.1 Description

After the opening of the tunnel through Ólafsfjarðarmúli (Múlagöng) in 1990, a discussion to build tunnels between Siglufjördur and Ólafsfjörður emerged. In 1994, ICERA appointed an advisory group to conduct a feasibility study for the project. Much of the advisory group's efforts focused on the tunnel options between Siglufjördur and Ólafsfjörður, since it was not considered feasible to rebuild the current mountain road, Lágheiði, in accordance wiht a new road standard, and keep it open the whole year with winter service. A road tunnel was considered a more desirable option for increased cooperation and even integration of municipalities in the region. The advisory group submitted a report in November 1999, suggesting that the so-called Héðinsfjörður tunnel route should be selected. The main arguments for the road tunnel are that the whole western region of northern Eyjafjörður would benefit from it, and it would contribute to a positive sustainable rural development for the local municipalities and strengthen the tourism sector. Figure 4-12 shows the tunnel location in northern Iceland (*Tröllaskagi*).

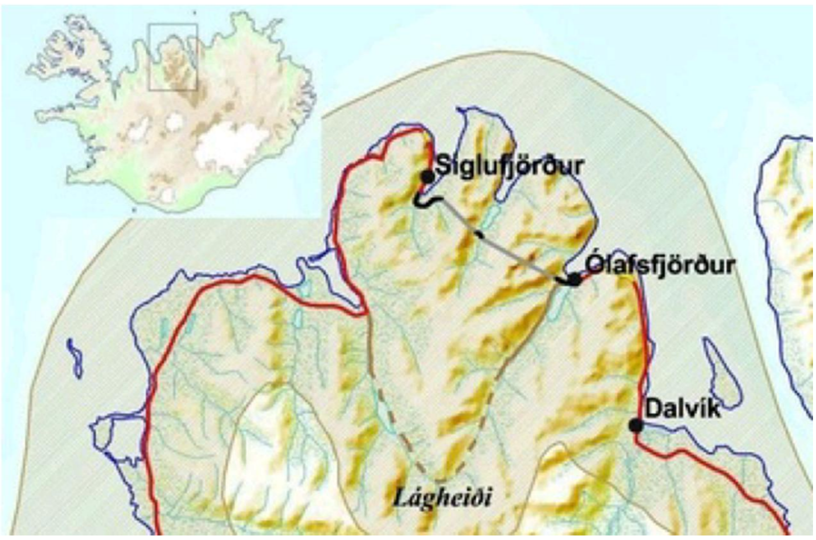


Figure 4-12 Héðinsfjarðargöng, 2010

The road tunnel between Siglufjörður and Héðinsfjörður is about 4 km long with a day zone through Héðinsfjörður, followed by a 6.2 km long tunnel to Ólafsfjörður. The distance between the two towns, Siglufjörður and Ólafsfjörður would change from 62 km to about 15 km, i.e. shorten the distance by 47 km. The traffic demand forecast in the year of opening was expected to be about 350 AADT, but considerable uncertainty was associated with the forecast. The total cost of this road tunnel connection was estimated to be at about IKR 5.3 billion at 1999 prices for a two lane tunnel variant classified as (T8.5)[8]. This was compared to the rebuilding of the road over Lágheiði, with a calculated IRR of nearly 7%, assuming a considerable increase in total traffic volume. Source (*Jarðgagnaáætlun*) [27] and (*Vegtenging milli byggðalaga á norðanverðum Tröllaskaga*) [39].

Preparation work prior to the tunnel excavation was done in 2003 and 2004. The tunnel excavation started in august 2006, with a scheduled completion in December 2009. The estimated total project cost was IKR 7.6 billion at 2006 prices (including prior preparation work). In the ICERA Environmental Impacts Assessment report (EIA), issued in July 2001, forecasted traffic demand is 350 AADT. In 2010 a special report on the traffic demand forecast for the project was published by Heiðarsson [40], where it is concluded that expected traffic could be approximately 550-700 AADT and could even be higher.

4.5.2 Data analysis

The tunnel was formally opened for traffic on October 2nd 2010. During the period October 14th through 26th 2010, a traffic volume of 420 AADT was measured. The final project cost was IKR 14.2 billion at 2011 prices. The increased project costs, i.e. IKR 2.1 billion at 2011 prices, can mainly be traced to severe problems with water leakage in the Ólafsfjörður tunnel and an increase in capital cost due to the economic crisis in 2008. Source ICERA website [41]

Table 4-4 Héðinsfjarðargöng, Actual demand vs forecasted

Year	Actual demand	Forecasted demand	Inaccuracy in %
2011	548	350	56.5
2012			

[8] Tunnel classification according to Norwegian Public Roads Administration, T refers to tunnel with in meters.

Figure 4-13 shows the calculated percentage inaccuracy value, from first year of operation in 2011 for Héðinsfjrðargöng. This inaccuracy value is presented here on a chart from the findings of Flyvbjerg et al.

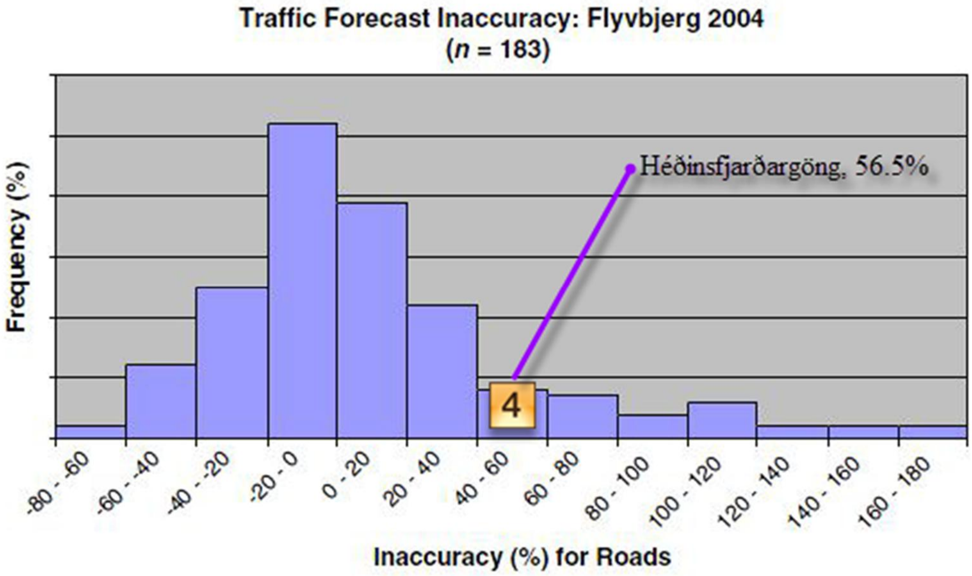


Figure 4-13 Héðinsfjarðargöng, inaccuracy plot

4.5.3 Summary

When plotting the inaccuracy value of the first year of operation for Héðinsfjarðargöng on the distribution chart by Flyvbjerg et al., then it fits in the range +40-60% as shown by the marker (4) on Figure 4-13. This positioning indicates that the traffic forecast is quite inaccurate for the first year of operation. One of the possible reasons for this inaccuracy (deviation from forecasted values) is underestimation of generated traffic and lack of proper understanding of travel behavior and trip distribution.

The total project cost escalated by IKR 2.1 billion at 2011 prices, and according to ICERA, it can be traced to the severe water leakage and to changes in the national economic environment following the crisis in 2008. The tunnel opened for traffic ten months later than scheduled. Whether the main argument, i.e. that the whole northwestern region of Eyjafjörður would benefit from this project, and the completed road tunnel project would contribute to a positive sustainable rural development for the involved municipalities. One has to wait until future research based on an ex-post analysis answers that question.

Chapter 5. Results and Discussion

5.1 Introduction

The purpose of this study was to conduct an ex-post analysis on four Icelandic road tunnel projects, by examining the accuracy of traffic demand forecasting. This was done by comparing their actual traffic numbers (AADT), or actual demand with their forecasted demand. In this section, the results of the case study findings are presented.

Like the studies referred to in chapter 2.3, the findings for the Icelandic case studies all show an underestimation in traffic forecasts. Thus, there is more traffic measured in AADT terms, than predicted during project evaluation. There seems to be a general tendency to underestimate traffic for the first year of operation, i.e. there is more traffic than predicted. See further a brief discussion on the case studies here below. Summary of the case study findings by percentage inaccuracy are presented in Table 5-1.

One might argue that focusing only on the first year of operation does not contribute much to a socio-economic analysis of a road project with a discounted NPV period of 25 to 30 years. But Welde and Odeck [8] point out that according to the principles of discounting, the first years of operation are crucial for both financial and social viability. If a project fails to meet its revenue expectations in the first five years, the risk of a negative outcome increases considerably. This point is also stressed in chapter 1.3.

According to Welde and Odeck [8], no acceptable level of accuracy for traffic forecasting is defined and must be regarded as an empirical matter. The authors suggest an acceptable range of ±10%. This research recommends a non-uniform spread of accuracy ranging from -5% to +15%, rather than ±10%, thus reflecting the findings of Flyvbjerg et al. [5] and Salling [42]. That is also the recommended spread of accuracy range by AACE International [43] for project cost and the accuracy could be further classified as a Class 3 estimate[9], which forms the basis for budget authorization, appropriation, and/or funding decisions.

[9] See referred textbook for further definition

Table 5-1 Summary of Case study findings

Case Study	Actual demand, AADT	Forecasted demand, AADT	Inaccuracy in (%)
C1, Breiðdals- og Botnsheiði	547	533	2.6
C2, Hvalfjarðargöng	2824	1700	66.1
C3, Fáskrúðsfjarðargöng	594	300	98.0
C4, Héðinsfjarðargöng	548	350	56.5

Where, (1) measured value AADT is traffic volume for first year of operation; (2) forecasted demand is obtained from relevant case study, and (3) inaccuracy measured in percentage of forecasted demand. See Equation 2-1 for definition.

5.2 Discussion of case studies

5.2.1 Case study one (C1), Breiðadals- and Botnsheiði

In the Breiðadals- and Botnsheið case, the traffic forecast made especially for this project, Vegamál [31], is quite accurate for the first year of operation, i.e. 1997, where the estimated increase (jump) in traffic was estimated to be 25%, which can be classified as generated traffic according to O'Flatherty [20], see also section 2.2. The inaccuracy is almost constant at approximately +20% for the next five years. See Table 4-1 and Figure 4-4 for further detail. This can possibly be explained by underestimated generated traffic. However, there is a negative average annual traffic growth by (-0.5%) in the period 2004 to 2010, reflecting the declining population in the region. According to the line plot in Figure 4-4, and with an imagined extended data trend for actual demand to next five years, the lines would probably cross in the time period 2014-2016. Further, there is no evidence of a ramp-up effect, i.e. a systematic improvement in traffic forecasting accuracy after the opening year.

5.2.2 Case study two (C2), Hvalfjarðargöng

In the author’s opinion, the traffic forecast for the Hvalfjarðargöng project has failed to take generated traffic into account, and to estimate normal traffic growth. Annual average traffic growth for the period 2000 to 2007 is approximately +9%. In 2008, due to the economic crash in Iceland, the traffic growth halts and has been negative from 2008 through 2011, with an average of (-2.3%) for the period. See Figure 4-7 for clarification. Kristinsson [22], predicts that this “correction of the traffic bubble” will have a pivot point in the years 2014/2015, with an annual average traffic growth rate of +1.5 to +2.5%. See section 2.2.2 for further reading.

This case has all the same characteristics as the previous one, but the sited leading studies, show a tendency of overestimation in traffic demand for toll-road projects. One might, therefore, argue that this specific project has some other striking characteristics that do not exist in comparable foreign projects. A possible explanation could be that development traffic related to nearby summerhouse colonies, and land development for heavy industries at Grundartangi was not sufficiently accounted for. Furthermore, the road toll fee is discounted by some 70%, if 100 trips are prepaid.

A calculated inaccuracy of 66.1% for the first year of operation means a drastically underestimated traffic forecast. Further there is no evidence of a ramp-up effect, i.e. a systematic improvement in traffic forecasting accuracy after the opening year.

5.2.3 Case study three (C3), Fáskrúðsfjarðargöng

For the case of Fáskrúðsfjarðargöng, no traffic forecast is available. However, a pre-feasibility study conducted by ICERA for the project indicates an expected AADT of 300 for the first year of operation. It is further speculated that AADT could reach a value of 1000 after 20 to 30 years after the opening the road tunnel. This means an annual traffic growth rate of approximately +6.0%. According to this data, the case is similar to the case of Hvalfjarðargöng, i.e. the project has failed to take account of, or underestimated generated traffic, and also the estimation of normal traffic growth. Average annual traffic growth rate for the period 2007 to 2011 is negative by (-2.3%). See Figure 4-10 for clarification.

A calculated inaccuracy of 98.0% for the first year of operation, means an underestimated traffic forecast, where actual traffic is almost double the estimated traffic. Further, there is no evidence of a ramp-up effect, i.e. a systematic improvement in traffic forecasting accuracy after the opening year.

5.2.4 Case study four (C4), Héðinsfjarðargöng

For the case of Héðinsfjarðargöng, no traffic forecast for is available. However, a report published by ICERA for the project indicates an expected AADT of 350 for the first year of operation (2011). Data availability for actual and predicted traffic values is very limited at this point in time. An inquiry has been sent to ICREA for the 2012 reference value for actual traffic. In 2011, the first year of operation, AADT was 548, indicating that the project failed to take generated traffic into account. The aforementioned AADT value fits better with the study of Heiðarsson [40], in which the author predicted an AADT value of 550-700.

A calculated inaccuracy of 56.5% for the first year of operation results in an underestimated traffic forecast. In the author's opinion, future traffic trend for this road tunnel project will resemble that of Fáskrúðsfjarðargöng, i.e. a very slow or negative growth trend in AADT for the years to follow.

Chapter 6. Conclusions

6.1 Introduction

This chapter summarizes the findings of this thesis and achieved objectives, while also answering the research questions set forth in section 1.4. A final conclusion is drawn and further research on the topic recommended.

The research questions were as follows:

1. What is the difference between forecasted traffic demand and the actual figures in the selected cases?
2. Can the occurring difference, if any, be explained?

6.2 First research question

What is the difference between forecasted traffic demand and the actual figures in the selected cases?

Like the studies referred to in chapter 2.3, the findings of the Icelandic case studies all show an underestimation in traffic forecasts. Thus, there is more traffic, or actual demand, measured in AADT terms for the first year of operation compared with forecasted traffic which was estimated during project evaluation or the approval stage. There seems to be a tendency to underestimate traffic for the first year of operation and overestimate the forecasted annual traffic growth rate.

For the non-toll projects, i.e. case studies one, three and four, the findings are consistent with those of Flyvbjerg et al., and Nicolaisen, et al, thus showing a tendency for traffic demand forecast to be underestimated. However, the toll-road project in case study two has the same characteristics as stated above while all leading sited studies, on the contrary, show a tendency for overestimation in traffic demand for toll-road projects. Therefore, one might argue that this specific toll-road project has some other striking characteristics that do not exist in comparable foreign studies.

6.3 Second research question

Can the occurring difference, if any, be explained?

Possible explanations for the observed difference between the estimated traffic demand and actual traffic demand in the cases studied could be: (1) Planners may have ignored the existence of generated traffic (induced, converted, and development traffic) or underestimated its parameters. (2) Standard national traffic growth forecasts do not incorporate local variations based on population trends in the local areas. However, some degree of inaccuracy for traffic demand forecast should be expected or taken into account. The author suggests and recommends a range of accuracy from -5% to +15%, as argued in section 5.1.

6.4 Final conclusion

The research presented in this thesis project focuses on accuracy in traffic demand forecasting in four selected Icelandic road tunnel projects. First, a comprehensive literature review was conducted to gain understanding of relevant theory, variables involved and previous research conducted on the topic. Second, data was obtained from the Icelandic Road Administration (ICERA) and data tables generated. Third, case studies were presented, followed by the results of the studies, with some discussion on each case study. The case study projects for the three non-toll road projects all show similar results in comparison, with leading foreign studies on accuracy in travel demand forecasting, and thus reflecting their findings and indicating evidence of inaccuracy by underestimation. The Icelandic toll-road project studied does, however, not reconcile with comparable foreign studies.

It is recommend that future road tunnel projects should be appraised according to the methods of socio-economic analysis, as set forth and proposed by the Icelandic parliamentary resolution, presented here in Chapter 1. Furthermore, the traffic forecasts should be scrutinized and peer-reviewed before final approval projects.

As for the final remark, the author finds it appropriate to quote Flyvbjerg et al. [5]. “But even for roads, for half the projects the difference between actual and forecasted traffic is more than ±20%. On this background, planner and decision makers are well advised, to take with a grain of salt any traffic forecast that does not explicitly take into account the uncertainty of predicting future traffic.”

6.5 Further research

This research compared and discussed accuracy in traffic demand forecasting for the four selected case study projects. However, further research is needed in order to produce a large Icelandic data set (N>32) for a more detailed comparison with previous studies in accuracy of traffic demand forecasting. Following are a few thoughts on other related issues that have an effect on socio-economic appraisals for public transportation projects that need more research in an Icelandic context:

- A comparison study on construction cost for Icelandic road projects, i.e. roads, motorways and tunnels.
- Follow up on UNITE study result, i.e. for applying quantitative risk assessment (QRA) and Monte Carlo simulations, thus if recommend Erlang (for project cost) and Beta Pert (for travel time savings) probability distributions can be directly imported.
- Better understanding of travel behavior and trip distribution as a possible source for traffic forecast modeling error, thus considering population, economic and development trend in a region.
- The concept of willingness to pay for toll-road projects, value of travel time and travel time savings. (Not equal for all locations?).
- The choice of discount rate and related discounting issues.
- Need-based project prioritization when investment funds are limited. (Other methods than traditional CBA and socio-economic analysis).

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Chapter 8. Author’s Biography

Guttormur earned a Bachelor of Science degree in Civil Engineering / Construction management from Tækniskóli Islands (TI) in 1997. After graduating from TI, Guttormur has worked for the following companies listed below in a chronological order.

- ISTAK Ltd., prime contracting company, 1997 – 2002, Construction
- Fjölhönnun Consulting Engineers, 2002 – 2007, Road design
- THG Architects, 2007 – 2010, Construction Management
- Hnit Consulting Engineers, 2011 - , (Norconsult AS, Norway), Road design

In 2006, the pursuit of a Master of Science degree in Civil Engineering / Construction management began at Reykjavik University (RU) as a part time study, while working full time for Fjölhönnun Consulting Engineers. In 2009 the studies came to a halt in the wake of the economic crisis in Iceland. The study program was continued in 2012 with the aim of completing the Master Thesis. Following the completion of his thesis, Guttormur will continue to work in Norway for Norconsult AS in road/highway design, and possibly apply for a grant from ICERA to continue studies on the thesis subject.

Chapter 9. Appendix

9.1 A.1 (ADU) data table, ICERA

Following is a sample of ICERA data table, obtained from their website. The data table shown is for the year 2000, and reference road number is; 1-f8, Hvalfjarðargöng,. (ADU = AADT).

Umferðartölur 2000

Vegnr	Kaflanr	Vegheiti	Heiti upphafspunkts	Heiti endapunkts	Lengd	ÁDU	SDU	VDU	Eknir þ. km
1	f2	Hringvegur	Nesbraut (49)	Úlfarsfellsvegur (430)	1,92	27209	29239	24562	19.068
1	f3	Hringvegur	Úlfarsfellsvegur (430)	Hafravatnsvegur (431)	4,90	16278	18178	14234	29.113
1	f4	Hringvegur	Hafravatnsvegur (431)	Þingvallavegur (36)	1,61	8536	9452	7474	5.016
1	f5	Hringvegur	Þingvallavegur (36)	Brautarholtsvegur (458)	11,96	4503	6055	3128	19.657
1	f6	Hringvegur	Brautarholtsvegur (458)	Hvalfjarðarvegur (47)	3,61	3704	4979	2573	4.881
1	f7	Hringvegur	Hvalfjarðarvegur (47)	Hvalfjarðargöng, syðri endi	0,94	3135	4234	2152	1.076
1	f8	Hringvegur	Hvalfjarðargöng, syðri endi	Hvalfjarðargöng, nyrðri endi	5,76	3241	4438	2207	6.814
1	g0	Hringvegur	Hvalfjarðargöng, nyrðri endi	Akrafjallsvegur (51) við Innrihólm	0,48	3135	4234	2152	549
1	g1	Hringvegur	Akrafjallsvegur (51) við Innrihólm	Akrafjallsvegur (51) við Urriðaá	10,93	2566	3652	1672	10.237
1	g2	Hringvegur	Akrafjallsvegur (51) við Urriðaá	Hvalfjarðarvegur (47)	1,10	2739	3919	1800	1.100
1	g3	Hringvegur	Hvalfjarðarvegur (47)	Höfn	11,64	2603	3846	1681	11.059
1	g4	Hringvegur	Höfn	Borgarfjarðarbraut (50)	8,41	2416	3604	1394	7.416
1	g5	Hringvegur	Borgarfjarðarbraut (50)	Borgarnes, Borgarbraut (531)	2,48	2723	4016	1640	2.465
1	g6	Hringvegur	Borgarnes, Borgarbraut (531)	Hrafnaklettur	1,15	5716	7356	4069	2.399
1	g7	Hringvegur	Hrafnaklettur	Snæfellsnesvegur (54)	0,80	5308	7327	3695	1.550
1	g8	Hringvegur	Snæfellsnesvegur (54)	Hvítárvallavegur (510)	8,60	1894	3114	954	5.945
1	g9	Hringvegur	Hvítárvallavegur (510)	Borgarfjarðarbraut (50)	9,12	1652	2717	832	5.499
1	h0	Hringvegur	Borgarfjarðarbraut (50)	Laxfoss	7,76	1419	2405	746	4.019
1	h1	Hringvegur	Laxfoss	Vestfjarðavegur (60)	10,10	1132	1917	594	4.173
1	h2	Hringvegur	Vestfjarðavegur (60)	Norðurárdalsvegur (528)	10,70	922	1538	482	3.601
1	h3	Hringvegur	Norðurárdalsvegur (528)	Norðurá við Fornahvamm	9,02	890	1490	471	2.930

9.2 A.2 Data table from Fridleifur, ICERA

Summary table for Icelandic road tunnels, traffic (AADT), and forecasts, obtained from Fridleifur at ICERA Akureyri.

Yfirlitstafla fyrir jarðgöng, umferð og spár

Nafn ganga	Vegnr.	Fyrsta heila ár eftir opnun	Viðmiðunar ár	Umferðarspá fyrir viðmiðunarár			Raunumferð á viðmiðunarári	Hlutfallslegur munur á spá og raunumferð		
				lág	Há	Líklegast		lág %	há %	Líklegast %
Strákagöng	76-10	1968	-	var ekki gerð						-
Oddskarðsgöng	92-10	1978	-	var ekki gerð						-
Múlagöng	82-06	1991	**2010**	300	400	**350**	453	-51%	-13%	**29,4%**
Breiðadals og Botnsheiðargöng	60-46/47 og 65-01	1997	**2000**	Ekki gerð		**588**	637			**8,3%**
Hvalfjarðargöng	1-f8	1999	**1999**	1460	3085	**1752**	2869	-97%	7%	**63,8%**
Fáskrúðsfjarðargöng	96-04	2006	**2010**	321	365	**343**	561	-75%	-54%	**63,6%**
Almannaskarðsgöng	1-v5	2006	**2010**	323	387	**355**	311	4%	20%	**-12,4%**
Bolungarvíkurgöng	61-45	2011	**2011**	Ekki gerð		**810**	797			**-1,6%**
Héðinsfjarðargöng	76-15	2011	**2011**	200	500	**350**	548	-174%	-10%	**56,6%**

9.3 A.3 INTP, aims and objectives

Icelandic National Transport Plan (INTP). Statement of aims and objectives.

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Eftirfarandi eru framkvæmdamarkmið vegamála:

1. Byggja upp grunnnet stofnvega sem skilgreint er í samgönguáætlun með fullu burðarþoli og bundnu slitlagi.
2. Endurbyggja/breikka einbreiða kafla með bundnu slitlagi þar sem bundið slitlag var lagt á gamla vegarkafla án endurbóta og sem reynst hafa hættulegir, svo og kafla þar sem vegferill er ónothæfur.
3. Breikka vegi þar sem umferð er svo mikil að flutningsgeta og umferðaröryggi verða vandamál. Aðgreina akstursstefnur eftir atvikum.
4. Grafa jarðgöng í samræmi við jarðgangaáætlun.
5. Útrýma einbreiðum brúm á vegum með umferð yfir 200 ÁDU.
6. Lagfæra vegi á hættulegum stöðum í samræmi við sérstaka áætlun.
7. Hefja endurbætur á helstu stofnvegum á hálendi. Markmið endurbótanna er að koma þessum vegum í „gott horf" samkvæmt nánari skilgreiningu.
8. Girða meðfram vegum þar sem þörf krefur og mæla fyrir um.
9. Byggja/endurbæta vegi og brýr á höfuðborgarsvæðinu í þeim mæli að umferðarástand versni ekki frá því sem er nú, sbr. markmið sveitarstjórnanna í svæðisskipulagi höfuðborgarsvæðisins.

Áætluð fjárþörf a.m.k. næstu 20 árin og fjárveitingar samkvæmt samgönguáætlun 2011–2022 til að ná framangreindum markmiðum eru sýndar í eftirfarandi töflu:

Tafla 15. Áætluð fjárþörf til 2030+ til að ná framkvæmdamarkmiðum og fjárveitingar til 2022.

	Fjárþörf til 2030+ millj. kr.	**1. tímabil** 2011–2014 millj. kr.	**2. tímabil** 2015–2018 millj. kr.	**3. tímabil** 2019–2022 millj. kr.	**Samtals** 2011–2022 millj. kr.
Stofnvegir	254.000	13.233	15.157	24.323	52.713
Tengivegir	38.000	4.146	3.198	2.450	9.794
Jarðgöng	108.000	95	10.700	12.700	23.495
Samtals	**400.000**	**17.474**	**29.055**	**39.473**	**86.002**

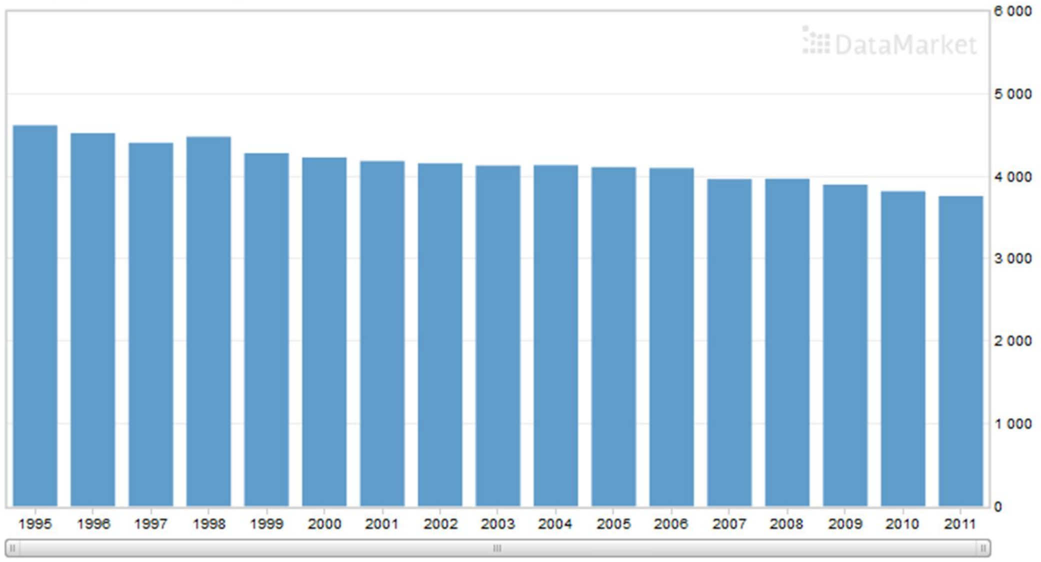
Hluti kostnaðar við jarðgöng er vegna jarðganga þar sem tekin verða veggjöld eins og við Vaðlaheiðargöng og tvöföldun Hvalfjarðarganga.

9.4 A.4 Population graph, Isafjarðarbær

The following data graph shows the population trend, for the municipality of Ísafjarðarbær, located in northwestern Iceland. Source, *Datamarket* and *Samband Íslenskra sveitarfélaga*.

Íbúafjöldi sveitarfélaga 2011

Einingar: Fjöldi **Svæði:** 4200 Ísafjarðarbær



Heimildir: Samband íslenskra sveitarfélaga

Leyfi: Íbúafjöldi sveitarfélaga 2011
Þér er heimilt að afrita og endurdreifa gögnunum svo lengi sem gagnaveitu (Samband íslenskra sveitarfélaga) og DataMarket er skýrt getið í heimildum um uppruna gagnanna.

Íbúafjöldi sveitarfélaga 2011

Einingar: Fjöldi **Svæði:** 4200 Ísafjarðarbær

Ar	4200 Isafjarðarbær
1995	4 615
1996	4 519
1997	4 403
1998	4 476
1999	4 278
2000	4 225
2001	4 182
2002	4 153
2003	4 127
2004	4 133
2005	4 109
2006	4 098
2007	3 963
2008	3 968
2009	3 897
2010	3 816
2011	3 758

Heimildir: Samband íslenskra sveitarfélaga

Leyfi: Íbúafjöldi sveitarfélaga 2011