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Thermal control of heavy vehicles

System design and impact on tunnel projects

Fredrik Omdal

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Name: Fredrik Omdal				
Professor in charge/supervisor: Arvid Aakre				

Abstract:

This master thesis examines the possibility of implementing a thermal control for heavy vehicles on the north side of the new undersea tunnel of Rogfast. The safety aspect is the reason for implementing, and it will be the first of its kind in Norway if built. An automatic control is wanted, without the presence of personnel, which is not the standard for similar controls in other mountainous countries. It was therefore developed flowcharts describing different possible ways to execute such a control. These flowcharts served as a base when general solutions later were made for the different alternatives, including plans over signing and marking necessary. These general solutions were made such that other similar projects also can make use of them, and therefore only need small changes according to the projects parameters. Based on these general solutions, the area for the Rogfast project was examined, and the solutions most fitting to the project was chosen for further work. These solutions were modelled and further narrowed down to two final proposals that also include plans for signing and marking of the area. The software's used to make the different designs was AutoCAD and Novapoint. Finally, a small economic analysis was conducted. This to examine the possible positive impacts a control of this kind could have on a project.

Keywords:

1. Thermal control
2. Heavy vehicles
3. Tunnel
4. Design

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Preface

This master thesis is written by Fredrik Omdal at the Department of civil and transport engineering at the Norwegian University of Science and Technology (NTNU) in cooperation with the Norwegian public road authorities (NPRA). This thesis builds on a pre-study conducted in the fall of 2015 as a part of the course TBA4542, and was compiled during the summer and early fall in cooperation with NPRA and NTNU. The master thesis is the final stage of the Master of Science at NTNU and is credited 30 points under the course TBA 4945 Transport in the spring of 2016.

The theme for the thesis was chosen out of own interest for the large undersea tunnels being constructed in my home region. I wanted to be a part of one of these groundbreaking projects, and found an interesting subject after talking to the project manager of Rogfast. The theme was further narrowed down and specified in cooperation with my supervisor at NTNU before the start of the pre-study.

Two appendices follow the thesis. One directly after, and one external. The external appendix contains all the CAD-drawings in a larger format to make it possible to read.

Big gratitude is directed towards my main supervisor at NTNU, Arvid Aakre, for guidance and help along the process. Big thanks also goes to the NPRA for giving me an exciting task within the project I wanted to work on, as well as for assistance. I would also like to thank Norconsult for help and support along the way.

Trondheim, June 2016

Fredrik Omdal

Abstract

In recent years, there have been multiple cases of fires and potential fires in Norwegian tunnels. This has made the question about implementation of a thermal control on heavy vehicles before they enter the tunnel highly actual. The Norwegian public road administration wants a solution like this to detect and get rid of the vehicles with bad conditions before they enter the new undersea tunnel of Rogfast, and therefore reducing the probability of a tunnel fire significantly. A control like this has never been implemented before in Norway, and very few other places in Europe. This makes the knowledge base very limited, and the need for a solution fitted to the Norwegian conditions and regulations is high. It is important to find out what effects such a control have on the geometrical design of the area, this will again lead to new signing, marking, and maybe some special conditions needed to look upon. How the system will be executed in combination with the surroundings, and the effect it will have on the economy of the projects, are key elements to examine.

The thesis is written in collaboration with the Norwegian public road authorities, and builds on a term paper conducted in the fall of 2015 with the same theme. The work of the thesis includes:

- Literature search on different subjects as thermal theory/solutions/real life implementations, minimum demands concerning signing and marking, accidents involving fire, and probabilities/scope of these accidents.

- Development of flowcharts, based on ideas from the term paper, describing the different parts and actions of a thermal control before entering a tunnel.

- Constructing general solutions based on the developed flowcharts, as well as the minimum demands found in literature.

- A real life example, showing how the general solutions can be used on an actual project with minor adaptions.

- A minor economic analysis showing the possible savings of such a control.

The work went systematically forward according to the main subjects listed over, with the modeling of the general solutions and Rogfast as the two main time consuming activities. A lot of the literature found were easily accessible from the NPRA website and other contacts from the NPRA, while other literature were found using the university library among other search engines. The development of the flowcharts were first made by hand on paper, and then implemented in Latex using the Tikz package. All the drawings and calculations in the general solutions and the real life example of Rogfast were made using AutoCAD and Novapoint. The economic evaluation was conducted in Excel, and the writing as a whole was done in Latex.

The results of this thesis includes:

- Flowcharts describing six different ways to execute a thermal control based on theory and previous experience.

- General solutions in correct scale of these six alternatives based on the flowcharts and the theory concerning minimum demands for signing and marking.

- An example of implementation in a real life project, including complete geometrical drawings as well as plans for marking and signing of the area for several solutions after considering the different alternatives. Here it is shown how the flowcharts and general solutions can be used, with minor adaptions, to speed up the design process.

- A small economic analysis showing how a thermal control can contribute notable to reduce accident costs related to fire in vehicles.

Directly connected to the topic of this thesis, further studies may be needed on subjects as: new solutions and systems for detecting vehicles with thermal faults that may be executed in higher speeds and in normal traffic, more thorough safety estimates of implementing this kind of control on projects, and the costs of building the control and the control area. This included the cost of maintenance per year to be able to conduct a benefit-cost analysis using the benefits from this paper.

Sammendrag

I de siste årene har det vært flere tilfeller av branner og tiløp til branner i norske tunneler. Dette har gjort at spørsmålet om å innføre en termisk kontroll av tunge kjøretøyer i forbindelse med tunneler meget aktuelt. Statens Vegvesen ønsker en løsning som dette for å detektere og bli kvitt de kjøretøyene som er i dårlig stand før de kjører inn i den nye undersjøiske tunnelen Rogfast, og dermed redusere sannsynligheten for en tunnelbrann signifikant. En kontroll som dette har aldri før blitt implementert i Norge, og ytterst få steder ellers i Europa. Kunnskapsbasen er derfor svært begrenset, dette gjør behovet stort for en løsning tilpasset norske forhold og bestemmelser. Det er viktig å finne ut hvilken effekt en slik kontroll vil ha på den geometriske utformingen av området, og hvilke krav dette igjen vil stille til skilting og oppmerking av området. Det må også undersøkes om en slik kontroll fører til noen nye utfordringer som må ses på. Hvordan systemet vil bli utført i kombinasjon med omgivelsene, og hvilken påvirkning det vil ha på prosjektets økonomi, er andre nøkkelelementer å undersøke.

Denne masteroppgaven er skrevet i sammarbeid med Statens vegvesen, og bygger på prosjektoppgaven med samme tema gjennomført høsten 2015.
Masteroppgaven omfatter følgene elementer:

- Literatursøk på flere området som: termisk teori/løsninger/implementasjoner i virkeligheten, minimumskrav knyttet til skiltning og oppmerking, ulykker i tilknytting til brann, og sannsynligheten/omfanget av slike ulykker.

- Utviklingen av flytskjemaer, basert på ideer fra prosjektoppgaven, som beskriver de forskjellige elementene en termisk kontroll krever.

- Konstrueringen av generelle løsninger basert på de utviklede flytskjemaene, samt minimumskravene funnet i litteraturen.

- Et eksempel fra virkeligheten som viser hvordan de generelle løsningene, med små tilpassinger, kan bli brukt på et faktisk prosjekt.

- En liten økonomisk analyse som viser den mulige nytten ved implementering av en slik kontroll.

Arbeid skred frem systematisk etter temaene nevnt over, med modelleringen av de generelle løsningene og Rogfast som de to mest tidskrevende temaene. Mye av litteraturen ble innhentet uten problemer fra Statens vegvesen sine hjemmesider eller via kontaktpersoner hos dem, mens annen litteratur ble funnet ved å bruke universitetsbiblioteket og andre søkemotorer. Utviklingen av flytskjemaene ble først gjort for hånd på papir før de ble finalisert og gjort ordentlig i Latex ved å bruke tileggspakken Tikz. Alle tegningene og kalkulasjonene vedrørende de generelle løsningene og eksempelet fra virkeligheten på Rogfast ble utført ved å bruke AutoCAD og Novapoint. Den økonomiske evalueringen ble gjennomført i Excel, og skrivingen i sin helhet ble gjort i Latex.

Resultatene fra denne masteroppgaven omfatter:

- Flytskjemaer som beskriver seks forskjellige måter å utføre den termiske kontrollen på basert på teori og tidligere erfaringer.

- Generelle løsninger i korrekt skala for alternativene som baserer seg på flytskjemaene og teorien omfattende minimumskrav for skilting og oppmerking.

- Komplette geometriske tegninger samt planer for skilting og oppmerking av området på Rogfastprosjektet for flere løsninger etter å ha vurdert de forskjellige alternativene. Her er det vist hvordan flytskjemaene og de generelle løsningene kan bli brukt, med små endringer, for å minimiere tiden brukt på utviklingen av løsningene på et faktisk prosjekt.

- En liten økonomisk analyse som viser hvordan en termisk kontroll kan bidra merkbart til å redusere ulykkeskostnader knyttet til brann i kjøretøyer.

Knyttet til denne masteroppgaven, vil videre studier være nødvendig på temaer som nye løsninger og systemer for detektering av kjøretøyer med termiske feil som kan bli utført i høyere fart og i normal trafikk, mer dyptgående estimater av sikkerhetsforbedringer ved å innføre en slik kontroll på prosjekter, og kostnadene knyttet til å bygge kontrollen og området rundt.Dette inkludert kostnadene for vedlikehold per år for å kunne utføre en kost-nytte analyse basert på nytten beskrevet i denne oppgaven.

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Chapter 1

Introduction

In recent years, there have been multiple cases of fires and potential fires in Norwegian tunnels. This has made the question about implementation of a thermal control on heavy vehicles before they enter the tunnel highly actual. The Norwegian public road administration wants a solution like this to detect and get rid of the vehicles with bad conditions before they enter long tunnels in new projects, and therefore reducing the probability of a tunnel fire significantly in these tunnels. A control like this has never been implemented before in Norway, and very few other places in Europe. This makes the knowledge base very limited, and the need for a solution fitted to the Norwegian conditions and regulations is high. Chapter 2 in this thesis therefore looks into the theory and background for a thermal control.

It is then important to find out what effects such a control will have on the geometrical design of the area. This will again lead to new signing, marking, and maybe some special conditions needed to look upon. Chapter 3 addresses some theory concerning the signing and marking with respect to the Norwegian regulations, and gives examples of signs and marking that will be needed in a project that has a thermal control. Concerning the geometrical design of the area, chapter 4 looks into several different possibilities to execute the control. It shows the different elements needed, either being accepted or not, and the consequences for vehicles being rejected in the thermal control. In this chapter different alternatives is defined and described, before a flowchart for the given alternative is presented as well as both a geometrical solutions and a plan for signing and marking. These drawings are presented as an overview, and is better described in larger scale in the external appendix.

How the system will be executed in combination with the surroundings, and show how it can be implemented on an actual project is described by working with the new undersea tunnel of Rogfast which will be built on the western coast of Norway. This is a large project, and will serve as a great real life example of how a thermal control can be implemented before the tunnel to reduce accidents involving fire in heavy vehicles. In Chapter 5 the project as a whole is first described, before presenting some of the key regulations and dimensions of the project. Based on these restrictions two of the alternatives that are most suited is examined further, showing how the general solutions can be worked with in a specific project with

minor alterations. The alternatives are further modeled and discussed before a recommendation is given. These drawings are also just given as an overview, and can be found in a larger format in the same external appendix as the general solutions.

In Chapter 6 the effect a thermal control can have on the economy of a project is described. It is in this chapter first looked into previous accidents involving fires, and some background related to economic parameters. From this it is deducted some probabilities and likely scenarios that can occur without a thermal control. These scenarios are then linked with the socioeconomic costs of accidents and delays, in addition to the direct cost of the accident itself. To sum up and show the impact a thermal control can have on a projects economy, some key numbers concerning the possible savings by preventing accidents is presented.

Lastly, in Chapter 7 the thesis is concluded and possible further work is discussed.

Chapter 2

Thermal control

2.1 Need for thermal control

In the recent years, there have been multiple cases of serious fires in road tunnels both in Norway and in Europe. Some examples worth mentioning are[3]:

- The fires in Gudvangatunnelen. One of these fires reached a strength of 30-40MW. 88 persons were evacuated and 66 of those treated for smoke injuries. The tunnel closed for 6 and 2 weeks following the fires.

- The fire in Oslofjordtunnelen. This fire reached 70-90 MW in strength and 34 persons were evacuated. 31 of these treated for smoke injuries. The tunnel closed for over 2 weeks following the fire.

- The fire in the Mont Blanc Tunnel. This fire reached an estimated strength of 200MW and demanded 39 lives and a lot more injured. The tunnel closed for three years following the accident.

- The fire in the St. Gotthard tunnel. This fire reached an estimated strength of 200MW and demanded 11 lives and a lot more injured. The tunnel closed for 2 months following the accident.

In an analysis made by the Institute of Transport Economics in Norway, the extent of fires in Norwegian tunnels coming from vehicles in the years from 2008 to 2011 is examined.[15] It is here stated that driving in a tunnel is normally as safe, or safer, as driving in an open air environment. However, the potential disaster coming from a fire in a tunnel is at a much higher level. The analysis show that there is an average of 21.25 fires per year per 1000 tunnels. The same number for smoke without fire is 12.5. There is usually no harm to people or the tunnels and only 8 minor and 8 major cases of injury among people were found of the 135 instances of fire in these 4 years. 40 of these 135 incidents damaged vehicles and 20 did damage to the tunnel. Technical problem was the main cause for accidents related to heavy vehicles, both for fire and for smoke.

When it comes to which type of tunnels that are most exposed for accidents, undersea tunnels are overrepresented in comparison to other types of tunnels. The 41 tunnels that are either undersea or have a heavy gradient, which is about 4 % of the total number of Norwegian tunnels, have 44 % of the accidents involving fire or smoke. In these accidents heavy vehicles were the main group, and technical problems the main cause of the accidents.

To sum up, the need for improvement is big at undersea tunnels, and especially for heavy vehicles involving technical problems. One way of coping with this problem will be to implement a thermal control before entering the tunnel.

2.2 Theory

2.2.1 Thermography

All bodies over the absolute zero temperature of $-273.15\,°C$ emits electromagnetic radiation. This forms the base for infrared thermography, while there is a correlation between the surface and the spectral composition of the emitted radiation from a body. This means that if you can determine the radiation intensity of a body, you can find the temperature without needing to be in contact with it.[7]

Infrared light is the part of the electromagnetic spectrum that lies just after the red color in the visible light section, ranging from $0.76\,\mu m$ to $1000\,\mu m$. The part of the range that is used for temperature measurement is only from $0.76\,\mu m$ to $20\,\mu m$, this while the energy available beyond $20\,\mu m$ is very hard to detect using current IR detectors.[7]
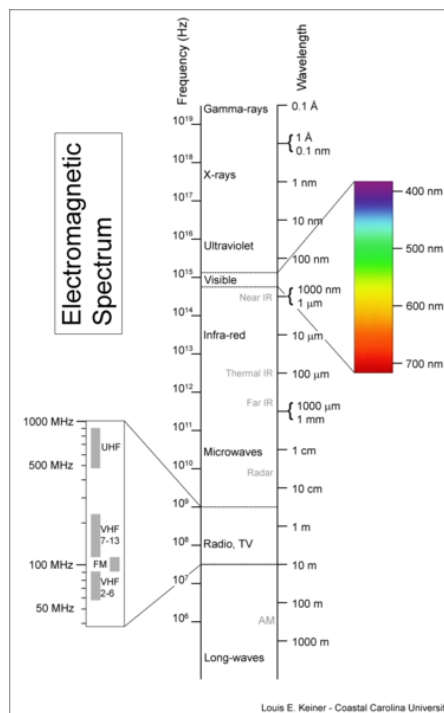
Figure 2.1: The Electromagnetic Spectrum

Electromagnetic waves, including heat radiation, behaves similar to visible light. The principles of measuring, detecting and making use of it in applications therefore gets easier when thinking of it as visible. The infrared energy travels in straight lines between the source until it reaches other surfaces who reflects and/or absorbs the energy. How much that is absorbed and reflected of the energy from a surface of a body is known as the emissivity of the material.

To describe the emissivity of a body it is assigned a value ranging from 0 to 1.0. This is given with the base in a theoretical Black Body, stated by Kirchhoff's law of thermal radiation.[4]

$$\alpha_\lambda = \epsilon_\lambda \tag{2.1}$$

where α is the absorptivity, and ϵ is the emissivity.

This law describes that an object at thermal equilibrium will absorb the same amount as emitted, and is known as a perfect black body.

Planck's radiation law describes the spectral spread of the emitted radiation from a black body.[4]

$$M_\lambda = \frac{c_1}{\lambda^5 * [e^{\frac{c_2}{\lambda * T}} - 1]} \tag{2.2}$$

where

$$c_1 = 3,74 * 10^{-16} W m^2$$
$$c_2 = 1,44 * 10^{-2} K m$$

M is the exitance, and λ is the wavelength.

This kind of substance does not occur in nature but is given the value 1.0 for theoretical reasons. The contrary will be a substance of the value 0, which reflects and transmits all infrared energy. This means that different materials will emit infrared energy at different temperatures, according to the materials molecular structure and its surface characteristics. In other words, the spectral composition

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of the radiation emitted from the body varies with its temperature.

To get the spectral radiation intensity over all wavelengths from the body, and therefore the value of the entire radiation emitted, you can integrate over the specter of wavelengths. This is known as the Stefan Boltzmann's law.[10]

$$M = \sigma * T^4 \tag{2.3}$$

where
$$\sigma = 5,67 * 10^{-8}\frac{W}{m^2 K^4}$$

M is the exitance, and T is the temperature.

This is a much more practical and applicable value, and can be used for calculations like estimating the heat balance of objects, while the law states that the hotter an object becomes, the more infrared energy it emits.

When looking into Plack's radiation law, you can see that the wavelength where a black body emits maximum radiation shifts depending on the temperature. This phenomenon is described by a derived function named Wien's displacement law.[10]

$$\lambda_{max} * T = 2896\mu mK \tag{2.4}$$

where λ is the wavelength, and T is the temperature.

This formula shows that the warmer a body get, the more the radiation shifts towards smaller wavelengths, and vice versa.

2.2.2 Thermal cameras

Therefore, as we see, the emittance of objects to be measured is strongly dependent on the wavelength. Factors that can influence the measurement is the material composition, surface roughness, angle to the surface, the degree of polarization, oxide films on the surface among others. Another factor that affects the results when measuring the emittance of an object is the wavelength sensitivity of the sensors. This is known as the sensors' spectral response.[7] Basic infrared thermometer design consist of a lens collecting the energy emitted by the measured body. It has a detector for converting the measured energy into an electrical signal, and an emissivity adjustment to match the calibration of the sensor in respect to the characteristics of the measured object. It also has an ambient temperature compensation circuit to avoid that variation within the temperature is transferred to the final output. This kind of design is limited in application area and struggle to have satisfactory measurements.

Figure 2.2: Example of an infrared photography

The modern infrared thermometers build on this simple concept but is further enhanced to improve the application area and measurement output. Some of the features included in the modern thermometers are a greater variety of sensors, they filter the infrared signal selectively, the output is linearized and amplified, and the final outputs is standardized as for example mA or Vdc. Especially the selective filtering of the signal has helped making the infrared thermometers better.[7]
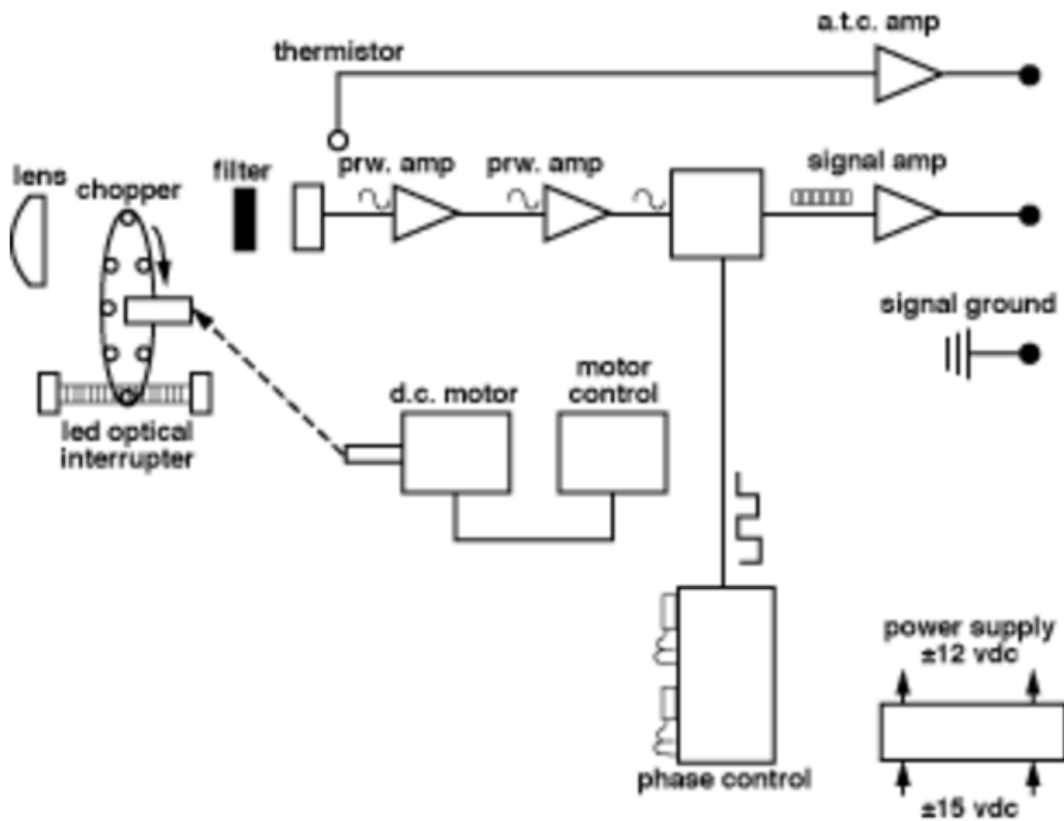
Figure 2.3: Overview of the different parts of a modern infrared thermometer

2.2.3 Control by thermal cameras

The "'Nasjonal tiltaksplan for trafikksikkerhet på veg 2014-2017"' states that it is in particular the control of breaks and the securing of the load that can be expected to contribute to a reduction of fatalities and severe damages in traffic. It further states that the NPRA will continue their work in specifying their controls based on this. The goal is to concentrate more on the vehicles expected to have faults, and therefore the controls should be executed when the effect on safety is highest. They also see that foreign vehicles more often come with faults, especially during winter conditions. The amount of controls on breaks and accompanying parts of the vehicle system is intended to be increased, and thermal cameras can be used in the selection of vehicles that is going to be controlled when it comes to brakes, wheels and the power train. This has been tested on the control station and will be implemented as a normal part of the control. High-speed thermography, that includes selection of vehicles will be tested out, and the NPRA will also consider the possibility of using video systems to measure physical sizes like height, length, and number of axles. One of the follow-up measures of this plan that shows the importance of thermal cameras in future controls is formulated as follows: The NPRA will take in use thermography as an ordinary part of the control of vehicles to discover faults in breaks.[24]

2.3 Examples of implementation

In this section, some examples of projects that have taken thermal solutions in use are presented.

2.3.1 St.Gotthard

Following the main principles from the system used in the St.Gotthard tunnel in Switzerland are presented. The information and figures are extracted from a summary made by the NPRA after inspecting the system in Switzerland.[23]

The heavy vehicles are measured when approaching the tunnel by using thermal cameras and laser scanners hanging in a portal over the road. This is done while in motion on the road, but while driving in a dedicated lane for heavy vehicles.

Figure 2.4: Thermal portal at St. Gotthard in Switzerland
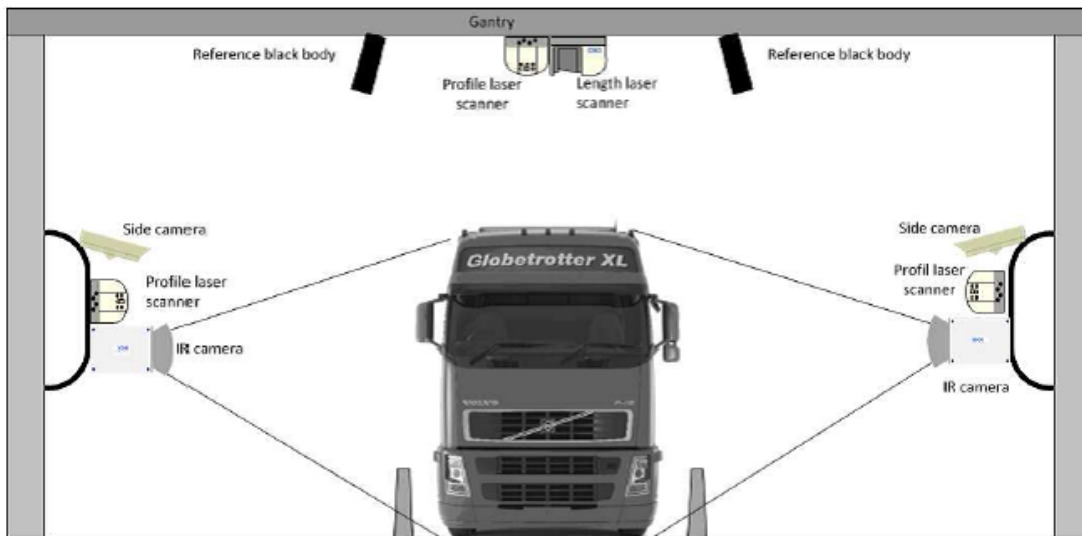
Figure 2.5: Illustration of infrared cameras at the thermal portal
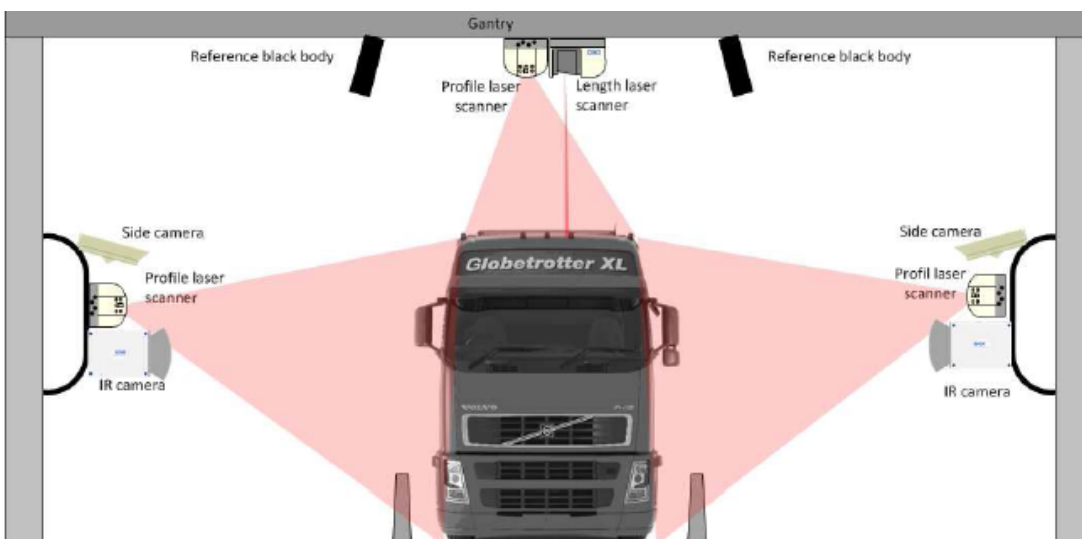
Figure 2.6: Illustration of laser scanners at the thermal portal

The thermal cameras measures and shows eventual hotspots on the vehicle, while the laser scanners measures the length and width of the vehicle.

This gives a 3D-image of the vehicle including the eventual hotspots as shown under.

Figure 2.7: Example of 3D image with thermal results obtained from the thermal portal

This image can be rotated and examined further on the operators screen. If the system detects a violation of the maximum values allowed, the vehicle will be taken out of the road for further control. As shown in a flowchart over the system on the next page produced by SICK, the company who delivers this solution, the time from the vehicle has driven through the portal and been measured to the analysis is done should take a maximum of 5 seconds. The flowchart also describes other elements of the system not relevant for this topic.
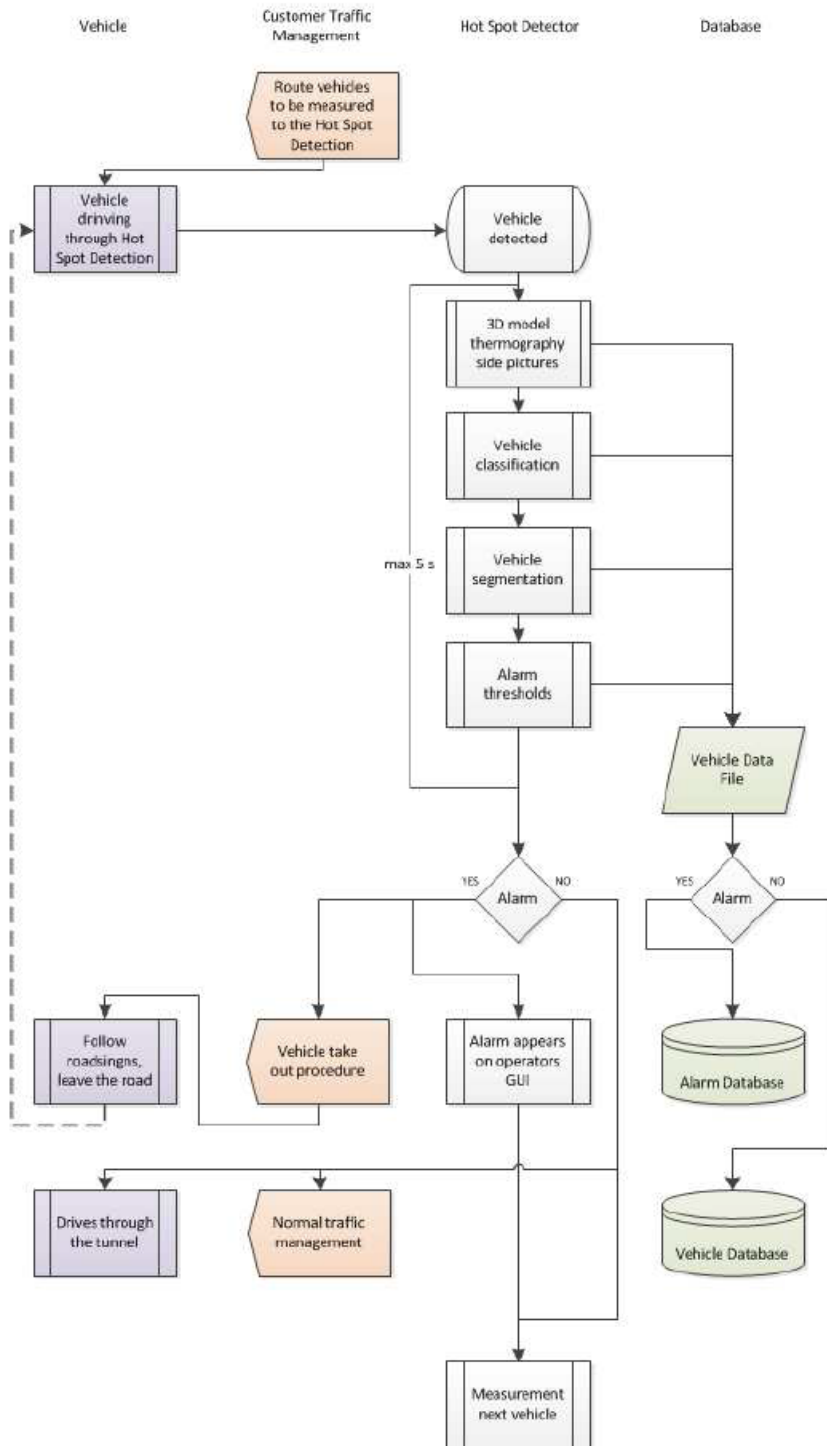
Figure 2.8: Flowchart describing the thermal control system delivered by SICK

2.3.2 Karawanken tunnel

Similar to the St.Gotthard tunnel the Karawanken tunnel on the border from Austria to Slovenia makes use of a hotspot detection system delivered from SICK's subsidiary ECTN AG. This system is very similar to the one described in the previous example and uses the combination of data by measurements coming from both thermal imaging cameras and laser measurements sensors. The measurement is done from a portal in free flow traffic, but on a dedicated lane for vehicles weighing more than 7,5 tons. The accepted vehicles continue and is implemented on the main road again, while the rejected ones is taken out by signal and barrier and have to drive to a dedicated parking area to cool down before trying again.[1]

2.3.3 Mont Blanc Tunnel

After the large fire in 1999 there were made several security upgrades to this tunnel before reopening in 2002. One of these features was to install infrared heat sensors at both ends of the tunnel to detect overheated heavy vehicles before they enter the tunnel similar to the other two examples mentioned. This also is done by driving in a dedicated lane and passing a portal containing the sensors before being accepted or rejected. Once rejected the trucks has to cool down before they can be reimplemented in the traffic.[13]

2.4   Summary

Other manual solutions, both in measuring and monitoring, are possible and is in use on different control stations. However, considering the labor this will need to have, an automatic system like the ones described seems to be a better solution. These solutions are also firmly tested in other projects similar to the ones mentioned, and have proven their worth detecting possible dangerous vehicles. The common denominator of these solutions is that there is a need for a dedicated lane for the vehicles going to be checked and a certain length after the control to process the results. There also seems to be a limit to how fast you can drive through the portal, and a minimum headway between the vehicles is needed. An area for the rejected vehicles to cool down, and possibly be checked manually, should be situated close by.

Chapter 3

Signing and marking

3.1 Signing theory

3.1.1 General

As of the sign paragraph §2 the validity and area of effect is as follows[20]:

- Public signs is valid from the time of installation and disclosure.

- It is valid for the allowed driving direction and for the group of drivers it is pointed towards. If there is multiple lanes in the same driving direction and there is signing over the particular lanes, they are only valid for this lane.

- They can be designed so that they show two or more different symbols and/or texts. In this case, they can differ a bit from the regulations.

Traffic signs are an important part of the system that inform, warn and lead the driver, and it therefore has a major impact on the roads safety and effectiveness. Only signs described by the regulations are statutory, other signs are not mandatory to follow or to know the meaning of. The Norwegian signing follows the guidelines given in the Vienna Convention in 1968, and Geneva Convention in 1971, 1973 and 1975. These European collaborations is formed to ease the international traffic and to have consistent signing throughout Europe. It also follows the Norwegian road-law and regulations, any exception from these has to be applied for.

A traffic sign shall deliver a message to the road users, and the message should result in a wanted action or behavior. For this to happen the road user must under any circumstances and visibility situations be able to:

- discover the sign

- perceive or read the message of the sign

- understand the message of the sign

- believe and respect the signage

- access and react on the message

This process should occur in the matter or seconds, and often under difficult conditions and with other disturbances. This puts restrictions on what we are able to perceive and read, and it therefore limits the load of information that can be given on a single sign. This leads to a need for regulations on design, placement and number of signs. You should therefore have as few signs as possible, but as many as necessary. This implies a restrictive use of signing to only where it is needed to understand and perceive the traffic situation or regulations. The signs should have simple, short, clear and uniform meanings. Figures that are intuitive is easier to understand than text, and the combination of figure and text could be hard to understand and should be avoided if possible.

3.1.2 Placement and design

The signs should not be at, or directly succeeding, retardation or acceleration lanes. The free sight to the sign should be as given in table under:

Speed limit	Distance
50 km/h	70m
60 km/h	80m
70 km/h	100m
80 km/h	110m
90 km/h	130m
100 km/h	140m

Table 3.1: Free sight distances needed to signs at different speed limits

The distance will be longer for directional signs. Distance between signs referring to the same driving direction should have a distance of minimal 100 meters between them if there are no competition of space, down to a minimum of 50 meters if space is scarce. If shorter distance is needed, the visibility and readability of the signs have to be examined thoroughly. Overhanging signs could be used to refer to a specific lane.

The signs must not hinder the sight to the next one, and the side placement should be as follows:

Speed limit	Distance
<=60 km/h	0,5m<x<2,0m
70 or 80 km/h	1,0m<x<3,0m
>=90 km/h	1,5m<x<4,0m

Table 3.2: Side placement of signs according to speed limits

The size of the sign itself will be accordingly:

Speed limit	Lanes	Size
50 km/h	Twolane	LS
	Multilane	MS
60 to 80 km/h		MS
90 km/h	Twolane	MS
	Multilane	SS
100 km/h		SS

Table 3.3: Sign sizes according to speed limits

When it comes to the reflectiveness of the signs there are three classes,1,2,3, where 1 reflects the most and 3 the least.[19] In the following table the class is given in rural areas for each group of sign that are relevant. If there are a combination of two classes on a sign, or more than one sign at the same pole, the highest class is chosen.

Sign Group	Class
All signs not lighted	3
Danger signs	2
Yield signs 202,204,210,212	2
Yield signs 206,208,214	1
Prohibition signs	1
Injunction signs	1
Information signs	1
Service signs	1
Direction signs	1
Complimentary signs	Same as main
Guidance signs	3
902,904	2

Table 3.4: Sign reflectors for relevant signs

Information should be signed in English as well as in Norwegian.

3.2 Relevant signing

In this section the signing needed for making an area for a thermal control is described and shown. The names given to each section is later used in the flowcharts presented in chapter 4. The figures of the different signs as well as parameters are taken from the NPRA handbook N300.[20] The text shown inside the figures are in Norwegian.

Only the signs that are needed for the specific solutions will be taken into consideration. Signs describing factors that does not have anything to do with the thermal control, as for example signing needed for the tunnel, are not taken into consideration here. Additional signing can also prove to be necessary if there is some special situations to consider in a project.

A violation control is recommended on both the lane that is not meant for heavy vehicles, as well as one the one meant for heavy vehicles after the separation signal. This to control that vehicles does not skip the control, or ignore the result of the control.

3.2.1 Information of control

To inform drivers of the control, it could be used a version of the sign 560 with text similar to "Thermal control of heavy vehicles", in combination with sign 558 to inform the drivers that the control is automatic. Some control stations in Norway uses a variable message sign instead of a static one, but since this control is automatic an active all the time, the need for a sign that can be turned off is limited. Extra information on the sign regarding the route or distance to the control could exclude the need for sign 306.5 in the next section.

(a) 560   (b) 558   (c) Combination
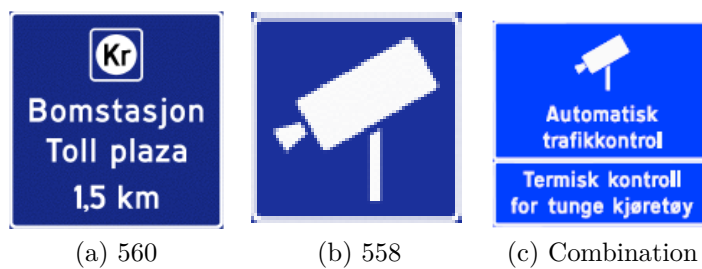
Figure 3.1: Signs giving information of the thermal control

3.2.2 New lane for heavy vehicles

To give info about the lane restrictions for heavy vehicles leading in to the control if no extra info was given in the information about the control, sign 534 could be used supplemented with sign 306.5 on some of the lanes to inform heavy vehicles where they can and cannot drive. Eventually the lanes can first be split up, and then sign which lanes that heavy vehicles are not allowed to drive in by using overhanging signs referring to the specific lanes. It should also be considered if it is necessary to sign that it is prohibited for light vehicles to drive in the dedicated lane for the thermal control. This to prevent queuing before the control. This would also prevent people from using the area dedicated to the 2.control or for cooling down as a parking space.

(a) 534.H02   (b) 306.5
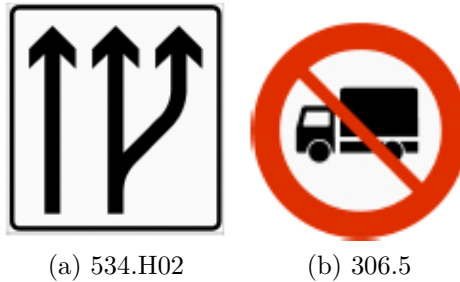
Figure 3.2: Signing of new lane for heavy vehicles

3.2.3 Lower speed limit

Sign 362 will be the only option.

Figure 3.3: Sign 362, displaying new speed limit

3.2.4 Cancel speed limit

The sign 364 should be used to cancel the given speed limitation if normal speed, sign 362 must be used again with a new speed limitation if the intended speed is other than 80km/h.

Figure 3.4: Sign 364, canceling the speed limit

3.2.5 Merging

To sign the merging sign 531 should be used on both main and secondary road as shown under. Sign 536 should be used on solutions were the lane continues as an extra lane.

(a) 531   (b) 536
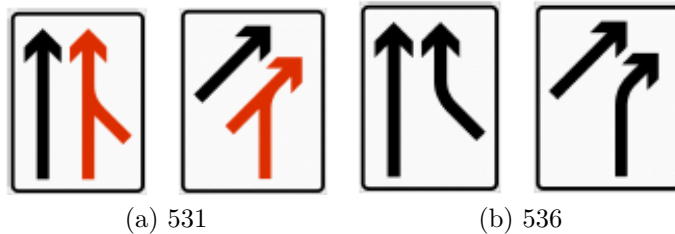
Figure 3.5: Signing of merging

3.2.6   2.control, manual

It could be necessary to use signs like sign 324 if the situation is complex to tell the drivers that they have to stop before they enter the area for the second control. In solutions with a bit of driving distance before the second control, sign 802 could be used to indicate when the control occurs.

(a) 324   (b) 802
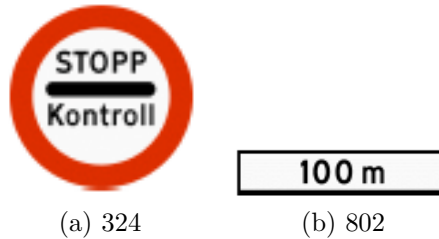
Figure 3.6: Signs informing of upcoming control

3.2.7   Rejection by light signal

Here it will be the need of a signal like signal 1090 or 1092 to tell the drivers if they have passed the control, or more importantly if they have not. This signal could be combined with a combination of sign 404 and sign 808. This eventually has to come before the signal so that the drivers know what to do in case of a red signal/rejection. If on a dedicated lane with low speed and fairly low volume, a barrier could also be considered to make sure every rejected vehicles stops.

(a) 1092   (b) 404   (c) 808
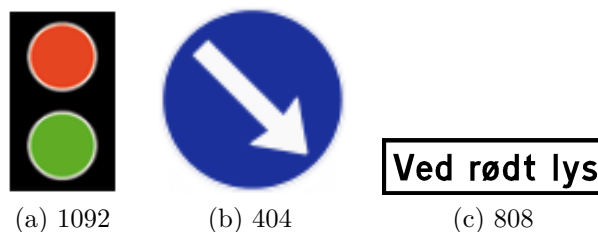
Figure 3.7: Signs explaining the procedure after being rejected by thermal control

3.3 Marking theory

Road marking in this context refers to marking on the road surface with paint, plastic, reflectors or other suitable materials. Road marking is an important part of the road users' ability to read and understand the traffic situation, be lead and warned, and it is therefore an important part of making the road effective and safe. The Norwegian road marking system follows the international convention, the Vienna Convention, on signing and signaling. Road marking is under law regulations, every user of the road has to obey the banning and injunctions these indicate. Generally road marking should:

- Lead, warn and regulate traffic. It could also be used to clarify provisions given by signs or regulations.

- Consist of lines, symbols or text

- Transverse markings should only be used as a supplement to signs.

- Markings separating opposite driving directions is yellow, other markings is white

- Reflectors in the road could be used as a supplement to the ordinary marking.

It is important that the marking of the road is planned carefully so that it is intuitive and consequent all over the road network. It should be planned in coherence with the signing so that they function as one system of information. Longitudinal marking should be used for separating the road in different lanes and to indicate the roads outer edge. Transverse marking, as well as symbols and text, should as listed only be used as a supplement to signs if nothing else is given.[17]

3.4 Relevant marking

In this section, the marking needed for making an area for a thermal control is described and shown. The names given to each section is later used in the flowcharts presented in chapter 4. The figures of the different signs as well as parameters are taken from the NPRA handbook N302.[17]

3.4.1 Lane addition

The marking required for the solutions including lane addition after the first control is here shown. It includes the lines 1012 for the edges, 1014 for the restricted area, 1000 for the lane separation, and 1004 for the first length after the restricted area.
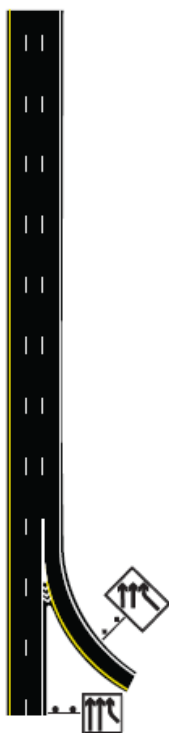
Figure 3.8: Solution for marking of lane addition

3.4.2 Exchange lane

Here a solution for an exchange lane is shown. The separation lane uses marking with spacing of 2-2 in meters, and it should be at least 300 meters for roads with a speed limit of 80 km/h, and at least 700m for roads with a speed limit of 100 km/h. The lines used are 1006 for lane separation, 1014 for the restricted area, 1004 for the first length after the restricted area, 1012 for the lane edges, and 1008 for the exchange lane.
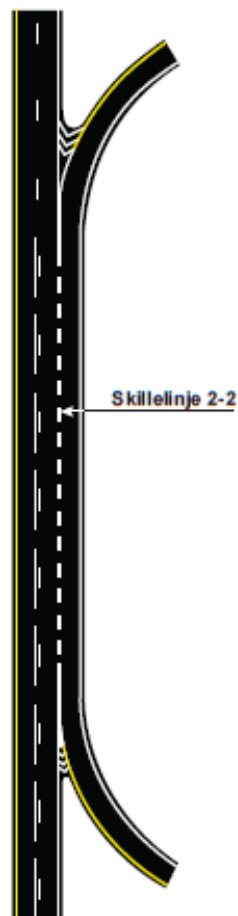
Figure 3.9: Solution for marking of an exchange lane

3.4.3 Lane separation

The solution for lane separation is here shown. Distances shown for the marking is based on the speed level. Here the lines used are 1000 for lane separation, 1004 for the first length after the restricted area, 1008 for the exchange lane, 1012 for the lane edges, and 1014 for the restricted area.
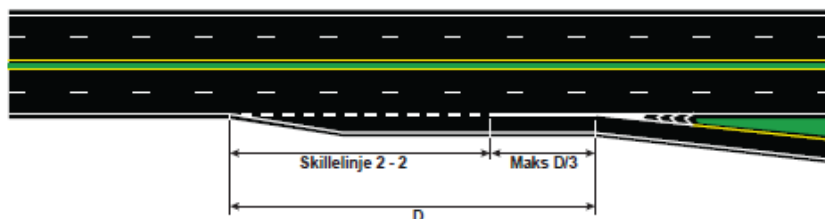
Figure 3.10: Solution for marking of a retardation lane

3.4.4 Lane subtraction

In the case that there is two or more lanes before the separation should take place, and there should be one lane less on the main road, this solution for lane subtraction should be used. Lengths for marking is given in both total and relative values. The lines used are 1000 for the first part of the lane separation, 1008 for the second part of the lane separation, and 1004 for the last part of separation, then 1014 for the restricted area, and 1012 for the lane edges. In addition, there are arrows of type 1034 in the lane being subtracted.
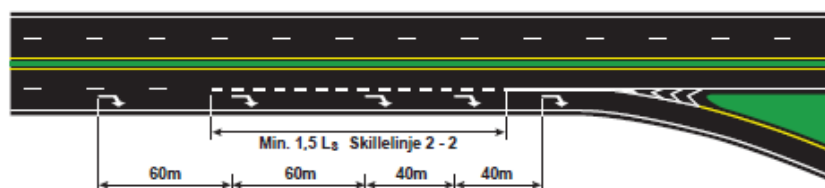
Figure 3.11: Solution for marking of lane subtraction

3.4.5 Merging

The solution for marking of the merging, and the acceleration lanes, are here shown. Distances for marking is given with respect to the speed level, but this is based on light vehicles. On lanes dedicated for heavy vehicles, the distance available for acceleration should be considered increased. This to ensure that the heavy vehicles will be able to reach the speed limit and thereby improve the merging onto the main road. Here 1014 is used for the restricted area, then 1004 for the first part, 1008 for the second part. 1006 is used for the lane separation and 1012 for the lane edges.
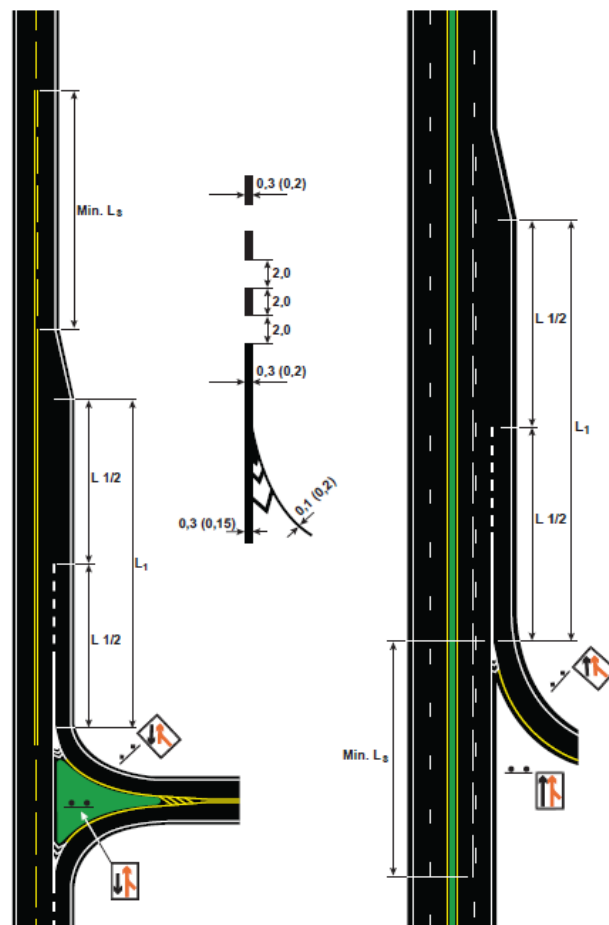
Figure 3.12: Solution for marking of an acceleration lane

3.4.6 Combined solutions

Some combined solutions are here shown, both for two and four lanes, with and without barrier between driving directions.
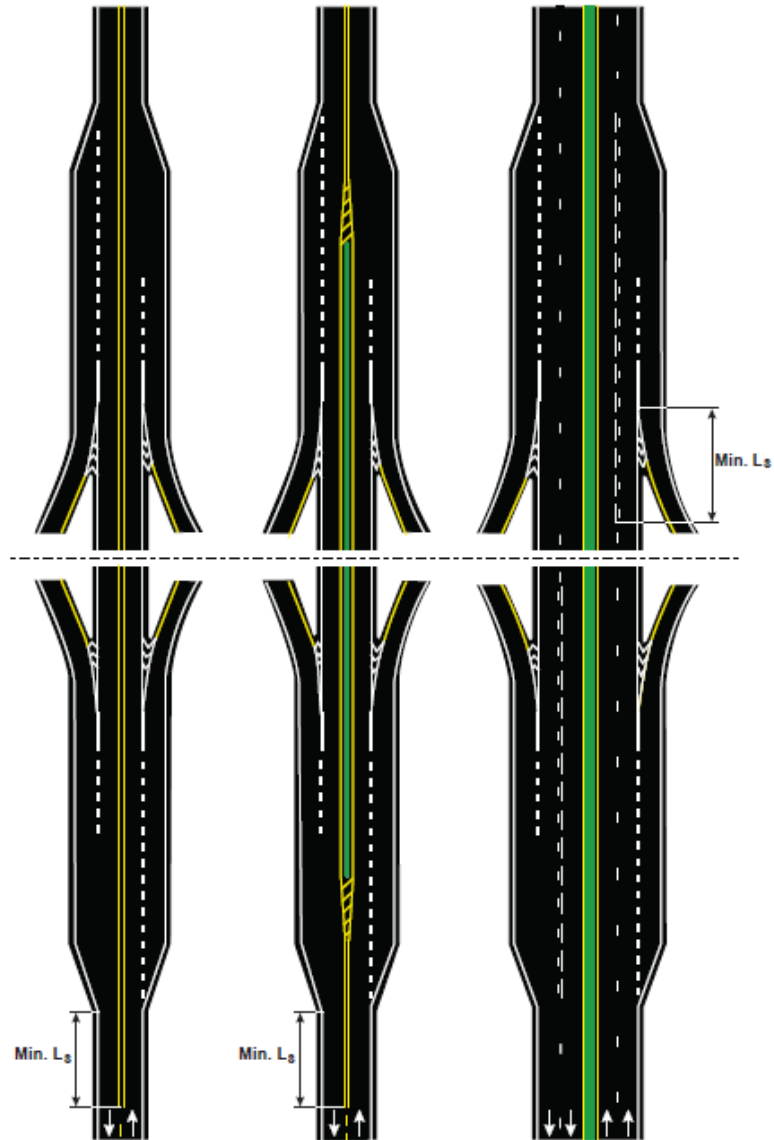
Figure 3.13: Combined solution for marking of the start and end of an intersection area

Chapter 4

General solutions

4.1 Introduction

Building on the ideas presented in the pre-study, flowcharts describing the different solutions regarding the execution of a thermal control before entering a tunnel, as well as an overview over the general solutions, is presented in the following pages. The solutions are divided into two main solutions, 1 and 2, the difference being having a separated lane or not for the thermal control. These solutions are further divided into three alternatives, A, B and C, regarding what happens after a vehicle is being rejected at the first control. This includes:

- alternative A, a loop on the same side

- alternative B, a parallel solution on the same side of the main road, and

- alternative C, a parallel solution on the other side of the main road.

Here the second control is described as a manual control, this can also be changed to driver-actuated types of actions if the control is at a place without personnel present to perform the execution of a manual control. Exiting the second part of the control can also happen in various ways described in the drawings. The different alternatives is described more thoroughly in the start of each section.

The flowcharts intend to show which processes that are needed to implement the control, starting with information of the control and ending with standard road dimensions before entering the tunnel. These flowcharts served as a base when the general solutions later were made.

For the Rogfast project it is shown how some of these solution can be changed slightly to accomplish the project requirements, see chapter 5.

In each section succeeding the flowchart for the solution, the general solutions will be presented and then the signing and marking. The general solutions only relies on the standard and/or the speed level of the road. They can therefore easily be changed to the requirements of another standard by changing the minimum lengths. They are here made for the H8 standard, and 100 km/h.

The drawings shown here are only overviews, and are presented to illustrate the different solutions. The scale will be too small for detailed consideration of the solutions. For full scale versions of the drawings see Appendix B. These are made for the A1 format, and can be found in full scale as attached pdf files in the digital version of the thesis, but is printed in A3 in the external appendix because of convenience when presenting on paper.

4.2   Alternative 1A

The 1A solution has two lanes throughout the whole distance on the main road (could also be one), and the thermal control is executed over both lanes. Rejected vehicles will be taken out from the main road onto a loop for the second control or to cool down. To make this solution possible it is needed to use an exchange lane. This while the distance between an incoming and outgoing lane is too short if the solution should be as compact as possible. When designing for 100/110 km/h this exchange lane must be a minimum of 700 meters long (a minimum of 300 meters if 80 km/h or less). The road is being designed for module-trucks, meaning that the absolute minimum radius is 13m. A more realistic speed of 40 km/h demands at least 35m of radius. This means that there has to be retardation and acceleration lanes to get to the appropriate speed level when exiting into the loop, and onto the main road again. The length needed for getting down and up from 40km/h is 330 meters for deceleration and 160 meters for acceleration. The length needed in between of the two 180 degree curves defining the loop will therefore be at a minimum of 1190 meters. In addition, a side area of a minimum of 70 meters for the curves is needed. This makes the area needed for this solution at this design speed very demanding, and seems like a very bad solution at higher speed levels. If there is a lower speed level, this solution could be a better alternative, while both the exchange lane itself and the acceleration/retardation lanes would be shorter. The vehicles still being rejected following the second control leaves the area at the same side, while the accepted ones get onto the main road again without driving through the control a second time. If this area is for cooling down, the vehicles must enter the main road before the control to be controlled again. The area for the second control/cooling down should be placed inside the loop to make use of some of the area that is demanded for this solution. The total minimum length of this solution will be 1500 meters from the last connection before the tunnel to the last segment needed.
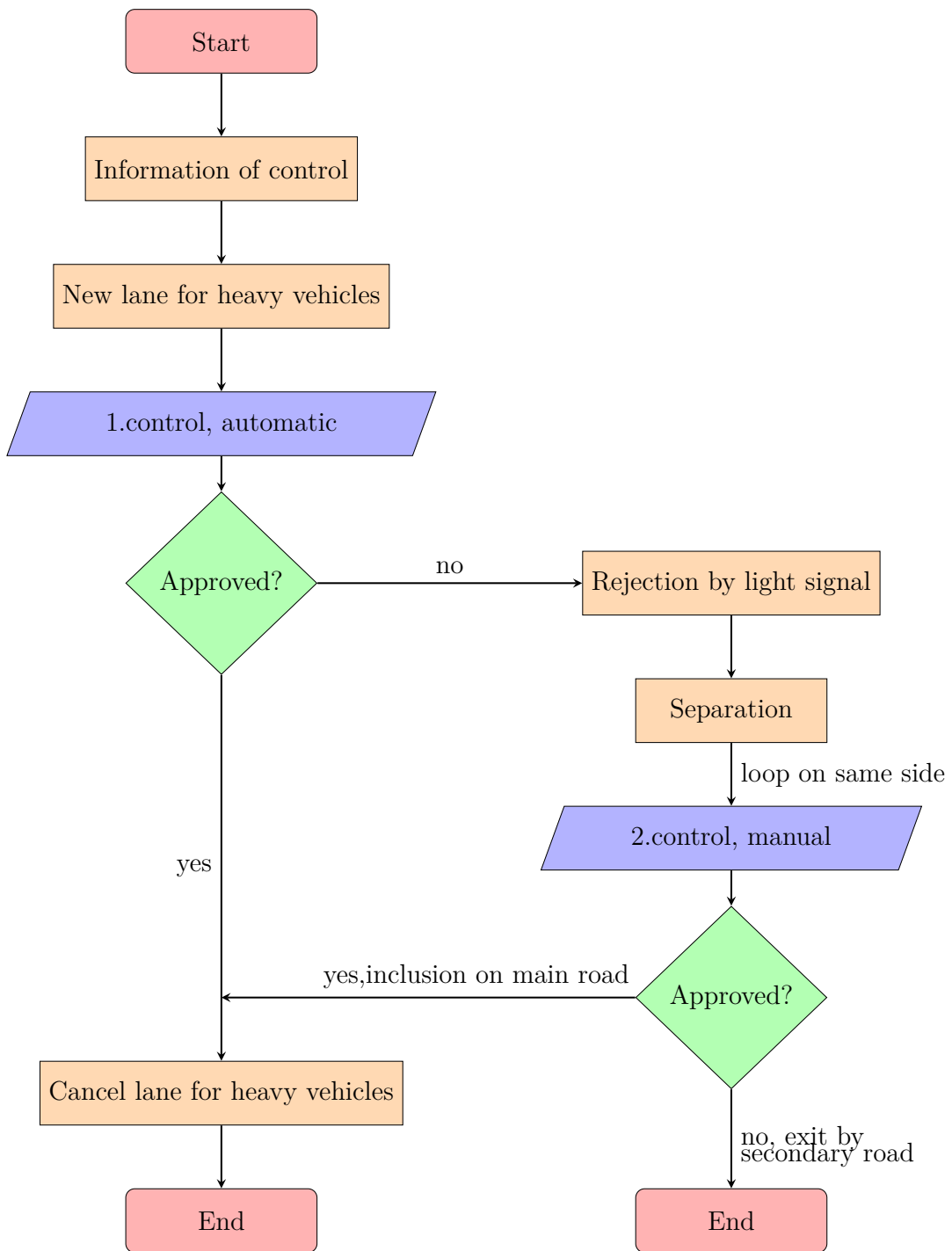
Figure 4.1: Flowchart describing the 1A alternative
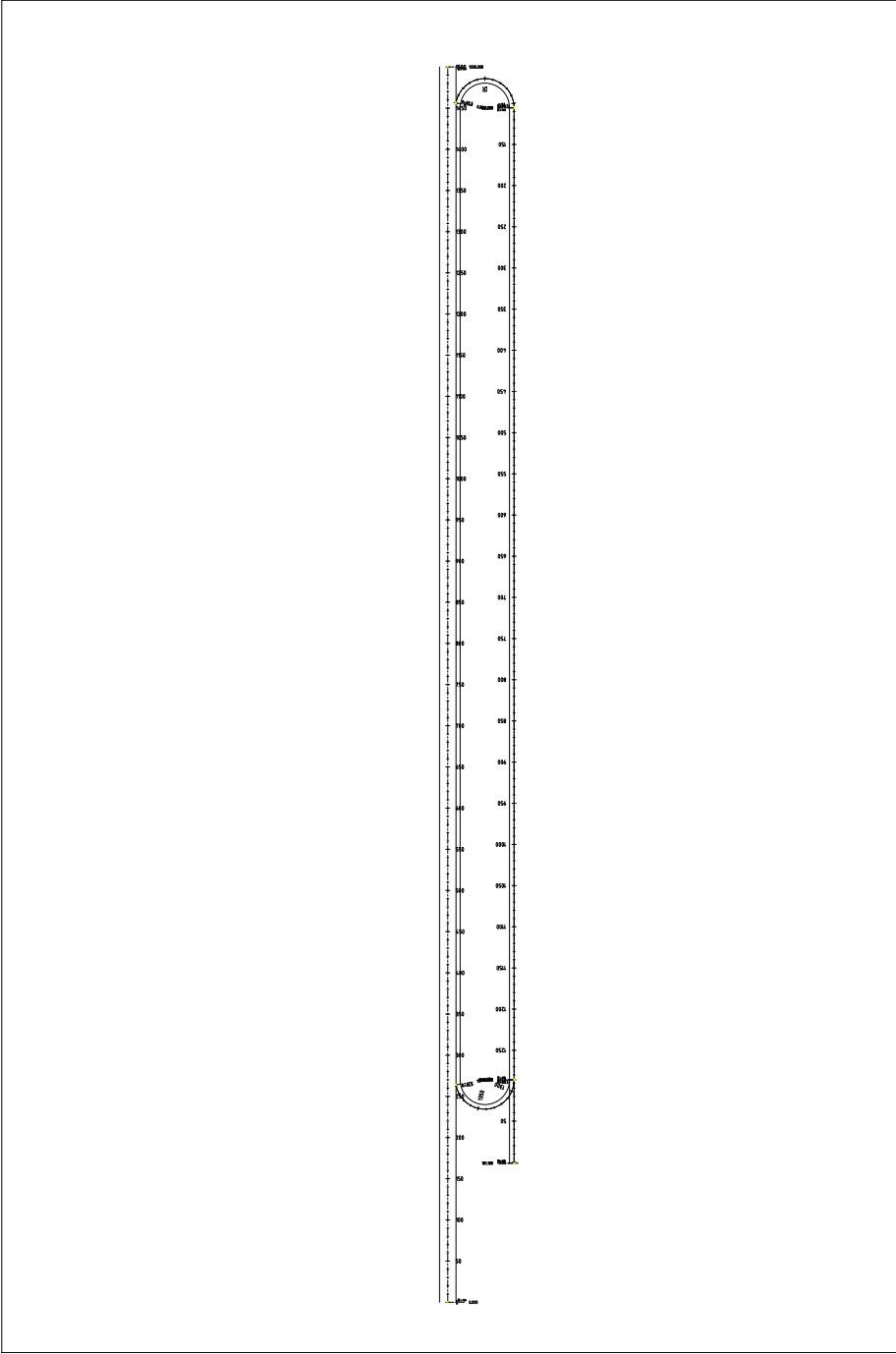
Figure 4.2: Overview of the geometry on the 1A alternative

POS	SKILT – TEGN	SKILT NR.	RE-FLEKS	STØRR. TEKST	ANTALL	MERKNAD
1		560.5	1	SS	2	-
2		306.5	1	SS	1	Overhengende skilt
3		362.40	1	SS	1	-
4		1092	-	-	1	Tolyssignal
5		362.100	1	SS	2	-
6		531.202	1	SS	1	-
7		531.102	1	SS	1	-

POS	LINJETYPE	NR.	Bred.	Leng.	FARGE	Sum-Tegn.001	MERKNAD
1	Heltrukken kantlinje	1012.1	0,15	Hel	Hvit	x	-
2	Kjørefeltlinje	1000	0,15	Hel	Hvit	x	-
3	Skillelinje	1008	0,2	Hel	Hvit	x	2 – 2
4	Sperrelinje	1004	0,15	Hel	Hvit	x	-
5	Sperreområde	1014	0,15	Hel	Hvit	x	-
6	Kjørefeltlinje/varsellinje	1006.1	0,15	Hel	Hvit	x	-

Figure 4.3: Overview over the signing and marking on the 1A alternative

4.3 Alternative 1B

This solution has two lanes throughout the whole distance on the main road (could also be one), and the thermal control is executed over both lanes. Rejected vehicles will be taken out from the main road onto a parallel road where the area for the second control is placed. Accepted vehicles will continue onto the main road again, while the rejected vehicles will take a secondary road either on the same side of the main road, or by crossing the main road onto the other side. In every case, the radius of the secondary road and the speed level must be considered. It should not be a problem while every vehicle comes from a starting position out of the second control, and therefore do not have to break down from a higher speed. This solution is quite extensive in length, and comes to a total minimum of 1700 meters from the last connection before the tunnel to the last segment needed. The side area needed for this solution does not have to be of great nature, but if crossing the road is the best solution, extra costs will occur with a tunnel/bridge. In case of crossing, it is also possible to connect the secondary road to the main road again, so that the transport out of the area for the rejected areas is quicker, and takes less area if no smaller road is already present. A drawback with this solution is that an area for cooling down before being controlled again is not possible. It therefore demands manual labor on the second control.
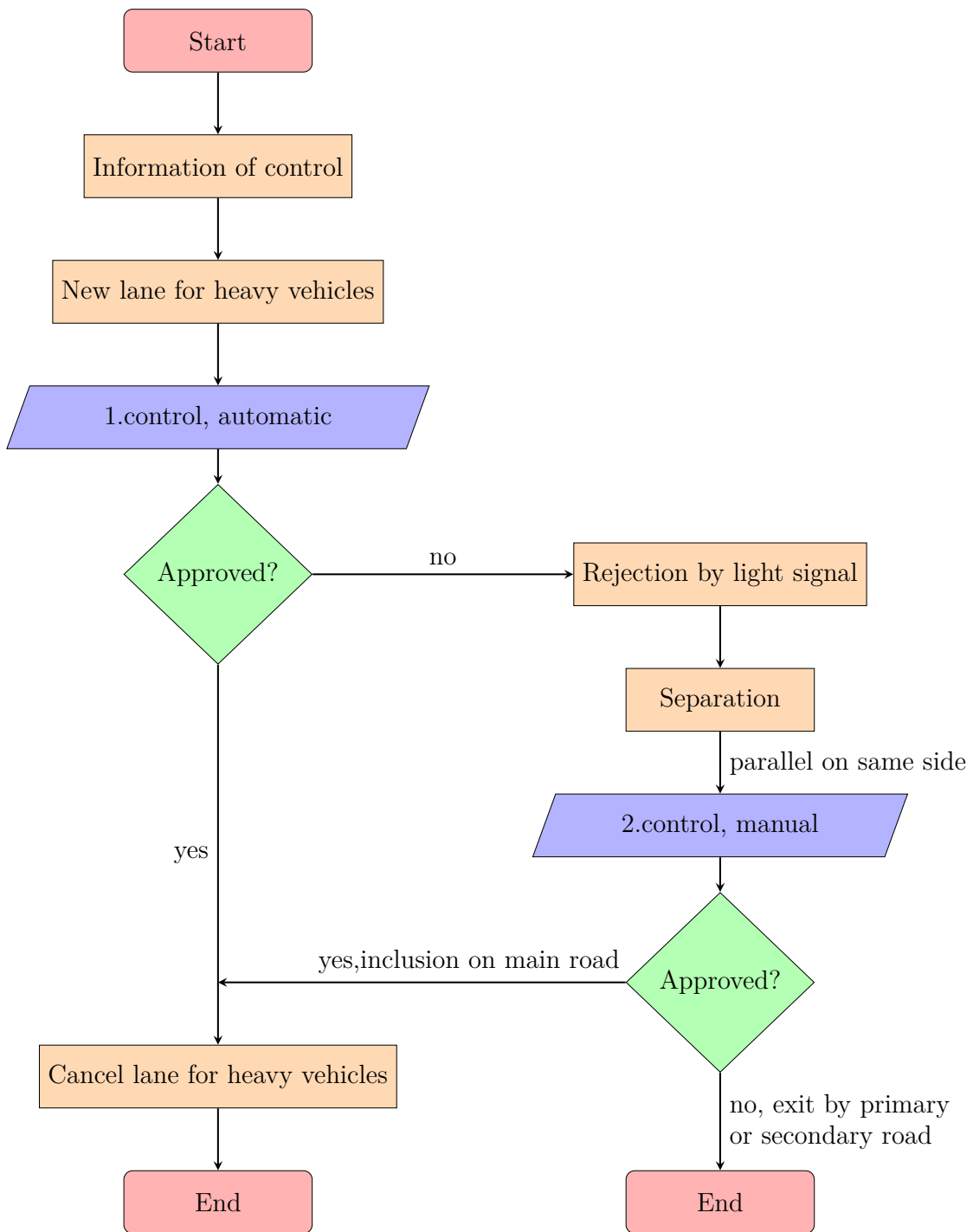
Figure 4.4: Flowchart describing the 1B alternative
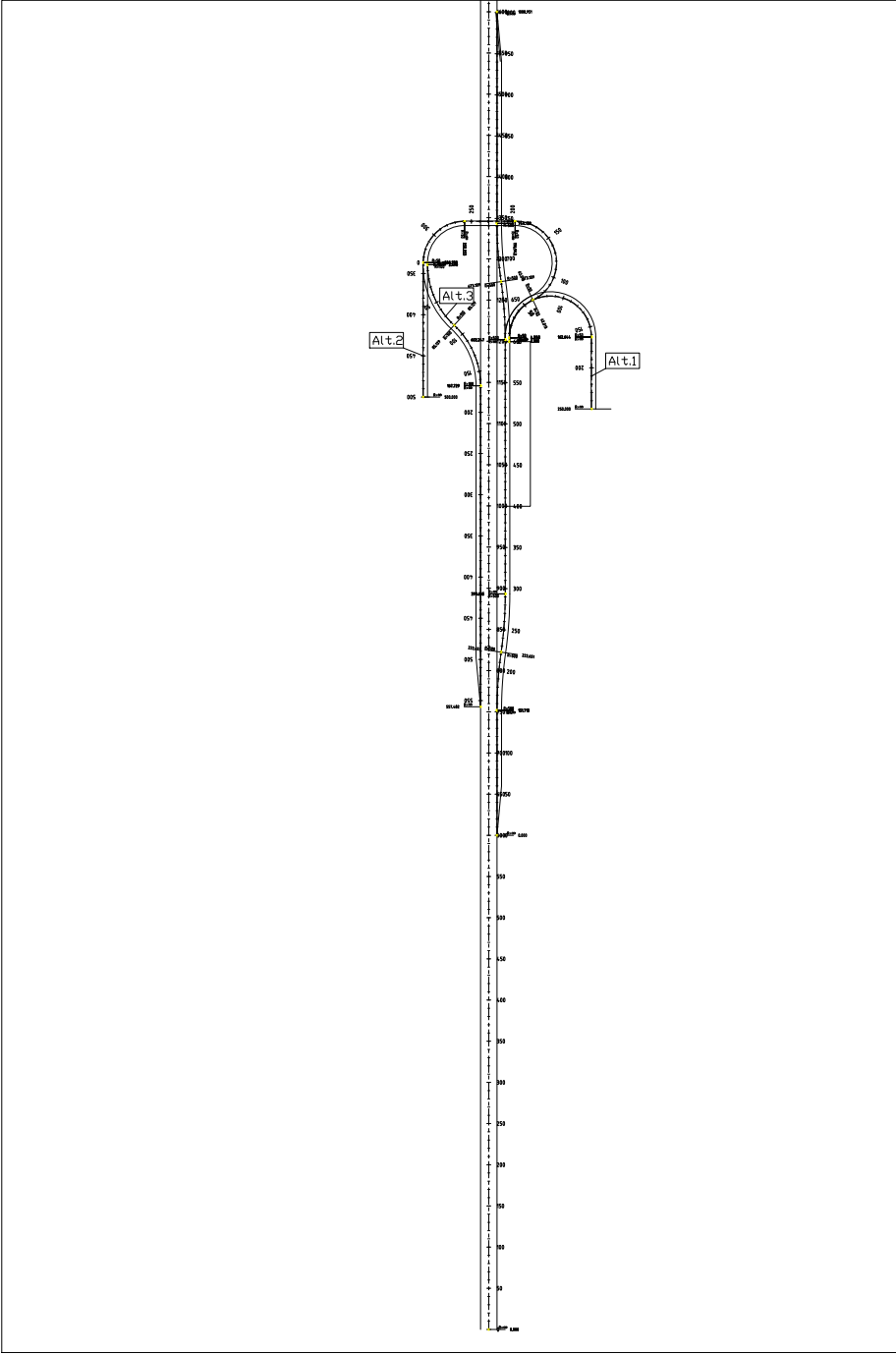
Figure 4.5: Overview of the geometry on the 1B alternative

Skilt- og oppmerkingsplan   Tegnforklaring

POS	SKILT – TEGN	SKILT NR.	RE-FLEKS	STØRR-TEKST	ANTALL	MERKNAD
1		560.5	1	SS	1	
2		306.5	1	SS	1	Overhengende skilt
3		362.40	1	SS	2	
4		1092	–	–	1	Tolyssignal
5		362.100	1	SS	2	–
6		531.202	1	SS	2	–
7		531.102	1	SS	2	–

POS	LINJETYPE	NR.	Bred.	Leng.	FARGE	Sum-Tegn.001	MERKNAD
1	Heltrukken kantlinje	1012.1	0,15	Hel	Hvit	x	–
2	Kjørefeltlinje	1000	0,15	Hel	Hvit	x	–
3	Skillelinje	1008	0,2	Hel	Hvit	x	2 – 2
4	Sperrelinje	1004	0,15	Hel	Hvit	x	–
5	Sperreområde	1014	0,15	Hel	Hvit	x	–
6	Kjørefeltinje/varsellinje	1006.1	0,15	Hel	Hvit	x	–

Tegnforklaring:
Skiltstolpe, enkel
Skiltstolpe, dobbel
① Skilthenvisning
1 Linjehenvisning

Figure 4.6: Overview over the signing and marking on the 1B alternative

4.4 Alternative 1C

This solution has two lanes throughout the whole distance on the main road (could also be one), and the thermal control is executed over both lanes. Rejected vehicles will be taken out from the main road and cross over to the other side of the road for the second control or area to cool down. There the road will be parallel to the main road, in the other driving direction. Here both accepted and rejected vehicles has to follow a secondary road, or by inclusion on the main road again, back to the last connection. They will then have to drive through the control again, but with an exception if accepted at the secondary control to prevent a second rejection. If the solution is based on an area for cooling down, there is no exception, and the vehicles must pass the control as normal to be accepted. The area for the second control or cooling down do not need to be in direct succession to the crossing, it could be placed where it is best suited anywhere in between the crossing and the implementation on the main road again. This solution is the shortest one, with a total minimum length of 950 meters from the last connection before the tunnel to the last segment needed. This is because the area on the other side goes against the driving direction on the other side and makes use of the same stretch, but on the other side. The side area demanded is therefore moderate, but a crossing of the main road is needed in every case by bridge or tunnel. Here the speed level is important to consider to fulfill minimum demands for the ramp going under/over the main road, and choosing a radius coherent with this.

Figure 4.7: Flowchart describing the 1C alternative

Figure 4.8: Overview of the geometry on the 1C alternative

Skilt- og oppmerkingsplan   Tegnforklaring

POS	SKILT - TEGN	SKILT NR.	RE-FLEKS	STØRR. TEKST	ANTALL	MERKNAD
1		560.5	1	SS	1	-
2		306.5	1	SS	1	Overhengende skilt
3		362.40	1	SS	2	-
4		1092	-	-	1	Tolyssignal
5		531.202	1	SS	2	-
6		531.102	1	SS	2	-

POS	LINJETYPE	NR.	Bred.	Leng.	FARGE	Sum: Tegn.001	MERKNAD
1	Heltrukken kantlinje	1012.1	0,15	Hel	Hvit	x	-
2	Kjørefeltlinje	1000	0,15	Hel	Hvit	x	-
3	Skillelinje	1008	0,2	Hel	Hvit	x	2 - 2
4	Sperrelinje	1004	0,15	Hel	Hvit	x	-
5	Sperreområde	1014	0,15	Hel	Hvit	x	-
6	Kjørefeltlinje/varsellinje	1006.1	0,15	Hel	Hvit	x	-

Tegnforklaring:
- Skiltstolpe, enkel
- Skiltstolpe, dobbel
- Skilthenvisning
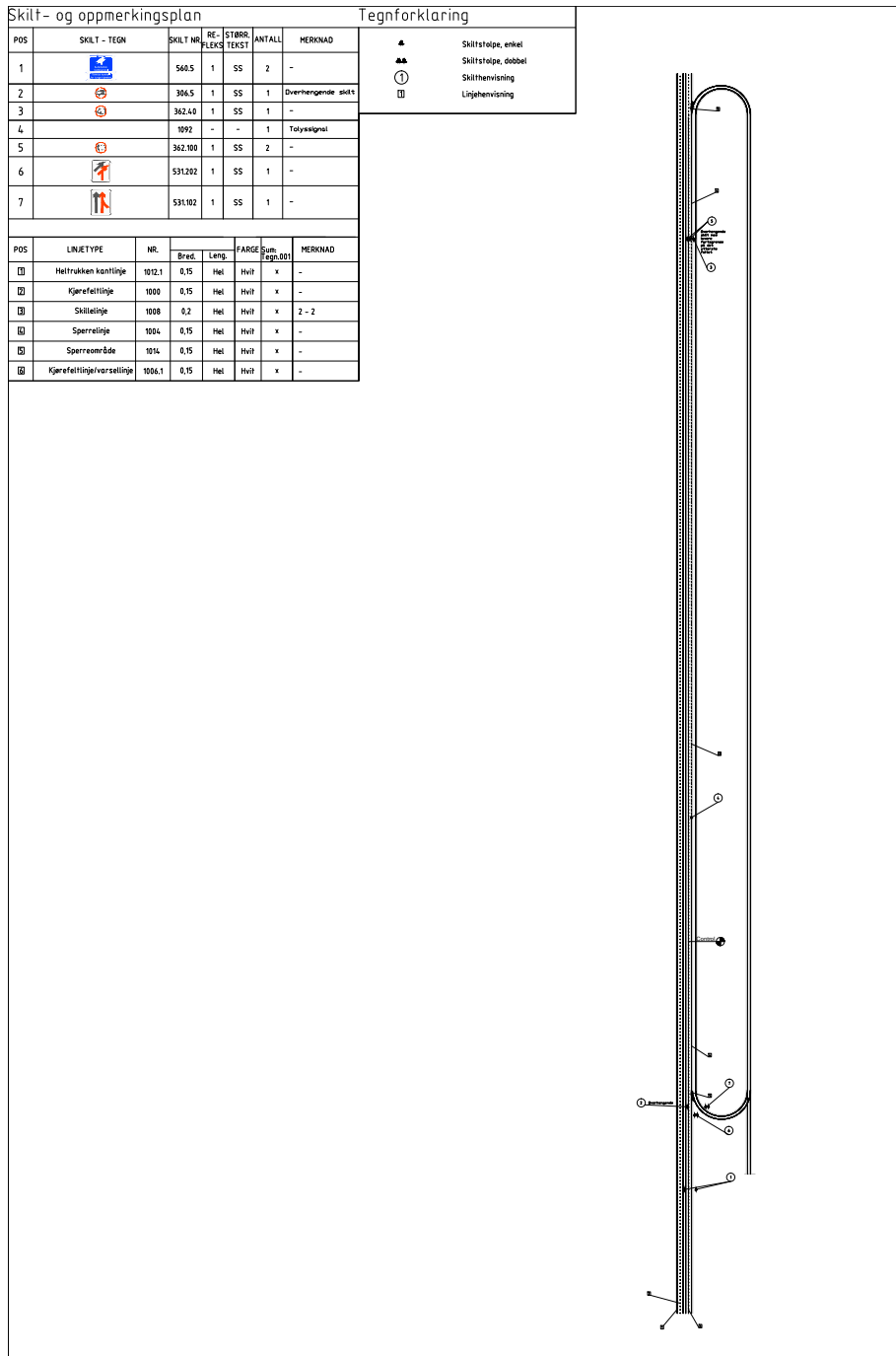- Linjehenvisning

Figure 4.9: Overview over the signing and marking on the 1C alternative

4.5   Alternative 2A

This solution has two lanes throughout the whole distance on the main road (could also be one), and the thermal control is executed on a separate, dedicated lane for heavy vehicles parallel to the main road. The accepted vehicles continue to the main road again by merging, and the rejected vehicles is separated to a secondary road leading to the second control or area for cooling down. The area for control in this solution is on a loop at the same side of the road. Accepted vehicles in the case of a second control is included on the side road again, but must give way for the other traffic, preferably after the first control. The vehicles then follows the same path as an accepted vehicle in the first control and merges onto main road again. Rejected vehicles from the second control is lead away on a secondary road on the same side of the main road. This solution also gives an opportunity to make the rejected vehicles park and cool down before driving through the control again. This could prevent the need for a second manually control in many cases, especially on low traffic roads. This means that the loop must connect with the main road again before the control in order to work. This solution has a total minimum length of 1500 meters from the last connection before the tunnel to the last segment needed. The side area is quite demanding while it first is an extra lane, and then a loop on the same side of the road. This can however be quite compact while the speed level can be regulated low, and is therefore limited to the area needed for the secondary control.
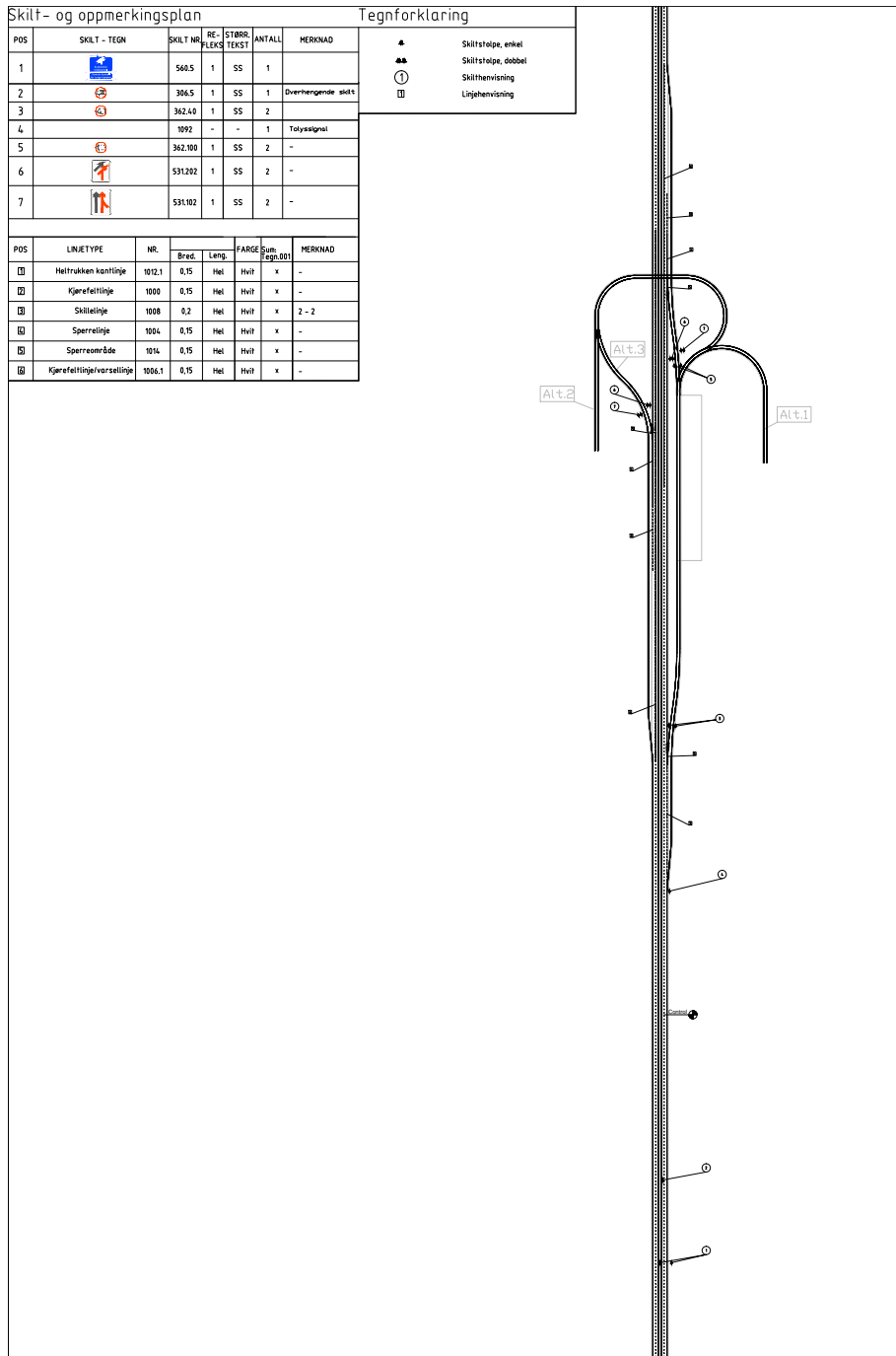
Figure 4.10: Flowchart describing the 2A alternative

Figure 4.11: Overview of the geometry on the 2A alternative

Skilt- og oppmerkingsplan

POS	SKILT - TEGN	SKILT NR.	RE-FLEKS	STØRR. TEKST	ANTALL	MERKNAD
1		560.5	1	SS	2	-
2		534.H02	1	SS	2	Kan kombineres med 306.5
3		306.5	1	SS	2	Overhengende skilt Vise at lastebiler må ta av senere.
4		362.40	1	SS	2	-
5		202	2	SS	4	-
6		1092	-	-	1	Tolyssignal
7		362.100	1	SS	2	-
8		531.202	1	SS	1	-
9		531.102	1	SS	1	-

POS	LINJETYPE	NR.	Bred.	Leng.	FARGE	Sum: Tegn.001	MERKNAD
1	Heltrukken kantlinje	1012.1	0,15	Hel	Hvit	x	-
2	Kjørefeltlinje	1000	0,15	Hel	Hvit	x	-
3	Skillelinje	1008	0,2	Hel	Hvit	x	2 - 2
4	Sperrelinje	1004	0,15	Hel	Hvit	x	-
5	Sperreområde	1014	0,15	Hel	Hvit	x	-
6	Kjørefeltlinje/varsellinje	1006.1	0,15	Hel	Hvit	x	-
7	Vikelinje	1022	-	-	Hvit	x	-

Tegnforklaring

♠	Skiltstolpe, enkel
♠♠	Skiltstolpe, dobbel
①	Skilthenvisning
1	Linjehenvisning

Alt.1

Alt.2

Figure 4.12: Overview over the signing and marking on the 2A alternative

4.6 Alternative 2B

This solution has two lanes throughout the whole distance on the main road (could also be one), and the thermal control is executed on a dedicated lane for heavy vehicles parallel to the main road. The accepted vehicles continue onto the main road again by merging, and the rejected vehicles is separated onto a secondary road leading to the second control. In this solution the second control is parallel to the main road on the same side, and exclude the possibility of an area for cooling down, while there is no way to be controlled again at the first control. The accepted vehicles is included on the parallel road again, but must give way for the other traffic. It then follows the same route as accepted vehicles from the first control onto the main road. Rejected vehicles from the second control is lead away on a secondary road, either on the same side, or on the other side of the main road by crossing. If crossing it can be included on the main road again. This solution has a total minimum length of 1750 meters from the last connection to the last segment needed before the tunnel. The side area demanded is quite moderate while it is parallel. The secondary road could be quite demanding, and if it needs to cross, the road there will be in the need of a tunnel or a bridge.
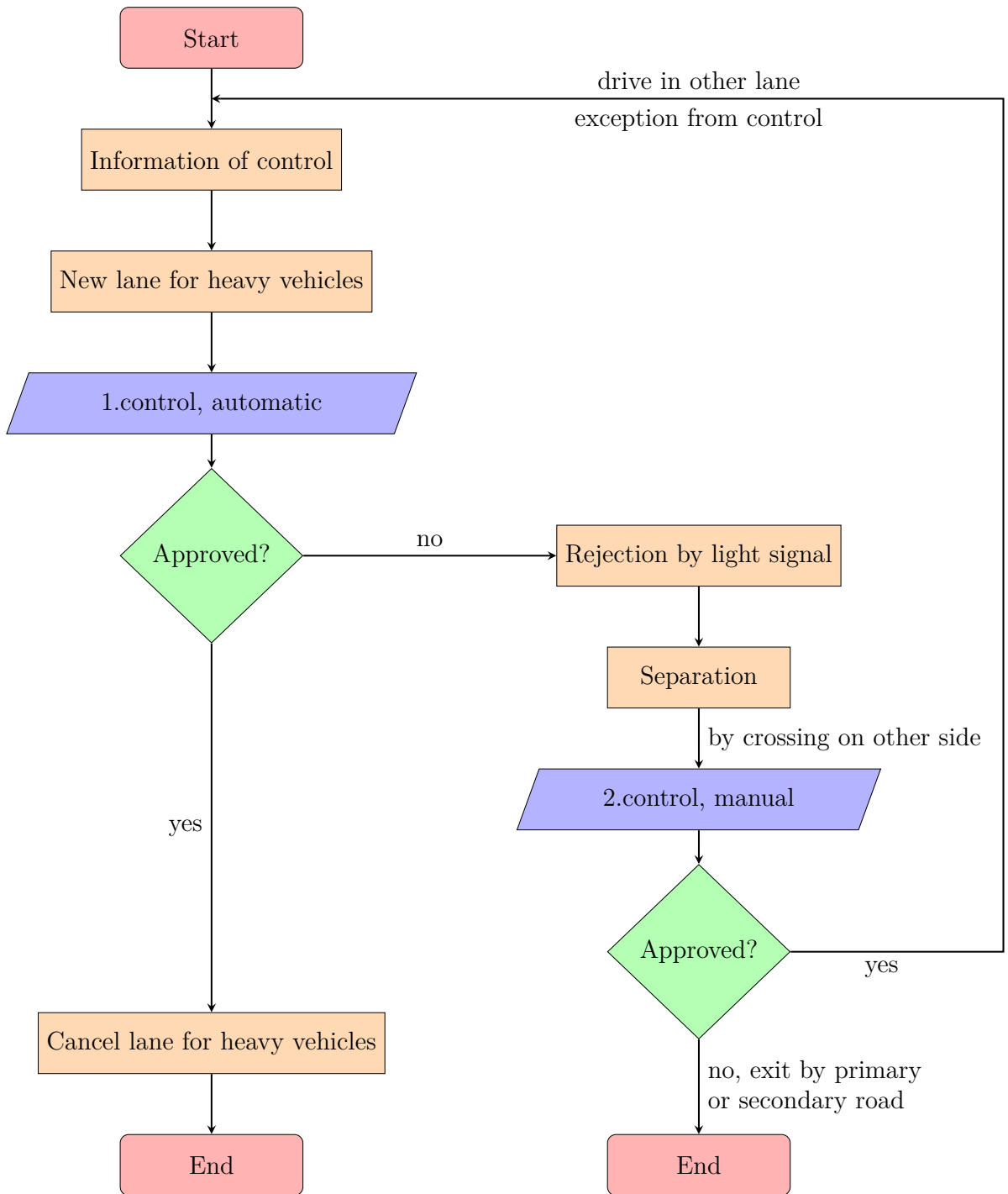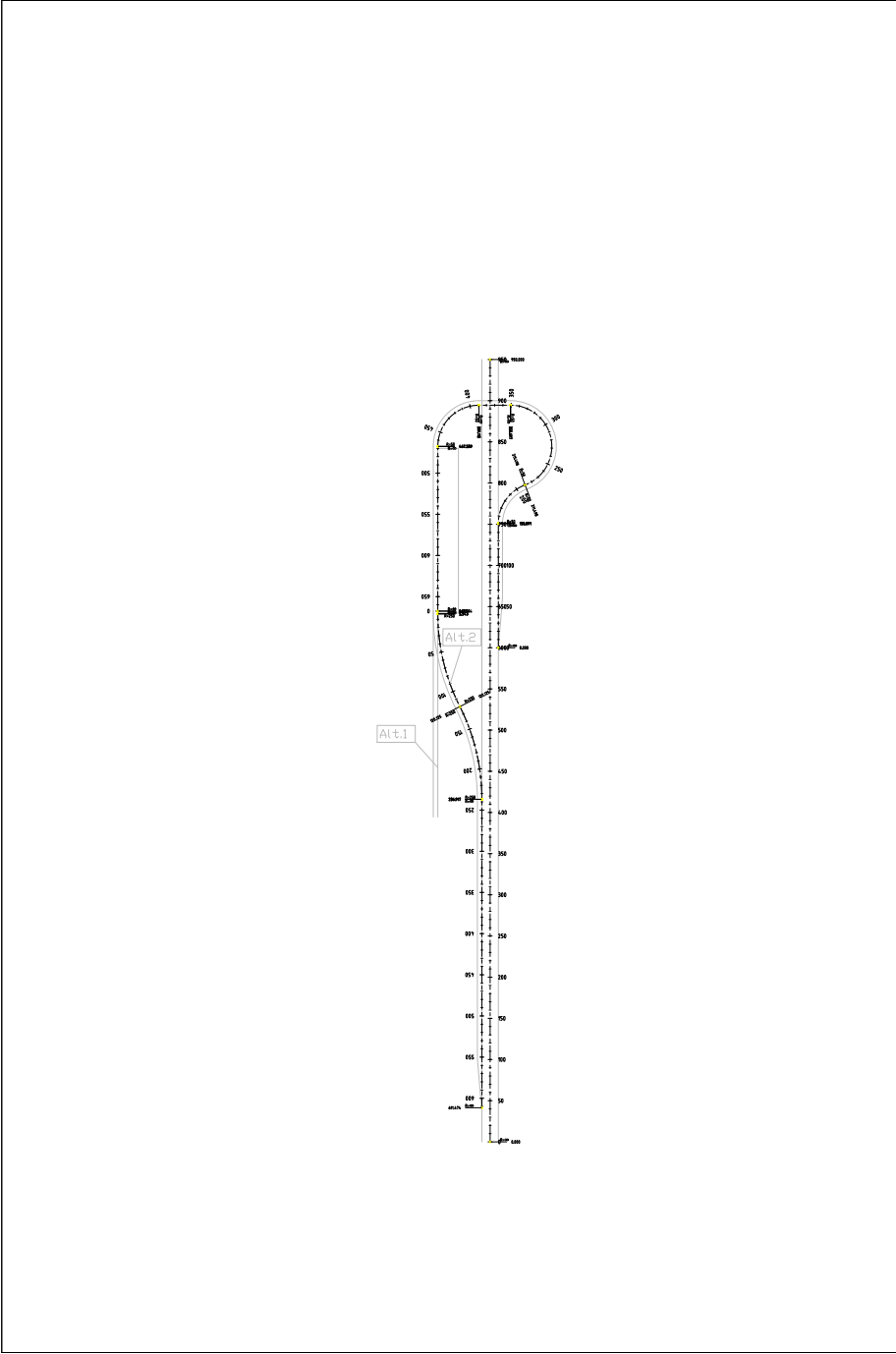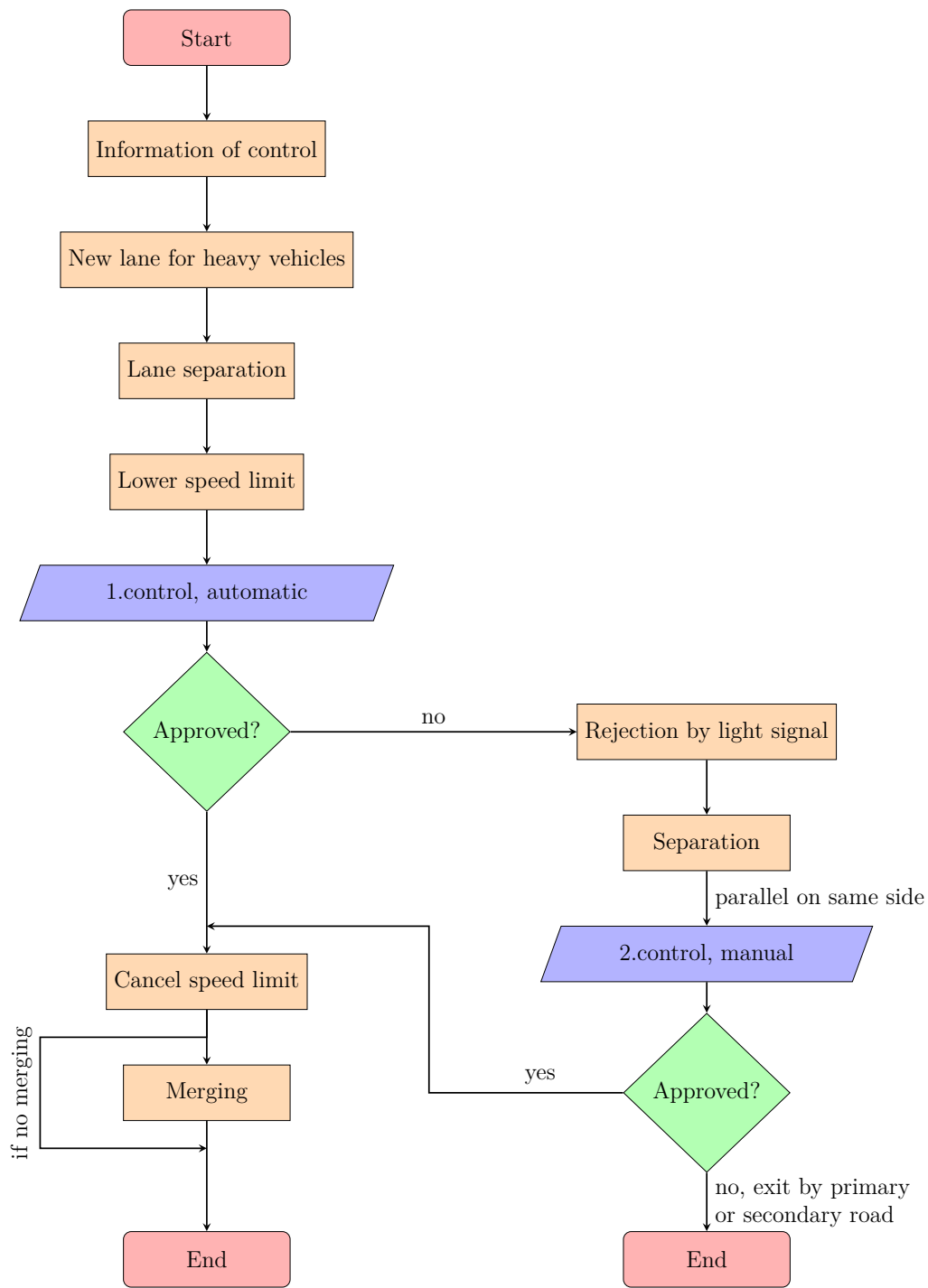
Figure 4.13: Flowchart describing the 2B alternative
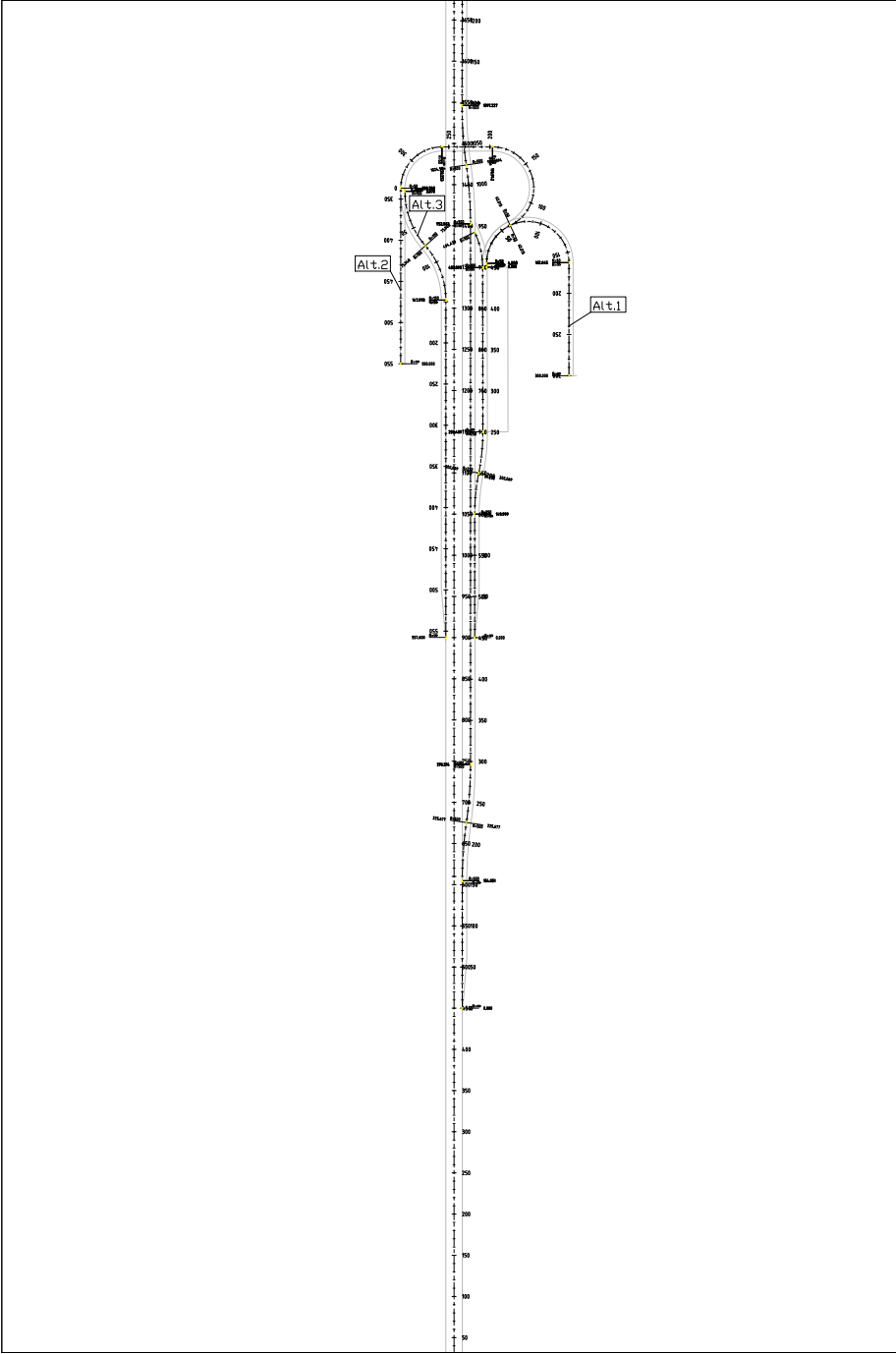
Figure 4.14: Overview of the geometry on the 2B alternative
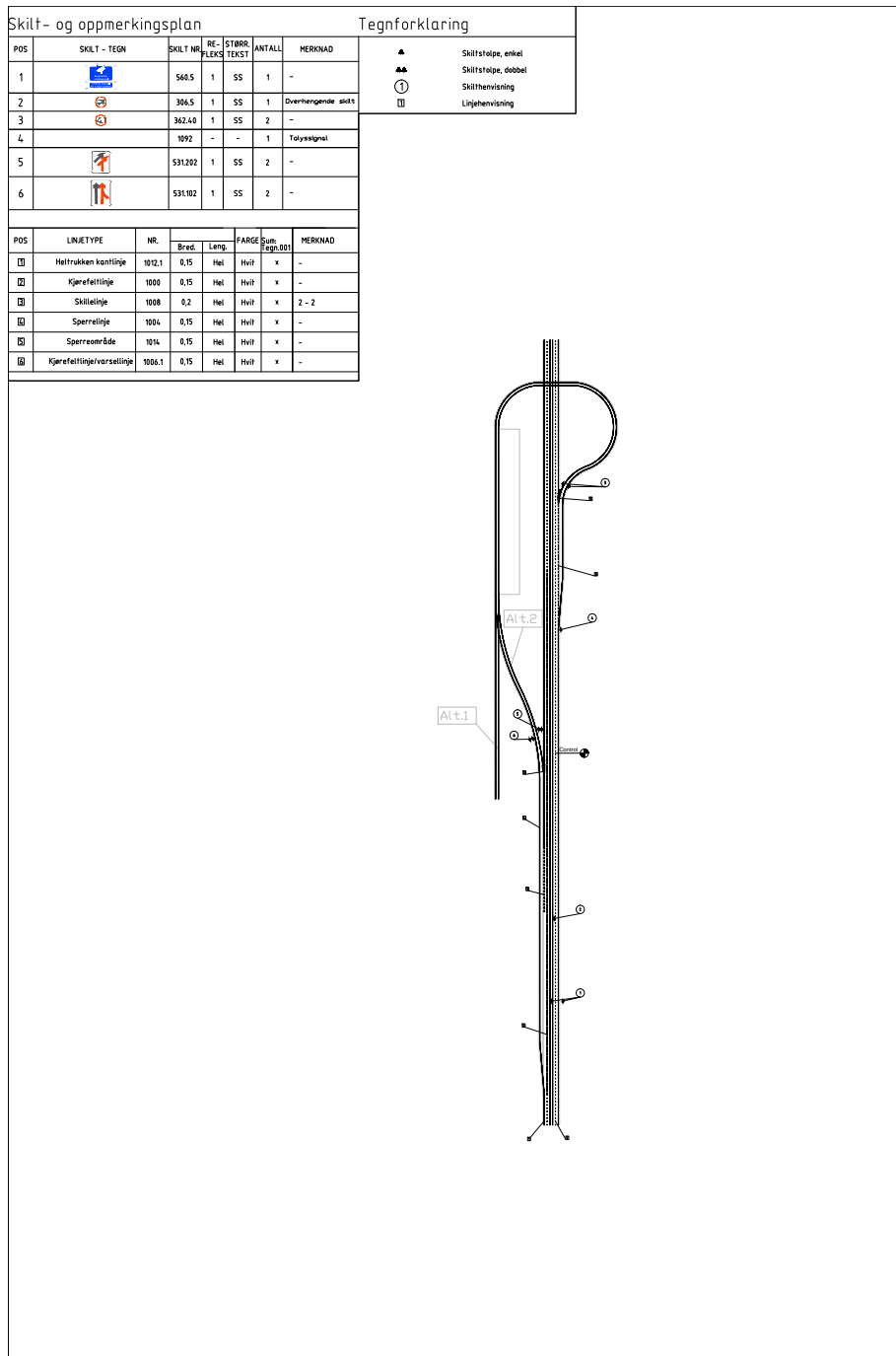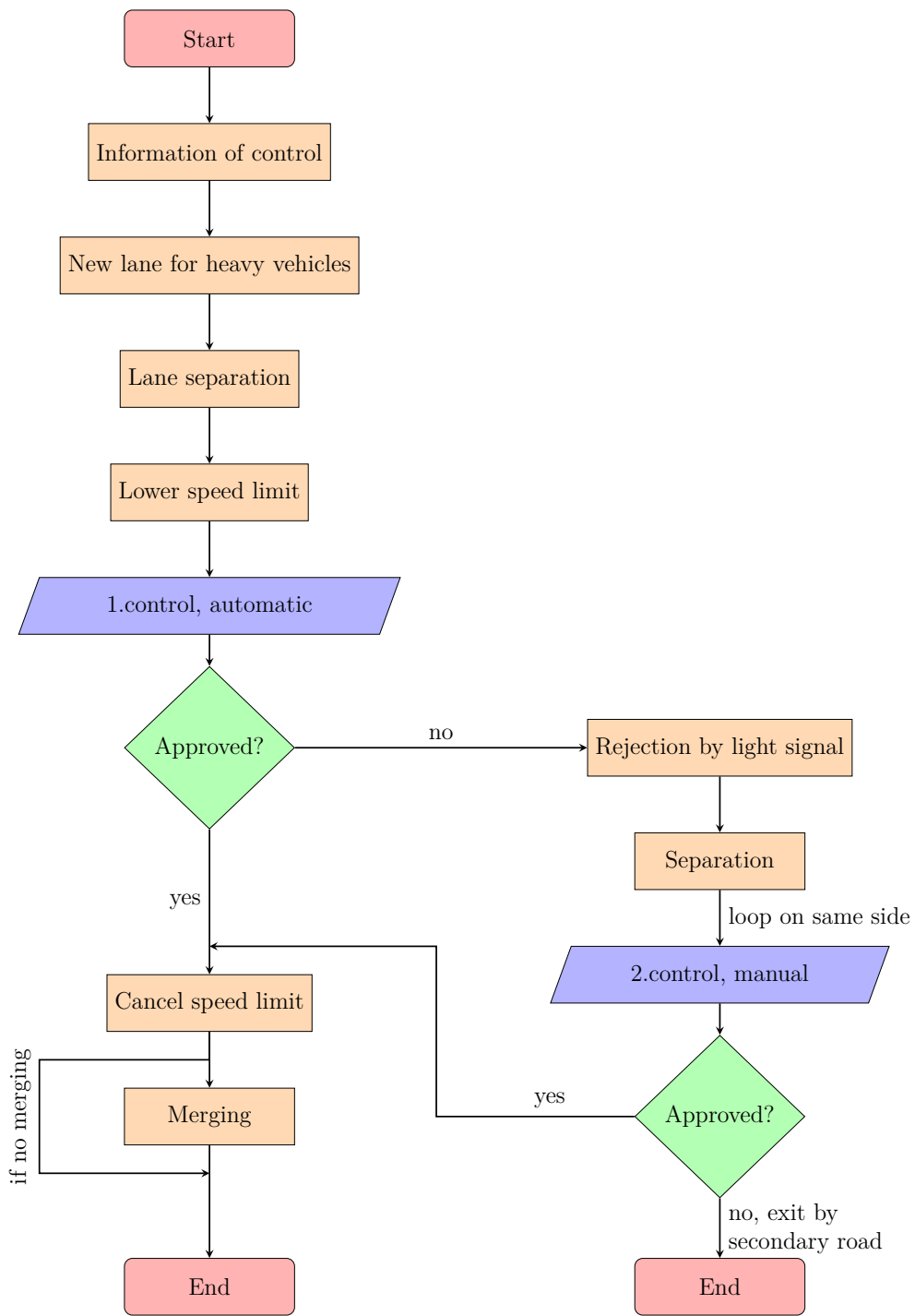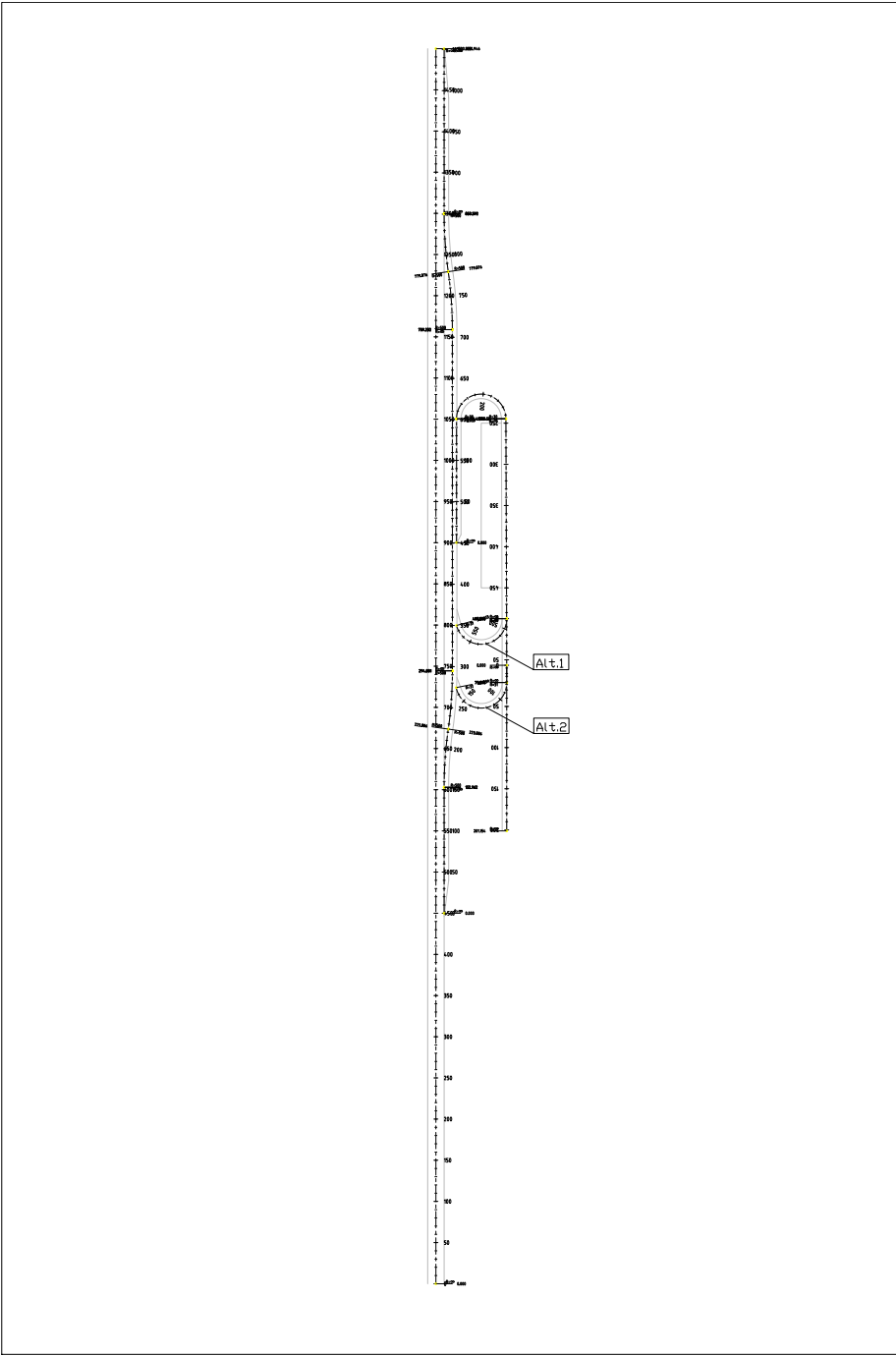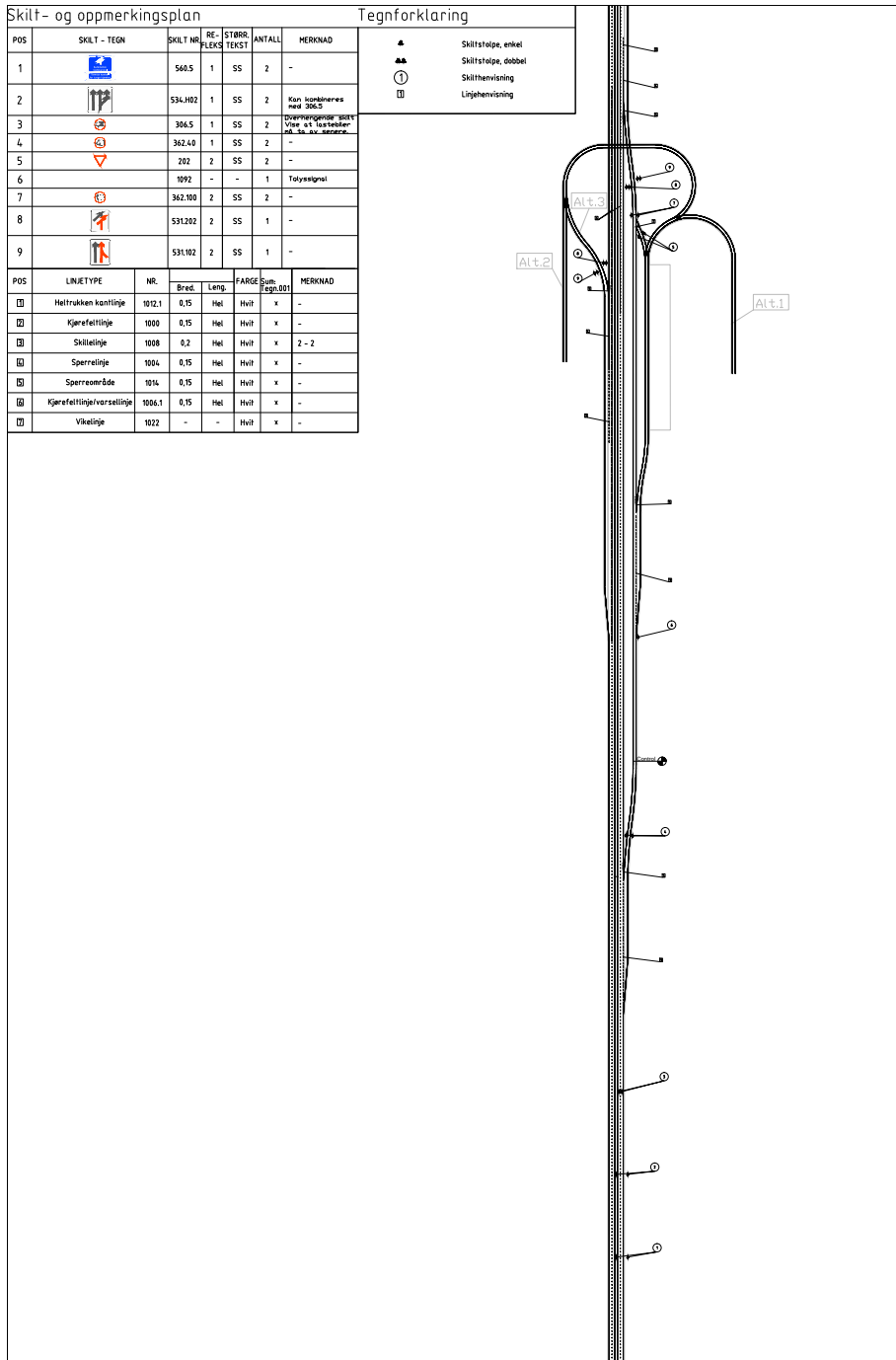
Figure 4.15: Overview over the signing and marking on the 2B alternative

4.7 Alternative 2C

This solution has two lanes throughout the whole distance on the main road (could also be one), and the thermal control is executed on a dedicated lane for heavy vehicles parallel to the main road. The accepted vehicles continue onto the main road by merging, and the rejected vehicles is separated onto a secondary road leading to the second control on the other side of the main road. This control or area for cooling down do not need to be in direct succession to the crossing, it could be placed where it is best suited anywhere in between the crossing and the implementation on the main road again. Here both accepted and rejected vehicles has to follow a secondary road, or by inclusion on the main road again, back to the last connection. They will then have to drive through the control again, but with an exception if accepted at the secondary control to prevent a second rejection. If the solution is based on an area for cooling down, there is no exception, and the vehicles must pass the control as normal to be accepted. This solution has a total minimum length of 1400 meters from the last connection before the tunnel to the last segment needed. The side area is moderate, but a crossing of the main road is needed in every case by a bridge or a tunnel. The speed level is here important to fulfill the minimum demands for the ramp going under or over the main road, and choose a radius coherent with this.
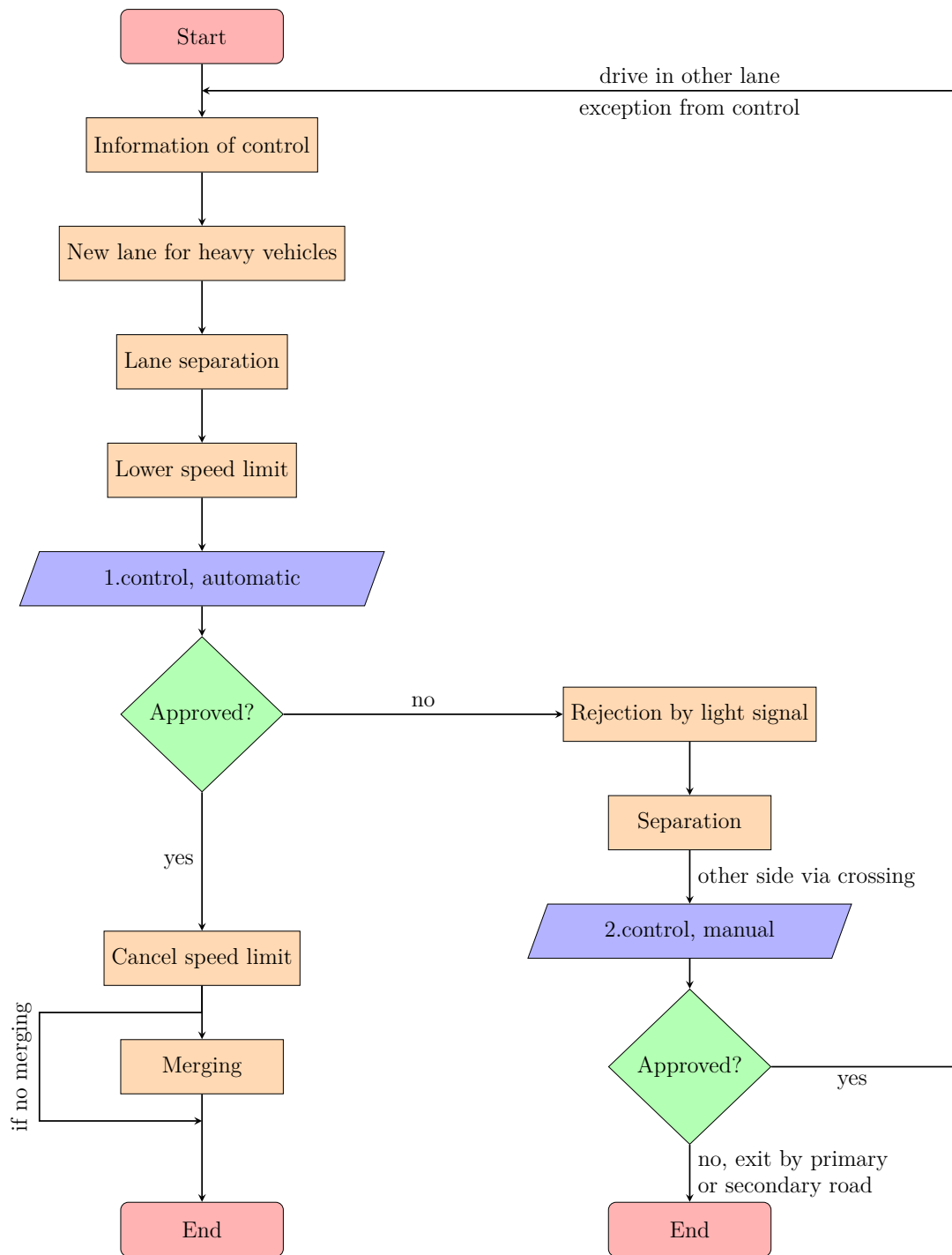
Figure 4.16: Flowchart describing the 2C alternative
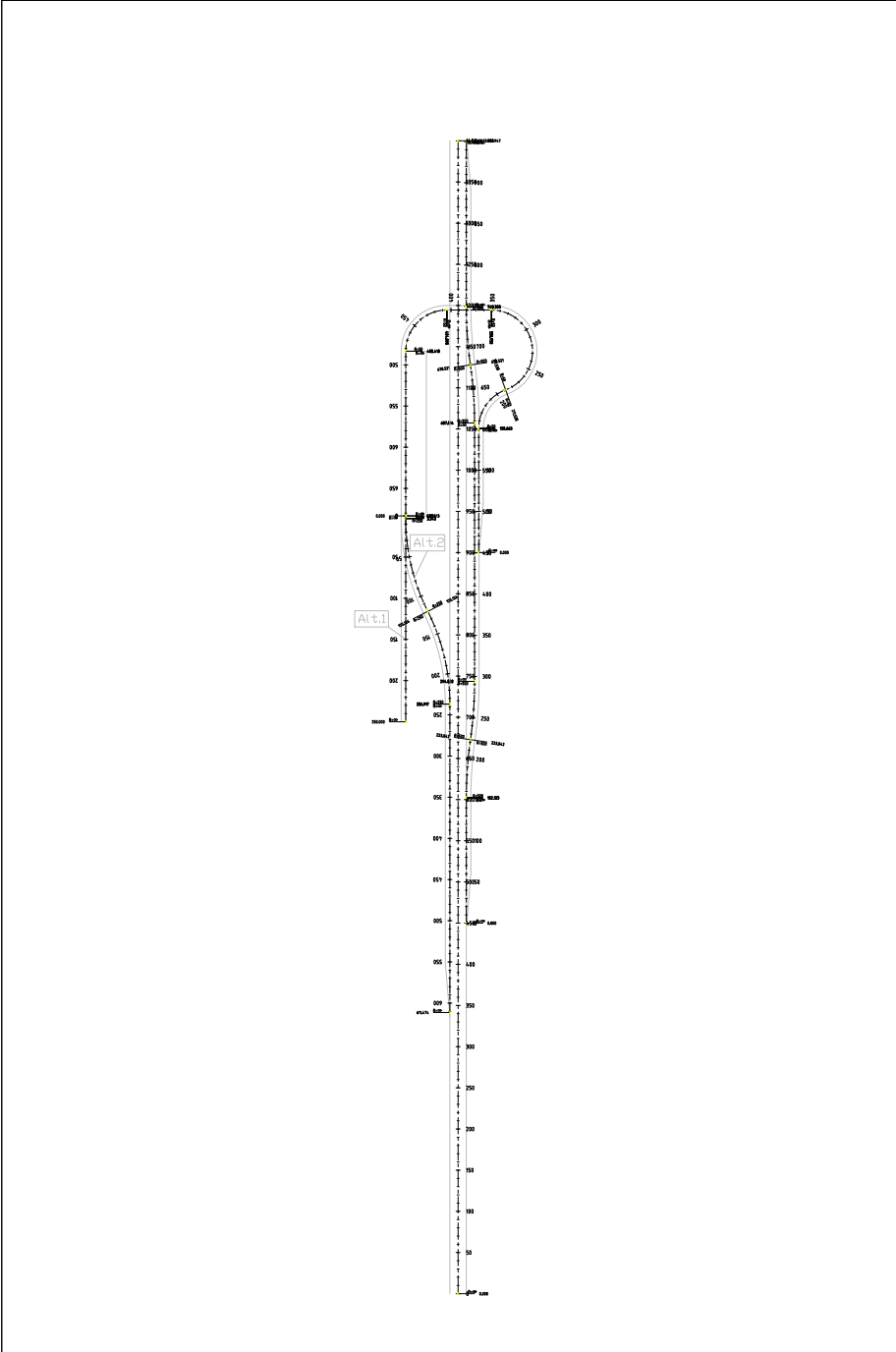
Figure 4.17: Overview of the geometry on the 2C alternative

Skilt- og oppmerkingsplan

POS	SKILT – TEGN	SKILT NR.	RE-FLEKS	STØRR. TEKST	ANTALL	MERKNAD
1		560.5	1	SS	2	-
2		534.H02	1	SS	2	Kan kombineres med 306.5
3		306.5	1	SS	2	Overhengende skilt Vise at lastebiler må ta av senere.
4		362.40	1	SS	2	-
5		1092	-	-	1	Tolyssignal
6		362.100	1	SS	2	-
7		531.202	1	SS	2	-
8		531.102	1	SS	2	-

POS	LINJETYPE	NR.	Bred.	Leng.	FARGE	Sum: Tegn.001	MERKNAD
1	Heltrukken kantlinje	1012.1	0,15	Hel	Hvit	x	-
2	Kjørefeltlinje	1000	0,15	Hel	Hvit	x	-
3	Skillelinje	1008	0,2	Hel	Hvit	x	2 – 2
4	Sperrelinje	1004	0,15	Hel	Hvit	x	-
5	Sperreområde	1014	0,15	Hel	Hvit	x	-
6	Kjørefeltlinje/varsellinje	1006.1	0,15	Hel	Hvit	x	-

Tegnforklaring

- Skiltstolpe, enkel
- Skiltstolpe, dobbel
- Skilthenvisning
- Linjehenvisning

Figure 4.18: Overview over the signing and marking on the 2C alternative

4.8   Comparison of the alternatives

The lengths of the three alternatives in the 1–solutions vary considerably in length, from 950 meters on the C alternative to 1500 and 1700 meters on the A and B alternatives. This is mainly because the two first solutions takes place at the same side and direction as the driving direction, while the C alternative is on the other side going towards the original driving direction. This means that the last alternative is parallel to length already needed for signing and other things, and therefore compresses the length. The obvious drawbacks with this alternative is the need for crossing of the main road, and that there is no inclusion on the main road again for the accepted vehicles after the second control. The first two alternatives allows for inclusion on the main road again, and do not need to cross the main road if the secondary road does not demand this. When looking on the side area demanded the A alternative has the biggest need, while the loop needs space. Much of this space can be used for the second control itself, making more use of the space already needed. The B alternative with a parallel solution demands the least side area, but exclude the possibility of an area for cooling down, while it has no way to get controlled again at the first control. The situation is more or less the same for the 2–solutions, with the exception that there are one more lane for the first control. This makes the task of separating and controlling the speed level of the vehicles easier. These alternatives therefore demands less of the control equipment, while the parameters can be controlled according to the limits of the system. The alternatives does not vary as much in length, ranging from 1400 to 1750 meters, but have the same points considering the side area needed as the alternatives in the 1 solutions.

A factor that highly favors the 1–solutions is that there is one less lane needed. This can however prove to be hard to implement, while the thermal control may need lower speed and the speed level is much more easily regulated on a separate lane, both in regards to the control and the secondary roads. With a dedicated, separated lane it is also much easier to control that all heavy vehicles passes through the control, and to separate the ones who do not pass the control.

All the alternatives has its positive and negative features, and in every case, the alternative should be selected based on the topography in the area for control, and other factors limiting the area for design. This can be existing building, roads, green areas and so on. The alternatives can also be further expanded and fitted to the situation. These alternatives only shows the minimum area needed for the control and could favorably be expanded in some areas. The control can also be placed further away from the road, with secondary roads going to and from this location. This should not be done for the initial control, while all heavy vehicles must pass this, and will lead to a great loss of time if taken away from the main road system. In the following table, the main features of the different alternatives will be summed up:

Alternative	1A	1B	1C	2A	2B	2C
Total minimum length	1500m	1700m	950m	1500m	1750m	1400m
Impact on side area	Large	Small	Medium	Large	Medium	medium
Main side of main road	Right	Right	Left	Right	Right	Left
Separate lane for control				x	x	x
Inclusion after 2. control	x	x		x	x	
Cool-down possible	x		x	x		x

Table 4.1: Main features of the different alternatives
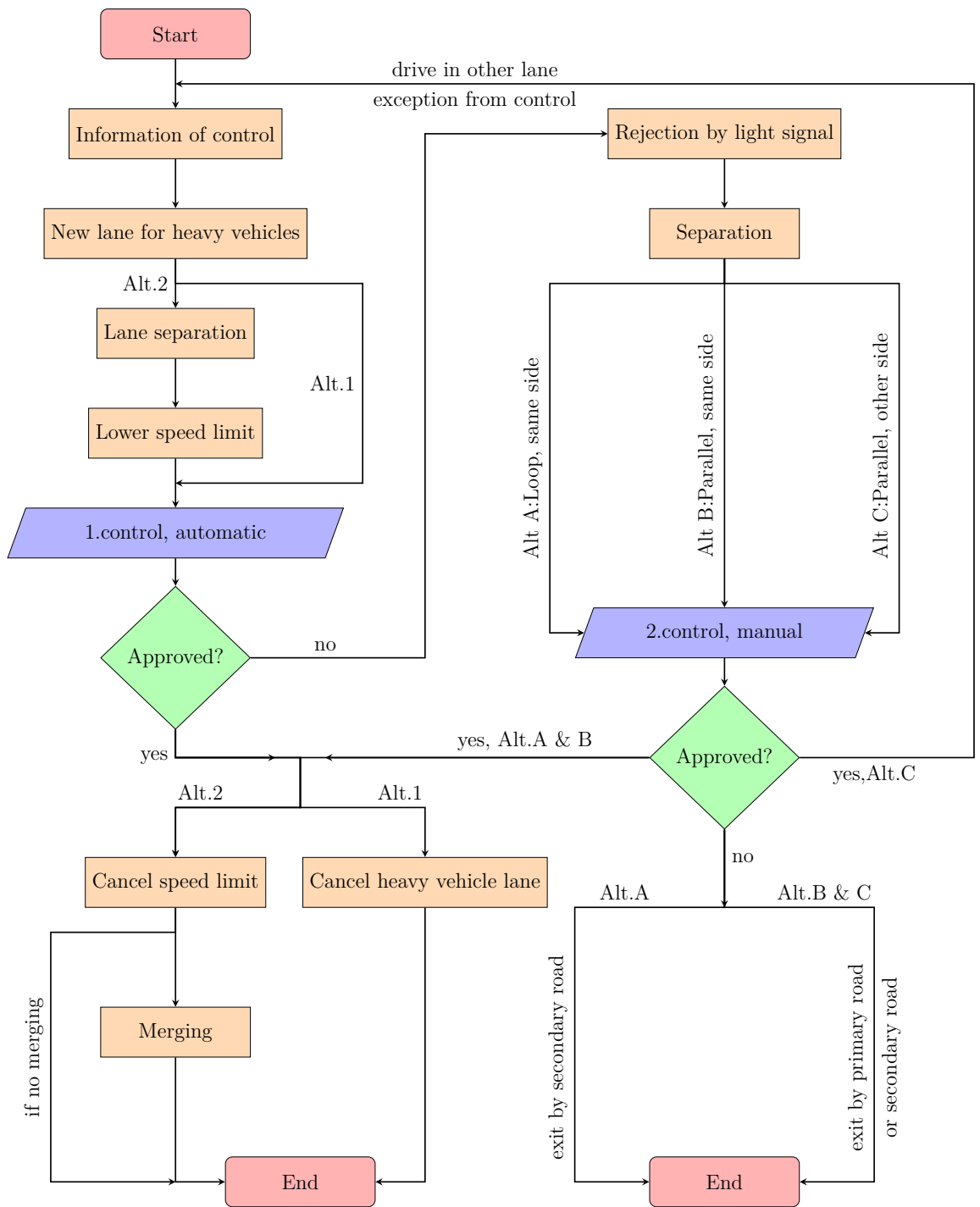
Figure 4.19: Flowchart describing all the alternatives combined

Chapter 5

Rogfast, case study

5.1 Background

The National transport plan for 2014-2023 states that one of the main investments from the government on national roads will be on the stretches between the fjord-crossings of E39, and that the project E39 Rogfast will be built.[12] Ferry-free E39 will connect the different western counties of Norway, allowing for much more effective transport between the main cities, and is seen as one of the foundations for the economic future for the western part of the country, and for the country as a whole. This project is a very important part of this strategy, and will connect the area of Stavanger with the areas of Haugesund and Bergen.[25]

Figure 5.1: Overview over the ferry-free E39 concept from NPRA

The main goals that are set for realizing the Rogfast project is[21]:

- To contribute in making E39 an important connection for the western Norway as a part of a national transport corridor along the western coast.

- Contribute to develop a coherent transport system for goods, linking the central harbors and other important nodes along the western coast.

- Contribute to develop a common work– and living area for Nord–Jæren and for the western part of the country.

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Boknafjorden is an inlet fjord, meaning that it is shallow near the sea outlet, and deeper within its inner part. This kind of fjord is formed by glacial erosion, mainly beneath sea level at the time, where the eroded masses where pushed out with the ice to the sea and formed a threshold here.[2] The threshold for Boknafjorden goes in a bow from Tungenes in the south, via Kvitsøy, to Arsvågen in the north.
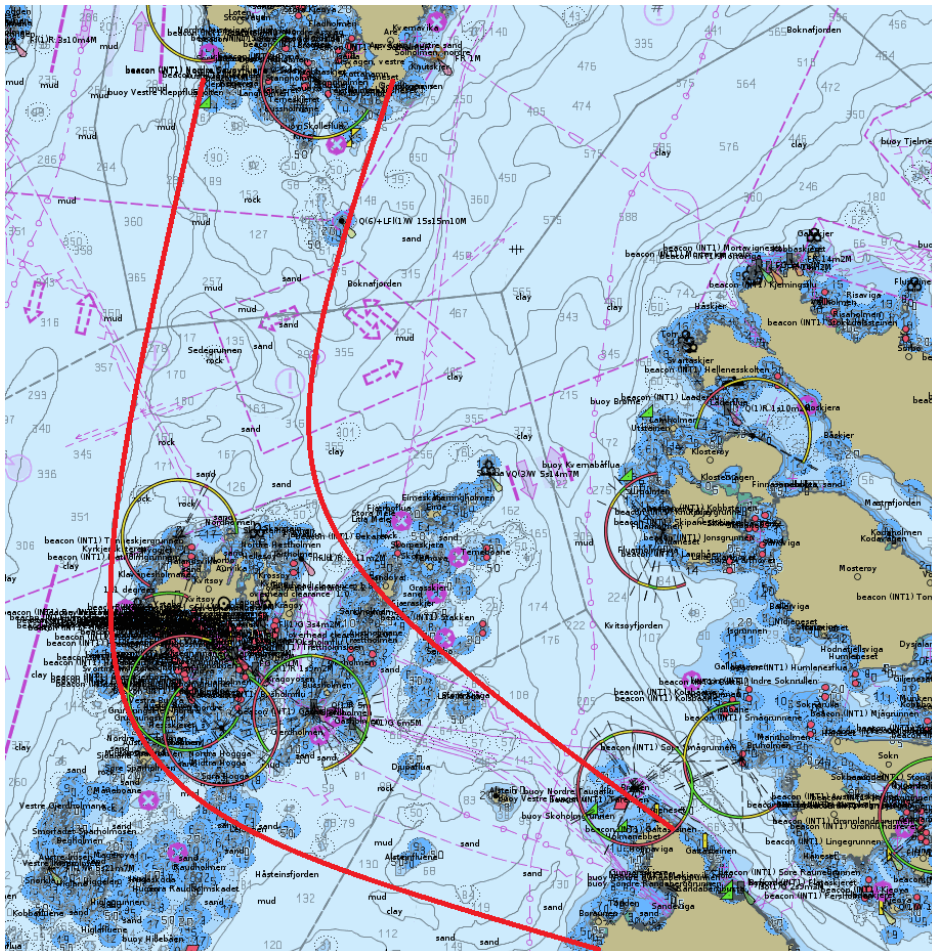
Figure 5.2: Sea depths in the outlet of Boknafjorden with threshold indicated in red where the Rogfast tunnel will be built

To prevent too long and steep climbs, the undersea tunnel has to follow this threshold. This makes it convenient to include Kvitsøy as a part of the project, and thereby connecting this island to the mainland.[25] Under these circumstances the planned project consists of:

- The main tunnel, going from Harestad in the south to Laupland in the north, a 26,7 km long two-barrel undersea tunnel

- A smaller, 4km one-barrel tunnel connection to the island of Kvitsøy. This tunnel will be connected with the main tunnel in a crossing-free intersection undersea.

- Several smaller side roads and connections to the new road.

- Mass depots on each of the three entrance areas.

The main tunnel will have a maximum inclination of 5% while the secondary tunnel will have a maximum of 7%. It will be dimensioned for 110 km/t and has an expected construction time of 7-8 years. Today the fjord is being crossed by ferry, and it is Norway's second highest traveled ferry-stretch with and aadt of 4157 in 2014. This is expected to increase to 6000 in 2025 when the planned opening occurs, and within 2045, this number is expected to be in the area of 13000. In addition to the enormous pressure this would have put on the ferries, the two present under sea tunnels leading to the ferry would not fulfill safety factors coming with those high aadt numbers.[25]
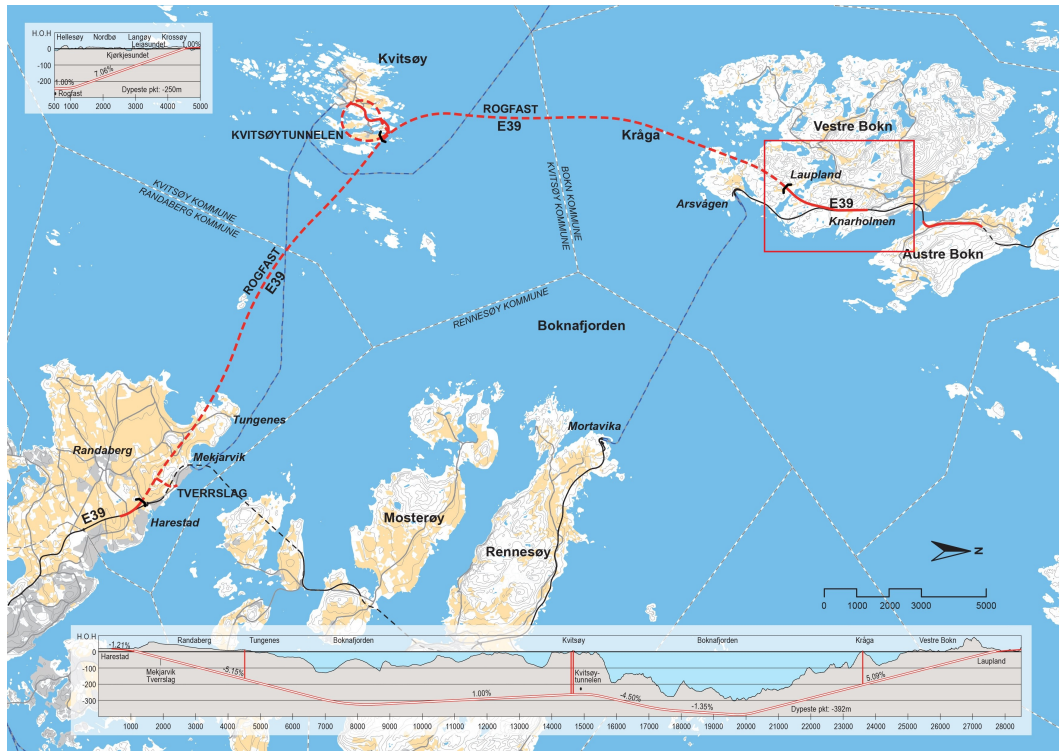
Figure 5.3: Overview of the Rogfast project with area of interest for the thermal control indicated in the red box

The area for the control lies within the spatial plan of Laupland-Knarholmen in the municipal of Bokn at the north end of the Rogfast project. The landscape is coastal with bare, hilly topography. This makes impacts very visible and you have to consider the esthetics of the landscape while planning to prevent big eye soars. This again means that the road and accompanying structures should follow natural lines made from the surroundings and not break up the natural forms. This is a challenge while a control like this quickly claims a lot of land. Another restriction on the placement of the area is that it has to be after the last entry on the road before the tunnel, this to ensure that every vehicle passes through the control.

5.2 Alternative assessment

When examining what alternative to choose for this specific project the zoning plan and its related road geometry found in Appendix D is used as a base. The main road line is used as a restriction, excluding the alternative to move this road. The main road goes more or less parallel with the existing road until the roads bend off from each other about 1km before the tunnel entrance.

5.2.1 Road standard

The new E39 at Laupaland in Bokn will have the H8 standard and will be built for a speed of 110 km/h. From the new guidelines of "NA-rundskriv 2015/2" the dimensions is as follows for AADT 12000-20000:
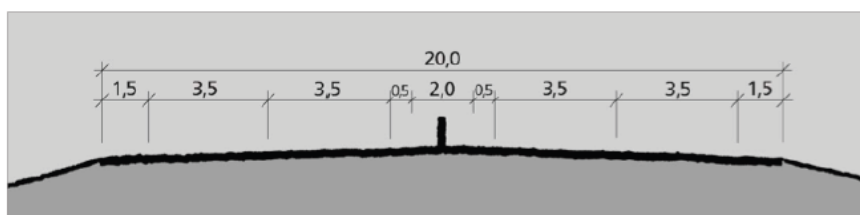
Figure 5.4: Dimensions of the H8 road standard

This gives the following restrictions according to the Handbook N100.[22]

Horisontalkurvatur			Vertikalkurvatur				
$R_h{}^1$	Klotoide	Siktlengde[2, 3]	$R_{v,høy}$	$R_{v,lav}$	Overhøyde	Stigning	Res. fall
	Min	Stopp	Min	Min	e	Maks	Maks	Min
800	260	260	14100	3800	7,5	5,0	9,0	2
900	265	260	14100	3800	7,0	5,0	9,0	2
1000	270	260	14100	3800	6,5	5,0	9,0	2
1200	275	260	14100	3800	5,6	5,0	9,0	2
1400	275	260	14100	3800	4,7	5,0	9,0	2
1600	275	260	14100	3800	3,7	5,0	9,0	2
≥ 1750	275	260	14100	3800	3,0	5,0	9,0	2

Figure 5.5: Restrictions for the H8 design

This means that there is planned two lanes in each direction for the new main road. In the zoning plan, there are only one lane in each direction at the northernmost points before the control. This is assumed extended to two lanes in each direction all the way when discussing alternatives here. The planned speed limit of 110 km/h favor the alternatives that has a separated lane for the control with opportunity for lowering the speed limit. This because it can prove to be hard to execute the control under such high speeds. The separation process also gets a lot easier with a dedicated lane for those driving through the control.The secondary road leading away from the control area in the 2A alternatives have a very limited area and difficult topographic prerequisites and is therefore dimensioned after the requirements for ramps, with width as necessary for module trucks. Following are the dimensions from the N100 handbook.[22] The handbook also states that ramps should be designed with transaction curves and have a maximum inclination of 8% when designed going over the main road. This in combination with smaller radius induces low speed on the short stretch over to the connecting road.
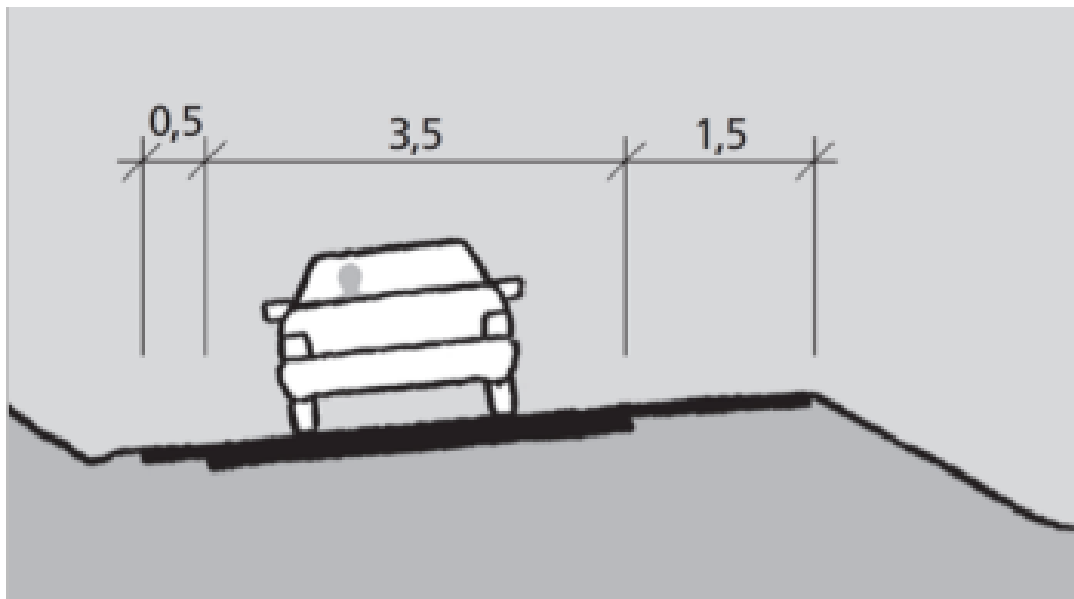
Figure 5.6: Dimensions of the ramp design

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5.2.2 Length

The first thing to notice is that the length from the last connection on the road to the tunnel (here emergency exit before tunnel) is long enough for all the alternatives. There is at least 2000 meters (more likely about 2500 meters) and the longest alternative is 1750 meters. This means that the length is not a excluding factor itself, and all alternatives is examined further. The extra length available can be used to displace some elements, making the solutions even more fitted to the surroundings.

5.2.3 Side area

Running along the driving direction towards the tunnel, the western side, there is hilly landscape. There already are a lot of cutting in the terrain, and with the new main road placed even further to the west, the space on the western side is very limited if minimal impacts on the surroundings is sought after. There are however some areas with flatter, easier ground that can be favorable places to have the control. The eastern side is more easy to work with for long parts of the distance, being flatter and more open. This favors the alternatives that have elements on the other side of the main road. The different alternatives needs fillings that seems to exceed the cuttings, but this should not be a problem since there is enormous amounts of masses available from the tunnel.

5.2.4 Existing infrastructure

The old main road is going to be kept as a secondary road, and lies on the east side of the new main road for all of the length. There are also some small local roads on the western side of the new main road, but these are not suited for heavy vehicles. This again favor alternatives that have the secondary, exiting road on the eastern side of the main road.

5.2.5   Comparison and choice for further examining

When considering the first automatic hot spot detection, it seems that with the solutions implemented on the marked today, discussed in Chapter 2, a dedicated lane for those driving through the control is preferable. This has been done several places in Europe and has proven its worth. You can then lower the speed level through the control, making the results better and the separation of eventually declined vehicles much easier and more direct. This means that the alternative 2x will be best suited for the current solutions on the marked. When examining the different solutions within this alternative in the light of the factors discussed above some conclusions can be drawn. The space for the control should be in one of the areas with a bit room on the eastern side to allow the approved vehicles to continue to the main road without further delay. The exiting road for declined vehicles should be connected to the existing road on the eastern side to prevent more land than necessary being used for the infrastructure. The area for the control is planned with a minimum of personnel present, this favors solutions that presents an alternative for the drivers to park and cool down before trying to get accepted a second time without involvement of personnel. This would be solution A and C, while B offers a more direct implementation on the main road again if there is personnel present to make the second, manual control. The A alternative demands more side area on the western side of the road, but significantly reduces the driving distance for the vehicles after cooling down. The C alternative is more suited to the topography of this project, having most of the infrastructure on the eastern side of the road. The drawback is that vehicles has to drive all the way back to the last intersection before the control to make a second try of passing.

To sum up, alternative 2A or 2C seems to be the best choice for this project. 2A with an exiting road to the eastern side would be the best solution if there proves to be enough space for the loop on the west side of the road. There will have to be space for about 100x400 meters on the west side for this solution. If this proves to be difficult, the 2C alternative would be the best solution. Further studies will be on these two alternatives for the Rogfast project. It will show modified flowcharts regarding the cooling area instead of a manual control, and then solutions based on these modified flowcharts as well as the general solutions for the selected alternatives.

5.3 Modified flowcharts

5.3.1 2A Rogfast
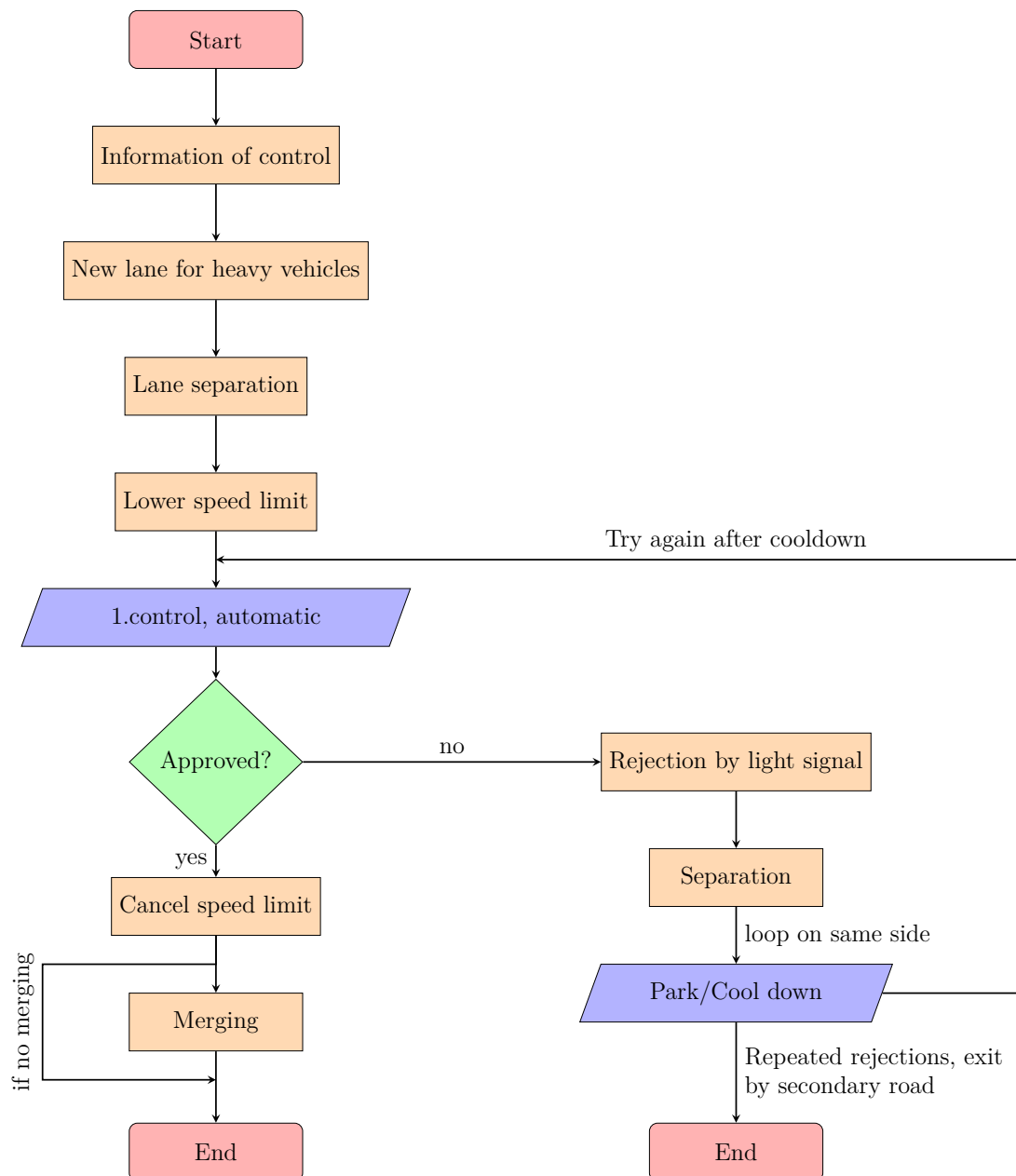
Figure 5.7: Flowchart describing the Modified 2A alternative

5.3.2   2C Rogfast
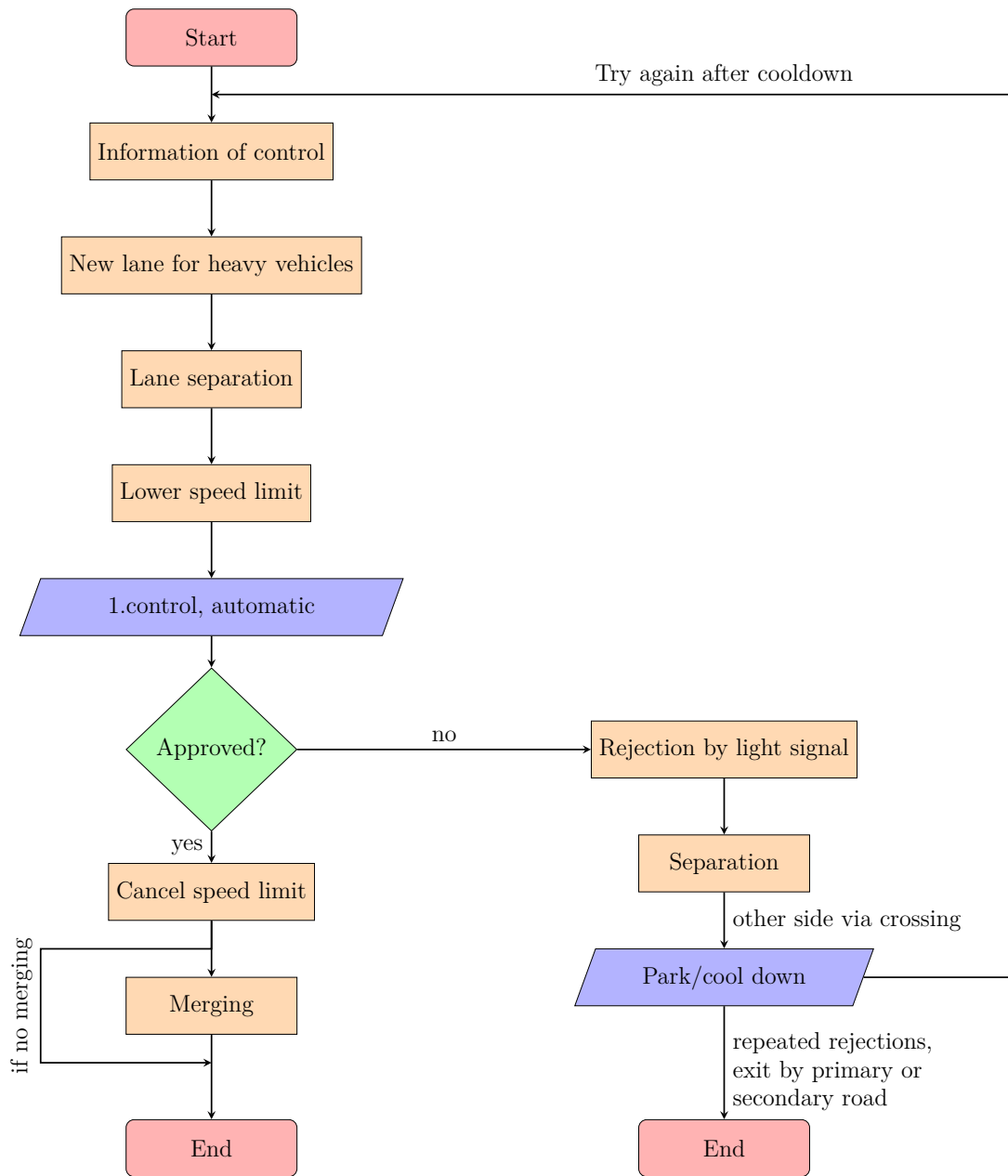
Figure 5.8: Flowchart describing the Modified 2C alternative

5.4 Description of the alternatives

The extra lane on the main road is made as an extra lane with an area of 5 meter in between. The lane is moved down/up the road when examining the two different areas. The line geometry is as mentioned not changed and is used as a restriction. It is assumed H8 with two lanes in each direction.

The drawings that is discussed below can be found in Appendix D. These are made for the A1 format, and can be found as attached pdf files in the digital vermsion of the thesis, but is here printed in A3 because of convenience when presenting on paper.

The following illustrations shows the main area of road between the tunnel and the first intersection and the most suited locations for the main elements of the control when considering the limitations and topology. The areas illustrated show an estimate over the area needed and its placement with respect to the new main road in red. These are the areas for the four alternatives that are described further and in more detail in the following pages.
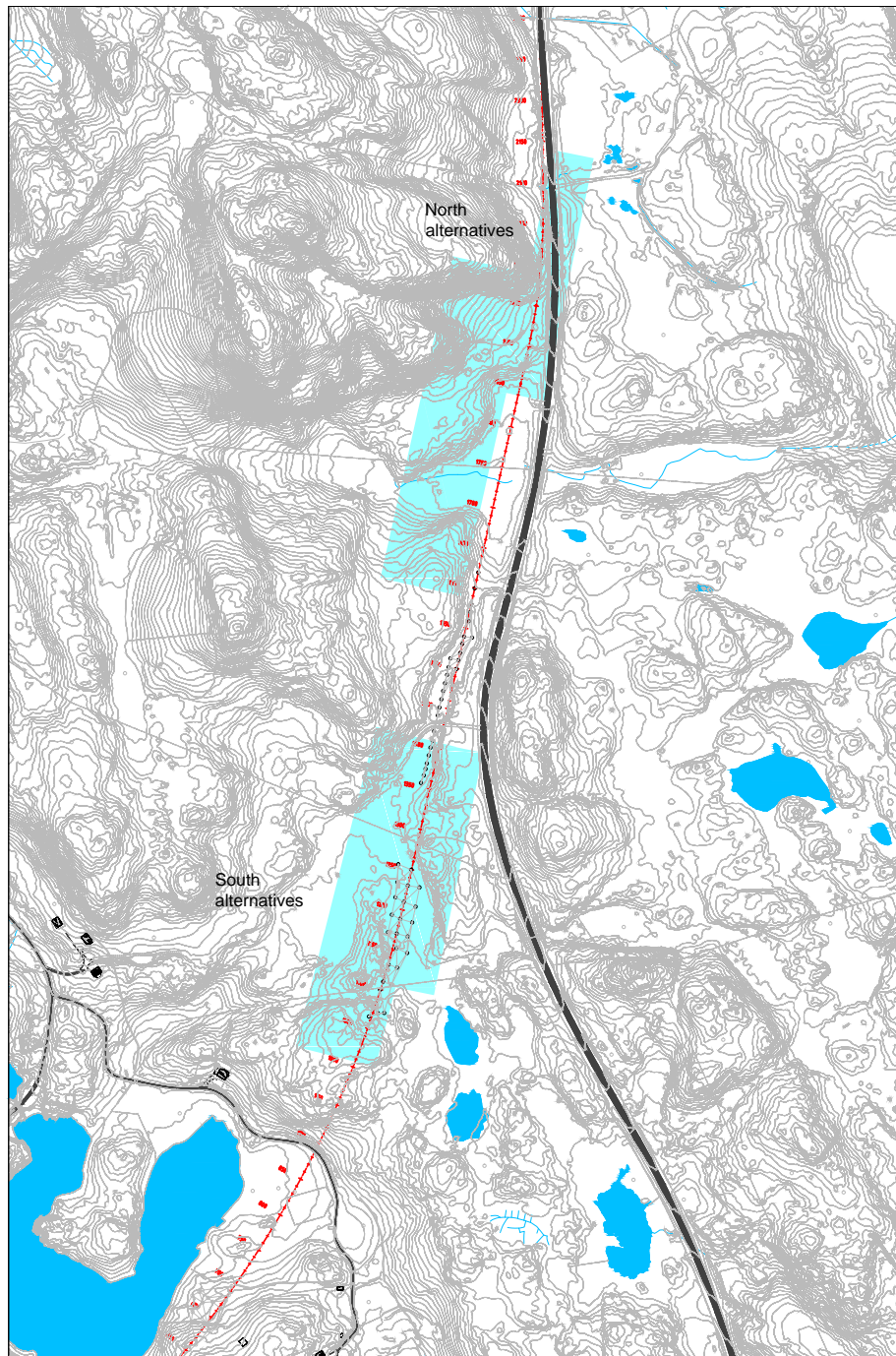
Figure 5.9: Possible locations for placement of the main elements of the thermal control on the different alternatives

5.4.1 2A North alternative

For the 2A solution, there are two suitable locations as shown previously, this solution is the northernmost one. Here there is room for the loop without the need of removing very much of the terrain. The main road have a small inclination on this stretch, and is almost at the same level as the terrain at the end. This makes the need for a filling limited to the middle of the solution at this location. The biggest problem is leading the vehicles that do not get accepted away from the area. A bridge or tunnel is hard to accomplish, while the road is close to the terrain and at the same level. The road leading away need to go down or up a lot on limited space after the control area to be able to cross the main road.

Figure 5.10: Overview of the geometry on the 2A North alternative

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5.4.2 2A South alternative

The second location for the 2A alternative is a bit further south. There will here be a need for some cutting in the start and end of the loop to get the needed length. Because the main road lies elevated over the terrain, there will be the need for quite a substantially filling on the marsh area where the loop is located. This to make the side constructions on the same level as the main road and not have to decline or incline from the main road. The road leading the vehicles that do not get accepted by the thermal control away from the area is hard to construct without large impacts on the surroundings. A lot of cutting is needed in the terrain at the start of the secondary road, and a longer bridge is needed to get over the roads to a suitable area on the other side. The descent down to the old road again after the bridge will also need to be very steep to prevent a long alternative following that the terrain declines in the same direction.
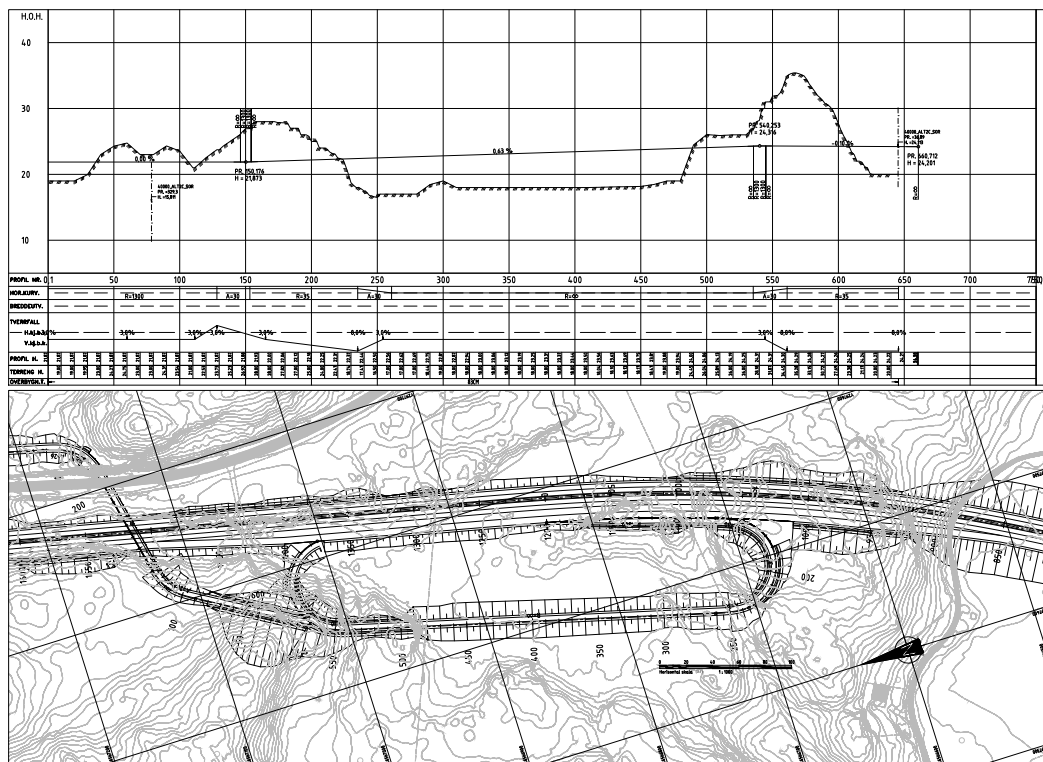
Figure 5.11: Overview of the geometry on the 2A South alternative

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5.4.3   2C North alternative

In this solution, the northernmost one, the little area of space at the western side of the road is used to get the road down and under the main road. The main road is here planned substantially higher in the terrain than the old road, and it will therefore not be a problem connecting to the old road again after getting under the main road. The space on the eastern side of the road between the main road and the old road is limited, and constructing an area for cooling down for the rejected vehicles here will be difficult. The area must therefore be on the other side of the old road or the old road must be rerouted around to hinder crossing of the road to get into this area. This area for cooling down can be built at any place between the crossing and the first possible connection to the main road again, and it can therefore prove easier to build it further up the old road where it is flatter and there is more space available. You then avoid the problem with rerouting or crossing the old road at the point where the roads connect.
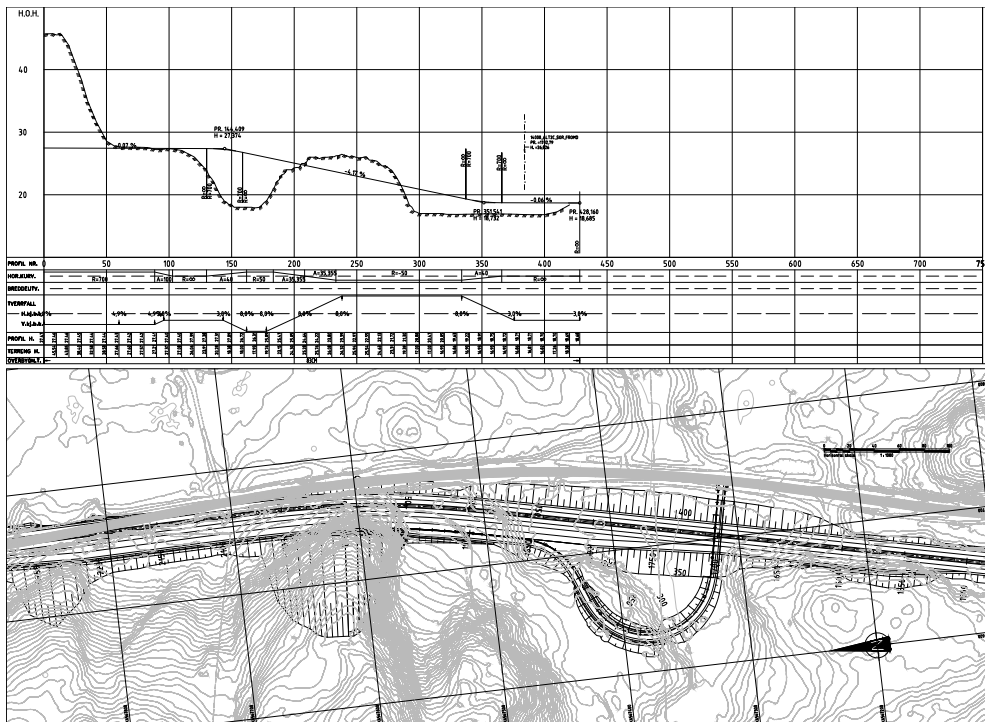
Figure 5.12: Overview of the geometry on the 2C North alternative

5.4.4   2C South alternative

This solution tries to make use of the flatter area a bit further south on the western side, as well as the space between the old and new road for a possible area for cooling down of the rejected vehicles. This will lead to a longer ride back for the rejected vehicles in comparison to the other alternative, but tries to make use of the land available in a better way. The western side suits this solution well, while there are no hindrances for making the ramp down to a suitable level under the main road. The problem lies on the other side, while the terrain rises towards the old road and the main road lies on level with the terrain where the crossing needs to be. The height difference from the needed clearance under the main road and up to the old road is barely enough to get up with a 5% inclination, and therefore makes it difficult to put an area for cooling down by its side. The secondary road can be bent to make longer distance if clearance under the main road needs to be bigger or the inclination smaller, but will lead to a lot of land use. The area should be possible to construct on an intermediate level with an exit on the inclination up to the old road. Alternatively there could be constructed an area for cooling down further down the road since the vehicles has to drive back in order to try again anyway. Another element that can prove to be difficult to handle is the small lakes and wet area nearby, especially on the eastern side. These, however, can most likely be filled with masses from the tunnel if this does not interrupt the natural waterways.
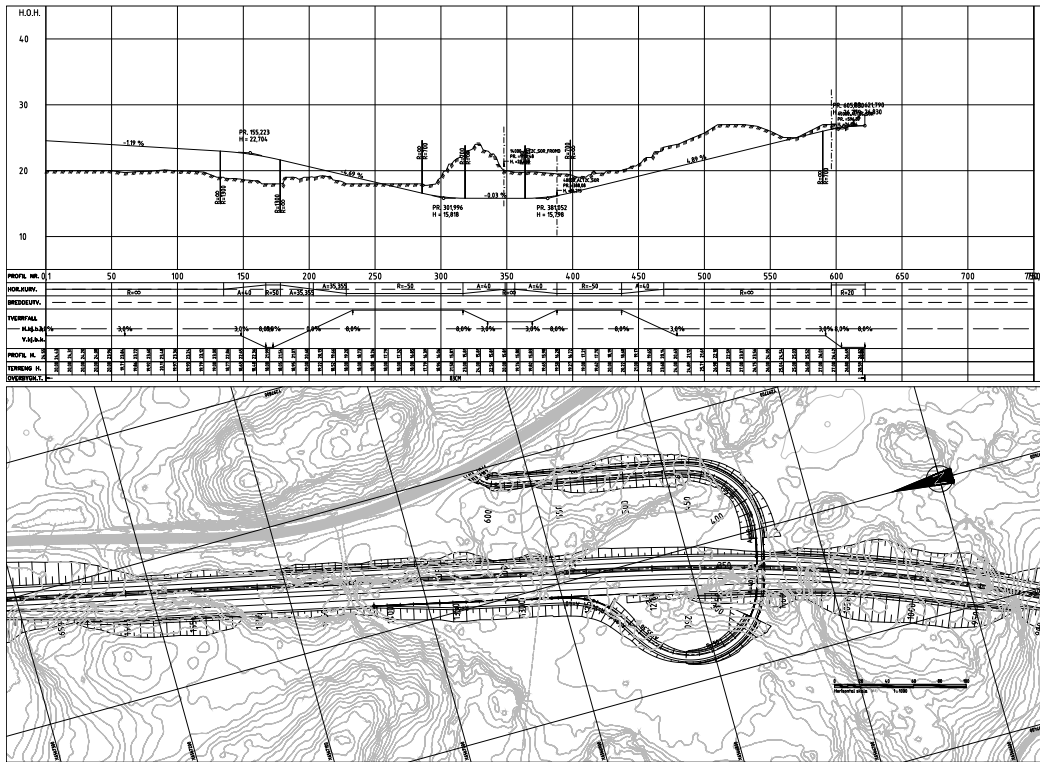
Figure 5.13: Overview of the geometry on the 2C South alternative

5.4.5   Preliminary conclusion and selection

When comparing the two 2A alternatives described over, both loops fits quite well with the terrain, despite both having the need for some cutting and filling. The north alternative seems to fit the terrain best, while the south alternative cuts significantly at the north end. This is also the fact for the secondary road leading away from the south alternative. It cuts much more than the same road in the north alternative, and is also longer, have a longer bridge, and is steeper than the other alternative. The south alternative also lies on a marshy area that may need to be worked on more than the north alternative. This taken into consideration, the north alternative would be the recommended one of the two.

The two 2C alternatives both works well with the terrain on the western side of the road. The north alternative gets down to a suitable level without too much impact on the surroundings, it also has an easy finish due to the fact that the new main road lies much higher than the old road. This also helps making it a short alternative. The south alternative does not need to get as far down as the north one, and is a better choice at the west side of the road. The problem occurs after crossing under the new main road, it then has to climb a lot to get up to the old road. It therefore has a steep, and in comparison long, inclination. There is also a small pond nearby may need to be done something with when considering this alternative. Another drawback with the south alternative is that you have to drive longer if you are rejected by the control to try again. Both alternatives can have the area for cooling down at any time before connecting with the main road again. Taking all this into consideration when comparing these alternatives, the north one seems to be the best choice of the two.

The 2A north and 2C north alternatives is therefore the recommended ones, and signing and marking is therefore made for these two alternatives.

5.5 Signing and marking

The signing and marking of the two alternatives in this project is more or less directly transferred from the general solutions. The road has very good sight conditions on this stretch, and visibility is generally very good. Small changes can be made to fit the terrain better when slope of cuttings and fillings among other details has been decided.
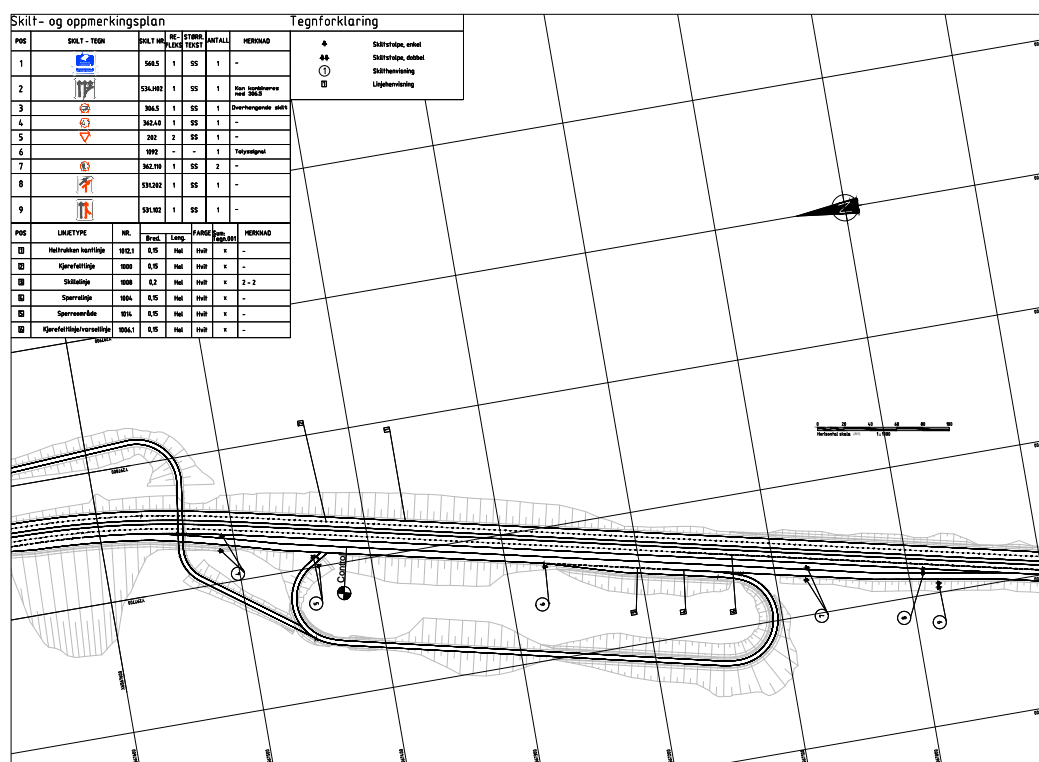
Figure 5.14: Overview of the signing and marking on the 2C second alternative

Chapter 6

Economic evaluation

6.1 Background and parameters

In the article "Rogfast - consequences for society, economy and environment" it is stated that about 16 % of the traffic over Boknafjorden is heavy vehicles. Here heavy vehicles is defined as vehicles over 6 meters, and the average crossings is 470 per day, or 170000 a year. Further dividing of the heavy vehicles into 6-14 meter and over 14 meter shows that 204 per day, or 75000 per year is the lighter heavy vehicles between 6-14 meter and 267 per day, or 95000 per year is the heavier ones over 14 meter. The increase from the 2000 values of heavy traffic has been 90 %.[11]

From an analysis made of the Norwegian Institute of Transport Economics[15] there were the following accidents related to fires over a 4 year span from 2008-2011.

Type	Number
Total	135
Minor injury	8
Major injury	8
Damage to vehicle	40
Damage to tunnel	20

Table 6.1: Overview over accidents involving fire in Norwegian tunnels in a 4 year span from 2008 to 2011

44 % of these accidents occurred in undersea tunnels or tunnels with high inclination. This shows that the savings can be significant for this type of tunnel, especially when you take into consideration the socioeconomic loss these accidents leads to when you have to close the tunnel following a major accident.

The number of expected deaths in Rogfast following a fire in a truck of 20MW will be 1,5 per 100 years. Per 1000 years there will be 5,6 persons killed by a 1000MW fire. Accidents including dangerous goods will lead to an expected 2,04 deaths per 100 years. Total number of expected deaths per 100 years is therefore 4.1 persons. This shows that the expected frequency of catastrophic accidents will be relative low. One reason for this is the planned safety measures and the above average standard of this tunnel compared to other Norwegian tunnels.[18]

The socioeconomic costs of accidents is given in a report from the Norwegian Institute of Transport Economics and is shown in the table under.[6]

Severity	Total accident cost [NOK]
Material damage	30000
Light injury	614000
Serious injury	8140000
Very serious injury	22930000
Killed	30220000

Table 6.2: Socioeconomic costs related to accidents calculated by the Norwegian Institute of Transport Economics

In 2014 about 25% of all controlled heavy vehicles showed faults. Of the 2159 vehicles that where prohibited from driving further, 348 where from technical causes. Severe faults on tires and on the brakes were some of the big problems. 348 out of 8636 gives a percentage of 4% that have technical problems. Numbers from 2013 shows the same tendency.[5] Following the closing of Gudvangatunnelen in 2013, 115 heavy vehicles where stopped on one day and controlled. 20 of these had faults, where heating of the brakes were the main problem. This gives a percentage of 17%, but not all these were related to brakes. It is natural that more was stopped here concerning the brakes than the mentioned control in Sør-Trøndelag, while the topography is much more demanding in the western part of the country. This indicates that the number one can expect in relation to the Rogfast project is in between these values, but more closer to the large selection of cases in Trøndelag.

In the paper "Konseptvalgutredning for E39 Kyststamvegen - Boknafjordkryssingen" the savings related to travel time could be up to 40% on the stretch.[16]

In minutes on the stretch from Stavanger to Aksdal the potential savings for light vehicles is 38 minutes, and for heavy vehicles 41 minutes. In the paper "Nytte-kostnadsanalyser ved bruk av transportmodeller" (benefit-cost analysis using transport models) the different hourly rates related to transport are given. Following the table for trips over 200 km are given in NOK (2013) for light vehicle and heavy vehicles. [14] For heavy vehicles the hourly rate is taken from the analysis made of Econ pöyry[11].

Transport mode Purpose of travel	Light vehicle	Heavy vehicles
Work	444	700
To/from work	215	-
Leisure	167	-

Table 6.3: Hourly rates [NOK] of travel per mode and purpose

In the paper "Reisevaneundersøkelse for riksvegfergesambandene" the travel habits and purpose for travel on the different ferries on the Norwegian main roads were examined. The examination method was a questionnaire and were conducted on board the ferry on Wednesdays and Fridays. The main results show that a third of the travels were work related. Leisure/vacation is the most normal cause for travel for private travel purposes. Following the different travel purposes on the stretch over Boknafjorden is presented.[9]

Purpose	%
To/from work	16
Duty	21
Professional transport	3
To/from school	2
Visitation	22
Vacation/leisure	21
Private appointment	10
Other	5

Table 6.4: Travel purposes on the ferry stretch over Boknafjorden

From this we can conclude with the following distribution of the travel purposes over this stretch.
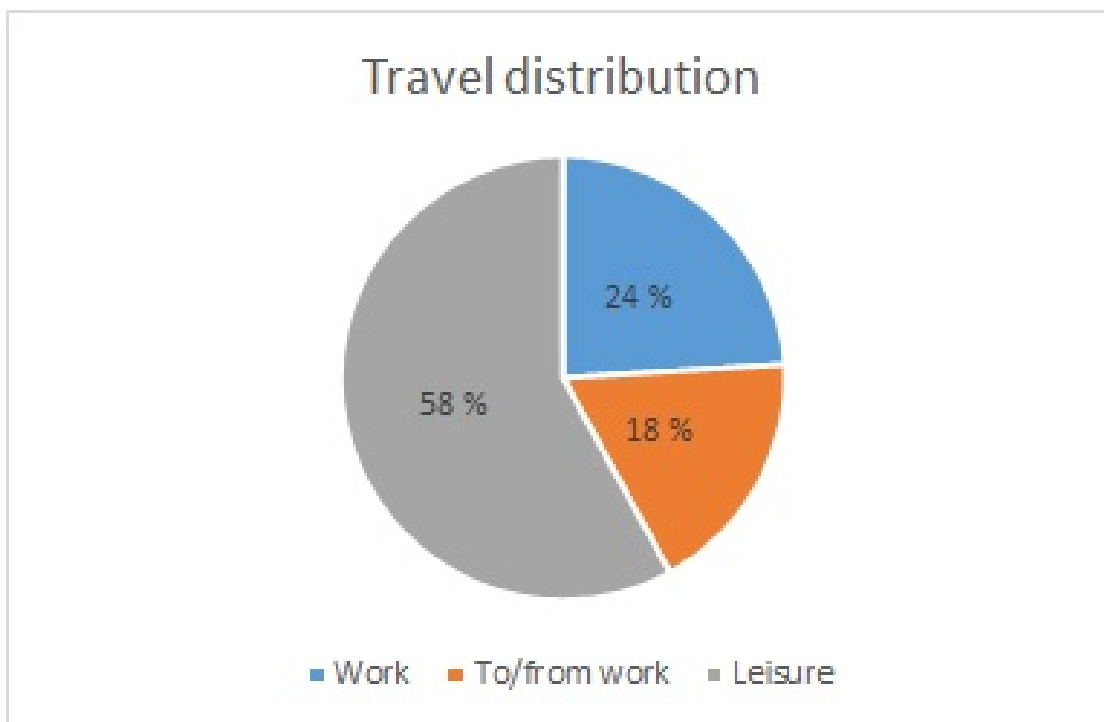
Figure 6.1: Generalized travel distribution over Boknafjorden

Using this information combined with calculation about the alternative route in case of an accident gives us an estimate of the transport costs related to a closing of the tunnel.

6.2   Scenarios

For details considering the calculations see calculations in Appendix E

In the risk analysis of fire in tunnels a table consisting of expert assessments when it comes to the distribution of the intensity of the fires is given.[3] This table shows that 51% of the fires in heavy vehicles do not exceed a strength of 5MW. 92% of the fires do not exceed 50MW. This leaves 8% stronger than 50MW. This forms the foundation for accessing three different scenarios and their consequence and probability, respectively the small, medium and large scenario. For examples regarding the different strengths of fires see Chapter 2 and scenarios below.

As mentioned in Chapter 2 44% of all accident involving fire and smoke in tunnel occurs in the long, steep tunnels and undersea tunnels. There is 33.75 accident involving fire and smoke per 1000 tunnels per year, where 21.25 of these involve fire. This means 9,35 accident per year in steep tunnels/undersea tunnels. Of these about 53% is caused by heavy vehicles, where 50% of these again where caused by technical problems. This gives 2,48 accident per year in steep tunnels/undersea tunnels caused by technical problems in heavy vehicles.

There is, according to an analysis made by the Institute of Transport Economics in Norway regarding fires in tunnels, 41 tunnels that are undersea or have an heavy gradient. This is about 4% of the total number of tunnels in Norway. The number is likely a bit higher, while new tunnels as Ryfast and Rogfast is built/being built. It will therefore be worked further with an estimate of 45 tunnels. Dividing the accidents evenly over these 45 tunnels gives an accident rate of 0.0551 accidents per year per tunnel. Further dividing these accident according to the distribution gives 0,0281 accidents up to 5MW, 0.0226 accident between 5 and 50MW and 0,0044 accidents over 50MW a year. In other words 2,81 accidents under 5MW, 2,26 accidents between 5 and 50MW, and 0,44 accidents over 50MW per 100 years. The expected number of 4.1 deaths per 100 years in the Rogfast tunnel seems to correlate quite good with this taken the modern technology and safety measures in the tunnel into consideration along with other the other causes for accidents besides fires.

6.2.1 Small accident

Fires under 5MW are more related to fires in light vehicles opposed to heavy vehicles, and will likely not claim any lives. Severe injuries will also be limited. In this calculation of a small fire accident, it is assumed that no lives is lost, injury is limited to 2 persons with minor impact from the smoke, and no severe damage is done to the tunnel. The tunnel will be closed for 1 day to get the car out, check the tunnel for damages, and clean up. During this period all the traffic will go in the other barrel. The speed limit will be lowered to 70km/h, this because of the increased risk of a meeting accident without a barrier. The time loss for the delay in traffic will be 605300 NOK/hours*day for light vehicles and 350000 NOK/hours*day for heavy vehicles. The travel time through the Rogfast tunnel is according to the NPRA in the conceptual assessment[18] 24 minutes for heavy vehicles and 19 minutes for light vehicles. In addition, there will be some repercussions leading to a bit more loss, but this is not considered here. This gives an loss of 0.114h for the light vehicles and 0.144h for heavy vehicles when considering the lower speed limit.

- The direct cost will include the emergency vehicles and personnel, the removing of the vehicle that caught fire, inspection of the tunnel, and cleaning of the tunnel. The cost here is difficult to predict, as it will vary a lot with each accident. Nevertheless an estimate of 1 MNOK is used here for this calculation.

- The socioeconomic cost of 2 persons with light injury will be about 1.2 MNOK

- The loss coming from the delay in traffic following rerouting and lowering of the speed limit as mentioned during the closed day will be in the area of 0.12 MNOK.

The total cost for a small accident with a strength of 5MW and the consequences as described will be in the area of 2.35 MNOK.

6.2.2 Medium accident

When looking on an example of a fire with a strength between 5 and 50MW, the fire in Gudvangatunnelen in 2013 and 2015 can be used as a reference and a starting point for calculations. The fire in Oslofjordtunnelen can also be used despite this fire reaching a strength a bit over this interval (70-90MW). Both fires in Gudvangatunnelen involved a lot of people, 70 and 35, this because there was in both occasions a tourist bus involved. In this analysis the estimates given in the "riskanalysis of fire in tunnels"[3] will be used to get a homogenous base for the calculations. It is assumed that 25 people are affected directly by the fire, no one dies, but 5 persons are severely injured following direct impacts from the fire and smoke, or indirect by the chaos inflicted by it. From the examples over it can be assumed that the tunnel will get damages on elements as the concrete and electrical components, and will have to be closed for about 2 weeks.

- The direct costs of fixing the Gudvangatunnel was about 40 million following the fire in 2013[8]. It would most likely be a bit more in Rogfast taken the modern equipment and standard into consideration, and 50 MNOK will be used.

- The socioeconomic cost related to the injuries will be 40,7 MNOK.

- A total loss of 1,67 MNOK in travel time is expected for closing one of the barrels over two weeks with the delay in traffic as mentioned before, coming from the rerouting and lowering of the speed limit.

This gives a total of 92,4 MNOK in cost related to a medium fire with an strength between 5 and 50MW.

6.2.3 Large accident

As we could see from the listing of accidents in Chapter 2, the most severe accident reached an estimated power of about 200 MW. The estimate worked out in the paper "Riskanalysis of fire in tunnels"[3] where the analyzed scenario was a fire in a truck carrying woodwork reaching a power of 170 MW will be used as an example. The damage on the tunnel forces it to be closed for one month. Three different tunnels were analyzed in this paper, where Rogfast will fall in between the "old, long, one-barrel undersea tunnel" and "modern, high-traffic, two-barrel tunnel" categories. In traffic and topology, it will be more like the first one, but in technology and barrels it will be more like the second one. I will therefore use the impact described on the first one and the costs of the second one to try to combine these. When examining number of expected deaths and injuries following a fire of this magnitude, 10 of 25 persons caught in the smoked part of the tunnel will die in the first example. This is due to long and steep tunnel that make evacuation hard, and quite long time before rescue personnel can reach the accident. In addition, 10 is assumed physically injured and 5 psychically injured. In the second example only 2 is expected to die following the fire, 5-10 physically injured and 0-5 psychically injured. This despite 225 persons being affected. Modern technology in the tunnel and short escape routes in combination with fast help from rescue personnel is the reason for this. The Rogfast tunnel will be very long and quite steep, with quite long response time from the emergency personnel. However, it will have modern technology with several rescue rooms among other safety measures and will in this way be more similar to the second example. It is therefore reasonable to assume that the number of affected people will be in the same number as the first example, about 25 directly affected. The number of deaths and injured will more likely be in the number of the second example despite the difficult topography and length. This because of the technology and possibility to escape into the parallel barrel. Therefore, for this magnitude of fire it is assumed that 2 will die from difficult conditions like crashing nearby the fire or inhaling much smoke that leads to premature death. 10 is assumed severely injured following direct impacts from the fire and smoke, or indirect by the chaos inflicted by it.

The cost of fixing the tunnel is assumed to be in the same order as the high trafficated modern tunnel in the second example. This because of the modern equipment in the tunnel and the fact that it is a long undersea tunnel. The traffic is expected to be handled in the same way as the other examples described before with two-way traffic in one barrel.

- The direct cost is reflected to be in the area of 100 to 150 MNOK in the high trafficated, modern, two-barrel tunnel. Assume that it will be in the same size for this tunnel when considering the modernity and complexity of the tunnel. Going further with 150 MNOK.

- The socioeconomic cost related to the deaths and injuries following the accident will be about 141,8 MNOK.

- A total loss of 3,58 MNOK in travel time is expected for closing one of the barrels for a month with the delay in traffic as mentioned before, coming from the rerouting and lowering of the speed limit.

The total cost of a severe accident involving a fire over 50MW in strength, and the following closing of one barrel for a month, will be about 295,4 million NOK.

6.3 Summary

Given the probability and costs as predicted in the previous section, a total of 345,3 MNOK could be lost due to fire accidents in the tunnel over a span of 100 years. To break even this means 3,45 MNOK could be spent each year on a thermal control given that this would prevent all accidents. This is not likely, but it would contribute immensely to take out the worst cases.

- Taking away only the large accidents would save about 130 MNOK alone. This means that 1,3 million could be justified each year on a thermal control.

- Preventing the large and fifty percent of the medium accidents would save 234,4 MNOK.

- Excluding medium and large accidents including fire as a whole would save 338,7 of the 345,3 MNOK.

As one can see from this simple calculation there can be much to gain including a thermal control preventing the worst cases of heavy vehicles from driving into the tunnel. Even if the control only prevents the absolute worst cases, it still saves the society enormous amount of money. It is of course not given that the control will stop all the worst cases, but considering that these already should be in a much worse condition than other before entering the tunnel implies that a control would catch more of these cases than not. The scenarios are constructed from previous accidents and probable outcomes, and it is important to note that this may differ substantially from what actually occurs following an accident. It is also important to note that this small analysis only takes possible savings into consideration, costs connected to the building and maintenance of the control and area needed must be taken into the equation before deciding on implementing this kind of control or not.

Chapter 7

Conclusion

7.1 Conclusions

Tunnels is as safe or safer to drive in as on an open road, but the consequences of an accident is often much worse. Fire in tunnels is a severe accident, and could in the worst case claim many lives and cause enormous costs for the society. The accidents is often traumatizing, with a lot of smoke and fire, giving images that make an impression on everyone. In Norway there have been several accidents involving fire in tunnels the last years, causing many injuries and limiting the traffic for large periods of time. When it also is stated that 44% of the accidents involving fire is in 4% of the total tunnels in Norway, the undersea and very steep tunnels, it seems clear that there is an area of focus available for improving safety.

A thermal control of heavy vehicles has proven its worth in several projects in central Europe, preventing potential dangerous vehicles from entering the tunnel. The worst cases is therefore taken out of the equation, and the probability of severe accidents that involve fire is reduced significantly. Thermal solutions is in constant development, increasing their range, speed and accuracy. The solutions in use for the moment however have their limitations, especially when it comes to the speed. Sound and tested solutions, as the ones in St.Gotthard and Karawanken, have a separate lane for the vehicles being controlled where speed and other factors can be controlled. This makes the control sounder, but it demands quite a lot of extra area on the sides of the road and takes the vehicles controlled out of the traffic. New solutions being developed increases the speed that the vehicles controlled can have, and may make it possible to control all the vehicles in free flowing traffic. The solutions proposed here however takes into account that vehicles may need its own lane, and that the speed may need to be reduced.

The flowcharts developed are separated in two main alternatives, the difference being having a separate lane for the control or not. This means that the first solutions is more intended for the future, new solutions that can measure and control in free flow traffic, while the seconds solutions is more in the conservative, sound way of testing and controlling the heavy vehicles. These solutions are again separated in three alternatives that describes possible ways to deal with and take out the rejected cases from the main road. The alternatives further describes how

a 2.control or an area for cooling down can be designed with respect to the main road, and how the vehicles is further directed depending on approval or not. The flowcharts describes the different elements needed to execute the thermal control, starting with information of the control and ending as the standard main road again, and served as a basis when the general solutions were made.

The general solutions are meant to be a starting point for implementing a thermal control on actual projects, describing geometry, elements, as well as signing and marking that are needed. The alternatives suited to a specific project can be selected depending on the availability of space, and the surroundings, where the control should be placed. These solutions are as mentioned based on the alternatives from the flowcharts, and its parameters is coming from minimum demands set by the NPRA's handbooks. In this way, one is certain that the solutions made based on the general solutions fulfills the design criteria concerning the parameters mentioned. This also means that the solutions can be stretched to fit the surroundings better if there is extra space available.

The new undersea tunnel of Rogfast serve as a great example of how the general solutions can be implemented and used in a real life project. This project is a new, long undersea tunnel that sets high demands for safety, but also large limitations in space and impact wanted on the surroundings. The area examined here is on the north side of the tunnel. The topology is demanding, but it is situated in a rural area creating some extent of freedom when it comes to space. The designed main road is used as a limitation, and it is sought after to make as little impact on the surrounding area as possible, as well as make use of the existing infrastructure where this can be done. The length from the last entry on the main road to the tunnel entrance is quite extensive, making it easier to implement the control where it is best suited. When the area was examined, there were two locations that was more suited than others for the control when all the alternatives that included a separate lane were considered. Two of the alternatives, the 2A and 2C alternative, were modeled further on each of the locations using the general solutions, before the best location, the northern one, was chosen based on the geometrical situation. The two solutions situated at this location were further developed with plans for signing and marking, again using the general solutions, and serves as the two

proposed solutions for implementing a thermal control on this specific project.

A small economic analysis has been conducted to examine what benefits a thermal control can add to the project. The analysis is based on earlier statistics and probabilities, and describes three different scenarios connected to the severity of the accident. The analysis shows that it can be saved a considerably amount of money when taking time- , direct- and socio- economic cost of the prevented accidents into consideration. It is therefore strongly recommended to consider implementing such a control when starting new tunnel projects, or when improving old ones.

7.2 Further work

Subjects that would favor from further work could include:

- **New thermal solutions:** When examining the solutions available for thermal control as of now, new solutions being tested that can handle higher speeds and mixed traffic better came up. One solution that is considered on Norwegian projects makes use of automatic sign recognition after the thermal portal to inform the drivers of the result. These new and improved solutions need to be examined with the purpose of implementing them in thermal controls when they become available.

- **Safety estimates based on historic data:** To know the real effect of a thermal control on the safety of projects, data from projects where they have already been implemented should be examined and analyzed. This to make good estimates on how many potential accidents is being prevented and thereby get a good foundation for later calculating the benefits of the control.

- **Cost-benefit analysis:** The cost of building and maintaining the control, as well as the area needed in combination, should be examined. These results should be used to compare the cost with the benefits presented in this paper, and make a cost-benefit analysis for the thermal control in each project where it is applicable before deciding on implementation.

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Appendix A

Specification of Master Thesis

O NTNU

Faculty of Engineering Science and Technology
Institute of Civil and Transport Engineering

MASTER DEGREE THESIS
Spring 2016
for

Fredrik Omdal

Thermal control of heavy vehicles
-   system design and impact on tunnel projects

BACKGROUND
In recent years, there have been multiple cases of fires and potential fires in Norwegian tunnels. This has made the question about implementation of a thermal control on heavy vehicles before they enter the tunnel highly actual. The Norwegian public road administration wants a solution like this to detect and get rid of the vehicles with bad conditions before they enter the new undersea tunnel of Rogfast, and therefore reducing the probability of a tunnel fire significantly. A control like this has never been implemented before in Norway, and very few other places in Europe. This makes the knowledge base very limited, and the need for a solution fitted to the Norwegian conditions and regulations is high. It is important to find out what effects such a control have on the geometrical design of the area, this will again lead to new signing, marking, and maybe some special conditions needed to look upon. How the system will be executed in combination with the surroundings, and the effect it will have on the economy of the projects, are key elements to examine.

TASK
Task description
Develop flowcharts and general solutions for different alternatives of executing a thermal control and show how these can be used in a real life project when designing the area. Base these solutions in theory and conduct a small economic analysis regarding benefits of the control.

Objective and purpose
The first goal of this paper will be to present flowcharts describing the thermal control from start to end, and the limits these puts on the design of the area where it will be executed. The second goal will be to make general solutions for this type of control, looking on the geometrical challenges, as well as the signing and marking needed to make the control flow nicely and make minimal impact on the rest of the traffic. These will be made using the developed flowchart as a foundation. This is to make sure the solutions is rooted in theory and fulfills minimum requirements that is set by the different handbooks from NPRA. All this will be supplemented with the practical example of Rogfast, showing that the general solutions, with minor changes, can be implemented in a real life project. Finally, it will be considered what the thermal control's effect is on the economy of the project based on the expected safety improvement.

Subtasks and research questions
Here the research questions used for this paper are listed:
- How should the control be carried out?
  Components of the control, flowcharts
- What is the effect of the control on the design of projects?
  Geometry, signaling, marking
- How will this affect the economy of the project?
  Economic analysis based on expected safety improvement

General about content, work and presentation

The text for the master thesis is meant as a framework for the work of the candidate. Adjustments might be done as the work progresses. Tentative changes must be done in cooperation and agreement with the professor in charge at the Department.

In the evaluation thoroughness in the work will be emphasized, as will be documentation of independence in assessments and conclusions. Furthermore the presentation (report) should be well organized and edited; providing clear, precise and orderly descriptions without being unnecessary voluminous.

The report shall include:
➤ Standard report front page (from DAIM, http://daim.idi.ntnu.no/)
➤ Title page with abstract and keywords.(template on: http://www.ntnu.no/bat/skjemabank)
➤ Preface
➤ Summary and acknowledgement. The summary shall include the objectives of the work, explain how the work has been conducted, present the main results achieved and give the main conclusions of the work.
➤ The main text.
➤ Text of the Thesis (these pages) signed by professor in charge as Attachment 1.

The thesis can as an alternative be made as a scientific article for international publication, when this is agreed upon by the Professor in charge. Such a report will include the same points as given above, but where the main text includes both the scientific article and a process report.

Advice and guidelines for writing of the report is given in "Writing Reports" by Øivind Arntsen, and in the departments "Råd og retningslinjer for rapportskriving ved prosjekt og masteroppgave" (In Norwegian) located at http://www.ntnu.no/bat/studier/oppgaver.

Submission procedure
Procedures relating to the submission of the thesis are described in DAIM (http://daim.idi.ntnu.no/). Printing of the thesis is ordered through DAIM directly to Skipnes Printing delivering the printed paper to the department office 2-4 days later. The department will pay for 3 copies, of which the institute retains two copies. Additional copies must be paid for by the candidate / external partner.

On submission of the thesis the candidate shall submit a CD with the paper in digital form in pdf and Word version, the underlying material (such as data collection) in digital form (e.g. Excel). Students must submit the submission form (from DAIM) where both the Ark-Bibl in SBI and Public Services (Building Safety) of SB II has signed the form. The submission form including the appropriate signatures must be signed by the department office before the form is delivered Faculty Office.

Documentation collected during the work, with support from the Department, shall be handed in to the Department together with the report.

According to the current laws and regulations at NTNU, the report is the property of NTNU. The report and associated results can only be used following approval from NTNU (and external cooperation partner if applicable). The Department has the right to make use of the results from the work as if conducted by a Department employee, as long as other arrangements are not agreed upon beforehand.

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Tentative agreement on external supervision, work outside NTNU, economic support etc.
Separate description is to be developed, if and when applicable. See
http://www.ntnu.no/bat/skjemabank for agreement forms.

Health, environment and safety (HSE) http://www.ntnu.edu/hse
NTNU emphasizes the safety for the individual employee and student. The individual safety shall
be in the forefront and no one shall take unnecessary chances in carrying out the work. In
particular, if the student is to participate in field work, visits, field courses, excursions etc. during
the Master Thesis work, he/she shall make himself/herself familiar with "Fieldwork HSE
Guidelines". The document is found on the NTNU HMS-pages at
http://www.ntnu.no/hms/retningslinjer/HMSR07E.pdf

The students do not have a full insurance coverage as a student at NTNU. If you as a student want
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and personal injury insurance.

Startup and submission deadlines
Startup and submission deadlines are according to information found in DAIM.

Professor in charge: Arvid Aakre

Department of Civil and Transport Engineering, NTNU
Date: 10.01.2016, (revised: 07.06.2016)

_____
Professor in charge (signature)

Appendix B

general solutions

See external drawing appendix.

Appendix C

Plan over signing and marking

See external drawing appendix.

Appendix D

Rogfast, case study

D.1 Zoning plan from NPRA

Format: A1   Filnavn: \\cowi.net\projects\A035000\A016140\35_Ny_regulering_Bokn\FAGOMRÅDER\Arealplan\Reguleringsplan_Bokn.dwg   Xref: T_Kart.dwg   T_Geom_311.dwg

TEGNFORKLARING

PBL § 12-5 AREALFORMÅL

1. BEBYGGELSE OG ANLEGG

Næringsbebyggelse (1300)

2. SAMFERDSELSANLEGG OG TEKNISK INFRASTRUKTUR

Annen særskilt angitt bebyggelse og anlegg (1590)

Kjøreveg (2011)

Annen veggrunn – teknisk anlegg (2018)

Annen veggrunn – grøntareal (2019)

5. LANDBRUKS-, NATUR OG FRILUFTSOMRÅDER SAMT REINDRIFT

LNFR areal for nødvendige tiltak for landbruk og reindrift og gårdstilknyttet næringsvirksomhet basert på gårdens ressursgrunnlag (5100)

PBL § 12-6 HENSYNSSONER

a.1) SIKRINGSSONER

Frisikt

d) BÅNDLEGGINGSSONER

Båndlegging etter lov om kulturminner

OMRÅDEBESTEMMELSER

Bestemmelsesområde – Vilkår for bruk av arealer, bygninger og anlegg

Anlegg- og riggområde

Anlegg- og riggområde – Massedeponi

LINJETYPER OG PUNKTSYMBOLER

Planens begrensning

Formålsgrense

Frisiktlinje

Tunnel

Regulert støyskjerm

Bru

Tunnel

Tunnel

Grense for båndleggingssone

Grense for sikringssone

Grense for bestemmelsesområde

Tunnelåpning

Horisontalt Skala
1 : 1000 (A1)

Høydereferanse: NN54
Koordinatsystem: UTM sone 32 euref89

FKB SOSI-fil
Ekvidistanse 1m

Kartutførsel: 03.09.2013
Kilde: Bokn kommune

Revidjoner

Vertikalnivå 2

Bokn kommune
Detaljregulering for Laupland – Knarholmen

E39 ROGFAST

Saksbehandling iflg. Plan- og Bygningsloven

COWI
Statens vegvesen

Top margin:
Format: A1   Filnavn: \\cowi.net\projects\A015000\A016140\35_Ny_regulering_Bokn\FAGOMRÅDER\Arealplan\Reguleringsplan_Bokn.dwg   Xref: T_Kart.dwg   T_Geom_311.dwg

Plott-pålk 06.01.2015 15:26

Map coordinate labels: 5567200, 5567300, 5567400, 5567500, 5567600, 5567700
Y297700, Y297800, Y297900, Y298000, Y298100, Y298200, Y298300, Y298400

Map annotations: o_AVG, Frisikt 6x54m, Frisikt 4x54m, 13/1, 11/178, Sandvika, K

Legend:

TEGNFORKLARING

PBL § 12-5 AREALFORMÅL

1. BEBYGGELSE OG ANLEGG
   Næringsbebyggelse (1300)
   Annen særskilt angitt bebyggelse og anlegg (1590)

2. SAMFERDSELSANLEGG OG TEKNISK INFRASTRUKTUR
   o_KVT – Kjøreveg (2011)
   o_AVT – Annen veggrunn – teknisk anlegg (2018)
   o_AVG – Annen veggrunn – grøntareal (2019)

5. LANDBRUKS-, NATUR OG FRILUFTSOMRÅDER SAMT REINDRIFT
   LNFR – LNFR areal for nødvendige tiltak for landbruk og reindrift og gårdstilknyttet næringsvirksomhet basert på gårdens ressursgrunnlag (5100)

PBL § 12-6 HENSYNSSONER

a.1) SIKRINGSSONER
   Frisikt

d) BÅNDLEGGINGSSONER
   Båndlegging etter lov om kulturminner
   Bryggeforbud rundt veg, bane og flyplass

OMRÅDEBESTEMMELSER
   Bestemmelsesområde – Vilkår for bruk av arealer, bygninger og anlegg
   Anlegg- og riggområde
   Anlegg- og riggområde – Masseteopni

LINJETYPER OG PUNKTSYMBOLER
   Planens begrensning
   Formålsgrense
   Frisiktlinje
   Regulert støyskjerm
   Bebyggelse som forutsettes fjernet
   Bebyggelse som forutsettes fjernet
   Tunnel
   Tunnel
   Tunnel
   Grense for båndleggingssone
   Grense for sikringssone
   Grense for bestemmelser
   Grense for bestemmelser
   Tunnellåpning

Title block:

Vertikalnivå 2
Saksbehandling iflg. Plan- og Bygningsloven
Kunngjøring om oppstart av planarbeid		110214
1.gangsbehandling		
Offentlig ettersyn fra		
2.gangsbehandling		
Vedtak i Bokn kommunestyre		
Kunngjøring av planvedtak		

Bokn kommune
Detaljregulering for Lauplad – Knarholmen
E39 ROGFAST

Horisontal skala   1 : 1 000 (A1)
0 20 40 60 80 100

Høydereferanse: NN54
Koordinatsystem: UTM sone 32 euref89

Kartprosjeksjon: FKB-SOSI-fil
Kartutførelse: 03.09.2013
Kilde: Bokn kommune

Revisjoner
Sist rev.   Dato   Tegn.nr   PlanID
09115   R315   20140x

COWI
Statens vegvesen

Konsulent
Saksnr.   Sign.
Dato   Sign.

Prosjektnummer: 11E0039n_76

Y297200
Y297300
Y297400
Y297500
Y297600
Y297700
Y297800
Y297900

13/71
13/182
13/73
13/72
13/4
13/7
13/7
13/6

57 23

Vonddg

LNFR

TEGNFORKLARING

PBL § 12-5 AREALFORMÅL
1. BEBYGGELSE OG ANLEGG
   N   Næringsbebyggelse (1300)

2. SAMFERDSELSANLEGG OG TEKNISK INFRASTRUKTUR
   o_ASF   Annen særskilt angitt bebyggelse og
            anlegg (1590)
   o_KV1-4 Kjøreveg (2011)
   o_AVG   Annen veggrunn – teknisk anlegg (2018)
   o   Annen veggrunn – grøntareal (2019)

5. LANDBRUKS-, NATUR OG FRILUFTSOMRÅDER
   SAMT REINDRIFT
   LNFR   LNFR areal for nødvendige tiltak for
            landbruk og reindrift og
            gårdstilknyttet næringsvirksomhet
            basert på gårdens ressursgrunnlag (5100)

PBL § 12-6 HENSYNSSONER
a. Il SIKRINGSSONER
            Byggeforbud rundt veg, bane og flyplass
            Frisikt

d. BÅNDLEGGINGSSONER
            Båndlegging etter lov om kulturminner

OMRÅDEBESTEMMELSER
   #2-6   Bestemmelsesområde – Vilkår for
            bruk av arealer, bygninger og anlegg
   #1   Anlegg- og riggområde
   H0   Anlegg- og riggområde – Massedeponi

LINJETYPER OG PUNKTSYMBOLER
            Planens begrensning
            Formålsgrense
            Frisiktslinje
            Regulert byggegrense
            Bru
            Tunnel
            Bebyggelse som forutsettes fjernet
            Grense for båndleggingssone
            Grense for sikringssone
            Grense for bestemmelser
            Tunnelåpning

Horisontal skala   1 : 1 000 (A1)
0 20 40 60 80 100

Høydereferanse: NN54
Koordinatsystem: UTM sone 32 euref89
Kartprojeksjon: FKB SOSI-FL
Ekvidistanse: 1m
Karturl:hkwv. 03.09.2013
Kilde: Bokn kommune

Bokn kommune
Detaljregulering for Laupland – Knarholmen
E39 ROGFAST

Vertikalnivå 2

Saksbehandling iflg. Plan- og Bygningsloven
Kunngjøring om oppstart av planarbeid
1. gangsbehandling
Offentlig ettersyn fra
2. gangsbehandling
Vedtak i Bokn kommunestyre
Kunngjøring av planvedtak

Rev.   Revisjonen   Dato   Sign.

Konsulent
COWI

PlanID
2014.4

Saksnr.
119/11 119/21

Dato
19/09/15

Tegnnr.
R314

PROF-nummer
1TE10039r_76

Statens vegvesen

Sist rev.

D.2 Geometry

See external drawing appendix.

D.3   Plan over signing and marking

See external drawing appendix.

Appendix E

Economic evaluation

Probabilities

	Percent	
Fire accidents	21,25 /year	
% of total in undersea tunnels	44 %	0,44
% caused by heavy vehicles	53 %	0,53
% caused by technical problems	50 %	0,5

Number of fires in undersea tunnels per year caused by heavy vehicles with technical problems   2,4778

Number of tunnels   45

Accident of this type divided evenly on tunnels   0,0551

	Percent		**Accident in one tunnel divided by chance of strength**
% <5MW	51 %	0,51	0,0281
% 5<x<50MW	41 %	0,41	0,0226
% >50MW	8 %	0,08	0,0044

	Accidents per 100 year
Small	**2,81**
Medium	**2,26**
Large	**0,44**

Small scenario - Time costs

Travel time Stavanger-Aksnes		36% delay time (110km/h->70km/h)
light	19,00 min	6,84 min
heavy	24,00 min	8,64 min

Time loss		Volume
Light	6,84 min	2500 veh/day
Heavy	8,64 min	500 veh/day

Light

	Value	Persentage	Loss per hour per day	Loss Rogfast per day
Work	444,00 kr/h	0,24	kr 266 400,00	kr 30 369,60
To/from	215,00 kr/h	0,18	kr 96 750,00	kr 11 029,50
Leisure	167,00 kr/h	0,58	kr 242 150,00	kr 27 605,10
			kr 605 300,00	

Heavy

	Value	Persentage	Loss per hour per day	Loss Rogfast per day
Work	700,00 kr/h	1,00	kr 350 000,00	kr 50 400,00

Light	total	kr 69 004,20

Heavy	Total	kr 50 400,00

Total
kr 119 404,20

Small scenario - Socioeconomic costs

Direct costs

	Number	Cost		Total
Light injury	2	614000		1228000
				Total 1000000

Total

Small scenario 2347404

Medium scenario - Time costs

Travel time Stavanger-Aksnes		36% delay time (110km/h->70km/h)
light	19 min	6,84 min
heavy	24 min	8,64 min

	Time loss	Volume
Light	6,84 min	2500 veh/day
Heavy	8,64 min	500 veh/day

		Value		Persentage	Loss per hour per day		Loss Rogfast per day	
Light	Work	444,00	kr/h	0,24	kr	266 400,00	kr	30 369,60
	To/from	215,00	kr/h	0,18	kr	96 750,00	kr	11 029,50
	Leisure	167,00	kr/h	0,58	kr	242 150,00	kr	27 605,10
					kr	605 300,00		
Heavy	Work	Value 700,00		Persentage 1,00	Loss per hour per day kr	350 000,00	Loss Rogfast per day kr	50 400,00

	total day	total 2 weeks	Total day
Light	kr 69 004,20	kr 966 058,80	kr 119 404,20

	Total day	total 2 weeks	Total 2 weeks
Heavy	kr 50 400,00	kr 705 600,00	kr 1 671 658,80

Medium scenario - Socioeconomic costs

Direct costs

	Number	Related costs		Total
serious injury	5	8140000		kr 40 700 000,00

modern, long tunnel

Total   kr 50 000 000,00

Total

Medium scenario   kr 92 371 658,80

Large scenario - Time costs

	Travel time Stavanger-Aksnes		Delay, 110 km/h --> 70 km/h, 36% delay time
Light	19 min		6,84 min
Heavy	24 min		8,64 min

	Time loss	Volume
Light	6,84 min	2500 veh/day
Heavy	8,64 min	500 veh/day

Light

	Value	Persentage	Loss per hour per day	Loss Rogfast per day
Work	444,00 kr/h	0,24	kr 266 400,00	kr 30 369,60
To/from	215,00 kr/h	0,18	kr 96 750,00	kr 11 029,50
Leisure	167,00 kr/h	0,58	kr 242 150,00	kr 27 605,10
			kr 605 300,00	

Heavy

	Value	Persentage	Loss per hour per day	Loss Rogfast per day
Work	700,00 kr/h	1,00	kr 350 000,00	kr 50 400,00

	Total day	Total month
Light	kr 69 004,20	kr 2 070 126,00
Heavy	kr 50 400,00	kr 1 512 000,00

Total day	Total month
kr 119 404,20	kr 3 582 126,00

Large scenario - Socioeconomic costs

	Number	Related costs		Total		
Serious injury	10	kr	8 140 000,00	kr	81 400 000	
Death	2	kr	30 220 000,00	kr	60 440 000	
				Total		
				kr	141 840 000	

Direct costs

		Total	
Modern, long tunnel			
		Total	
		kr	150 000 000

Total

	Large scenario	
	kr	295 422 126

Total 100 years

	Number of accidents		Cost of accident		Total	
Small	2,81	kr	2 347 404,00	kr	6 596 205,24	
Medium	2,26	kr	92 371 658,80	kr	208 759 948,89	
Large	0,44	kr	295 422 126,00	kr	129 985 735,44	

Total all

kr 345 341 889,57

Large + 50% medium   kr 234 365 709,88

Large + medium   kr 338 745 684,33