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Business Cases for realization and deployment of ITS, with focus on Cooperative Services

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Master of Science in Communication Technology
Submission date: September 2012
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Abstract

There is an increasingly interest for implementation of Intelligent Transportation Systems around the world, and in some countries it is already successfully deployed and up and running. The reason for the desire for an ITS network is known user and environmental benefits, which in broad terms include safer road usage, efficiency and being environmental friendly.

ITS is defined as a set of many advanced applications which aim at providing innovative services relating to different modes of traffic and transport management. In Norway, a technical solution for adapting ITS is already established after years with research and development, but there is a main factor holding back implementation; the question of who is financially responsible and whether it will benefit, or not, the organization that takes the responsibility.

This thesis discusses the questions listed above through a cost benefit analysis and business models based on case studies formed by suggested ITS services. In order to generate business models it was necessary with an overview of interrelationships and responsibilities between various roles and stakeholders. Together with roles and stakeholders, user benefits and needs were posted and used in the case study and cost benefit analysis.

Further, after addressing necessary terms and conditions, three case studies are suggested, formed by a special ITS service and the geographical area of Trondheim. These case studies include a model and a cost and revenue analysis used as subject to the cost and benefit analysis in the following chapter. In the cost benefit analysis the three different alternatives are compared against each other to find the most beneficial solution. The result from the cost and benefit analysis is in the end used as groundwork for the proposed business model, with elements for a ITS solution's value proposition, infrastructure, customers and finances.

Sammendrag

Det er en økende interesse for gjennomføring av Intelligente Transportsystemer rundt om i verden, og i noen land er det allerede vellykket implementert og i drift. Grunnen bak et stadig ønske om realisering av et ITS nettverk er bruker- og miljømessig fordeler som i bred grad inkluderer tryggere veibruk, effektivitet og miljøvennlighet.

ITS er definert som et sett med avanserte applikasjoner som tar sikte på å tilby innovative tjenester relatert til forskjellige modeller for trafikk og transport administrasjon. I Norge har det etter flere år med forskning blitt utarbeidet en teknisk løsning for realisering av ITS, men implementering holdes tilbake av en viktig faktor; nemlig spørsmålet om hvem som skal ta det finansielle ansvaret og hvorvidt det vil gi nytte for organisasjonen som tar på seg ansvaret.

Denne masteroppgaven diskuterer spørsmålet presentert ovenfor ved hjelp av kost nytte analyse og foretningsmodeller basert på casestudier av gitte ITS tjenester. For å generere foretningsmodeller var det nødvendig med en oversikt av innbyrdes forhold og ansvar mellom forskjellige roller og aktører. I tilegg til roller og aktører ble brukernytte og -behov adressert og brukt i casestudiene og i kost nytte analysen.

Videre, etter å ha listet opp nødvendige krav ble tre case studier foreslått og formet av gitte ITS tjenester og Trondheim som geografisk område. Disse casestudiene inkluderer en modell og en kost og inntekts analyse som i senere kapitler blir brukt som utgangspunkt for kost nytte analyser. I kost nytte analysen blir de tre ulike alternativene sammenlignet med hverandre for å finne den løsningen som gir størst nytteverdi. Resultatet av kost nytte analysen blir til slutt brukt som grunnlag for foretningsmodellen som blir foreslått, og inneholder elementer for en ITS løsnings verdimålsetninger, infrastruktur, kundebase og økonomi.

Preface

This thesis is submitted to the Norwegian University of Science and Technology (NTNU) for partial fulfilment of the requirements for the degree of master of science.

This work has been performed at the Department of Telematics, NTNU, Trondheim, with Steinar Andresen as professor and with Erik Olsen at Statens Vegvesen as supervisor.

I would like to thank my supervisor Eirik Olsen for his valuable input and frequently feedback. I appreciate his enthusiasm and that he has been a driving force throughout the project.

I would also like to thank my professor Steinar Andresen, Runar Søraasen and Morten Welde, for their insightful contribution, and to send them my appreciation of their valuable time.

Finally I would like to thank my family and friends, and the girls at my office, Silje, Maja, Julianne and Nina for their motivation and support.

Oslo, September 2012

Line Bomnes Valåmo

Abbreviations

AAA Authentication, Authorization, and Accounting

CAN Controller Access Network

CapEx Capital Expenditures

CN Celluar Network

CO2 Carbon Dioxide

DSRC Dedicated Short-Range Communication

ETSI the European Telecommunication Standards Institute

EU European Union

E39 European Route number 39

E6 European Route number 6

GHz Gigahertz

GNSS Global Navigation Satellite System

HW Hardware

ITS Intelligent Transportation Systems

LAN Local Area Network

LDM Local Dynamic Map

MAC Media Access Control

NOK Norwegian Kroners

OBU On Board Unit

OpEx Operational Expenditures

SW Software

V2I Vehicle to Ifrastructure

V2V Vehicle To Vehicle

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Chapter 1

Introduction

Deployment and realization of an ITS network is in severe interest of professional communities and national road authorities worldwide. In some countries ITS is already successfully up and running, partially or fully deployed. The most important reason for a desired ITS is user and environmental benefits in terms of safer road usage, efficiency and being environmental friendly.

Intelligent Transport Systems are defined as a set of many advanced applications which aim at providing innovative services relating to different modes of traffic and transport management, as well as fulfilling user needs by enabling better information and a safer,smarter and more coordinated use of transport networks.

As a result of increased population growth, urbanization, motorization and changes in density of the population; traffic congestion is increasing all around the world. Congestion rises problems such as reduced efficiency of transportation infrastructure, longer travel times, pollution and fuel consumption. ITS provides a coordination of new technology for simulation, real-time control and communication network, and is hence a solution for problems caused by congestion.

1.1 Motivation

After years with research and development, a technical solution for adapting ITS is already in place, but there is a main factor holding back implementation; the question of who is financially responsible and whether it will benefit, or not, the organization who takes that responsibility.

A major impact on the process of deciding who is financially responsible is the definition of roles and stakeholders. The study of the organisational architecture supports an analysis of the overall ”non-technical” aspects of ITS and it provides an overview of the interrelationships and responsibilities of various actors. This helps to find the level of involvement of each actor and to ensure some key factors;

- The construction of an overall sustainable business
- Ensuring that functionalities required by the system are met
- The identification of and addressing legal issues and risks resulting from relationships between different actors, and to clearly refine boundaries of responsibility

It is also useful to address some vital issues such as public-private partnership, the level and scope of public involvement, and the participation level and opportunities for vehicle makers.

User needs and benefit are crucial in the decision whether to introduce an ITS solution or not. This will be the main drivers for implementing the system, but might as well post critical issues and even showstoppers. As stated earlier the most important reason for a desired ITS is user and environmental benefits in terms of safer road usage, efficiency and being environmental friendly.

User benefits are together with financial benefits the clear way to estimate whether or not to invest in an ITS solution. And it is crucial for an organization to be able to calculate these benefits when deciding to take part in the introduction of such a system.

The Trondheim area is subject to a test-case of an ITS solution in Norway, and is therefore an easy choice as a case study.

1.2 Scope

This thesis will discuss the benefits for the organization willing to invest in and be responsible for the realization of an ITS solution, as well as looking at who should be responsible for the different actions and in the end form a business case based on the information gathered throughout the previous chapters.

The first part of this thesis will present the roles and stakeholders essential for the introduction of a ITS solution, and also looking at user benefits and needs. This information is vital for later sections; business cases is created based on roles and cost and benefit analysis are calculated from, among others, measured benefits.

In order to determine if and by whom ITS should be implemented, necessary use cases based on specific services and at a defined geographical area will be presented. These use cases are models for the cost and benefit analysis formed in chapter 5, which present calculations on cost, revenue, profit and benefits. All of the components listed in this section will together form an business case for both the specific case and services in this study and for a more general case based on the experience from the case study.

1.3 Limitations in Scope

Since there was only a limited time available, we had to put some limitations on the scope for this thesis.

In agreement with supervisors, only one core service was considered as a case study. This service on the other hand,enables opportunities for other ITS services.

Several assumptions considering the cost and benefit analysis had to be made in order to be able to do calculations. These assumptions are posted in subsection 3.2.1.2, 3.4.1.3 and 3.6.1.3.

1.4 Methodology

1.4.1 Use Cases

Three different use cases based on the same service is generated and discussed. Each use case include a model presenting charges, enforcement, and assumptions, and a cost and revenue analysis.

1.4.2 Cost and Benefit Analysis

In order to measure the benefit of introducing an ITS solution, a cost benefit analysis was created in each of the tree use cases. A cost benefit analysis is used to evaluate the total expected cost of a project compared to the total anticipated benefits for determining whether the proposed solution is worthwhile for a company or organisation [2]. If the result of this method shows that the overall benefits associated with the suggested solution outweigh the incurrent costs, it is expected of the company or organisation to follow through with the implementation.

Inputs in the cost benefit analysis is expected costs, revenue stream, quantifiable benefits and non-quantifiable benefits. The three last ones are added together and then subtracted from the first one to determine whether the positive benefits outweigh the negative costs.

1.4.3 Business model

The business model is based on Alexander Osterwalders framework where the Business Model Canvas will be used as a template. The business model is formed by elements describing a firm's value proposition, infrastructure, customers and finances.

1.5 Document Structure

The structure of the following chapters in this thesis is listed under.

Chapter 2 - Roles and Stakeholders presents the various roles and stakeholders essential in the realization of an ITS solution.

Chapter 3 - User Needs and Benefits looks at user benefits and needs important for the total benefit level of an ITS solution.

Chapter 4 - Use Cases suggests 3 different use cases based on the same service but with different realization strategies.

Chapter 5 - Cost and Benefit Analysis presents and compares cost and benefit analysis, in terms of cost, revenue, profit and benefits for each of the use cases in Chapter 4.

Chapter 6 - Business Model describes a business model, based on A. Osterwalders framework for the introduction of an ITS solution.

Chapter 7 - Conclusion and Further Work concludes the thesis.

Chapter 2

Roles and Stakeholders

This chapter will present a set of roles needed for a ITS implementation, i.e the organisational architecture. These roles are profiled in means of motivations, commercial, institutional and legal responsibilities, and related activities.

2.1 Organisational Architecture

The organisational architecture is, first of all, a support tool for analysis of potential business models[30]. It provides an overview of required functions and interrelationships among the different actors, which allows the value chain to be identified, and in general the organisational complexity of each proposed solution.

It is also,for the same reason, functional when it comes to studying deployment scenarios, as well as analysis of legal prospect. In the latter case, particularly to define the legal responsibilities in interactions between stakeholders that are governed by contracts or general agreements.

This type of study is especially necessary for a cooperative system since the number of stakeholders are particularly high, and because it may hide implications which can be addressed and resolved in advance only with a targeted analysis.

A role is defined as a set of homogeneous functionalities that are necessary to be performed in order to realize the system. The same entity can cover one or more roles to a specific implementation. The relationships among all proposed roles are specified in figure 2.1.

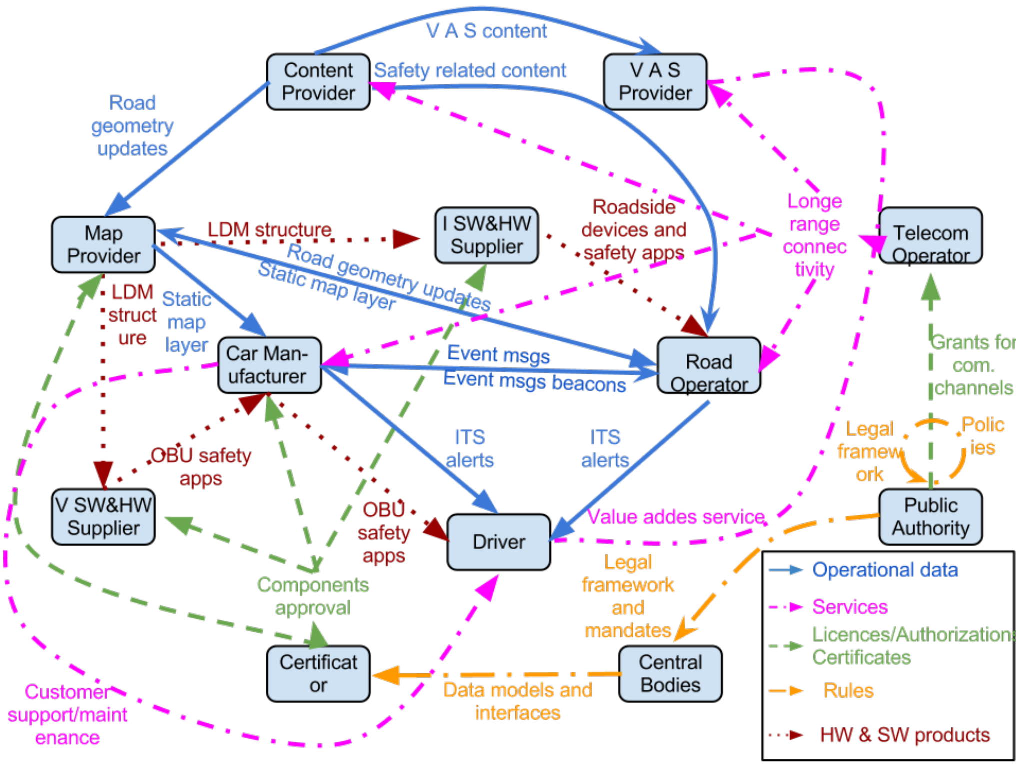

Figure 2.1: Four types of relationships among roles are presented with different colours. Figure based on [30], and widely explained in the following sections.

2.2 Public Authority

2.2.1 Functions and Responsibilities

It is commonly known that the realisation of a successful European standard platform for V2X (Vehicle to either Vehicle or Infrastructure) cooperative systems can not be reached without a great involvement of public authorities, although a few important commercial cases of widespread V2I-communication-based systems currently on the market were initiated by private players[8].

It is also recognised that in the implementation of an European cooperative system the action of the Public Authorities of the member states shall be coordinated centrally at EU level[30]. This key role as a policy maker at a supranational level should be focused at easing the process of introduction of cooperative systems, gradually eliminate barriers to interoperability. Public authorities in each member state are responsible for the transport network at both national and local level, and have an interest in safety of travellers as a whole. Thus the role of national public authorities will be actively participation in the deployment of cooperative systems, through realization of the institutional and economic initiatives outlined at EU level in order to trigger and achieve its implementation at a national level.

The economic commitment by the public authority differ, in means and at what level of government(local or national) it is being achieved, between each member state in Europe. Regarding institutional initiatives on a national or local level, public authorities are responsible for determining structure of politics and agreements that provide long-term stability of the system. This should be determined with respect to business risk, technical and national political problems due to introduction of certain mechanisms, and with the consideration that long-term stability might be weakened by the revenue since visions and level of involvement in road safety differ between governments.

Public-private partnerships are known to be a strong driving force behind enabling large scale deployment of cooperative systems. Collaboration between public authorities and the business sector is important in both implementation of vehicle and roadside infrastructure and for sharing financial investments and returns. This dual role, economic and institutional, is entitled by the benefit road safety brings to the society; governments carrying the cost of accidents are, together with road users, the main beneficiaries of the road safety system and thus expected to act as main funders. In this way, governments are able to reallocate benefits on roles that would otherwise receive no advantage and hence have no reason to join in.

Another important role of the national public authority is to provide the legal means necessary to allow ITS implementation in a consistent and interoperable manner at an European level. The regulation of using cooperative systems will be a responsibility of each single member state; essentially including one or more of the following actions:

- Create administrative structures needed to establish the necessary organizational settings for specific applications (through regulations or by contract)

- Impose contractual arrangements upon parties in the chain of production and operation to combine their liability exposures to each other

- Require that data and exchange formats must comply with each other, through contracts or regulations
- Require a certain data and service quality, through contract or regulation
- Setting performance requirements for system hardware, most likely through regulation
- Modify tort and insurance law
- Change traffic rules

In this context, public authority should also establish enforcement strategies, in means to guarantee a safe and secure use of the system, i.e to ensure that the vehicle infrastructure system work effectively and bogus operators are excluded from the system

As for legal framework, public authorities must ensure that usage of devices specified for the system are allowed by the national security and public health rules. Moreover, local authorities will issue the necessary administrative procedures to allow installation of ITS subsystems and confirm that their operation is in compliance with the standards for the local jurisdiction. Additionally, public authority is in charge of providing grants for communication channels and frequency bands, where needed for implementation of a cooperative system.

2.2.2 Relationships

The public authority will, in most cases, be a legislature acting under its statutory powers, where relations are primarily law-giver to those who must follow the law. It is unlikely to be a significant deal of circumstances in which contracts are necessary, except in cases regarding contracts to provide long-range communication where licenses are subject to certain conditions, which can be negotiated on a case by case basis.

An important relationship for public authorities follows from the required institutional collaboration with key agencies to ensure consistency between standards and local laws.

At last, when providing economic-financial support for implementation of the cooperative systems, public authorities have to be in negotiating relationships with the commercial parties that have an interest in the market.

2.2.3 Stakeholders

Stakeholders involved in the public authority role is listed underneath.

- National Ministries of Transport (acting under the EU directives)
- Local authorities which are able to issue rules on traffic circulation and / or grants for communication channels
- National communications licensing agencies

Entities acting as public authorities may also play a variety of other roles, for instance road operator or content provider.

2.3 Central Body

2.3.1 Functions and Responsibilities

There are two main categories of tasks which need to be completed, excluding those for economic-financial support, for the deployment of ITS at an European level; functions at legislative level and those for pushing and coordinating standardization[2]. While the responsibility of the first task is given to the public authority, the latter is delegated by EU to external organisations by issuing specific mandates. In this thesis, the presented role is named central body.

Concerning system architecture, protocols and transmission formats, ETSI - The European Telecommunications Standards Institute[9], published in 2010 the following basic standards and technical specifications on EU mandate:

- A basic set of application requirements, including standards for cooperative awareness messages and decentralized environmental notification messages
- Standards and specifications for the ITS architecture
- GeoNetworking specifications for media-independent and -dependent functions to be able to deploy the protocol for 5,9 GHz and other media
- Profile standards for the physical/MAC layer in the architecture
- Threat vulnerability and risk analysis on security

The central bodies include other types of entities such as organisations representing special operational components of ITS, in its role of standardization of technologies[30].

2.3.2 Relationships

The central bodies receive mandates from, and has hence a relationship to, the EU for definition of standards ensuring interoperability and security of cooperative systems.

Relationships between standardization institutions and other player include negotiation at a strategic level, in order to achieve standards shared between the parties. These relationships concern the majority of operational roles of future cooperative systems, in form of industrial associations where collaboration between the different entities result in publication of standards, guidelines, frameworks for system development and certification, harmonization of data and exchange formats.

2.3.3 Stakeholders

Stakeholders involved in the central body role is:

- Standardization entities at European level
- Other international standardization organisation
- Organisations representing special industrial interests
- Industrial driven EU initiatives

2.4 Road Operator

2.4.1 Function and Responsibilities

A road operator is in charge of the management of a certain portion of the road network, and the role includes all activities needed to ensure a safe, correct and efficient use of the road infrastructure[30].

The rode operator role is involved in the V2I part in implementation of ITS, where they invest in infrastructure motivated by preventing accidents and hence reduce cost of incident management. It is highly desirable with participation of road operators in deployment of cooperative systems; a road operators investment in infrastructure enables deployment of vehicle to infrastructure communication systems, which benefits the society as a whole. The roadside system will often be operated by the road operator of the specific network, but it can also be outsourced to another organisation, i.e a road operator might involve a third party subcontractor to provide and run the roadside system.

Within the role as a road operator, ownership of the roadside devices is also included. The road operator is therefore in charge of purchasing equipment and software needed to run ITS applications, installation of necessary facilities and related maintenance. Additionally, the road operator has the legal responsibility for the safety information displayed to the road users of its network. In some cases, the road operator needs to forward safety related content available at the control centre to the roadside unit. The road operator might also be asked to provide, periodically or event based, the network geometry constant update for the static map layer corrections, to the map provider.

2.4.2 Relationships

The case where the road operator act as the organisation hosting roadside installations requires commercial agreements with suppliers, certification entities and the telecom operators.

The relationship between the road operator and the driver might undergo some form of regulation at a portion of the road network. Since there probably will not be a contract between the driver and the road operator, the driver may have to accept terms and conditions, in form of regulations and rules established by the road user (by powers of delegated legislation), as a precondition before using the road.

A cooperation between road operators and public authorities is desired at different geographical levels to identify critical areas or road network black spots[1], where an ITS V2I would be especially desired. Different road operators should also cooperate to ensure similar services and equal information to road users.

2.4.3 Stakeholders

Stakeholders involved in the road operator role are:

[1] black spot is defined a part or an exact location on the road network infrastructure where serious road injuries or casualties occurs for at least 2 times a year for a time period of the recent 3 years[?]

- Motorway operators
- Bridge and tunnel operators
- Urban road operators
- Road authorities
- Local administration authorities

2.5 Car Manufacturer

2.5.1 Functions and Responsibilities

The car manufacturer role is constitute the responsibility of manufacturing vehicles with an installed cooperative system, either as car embedded or as an aftermarket product.

There are two possibilities for instalment of ITS On Board Units (OBUs); the most probable option, in which the OBU functions will be performed by a native system, and a second alternative where the OBU may be supplied as an aftermarket product, and thus by an entity which is not the vehicle manufacturer. In the first case, the car manufacturer is responsible for instalment, while in the latter, a third party supplier of the OBU comes into play. In both options, the fundamental responsibility of the car manufacturer is management of data from vehicle system controls, such as engine, movement and devices, and on board detection systems; radar, cameras and etc., addressed to the OBU through the open platform.

Because of this functionality, the car manufacturer gets responsibilities of a business nature; the attractiveness of vehicles equipped with an telematic platform is not only linked to cooperative systems for safety, but also by value added services which will be offered the driver through the standard platform. These types of services might be dynamic navigation services, business services, assistance, support to fleet and freight, emergency and so on, allof them possible subjects to competition with suppliers of portable devices for navigation.

At a strategic level, the role of the car manufacturer is essential for development of cooperative systems, which makes its involvement in deploying process crucial. The car manufacturer role is also essential when evolving systems towards haptic cooperative safety applications, such as active braking assistance.

2.5.2 Relationships

Manufacturers producing vehicles which are ready to host OBU will need certification of compliance of their vehicle platform with ITS specifications, including performance of detection systems, network CAN-bus and interfaces.

At a strategic and deployment level, car manufacturers promote and support actions for development, standardization and deployment of cooperative systems through their own commercial purposes, both individually and through associations.

2.5.3 Stakeholders

Stakeholders involved in the car manufacturer role are:

- Car manufacturers
- Van and truck manufacturers
- Motorcycle manufacturers

2.6 Map Provider

2.6.1 Functions and Responsibilities

The map provider is the Local Dynamic Map (LDM) component supplier for the ITS platform, including the structure of the software database and characteristics of data on the road network, forming the static layer of the map[30]. A map provider is responsible for producing the framework of the LDM database software, which implements data models and interfaces in consistence with standard specifications issued by the central bodies. It further holds the responsibility for providing geo-referenced data relative to certain areas, by collecting, processing and distributing them to the LDM static layer, where the detail level and features are established by the system specifications.

Both the geo-referenced information and the database software platform are delivered to the organisations responsible for manufacturing the OBU and roadside infrastructure. But, on the other hand, both LDM structure and the static map layer content must periodically be updated under the map providers responsibility. In order to ensure an efficient update, road operators and content providers may be asked to formally commit with the map provider. When updating devices already operating on vehicles, the content will be provided to the organisation holding the contract with the driver, while on the infrastructure side, updates will be delivered to the road operator.

There is a risk for vehicles running into accidents caused by a wrong alarm because of a non-updated map content. One option for avoiding this would be to prevent automatically usage of the system when its not properly updated, a second option would be to channel downloaded content of updates via long range communication and for it to be triggered automatically.

To avoid misleading warnings when performing planned initiatives on the road geometry, procedures should be optimized in order to minimize the time needed, or to at least put the system in a down state. This issue display the great need of involving road operator when deploying a cooperative system.

2.6.2 Relationships

The activity of map providers is ruled by contractual agreements with the appropriate entities, when first issuing the map product and for the following releases of periodically updates.

Sales contract will be needed when providing and periodically updating LDM structure and static map layer to the providers of vehicle and infrastructure, software and hardware. Also agreements with road operators and content providers will be necessary to define the acquisition of information about the road network, including the frequency of updates and and physical procedure of data exchange. Delivering this type of information might be regulated by formal responsibilities of the road operator.

Finally, the map producer must apply for certification of his product in compliance with procedures established by the government.

2.6.3 Stakeholders

Stakeholders involved in the map provider role are:

- Companies producing digital maps for navigation and location based services

2.7 Vehicle Software and Hardware Supplier

2.7.1 Functions and Responsibilities

The vehicle HW and SW supplier role has the responsibilities typical of the providers of systems, equipments and applications needed to run ITS functionalities on board in vehicles, i.e the software applications and the hardware device forming the OBU[30]. Entities of this role will manufacture and deliver the OBU to organisations responsible for delivering ITS functionalities to drivers; car manufacturers if its the embedded solution and aftermarket suppliers or installers for the aftermarket solution.

Developing OBU components require a strong collaboration among the various technological roles at the product development stage. In the final industrial product most of the functions will probably be implemented in one common processor, which imply a central role of the electronic supplier manufacturing the integrated circuit.

At a strategic level, electronic suppliers are vital for a successful deployment of cooperative systems since they will strongly limit the cost for cooperative devices. To trigger an effective economies of scale will be a significant commercial challenge for these companies and for the system as a unit. The major problems to be solved in the future at a strategic level are large-scale electronics integration and standardisation. The compliance of products provided along the supply chain, towards standards and regulations will be verified by private certification entities and public technical organisations (set up by the approval authority).

Additionally, on the liability level the vehicle SW and HW supplier will comply with the relevant national version of the Product Liability Directive when exposing to the public.

2.7.2 Relationships

It will be necessary with sale contracts between the vehicle HW and SW supplier and the manufacturer of the OBU device as well as the software application provider, and between first- and second-level vehicle HW and SW suppliers for provision of the final product parts. These contracts might address liability conflicts in case of an malfunctioning system.

The vehicle HW and SW supplier should also issue a sale contract with the map provider for delivery of LDM which will be hosted on their product.

And finally, vehicle HW and SW suppliers must apply for certification of their product in compliance with procedures established by the government.

2.7.3 Stakeholders

Stakeholders involved in the vehicle HW and SW supplier role are:

- Silicone suppliers
- Automotive components suppliers
- Software developers for automotive industry

2.8 Infrastructure Hardware and Software Supplier

2.8.1 Functions and Responsibilities

Functions and Responsibilities The infrastructure HW and SW supplier role has the responsibilities typical of the providers of roadside components; supplying roadside units, sensors, communication systems, ITS software platform and safety applications, needed to run I2V ITS functionalities[30].

There are different levels of supply chain in the infrastructure HW and SW role; from provision of basic piece parts to delivery of a running system on some portions of the road network to managing entities.

The system and installations shall meet requirements from the road operator, be consistent with standards defined by central bodies and respect regulations for approval of automatic components, which are stated by the national approval authorities.The compliance of products provided along the supply chain, towards standards and regulations will be verified by private certification entities and public technical organisations (set up by the approval authority).

2.8.2 Relationships

At first level, it will be necessary with sale contracts between companies installing and delivering a running system on some portions of the road network and the road operator. At a second level, companies producing and installing the piece parts, where the contracts should address liability conflicts in case of an malfunctioning system.

The first level installers of the system should also issue a sale contract with the map provider for delivery of LDM which will be hosted on their product.

Infrastructure HW and SW suppliers must apply for certification of their product in compliance with procedures established by the government. And at a local level, suppliers must ensure that their operations are complying with the laws in force, by issuing the needed administrative procedures with the relevant authorities for approval to install ITS subsystems.

2.8.3 Stakeholders

Stakeholders involved in the vehicle HW and SW supplier role are:

- Manufacturers of roadside devices
- Suppliers of telematic systems for road traffic management
- Software developers for roadside devices and systems

2.9 Certification Provider

2.9.1 Functions and Responsibilities

The certification provider role has the responsibility as the entities applying the necessary procedures in order to confirm and certify that ITS installations is consistent with regulations for approval of automated components, stated by the national approval authorities, and on standards defined by central bodies. The certification will include both components for roadside V2I applications and those which will form the OBU.

Since cooperative systems introduce new issues compared to autonomous advanced driver assistance systems, the approval of components in order to allow their use on European road will require action at a policy level. Firstly, it will be necessary to regulate verification of V2I and V2V communication links, and secondly to clarify (for data processing) where and how to address the mechanisms of approval[24].

In order to ensure a safe and efficient provision of ITS functions throughout Europe, mechanisms for approvement of roadside equipment and OBU should be in conformity between the different member states.

2.9.2 Relationships

All roles that may be subject to submitting products or services to the certification provider is listed under.

- Vehicle and infrastructure hardware and software suppliers, for devices, the ITS software platform and its applications, and communication links
- Map providers, for LDM, where the subjects for certifications are the database structure and the data upgrades
- Car manufacturers, for the open platform, if the aftermarket option for instalment of OBU will prove to be viable
- Car manufacturers and road operators, for the running OBU and roadside infrastructure as a whole

2.9.3 Stakeholders

Stakeholders involved in the certification provider role are:

- Technical bodies of public approval authorities
- Private certification entities

2.10 Content Provider

2.10.1 Functions and Responsibility

The content provider role is responsible for supplying the system with information coming from sources that are not part of the ITS installation or infrastructure[30].

The provided information is either safety-related, in case it is required by certain ITS applications, or non-safety related content for value-added services. In the latter case, The content is addressed to drivers through the ITS platform by the value added service providers. Safety related content is restricted to a few ITS use cases, but it could raise many others with a future broad deployment of the system.

Another type of content expected is additional services offered to the subscriber in order to increase attractiveness of the overall service. In this case, the content provider is functioning as a subcontractor of the value added service provider in the supply chain of additional services, which implies that there is no direct relationship between between end user and content provider.

When implementing the data exchange, necessary technical activities will require interaction between the content provider and other roles, i.e value added service providers or road operators. And it seems unlikely that content providers will be permitted to directly deliver safety related data to vehicles.

To guarantee consistency with the system, the process of attainment of external data should be properly regulated. This would involve; validation of data source and definition of communication links, the necessary format inversions and procedures for data attainment by the roadside infrastructure. Some form of approval for this process should be performed, which may involve certification entities.

Another possible category of content from external actors is information on road geometry, which is necessary for a constant update of the LDMs static map layer in order to comply with the actual network.

2.10.2 Relationships

Supply contracts will be used to regulate the relationship between content producers and the receiver. Content addressed to suppliers of value added services will not involve a safety factor, but safety related content designed for safety applications on the other hand, will establish needs for boundaries of legal responsibility of parties. Boundaries for legal responsibility is necessary in order to handle possible cases of system failure, which may have a negative effect on safety of road users.

The content provider will, in the majority of cases, need to rely on a telecom operator for delivering its data to the concerned parties.

2.10.3 Stakeholders

Stakeholders involved in the content provider role are; for safety related content provided to ITS applications:

- National governmental organisations
- Road operators
- Roadside assistance services
- Civil defence

- Weather institutes
- Emergency operative centres

For provision of non safety related content to value added services:

- Managers of traffic control
- Road operators
- Managers of traffic information
- Business directories
- Fleet monitoring systems
- Coordination centres for public transport

For road network geometry inputs provided for updates of static map layer:

- Local public authorities
- Road operators
- Drivers associations

2.11 Value Added Service Provider

2.11.1 Functions and Responsibilities

The value added service provider role constitute the responsibility of all entities providing drivers with V2I based services and applications through the integrated ITS platform[30]. The additional value added services are considered essential in raising the attractiveness of the pure road safety cooperative systems. Suppliers of commercial products and services may be tempted to utilize V2I and V2V communication because of the opportunity to offer services and products targeted directly on the driver. With an available open platform, public authorities and road operators might see the possibility to implement certain services at low cost and with advantages from an interoperable system.

This services would probably be offered in a pay-per-use sense and would normally be based on a variety of channels. The value added services would consider one or more of the following areas:

- Restricted access
- Traffic efficiency services

- Road pricing
- Freight and fleet management
- Parking
- Infotainment
- Commercial advices

2.11.2 Relationships

The drives purchases the service he is interested in, which implies a contract that requires a pay for usage or a lump sum payment.

Provision of services where third parties contents are required would imply a need to conclude commercial supply contracts. There is also necessary with a contractual relationship between the value added service provider and the telecom operator, in order to deliver the service to the OBU.

Standardization will be needed to define rules for enabling a safe coexistence of two different sources of information on the same unit.

2.11.3 Stakeholders

Stakeholders involved in the value added service provider role are:

- Telecom operators
- Road operators
- Companies manufacturing devices for navigation
- Fleet managers
- Car manufacturers
- Suppliers of commercial products and services

2.12 Telecom Operator

2.12.1 Functions and Responsibilities

The telecom operator role is responsible for providing wireless and wired connectivity within the application scenarios where long-range communication is needed[30]. This is most frequently needed when exchanging content between value added services providers and drivers, and more rarely in cases exchanging contents between roadside infrastructure and external content providers.

The ad-hoc networks triggered automatically for V2V and V2I communications do not require to be managed by a dedicated entity. A telecom operator is thus not required for the pure ITS cases of application, where the roles responsible for the host inside the vehicle and on infrastructure would take care of communication.

Other activities performed by the telecom operator include selling connectivity, deployment, operations and maintenance of the communication network, as well as provide access to certain telecom network capabilities, including identity management, mobile network, AAA, billing and presence[25].

2.12.2 Relationships

There will be necessary with contracts for service provision with the following roles:

- Car manufacturer
- Road operator
- Content provider
- Value added service provider

When the long-range communication involves protocols with non freely operated frequencies, the related authorities of the concerned member state will grant the relevant licenses.

2.12.3 Stakeholders

Stakeholders involved in the telecom role are:

- Telecom providers
- Internet service providers
- Road operators managing a developed communication network

2.13 End User

2.13.1 Functions and Responsibilities

An end user is defined as an actor using ITS services on a client device, i.e the OBU [20]. The end user role can be seen as either a driver; represented by the human entity controlling a licensed vehicle on the road network, or a traveller; the human entity currently using facilities of the system to help them complete or plan their journey.

These following sub-types of the stakeholder driver is used to describe ITS roles:

Private vehicle driver A person who is driving a car or a light van.

Freight vehicle driver A person driving a vehicle designed for, and with a licence to, carry freight of any kind

Emergency vehicle driver A person who is driving a vehicle designed for, and belonging to, an Emergency service

Hazardous freight vehicle drivers A person driving a vehicle designed for, and licensed to, carry hazardous freight

Public transport vehicle driver A person who is driving a vehicle licensed to carry fare-paying passengers

And there are two different types of the stakeholder traveller;

Dynamic traveller This is a human entity currently using the facilities of the system to help him complete his journey. The system might communicate with more than one human entity, where each of them are a dynamic traveller.

Static traveller This is a human entity currently using the facilities of the system to plan a journey. The system might communicate with more than one human entity, where each of them are a static traveller.

2.13.2 Relationships

Both the road operator and the car manufacturer provides the road user with operational data, in form of ITS alerts[30]. Additionally, the car manufacturer is responsible for customer support and maintenance of the drivers OBU, as well as provision of OBU safety applications. The telecom operator offer value added services, displayed through the OBU, for end users.

2.13.3 Stakeholders

Stakeholders involved in the end user role are[20]:

- Drivers
  - Private vehicle driver
  - Freight vehicle driver
  - Emergency vehicle driver
  - Hazardous freight vehicle driver
  - Public transport vehicle driver
- Traveller
  - Dynamic traveller
  - Static traveller

Chapter 3

User Needs and Benefit

This chapter will present a variety of user benefits, obtained by the introduction of an ITS solution, and general user needs in terms of main drivers, critical issues and showstoppers.

3.1 Benefits

The main driver for implementation of ITS is the provided benefit to the society as a whole. This benefit is present within a variety of categories, which will be addressed in this section.

3.1.1 Safety

A clear goal of the transportation system is to provide a safe environment for road users while still improving the performance of the system[18]. Even though the occurrence of crashes and accidents are unavoidable, ITS services aim to minimize the risk of incidence. The goal is to decrease the occurrence of crashes and, if an incident arises, to lower the likelihood of fatal accident. To quantify safety performance, effectiveness are measured by the overall fatality rate, accident rate, injury rate and dangerous goods accident rate, calculated by the amount of money insurance companies pay out.

3.1.2 Efficiency

An explicit goal of several ITS components is to reduce delay and travel time. In order to decrease delay and travel time throughput needs to be improved, which means that the system is operating closer to its theoretical capacity. To measure effectiveness and evaluate mobility, it is common to use the amount of delay and travel time and variability in travel time.

Delay may be measured in several different ways; for systems most frequently as second and minutes of delay per vehicle, for users of the system in person-hours, and for freight shipments as time past scheduled arrival time of the shipment. It may also be estimated by the experienced amount of stops for the driver before a project is deployed or implemented.

Travel time variability constitute the diversity in overall time from an origin to a destination within the system, and this measure of effectiveness applies for inter-modal freight movement as well as personal travel. Decreasing variable travel time improves reliability of estimates on arrival time, which benefits travellers and companies in planning and scheduling decisions. With an improvement in operations and incident response, and by providing information on delays, it is possible for ITS services to reduce the variability of travel time in transportation networks.

3.1.3 Vehicle Operation

An implementation of ITS can reduce operating costs and allow improvements on productivity. Some applications may save time when completing business or regulatory processes, enabling an increase in economic efficiency. In the event of public businesses, ITS alternatives for improvement of transportation may have lower cost for acquisition and life cycle compared to the traditional case. Other ITS applications will enable collection and synthesis of data which may translate into cost savings and improved performance. This cost saving and the efficiency of operations enabled by ITS services may benefit both public and private entities in more productive use of their resources. The estimate on effectiveness for vehicle operations is quantified by cost savings as a result of implementing ITS.

3.1.4 Environment

As stated by the European Commission, transport contributes with one fifth of all CO2 emissions in Europe, making a severe impact on the world's climate[7]. It is important to consider air quality and energy impacts of ITS services, especially for non attainment regions; areas of the country where the air pollution level sustainably exceed the national ambient air quality standards[?]. Environmental benefits can in most cases only be measured by use of analysis and simulations. Problems relevant to regional estimations include the little impact of individual projects and the large amount of exogenous variables, i.e weather, contribution from stationary sources, air pollution drifting from other regions into an area, and the time evolving nature of ozone pollution.

3.2 User Needs & Applications for Personal Services

The main drivers for ITS personal services are, first of all, users want their vehicle to be as connected as possible, with a rich offer of location based services[29]. Secondly, telematic services are essential in order for future improvements on road safety, traffic and transport system efficiency, and environmental sustainability to be effective.

3.2.1 Main Drivers

- Consumers want safer, cheaper and better mobility
- The concern about growing traffic congestion, mobility cost and the unreliability of the journey
- Increased awareness and concern about environmental impacts of mobility

3.2.2 Critical Issues and Showstoppers

The most critical issues for are:

- Highest quality of information will require cooperative ITS
- Protection of personal data, privacy and liability
- A significant improvement can only be delivered with V2I communication

And showstoppers may be:

- Lack of standards which implies high prices and no interoperability
- Lack of acceptance among users

3.3 User Needs & Applications for Public Services

Use of ITS public services enables car manufacturers to promote safety, economy and lower emissions, as well as promoting the possibility for OBU manufacturers to develop products connecting the vehicle to a communication network[29]. It also provides the public authorities the ability to manage mobility better, in means of less impact on the environment and greater efficiency. From the consumers perspective the focus is on precisely tailored solutions for the single drivers need which differ according to situations[19].

3.3.1 Main Drivers

- Making affordable and attractive products and services available
- The need for accurate and timely data on traffic flows, incidents and problems for the entire road network
- Quick access to, and correct information about, traffic accidents, especially if there is dangerous goods involved or a fire
- The growing pressure of congestion, environmental impact on traffic, charging and access control

3.3.2 Critical Issues and Showstoppers

Addressed critical issues for public services:

- The awareness and public vision of what ITS can do

And a showstopper might be:

- Lack of public confidence in data security and the benefit of ITS applications

3.4 User Needs & Applications for Commercial Services

The main goal with ITS commercial services is to increase road safety and security, as well as to decrease CO2 emissions benefiting the society in an environmental way[29]. There will be an increased need transport efficiency on the existing infrastructure and improved support for inter-modal and co-modality solutions. Other drivers for commercial ITS services may be; consumption behaviour (growth in Internet trade and impact on deliveries), increased demand for goods transportation, and support of users when new legislations take effect.

3.4.1 Main Drivers

- The pressure to reduce costs and to increase reliability and profitability
- There will be new regulations on truck operations, especially within cities
- A growth of new and open models for both technology and applications

3.4.2 Critical Issues and Showstoppers

Some critical issues needs to be addressed:

- All types of transport, standard as well as special, which includes dangerous goods or high value goods, need to benefit from the system
- For a significant improvement in operations it is necessary with connectivity between trucks and Internet services

And some showstoppers:

- A lack of standards and harmonization
- Driver resistance
- A lack of affordable products

Chapter 4

Use Case

This chapter will introduce three different use cases of tolling solutions in the Trondheim area. Each solution discussed in this chapter is introduced as an alternative; the 0-alternative which is today's up and running system, and the 1- and 2-alternative presenting two different solution based on new improved technology provided by the introduction of ITS.

4.1 Scenario

In Trondheim a tolling system is used to finance road infrastructure and constructions to achieve a satisfactory level of road use experience. Drivers have to pay a certain fee when they pass specified points on the road network, and each driver is hence charged based on his level of road usage.

4.2 0-Alternative

4.2.1 Model

The 0-alternative presents the current situation of payment systems for road users in Trondheim today. In Norway there's a long tradition for using road tolls to finance road construction as well as being the payment source for use of the road network, and the electronic toll collection system AutoPASS is currently deployed throughout the country[12].

AutoPASS is owned by the Norwegian Public Roads Administration and aimed towards a more efficient operation of payment services. These toll stations are automatic and with an AutoPASS agreement road users can drive straight through all marked toll stations, charged in line with the already signed agreement[1]. This is the easiest way to pay road tolls and road users get a discount (normally about 20%) within the area the contract is signed. Without an AutoPASS tag, road users passing a toll station will receive an invoice for crossing. A photograph of the vehicles identifier is captured while running through, which will then be controlled against the register of motor vehicles and the invoice is sent to the registered car owner - with no additional fee. Optionally, road users may pay the road toll within three days online or at a service station, usually a gas station close by the toll plaza.

Today's payment system use Dedicated short-range communication (DSRC), a short to medium range communication service specifically designed for automotive use[4]. DSRC is assigned the 5.8 GHz band for wireless communication and supports both public safety and private operations in V2I and V2V communication environments[11]. In the AutoPASS case, the DSRC technology is responsible for the communication between the toll station and the AutoPASS tag placed in the vehicle.

4.2.1.1 Charges

About half of the toll stations in Trondheim, mostly those situated in the central area, are part of the Environmental Package[6]. The remaining toll stations are divided into two groups based on location, namely E6 East and E39 Øysand-Thamshamn, as shown in figure 4.1. The Environmental Package is a collaboration between the city of Trondheim, Norwegian Public Roads Administration and Sør-Trøndelag County Council, with the intention to lower the traffic volume in the city center. To achieve the primary goal of reducing CO2 emissions with 20% within 2018, road users are charged 40% less to drive outside the central area.

Within the area covered by the Environmental Package road users will reduce their costs passing a toll station by 20% if they sign the AutoPASS agreement, except the toll station at Kroppan bridge which does not give discounts. For toll stations at E6 East and E39 Øysand-Thamshamn, road users get discounts depending on which type of AutoPASS agreement they've signed. Details on charges are shown in tabels 4.1, 4.2 and 4.3.

4.2.1.2 Assumptions

In order to make realistic calculations of costs and revenue some assumptions were made.

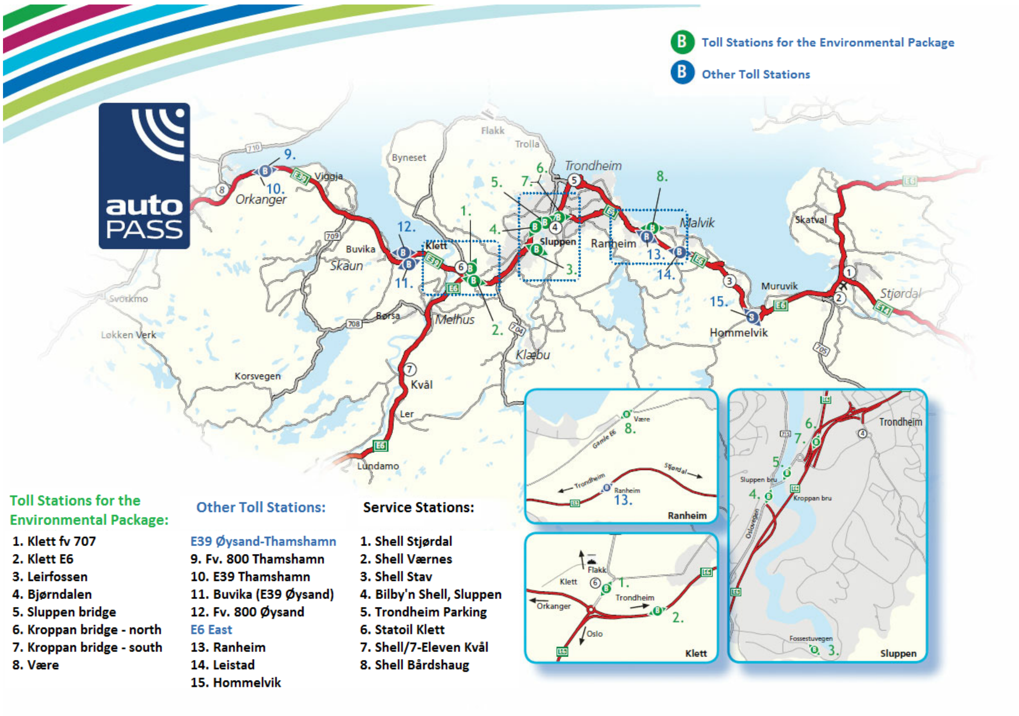

Figure 4.1: Map of all toll stations in Trondheim. Figure from [15]

Charges (NOK)	Vehicles < 3500 kg	Vehicles > 3500 kg
Ordinary tariff	10,-	20,-
Ordinary tariff with AutoPASS contract	8,-	16,-
Tariff weekdays 7am-9am and 3pm-5pm	20,-	40,-
Tariff weekdays 7am-9am and 3pm-5pm with AutoPASS contract	16,-	32,-
Tariff E6 Kroppan bridge (no discounts)	5,-	10,-

Table 4.1: Charges for passing toll stations within the Environmental Package, with and without an AutoPASS agreement. Table based on [15]

- By the population in Trondheim of 177 173 people[13], it is assumed to be an average of 3 persons per household and that 80% of all households own a car.
- The operational costs are based on numbers from 2010 with the assumption that the annual cost will be the same for the next 15 years.

Vehicles < 3500 kg	Charges (NOK) E6 Trondheim - Stjørdal	Charges (NOK) E6 Trondheim - Stjørdal	Charges (NOK) E6 Trondheim - Stjørdal	Charges (NOK) E39 Øysand - Thamshamn
Type of agreement	Ranheim	Leistad	Hommelvik	E39 and fv.800
Basic price	32,-	15,-	15,-	20,-
Prepaid 2000 NOK	22.40 (30%)	10.50 (30%)	10.50 (30%)	14.00 (30%)
Prepaid 4000 NOK	19.20 (40%)	9.00 (40%)	9.00 (40%)	12.00 (40%)
Prepaid 7000 NOK	16.00 (50%)	7.50 (50%)	7.50 (50%)	10.00 (50%)
Postpaid Private	25.60 (20%)	12.00 (20%)	12.00 (20%)	16.00 (20%)
Postpaid Business	22.40 (30%)	10.50 (30%)	10.50 (30%)	14.00 (30%)

Table 4.2: Charges for vehicles under 3500 kg passing toll stations at E6 East or E39 Øysand-Thamshamn with different types of AutoPASS agreements. Table based on [15]

Vehicles > 3500 kg	Charges (NOK) E6 Trondheim - Stjørdal	Charges (NOK) E6 Trondheim - Stjørdal	Charges (NOK) E6 Trondheim - Stjørdal	Charges (NOK) E39 Øysand - Thamshamn
Type of agreement	Ranheim	Leistad	Hommelvik	E39 and fv.800
Basic price	64,-	30,-	30,-	40,-
Prepaid 2000 NOK	44.80 (30%)	21.00 (30%)	21.00 (30%)	28.00 (30%)
Prepaid 4000 NOK	38.40 (40%)	18.00 (40%)	18.00 (40%)	24.00 (40%)
Prepaid 7000 NOK	32.00 (50%)	15.00 (50%)	15.00 (50%)	20.00 (50%)
Postpaid Private	51.20 (20%)	24.00 (20%)	24.00 (20%)	32.00 (20%)
Postpaid Business	44.80 (30%)	21.00 (30%)	21.00 (30%)	28.00 (30%)

Table 4.3: Charges for vehicles over 3500 kg passing toll stations at E6 East or E39 Øysand-Thamshamn with different types of AutoPASS agreements. Table based on [15]

- In computations of sales revenue, it is assumed that the annual growth in traffic follow the population projection found in [22], with associated calculations in Appendix A.

- In order to be able to generate an operational model, cars from districts outside of Trondheim has not been taken into account. This is the same in all three models and should therefore be a satisfying approach. Each road users driving habits (i.e how often and where they drive) are not considered, but rather the average driving path of all drivers.

4.3 Cost and Revenue Analysis of 0-Alternative

This section will present a cost and revenue analysis for the current road payment system in Trondheim.

4.3.1 Costs

The expenses for deploying, operating and maintaining today's toll station network is divided into two main categories; investment and operational costs, which in an economical sense are known respectively as Capital Expenditures and Operational Expenditures. Investment costs (CapEx) constitute expenses for AutoPass tags installed in all vehicles in Trondheim, as well as costs on equipment and plant arising from deployment of toll stations. Operational costs (OpEx), on the other hand, represent expenses related to the operation of the toll system, such as payroll, receivables, sales and other administrative expenditures.

Both CapEx and OpEx of the current system are calculated based on data from Trøndelag Bomveiselskap as [15], the company responsible for operating toll stations in Trondheim. The data gathered by this company only presents expenditures from the Environmental Package and E6 South. The estimated total cost of deploying, operating and maintaining today's system for the next 15 years is 576,204,688 NOK, with CapEx of 31,524,613 NOK and OpEx of 544,680,075 NOK. Table 4.4 and table 4.5 present, respectively, a detailed CapEx and OpEx cost structure.

Investment costs (CapEx) (NOK)	Trondheim
Equipment	15,300,000
Plant	11,500,000
AutoPASS tags for vehicles	4,724,613
Total Amount	**31,524,613**

Table 4.4: CapEx of the existing road payment system in Trondheim. Table based on [15]

4.3.2 Revenue

The revenue from the road payment system is based solely on charges from vehicles passing toll stations. There are two main cash flows; income from road users with AutoPASS agreement and from those who manually pay

Operating costs (OpEx) (NOK)	For one year	For 15 years
Salaries and social expenses		
Expensed remuneration	255,200	
National Insurance contributions	71,233	
Secretary allowance/Daily management	150,000	
Holiday pay	0	
Total amount on salaries and social expenses	**476,433**	**7,146,495**
Other sales and administrative expenses		
Money retrieval and processing	1,127,000	
Use of central system	4,883,000	
Operating toll station/Norwegian Public Roads Administration	1,181,000	
Operating agreement	23,338,000	
Extra assistance and consultant fees	857,000	
Bank fees	819,000	
Other operating expenses	249,523	
Total amount on other sales and administrative expenses	**32,454,523**	**486,817,845**
Loss on receivables	**3,381,049**	**50,715,735**
Total amount	**36,312,005**	**544,680,075**

Table 4.5: OpEx of the existing road payment system in Trondheim. Table based on [15]

each time they pass a toll station. Fees for illegal passages also contributes with a minor share of the sales revenue.

In this section as well, calculations are based on numbers from Trøndelag Bomveiselskap AS[15]. The total revenue from the Environmental Package and E6 East for 2010 are 412,416,215 NOK, with elaborations presented in table 4.6. A more explanatory income structure of the Environmental Package is shown in table 4.7. By using the numbers from 2010 as an estimated revenue for 2012 and an annual growth rate as presented in Appendix A, the total sales revenue for the next 15 years is 6,763,846,360 NOK.

4.3.3 Result

The result of the cost and revenue analysis is displayed in figure 4.2. Based on calculations of cost and revenue, the total profit for year 2012 to 2026 is 6,187,641,672 NOK.

Sales Revenue (NOK millions)	E6 East (2010)	Environmental Package (2010)	Total 2010	Total of the next 15 years
Manual road tolls	35.2	30.6	65.8	-
Subscription fee	165.2	175.4	340.6	-
Fee for illegal passages	3.9	2.1	6.0	-
Other incomes	0.0	0.0	0.0	-
Total amount	**204.3**	**208.1**	**412.4**	**6763.8**

Table 4.6: Sales revenues from today's road payment system in Trondheim. Table based on [15]

Sales revenue 2012 (NOK)	Environmental Package
Income from road tolls	
Vehicle < 3500 kg	187,786,228
Vehicle > 35000 kg	19,941,900
Total income from road tolls	**207,728,128**
Whereof additional fee	1,714,962
Other incomes	**423,326**
Total amount	**208,151,454**

Table 4.7: Specified income streams from the Environmental Package. Table based on [15]

4.3.4 Benefits

The clearest benefit from an electronic toll collection system is the revenue, and hence the profit, which is used to maintain and implement new road infrastructure. Without the income stream, there would be no money to spend on the road network, and taxpayers probably would have had to cover road infrastructure costs. Tolling is, in that sense, a fair way to finance road network costs, where road users pay after degree of usage.

Another utility is the possibility to control usage of roads and traffic flow to a certain extent. By charging higher in given areas, the traffic will as a consequence decrease and thus lower usage of the road.

4.4 1-Alternative

4.4.1 Model

The 1 alternative present a proposed next-generation solution for road toll collection in Trondheim. This proposal is a Global Navigation Satellite Sys-

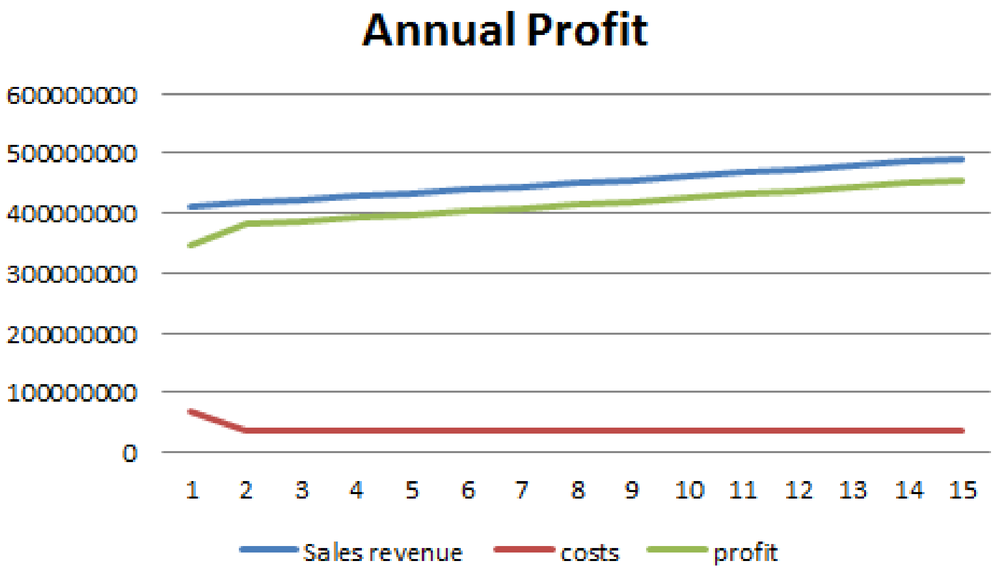

Figure 4.2: Annual profit based on costs and sales revenue from year 2012 to 2026. Figure based on[15] [22]

tems (GNSS) based tolling, which is increasingly considered as a sustainable electronic toll collection solution around the world[14]. The objective of GNSS based tolling is the same as for the current solution, to finance road infrastructure, but with an additional purpose to reduce traffic congestion, by congestion charging.

Today's road toll collection system works sufficiently, but several road operators have addressed a lack of flexibility. GNSS based tolling does not require toll stations or any fixed roadside equipment for charging, only a GNSS activated On-Board Unit (OBU), enabling the vehicle itself to report charging to a tolling back-office, using cellular Communication Networks (CN)[5]. The architecture of the system is shown in figure 4.3. In addition, a GNSS based system allows easy modification and possible extensions of the tollable areas.

The allocation of virtual toll stations, shown in figure 4.4, are basically the same as regular toll stations in the current electronic toll collection system. In the GNSS based tolling scheme, an environmental zone (equal to the Environmental Package in the 0-Alternative), highlighted with a green dashed line on the map, covers the central area of Trondheim. The environmental zone is more expensive to enter and aims at lowering the traffic and hence pollution in the city center. The allocation of an environmental zone in

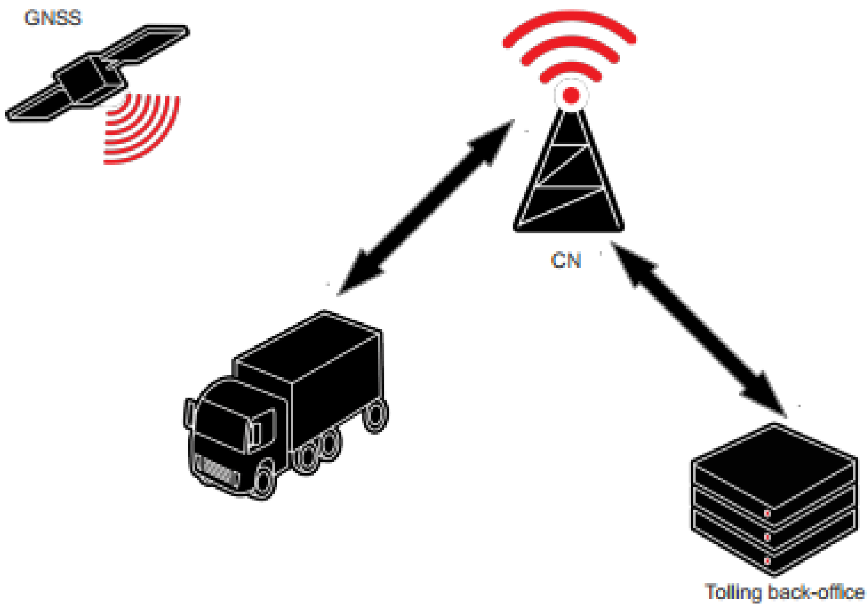

Figure 4.3: Architecture of a GNSS based tolling system. Figure from [5]

the GNSS solution as well is due to regulations in the current tolling system; it might make it more applicable for the authorities if they know that they can achieve the already existing benefits (plus additional ones) with an introduction of ITS.

In GNSS, satellites are transmitting, at a fixed frequency, their own position and a accurate time stamp, which are used by the receiver to compute its own location on earth[23]. This computation will never be exact due to uncertainty in measurement of the distance between the earth and each satellite. In certain environments the GNSS receiver has some trouble receiving signals from the satellites, such as in urban districts where several satellites may be obstructed by buildings. To improve the accuracy in calculations of the receiver's position it is possible to integrate other external information based on fixed ground infrastructure. This, however, implies a more expensive and refined OBU, and the extension will not be implemented in the case study in this thesis.

The system can support a variety of schemes for road user charging. The simplest scheme is tolling by distance where the OBU calculate the driven distance based on frequently puted positions[5]. This distance-based scheme may be overlayed with schemes charging higher within some geographical

Figure 4.4: Map of all virtual toll stations for the GNSS based tolling system. Figure based on [5],[15]

areas, or time-of-day schemes where the charge depends on the actual time. Another toll charging scheme is virtual toll stations, where the OBU records when vehicles passes defined cross sections or geo-fences, which corresponds to the current toll collection system, but without the road infrastructure. Virtual toll stations allow using a charging scheme similar to the one used today in Trondheim, with the additional possibility of computing a distance based charge.

4.4.1.1 Enforcement

An efficient enforcement scheme must be developed to ensure that road users comply to the tolling regime. The types of fraud a tolling operator might experience include consciously tampering with the OBU and electronic jamming or spoofing of GNSS signals. Due to the lack of roadside equipment in a GNSS based tolling system, ensuring that toll eligible vehicles have a proper functioning OBU installed is almost impossible without an enforcement regime.

There are two types of enforcement methods, stationary and mobile, which are accomplished by means of, respectively, stationary systems positioned in strategic locations and patrolling vehicles[5]. Stationary enforcement require roadside infrastructure placed in strategic areas where the road users can not evade by choosing a different route. The roadside equipment comprise services, functions, processes and systems to automatically check compliance with vehicles OBU.

A combination of stationary and mobile enforcement, where the latter provides a greater surprise effect since checks can be executed any place at any time, results in a proper detection system of illicit use of OBU. Toll eligible vehicles without a proper functioning OBU should be detected with a likelihood of 33%, estimated using a game theoretical concept with elaborations shown in figure 4.5. Game theory is known as the study of strategic decision making, more formally defined as a study of mathematical models of cooperation's and conflict between decision-makers who are both intelligent and rational[26]. This approach uses the enforcement game model to find a mixed strategy equilibrium, meaning both road user and operator's best response to each others actions[27]. The likelihood of compliance and enforcement in a equilibrium is found by solving the pay off equations. Based on this approach and a 24,990 NOK fine (5 times the average road toll charge per vehicle per year), the computed rate of vehicles that does not comply with the tolling regime is 0.91%.

	enforce	not enforce
comply	-fee, fee-cost	-fee, fee
not comply	-fine, fine-cost	gain, -fee

	e	(1-e)
c	-4998, 4725	-4998, 4998
(1-c)	-24990, 24717	4998, -4998

*Fee: average road toll charge
*Fine: fee for illicit use of OBU
*Gain: what a road user saves on using illicit OBU
*Cost: average enforcement cost
*e: likelihood of enforcement
*c: likelihood of compliance
*1-e: likelihood of no enforcement
*1-c: likelihood of no compliance

Pay off equations for road user:
1. e*(-4998) + (1-e)*(-4998)
2. e*(-24990) + (1-e)*(4998)

Pay off equations for toll operator:
3. c*(4725) + (1-c)*(24717)
4. c*(4998) + (1-c)*(-4998)

Equilibrium equations:
Eq.1 = Eq.2 => e=0,33
Eq.3 = Eq.4 => c=0,9909

Figure 4.5: Game theory enforcement model. Figure based on [27].

As a result of the calculations in figure 4.5 and the road map in Trondheim, it is considered appropriate with 4 stationary and 1 mobile enforcement system, the allocation of the stationary ones is shown in figure 4.6. The patrolling enforcement vehicle will operate 24 hours a day all year round.

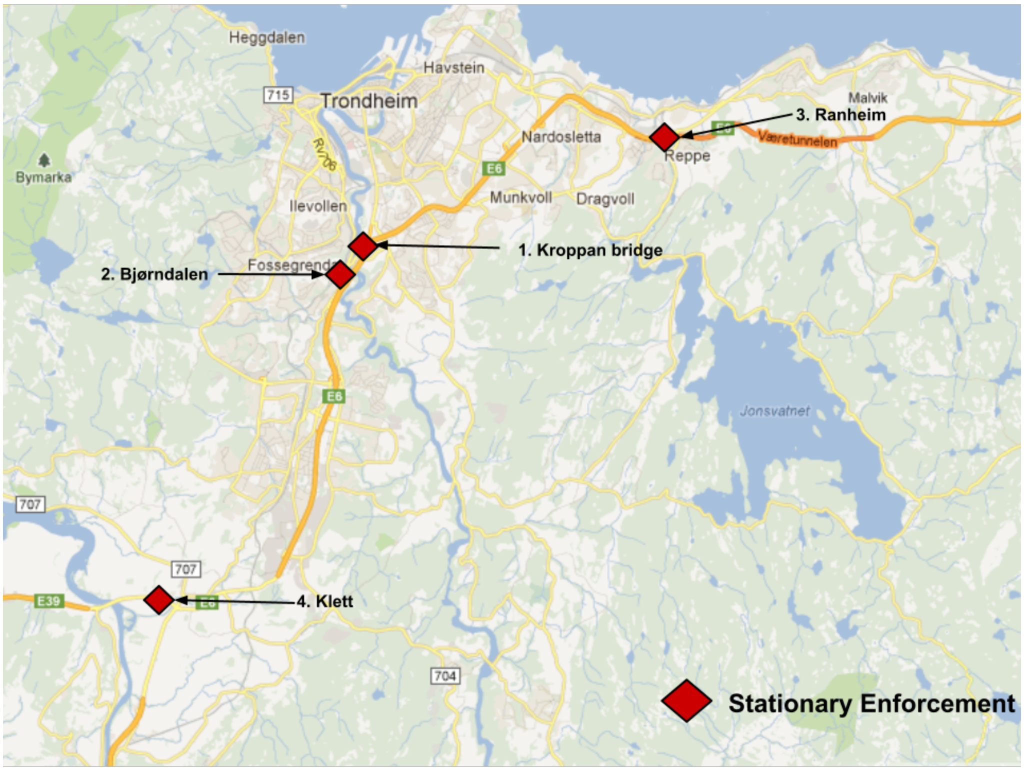

Figure 4.6: Map with locations of stationary enforcement. Figure based on [5],[15]

4.4.1.2 Charges

As for the 0-alternative, road users will be charged greater to access Trondheim central area (the Environmental Package) opposed to driving outside the city. The different charging areas are shown in figure 4.4. This pricing structure aims at the same goals as in the Environmental Package, namely to decrease the traffic load within the central area and hence reduce CO2 emissions. Road users driving outside the central area reduce their costs with approximately 40%.

The charges for passing virtual toll stations are based on the pricing from today's toll collection system and the cost and revenue analysis presented in the following subsection. Details on pricing for each virtual toll station can be seen in table 4.8.

Charges (NOK)	Vehicles < 3500 kg	Vehicles > 3500 kg
Ordinary tariff within the environmental zone	8	17
Tariff weekdays 7am-9am, 3pm-5pm within the environmental zone	17	33
Tariff E6 Kroppan bridge	5	10
Tariff Ranheim	21	42
Tariff Leistad	10	20
Tariff Hommelvik	10	20

Table 4.8: Charges for all virtual toll stations. Numbers based on [15],[22]

As for enforcement, road users not complying to the tolling regime should be detected with a certainty of 33%. Fees for illicit use of OBU need to be 5 times the average annual charge in order to be effective, hence 24,990 NOK.

4.4.1.3 Assumptions

In order to make realistic calculations of costs and revenue a great deal of assumptions had to be incorporated.

- All anticipations made in the 0-Alternative section is assumed accurate in this section as well.
- The cost, both OpEx and CapEx, of one stationary enforcement plant is assumed to be the same as for each toll station. And three stationary enforcement systems are expected to be sufficient.
- As for mobile enforcement, it is anticipated a demand of one vehicle with two officers on duty 24 hours a day, with an average salary of 220 NOK an hour.
- Charges are calculated by average charges from the current toll collection systems combined with numbers from the revenue stream. See Appendix A for elaborations.
- Fees for enforcement are computed based on numbers from [15], assuming that data from 2010 is accurate today.

4.5 Cost and Revenue Analysis of 1-Alternative

This section will present a cost and revenue analysis for the GNSS based tolling system.

4.5.1 Costs

As in the 0-alternativ, expenses for deploying, operating and maintaining a GNSS based tolling system is divided into OpEx and CapEx. CapEx, or investment costs, represent expenses on equipment and plant arising from deployment of enforcement systems (mobile and stationary), and GNSS OBU for all vehicles in Trondheim. While operational costs, OpEx, constitute expenses for salaries, receivables, sales and other administrative expenditures.

All calculations on expenditures are based on numbers from Trøndelag Bomveiselskap AS[15] and assumptions introduced in the section above. The data obtained from this company only present costs from Trondheim central area (the Environmental Zone) and E6 East. With three stationary and one mobile enforcement scheme, the total costs for a GNSS based tolling system in Trondheim for the next 15 year, is calculated to 510,093,616 NOK. Where CapEx and OpEx, respectively, constitute 83,780,311 NOK and 426,313,305 NOK of the total amount. A explanatory cost structure is presented in table 4.9.

Costs (NOK)	2012	2012-2026
CapEx		
Equipment	6800000	
Plant	5111111	
Mobile enforcement	1000000	
GNSS OBU	70869200	
Total CapEx	**83780311**	**83780311**
OpEx		
Salaries and social expenses	4330833	
Other sales and administrative expenses	20709005	
Loss on receivables	3381049	
Total OpEx	**28420887**	**426313305**
Total Amount	**112201198**	**510093616**

Table 4.9: CapEX and Opex for a GNSS based tolling system. Numbers based on [15]

4.5.2 Revenue

The computed revenue from the GNSS based tolling system is almost solely from road toll charges, but due to fees for illicit use of the GNSS OBU, enforcement regime contributes with a minor share. The revenue is calculated by numbers obtained from [22] combined with numbers from [15].

Road user charges for a GNSS based tolling system can not be higher than those from the 0-alternative, due to regulations by the government; it is not allowed to higher charges without consent if the goal is to increase profit. As a result of that fact, the income level is basically the same for GNSS tolling and the current electronic toll collection system.

The total revenue for the next 15 years from the GNSS based tolling system is 6,723,326,875 NOK, with elaborations presented in table 4.10.

Revenue (NOK)	2012	2012-2026
Road tolls		
Vehicles < 3500 kg	366130177	
Vehicles >3500 kg	38881081	
Total road tolls	**405011258**	
Whereof additional fee	419186	
Fee for illicit use of GNSS OBU	**3371526**	
Total amount	**408382784**	**6697695943**

Table 4.10: Revenue for a GNSS based tolling system. Numbers calculated from [15],[22]

4.5.3 Result

The result of the cost and revenue analysis is displayed in figure 4.7, with elaborations in Appendix A. From calculations of cost and revenue, the total profit for year 2012 to 2026 is 6,213,233,259 NOK.

4.5.4 Benefits

In this alternative, as well as the first one, the main benefit is the profit created by the revenue, used to maintain old and implement new road infrastructure. Without these money, taxpayers would supposedly have had to cover road infrastructure costs, which makes tolling a fair way of financing where users pay after consumption.

The possibility to control usage of roads and traffic flow to a certain extent is another important utility. By charging higher in given geographical areas,

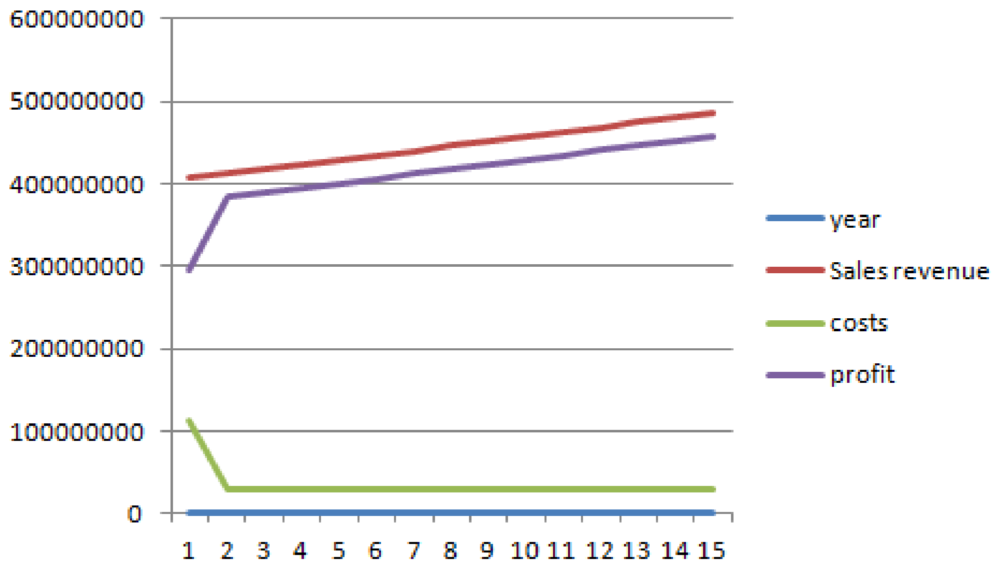

Figure 4.7: Annual profit for year 2012 to 2026. Numbers based on [5],[15]

the traffic will as a consequence decrease and thus lower usage of the road in the desired region.

Opposed to the current toll collection system, the GNSS based solution will provide less maintenance of roadside equipment, and is hence more cost efficient. Since the only road side equipment used is for enforcement, the system is way more flexible and allows a great deal of extensions and changes in the years to come.

With the flexibility of virtual toll stations, there is a huge benefit when it comes to reallocation of different zones. In case the authorities wants to extend with more zones, adjust the location of the existing ones, or do any kind of changes; it will not affect the infrastructure since it is solely based on virtual toll stations.

4.6 2-Alternative

4.6.1 Model

The 2-alternative present another GNSS based road toll collection system in Trondheim. Electronic toll collection with GNSS brings out a lot of possibilities, which is why a second solution is suggested in this section. The main objective of this second GNSS scheme is the same as for both the current solution and the first GNSS based tolling system; to finance road infrastructure and to, in some extent, reduce traffic flow.

This second GNSS based tolling system provides the same flexibility as the first one, and all technology presented in the 1-alternative apply to this system as well. A GNSS based tolling system can support a variety of schemes for road user charging, where tolling by distance and virtual toll stations were addressed in greater detail in the earlier sections. Tolling by distance allows a overlay by schemes charging higher within some geographical areas or at certain time slots during the day[5]. The GNSS solution presented in this section is based on a charging system depending on these features, namely geographical areas and time-of-day schemes.

Each geographical area, zone, represent different levels of road toll charges, starting with the green zone at a low charge, yellow a little higher and ending at red as the most expensive. Inside the zone, charges varies from what time of the day it is. The location of each zone follows where congestion normally occur and areas sensible to pollution, a map of Trondheim with the respective zones are shown in figure 4.8 and 4.9.

Figure 4.8: Allocation of Zones. Figure based on [5],[15]

Figure 4.9: Red and yellow zone in Trondheim central area. Figure based on [5],[15]

With this GNSS based tolling solution, the entries to each zones may not be adequate accurate. The system should therefore announce when the road user is at a particular distance from a new zone, i.e notifying the road user before he is charged.

4.6.1.1 Enforcement

All GNSS based tolling systems need some kind of enforcement[5]. In this case the enforcement scheme proposed in the 1-Alternative is sufficient, and no moderations are needed. A combination of four stationary and one mobile enforcement system, with both stability from fixed infrastructure and the surprise effect from mobility, achieves a proper level of detection against illicit use of OBU. Allocation of stationary enforcement are shown in figure 4.6 in subsection 4.4.

As in the earlier posted enforcement scheme, toll eligible vehicles should be detected with a certainty of 33% and the fine for illegal usage should be 5 times the average road toll per vehicle per year, 24,990 NOK.

4.6.1.2 Charges

The main charging difference between this tolling system and the previous solutions is that in the latter the road user normally passes at least two toll stations, and hence, is charged twice each trip. In this tolling by distance approach, a vehicle is only charged when it enters a zone, i.e only once per trip if it stays in just one zone.

The passing charges are estimated to give the same income level as the 0- and 1-Alternative, and based on the same goals, to reduce emissions and keep the traffic flow low in certain areas. Each zone in figure 4.8 is strategically placed, where the red zone is downtown Trondheim, the yellow one is entered when driving of the bypass road towards the city center, and the green zone is outside the central area runned onto at Hommelvik, Orkanger and Melhus. Charges for entering the different zones are stated in table 4.11.

Charges (NOK)	Vehicles < 3500 kg	Vehicles > 3500 kg
Red zone, ordinary	25	50
Red zone, between 7-9am, and 3-5pm	33	66
Yellow zone, ordinary	20	40
Yellow zone, between 7-9am, and 3-5pm	27	54
Green zone	15	30

Table 4.11: Charges for the second GNSS based tolling system. Numbers calculated from [15],[22]combined with charges in 4.4

Charges for enforcement are, as stated in the section above, the same as for the 1-Alternative, 24,990 NOK.

4.6.1.3 Assumptions

In order to make realistic calculations on costs and revenue, the following assumptions were incorporated.

- All anticipations made in the 0-Alternative section is assumed accurate in this section as well.
- The cost, both OpEx and CapEx, of one stationary enforcement plant is assumed to be the same as for each toll station. And four stationary enforcement systems are expected to be sufficient.

- As for mobile enforcement, it is anticipated a demand of one vehicle with two officers on duty 24 hours a day, with an average salary of 220 NOK per hour.
- Charges are calculated based on average charges from the current toll collection systems, and with the assumption that a road user on average passes two toll stations each trip. See Appendix A for elaborations.
- Fees for enforcement are computed based on numbers from [15], assuming that data from 2010 is accurate today.
- Division of zones are anticipated sufficient based on today's classification (Environmental Package) and areas sensible for congestion.

4.7 Cost and Revenue Analysis of 2-Alternative

4.7.1 Costs

As for the previous alternatives, expenses for deployment of, operations and maintenance of this second GNSS based tolling system is divided into CapEx and OpEx. CapEx here constitute investment expenditures due to equipment and plant for enforcement deployment (both mobile and stationary) and GNSS OBU for every vehicle in Trondheim. OpEx, on the other hand, represent expenses for salaries, receivables, sales and other administrative expenditures.

Numbers gathered from Trøndelag Bomveiselskap AS[15] and assumptions in subsection 4.6.1.3 lay the groundwork for all calculations in this section. Since enforcement and equipment are the same in the first and the second solution for a GNSS based tolling system, the cost structure in the 2-Alternative equals the 1-Alternative, and hence, the total cost for the next 15 years is estimated to be 510,093,616 NOK. Where CapEx and OpEx, respectively, constitute 83,780,311 NOK and 426,313,305 NOK of the total amount. A detailed cost structure is presented in table 4.12.

4.7.2 Revenue

The revenue stream for the second GNSS based tolling system is almost solely covered by road toll charges, but due to fees for illicit use of the GNSS OBU, enforcement regime contributes with a minor share. The revenue is

Costs (NOK)	2012	2012-2026
CapEx		
Equipment	6800000	
Plant	5111111	
Mobile enforcement	1000000	
GNSS OBU	70869200	
Total CapEx	**83780311**	**83780311**
OpEx		
Salaries and social expenses	4330833	
Other sales and administrative expenses	20709005	
Loss on receivables	3381049	
Total OpEx	**28420887**	**426313305**
Total Amount	**112201198**	**510093616**

Table 4.12: Costs for the second GNSS based tolling system. Numbers calculated from [15],[22]

calculated by numbers obtained from [15], [22] and assumptions made in 4.6.1.3.

Road user charges have to be approximately the same as in the current tolling system, due to regulations by the government; it is not allowed to higher charges without consent if the goal is to increase profit. The average charge in this solution and the previous ones, differ with only 0,3 NOK, and the income level is therefore basically the same, but a bit higher for the second GNSS based tolling system. The total revenue for the next 15 years from this alternative is 6,805,039,204 NOK, with elaborations presented in table 4.13.

Revenue (NOK)	2012	2012-2026
Road tolls		
Vehicles < 3500 kg	371889596	
Vehicles >3500 kg	39492701	
Total road tolls	**411382297**	
Whereof additional fee	423326	
Fee for illicit use of GNSS OBU	**3404826**	
Total amount	**414927892**	**6805039204**

Table 4.13: Revenue for the second GNSS based tolling system. Numbers calculated from [15],[22]

4.7.3 Result

The result of the cost and revenue analysis is displayed in figure 4.10, with elaborations in Appendix A. Based on computations of cost and revenue, the total profit for the second GNSS based tolling system is, from year 2012 to 2026, 6,213,233,259 NOK.

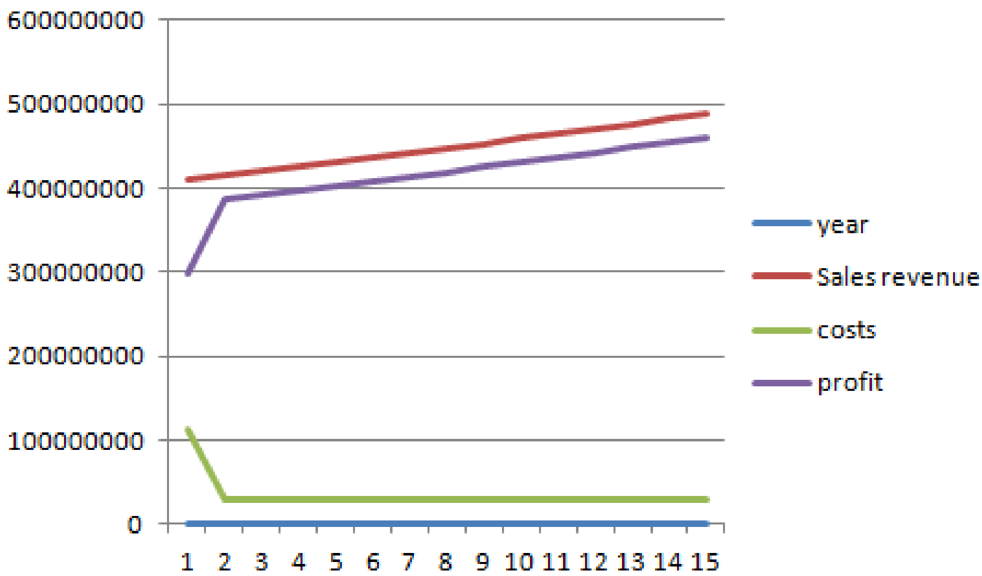

Figure 4.10: Annual profit for year 2012 to 2026. Numbers based on [5],[15]

4.7.4 Benefits

As for both previous alternatives, the clearest benefit is the profit obtained from the revenue, used to maintain old and deploy new road infrastructure. Without the revenue stream, taxpayers would probably be the ones that had to cover road infrastructure costs, making tolling a fair way of financing, where road users pay after consumption.

Another utility, stated in both earlier alternatives, is the possibility to control road usage and traffic flow to a certain level.When charging higher in given geographical regions, traffic will as a consequence decrease and lower usage of the road follows in the desired area.

Opposed to today's toll collection system, a GNSS based solution will provide less maintenance of roadside equipment, and is hence more cost efficient. For both GNSS solutions, where the only roadside equipment in use is for enforcement, the system is way more flexible and allows a great deal of extensions and changes in the years to come.

With the flexibility of virtual toll stations, there is a huge benefit when it comes to reallocation of different zones. In case the authorities wants to extend with more zones, adjust the location of the existing ones, or do any kind of changes; it will not affect the infrastructure since it is solely based on virtual toll stations.

Chapter 5

Cost and Utility Analysis

In this chapter the three different alternatives stated in chapter 4 are compared and discussed in terms of cost, revenue, profit and utility. Further, future potential of each alternative is addressed and analysed with regard to the earlier discussed input.

5.1 Cost, Revenue and Profit

5.1.1 Cost

There is one main difference in calculations of costs between the current electronic toll collection system and a GNSS based tolling system, namely expenses for roadside equipment. In the latter case, toll stations are virtual and hence no roadside infrastructure needed, opposed to today's system where all toll stations are fixed. This affects both CapEx, where it contributes with expenses on infrastructure and equipment, and OpEx, for operating and maintaining toll stations.

In the 1- and 2-Alternative, enforcement infrastructure and equipment are required in order to avoid illicit use of the OBU. These costs compensate for the low expenditure on roadside tolling equipment, but is still lower compared to the current system. Stationary contributes to CapEx and OpEx in the same matter as toll stations in the 0-Alternative, while mobile enforcement higher the OpEx due to expenses for 24/7 workforce.

Another CapEX differing between the two systems are the OBU price. In the first case this is just a AutoPASS tag, at a price of 100 NOK per vehicle, while for GNSS the OBU costs 1500 NOK a piece.

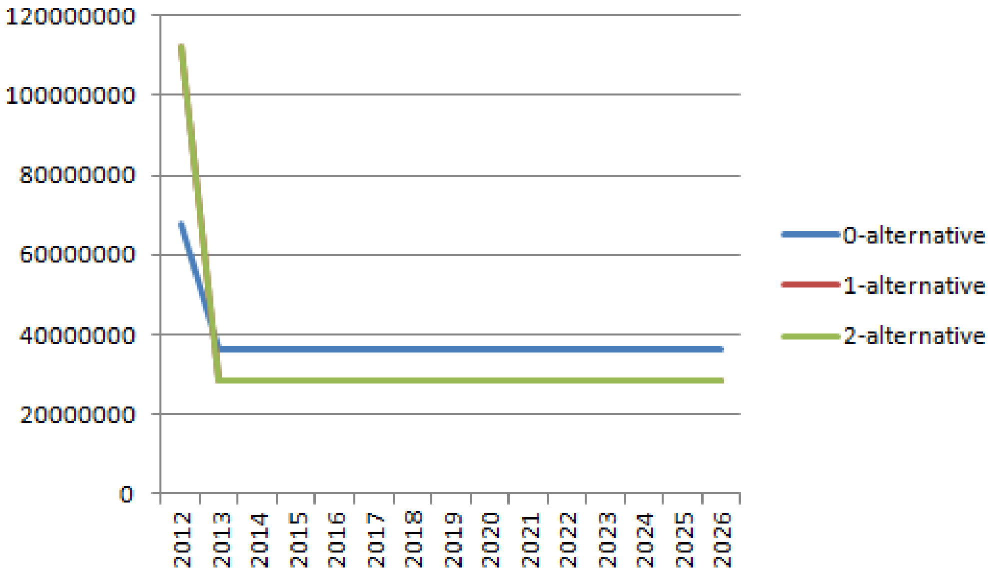

Figure 5.1: Comparison of cost in the 0-, 1- and 2-Alternative. The red line equals the green line, and thus does not appear in the figure. Figure based on numbers from chapter 4

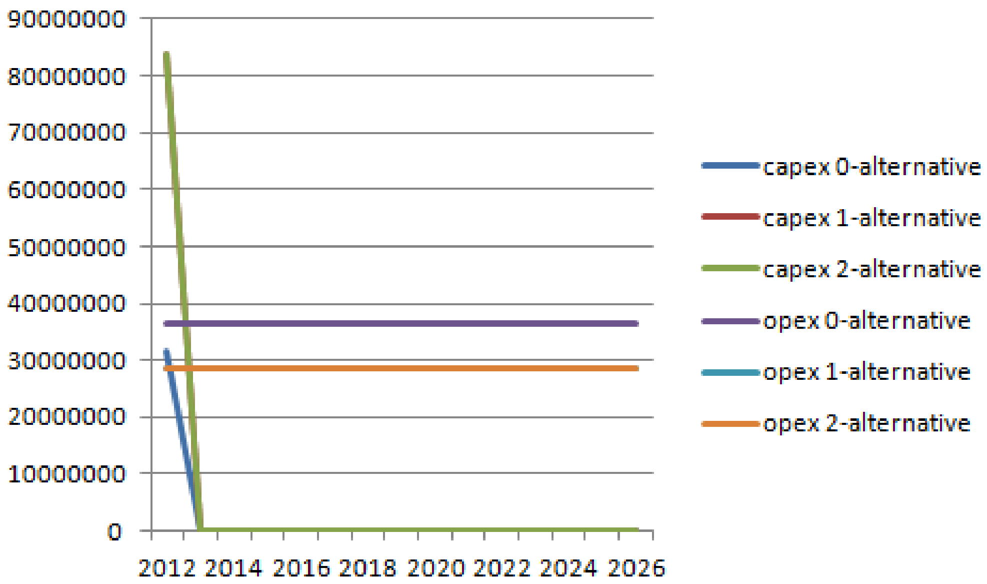

Figure 5.2: Comparison of CapEx and OpEx in the 0-, 1- and 2-Alternative. The red line equals the green line, and the light blue line equals the orange line, and thus does not appear in the figure. Figure based on numbers from chapter 4

A comparison of cost structure, both CapEx and OpEx, between the 3 alternatives is shown in figure 5.1 and 5.2, and total costs are displayed in table 5.1. The costs of the 1- and 2-Alternative are equal since they are using the same GNSS system with a similar enforcement scheme. The total costs for the 0-Alternative is 12.9% higher the two others, and so far, investing in a GNSS based tolling system seems reasonable.

Costs (NOK)	CapEx	OpEx	Total
0-Alternative	31524613	544680075	576204688
1-Alternative	83780311	426313305	510093616
2-Alternative	83780311	426313305	510093616

Table 5.1: Total cost in the 0-, 1- and 2-Alternative. Figure based on numbers from chapter 4

5.1.2 Revenue

The revenue stream is, for all three alternatives, almost solely from road charges, with only a minor additional contribution from fees for toll eligible vehicles.The income level is in all cases based on numbers for 2010 from Trøndelag Bomveiselskap as [15], combined with toll charges and estimated population growth [13].

As addressed above, road charges are the most important income, and basically the reason why road collection systems are used. These charges has to be the same for a GNSS based tolling system as the current electronic toll collection system, due to regulations by the government; it is not allowed to higher charges without consent if the goal is to increase profit. Because of that, the main income stream is close to equal for the 0-, 1- and 2-Alternative. Fines from road users who does not comply with the tolling regime contributes with a small share to the total revenue. For today's system, these fines origin from fees when vehicles passes toll stations without paying, while for both GNSS based tolling systems, this income are from enforcement where vehicles caught for illicit use of OBU are charged with a fine.

Revenue (NOK)	2012-2026
0-Alternative	6763846360
1-Alternative	6723326875
2-Alternative	6805039204

Table 5.2: Total revenue for the 0-, 1- and 2-Alternative. Table based on numbers from chapter 4

When comparing the revenue structure, shown in figure 5.3, all alternatives are close to equal. The curves for each alternative evolves in a similar manner; they are linear and with the same slope (1,01% annual increase due to population growth). Elaborations of the total revenue from 2012-2027 is stated in table 5.2, where total revenue of the 2-Alternative is 0,61% higher than the 0-Alternative, and 1,2% greater than the 1-Alternative. Even though the margins between each different system is small, the second GNSS based tolling solution is the one that provides the highest revenue.

5.1.3 Profit

The profit is calculated as the result of combining costs and revenue, and by looking at the two previous sections there should be a pretty clear image on the outcome. An explanatory diagram of profits for all alternatives is displayed in figure 5.4, and details on the total profit from 2012 to 2026 are stated in table 5.3.

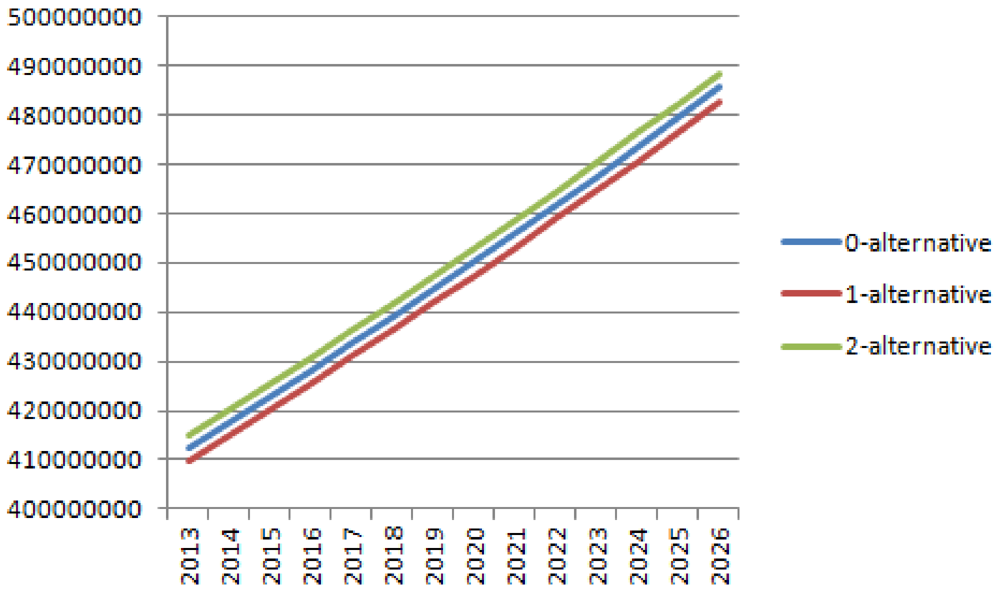

Figure 5.3: Comparison of revenue in the 0-, 1- and 2-Alternative. Figure based on numbers from chapter 4

Profit (NOK)	2012-2026
0-Alternative	6187641672
1-Alternative	6213233259
2-Alternative	6294945588

Table 5.3: Total profit for the 0-, 1- and 2-Alternative. Table based on numbers from chapter 4

The 0-Alternative starts in 2012 with the highest profit, mainly because of a lower CapEx than the two other alternatives the first year, but the 0-Alternative curve does not increase as much as the other, due to a higher OpEx every year, and ends up with the lowest total profit. The profit for the 0-Alternative from 2012-2026 is equivalent to 98.29% of the highest total profit.

Both GNSS based tolling alternatives have a significantly higher CapEx than today's system and thus a substantially lower starting point. Even so with, compared to the 0-Alternative, a reduced OpEx the 1- and 2-Alternative finish with the two greatest total profit. The 1-Alternative has a profit from 2012-2026 corresponding to 98.7% of the highest, namely the 2-Alternatives, total profit. The difference between the two GNSS solutions

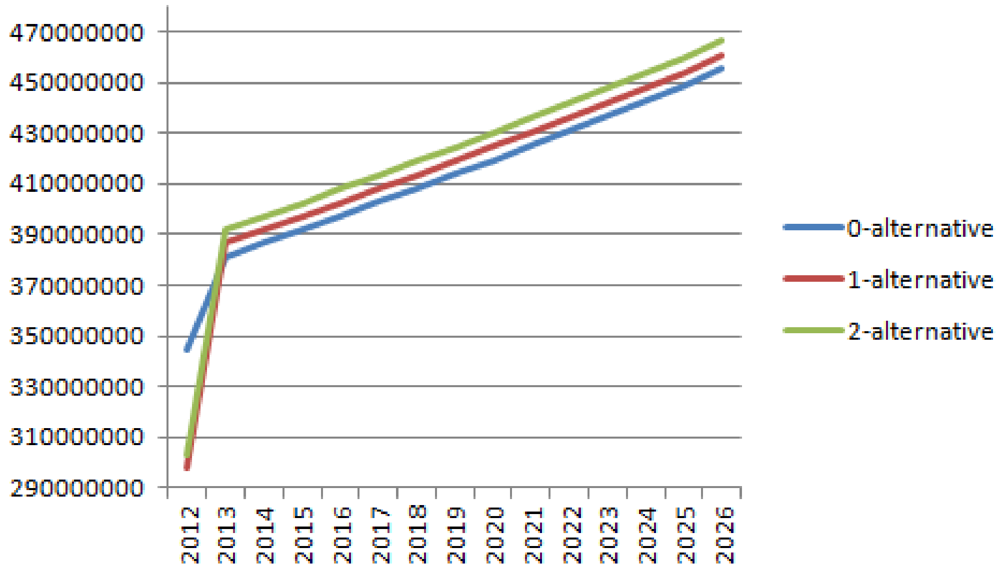

Figure 5.4: Comparison of profit in the 0-, 1- and 2-Alternative. Figure based on numbers from chapter 4

occurs due to the 2-Alternatives greater revenue stream, and the second GNSS based tolling system is hence the best option in terms of profit.

5.2 Benefit

The most important benefit, equally in all three alternatives, is the he profit created by the revenue, used to maintain old and implement new road infrastructure. Without the income stream, taxpayers would supposedly had to be the ones covering road infrastructure costs, which makes tolling a fair way of financing, where road users pay after consumption. As mentioned in earlier sections, the 2-Alternative has the highest total profit and obtain thus most benefit from it. Even so, the 0- and 1-Alternative follows closely with, respectively, a value at 98.3% and 98.7% of the greatest total profit, and hence benefit from profit does not differ much in practice.

Another utility present in all alternatives is the possibility to control usage of roads and traffic flows to a certain extent. When charging higher in given areas, traffic will as a consequence decrease and thus lower usage of the road in the desired region. This is enabled by; the Environmental Package in the 0-Alternative, environmental zone in the 1-Alternative, and construction of different charging areas in the 2-Alternative, all with a equal benefit level.

For the 1- and 2-Alternative, there are some additional benefits compared to the 0-Alternative. A GNSS based solution will, opposed to the current toll collection system, provide a lower need for maintenance of roadside equipment, and is hence more cost efficient. For both GNSS solutions, where the only roadside equipment in use is for enforcement, the system is far more flexible and allows a great deal of extensions and changes in the years to come.

5.2.1 Possibilities

A GNSS based tolling system has potential for different extensions, benefiting the society in various ways.

With GNSS, satellites are transmitting, at a fixed frequency, their own position and a accurate time stamp, which are used by the receiver to compute its own location on earth[23]. These computations can be used to calculate the distance driven and hence the average speed on a desired route section. When using satellites and OBUs to detect speeding, combined with the suggested enforcement regime, cost for road side equipment and patrolling vehicles will be avoided.

Another possibility with a GNSS solution is to pay for parking the same way as vehicles are charged in the tolling system. The area of a parking lot is marked as a zone, where the OBU sets a time stamp when accessing, and total time spent inside the parking lot is registered when exiting. If the total time is less than a certain number of minutes, for instance 15, the road user does not pay at all, which enables going into a parking lot and just drive through if there is no available parking spots.

5.2.2 Quantifiable Benefit

In order to do calculations on a cost-benefit analysis, benefits are separated into quantifiable and unquantifiable[10]. Quantifiable benefits can be represented by numbers, and is thus the parameter used in computations of benefit.

In this analysis, quantifiable benefits are

- income
- cost saved on reduced emission
- cost saved on accidents, wear and noise (due to lower traffic flow)

- lapsed costs (compared to 0-Alternative)

5.2.3 Non-quantifiable Benefit

This is the benefit unable to represented in numbers. For this cost-benefit analysis non-quantifiable benefits are

- the value of using new and better technology
- flexibility, compared to 0-Alternative depending on fixed roadside infrastructure
- the possibilities a GNSS system provides.

5.2.4 Assumptions

In this chapter as well, some assumptions had to be made in order to do computations of benefit;

- It is assumed that the zone allocation in the 2-Alternative and its charging structure impacts the traffic flow in the red zone by increasing 20%.
- Calculations of benefit in all alternatives are based on numbers from previous sections, the Klimakurs workgroup [21] and SINTEF [31], with the anticipation that the data provided is accurate.

5.3 Calculated Benefit for all Alternatives

In order to display the effect of reducing traffic by the Environmental Package (0-Alternative) and environmental zone (1-Alternative), calculations of benefit for the 0-Alternative is provided and used in combination with calculated benefit for the 1- and 2-Alternative.

5.3.1 0-Alternative

Since the 0-Alternative is the basis for the analysis, where the 1- and 2-Alternative is compared with it, benefits for lapsed cost are non existent. The only parameters used to find the calculated benefit are income, saved cost by the reduction of emissions, and saved cost for accidents, wear and noise. The total calculated benefit for 2012-2026 are 7,464,550,737, with elaborations shown in table 5.4.

Calculated benefit 0-Alternative (NOK)	2012	2012-2026
Benefits		
Income	412416215	6763846360
Cost saved by reducing emissions 40%	5922271	88834065
Cost saved on accidents, wear and noise	79205000	1188075000
Total benefit	**497543486**	**8040755425**
Costs (CapEx and OpEx)	**67836618**	**576204688**
Calculated benefit	**429706868**	**7464550737**

Table 5.4: Calculated benefit for the 0-Alternative. Table based on [21],[31].

5.3.2 1-Alternative

The calculated benefit present the increased benefit level for using the 1-Alternative compared with the 0-Alternative. Benefit parameters used in the computation are lapsed cost, income, saved cost from reduction of emissions, and saved cost for accidents, wear and noise. Computations are explained in table 5.5, which shows a total calculated benefit for 2012-2026 at 7,556,253,396 NOK.

Calculated benefit 1-Alternative (NOK)	2012	2012-2026
Benefits		
Lapsed cost	-44364580	66111072
Income	409945595	6723326875
Cost saved by reducing emissions 40%	5922271	88834065
Cost saved on accidents, wear and noise	79205000	1188075000
Total benefit	**450708286**	**8066347012**
Costs (CapEx and OpEx)	**112201198**	**510093616**
Calculated benefit	**338507088**	**7556253396**

Table 5.5: Calculated benefit for the 1-Alternative. Table based on [21],[31].

5.3.3 2-Alternative

In the 2-Alternative, as for the 1-Alternative, the calculated benefit present the increased benefit level compared to the 0-Alternative. Here all quantifiable benefit parameters are used, and the result are displayed in table 5.6. The total calculated benefit for the 2-Alternative from 2012-2026 is 7,720,346,955 NOK.

Calculated benefit 2-Alternative (NOK)	2012	2012-2026
Benefits		
Lapsed cost	-44364580	66111072
Income	414927892	6805039204
Cost saved on emission by yellow zone (40%)	5922271	88834065
Cost saved on A, W and N by yellow zone (40%)	79205000	1188075000
Cost saved on emission by red zone (20%)	382082	5731230
Cost saved on A, W and N by yellow zone (20%)	5110000	76650000
Total benefit	**461182665**	**8230440571**
Costs (CapEx and OpEx)	**112201198**	**510093616**
Calculated benefit	**348981467**	**7720346955**

Table 5.6: Calculated benefit for the 2-Alternative. Table based on [21],[31].

5.3.4 Result

Figure 5.5 and 5.6 displays the result of the cost-benefit analysis. The 2-Alternative has the highest overall calculated benefit, closely followed by the 1-Alternative, even though they both, compared to the 0-Alternative, start out with a lower calculated benefit the first year. The 1- and 2-Alternative has, respectively, a 1.2% and 3.4% greater total calculated benefit than the 0-Alternative.

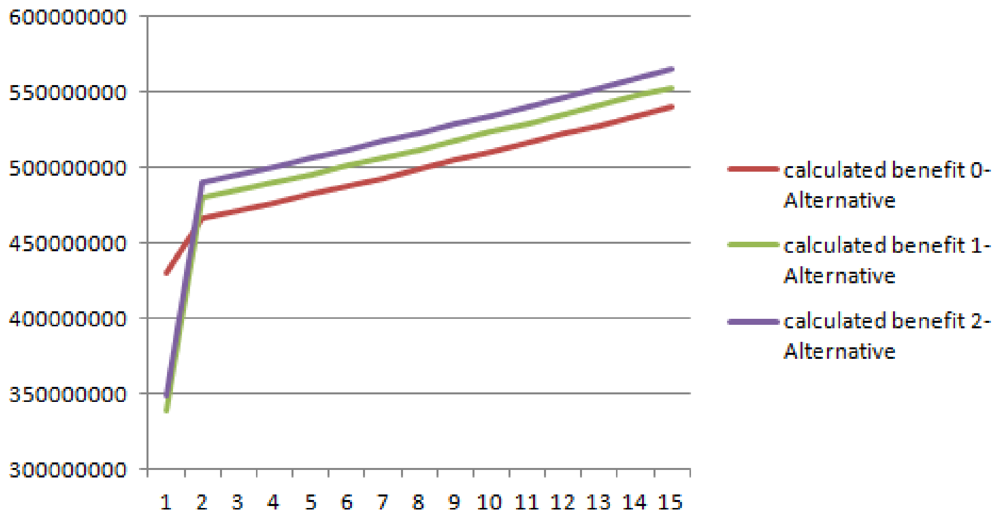

Figure 5.5: Calculated annual benefit for the 0-, 1- and 2-Alternative. Numbers from [21],[31].

These numbers does not include the non-quantifiable benefit, meaning that

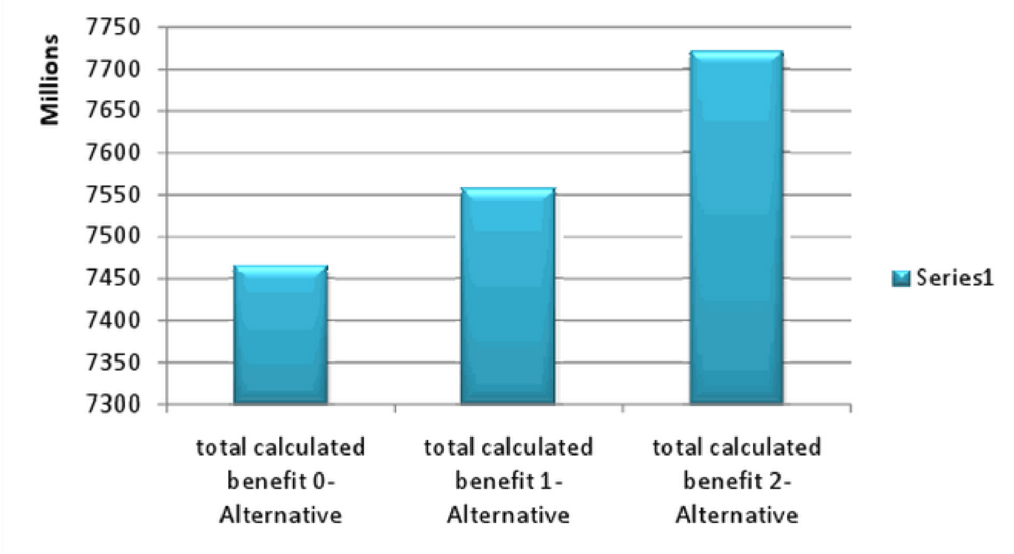

Figure 5.6: Calculated benefit for the 0-, 1- and 2-Alternative. Numbers from [21],[31].

the 1- and 2-Alternative have a even higher benefit level than shown in figure 5.5 and 5.6. Based on this fact and the result of the cost-benefit analysis, it would be a clear choice to implement a GNSS based tolling system.

5.4 Calculated Benefit for only the 1- and 2-Alternative

A more traditional calculation of benefit is provided in this section, where benefits are only shown for the 1- and 2-Alternative [10]. The 0-Alternative represents a zero level, and benefits provided upon this by the GNSS solutions are parameters in the calculated benefit.

5.4.1 1-Alternative

The calculated benefit present the increased benefit level for using the 1-Alternative compared to a zero level. Benefit parameters used in the computation are lapsed cost and income, since the benefit from reduced emissions, and accidents, wear and noise is present in the 0-Alternative. The total calculated benefit for 2012-2026 are 6,279,344,331 NOK, with elaborations shown in table 5.7.

Calculated benefit 1-Alternative (NOK)	2012	2012-2026
Benefits		
Lapsed cost	-44364580	66111072
Income	409945595	6723326875
Total benefit	**365581015**	**6789437947**
Costs (CapEx and OpEx)	**112201198**	**510093616**
Calculated benefit	**253379817**	**6279344331**

Table 5.7: Calculated benefit for the 1-Alternative. Table based on [21],[31].

5.4.2 2-Alternative

In the 2-Alternative, as in the 1-Alternative, the calculated benefit present the increased benefit compared to a zero level. In this alternative, quantifiable benefit on saved costs because of reduced emission, and lower rate of accidents, wear and noise, appears. The zone alignment in the 2-Alternative provides additional reduction on traffic in downtown Trondheim, and hence lower emissions, accidents, wear and noise. Computations are explained in table 5.8, showing a total calculated benefit for 2012-2026 at 6,443,437,890 NOK.

Calculated benefit 2-Alternative (NOK)	2012	2012-2026
Benefits		
Lapsed cost	-44364580	66111072
Income	414927892	6805039204
Cost saved on emission by red zone (20%)	382082	5731230
Cost saved on A, W and N by yellow zone (20%)	5110000	76650000
Total benefit	**376055394**	**6953531506**
Costs (CapEx and OpEx)	**112201198**	**510093616**
Calculated benefit	**263854196**	**6443437890**

Table 5.8: Calculated benefit for the 2-Alternative. Table based on [21],[31].

5.4.3 Result

The 2-Alternative has again the highest calculated benefit, shown in figure 5.8 and 5.7, with 2,6% greater total benefit than the 1-Alternative. On the other hand, since both alternatives has such high calculated benefit, the 1-Alternative is anticipated an almost equally good choice of solution as the 2-Alternative.

The numbers given in this section does not include the non-quantifiable benefit, meaning that the 1- and 2-Alternative have a even higher benefit

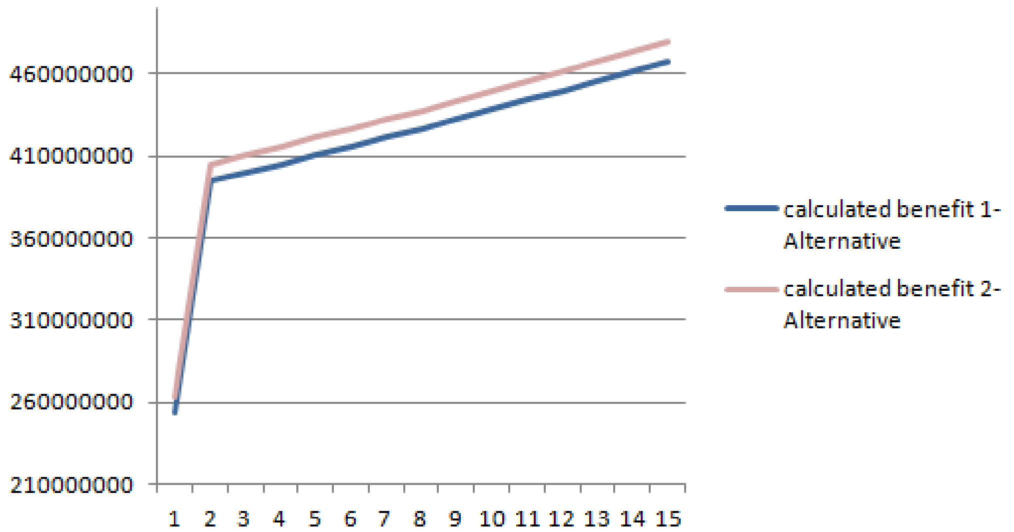

Figure 5.7: Calculated annual benefit for the 1- and 2-Alternative. Numbers from [21],[31].

level than shown in figure 5.8 and 5.7. And as anticipated in the first cost-benefit calculation, a GNSS solution is obviously the best option.

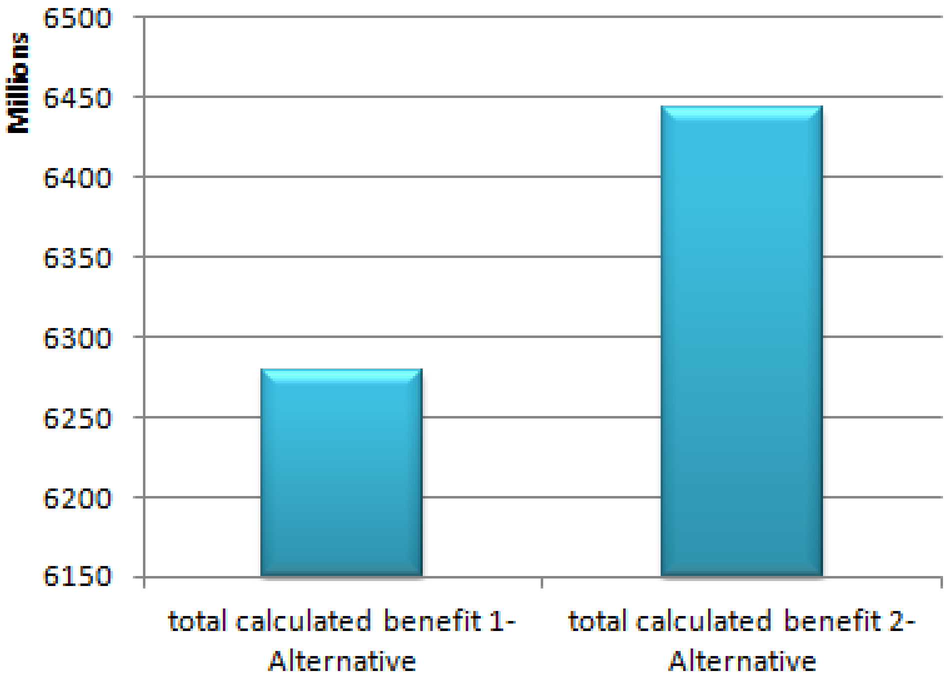

Figure 5.8: Calculated benefit for the 1- and 2-Alternative. Numbers from [21],[31].

Chapter 6

Business Model

This chapter will form a business model based on the use case and cost-benefit analysis in chapter 4 and 5. The business model proposed here will be specified for a GNSS based tolling system, but also with an approach to a more general ITS solution based on the findings from the tolling solution.

6.1 Business Model Canvas

On of the most common definitions of a business model is given by Alexander Osterwalder [17];

> A business model describes the rationale of how an organization creates, delivers, and captures value

Osterwalder is an Author, Speaker and Advisor on Business Model Innovation, and is first and foremost known for his work of a proposed reference model, called Business Model Canvas [16],[28]. This model is based on resemblance in a wide range of business model concepts, and, nowadays, one of the most popular frameworks for describing business models.

Osterwalders Business Model Canvas will be used as a template in this chapter, with elements describing a firm's value proposition, infrastructure, customers and finances; each element represented in separate sections [17]. A graphic based on the Business Model Canvas is displayed in figure 6.1.

6.2 Customer Segment

An organization always serves one or several customer segments.

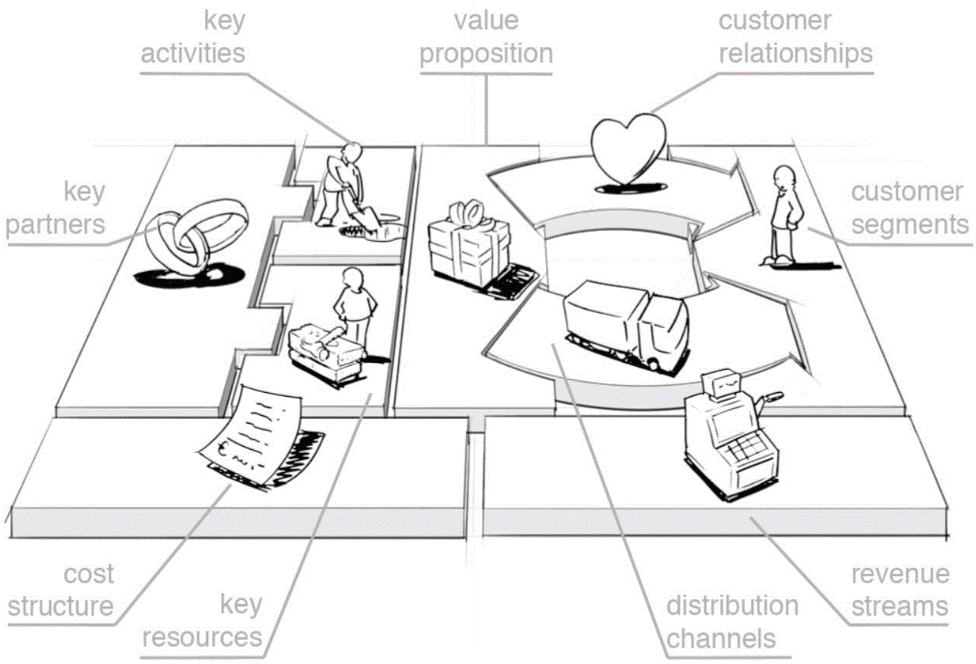

Figure 6.1: Osterwalder Business Model Canvas. Figure from [3]

6.2.1 1- and 2-Alternative

For a company providing a GNSS based tolling system, the main customer segments are vehicle owners/drivers and truck drivers, but people using cars in general are also affected by a tolling regime. In other words, the customers are one large group with broadly similar needs and problems. The providers of the tolling system do not distinguish between different segment, and is hence serving a mass market.

6.2.2 ITS in General

In a general sense of ITS distribution, the customers will be similar to those listed above, but it will affect public transportation as well. The various services might in addition distinguish between truck and other vehicle drivers in a greater sense. Even so, since a fully deployed ITS solution will influence the whole population of Trondheim, and in an overall term not differentiate between each segment, it also serves a mass market.

6.3 Value Proposition

With value proposition, an organisation seeks to solve customer problems and satisfy customer needs. This element describes the package of products and services that create value for a specific Customer Segment

6.3.1 1- and 2-Alternative

A GNSS based tolling system mainly provides value through collecting toll charges in an efficient way and with this profit improve and maintain the road infrastructure, hence give road users a safe and satisfactory road network.

Opposed to today's tolling system GNSS provides a technology based newness. With a GNSS solution vehicles are equipped with OBUs, installed by car manufacturers and communicating with satellites, customized for the customer giving them an ease since they effortless just drive and pay the bill in the end of the year. This solution hence increase performance from the current electronic tolling system.

With allocation of different charging zones, environment in the 1-Alternative and green, yellow and red in the 2-Alternative, traffic flow and emissions are reduced in certain areas. A reduction in emission provides the customers with an healthier environment and eased conscience regarding pollution. When decreasing traffic flow, it follows a reduction in accidents, wear and noise, gaining customers in an obvious way.

6.3.2 ITS in General

With a fully deployed ITS solution, all values listed above would be present, and several additional due to the variety of services such a solution gives. The value from collecting toll charges, thus providing road infrastructure, and environmental benefits gains the total ITS solution in a similar way since the GNSS based tolling system is part of the total ITS.

An overall implemented ITS will offer a broad range of services, benefiting the customer in several significant ways, customized for an easier and safer use of today's road network. With new communication equipment, which increases performance installed in all vehicles it is supposed to significantly reduce the number of people killed by traffic. To decrease number of accidents and provide a safer transport environment is the main driver for deploying ITS.

The efficiency of such a system is another important value given the customer. By, for instance, a parking solution enabling the user to know where there are vacant parking and even order a spot in advance, which benefits each driver personally and the traffic flow since there is no need for driving around searching, both in a time consuming way.

6.4 Channels

An organisation deliver their value proposition through communication, distribution and sales channels, and this element describes in which way the organisation reaches its customer segments.

6.4.1 1- and 2-Alternative

In order to implement a GNSS based tolling system an OBU needs to be installed in all legally registered vehicles, thus every driver has to be aware of the new system. The tolling regime will be forced upon all road users by the government, which would be the clear channel for providing awareness and information about the product.

Car manufacturers will be compelled by law to provide all new vehicles with an integrated OBU, and OBUs will be installed manually in cars purchased before the system take effect. All OBUs are prepaid by the organisation providing the GNSS tolling system, meaning that car owner and truck companies are not charged for the equipment.

6.4.2 ITS in General

If ITS were to be implemented the government would be the one responsible for equipment in cars (in the same manner as for the GNSS solution), and providing awareness and information about the new system to the whole population, preferably well ahead before the system takes effect.

Vehicles and transportation infrastructure will be forced to legally comply with the ITS regime, giving car manufactures the responsibility of all in-car equipment. Old vehicles will, as for the GNSS solution, get OBUs manually installed, and vehicle owners are not charged directly for the in-car equipment.

6.5 Customer Relationships

An organisation need to establish and maintain customer relationships, where the types of relationships a company can establish with specific customer segments are part of this element.

6.5.1 1- and 2-Alternative

The organisation responsible for deploying the GNSS tolling system provides customers, through third parties the necessary equipment to comply with the tolling regime. Maintenance and service of the OBU is done by the same third company and there is hence no direct contact between the organisation and the customer when handling equipment.

Since the GNSS system is highly automated, and each OBU has a registered owner, road user pays for tolling charges online or at a bank when receiving a fee. If there is any problems or the customer has questions he can get personal assistance through call centres and service stations.

6.5.2 ITS in General

For ITS in general the same applies as for the GNSS based tolling system. In addition, it is in some extent necessary with customer contact for awareness and informing about the system. This will be done in an automated manner, where the whole population is provided with information in the same way. This relationship needs to be build years in advance before ITS takes effect.

6.6 Revenue Stream

Revenue streams are the result a organisation gains from successfully offering the value proposition to customers, generated in cash flows.

6.6.1 1- and 2-Alternative

A GNSS tolling system is based on usage fee; the customer is charged by usage of a particular service, here for using the road network. The revenue stream for a GNSS solution is therefore almost solely based on road toll charges, but due to fees for illicit use of the GNSS OBU, enforcement regime contributes with a minor share. Calculations of revenue are explained in greater detail in chapter 4 .

The pricing structure is customer segment dependent, meaning that price depends on the type and characteristic of a customer segment. In the proposed GNSS solution these segments are vehicles over 3500kg and under 3500kg, where charges which differ in a smaller sense between the 1- and 2-Alternative, are presented in figure 4.8 and 4.11 in chapter 4.

Additionally, charges also depend on geographical regions marked as zones. For the 1-Alternative there is only one higher charged zone, the environmental zone, shown in figure 4.4 in chapter 4. This zone is located with regard to where congestion normally occur and areas sensible to pollution, and aims for reduced emissions and traffic flow in the central area of Trondheim. The 2-Alternative, on the other hand, has three levels of zones; red, yellow and green, which is respectively charged from high to low. Figure 4.8 in chapter 4 shows the allocation of zones, where the red zone cover downtown Trondheim, the yellow one covers most of the central area, while the green zone range to the outer points of the city.

6.6.2 ITS in general

The GNSS based tolling solution would be the generator of revenue for ITS, and the revenue stream is hence based on usage fee with the same specifications as stated in the previous section. The only thing different is the amount charged, since deployment of ITS would be more expensive than solely implementing a GNSS solution. Road users will therefore be charged at a higher rate, in order to get enough revenue to be a profitable solution.

6.7 Key Resources

Key resources are the necessary assets an organisation needs to offer and deliver the elements described in previous sections, these assets are required to make a business model work.

6.7.1 1- and 2-Alternative

A GNSS based tolling system's main resource is the physical equipment, namely the OBU and roadside infrastructure for enforcement. Car manufacturers are responsible for producing and installing the OBU for vehicles, while another production company is required for manufacturing and deploying the roadside infrastructure.

An implemented infrastructure enables another important resource, the actual toll collection. Toll collection depends on human and automated resources for billing, call centers, personal assistance and service. The latter require help from professionals, but resources for billing, call centers and personal assistance can be realized within the organisation.

6.7.2 ITS in General

A fully deployed ITS require a lot more roadside infrastructure and equipment for communication between vehicles. It would therefore depend on additional production companies specialised in providing that certain kind of equipment. Communication also require a network for data to be transmitted, this can be both cellular networks or Local Area Networks (LAN). In both cases it would be necessary with cooperation with a network provider in order for an ITS solution to work.

In-vehicle equipment for communication is installed by a car manufacturer. It might be reasonable to have a third party producing the OBU, which would make it equal for all car manufactures and easier to control by the legal department. In this way, a manufacturing company would produce and deliver OBU to car manufacturers which would be responsible for installing the equipment in all produced vehicles.

Deploying and operating a payment regime is an important resource, which in this case would be a GNSS based tolling system. This indicates that all key resources listed for the GNSS solution in the previous subsection applies for ITS in general in the same manner as for just a tolling solution. Resources for billing, call center and personal assistance due to toll collection will be realized within the organisation.

6.8 Key Activities

The Key Activities describes the most important actions an organisation must take in order to operate successfully and to make its business model work .

6.8.1 1- and 2-Alternative

The first activity in realizing a GNSS based tolling system is to deploy roadside infrastructure and implement OBUs in all vehicles, as well as informing road users about the change. As pointed out in the Key Resource section, these activities will be performed by professionals and car manufacturers. When all equipment is installed and up running, the system will start charging road users by GNSS.

After deployment there will be need for service, support and maintenance of the equipment and infrastructure. Maintenance of plant for enforcement will be operated by the same professional who produced and deployed the infrastructure, while service and support of OBUs will be performed by car manufacturers.

The last key activity is managing toll collection, in means of billing, invoices, running call center and personal assistance. Management of toll charging is operated within the organisation.

6.8.2 ITS in General

The first activity for ITS in general is to inform and make all citizens aware of the new system well in advance before it is realized. Since the system will be forced by the government they might be responsible for providing this information.

At the same time as information is provided, production and deployment of infrastructure and equipment for vehicles will start. Activities for implementing roadside equipment are performed by specialists in roadside infrastructure and network deployment, while OBUs will be produced by professionals and later installed by car manufacturers.

After the system takes effect there will be necessary with a great deal of service support and maintenance of equipment and infrastructure. Maintenance of plant and roadside infrastructure will be operated by the same specialists as for deployment , and service and support of in-car equipment will be provided by car manufacturers and professionals.

Since toll collection is a key resource it demands some key activities, which are all listed in the previous subsection. Some of these activities will be part of the deployment and maintenance scenario stated earlier, the remaining ones are for managing toll collections. There is hence a need for activities operated by the organisation in the ITS solution as well as for GNSS tolling.

6.9 Key Partners

In an organization's business model some activities are outsourced and some resources are acquired outside the enterprise. The Key Partnership element describes the network of suppliers and partners that make the business model work.

6.9.1 1- and 2-Alternative

The organisation providing a GNSS based tolling system has several partners, first and foremost partners for enforcement operations. Without stationary and patrolling enforcement, there would be no assurance that road users comply with the tolling regime. Secondly, there is a need for roadside and vehicle equipment when operating enforcement. This infrastructure is produced and deployed by specialists in the tolling field, who are also responsible for maintenance and service of the equipment.

Another important partner is car manufacturers, since they are producing and providing vehicles with the OBU. Additionally, car manufacturers are responsible for service and support of the in-vehicle equipment.

This system is forced upon all road users by the government, and they are in charge for all regulations and the legal work. The government is also responsible for providing information and awareness about the GNSS solution to all residents in Trondheim. They are hence an important partner for the organisation providing the GNSS based tolling system,

6.9.2 ITS in General

ITS is a huge system, with a large number of different services, affecting the society in various ways. That is why providing this system requires several key partners. First and foremost the organisation need to cooperate closely with the government, since they regulate and is responsible for forcing it upon all citizens. They have the liability for all legal work and responsible for providing information and awareness to the population.

Manufacturing companies producing and maintaining the infrastructure and equipment is another key partner. The organisation providing ITS rely on their work in order for the system to work. Network operators are needed in order for the equipment in vehicles and roadside infrastructure to communicate with each other and for enabling vehicle to vehicle communication. Car manufacturers and professionals are handling production, implementation, service and support of the OBU.

6.10 Cost Structure

All business model elements presented in previous sections result in a cost structure. The cost structure describes the most important costs incurred to operate a business model

6.10.1 1- and 2-Alternative

The cost structure for a GNSS based tolling system is cost-driven; it focuses on minimizing cost in order to benefit greater from profit. Expenses for deploying, operating and maintaining the system is divided into OpEx and CapEx. Elaborations of cost structure can be displayed in figure 5.1 in chapter 5.

CapEx, or investment costs, represent expenses on equipment and plant arising from deployment of enforcement systems (mobile and stationary), and OBUs for all vehicles in Trondheim. This means the costs of having a company specialized on tolling equipment producing and deploying roadside infrastructure, and for car manufacturers producing and installing OBUs.

OpEx, on the other hand, constitute expenses for salaries, receivables, sales and other administrative expenditures. This is the cost from maintenance of roadside infrastructure and service and support of OBU, as well as cost for mobile enforcement and managing toll collection.

6.10.2 ITS in general

The cost structure for a fully deployed ITS will consist of among others expenses for a GNSS payment solution, and the cost structure will be separated into CapEx and OpEx in a similar manner, basically containing expenses for producing, deploying and maintaining the system.

For a ITS realization, CapEx will constitute investment expenditures due to equipment and plant for deployment of roadside infrastructure and in-car equipment for all vehicles. As for the GNSS solution alone, this represent the costs of roadside infrastructure, vehicle equipment and network solutions enabling V2V and I2V communication.

OpEx represent expenses for salaries, receivables, sales and other administrative expenditures. In a fully deployed ITS this means the cost from maintenance of roadside infrastructure by companies specialized in different fields, and service and support of OBU by professionals and car manufacturers. It also constitute expenses of management, including salaries, billing, call center and support.

Chapter 7

Conclusion and Further Work

7.1 Conclusion

After years with research and development, a technical solution for adapting ITS sis already in place, but there is a main factor holding back implementation; the question of who is financially responsible and whether it will benefit, or not, the organization who takes that responsibility.

This thesis has discussed the possible benefits for an organisation willing to invest in and implement an ITS solution. Based on the benefits of different stakeholders and roles, a business case has been proposed for realisation of an ITS solution.

As a case study, Trondheim was selected as the geographical region for the thought implementation of a GNSS based tolling solution. GNSS based tolling represents an important ITS service, and the results from the case study can be used as factors in the decision of implementing ITS in general.

The case study shows that there is significantly more value in a GNSS based tolling solution than today's electronic toll collection system. Virtual toll stations enables flexibility since there is a severe lower need for infrastructure than in the current system, which is both cost efficient and provides more possibilities for change and upgrades. Other important factors a ITS solution brings to the table is user and environmental benefits in terms of safer road usage, efficiency and being environmental friendly.

The result from the cost and benefit analysis shows that both GNSS based tolling solution provides a higher benefit level than today's electronic toll collection system, and the organisation responsible for the introduction of an ITS solution will hence benefit financially if they change to the new technological solution.

In the end the business model defines elements for a ITS solution's value proposition, infrastructure, customers and finances, based on the use cases and cost analysis in earlier sections of the thesis.

7.2 Further Work

Due to limitations in time, only one service was taken into considerations here. In future work a broader specter of services should be accounted for, enabling a more thorough business case study and a more extensive look at the benefit level. It might be more interesting to look at more than one type of services when forming a business model for an overall implementation of a ITS solution.

In the cost benefit analysis there may be possibilities to, in greater detail estimate non-financial benefits, which will give a even more detailed presentation of the benefit level an ITS solution can provide.

Another possible extension to the cost benefit analysis is to measure risk of deploying an ITS solution. This includes both risks of the accuracy in calculations and things that might go wrong or not according to plan. It is possible to study in depth the probability of the occurrence of incidents which causes risk and the consequences they might bring.

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The case study in this thesis is limited to the geographical area of Trondheim and hence the people living within this area, which means that people from the districts travelling into Trondheim is not considered. Future work should include traffic generated by people from the districts in addition to the traffic assessed in this thesis. This would require more advanced calculation of quantity of cars owned and driving habits.

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Appendix A

appendixA

The appendix constitute all calculations done in this thesis.

0-Alternative, costs

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CapEx	31524613	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OpEx	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005
Total Cost each year	67836618	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005

CapEx for 15 years	31524613
OpEx for 15 years	544680075
Total Cost for 15 years	576204688

0-Alternative

price for each chip	100
population of Trondheim	177173
persons per household	3
number of households	59058
percentage of households owning a car	80
number of households owning a car	47246
total price for chips for all cars	4724613

population growth

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
precentage of population growth		1,55	1,58	1,58	1,58	1,5	1,45	1,4	1,35	1,3	1,25	1,2	1,15	1,075	1
average annual population growth(%)		1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
average annual population growth		1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135
total population	177173	179573,1	182005,6	184471,2	186970,1	189502,9	192070	194671,8	197308,9	199981,8	202690,8	205436,5	208219,5	211040,1	213898,9
number of households	59057,67	59857,69	60668,55	61490,39	62323,36	63167,62	64023,32	64890,6	65769,64	66660,58	67563,6	68478,84	69406,49	70346,7	71299,64
number of households owning a car	47246,13	47886,15	48534,84	49192,31	49858,69	50534,1	51218,65	51912,48	52615,71	53328,47	54050,88	54783,07	55525,19	56277,36	57039,71
annual growth of cars		1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546

0-Alternative, revenue and profit

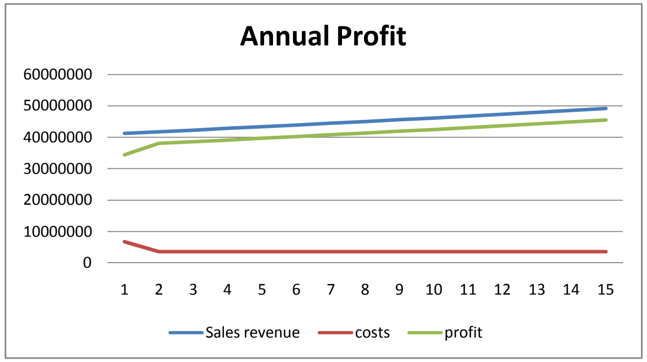
yearly traffic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
number of passings vehicle < 3500 kg	27944212	28322744	28706404	29095261	29489386	29888849	30293723	30704082	31119999	31541551	31968813	32401862	32840778	33285639	33736526
number of passings vehicle > 3500 kg	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469
total number of passings	30114681	30493213	30876873	31265730	31659855	32059318	32464192	32874551	33290468	33712020	34139282	34572331	35011247	35456108	35906995
annual growth of traffic		1,0125697	1,0125818	1,0125938	1,0126056	1,0126173	1,0126289	1,0126404	1,0126517	1,0126628	1,0126739	1,0126848	1,0126956	1,0127062	1,0127168

Sales revenue	412416215	417600160	422854327	428179667	433577144	439047735	444592431	450212235	455908165	461681252	467532542	473463093	479473979	485566289	491741125

total sales revenue 2012-2026	6763846360

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Sales revenue	412416215	417600160	422854327	428179667	433577144	439047735	444592431	450212235	455908165	461681252	467532542	473463093	479473979	485566289	491741125
costs	67836618	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005
profit	344579597	381288155	386542322	391867662	397265139	402735730	408280426	413900230	419596160	425369247	431220537	437151088	443161974	449254284	455429120

total profit 2012-2026	6187641672



1 (and 2)-Alternative

population growth

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
precentage of population growth		1,55	1,58	1,58	1,58	1,5	1,45	1,4	1,35	1,3	1,25	1,2	1,15	1,075	1
average annual population growth(%)		1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
average annual population growth		1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135	1,0135
total population	177173	179573,1	182005,6	184471,2	186970,1	189502,9	192070	194671,8	197308,9	199981,8	202690,8	205436,5	208219,5	211040,1	213898,9
number of households	59057,67	59857,69	60668,55	61490,39	62323,36	63167,62	64023,32	64890,6	65769,64	66660,58	67563,6	68478,84	69406,49	70346,7	71299,64
number of households owning a car	47246,13	47886,15	48534,84	49192,31	49858,69	50534,1	51218,65	51912,48	52615,71	53328,47	54050,88	54783,07	55525,19	56277,36	57039,71
annual growth of cars		1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546	1,013546

price for each GNSS OBU	1500
population of Trondheim	177173
persons per household	3
number of households	59058
percentage of households owning a car	80
number of households owning a car	47246
total price for GNSS OBUs for all cars	70869200

1-Alternative, costs

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CapEx	83780311,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OpEx	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
Total Cost each year	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887

CapEx for 15 years	83780311,1
OpEx for 15 years	426313305
Total Cost for 15 years	510093616

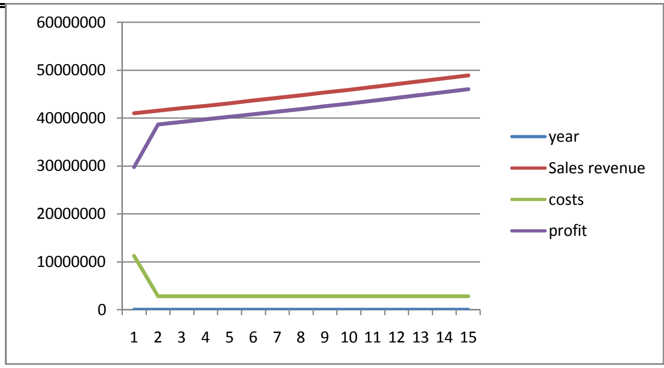
specialized costs	2012
capex	
equipment	6800000
plant	5111111,11
mobile enforcement	1000000
GNSS OBU	70869200
total capex	83780311,1
opex	
salaries and social expences	4330833
whereof salaries for mobile enforcement	3854400
other sales and administrative expenses	20709005
loss on receivables	3381049
total opex	28420887
total amount	112201198

1-Alternative, revenue and profit

yearly traffic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
number of passings vehicle < 3500 kg	27944212	28322744	28706404	29095261	29489386	29888849	30293723	30704082	31119999	31541550,9	31968813	32401862	32840778	33285639	33736526
number of passings vehicle > 3500 kg	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469
total number of passings	30114681	30493213	30876873	31265730	31659855	32059318	32464192	32874551	33290468	33712019,9	34139282	34572331	35011247	35456108	35906995
annual growth of traffic		1,0125697	1,0125818	1,0125938	1,0126056	1,0126173	1,0126289	1,0126404	1,0126517	1,01266283	1,0126739	1,0126848	1,0126956	1,0127062	1,0127168

Sales revenue	409945595	415098485	420321177	425614615	430979758	436417577	441929056	447515195	453177003	458915506	464731742	470626766	476601643	482657456	488795301

total sales revenue 2012-2026	6723326875



revenue	2012
road toll	
vehicles<3500kg	367385600
vehicles>3500kg	39014400
total income road tolls	406400000
wereof additional fee	423326
fee for illegal passages	3545595,2
total amount	409945595

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Sales revenue	409945595	415098485	420321177	425614615	430979758	436417577	441929056	447515195	453177003	458915506	464731742	470626766	476601643	482657456	488795301
costs	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
profit	297744397	386677598	391900290	397193728	402558871	407996690	413508169	419094308	424756116	430494619	436310855	442205879	448180756	454236569	460374414

total profit 2012-2026	6213233259

1-Alternativ, charges

average price on passings, based on 84% use of AutoPASS agreement

	vehicles < 3500kg	vehicles > 3500kg
ordinary tariff	8,32	16,64
weekdays from 7-9 and 3-5	16,64	33,28
E6 Kroppan bridge	5	10
Ranheim	21,248	42,496
Leistad	9,96	19,92
Hommelvik	9,96	19,92

new price for GNSS based tolling,equal to the average AutoPASS price

	vehicles < 3500kg	vehicles > 3500kg
ordinary tariff	8	17
weekdays from 7-9 and 3-5	17	33
E6 Kroppan bridge	5	10
Ranheim	21	42
Leistad	10	20
Hommelvik	10	20

1-Alternative, Enforcement

number of passings each day	98737	kun 9 bomstasjoner
number of passings a year	36039005	
passings by vehicles<3500kg	34222639	
passings by vehicles>3500kg	1816366	
average number of passings per vehicle < 3500kg a year	724,35	
average price per passing (price from 0-alt)	6,9	
average toll charge per vehicle a year	4998,015	
fee for illlegal use of OBU	24990,07	

Fee (average road toll charge)	4998,015
Fine (fee for illicit use of OBU)	24990,07
Gain (what a road user saves on using illicit OBU)	4998,015
Cost (average enforcement cost)	273,2734
e (likelihood of enforcement)	0,33
c (likelihood of compliance)	0,9909
(1-e)	0,67
(1-c)	0,0091
revenue from enforcement	3545595

	enforce	not enforce
comply	(-)fee, fee-cost	(-)fee, fee
not comply	(-)fine, fine-cost	gain, (-)fee

	e	(1-e)
c	(-)4998, 4725	(-)4998, 4998
(1-c)	(-)24990, 24717	4998, (-)4998

Pay off equations for road user
1. e*(-4998) + (1-e)*(-4998)
2. e*(-24990) + (1-e)*(4998)
Pay off equations for toll operator
3. c*(4725) + (1-c)*(24717)
4. c*(4998) + (1-c)*(-4998)

Equilibrium equations:
Eq.1 = Eq.2 => e=0,33
Eq.3 = Eq.4 => c=0,9909

2-Alternative, costs

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CapEx	83780311,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OpEx	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
Total Cost each year	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887

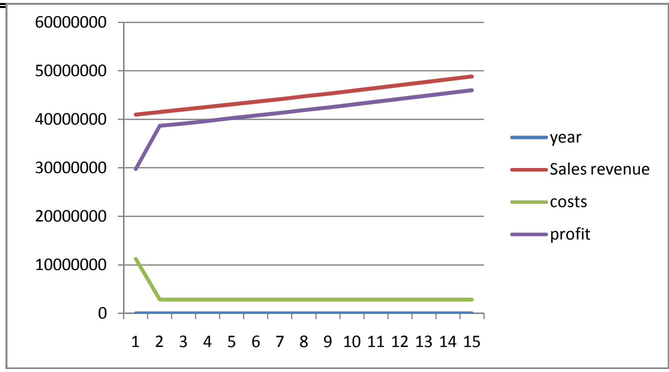
CapEx for 15 years	83780311,1
OpEx for 15 years	426313305
Total Cost for 15 years	510093616

specialized costs	2012
capex	
equipment	6800000
plant	5111111,11
mobile enforcement	1000000
GNSS OBU	70869200
total capex	83780311,1
opex	
salaries and social expences	4330833
whereof salaries for mobile enforcement	3854400
other sales and administrative expenses	20709005
loss on receivables	3381049
total opex	28420887

2-Alternative, revenue

yearly traffic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
number of passings vehicle < 3500 kg	27944212	28322744	28706404,2	29095261	29489386	29888849	30293723	30704082	31119999	31541551	31968813	32401862	32840778	33285639	33736526
number of passings vehicle > 3500 kg	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469	2170469
total number of passings	30114681	30493213	30876873,2	31265730	31659855	32059318	32464192	32874551	33290468	33712020	34139282	34572331	35011247	35456108	35906995
annual growth of traffic		1,0125697	1,01258181	1,0125938	1,0126056	1,0126173	1,0126289	1,0126404	1,0126517	1,0126628	1,0126739	1,0126848	1,0126956	1,0127062	1,0127168

Sales revenue	414927892	420143408	425429574	430787346	436217694	441721602	447300066	452954096	458684715	464492961	470379886	476346554	482394048	488523461	494735903



total sales revenue 2012-2026	6805039204

revenue	2012
road toll	
vehicles<3500kg	371889596
vehicles>3500kg	39492700,5
total income road tolls	411382297
wereof additional fee	423326
fee for illegal passages	3545595,2
total amount	414927892

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Sales revenue	414927892	420143408	425429574	430787346	436217694	441721602	447300066	452954096	458684715	464492961	470379886	476346554	482394048	488523461	494735903
costs	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
profit	302726694	391722521	397008687	402366459	407796807	413300715	418879179	424533209	430263828	436072074	441958999	447925667	453973161	460102574	466315016

total profit 2012-2026	6294945588

2-Alternative, charges

average price on passings, based on 84% use of AutoPASS agreement

	vehicles < 3500kg	vehicles > 3500kg
ordinary tariff	8,32	16,64
weekdays from 7-9am and 3-5pm	16,64	33,28
E6 Kroppan bridge	5	10
Ranheim	21,248	42,496
Leistad	9,96	19,92
Hommelvik	9,96	19,92
average price for passing	11,85466667	23,70933333
average number of passing per trip	2	2
average number of passings a year	30990799,69	1645529,187
average numbers of trips	15495399,84	822764,5934
average price per trip	23,70933333	47,41866667

new price for GNSS based tolling (second solution), equal to the average AutoPASS price

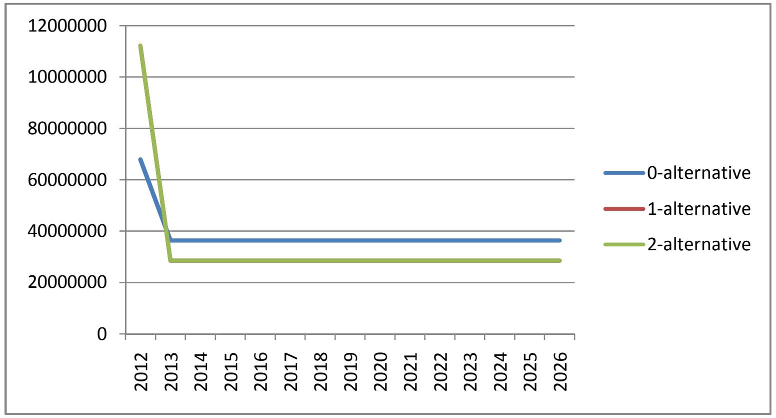
	vehicles < 3500kg	vehicles > 3500kg
red zone, ordinary	25	50
red zone, weekdays between 7-9am and 3-5pm	33	66
yellow zone, ordinary	20	40
yellow zone, weekdays between 7-9am and 3-5pm	27	54
green zone	15	30
average price for entering	24	48
average number of zones entered per trip	1	1
average numbers of trips	15495399,84	822764,5934
average price per trip	24	48
yearly income from toll charge	371889596,2	39492700,48

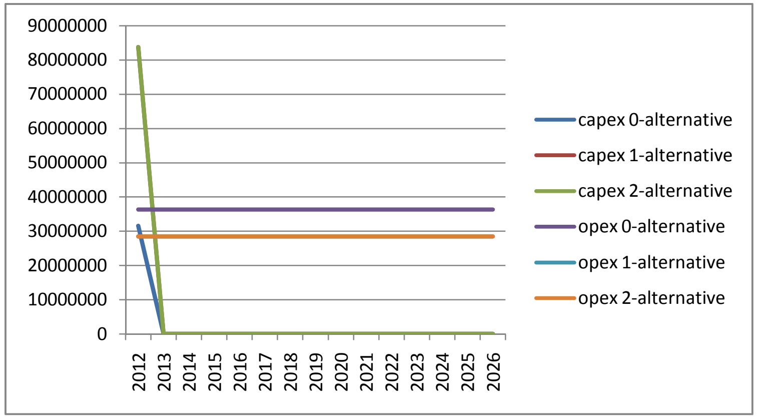
0- vs 1- vs 2-alternative, costs

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
0-alternative	67836618	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005
1-alternative	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
2-alternative	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887

total cost 15 years, 0-alternative	576204688
total cost 15 years, 1-alternative	510093616
total cost 15 years, 2-alternative	510093616

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
capex 0-alternative	31524613	0	0	0	0	0	0	0	0	0	0	0	0	0	0
capex 1-alternative	83780311	0	0	0	0	0	0	0	0	0	0	0	0	0	0
capex 2-alternative	83780311	0	0	0	0	0	0	0	0	0	0	0	0	0	0
opex 0-alternative	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005
opex 1-alternative	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
opex 2-alternative	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887

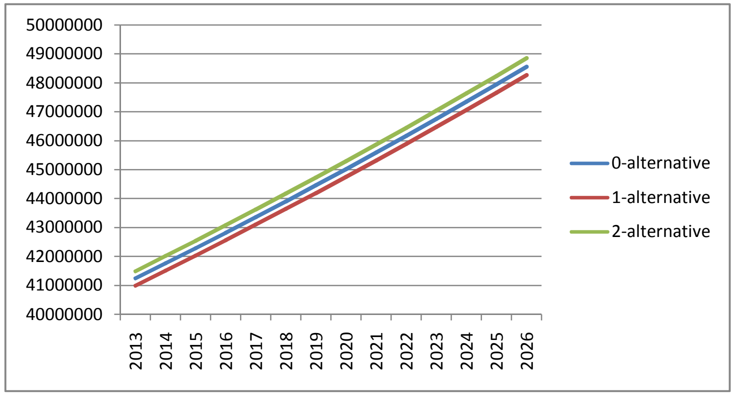




0- vs 1- vs 2-alternative, revenue

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
0-alternative	412416215	417600160	422854327	428179667	433577144	439047735	444592431	450212235	455908165	461681252	467532542	473463093	479473979	485566289
1-alternative	409945595	415098485	420321177	425614615	430979758	436417577	441929056	447515195	453177003	458915506	464731742	470626766	476601643	482657456
2-alternative	414927892	420143408	425429574	430787346	436217694	441721602	447300066	452954096	458684715	464492961	470379886	476346554	482394048	488523461

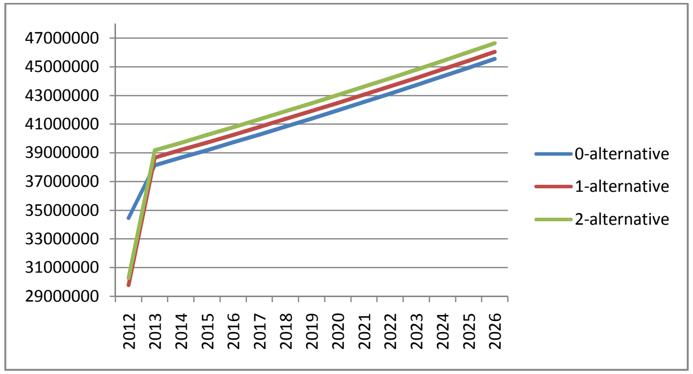
total revenue 15 years, 0-alternative	6763846360	1,0060902
total revenue 15 years, 1-alternative	6723326875	1,0121536
total revenue 15 years, 2-alternative	6805039204	



0- vs 1- vs 2-alternative,profit

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
0-alternative	344579597	381288155	386542322	391867662	397265139	402735730	408280426	413900230	419596160	425369247	431220537	437151088	443161974	449254284	455429120
1-alternative	297744397	386677598	391900290	397193728	402558871	407996690	413508169	419094308	424756116	430494619	436310855	442205879	448180756	454236569	460374414
2-alternative	302726694	391722521	397008687	402366459	407796807	413300715	418879179	424533209	430263828	436072074	441958999	447925667	453973161	460102574	466315016

total profit 15 years, 0-alternative	6187641672	0,982954
total profit 15 years, 1-alternative	6213233259	0,9870194
total profit 15 years, 2-alternative	6294945588	1,0131513



cost-benefit analysis, 0 alt

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
benefits															
income	412416215	417600160	422854327	428179667	433577144	439047735	444592431	450212235	455908165	461681252	467532542	473463093	479473979	485566289	491741125
cost saved by reducing emissions 40%	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271
cost saved on accidents, wear and noise	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000
total benefit	497543486	502727431	507981598	513306938	518704415	524175006	529719702	535339506	541035436	546808523	552659813	558590364	564601250	570693560	576868396
costs															
opex	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005
capex	31524613	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total cost	67836618	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005	36312005
calculated benefit	429706868	466415426	471669593	476994933	482392410	487863001	493407697	499027501	504723431	510496518	516347808	522278359	528289245	534381555	540556391

total calculated benefit	7464550737

Trondheim area:	
total driver km per day	3100000
emissions per day:	
from Nox (kg)	375,1
from PM10 (kg)	20,77
total CO2 emissions per day (kg)	395,87
total CO2 emissions per year (kg)	144492,55
cost of daily CO2 emissions (NOK)	40563,5
cost of annual CO2 emissions (NOK)	14805677,5
saved by reducing emissions 40%	5922271
daily cost of accidents, wear and noise:	
accidents (NOK)	310000
wear (NOK)	15500
noise (NOK)	217000
total daily cost of accidents, wear and noise	542500
total annual cost of accidents, wear and noise	198012500
saved by reducing traffic by 40%	79205000

cost-benefit analysis, 1 alt

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
benefits															
lapsed costs	-44364580	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118
quantifiable benefits															
income	409945595	415098485	420321177	425614615	430979758	436417577	441929056	447515195	453177003	458915506	464731742	470626766	476601643	482657456	488795301
cost saved by reducing emissions 40%	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271
cost saved by reducing accidents,wear and noise	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000
total benefit	450708286	508116874	513339566	518633004	523998147	529435966	534947445	540533584	546195392	551933895	557750131	563645155	569620032	575675845	581813690
costs															
opex	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
capex	83780311,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total cost	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
calculated benefit	338507088	479695987	484918679	490212117	495577260	501015079	506526558	512112697	517774505	523513008	529329244	535224268	541199145	547254958	553392803

total calculated benefit	7556253396

cost-benefit analysis, 2 alt

	2012	2013	2014	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
benefits														
lapsed costs	-44364580	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118
quantifiable benefits														
income	414927892	420143408	425429574	436217694	441721602	447300066	452954096	458684715	464492961	470379886	476346554	482394048	488523461	494735903
cost saved on emissions by yellow zone (40%)	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271	5922271
cost saved on reducing A,W and N by yellow zone (40%)	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000	79205000
cost saved on emissions by red zone (20%)	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082
cost saved on reduced A,W and N by red zone (20%)	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000
total benefit	461182665	518653879	523940045	534728165	540232073	545810537	551464567	557195186	563003432	568890357	574857025	580904519	587033932	593246374
costs														
opex	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
capex	83780311,1	0	0	0	0	0	0	0	0	0	0	0	0	0
total cost	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
calculated benefit	348981467	490232992	495519158	506307278	511811186	517389650	523043680	528774299	534582545	540469470	546436138	552483632	558613045	564825487

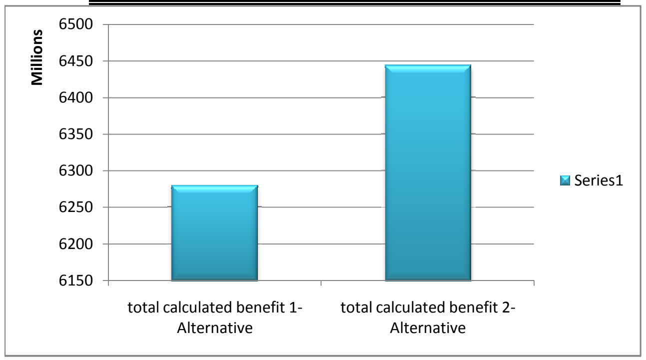
total calculated benefit	7720346955

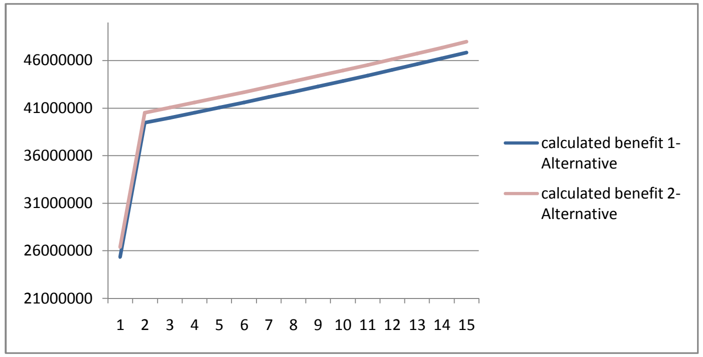
Trondheim central area:	
total driver km per day	400000
emissions per day:	
from Nox (kg)	48,4
from PM10 (kg)	2,68
total CO2 emissions per day (kg)	51,08
total CO2 emissions per year (kg)	18644,2
cost of daily CO2 emissions (NOK)	5234
cost of annual CO2 emissions (NOK)	1910410
saved by reducing emissions 20%	382082
daily cost of accidents, wear and noise:	
accidents (NOK)	40000
wear (NOK)	2000
noise (NOK)	28000
total daily cost of accidents, wear and noise	70000
total annual cost of accidents, wear and noise	25550000
saved by reducing traffic by 20%	5110000

cost and benefit 1-Alternative and 2-Alternativ vs 0-Alternative

1-Alternative	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
benefit															
income	409945595	415098485	420321177	425614615	430979758	436417577	441929056	447515195	453177003	458915506	464731742	470626766	476601643	482657456	488795301
lapsed cost	-44364580	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118
total benefit	365581015	422989603	428212295	433505733	438870876	444308695	449820174	455406313	461068121	466806624	472622860	478517884	484492761	490548574	496686419
costs															
opex	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
capex	83780311,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total costs	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
calculated benefit 1-Alternative	253379817	394568716	399791408	405084846	410449989	415887808	421399287	426985426	432647234	438385737	444201973	450096997	456071874	462127687	468265532
2-Alternative															
benefit															
income	414927892	420143408	425429574	430787346	436217694	441721602	447300066	452954096	458684715	464492961	470379886	476346554	482394048	488523461	494735903
cost saved on emissions by red zone (20%)	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082	382082
cost saved on reduced A,W and N by red zone (20%)	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000	5110000
lapsed cost	-44364580	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118	7891118
total benefit	376055394	433526608	438812774	444170546	449600894	455104802	460683266	466337296	472067915	477876161	483763086	489729754	495777248	501906661	508119103
costs															
opex	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
capex	83780311,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total costs	112201198	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887	28420887
calculated benefit 2-Alternative	263854196	405105721	410391887	415749659	421180007	426683915	432262379	437916409	443647028	449455274	455342199	461308867	467356361	473485774	479698216

total calculated benefit 1-Alternative	6279344331
total calculated benefit 2-Alternative	6443437890





Cost and benefit, 0- vs 1- vs 2-Alternative

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
calculated benefit 0-Alternative	429706868	466415426	471669593	476994933	482392410	487863001	493407697	499027501	504723431	510496518	516347808	522278359	528289245	534381555	540556391
calculated benefit 1-Alternative	338507088	479695987	484918679	490212117	495577260	501015079	506526558	512112697	517774505	523513008	529329244	535224268	541199145	547254958	553392803
calculated benefit 2-Alternative	348981467	490232992	495519158	500876930	506307278	511811186	517389650	523043680	528774299	534582545	540469470	546436138	552483632	558613045	564825487

total calculated benefit 0-Alternative	7464550737	
total calculated benefit 1-Alternative	7556253396	1,0122851
total calculated benefit 2-Alternative	7720346955	1,0342681