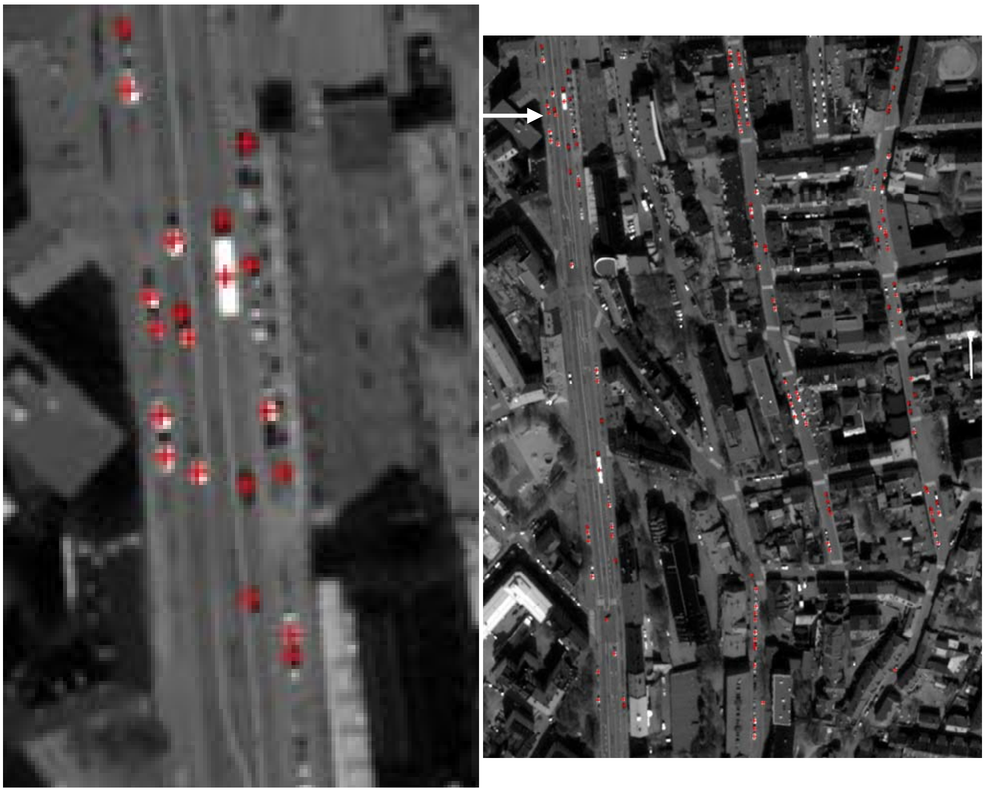
Norsk Regnesentral
NORWEGIAN COMPUTING CENTER

Report

Road Traffic Snapshot



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Abstract

The project "Road Traffic Snapshot" concerns a possible future service for counting vehicles in satellite images and generating traffic information based on these counts. The contents of the project has been to: (i) Define user requirements and technical specifications for the service; (ii) Make a service case implementation and; (iii) Validate and evaluate the implemented methodology, and discuss possibilities for the evolution of the project. For the purpose of the service case implementation, a service case area in the eastern central parts of Oslo has been considered. Our results indicate that a future system for automatic road traffic counts is feasible.

Keywords	Quickbird, Vehicle detection, Classification
Target group	Road traffic authorities
Availability	Open
Project number	236055
Research field	Earth observation
Number of pages	71

EXECUTIVE SUMMARY

The project “Road Traffic Snapshot” concerns a possible future service for counting vehicles in satellite images and generating traffic information based on these counts. The contents of the project has been to: (i) Define user requirements and technical specifications for the service; (ii) Make a service case implementation and; (iii) Validate and evaluate the implemented methodology, and discuss possibilities for the evolution of the project. For the purpose of the service case implementation, a service case area in the eastern central parts of Oslo has been considered.

The possible future users of the service have taken an active part in all phases of the project, especially the parts concerning the user requirements. For the current project the users are represented by the Norwegian Public Roads Administration, while Norwegian Computing Center and Norwegian Institute of Transport Economics are the technical partners.

In the first phase of the project we have evaluated different issues relevant to the technical implementation of a future service for generating road traffic data based on high resolution satellite images. We have analyzed how a future service might be organized in terms of users and the interactions between them, and we have also made an assessment of the service reliability. Furthermore, we have identified the products that might comprise a future service.

We have defined a prototype service comprising a user (the Norwegian Public Roads Administration for the service case), a service provider (Norwegian Computing Center for the service case) and different data providers. The user requests service delivery from the service provider, the service provider then requests data from the data providers, generates the products and delivers the products to the user. The different requests and data flows in this service will all be web-based, and this will provide for a uniform and consistent implementation. The principal factor influencing service reliability will be the availability of satellite images (determined by weather conditions). We expect that the service can be delivered one to two times per month for the service case area.

The service products have been defined in collaboration with the users. The products that are planned to be provided are a basic product (raw vehicle positions) as well as four derived products (road segment counts, queue indicators, parking overview and heavy vehicle traffic). The basic product is in itself interesting to the users, and it is also the basis for defining the other products. For the service case only the basic product has been provided.

Deriving the basic product requires that vehicles in the road network can be detected. Two different approaches have been evaluated, a segmentation based approach and a direct classification approach. We chose the segmentation based approach in which the road part of the image is first segmented into background (road surface) and bright and dark objects (vehicles and other objects). These objects are then classified using shape properties and other features in order to distinguish vehicles from objects such as road markings. This approach is very flexible and is well adapted to the resolution of the satellite imagery.

The process of detecting vehicles in the road network is complicated by a number of factors such as shadows from buildings and vegetation occluding the streets. In a parallel project financed by the Norwegian Research Council we have experimented with the use of the multispectral part of the satellite image data in order to generate masks for areas affected by such problems.

Given that vehicles can be detected, another challenge lies in separating between parked vehicles and vehicles that are driving. Using GIS information about parking regulations, parked vehicles can partly be detected as a function of their position in the road in combination with parking regulations. In narrow streets, the position of the vehicle may not be a sufficient indicator of whether the vehicle is parked or not, and other information must be used in addition. One possible source of information is satellite images taken with a short time lapse. In

such images parked vehicles can then be identified as those that do not move between the two acquisitions. We currently lack data for evaluating either method precisely.

The second phase of the project consisted of the service case implementation. For the service case area we acquired two satellite (Quickbird) images. In addition to the service case area we have defined two test case areas with slightly varying properties in order to allow for more exhaustive testing. For the service case implementation phase the base product is provided in the form of satellite images in which the position of every vehicle is marked. Visual inspection indicated that results are good and that vehicle omissions is the most frequent source of error.

In the third and final phase of the project the implemented methodology was validated and evaluated, and possibilities for the evolution of the project were discusses. For evaluating the performance of the system we have performed several experiments:

- We have compared the performance of human observers and were able to conclude that the problem is a very difficult one. Even human observers have sometimes problems in deciding what objects are cars and what objects are not cars in the raw satellite images. This is made evident by the consensus rate between two independent observers when asked to mark cars.
- When the human observers are asked to classify as vehicles or not vehicles the objects that have not been rejected in the preclassification phase, they have an overlap of 83% in the objects marked as cars. When this is compared with the automatic system, the automatic system will have roughly the same overlap with a human observer as the two independent observers will have between them. This indicates that the classification part of the system performs as well as a human observer does for the same task.
- When manually performed counts are compared with counts obtained using inroad equipment, there seems to be a good correspondence. In itself this is not a very important result since we obviously cannot rely on manual counts. However, the good correspondence between these counts makes it plausible that counts performed on only a small section of the road will provide data that are well correlated to what can be measured using inroad counting equipment. This means that a future automatic system with improved performance will provide useful data for the users.
- Comparisons between automatic counts and counts based on inroad equipment are also very promising. It is important to notice that even automatic counts are not 100% reliable.

In conclusion we have shown that a future system for automatic road traffic counts is feasible. Even if such a system observes only a snapshot of the road traffic situation, our results indicate that this information is relevant not only for that particular instance in time but also relevant for estimating the traffic load in a longer time period.

We strongly feel that the results of this project warrant further work to improve results and extend the methods. Although results are promising, several improvements are clearly possible and we will undertake the further development of our methodology in the near future. This development will be made in close collaboration with the users.

New technology will give new possibilities for better and more frequent estimation of different kinds of traffic statistics. New satellites are expected to deliver optical images with even higher resolution than the Quickbird images today. Adapting the methodology to such images will probably result in both better detection and more frequent observation of vehicles, at different times of the day. A disadvantage with optical images is that it is only possible to detect vehicles in images that are almost cloud free. In the future, high-resolution SAR images will be available. For such images, clouds are not a problem. An additional advantage with the radar images is that they contain information that might be used for obtaining velocity estimates for each vehicle.

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1 Abbreviations and acronyms

AOI	**A**rea **O**f **I**nterest
APB	**A**gency for **P**lanning and **B**uilding Services, City of Oslo
ASCII	**A**merican **S**tandard **C**ode for **I**nformation **I**nterchange
CD	**C**ompact **D**isk
DUE	**D**ata **U**ser **E**lement
ENVI	GIS and image processing software package.
EO	**E**arth **O**bservation
ESA	**E**uropean **S**pace **A**gency
ESRI	Software company making GIS and mapping software
Eurimage	Satellite data reseller
GIS	**G**eographic **I**nformation **S**ystem
IKONOS	High resolution optical satellite
NDVI	**N**ormalized **D**ifference **V**egetation **I**ndex
NIR	**N**ear **I**nfra**-R**ed
NPRA	**N**orwegian **P**ublic **R**oads **A**dministration (Statens vegvesen)
NR	**N**orsk **R**egnesentral (Norwegian Computing Center)
QuickBird	High resolution optical satellite
RTS	**R**oad **T**raffic **S**napshots
SCA	**S**ervice **C**ase **A**rea
TCA	**T**est **C**ase **A**rea
TØI	**T**ransport**ø**konomisk **I**nstitutt (Norwegian Institute of Transport Economics)
UTM	**U**niversal **T**ransverse **M**ercator
WP	**W**ork **P**ackage

2 Introduction

The project described in this report concerns a possible future service for counting vehicles in satellite images and generating traffic information based on these counts. The contents of the project has been to: (i) Define user requirements and technical specifications for the service ([7], [8]); (ii) Make a service case implementation ([9]) and; (iii) Validate and evaluate the implemented methodology, and discuss possibilities for the evolution of the project ([10]). For the purpose of the service case implementation, a service case area in the eastern central parts of Oslo has been considered.

The possible future users of the service have taken an active part in all phases of the project, especially the parts concerning the user requirements. For the current project the users are represented by the Norwegian Public Roads Administration, while NR and TØI are the technical partners.

2.1 Scope

This document contains a description of the ESA project “Road Traffic Snapshots” (RTS).

2.2 Contents

This report contains the following sections:

Section 3	contains a summary of input from the users to the technical specification.
Section 4	contains the specification of the service.
Section 5	contains the specification of the products and the methods.
Section 6	contains a description of the service case and additional test case areas.
Section 7	contains a description of the service case implementation, the service case product examples and the service case integration.
Section 8	contains a description of the validation activities.
Section 9	contains a description of the validation results and the end users assessment of the utility and products.
Section 10	contains a description of possible future services and the evolution of the project.
Section 11	contains our summary and conclusions.

3 User input to the technical specification

In order to ensure that the technical specification is based on user needs, the users have been consulted on a regular basis in this project. A project workshop was organized early in the project period in order to make it possible for users and developers to discuss user requirements. The following subsections contain a summary of the input from the users. Based on this user input, the user requirements found in Appendix A were formulated.

3.1 New possibilities

The users have focused on the numerous new possibilities for traffic monitoring that would arise if an operational road traffic snapshot service could be established based on satellite imagery. In particular, the following issues are important to the users:

- Satellite images provide snapshots of the traffic distribution in large areas and entire road networks. This is in strong contrast to the current practice where traffic statistics information is gathered only at very specific locations in the road network. Snapshots of entire road networks would be of great value for studying the distribution of cars not only on main roads but also on smaller roads. This is valuable for larger cities where a high volume of the traffic is known to be localized to small "backstreet" networks. It could also prove to be of great value for remote, sparsely populated, regions where traditional counting equipment is too expensive to be installed and maintained. In order to integrate this new type of information in existing systems for generating traffic statistics, the users would like that the link between satellite based information and the standard annual average daily traffic (AADT) loading could be established.
- Another point raised by the users is that road traffic snapshots might provide information about the distribution of heavy and light vehicles in the road network. Although such distributions already are available at specific locations based on point counting stations, a road traffic snapshot may provide this information for an entire road network. This is important for many reasons, both in order to ensure correct dimensioning of the road network, but also in order to study noise loading, pollution etc.
- Parked cars, undetectable using today's technology, could possibly be counted using satellite images. This represents a completely new type of information for use in traffic statistics that would be of great value to the traffic planning community.
- The dynamic aspect of traffic development has been addressed by numerous users as a very important issue. It is clear that the dynamic aspect of traffic, especially in dense urban areas, is very important in understanding the build-up of traffic jams etc. Using today's point based counting methodology, it can be difficult to appreciate the mechanisms leading to a traffic jam since regional coverage is difficult or impossible to obtain. If satellite images taken with short time intervals could be made available then it could become possible to study the evolution of the traffic situation in an entire area, this could also possibly show how jams are formed etc. Even though the number of images required for such a truly dynamic study might be impossible to obtain, it would be valuable if only a few images taken with some (short) time lapse between them could be made available. This could partly be used for analyzing the dynamic aspect of the buildup of different traffic situations, partly it could be used for separating between parked vehicles and vehicles that are in circulation.

3.2 Weaknesses and challenges

Several weaknesses of the satellite based road traffic snapshot have been identified by the users. These are:

- The resolution of the satellite images as well as a lack of time series of images makes it very hard to distinguish between parked and moving vehicles.
- A serious concern voiced by the users is the availability of satellite images. Few satellites provide the necessary resolution, they are all in sun synchronous operation thus images are taken at roughly 10:30 local time. This in itself is a limiting factor, but the true limiting factor lies in local weather conditions. The acquisition of a successful satellite image requires near perfect weather conditions, in particular the cloud coverage must be close to zero. Such conditions are relatively rare over the service case area. This combined with the low number of satellites available severely limits the number of successful images that can be expected per month. In order to alleviate this problem, links between existing inroad counting systems and data derived from satellite imagery should be sought.
- The lack of time series of images also makes it hard to observe the dynamic aspect of a traffic situation buildup. All users agreed that the current time for image acquisition (around 10:30 local time) is far from ideal, for the service case area images taken earlier in the day (between 08:00 and 09:00) during rush hour conditions would be of greater value.
- It is very important to the users that a link can be established between the road traffic snapshot data and the classical road traffic statistics parameters such as annual daily average traffic. The users have voiced their concern that the number of successful satellite images during a year might be too low in order to ensure that such a link can be established.
- Occlusions from tall buildings and vegetation, as well as their shadows, is a serious problem for this type of approach.

3.3 Links between existing data and parameters and the satellite based data

Existing systems for extraction of road traffic data are primarily based on inroad counting stations. These stations provide a count of the number of vehicles that pass a specific point in the road network as a function of time. Many techniques have been elaborated for extracting derived parameters from such vehicle counts. One very important parameter derived from such data is the so called AADT parameter (Annual Average Daily Traffic). This parameter indicates the average number of vehicles that will pass a given point in the road network per day, the average is based on an annual average. This parameter is crucial in determining the optimal dimensioning of the road network etc. and is as such a very critical parameter to the project users.

The users have on numerous occasions requested that steps be taken in order to evaluate whether the AADT can be derived from the satellite based vehicle counts. This would be advantageous for a number of reasons. First of all it would increase the value of the satellite based vehicle counts since the AADT parameter would be directly useful to the users. Secondly it would make it possible to derive AADT parameters for roads without counting stations. Finally, deploying and operating inroad counting equipment is very expensive, a satellite based alternative could potentially be very cost efficient.

3.4 Use of information

The users are not accustomed to data of this type and have pointed out the need for some time in order to integrate data from satellite based road traffic snapshots into their current working practices. It will also take them time to consider all possible uses of such data.

The users are very clear that satellite image based information will not replace traditional point based counts, but will rather be a very valuable supplement to these. The users are considering a parallel project to study the impact that satellite based data would have on their way of working with road traffic statistics.

3.5 Services and products

Users request data on a per road link basis (a road link is the section of a road between two intersections). The most important product is simply the position of the vehicles in the road network. This will in turn be the basis for generating derived products such as counts of vehicles on each road link, queue indicators, parking overviews and overviews of heavy and light traffic.

4 Service specification

This chapter describes the user relevant aspects of a possible future service for generating road traffic information based on satellite images. The specification is written based on extensive user input. This chapter focuses on the service level; a description of the specific products comprising the service is deferred to the next chapter.

4.1 Description of information service

4.1.1 Actors, service case

There are five types of actors involved in this service, the *users*, the *service providers*, *satellite data providers* and *GIS data* providers. For the purpose of validation, we will also need *ancillary data providers* that can provide data for use in the service validation process. Ancillary data providers will not necessarily be part of a regular service operation mode.

- **Users:** These actors make operational use of the products delivered as part of the service. For the designated service case area the users will be the Norwegian public roads administration and the Agency for roads and transport, City of Oslo.
  - **Norwegian public roads administration:** Administrates roads belonging to the national or county road networks
  - **Agency for roads and transport, City of Oslo:** Administrates roads belonging to the Oslo municipality road network
- **Service provider:** This actor generates the products that are included in the service. NR will fill the role of service provider in the framework of the road traffic snapshot project but will not be a service provider in a future operational project.
- **Satellite data providers**: These actors provide satellite data. The satellite data providers will be one of the many satellite image sales organisations, e.g.:
  - **Eurimage:** European reseller for Quickbird satellite images.
  - **Space Imaging Europe:** European reseller for IKONOS satellite images.
- **GIS data providers:** These actors provide the GIS data. By GIS data we mean digital elevation models necessary for orthorectification of the satellite images as well as masks for the road network. For the designated service case area the GIS data providers can be the Norwegian public roads administration or the Agency for planning and building services, City of Oslo.
  - **Norwegian public roads administration:** Maintains masks for the entire Norwegian road network, the organisation and metadata content of these data is tuned to traffic planning and monitoring.
  - **Agency for planning and building services, City of Oslo:** Maintains masks for the Oslo municipality road network, the organisation and metadata content of these data is tuned to general infrastructure planning and monitoring.
- **Ancillary data providers:** These actors provide other data relevant to the project, in particular data relevant to validation of the products. For the designated service case area the ancillary data providers can be the Norwegian public roads administration, the Agency for roads and transport, City of Oslo or the Agency for planning and building services, City of Oslo.
  - **Norwegian public roads administration:** Maintains a network of traffic counting stations distributed in the entire Norwegian road network. In the

service case area there are no such counting stations, but counting stations in the vicinity of the service case area can still be of interest.

  - **Agency for roads and transport, City of Oslo:** Maintains a network of traffic counting stations distributed in the Oslo municipality road network. There are no permanent counting stations in the service case area, but counting stations in the vicinity of the service case area can still be of interest. They also dispose of mobile counting stations that can be deployed in the service case area.
  - **Agency for planning and building services, City of Oslo:** Maintains full aerial photo coverage at several resolutions of the Oslo municipality. The renewal cycle is roughly three years.
  - **Institute of Transport Economics:** Can provide historical data related to traffic evolution, noise measurements etc. for the service case area.

4.1.2 Actors, operational scenario

In an operational scenario there will also be five generic types of actors involved in this service, the *users*, the *service providers*, *satellite data providers*, *GIS data* providers and *ancillary data providers*. Ancillary data providers will only be part of a regular service operation mode if repeated validations of results are necessary. Since no service is currently operational identifying the actors very precisely is impossible.

- **Users:** As for the service case, these actors make operational use of the products delivered as part of the service. The Norwegian public roads administration will be an active user as will the agencies for roads and transport of different Norwegian cities. TØI and other national institutes needing road traffic information for research and planning purposes will also be possible users.
- **Service provider:** This actor generates the products that are included in the service. The Norwegian public roads administration is a likely service provider in a future operational project.
- **Satellite data providers**: These actors provide satellite data. The satellite data providers will be one of the many satellite image sales organisations. In addition to those sales organisations mentioned as part of the service case, sales organisations for other satellites such as the South Korean COMSAT and other yet unlaunched satellites might be involved.
- **GIS data providers:** These actors provide the GIS data. For an operational service the GIS data providers can be the Norwegian public roads administration or the agencies for planning and building services of different Norwegian cities.
- **Ancillary data providers:** These actors provide other data relevant to the project, in particular data relevant to validation of the products. It is unclear whether such data providers will be necessary in an operational service. If so, likely ancillary data providers are the Norwegian public roads administration, the agencies for roads and transport and the agencies for planning and building services of different Norwegian cities. TØI might also play a role as ancillary data provider in an operational service.

4.1.3 Information flow

There are two types of information flow related to the service, request flows and data flows; this is illustrated in Figure 1. In the following two sections, these flows are discussed in detail.

4.1.3.1 Request flows

- **Service request (from user to service provider):** The user can request delivery of traffic snapshot data from the service provider on a per use basis or the products can be delivered on a regular basis upon completion of an initial order.
- **GIS data order (from service provider to GIS data provider):** The service provider can request GIS data from the GIS data providers; again this can be done on a per use basis or the GIS data can be delivered on a regular basis upon completion of an initial order form.
- **Satellite data order (from service provider to satellite data provider):** The service provider can request a satellite image from the satellite data providers. The satellite data providers for this project operate web portals for ordering on a per use basis.

4.1.3.2 Data flows

- **Service products (from service provider to user):** Once the satellite image and GIS data are acquired, the service provider derives the different road traffic snapshot products from the data and makes them available to the user.
- **GIS data (from GIS data provider to service provider):** The GIS data provider makes the requested GIS data available to the service provider.
- **Satellite data (from satellite data provider to service provider):** The satellite data provider makes the requested satellite data available to the service provider. The availability of such data depends on several factors, this is discussed in more detail in Section 4.1.4.

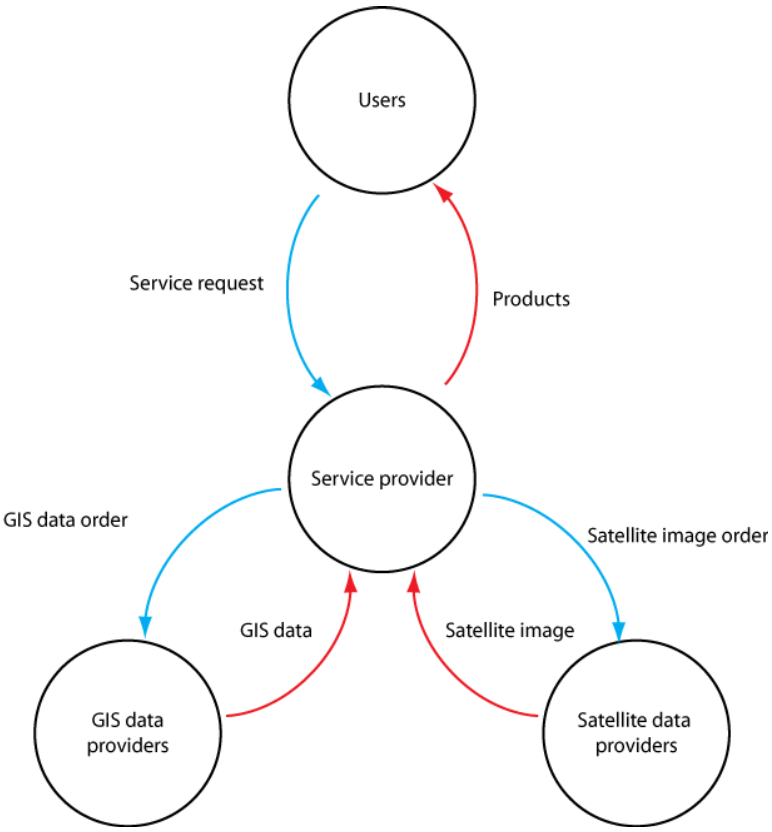


Figure 1: *Possible request (blue) and data (red) flows for the service. This figure illustrates the operation of the regular service.*

4.1.4 Service availability and reliability

Different users will typically require the service at different frequencies. The primary factor influencing the possible service delivery frequency as well as the reliability of the service is the availability of satellite images. Many factors influence the satellite imaging frequency:

- The primary factor influencing the satellite image delivery frequency is climatic conditions. A successful satellite image acquisition requires near perfect weather conditions, in particular the cloud coverage must be close to zero. Such conditions are not very common in the service case area.
- Another central factor determining the satellite imaging frequency is the satellite revisit frequency. The satellites capable of producing images with a resolution sufficient for use in this project have a revisit time of roughly one to three days depending on latitude and certain other parameters such as acceptable off-nadir angles. The buildings in the service case area are not very tall allowing for certain offnadir angles. Areas with taller buildings or narrower streets would require smaller offnadir angles. This will reduce the possible imaging frequency for these areas since the satellite will be in acceptable positions less frequently.
- The satellites that can be used in this project are sun-synchronous. This means that they pass over the service case area at the same time of day, for Oslo the satellites pass at roughly 10:30 local time. This completely limits the possibility of imaging the traffic situation at other times of the day unless supplementary data sources are introduced.

A reasonable estimate of the possible number of successful satellite images of the service case area is one to two images per month. The main risk in the project is linked to this reliability issue since the time between successful satellite images cannot be guaranteed. A service based on a completely regular image acquisition can therefore not be envisaged.

4.2 Service implementation

4.2.1 Implementation choices

4.2.1.1 Request methods

- **Service request (from user to service provider):** Different users will require service delivery at different frequencies. Some users will require infrequent (once or twice per year) deliveries whereas other users might require deliveries much more frequently (for instance on a monthly basis). Some users may want to order every service delivery specifically on a per use basis; other users might require that the service is delivered on a regular basis once an initial order has been placed. For the first type of user a simple request via telephone or mail would suffice, whereas users wanting to place orders on a regular basis might want to use a web based order form. Phone or email based solutions require no particular implementation, are flexible and well understood by the users. They do however not impose any particular format on the service request making errors and misunderstandings more likely. An internet solution using an online order form requires development and some initial training of the users; however, this solution will reduce the risks for errors and misunderstandings.
- **GIS data order (from service provider to GIS data provider):** The frequency of these requests is determined by two factors: GIS data update frequency and, obviously, user service request frequency. For the service case area the GIS data will undergo major updates every three years. Minor updates might occur more frequently. User service requests can occur much more frequently, but due to the GIS data update frequency requests for updated GIS information more frequently than once a year are unlikely. Requests for GIS data from the service provider to the GIS data provider can be by telephone, email or an internet order form.

- **Satellite data order (from service provider to satellite data provider):** The frequency of these requests is limited by user service request frequency. The request for satellite data from the service provider to the satellite image data provider will be by email submission of an order form or directly over the web.

4.2.1.2 Data delivery methods

- **Product delivery (from service provider to user):** This data delivery consists in transferring the products from the service provider to the users. The amount of data involved in this transfer is small and an email-based transfer can be used. Data transfer by mailing CDs or over the web are also possible. If a web solution is retained then a web portal with access to the product data would be necessary.
- **GIS data delivery (from GIS data provider to service provider):** This data delivery consists in transferring the necessary GIS data from the GIS data provider to the service provider. The GIS data providers for the service case area provide the following GIS data delivery methods:
    - The Norwegian public roads administration: Delivers GIS data via email or CD.
    - Agency for planning and building services, City of Oslo: Delivers GIS data through a web interface.
- **Satellite data delivery (from satellite data provider to service provider):** This data delivery consists in transferring the necessary satellite image data from the satellite image data provider to the service provider. Although no particular satellite image data provider has been selected for the given service, most large satellite image suppliers (e.g. Eurimage) propose, at least, data delivery by CD transferred by ordinary mail or through a web interface.

4.2.2 Selected implementation choice

We make the following implementation choices:

- **Implementation choice for request methods:** In order to accommodate all types of users in a standard ordering format we choose to base requests from the users to the service provider on a web based order form. This order form can be used to order one specific service delivery (on a per use basis) or a series of deliveries (on a regular use basis). Both the GIS and satellite data providers already operate web based order solutions, requests to these data providers will happen using these existing solutions.
- **Implementation choice for data delivery:** We choose to base all product deliveries on a web based interface except deliveries from the Norwegian public roads administration that will be performed via CD.

4.3 Architectural service design

Figure 2 illustrates the architecture of the service given the implementation choices explained in the previous sections. It is important to realize that this architecture is relevant for a fully operational service only and that the architecture implemented for the service case deviates from Figure 2 in important ways. In particular, for the service case, no web portal for ordering delivery of the service as well as the actual service delivery have been developed. All other aspects of the architecture are identical for the ordinary and the service case mode of operation.

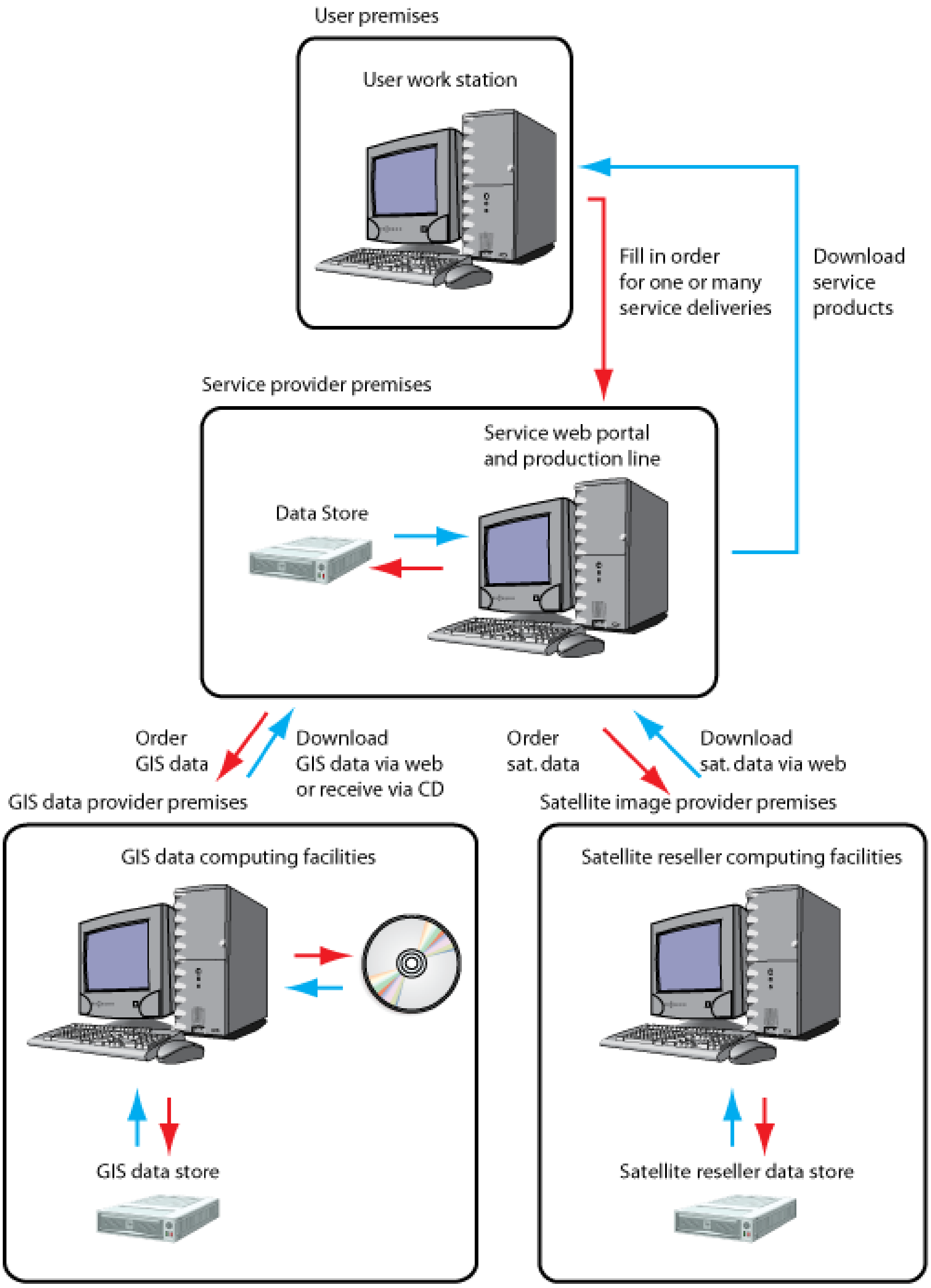


Figure 2: *The architecture of the proposed service. This architecture is relevant for a fully operational service only. The architecture implemented for the demonstration however deviates somewhat from this.*

5 Product specification

This section will first describe the products that a future operational road traffic snapshot service based on earth observation data could offer. A discussion of suitable methods for deriving these products, the input data needed to achieve this and an illustration of the product generation process is also provided.

5.1 Product description

For a future operational road traffic snapshot service we have currently defined one base product and four refined products derived from the base product. This is what we see today for a future service, however new needs may appear as more experience is gained. Also, the quality of the information that can be extracted will affect which products that will be useful. All of the suggested products have not been realized in this demonstrator project.

In the following we will give a description of the suggested products, their purpose and their relation to existing traffic information sources, and we will briefly discuss what is needed to derive these products. We will also indicate the representation and formats of the products. This may however be subject to changes as these products will represent a new type of information, and there are as yet no established procedures for handling some of these types of information.

5.1.1 Base product

The road traffic snapshot will have one base product from which other products may be derived. This product will in its simplest form consist of the geographical positions for the detected vehicles. When more information is extracted from the vehicles, this will be included in the base product as attributes to the vehicles. Such attributes may include vehicle class (light, heavy), direction (relative to road) and status (in traffic/parked). Inclusion of the different attributes will require that the necessary information can be obtained from EO images in combination with supporting GIS data.

A simple product as this will be very flexible. At this stage it is important to have a flexible product as the planned service is very much in its infancy, and the future utilization of the information coming from such a service may not yet be fully understood.

The base product will be intended for input to further processing for derivation of other products and may also be used as a product in itself for visualization of the captured traffic situation. Hence, formats that are suitable for both types of use should probably be produced. This may include e.g. a simple ascii file and a vector file for GIS import (for the users ESRI-compatible formats are convenient). In addition, the satellite image itself may be offered as a product to interested users.

5.1.2 Derived products

Other products may be derived from the base product. From discussions with the users we have identified the following products as interesting:

- *Road segment counts*. This product will consist of the number of vehicles traveling in each direction along a predefined road segment. Road segment counts are currently the base level information extracted from today's point-based installations, and hence the entity used today by the road authorities where each road segment has a unique identification number. The suggested product can be derived from the vehicle positions and the direction attribute of the base product, and will require that vehicle positions, directions and the status of the vehicles (parked/in traffic) can be determined and that the road segment definitions are available along with a road network. All other derived products will be based on the road segment definitions.
- *Queue indicator*. The purpose of this product will be to indicate road stretches where there is a queue. Queue information is today only available at the specific points of traffic counts

or where video surveillance is installed. There are different choices for how to realize the queue indicator. One is to identify each queue and reporting the start and end of these. Another way is to find the vehicle density of each road segment and report a queue when this density exceeds a limit. As road segments are currently the smallest entity used by the road authorities, we have at this stage chosen to use the latter approach for queue indication. Using this definition, the queue indicator can be derived from the base product. (For the first definition an alternative could be to derive this from the image by a specialized queue detector). Generation of the queue indicator will require a base product with direction and status attributes and definitions of road segments and a definition of queue (density threshold).

- *Parking overview*. This product is intended to provide an overview of parked vehicles in an area. This is a type of information that can not be provided by today's technology. Hence, there is currently no established procedure for handling this type of information. When the status (parked/in traffic) of vehicles is possible to determine, parking information can be derived from the base product. Again, the information will be provided per road segment, giving the number of parked vehicles for each segment.
- *Overview of heavy vehicle traffic*. The purpose of this product is to give an overview of the distribution of heavy vehicles in the road network. The existing in-road point measurements give vehicle counts and they separate vehicles into different classes. Hence, counts of heavy vehicles at these points exist, however an indication of the distribution over the road network is not available with current technology. Such an overview can be derived from the base product, when vehicle classes are included. We will report this information as the number and percentage of heavy vehicles per road segment.

5.1.3 Demonstration products

For the service case demonstration, the products will consist only of the base products.

5.2 Evaluation of methods

In the following we will give a brief overview of the problem of vehicle detection in satellite images and outline the main alternative methodological approaches that should be considered. An evaluation of the different approaches is then given, and finally the selected approaches are presented.

5.2.1 Overview of the problem

The main methodological challenge is related to the problem of vehicle detection in high-resolution images. Compared to vehicle detection in aerial images this poses special problems because of the low resolution compared to the objects sought for analysis. This does for instance make it more difficult to separate vehicles from other types of objects like trees, road markings etc. For the analysis of road networks in certain urban areas, there are also some additional problems. These include the analysis of areas with low contrast due to shadows from tall buildings, trees etc, and separation between parked and moving vehicles. In addition to detecting the vehicles, we will also look into the possibility of deciding the vehicle class (light or heavy).

5.2.2 Overview of alternative approaches

We have performed an initial analysis of possible strategies for vehicle detection, and as we see it there are two main alternative approaches; a *segmentation-based approach* and a *direct-classification approach*. For all the approaches we use a road network map in combination with the image so as to mask out the areas of interest. Hence, all the analysis is performed within the road network.

- *Segmentation-based approach.*

  Using this approach the objective is first to do a segmentation of the image into objects that are darker or brighter than the background and then perform a classification of the segmented regions. For the classification the aim is to separate vehicles from other objects (shadows, road markings etc) and possibly also to determine the class of vehicle (heavy or light).

  For the segmentation there are again two main alternatives. The first alternative is to use a multi-level thresholding (or clustering) technique to divide the area into three different classes: bright objects, dark objects and background (road surface). Such techniques have been proposed for this application in [1]. A variation of this is to use a gradient filtering prior to segmentation [5]. The second alternative is to estimate a model for the background, which will generally require that more than one image is available. This technique has been suggested in [4] and [5]. More specialized techniques may also be applied, as the one suggested in [3], where a specialized queue detector is used.

  The classification of the objects resulting from the segmentation will typically be based on features extracted from the objects, like shape, size and various spectral information. Depending on the difficulty of the task, a simple rule-based classifier may be used or a more sophisticated statistical classifier may be necessary.

- *Direct-classification approach.*

  Using this approach, the idea is to do a direct vehicle detection and classification based on a template-matching scheme. Templates must then be designed for the different types of vehicles (dark, bright, heavy, light). During matching the templates must be rotated according to the direction of each road segment. One type of template-matching scheme has been suggested in [2].

In addition to the approaches treated above special measures may be needed for the handling of shadows and separation between moving and parked vehicles.

- *Analysis of shadows.*

  Shadows may be identified initially (during a preprocessing step) by finding larger dark areas. When identified, these areas can be treated specially. This may include histogram transformations followed by a detection scheme as described above. Initial analysis indicates that there is some information in such areas, however the contrast is quite low and may not be sufficient to do a robust vehicle detection.

- *Separation of moving and parked vehicles.*

  Whether this is possible will depend on what additional information that can be made available. There are two main alternatives for determining this (which may also be combined):

  1) If images taken with some time interval can be made available, the separation can be achieved by analysing the difference between the two takes.

  2) If information about parking regulations for the road in the network is available, this information may be combined with information about each vehicles position within the road. Vehicles in certain areas (along the roadside) can then be assumed to be parked.

5.2.3 Evaluation of different approaches

For the evaluation, the image data and the different methods' potential have been analysed. Initial experiments have also been performed with some of the methods mentioned above and the availability of various additional data sources have been investigated. Based on this, approaches for the following problems have been evaluated: *vehicle detection, vehicle classification* and determination of *vehicle direction and movement.*

5.2.3.1 Vehicle detection

A few initial experiments applying the different approaches discussed in the previous section, have been performed. The experiments have mainly been carried out on a subimage of a Quickbird scene over Oslo. The intention of these experiments has been to get an initial indication of the relative performance of different approaches and their strengths and weaknesses.

5.2.3.1.1 Multi-level segmentation

Initial experiments with a multi-level segmentation approach have been performed. The segmentation approach assumes that a definition of the road network to be analysed is available through a mask delineating this area. For the area within the mask, the approach then assumes that the road surface is the dominating region covering the largest area within this mask. Based on this assumption, the histogram for the pixel values within the road network is analysed and the mean value of the road surface is determined at the peak of this histogram. Then Otsu's method for threshold selection is applied twice, once for the interval below this peak and once for the interval above this peak.

The results of experiments with this approach applied on a panchromatic Quickbird scene are quite promising. Some examples are given in Figure 3 (left). Here the road segments have been segmented into the three classes: road surface (grey), bright objects (yellow) and dark objects (blue). The red crosses marked in this figure are the positions of detected vehicles from an independent manual analysis of the image. Gradient filtering has also been tested for this panchromatic Quickbird scene. Results from these experiments are given in Figure 3 (right). Dark areas correspond to areas with high gradients and the red crosses mark the manual detections.

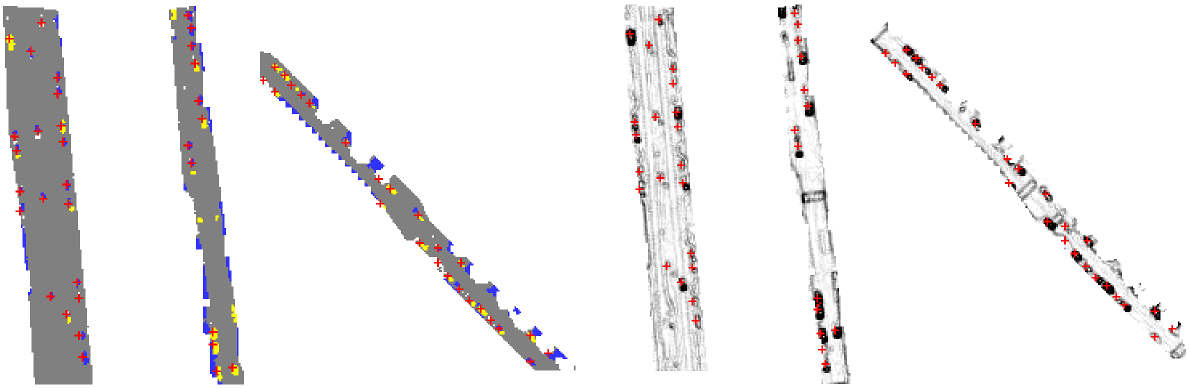


Figure 3: *Results from experiments with multilevel segmentation (left) and gradient filtering (right).*

The results indicate that both the multilevel segmentation approach and the gradient filtering could be considered for vehicle detection.

5.2.3.1.2 Background subtraction

To perform a background subtraction, a background model generally needs to be estimated from a time series of images. As suitable image scenes will typically be available only once or twice a month, the background may however change too much between acquisitions (due to weather and light conditions). Hence, this approach was not considered to be suitable for our problem. Another alternative is to perform a subtraction of two images acquired with a small time interval. Such images may be obtained from Ikonos (see more details on this in Section 5.2.3.3.1). However, two images is probably not enough to get a good background estimate.

Ikonos may also deliver a time series of images (see Section 5.2.3.3.1), but the images will have a large variation in viewing angle which will make them difficult to use for this purpose.

5.2.3.1.3 Feature extraction and classification

A segmentation as described in the previous sections will typically result in detection of different types of objects, where the objects corresponding to vehicles need to be identified. For this it is possible to use a classification approach. To get an impression of what can be achieved using such an approach, some experiments have been carried out where different types of features have been extracted for objects identified through segmentation. In these initial experiments the focus has been on shape properties and a selection of such features has been implemented and their ability for separation between object classes has been analysed. Spectral properties like variance, contrast etc. may also contribute, but have not yet been investigated.

The features that have been extracted and investigated, are the following:

- Properties of the *circumscribing box*:
    - Height, width, elongation and rectangularity.
- Properties of the *region*:
    - Direction, area and compactness.

Several of these features demonstrate a potential for distinguishing between different types of objects. Examples are shown in Figure 4.

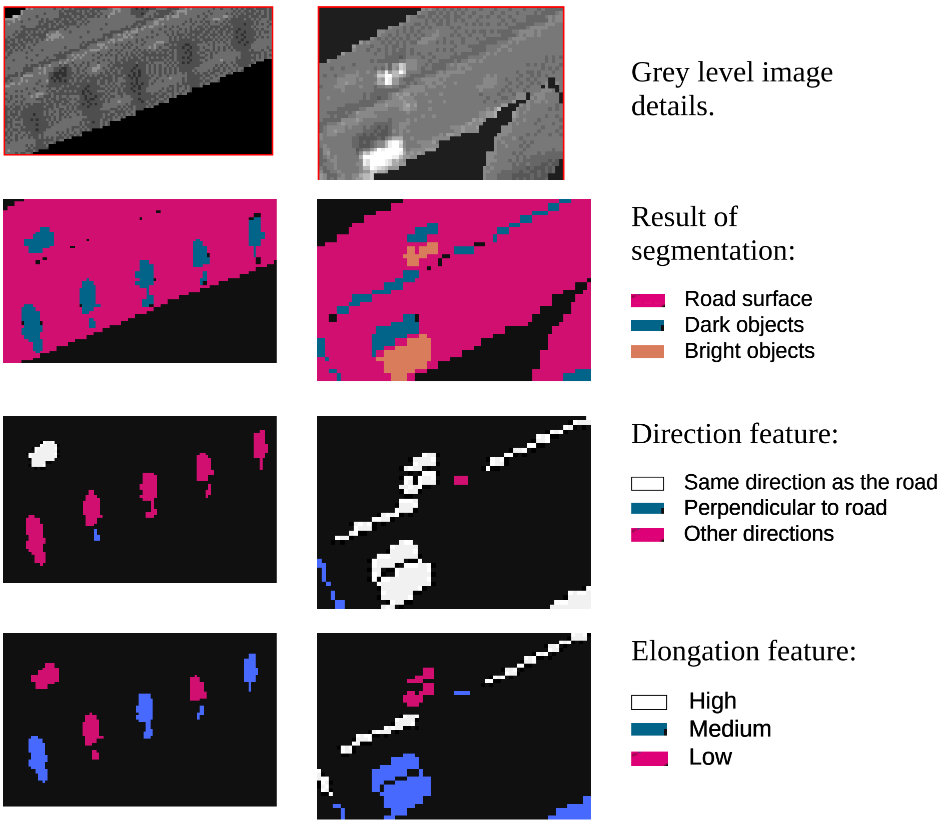


Figure 4: *Details of an analysed Quickbird image showing results of segmentation and feature extraction.*

For the classification, many different approaches can be used. The choice of approach will typically depend on factors like the number of classes that should be used, how well the classes are separated and the amount of available training data. Possible alternatives could be to use a statistical classifier or a neural net, but these methods require a thorough training. A simpler alternative could be to use a rule-based classifier.

5.2.3.1.4 Multispectral segmentation

In a parallel study (financed by the Norwegian Research Council) we have been working on approaches for analysis of urban areas, applying high resolution multispectral EO data. In this study we have looked into two different segmentation issues for aid in the analysis of these areas. The following gives a summary of the findings from this study.

Segmentation of vegetation

Trees shadowing the road can be a problem for the vehicle detection, both because vehicles may be hidden behind the trees and because trees may be confused with vehicles. The first problem can not be solved, but the second problem can be helped by segmenting trees (and other vegetation) by utilizing the multispectral information. We have done this by computing the NDVI (vegetation index) from the multispectral information. By thresholding the resulting NDVI image, the areas with vegetation can be identified and masked out.

From a multispectral Quickbird image we have performed a resampling to the resolution of the panchromatic image (using cubic interpolation). From the resulting image, NDVI was computed as: (NIR-R)/(NIR+R). Otsu's threshold selection was then applied to the NDVI image to obtain a vegetation mask. An example of a resulting vegetation mask is shown in Figure 5 (together with a road mask and a shadow mask).

Segmentation of shadowed areas

Some areas of the road will be very dark due to shadows from tall buildings. These areas need to be identified and analysed specially. To do this, the original 4 bands of the multispectral Quickbird image were clustered into 3 clusters using K-means clustering. The result was then resampled to the resolution of the panchromatic image and the cluster corresponding to the darkest pixels were selected as the shadow mask. In Figure 5 a combination of this shadow mask, the vegetation mask obtained from NDVI and a part of the road mask coming from the GIS are shown.

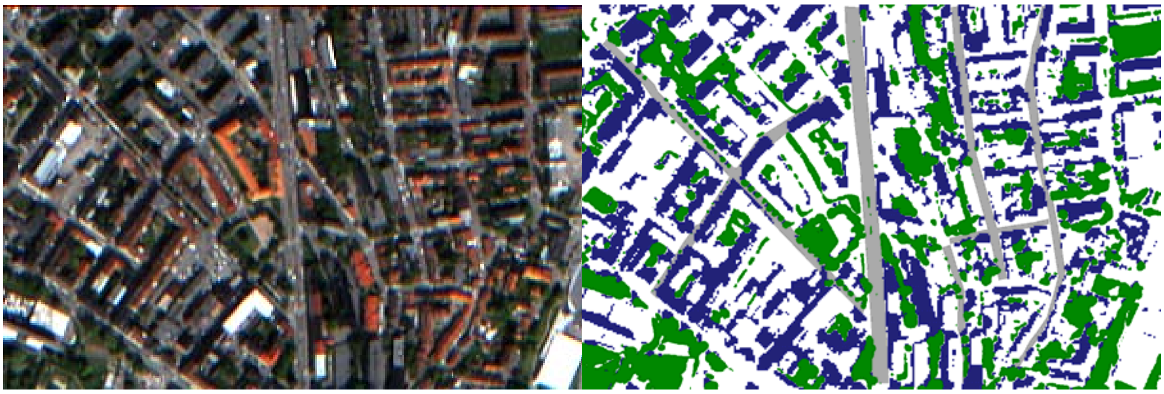


Figure 5: *RGB image (left) and the combined mask (right) with a subset of roads (grey), vegetation (green) and shadows (blue).*

5.2.3.1.5 Template matching

Template matching based on the panchromatic image has been considered. However, closer analysis of the Quickbird image revealed that the vehicles may appear as very different-looking objects depending on light conditions, vehicle direction etc. This approach was therefore not investigated further.

5.2.3.1.6 Shadow problem

Initial analysis of the shadowed areas has been performed, and indicates that information can be extracted also from these areas. Figure 6 shows an area of the road lying in the shadows. This area may be segmented and treated specifically by adjusting the mean and the standard deviation to match that of the road segments that are not in the shadows. Figure 6 (right) shows the result of applying the previously described multilevel thresholding to the scaled shadow

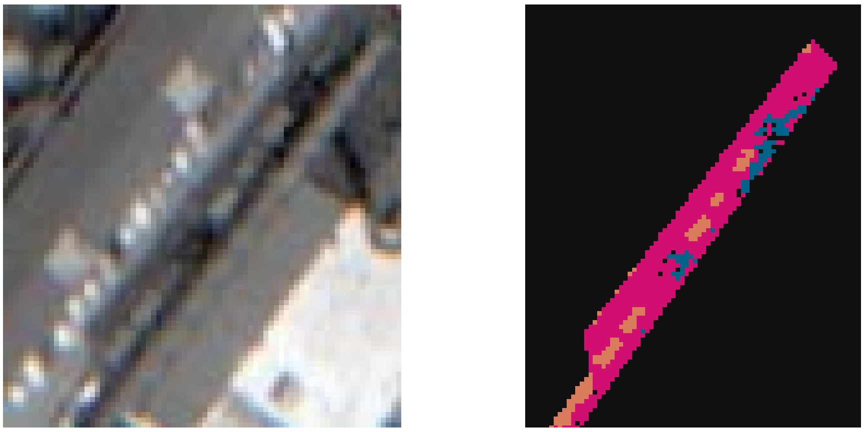


Figure 6: *Parked vehicles in a shadowed area (left) and result of multilevel segmentation of this area.*

areas. These illustrations show that information can be extracted also from these areas, but the segmentation methods may have to be tailored specifically to these areas.

5.2.3.2 Vehicle classification

We define the problem of vehicle classification as that of determining the vehicle class where we define two different classes: *light* or *heavy* vehicles. The vehicle class will be determined based on the size of the objects detected, and will typically be a bi-product of the classification or template-matching. Initial studies indicate that the vehicle size can be determined from the images when the vehicles have been identified.

5.2.3.3 Vehicle direction and movement

5.2.3.3.1 Image differencing

By investigating the difference between two images acquired with a (small) time interval it could be possible to determine both whether a vehicle is moving and, if the time difference is small, also which direction the vehicle is moving. To determine whether a vehicle is parked or in traffic a larger time difference is desirable to be able to separate between vehicles not moving because of red lights, queue etc. and vehicles that are parked. In either case such an approach requires that two EO-images can be acquired with a relatively small time interval. We have investigated the possibilities of acquiring and using such images.

Acquisition of image pairs.

For the Quickbird satellite the acquisition of two images of the same area during the same cycle, is an expensive operation as the entire satellite needs to be repositioned. Hence, for a practical application this is not a real alternative.

For the IKONOS satellite the acquisition of two (or more) images is possible. This can be obtained by repositioning the mirror of the satellite as it passes over the area to be imaged, which can give a series of images with different viewing angle and time intervals at the order of a minute.

During this initial phase of the project, it has not been possible to acquire this type of images, and we have therefore not been able to investigate the potential of utilizing these time series. Some initial experiments with single IKONOS images have however been performed to evaluate the effect of the somewhat lower resolution in these images (1m) compared to that of Quickbird (0.61m). The experiments indicate that detection is possible also here, but may be slightly more difficult than in the Quickbird images.

Utilizing the time delay between panchromatic and multispectral acquisition.

For the high-resolution satellites there is a small time delay between the acquisition of the panchromatic band and the multispectral bands. This time delay is approximately 0.2 – 0.4 sec. In [6] it is suggested to use the combination of panchromatic and multispectral and exploit this time delay to determine vehicle movement. In a parallel study (financed by the Norwegian Research Council) where we have been working on approaches for analysis of urban areas, applying high resolution multispectral EO data, we have performed some experiments to evaluate the potential of such an approach.

The conclusion of this study is that the information from comparison of vehicle positions computed from the panchromatic and the multispectral image will not be enough on its own to determine whether a vehicle is parked or not. There are several reasons for this. First, robust vehicle detection is difficult in the multispectral image, especially for small vehicles, and fewer vehicles will be detected in the multispectral than in the panchromatic image. Then, for low speeds the difference in positions may not be detectable and, finally, a non-moving vehicle is not necessarily parked (it may have stopped due to a queue, red lights, etc).

5.2.3.3.2 Exploitation of context and GIS information

A priori information on road directions, parking regulations or common parking patterns may also be of help in determining vehicle directions and movement, and existing ancillary data sources have therefore been investigated.

- Pairs of aerial images. For Oslo city, pairs of aerial images acquired with intervals varying from 5 seconds to a few minutes by overlapping flight crossings are available. These image pairs could, by analysing the differences between them, be used to find parked vehicles at the time of the image acquisitions and to derive from this which areas of the road that are used for parking. The images that are acquired with a few minutes overlap are probably best suited for this, however these alone will not provide a complete coverage.
- GIS information. Where GIS information including parking regulations and driving direction is available, this can be used in a similar way to establish which areas that are used for parking. From the Norwegian public roads administration information on parking regulations is available, but these only provide information on whether parking is allowed and do not specify parking zones. In addition to these parking regulations, information on the number of driving lanes in each direction is available.

On narrow roads parking may be allowed, but there may not be specific parking zones and parked cars may take up space in the driving lanes. In these cases static information about parking regulations in the area, will not be sufficient. Contextual information derived from vehicle positions may then be utilized. This may include information like the distance between vehicles, the vehicles' position relative to the road mask etc.

5.3 Selected approach and input data

5.3.1 Vehicle detection and classification

Based on the findings from the experiments, the best approach for solving this problem seems to be to use a segmentation and classification based approach. We therefore chose to solve this by using a multilevel segmentation followed by feature extraction and classification.

For the feature extraction we focused on shape-properties as these seem to contribute the most to the separation between vehicles and other objects. For the classification we chose to use a rule-based approach, as the initial experiments suggest that features like area, direction and elongation can separate vehicles from others using quite simple classification rules. Also, it may be difficult to collect the sufficient amount of ‘ground truth’ required by more sophisticated classification approaches.

The analysis may be based on IKONOS or Quickbird images. Quickbird has a slightly better resolution, while IKONOS may provide image pairs for difference analysis. However, the IKONOS image pairs may be difficult to acquire for the demonstration case, as such images do currently not exist in the archives. In addition to the satellite images, we will use a road network mask to limit the analysis to the road surface. Such masks are available from the Agency for planning and building services, City of Oslo.

5.3.2 Derivation of direction and parked/moving status

To determine whether a vehicle is parked or moving we will as a basis use GIS information in combination with extracted vehicle positions and contextual information. When available, pairs of IKONOS images may be used as an additional source to detect whether a vehicle is moving or not.

The traveling direction of a vehicle will be determined based on vehicle position and GIS information on the number and directions of lanes. We do not plan to use image pairs for this, as this will require matching up of vehicles between images and we expect this to be too difficult at this resolution.

5.4 Product generation system

The Figure below gives an outline of the product generation system based on the approach and the input data described in Section 5.3.

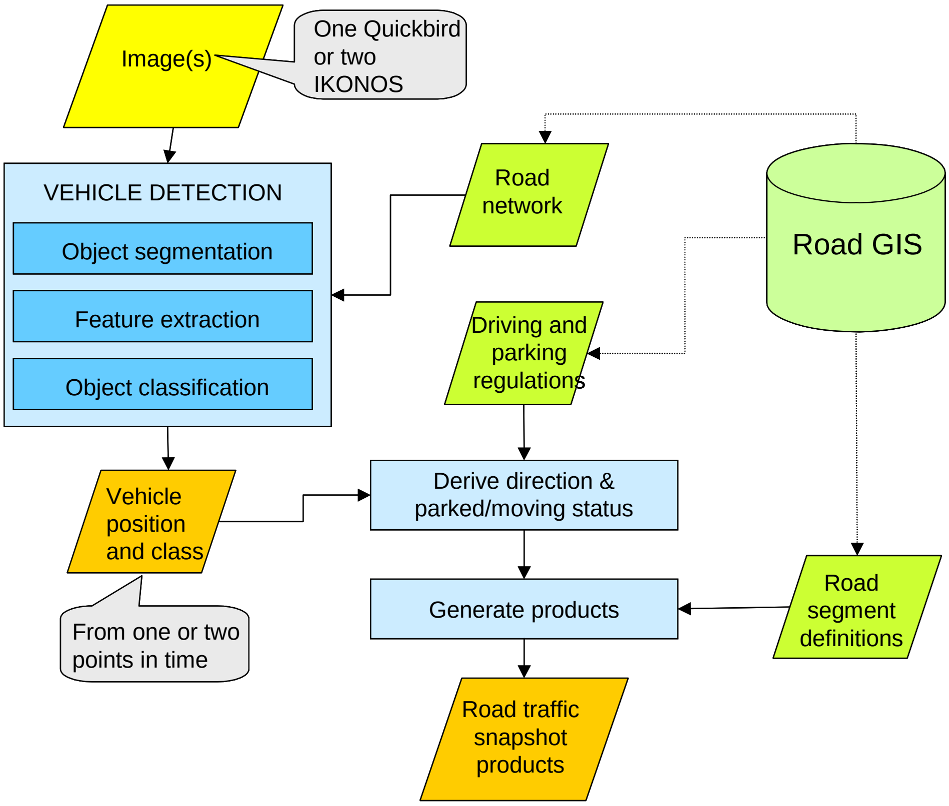


Figure 7: *Product generation system.*

6 Service case description

6.1 Service case area

The service case area (SCA) is located in the eastern, central parts of Oslo, Norway, it's location is shown on the map in Figure 8.

Figure 8: *Eastern parts of central Oslo, Norway. The location of the SCA is indicated by the blue circle.*

The SCA is relatively densely populated, the typical building structure in the area is a 4 to 5 stories high building, the construction period varies from late 1800 to more modern buildings. A typical building from the area is shown in Figure 9. Several of the roads crossing the SCA are heavily trafficked, particularly route 161 crossing the SCA in a north to south direction is an important traffic axis. Apart from route 161 which has several sections with four lanes, roads in the area are relatively narrow two lane roads. The speed limit in the area is almost exclusively 50 km/h.

Figure 9: *A typical building from the SCA, located roughly in the center of the blue circle shown in Figure 8.*

6.2 Available data

We dispose two Quickbird satellite images, both acquired in the month of May (2003 and 2006), covering the SCA and most of the Oslo municipality. Both satellite data sets are complete with both the panchromatic (0.6m resolution) and multispectral (2.4m resolution) channels. In addition we have acquired GIS data in the form of road masks and building outlines, these have so far not been used directly in the processing of the satellite data. We also dispose of a limited set of aerial stereo images (5-6cm resolution) and orthophotos (12.5cm resolution). Figure 10 shows part of the SCA as it appears in the Quickbird image acquired on the 28th of May 2003.

Data	Data type	Coverage	Resolution	Provider
QB satellite image (acquired 280503)	Raster	Oslo	Pan: 0.6m MS: 2.4m	Eurimage Quickbird Imagery Archive
QB satellite image (acquired 050506)	Raster	Oslo	Pan: 0.6m MS: 2.4m	Eurimage Quickbird Imagery Archive
Road mask	Vector	Oslo	NA	Agency for Planning and Building Services, City of Oslo (APB)
Road mask	Vector	Oslo	NA	Norwegian Public Roads Administration (NPRA)
Building mask	Vector	Oslo	NA	APB
Orthoimages	Raster	SCA	12.5cm	APB
Raw stereo images	Raster	SCA	5-6cm	APB

Table 1: *Overview of available data for the SCA.*

Figure 10: *Part of the SCA as seen in the Quickbird image acquired on the 28th of May 2003.*

6.3 Additional test case areas

The SCA is a relatively uniform area in terms of road and building dimensions and traffic load. In order to evaluate our methods more extensively we have also defined two subsidiary test case areas (TCA) so that the performance of our algorithms can be evaluated on a wider spectrum of input data. The first test case area, TCA-a, is defined as part of the main highway leading south from Oslo on the eastern shore of the fjord of Oslo. This TCA was chosen as a more open, straight road with traffic at higher speed than in the SCA (60 km/h as compared to 50 km/h in the SCA). TCA-a is shown in Figure 11. The second test case area, TCA-b, is defined as inner city main roads. This TCA was chosen since it shows large intersections in open surroundings with cars moving relatively slowly or at standstill. TCA-b is shown in Figure 12.

Figure 11: *TCA-a as seen in the Quickbird image acquired on the 28th of May 2003.*

Figure 12: *TCA-b as seen in the Quickbird image acquired on the 28th of May 2003.*

7 Service case implementation

7.1 Products

In the technical specification (see Section 5), we identified one base product and four derived products. The base product consists of the positions of vehicles detected in the road network. For the service case, we have chosen to focus on the base product.

A typical format for the base product will be a list (in ASCII format) of the positions of all the detected vehicles. For the purpose of the service case implementation, we provide this product as a satellite image in which the position of all detected vehicles are marked. There are several reasons for doing this: Georeferencing the satellite images used in this project is a straight forward but time consuming process. In order to save time, we worked directly on the satellite images without georeferencing them. All vehicle positions are therefore given as row and column coordinates relative to the satellite image and not in absolute geographical coordinates. While this approach is much less time consuming, vehicle positions can only be given in coordinates relative to the image. Another reason for choosing this delivery format is the ease with which visual inspections of the final result can be performed.

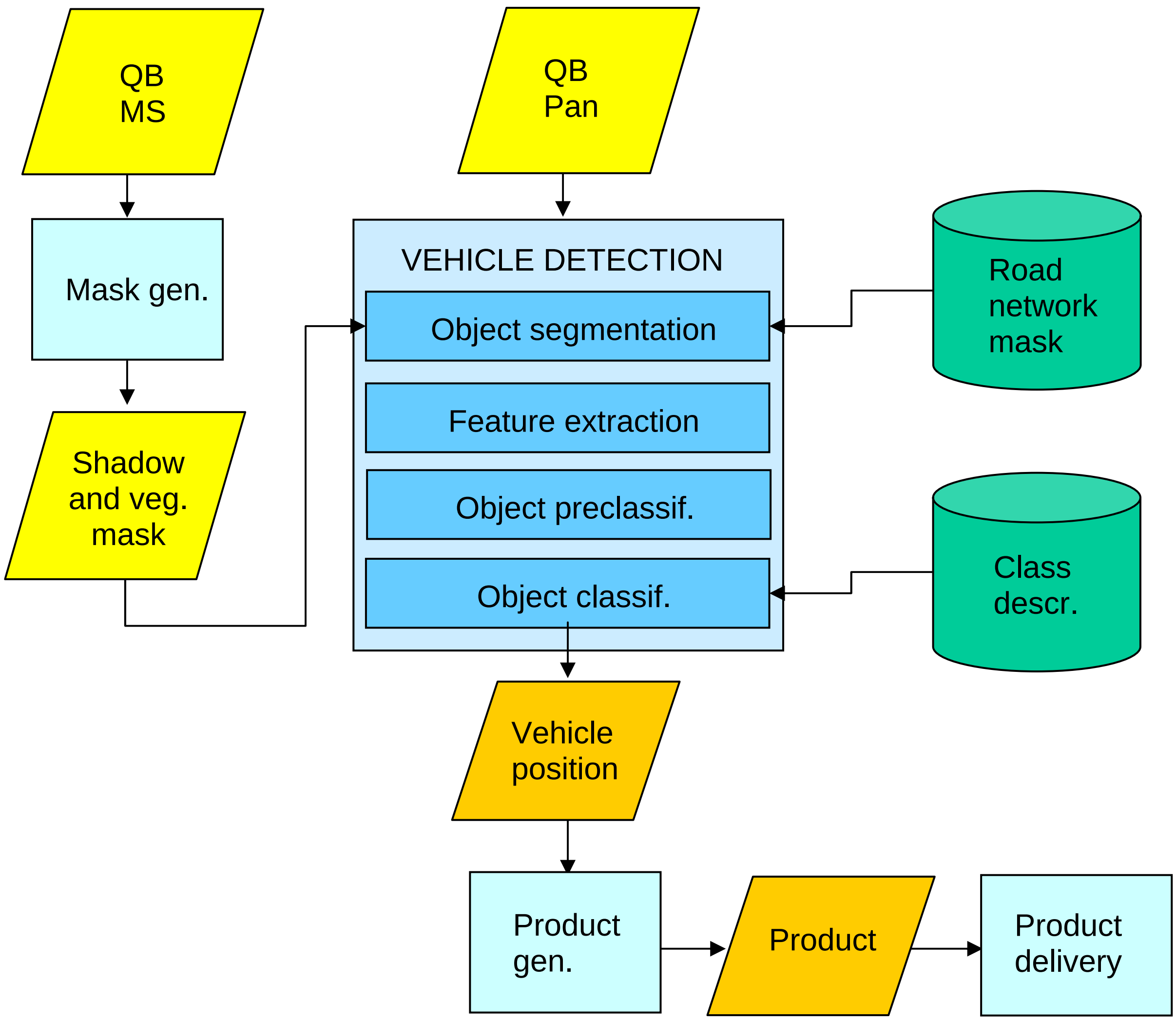


Figure 13: *The work flow in the service case. The only product derived is the base product. This is derived based on a Quickbird image.*

7.2 Work flow and methods

Figure 13 summarizes the product generation work flow that has been adopted in the service case implementation. In the following sections we will briefly explain the different steps in this workflow.

7.2.1 Vegetation and shadow masks

We have used masks indicating the presence of shadows or vegetation overlapping the roads. As explained in Section 5 and in [11], these masks are derived based on the multispectral channels of the satellite images. Methodology for doing this was developed in a parallel project. The vegetation mask is made by thresholding an NDVI image derived from the multispectral data after resampling to the resolution of the panchromatic data. The shadow mask is derived by clustering the resampled multispectral data into three classes and choosing the cluster corresponding to the lowest spectral values. The shadow and vegetation mask for the SCA based on the 2003 satellite image is shown in Figure 14. Similar masks were generated for the SCA and for TCA-a and TCA-b for both the 2003 and the 2006 acquisition.

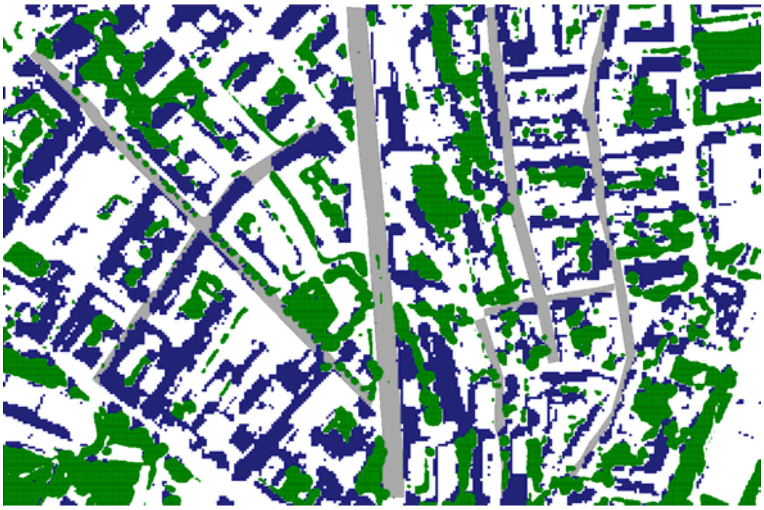


Figure 14: *Shadow (blue) and vegetation (green) masks for the SCA based on the 2003 satellite image. The manually drawn road masks are shown in gray. Notice that both the shadow and the vegetation mask in many cases overlap the road mask indicating that parts of the road surface are affected by the presence of vegetation and/or shadows.*

7.2.2 Road network mask definitions

Searching for vehicles in the satellite images should only take place in regions accessible to vehicles. This can be achieved by precise georeferencing of the satellite data followed by road mask generation based on the road GIS data. As explained in section 4.1 a precise georeferencing of the satellite images has not been performed in the framework of this project. We have chosen another approach that consists in manually drawing road masks directly on the non-referenced satellite imagery. This has been done for a number of streets that were judged interesting. We can do this without any loss of generality since the use of GIS data is a straightforward processing step for more extensive masking.

In Figure 15 we show an example of a road mask for the SCA as seen in the 2003 satellite image. Similar masks were drawn for the SCAs and the TCAs for both the 2003 and the 2006 satellite images.

Figure 15: *The road masks defined for the SCA.*

7.2.3 Object segmentation

Once the road network and the shadow/vegetation masks are available, the satellite image is segmented in order to detect candidate regions that could be potential vehicles. The segmentation procedure is based on a repeated application of Otsu's segmentation method, once to detect potential vehicles that are darker than their local surrounding and once to detect potential vehicles that are brighter than their surroundings. More details concerning this step are described in Section 5 and in [11].

7.2.4 Feature extraction

The segmentation step produces numerous vehicle candidate regions. In order to analyze these further, different features are extracted from the candidate regions. The currently used features are shape features and gray level features:

- Shape features:
    - Area, compactness, angle deviation, spatial spread, Hu moments, height and width of the bounding box, elongation and rectangularity.
- Gray level features:
    - Region mean, region standard deviation, region gradient mean, boundary gradient, local contrast and smoothness contrast ratio.

This step is described in greater detail in Section 5 and in [11].

7.2.5 Object preclassification

Once the features of every segment have been determined, a simple rule based classifier is applied in order to separate potential vehicle objects from obvious non-vehicles. This is done in a step-wise fashion following a coarse-to-fine strategy where the aim at each step is to assure that no vehicle class objects are removed erroneously. The steps in this process consider object features such as width, elongation, rectangularity, compactness and angle deviation. This process is described in greater detail in [11].

7.2.6 Object classification

Once the segments that are obviously not vehicles have been removed, we apply a statistical classifier to the remaining objects in order to detect the vehicles. This methodology was developed in a parallel project. The features of each object are organized in a feature vector, and each feature vector is then fed to the classifier. The classifier currently used is a quadratic discriminant analyzer, more details are given in [11]. The classifier will separate the candidate segments into one of four classes:

- Dark noise
- Bright noise
- Dark vehicle
- Bright vehicle

7.2.7 System training

The statistical classifier used by the system needs training. We have decided to train the system by splitting the SCA and TCA images into two groups of three images each. The training is done using one set of images while the tests are performed using the other set. Training is performed by applying the road and shadow/vegetation masks to the images followed by segmentation. The objects resulting from this procedure are then subjected to manual analysis. The manual analysis consisted in classifying the objects into one of the four categories listed above.

Only those objects for which the interpretation seemed certain were included in the final training set. For all but the class 'Bright noise', between 140 and 190 training samples were obtained; (Dark noise: 144, Bright noise: 38, Dark vehicle: 158, Bright vehicle: 186). The result of the system training phase is a statistical description of each of the four classes listed above. This description can be stored in a class description file. It is important to point out that training is done only once and that the resulting class descriptions can be reused in all subsequent classification processes.

7.2.8 Observability of streets in the service case area

One concern in this project is that of street observability. This is of particular concern in the SCA due to the presence of relatively tall buildings surrounding narrow streets. In such cases, it is clear that parts of the streets will not be observable for one or several reasons:

- As we have seen, shadows cast by buildings render vehicle detection much more difficult and in the present study we have chosen to ignore completely streets in shadow.
- Vegetation close to streets will completely mask visibility making vehicle detection impossible.
- Finally, if the satellite image acquisition is done at an offnadir angle, the buildings will be seen from the side which will also mask street visibility.

In order to obtain a rough idea of the percentage of the streets that are observable we have performed the following simple experiment: Based on the GIS data provided by the APB we made a mask for all the roads in the service case area by warping this onto the satellite image of the SCA. Calculating the intersection of this road mask with the inverted masks for vegetation and shadow we obtain a mask showing the parts of the road network that are not occluded by neither vegetation nor shadows. 52% of the road mask remains visible under these conditions. It should be pointed out that this very simple approach to calculating observability has several limitations:

1. First, it does not take into consideration the fact that for the satellite image we considered, the offnadir angle of the acquisition is such that many buildings will occlude parts of the streets. It is complicated to determine a mask for the part of the streets that are occluded due to this effect, and the estimate we provide must be considered a upper limit of what can be obtained in an acquisition with 0 offnadir angle.
2. A second problem is that parts of the roads that remain visible outside shadows and vegetation will be very thin or small segments in which only parts of a vehicle would be visible. It is very doubtful if the current system would function successfully on such

partially visible cars. Again, this means that the estimate of street observability must be considered an upper limit estimate.

Figure 16 shows the street map that was used. Figure 17 shows the modified street map after those parts that fall in shadow or under vegetation are removed.

7.3 Service case product examples

Figure 18 shows the base product for the SCA based on the satellite image acquired on the 5th of May 2006. Part a) of this figure shows the road masks used whereas part b) shows the system detected vehicles within this road mask. Figure 19 is a larger version of the same result whereas Figure 20 shows a zoom of the upper central part of the results image.

Figure 16: *Street map warped to the SCA area as observed in the acquisition of the 28th of May 2003.*

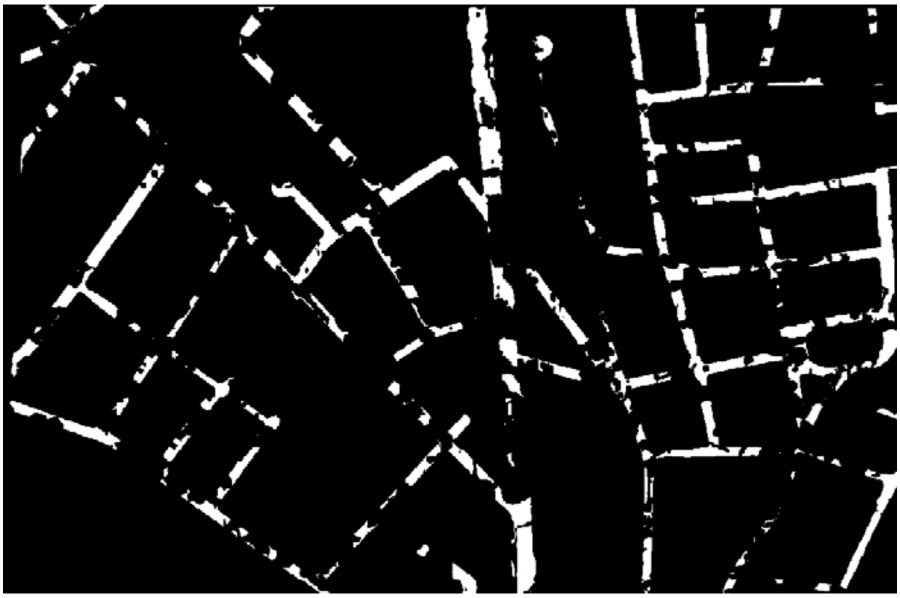
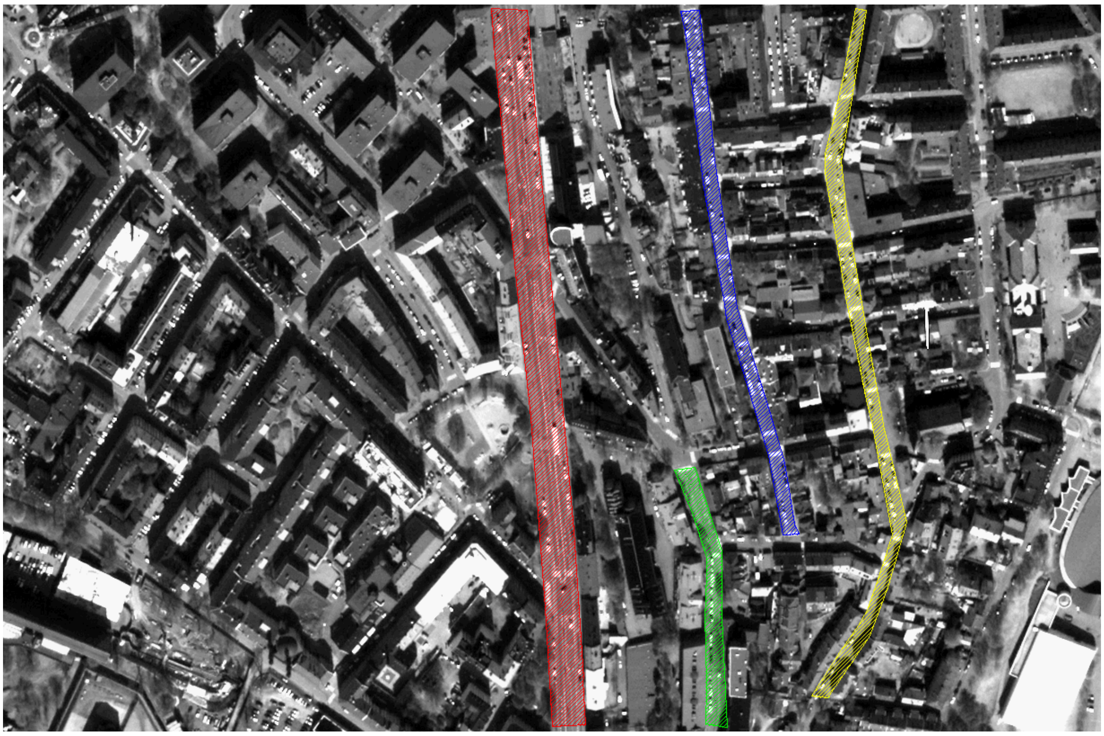
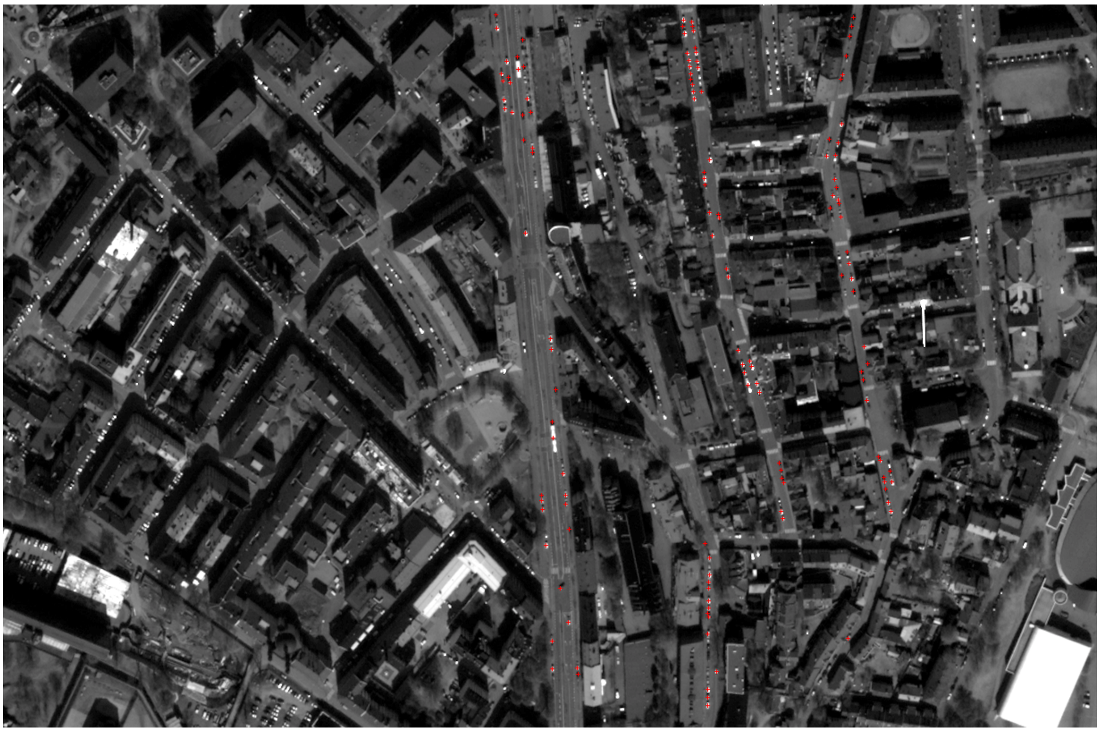


Figure 17: *The street map of the image shown in Figure 16 after removal of those parts that fall in shadow or under vegetation. The overlap of pixels between the two images is 52%.*



a)



b)

Figure 18: *Base product for part of the SCA. Part a) of this figure shows the SCA as seen in the 2006 satellite image. The road masks used in this image are also shown. Part b) of this figure shows the vehicles detected by the system as red crosses.*

***Figure 19**: Base product for part of the SCA. This figure shows the vehicles detected by the system as red crosses, it is a larger version of the image shown in Figure 18 b). Notice that compared to Figure 18 b), this version of the image is rotated 90 degrees counter-clockwise.*

Figure 20: *Base product for part of the SCA. This figure shows an enlarged version of the upper central part of the image shown in Figure 18 b).*

Observing these figures it is clear that the overall performance is quite good and a large number of the cars within each road segment are detected. When errors arise it is typically due to one of the following reasons:

- Vehicles with low contrast are prone to omission in the segmentation phase. If a vehicle is omitted in this phase, no detection is possible.
- Vehicles with low contrast may also result in severely fragmented or deformed detections that are in turn rejected as noise by the classifier.

Low contrast can be due to the color of the vehicle or it's immediate surroundings. There are also indications that the contrast is reduced in fast moving vehicles. It is also possible that the relatively low sun angle in the SCA will result in shadows as well as reflexes from car windows that can contribute to reduced contrast. In spite of some errors the results are very promising.

7.4 Service case integration

As described earlier, focus in the service case implementation has been on the base product. This is delivered to the user as maps of vehicle positions in the form of satellite images with every detected vehicle marked as a cross. This product makes it possible to estimate vehicle density in the different parts of the road mask. At a later stage, using the base product as input, it will be possible to generate the derived products.

The user has identified all these products as important, it is however important to point out that the user has no experience with this kind of product and that no previous attempt has been made at integrating such products in the daily routines of the user. It is therefore important to keep an open mind in the evaluation of the potential benefits of this project. We expect both the base product and the derived product to be valuable to the user in the future. We also expect that new and innovative uses of the project results will arise in the future as more experience is gained. The user has already indicated several wishes for further development:

High buildings and their shadows as well as vegetation can occlude parts of the road network. In practice, traffic data can not be derived for these parts. Since traffic load varies relatively smoothly, it will probably still be possible to estimate the traffic load in a region based on those roads that are observable. The user has requested that a map of street observability (as a function of satellite position, time of year etc.) is made available.

One innovative use of project results would consist in linking satellite derived road counts to the annual average daily traffic counts frequently employed by the user. Such a link would require sophisticated statistical methods linking the short time observations in the satellite images to annual averages. We are currently seeking financing for this work together with the user.

The users are also very keen to test the methodology in more remotely populated areas of Norway. These regions give rise to particular challenges for traditional counting methodologies, primarily due to the large costs of installing and maintaining a network of counting stations in remote and sparsely populated areas. In these areas, the problem with occluding buildings will be reduced and satellite based technology might provide a very viable alternative to traditional methods.

8 Validation activities

The validity of the products developed during this project is hard to assess and we have undertaken several validation activities to gain an understanding of their validity. We have assessed the validity of the products not only for the SCA, but also for other areas in order to gain a broader understanding of the quality of the results.

In the technical specification for this project we suggested that results should be evaluated using one of the following three methodologies:

1. Comparing results based on manual counts with results based on automatic counts.
2. Comparing results based on manual counts in aerial imagery with results based on automatic counts derived from downsampled versions of the same images.
3. Comparing results based on data from inroad counting equipment with automatically generated counts.

The main reason for applying several validation strategies is that each of the validation approaches has its strengths and weaknesses and a combination of approaches will probably give the best possible validation.

In the following sections we will discuss each of these validation approaches in greater detail. Results are deferred to the next chapter.

8.1 Manual versus automatic counts

For limited areas in different QuickBird images we have performed independent manual counts of vehicles within the road network. The independent counts were obtained by letting a (small) number of different persons count the vehicles they could see in the images and then report the position (image coordinates) of these vehicles. This makes it possible to compare the findings of the human observers with that of the system. Using several human observers also has the advantage that it is possible to distinguish those objects for which several observers agree, these objects are assumed to have a more certain interpretation than those identified by only one observer. The comparison of manual detections will also be indicative of the complexity of the detection problem.

8.2 Manual counts in aerial imagery compared to automatic counts on downsampled versions of the same imagery

The initial idea of this validation approach was to produce imagery closely mimicking the QuickBird imagery by downsampling and otherwise manipulating aerial imagery. Since vehicles are easily identified in aerial imagery (due to the much higher resolution) the idea was to identify vehicles in the aerial imagery and then verify if these were found by the automatic system when operated on the downsampled versions.

We had 12.5 cm aerial orthophoto imagery available for part of the original SCA. We then used ENVI to discard the color information and to downsample the imagery to 0.6 m resolution. The principal problem in this process lies in producing downsampled imagery with the correct visual appearance. It is evident that if the visual appearance of a real and a simulated QuickBird image are too different then it is highly likely that the automatic method will perform quite differently on the two images. We experimented with several different downsampling methods, downsampling kernels etc. but never succeeded in finding an approach that produce credible simulated QuickBird images.

This validation approach was therefore abandoned.

8.3 Counts from inroad equipment versus automatic counts

This kind of validation is very interesting because it will provide an indication of the system performance relative to that of data obtained by truly counting vehicles in the road (although this is also associated with errors). The main problem with this approach is that the inroad counts are accumulated, typically on a per hour basis, making direct comparisons impossible. As we shall shortly see, results are still indicative of a good correspondence between what is found in the satellite images and what is actually counted by the inroad counting equipment.

9 Validation results

In this section we report the validation results based on comparing manual and automatic counts. We also report the results from comparisons of automatic counts with inroad counts.

9.1 Manual versus automatic counts

For this validation experiment we used three images:

1. SCA: This is an image of the service case area obtained on the 5th of May 2003.
2. MV: This is an image of part of the main highway leading south from Oslo on the eastern seashore. This image was obtained on the 28th of May 2006.
3. UV: This is an image of part of a major thoroughfare in central Oslo. This image was obtained on the 28th of May 2006.

These images were all subjected to automatic analysis as well as manual analysis by two independent observers. As described earlier the automatic processing essentially consists in three steps:

1. Segmentation: In this step, candidate regions are extracted from the image.
2. Preclassification: The candidate regions are then subjected to an initial analysis aimed at excluding obvious errors.
3. Classification: The remaining candidate regions are then fed to a classifier in order to make a final decision as to their interpretation.

This three-step process opens for several errors. If the segmentation does not detect any region where there is a vehicle then obviously no detection can take place. Vice versa, the preclassification can throw away segments that are actually vehicles or let segments that are not vehicles pass to the next step. Finally, vehicles can be erroneously classified in the classification process.

Our first validation experiment consisted in determining how many vehicles that were lost due to errors in the segmentation and preclassification steps. These results are summarized in Table 1. The results are compared to counts obtained by two independent manual counts based on the same images. The total manual vehicle counts given in the first three columns of the table gives the results obtained by the two independent manual counts performed by two different persons (P1: person 1, P2: person 2). The column marked consensus gives the number of objects (positions) where both persons agree that there is a vehicle. The next columns summarize the number of vehicles that were missed by the segmentation and pre-classification process compared to the two manual counts.

Image ID and total number of segmented objects per image	Total **manual** vehicle count			Vehicles missed before classification according to manual counts	
	P1	P2	Consensus	P1	P2
Image SCA (528)	154	160	144	26	20
Image MV (255)	96	93	91	26	21
Image UV (836)	146	134	127	31	28
Total	**396**	**387**	**362**	**73**	**69**

Table 1: *A comparison of manual and automatic results for the three test areas described in the text.*

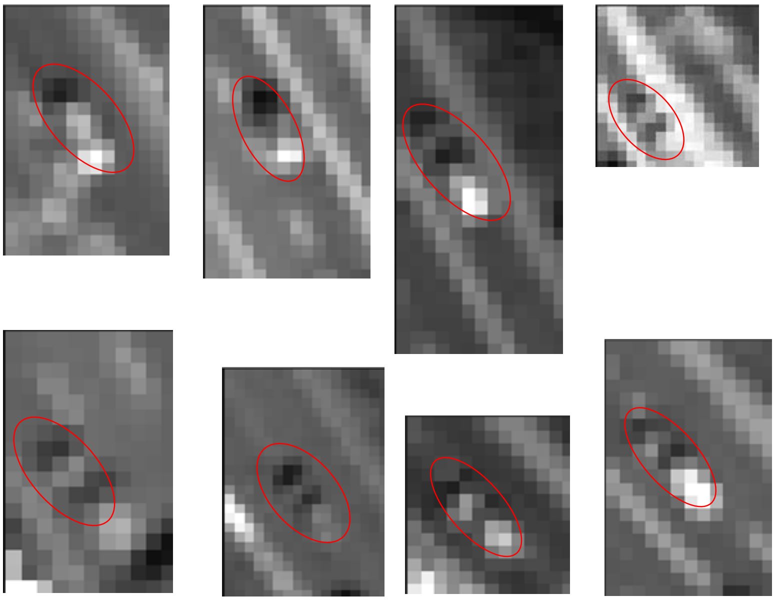


Figure 21: *Examples of manually identified vehicle objects that are not properly segmented. These objects have a low contrast to the background and are therefore fragmented into several very small parts that are not sufficiently large to be considered as a potential vehicle.*

As can be seen from these counts, there are a number of vehicles that are missed in this process. According to the two manual counts 69-73 vehicles are lost in this process. Inspection of the images for these cases revealed that this is generally due to bad contrast. The vehicle objects are hardly visible at all or severely fragmented. In the segmentation process this means that these vehicles can not be separated from the background, or that only very small parts of the objects that do not have the shape of a vehicle are found. Examples illustrating this are given in Figure 21. As can be seen here, the vehicles often consist of several parts; a shadow, the vehicle and a reflex from the back window. This may indicate that the sun angle has an effect on how the vehicles are imaged.

Looking at the results for the three areas separately, the highest percentage of missed objects appears for the MV sub-image. This area also contains the roads with the highest speed limit of the three test areas. Hence, this may indicate that the high speed is a factor that affects the contrast conditions in this case.

Table 2 summarizes the results of the two independent manual classifications that were performed. This classification was performed on the objects remaining after the pre-classification. The column to the left gives the number of objects that were classified. The next three columns give the number of these objects that were classified as vehicles by person 1 (P1) and person 2 (P2), while the column marked consensus gives the number of objects where both manual classifications agreed that the object in question was a vehicle. The rightmost column gives the percentage of objects where both manual classifications agreed on the class (vehicle/no-vehicle). In total the two independent manual classifications agree on the classification for 83% percent of the objects. This indicates that the interpretation of these images is not straightforward.

	Total number of objects classified	Number of objects manually classified as vehicles			Percentage overlap between P1 and P2
		P 1	P 2	Consensus	
Image SCA	205	126	126	106	80.5 %
Image MV	83	59	68	57	84.9 %
Image UV	211	111	111	94	84.3 %
Total	**499**	**296**	**305**	**257**	**83 %**

Table 2: *Result of manual classification.*

Table 3 summarizes the results of the automatic classification. The column to the left gives the total number of objects that were classified as vehicles. The total here is 303 vehicles, which is very close to that of the two manual classifications that gave 296 and 305 vehicles respectively (as reported in columns 2 and 3 in Table 2). The next two columns in Table 3 give the number of objects that were correctly classified as vehicles according to the two manual classifications. Again the numbers obtained here (256 and 252) are comparable to the number of vehicle-classifications where the two manual classifications agree (257, reported in column 4 in Table 2).

The two rightmost columns of Table 3 give the correct classification rates obtained as compared to the two manual classifications, P1 and P2. For P1 the total rate is 82.8%, while for P2 the total rate is 79.2%. These rates are close to the percentage of objects for which the two manual classifications are in agreement (83%, reported in column 5 in Table 2). Hence, this indicates that the performance of the automatic classification is comparable to that of a manual classification.

	Objects classified as vehicles	Correctly classified as vehicles		Correct classification rates	
		P1	P2	P1	P2
Image SCA	135	112	112	82.0 %	82.0 %
Image MV	65	56	59	86.7 %	81.9 %
Image UV	103	88	81	82.0 %	75.4 %
Total	**303**	**256**	**252**	**82.8%**	**79.2%**

Table 3: *Result of automatic classification.*

9.2 Comparison with counts from inroad equipment

The second validation experiment we performed consisted in comparing automatically obtained counts with counts obtained using inroad counting equipment. Such counts are available for a number of counting stations in the Oslo area. However, none of the previously considered areas are covered by permanent counting stations, and we had to consider other roads in order to perform this experiment. The three comparisons are based on data from the permanent counting stations at Frognerstranda[1], Teisen[2] and close to the Alcatel headquarters[3] in Oslo, we refer to the three images as Frognerstranda, Teisen and Alcatel. The counting equipment counts separately in both directions, we will refer to these directions as the *in* and *out* directions. The Frognerstranda and Teisen images were acquired on the 5th of May 2006, the Alcatel image was acquired on the 28th of May 2003. The inroad counting data for these dates are accumulated on an hourly basis. The 2003 image was acquired roughly in the middle of the corresponding observation interval (acquired at 12:35 local time). The 2006 image was acquired very late in the corresponding interval (acquired at 12:58 local time). For both images it is justified to compare the automatic counts with inroad counts accumulated both in the 12-13 interval and in the 13-14 interval.

	Sat. image (manual counts)			Road counts (from inroad equipment)			
Location	Date	Count in image	Predicted vehicles per hour	Counted vehicles 12-13	Predicted vehicles in counting area	Counted vehicles 13-14	Predicted vehicles in counting area
Frognerstranda out	5.5.2006	55	3138	2955	52	3344	59
Frognerstranda in	5.5.2006	63	3528	3100	55	3316	59
Alcatel out	5.5.2006	24	1623	1477	22	1691	25
Alcatel in	5.5.2006	27	1835	1679	25	1752	26
Teisen out	28.52003	32	1812	1951	34	2276	40
Teisen in	28.5.2003	19	1139	1466	24	1519	25

Table 4: *Comparisons of manually obtained counts with counts from inroad counting equipment.*

The comparisons between the manually obtained counts with those from inroad equipment are given in Table 4. For all the images an observation area was defined, one in each driving direction. In this observation area, the human observer counted the vehicles. Column three in Table 4 gives the number of vehicles that were counted in the observation area in each image. The length of the observation area along the road is easily calculated using GIS software. Knowing (both from local speed regulations as well as from the inroad counting equipment) what the local speed limits are, it is possible to estimate how many vehicles will cross a given point in the road per time unit. Thus, based on the manual counts in the observation area, we can estimates the number of vehicles that would pass the given observation point per hour. These estimates are given in column four of Table 4.

From the inroad counting equipment we can directly obtain the number of vehicles that passed the counting equipment in the time period encompassing the satellite image acquisition time. This is given in column 5 of Table 4. Furthermore, since we know the time it will take for a

[1] Road number: E18

[2] Name of road: Strømsveien

[3] At Økern; Name of road: Østre Aker vei

vehicle to cross the observation area defined in the satellite images we can calculate the number of vehicles that should be present in the observation area as predicted from the inroad counts. These predictions are given in column 6 of Table 4. Comparing columns 3 and 6 we see that the correspondence is relatively good. Actually, all manually obtained counts are within 21% of the estimates obtained based on the inroad counting equipment. Similarly, comparing columns 4 and 5 we find a good correspondence. Since the 2006 image was obtained late in the counting interval it also makes sense to compare results of manual counts with the following time interval. These results are also provided in the table.

The comparisons between the automatically obtained results with those from inroad equipment are given in Table 5. We used the same observation areas and applied the automatic method to these areas. The automatic classification does not separate the *in* and *out* directions.

Road segment	Alcatel	Frognerstranda	Teisen
Date	5th of May 2006	5th of May 2006	28th of May 2003
No. of cars estimated by automatic classification from satellite image	50	90	44
No. of cars in road segment estimated from inroad counts at 12 - 13 GMT	47	107	58
No. of cars in road segment estimated from inroad counts at 13 - 14 GMT	51	118	65
No. of automatic classified cars in percent of no. of cars estimated from inroad counts 12 -13 GMT	106.4 %	84.1 %	75.9 %
No. of automatic classified cars in percent of no. of cars estimated from inroad counts 13 -14 GMT	98.0 %	76.3 %	67.7 %

Table 5: *Comparisons of automatically obtained counts with counts from inroad counting equipment.*

As we have pointed out before, the 2006 image was acquired so late in the observation interval that comparisons with the following observation interval is reasonable. These results are very promising as all automatically obtained results are within 25% of the results based on inroad counts, with one exception, the Teisen result for the 13-14 interval. The Teisen image was actually acquired roughly in the middle of the 12-13 interval, and a comparison with data from the 13-14 interval should be expected to produce a poorer correspondence.

It is important to notice that even automatic inroad counts are not 100% reliable. Such data are uncertain because of inaccuracies in the instruments used for registering the vehicles. A large vehicle might for example be registered as two smaller vehicles. Besides, inaccuracies might occur in the postprocessing of the data when the single registrations are summarized to different kinds of counts.

9.3 Assessment of utility and products

9.3.1 Assessment from NPRA

The project is in an early stage and the results are promising. We think that this can be used to give us figures for how traffic is spread over the different areas of the roads. This is nearly impossible for us to get figures for today without very huge costs. By developing this technology and methods that make us able to estimate how the traffic is spread and classified over the total road area this will be a technologic breakthrough for us. We think that by linking it to our permanent counting-stations we will be able to develop methods that can estimate the traffic flows with classification for different road areas. There must also be established a system that is controlling both data and results. We think also that we will have to make a procedure that is sorting out in which areas we will be able to estimate the traffic flows and in which areas we are not able to do so. NPRA will contribute to a continuation of this project both by funds and recourses like counting equipment and development of systems.

More assessments from NPRA are given in the Assessment Sheet in Appendix B.

9.3.2 Assessment from TØI

The process of developing the base product has been very fruitful. The base product provides useful insight into the future possibilities for result is promising, but further work is needed in order to make this into an operative tool for researchers and planners in transport and environmental challenges.

An interesting aspect is the possibility of expanding the geographical area which can be studied at a given moment of time in order to show the density and spread of traffic. This provides new opportunities for studies both in urban and rural areas. Many sparsely populated areas are characterized with long transportation distances. In such cases the methods developed in this project may be especially useful in order to get updated knowledge about the traffic.

Desired developments and derived products should be described for urban areas. Parallel it should be worked with testing and adjusting the product for use in open landscape, forested areas and areas where roads follow narrow valleys. In a country with numerous and long tunnels, the satellite images may be used to estimate how many vehicles are invisible at time. (There are more vehicles on the road than can be seen from above).

A useful application related to current methods of traffic surveys is the possibility of observing the mix of traffic. For many purposes the volume and movements of heavy vehicles is of special interest.

More assessments from TØI are given in the Assessment Sheet in Appendix C.

9.3.3 Comments from NR

As described earlier, focus in the implementation and validation phase has been on the base product. This could be delivered to the user as coordinates of vehicle positions. Such a product makes it possible to estimate vehicle density in the different parts of the road mask. At a later stage, using the base product as input, it will be possible to generate the different kinds of derived products.

The user has identified all these products as important, it is however important to point out that the user has no experience with this kind of service and that no previous attempt has been made at integrating such products in the daily routines of the user. It is therefore important to keep an open mind in the evaluation of the potential benefits of this project. We expect both the base product and the derived product to be valuable to the user in the future. We also expect that new and innovative uses of the project results will arise in the future as more experience is gained. The users have already indicated several wishes for further development:

- High buildings and their shadows as well as vegetation can occlude parts of the road network. In practice, traffic data can not be derived for these parts. Since traffic load varies relatively smoothly, it will probably still be possible to estimate the traffic load in a region based on those roads that are observable. The user has suggested that a map of street observability (as a function of satellite position, time of year etc.) is made available.
- One innovative use of project results would consist in linking satellite derived road counts to the annual average daily traffic estimates frequently employed by the user.

Such a link would require statistical methods linking the short time observations in the satellite images to annual averages.

- The users are also very keen to test the methodology in more remotely populated areas of Norway. These regions give rise to particular challenges for traditional counting methodologies, primarily due to the large costs of installing and maintaining a network of counting stations in remote and sparsely populated areas. In these areas, the problem with occluding buildings will be reduced and satellite-based technology might provide a very viable alternative to traditional methods.

10 Future services, evolution of the project

As we have pointed out several times, the technology and products developed in this project are very new to the users. No experience with the use of this type of products exists and the project has been a learning process both for the users and the developers. During the course of the projects, many new ideas both for methodologies, products and their uses have appeared. In this chapter we recapitulate these.

10.1 Organizational aspects

Several organizational models could be envisaged for a future service. The original technical specification states that a future operational service includes five actors, these are the *users*, the *service providers*, *satellite data providers*, *GIS data* providers and *ancillary data providers*:

10.1.1 Users

These actors make operational use of the products delivered as part of the service. During the project period no major changes concerning who the potential users are have been discovered apart from the fact that TØI has identified that the need for such a future service probably is as great in several other countries as it is in Norway. In particular, TØI has identified a great need for such a service in the new EU member states. On a national level, the users remain the NPRA along with the agencies for roads and transport of different Norwegian cities. TØI and other national institutes needing road traffic information for research and planning purposes will also be possible users.

10.1.2 Service providers

This actor generates the products that are included in the service. Initially, this role was expected to be filled by the NPRA. However, during the course of the project other possible concepts have been identified. A particularly interesting approach lays in the future development of the software by SPACETEC in collaboration with KSAT in charge of the operational use of this software. SPACETEC has a long experience in the operationalization of remote sensing methodology, including the development of advanced graphical user interfaces etc. KSAT is a national and international provider of satellite image based products and services, such as oil spill detections.

10.1.3 Satellite data providers

These actors provide satellite data. The satellite data providers will be one of the many satellite image sales organizations. During the project period no major changes concerning these actors have been discovered**.**

10.1.4 GIS data providers

These actors provide the GIS data. For an operational service, the GIS data providers can be the NPRA or the agencies for planning and construction services of different Norwegian cities. During the project period no major changes concerning these actors have been discovered.

10.1.5 Ancillary data providers

These actors provide other data relevant to the project, in particular data relevant to validation of the products. One interesting possibility that has been widely discussed during different phases of the project has been that of using aerial imagery instead of or as a complement to satellite imagery. A number of national and international private companies could provide such data. A further discussion of the technical aspects of the use of aerial imagery is deferred to the discussion of the technical aspects of a future service.

10.2 Technical aspects

A number of interesting technical aspects of a future service have been discussed during the project. These are summarized in the following sections.

10.2.1 Aerial imagery

One recurring issue during the course of the entire project has been the use of aerial imagery. The need for such imagery arises for several reasons. One important need signaled by the users is the need for monitoring the dynamics of a traffic situation buildup. This would essentially mean that a number of images would have to be acquired over the same area during a certain period of time. Satellites have severe limitations for this kind of application. IKONOS can provide stereo imagery with a time lapse between the two images from a few seconds up to a minute. This could be interesting for distinguishing between parked cars and those in circulation, but obviously not very useful if a traffic situation is to be monitored over some time. Due to the possibility of changing the view angle, IKONOS and Quickbird can take a new image of the same area 2 to 5 days after the first image, depending on the conditions. The time of day will be close to the same, the difference will be no more than half an hour. Currently, only aerial imagery seems feasible for this kind of application.

Another advantage of aerial imagery over satellite imagery is that the resolution will be higher, and the higher resolution will typically be available in the multispectral bands. This allows for color image processing which can be very useful for such an application.

Aerial imagery is also very flexible from an operational point of view, aircraft can operate below clouds for instance, and thus some of the severe weather limitations applicable to satellites do not apply to aerial imagery acquisition (but variable light conditions in the scene will make automatic detection more difficult).

A major drawback of aerial imagery is that the viewing geometry changes significantly within an image. This can to some degree be compensated for by using a narrow angle camera. Large area coverage with small footprints obviously requires a large number of image acquisitions and this is both time consuming and costly.

10.2.2 Applications to other geographical regions

During the course of this project we have studied the SCA intensively. We obtain good results for this area, but see clear limitations due to the limited observability of streets etc. An interesting application that we have tried out is that of applying our methodology to larger roads in open landscapes. Although still difficult, many of the problems related to the SCA do not exist for this kind of road. Such roads are also of great interest to the users since they represent large traffic volumes and enormous investments. An indication of the importance these roads have for the users can be found by observing the position of permanent vehicle counting stations in Norway. None of these are placed in the municipality road network, they are all concentrated on county, national and European roads. For this reason we believe that it is very important to follow up this interesting application of the developed technology. This is also supported by the good correspondence we observe between manual counts in such roads and those provided by inroad counting equipment.

10.2.3 International applications

We have only applied the developed methodology to the national road network. However, traffic loads and road infrastructure investments are as important in many other countries and it would be very interesting to test our methodology outside of Norway. TØI has indicated that there is a great need for traffic statistics in the new EU member states, such as Poland.

10.3 Costs

The cost of satellite imagery is steadily being reduced and a full coverage (PAN and MS) of the municipality of Oslo (roughly 120 km^2) costs €1500. When considering this price, it is very important to realize that the price would obviously be negotiable if a larger volume of imagery was to be acquired. It is also important to realize that the current traffic monitoring schemes based on inroad counting equipment also are very costly. Both installation and operation of the counting equipment is expensive. One of the main reasons for considering the use of a satellite-based scheme in more remote parts of Scandinavia is the large costs related to maintaining the counting equipment. In northern Norway, a simple maintenance operation on a counting station can involve driving hundreds of kilometers. This type of cost is often hard to quantify, but must definitely be taken into account when comparing the traditional scheme with the satellite based scheme.

Although the price of the satellite imagery will probably be the most important part of the costs of an operational service, elaboration of the service products will also incur costs. At the current time it is impossible to estimate these costs.

11 Summary and conclusions

The project “Road Traffic Snapshot” concerns a possible future service for counting vehicles in satellite images and generating traffic information based on these counts. The contents of the project has been to: (i) Define user requirements and technical specifications for the service; (ii) Make a service case implementation and; (iii) Validate and evaluate the implemented methodology, and discuss possibilities for the evolution of the project. For the purpose of the service case implementation, a service case area in the eastern central parts of Oslo has been considered.

During the evaluation we have performed several experiments to estimate the performance of the system:

- We have compared the performance of human observers and were able to conclude that the problem is a very difficult one. Even human observers have sometimes problems in deciding what objects are cars and what objects are not cars in the raw satellite images. This is made evident by the consensus rate between two independent observers when asked to mark cars (see Table 1).
- When the human observers are asked to classify as vehicles or not vehicles the objects that have not been rejected in the preclassification phase, they have an overlap of 83% in the objects marked as cars. When this is compared with the automatic system, the automatic system will have roughly the same overlap with a human observer as the two independent observers will have between them (see Table 2 and 3). This indicates that the classification part of the system performs as well as a human observer does for the same task.
- When manually performed counts are compared with counts obtained using inroad equipment, there seems to be a good correspondence as made evident by Table 4. In itself this is not a very important result since we obviously cannot rely on manual counts. However, the good correspondence between these counts makes it plausible that counts performed on only a small section of the road will provide data that are well correlated to what can be measured using inroad counting equipment. This means that a future automatic system with improved performance will provide useful data for the users.
- Comparisons between automatic counts and counts based on inroad equipment are also very promising as made evident by table 5. It is important to notice that even automatic counts are not 100% reliable.

In conclusion we have shown that a future system for automatic road traffic counts is feasible. Even if such a system observes only a snapshot of the road traffic situation, our results indicate that this information is relevant not only for that particular instance in time but also relevant for estimating the traffic load in a longer time period.

We strongly feel that the results of this project warrant further work to improve results and extend the methods. Although results are promising, several improvements are clearly possible and we will undertake the further development of our methodology in the near future. This development will be made in close collaboration with the users.

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Appendix A: User requirements

Based on the user input, the following user requirements have been formulated.

Area of Interest (AOI) and requested Service Case Area (SCA)

The area of interest is all of Norway, but for this project the focus will be on a service case area as specified below.

Area of interest N. 1:	
Name:	*Norway*
Type:	*Urban and rural areas of Norway*
Geographical coordinates and size of AOI:	*Size is roughly 324000 km^2*
Geographical coordinates and size of SCA:	*Rectangle defined by (UTM zone 32 N):* *Upper left coordinates: 6643479N, 598674E* *Lower right coordinates: 6642648N, 599604E* *About 1km^2*
Brief Description:	*The initial focus will be the main urban areas of Norway, The SCA is the inner east central area of the capital of Norway, Oslo.*
Problems/threats to the area:	*The SCA is an area with heavy traffic, high air pollution and many inhabitants exposed to noise and insecurity, the E6 runs through the area. There are street corridors that may limit visibility, and areas with parked cars will challenge the pattern recognition algorithms.*
User organisations:	*Norwegian Public Roads Administration, the Agency for Roads and Transport, City of Oslo, the Agency for Planning and Building Services, City of Oslo and the Institute for Transport Economics.*
Available data:	*The SCA is covered by numerous satellite images and aerial photographs. Extensive vector data for the road network, buildings etc. in the SCA is also available.*

Products and services specifications

In this section, the products and services that will be developed in the project are specified. It should be pointed out that the accuracy of the different products is very hard to assess. This kind of data has never been extracted from satellite images and the users have no experience to aid in determining a reasonable accuracy. For this reason the minimum accuracy will be considered undetermined.

Base product

The base product will in its simplest form consist of the geographical positions of the detected vehicles. When more information is extracted from the vehicles, this will be included in the base product as attributes to the vehicles. Such attributes may include vehicle class (light, heavy), direction (relative to road) and status (in traffic/parked). The base product will be the focus of this project.

Description of product/service 1	
General Description	*Base product: Vehicle positions*
General product description	*The basic product consists of lists of positions of vehicles.*
Uses and benefits	*This is the base product allowing for the generation of several derived products. It is also in itself an interesting product allowing for plotting of vehicle positions in GIS systems etc.*
Areas of interest	*The main areas of interest are urban agglomerations and major transport corridors.*
Technical Product	*Text file containing vehicle positions.*
Product format e.g.:	*Text file*
Required minimum accuracy e.g.:	*Undetermined.*
Updating frequency	*Bimonthly data for areas of interest. This is dependent on the availability of satellite images.*
Validation data for this product/service	*Existing traffic counts from level 1 counting stations, manual comparative counts and comparisons with aerial photography.*
Available already at user's premises	*Not available*
Already available elsewhere	*Not available*

Derived product 1

This product will consist of the number of vehicles traveling in each direction along a predefined road segment. This product can be derived from the vehicle positions and the direction attribute of the base product, and will require that vehicle positions, directions and the status of the vehicles (parked/in traffic) can be determined and that the road segment definitions are available along with a road network.

Description of product/service 2	
General Description	*Derived product: Vehicle counts per direction*
General product description	*This derived product consists of lists of the number of vehicles per direction on a per road link basis.*
Uses and benefits	*This is a derived product allowing for the description of the number of vehicles travelling in each direction on a given road link. This product is essential for determining the traffic usage of a specified road segment.*
Areas of interest	*The main areas of interest are urban agglomerations and major transport corridors.*

Technical Product	*Text file containing the number of vehicles per direction for all road links.*
Product format e.g.:	*Text file*
Required minimum accuracy e.g.:	*Undetermined*
Updating frequency	*Bimonthly data for areas of interest. This is dependent on the availability of satellite images.*
Validation data for this product/service	*Existing traffic counts from level 1 counting stations, manual comparative counts and comparisons with aerial photography.*
Available already at user's premises	*Not available*
Already available elsewhere	*Not available*

Derived product 2

The purpose of this product will be to indicate road stretches where there is a queue. This will be done by calculating the vehicle density of each road segment and reporting a queue when this density exceeds a limit. The vehicle density is simply the fraction of the length of the road segment covered by vehicles. Generation of the queue indicator will require a base product with direction and status attributes and definitions of road segments and a definition of queue (density threshold).

Description of product/service 3	
General Description	*Derived product: Queue indicator*
General product description	*This derived product consists of traffic density indexes on a per road link basis.*
Uses and benefits	*This is a derived product allowing for the detection of possible queue situations on a given road link.*
Areas of interest	*The main areas of interest are urban agglomerations and major transport corridors.*
Technical Product	*Text file containing the value of the traffic density index on a per road link basis.*
Product format e.g.:	*Text file*
Required minimum accuracy e.g.:	*Undetermined.*
Updating frequency	*Bimonthly data for areas of interest. This is pending on the availability of satellite images.*
Validation data for this product/service	*Queue indicators based on manual comparative counts and comparisons with aerial photography.*
Available already at user's premises	*Not available*
Already available elsewhere	*Not available*

Derived product 3

This product is intended to provide an overview of parked vehicles in an area. This is a type of information that can not be provided by today's technology. Hence, there is currently no established procedure for handling this type of information. When the status (parked/in traffic) of vehicles is possible to determine, parking information can be derived from the base product. Again, the information will be provided per road segment, giving the number of parked vehicles for each segment.

Description of product/service 4	
General Description	*Derived product: Parked vehicles.*
General product description	*This derived product consists of lists of the number of parked vehicles on a per road link basis.*
Uses and benefits	*This is a derived product making it possible to study the distribution of the parked vehicles in the road network.*
Areas of interest	*The main areas of interest are urban agglomerations and major transport corridors.*
Technical Product	*Text file containing the number of parked vehicles per road link.*
Product format e.g.:	*Text file*
Required minimum accuracy e.g.:	*Undetermined*
Updating frequency	*Bimonthly data for areas of interest. This is pending on the availability of satellite images.*
Validation data for this product/service	*Parking indicators based on manual comparative counts and comparisons with aerial photography.*
Available already at user's premises	*Not available*
Already available elsewhere	*Not available*

Derived product 4

The purpose of this product is to give an overview of the distribution of heavy vehicles in the road network. The existing in-road point measurements give vehicle counts and they separate vehicles into different classes. Hence, counts of heavy vehicles at these points exist, however an indication of the distribution over the road network is not available with current technology. Such an overview can be derived from the base product, when vehicle classes are included. We will report this information as the number of light and heavy vehicles per road segment.

Description of product/service 5	
General Description	*Derived product: Light/heavy traffic mix*
General product description	*This derived product consists of a list of the number of light and heavy vehicles on a per road link basis.*
Uses and benefits	*This is a derived product allowing for the description of the number of heavy vehicles*

	compared to light vehicles. It will allow for the detection of heavy traffic corridors, areas exposed to traffic noise etc.
Areas of interest	*The main areas of interest are urban agglomerations and major transport corridors.*
Technical Product	*Text file containing the number of light and heavy vehicles on a per road link basis.*
Product format e.g.:	*Text file*
Required minimum accuracy e.g.:	*Undetermined.*
Updating frequency	*Bimonthly data for areas of interest. This is pending on the availability of satellite images.*
Validation data for this product/service	*Existing traffic counts from level 1 counting stations, manual comparative counts and comparisons with aerial photography.*
Available already at user's premises	*Not available*
Already available elsewhere	*Not available*

Appendix B: User Assessment sheet from NPRA

Assessment Sheet Template - DUE Innovator

1 A posteriori assessment of the requirements

Adequacy of the product specification requirements (including accuracy requirements) specified before projects start	Evaluation*:		
	L	M	H
		x	
Comment: The product specification was relevant and it was natural to begin with the requirements as the project listed out. But if we shall be able to test it out better, there must be a closer cooperation with the Norwegian Public Road Department (NPRA) and NR. NPRA will help NR to test out the products in a better way in the future and will take steps to make this possible.			

* L: Low M: Medium H: High

2 Products conformance with requirements

Product completeness versus the User Requirements	Evaluation:		
	L	M	H
		x	
Comment: The product is in its first stage, and the first aim was to see if it is possible for the system to count vehicles from the images. The answer is clearly yes, and the system gives us results that are promising, but there is still work to do in making the software better in counting vehicles from the images.			

Confidence in estimated product accuracy:	Evaluation:		
	L	M	H
		x	

f

Comment: There are some promising results, but we need to establish some test-sites that are better equipped to measure the results better than we are able to do today. NPRA will help NR and other participants to start out establishing better test-sites.

Product accuracy versus the User Requirements	Evaluation:		
	L	M	H
		x	
Comment: The results are promising, but we need a better test-site if we shall be able to consider if the system can give us data with good enough accuracy.			

3 Utility assessment

Benefits or cost-savings from demonstrated products/service versus current practices:	Evaluation:		
	L	M	H
			x
Comment: We don't think that this system can give us data that we can use instead of our ordinary permanent counting stations. The question for us is whether the system can be able to substitute and complement our short-time counting stations. The results for this are at the moment promising. If the system will be able to do so there are a lot of benefits for us and the whole society.			

Impact of products/service	Evaluation:		
	L	M	H
	x		

2

f

Comment: The product is at the moment in an early state of development and there is just testing that is going on. We hope that NR will test it out better in cooperation with us. Then we can be able to say if the results are good enough for further development. If this testing give us good results and we are able to start out working out a new methodological model, and this work to gives us good results, then there is good reason to believe that this system can substitute and complete much of the work and recourses which we are doing in this area today.

4 Future

Feasibility of integrating the products in the working practices:	Evaluation:		
	L	M	H
			x
Comment (please list necessary improvements without which the products will not be used): There will be possible to integrate the product with products and systems and make an efficient integrated system out of it.			

Probability of product integration in working practices (if necessary improvements made)	Evaluation:		
	L	M	H
		x	
Comment: Very good			

Approximate threshold price of operational product/service (including necessary improvements) for uptake	X € per …

3

f

Comment: (We are not able to comment on this)

Desired improvements of product:	Evaluation:		
	L	M	H
Comment: See other comments.			

Additional comments
If we can be able to estimate traffic flows over wide areas and perhaps be able to classify the traffic flows over wide areas, this is very promising for the future. NPRA is at the moment working with a new model for collecting and estimate traffic data and we hope that the output of this project can be integrated in the new model. NPRA will therefore try to help the project with resources (money) and in helping establishing test-sites with adequate equipment.

Overall evaluation	Evaluation:		
	L	M	H
			x
Comment: If the further development gives us good results, the future is promising. We will need to think of development of organisations, system development and customers needs to be able to make a good product.			

4

Appendix C: User Assessment sheet from TØI

ASSESSMENT SHEET TEMPLATE - DUE INNOVATOR

1 A posteriori assessment of the requirements

Adequacy of the product specification requirements (including accuracy requirements) specified before projects start	Evaluation*:		
	L	M	H
			x
Comment: Our assessment follows from comments in the next boxes.			

* L: Low M: Medium H: High

2 Products conformance with requirements

Product completeness versus the User Requirements	Evaluation:		
	L	M	H
		x	
Comment: The product is not yet ready for practical application. The possibilities have been shown and the relevance for users has been demonstrated.			

Confidence in estimated product accuracy:	Evaluation:		
	L	M	H
		x	

f

Comment: Also current methods of traffic counts could be more accurate. There are therefore no exact results to compare with. The validation shows that the results are within an acceptable interval compared with other methods.

Product accuracy versus the User Requirements	Evaluation:		
	L	M	H
		x	
Comment: Compared to current methods and practice the method provides acceptable accuracy for many applications. The accuracy can be improved by further developments. Further developments of the product may in some cases be found more dependable than other methods.			

3 Utility assessment

Benefits or cost-savings from demonstrated products/service versus current practices:	Evaluation:		
	L	M	H
			x
Comment: The evaluation (H) is based on expectations for further development of the method. There are certain applications where the method will give data/information which it is difficult or expensive to obtain by other survey methods.			

Impact of products/service	Evaluation:		
	L	M	H
	x		

2

f

Comment:
The product cannot at the current state replace the traditional methods for counting traffic. With further developments it will not only be a supplement, but in certain cases it can replace current methods or even provide better approaches to users' needs.

4 Future

Feasibility of integrating the products in the working practices:	Evaluation:		
	L	M	H
			x
Comment (please list necessary improvements without which the products will not be used): - The accuracy should be improved			

Probability of product integration in working practices (if necessary improvements made)	Evaluation:		
	L	M	H
		x	
Comment: - As it seems at this stage the method may serve as useful supplement to current methods - Users need information about the possibilities - Ideas for further applications may follow from experience - The development provides possibilities which should be studied further (for example the use in sparsely populated areas)			

Approximate threshold price of operational product/service (including necessary improvements) for uptake	X € per …

3

f

Comment:
(We are not able to comment on this)

Desired improvements of product:	Evaluation:		
	L	M	H
			x

Comment:

- Accuracy
- Research to adjust the method to improve performance both in urban and rural areas

Additional comments
Further research and development should be initiated as a continuation of this project. It should be decided what is the best organisation of the necessary follow-up.

Overall evaluation	Evaluation:		
	L	M	H
			x

Comment:
The project documents new possibilities for traffic counts and has been shown to have the potential for valuable practical use.

4