SINTEF REPORT

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TITLE

SPOT/UTOPIA experience

- a review of Norwegian based installations and simulations

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ABSTRACT

In Norway the Public Road Administration has always been focusing on priority for public transport. Therefore the Norwegian authorities have been interested in trying new methods for improving the travel time for buses and trams in the major cities.

After a study tour to Gothenburg, the city of Oslo showed interest in the Italian SPOT/UTOPIA concept. Peek Traffic, as a representative for Mizar, introduced in 1995 a SPOT/UTOPIA test areas at Grünerløkka together with the City of Oslo, Road and Transport Authority. Good results there have been the basis for further utilization.

SINTEF Roads and Transport has been a participant in the SPOT/UTOPIA installations and simulations in Norway since 1996. This report summarises the experiences SINTEF has done since the first involvement. The report is a part of a development project called SPOT Nordic where Peek Traffic engaged SINTEF supported by the Norwegian SkatteFUNN scheme.

Totally 3 installations are evaluated and 10 simulations cases are reviewed in this report. All the evaluations showed positive results for SPOT/UTOPIA. A typical payback time for the installations is less then 6 months.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Transport	Transport
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SELECTED BY AUTHOR	Priority	Prioritet

PREFACE

Traffic responsive signal systems can, compared to fixed signalling, achieve better traffic flow and at the same time give special priority to selected groups. In Norway the Public Authority are implementing the Italian SPOT/UTOPIA signal system in several areas. The aim of the installations is to give priority to public transport. Therefore the installations are founded by grants reserved for public transport.

SINTEF has been responsible for evaluations of the SPOT/UTOPIA system in several Scandinavian cities. As a support to the installation SINTEF has simulated the traffic flow under different priority schemes for public transport. This gives the Public Road Authority an opportunity to be certain on the effects of the set-up they implement.

PEEK Traffic is currently in the process of improving the SPOT algorithms as one step in an ongoing development of the system. The progress in PC technology gives possibilities that did not exist some years ago. New functions and schemes can now be implemented. This is an advantage with a distributed compared to a central system.

SINTEF has been assisting PEEK Traffic by testing the new SPOT algorithm compared to the older version. The work has been financed through the Norwegian SkatteFUNN scheme. This report summarises the work done by PEEK Traffic and SINTEF within the area of adaptive signalling.

The report is written by senior researcher Ørjan Tveit at SINTEF Civil and Environmental Engineering, Department for Roads and Transport. Ørjan Tveit has also been the project manager.

Trondheim, December 2003

Tore Knudsen

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SINTEF has been responsible for evaluations of the SPOT/UTOPIA system in several Scandinavian cities. As a support to the installation SINTEF has simulated the traffic flow under different priority schemes for public transport.

This report offers a summary of the results from the SPOT/UTOPIA cases SINTEF has undertaken.

Summary of installations

SINTEF has been involved in three on-street travel time studies. In the installations we have seen different schemes been tested. It is clearly that the most successful installations have been focusing on priority for public transport in a grid area.

City	Comparison of different signalling schemes with original signalling	Changes in travel time		Change in waiting time for pedestrians	Survey year
		Public transport	Private traffic		
Oslo, Grünerløkka	SPOT/UTOPIA with priority of public transport	-15 %	-15 %	-30 %	1998
Bergen, Christies gt	SPOT/UTOPIA without priority of public transport	-	-5 %	-10 %	1998
Trondheim Ila	SPOT/UTOPIA with priority of public transport	-10 %	-10 %	-	1999

Summary of results from on-street travel time studies

SPOT/UTOPIA has been installed and partially tested in several countries. In Norway the tests from on-street surveys are dated a few years back. This influences the results compared to the results from the simulations. Resent developments in the SPOT algorithms have improved the performance of the adaptive system.

An on-street survey has been planed for some years at Majorstua. However, it has been delayed due to ongoing construction work in the area. This survey will give a valuable evaluation of both the resent software improvements as well as validate the simulation work.

Summary of simulations

The simulations have been a valuable tool for the installations in Norway. In the first projects SPOT/UTOPIA seemed like a black box technology. After working with SPOT/UTOPIA through both simulations and installations it is easier to understand both the advantages and disadvantages for the adaptive model.

Positive expectations have grown into practical visualization of how to utilize the system. The results speak for it self with regard to a comparison to fixed time systems. SPOT/UTOPIA has proven to give better traffic flow for all investigated cases.

Another lesson learned is that public transport needs special attentions and a good detection system if this group is to achieve better results than private traffic. Normally both private traffic and public transport are sharing the same lanes. Therefore it is difficult to give advantages to public transport and not to private traffic.

City	Comparison of different signalling schemes with original signalling	Changes in travel time - morning rush		Changes in travel time - afternoon rush	
		Public transport	Private traffic	Public transport	Private traffic
Bergen Christies gt	SPOT/UTOPIA without priority of public transport		-4 %		
Tampere, Finland	SPOT/UTOPIA without priority of public transport		-9 %		
Trondheim Ila	SPOT/UTOPIA with aggressive priority of public transport	-34 %	-10 %	-32 %	-17 %
Trondheim Ila	SPOT/UTOPIA with priority of public transport	-40 %	-20 %	-40 %	-25 %
Oslo Majorstua	SPOT/UTOPIA with 10 % increase in traffic	-37 %	-21 %	-28 %	-11 %
Bergen Bystasjonen	SPOT/UTOPIA with priority of public transport	-31 %	-29 %	-26 %	-27 %
Chicago, USA	SPOT/UTOPIA with priority of public transport	-13 %	-15 %	-15 %	-3 %
Chicago, USA	SPOT/UTOPIA with revised priority of public transport	-22 %	-14 %		
Oslo Kvadraturen	SPOT/UTOPIA with priority of public transport	-33 %	-36 %	-21 %	-20 %
Oslo Fredriks gt	SPOT/UTOPIA with priority of public transport	- 63 %	- 36 %	- 50 %	- 35 %

Summary of results from simulations

Sensitivity studies

The *on-street cases* contain a sensitivity aspect when we divide the traffic flow into sub groups for 10 minutes intervals. The sensitivity testing is done by assessing the regression lines for fixed time signals and SPOT. In the cases at Grünerløkka, Oslo and Ila, Trondheim the regression lines for both signalling schemes are parallel. This shows that SPOT is able to maintain the improved traffic flow at all levels of traffic flow.

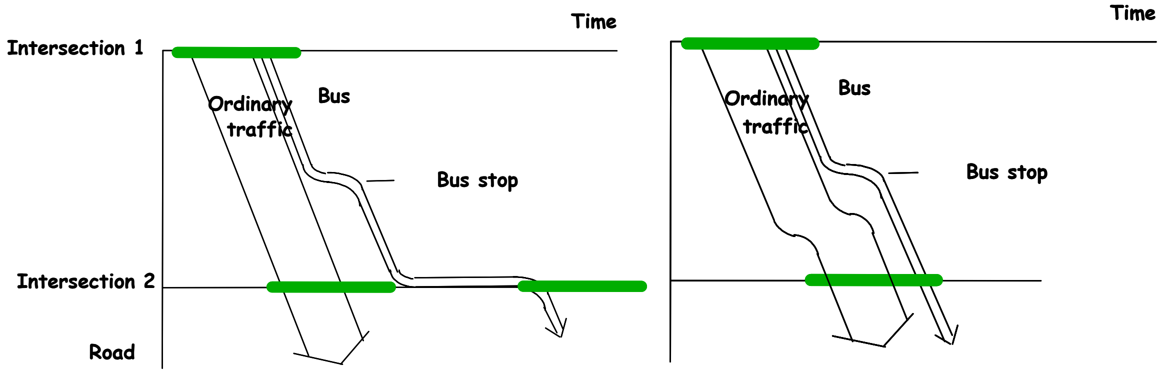
In the *simulation cases* sensitivity studies have been added at two different levels.

- Firstly the arriving traffic is adjusted according to a normal traffic profile. The average traffic flow is based on both manually and automatic traffic counts. The counts are normally valid for the whole rush period. If the simulation time covers one hour of traffic, the traffic profile may be implemented by firstly one period with 85 % traffic demand, secondly by one period with 110 % traffic and finally by one period with 100 % demand. Other combinations may also be valid.

- Secondly the average traffic flow has been increased by 10 - 20 % in the simulation cases for Christies gate, Tampere, Majorstua and Busstasjonen. In these cases SPOT has maintained its advantage to the fixed time signals.

Priority of public transport

In Europe there is a tendency to co-ordinate the traffic signals when we are providing priority to public transport. This approach secures that the benefits that are achieved in one intersection are maintained in the next intersection. *The detection system for public transport is the key to a good priority scheme.*



Priority of public transport

We have especially studied the priority and progression for the public transport in the simulation cases. The conclusions are that the detection system must be able to both give priority messages and modify the scheduled arrival time if there is delay. This will ensure that, if possible, the adaptive system gives priority.

Normally we would like a confirmation message once the public transport unit has passed the stop line. This message can shut down the current stage and enable other traffic flows in the intersection to get priority. This confirmation message may also serve as a request massage for a downstream intersection.

SPOT/UTOPIA has proven to give advantages for the public transport in both the simulation cases and in the on-street cases. The studies in Oslo, Bergen and Trondheim are very favourable. *If we use the Payback method to evaluate the economic effects of the installations, we normally get a payback time of less then 6 months.* Therefore these types of installations are highly recommended in Norway.

The status for SPOT/UTOPIA in Norway for 2004/2005 is expected to be:

- Trondheim – Totality of 44 SPOT intersections (10 new)
- Oslo – Totality of 80 SPOT intersections (32 new)

SPOT/UTOPIA will continue to be an important tool in priority of public transport for Oslo and Trondheim. We now have the knowledge to utilize the technique further in other Norwegian installations.

Further work

Still there are possibilities for improvements in the SPOT/UTOPIA concept. The progress in computer technologies gives possibilities that were excluded some years ago. New functions and schemes can now be implemented. This work embraces both old schemes, that previous hardware could not support, as well as new initiatives. A distributed system is normally limited by the local computing power. As the possible computing power increase the potential benefits from the system will also increase. This is an advantage with a distributed compared to a central system. A centrally based system is mainly limited by communication capacity.

In Norway the simulation work is accepted as a scheme to obtain the expected results from SPOT/UTOPIA installations. The simulations give valuable information on how to setup the system. One of key element that simulations can demonstrate is the differences in the signalling schemes between an adaptive system and a fixed time system. This is demonstrated in the cases for Trondheim and Chicago. Another key element in the evaluation process is the possible priority for public transport. The aims for priority may be high, but the actual results will always be linked with the characteristics of the detection system. The simulations can therefore demonstrate the differences obtained with various technical levels for the detection system.

Simulations of SPOT/UTOPIA areas will continue to be a valuable tool for both new and existing installations. The system has proven its assets and should be deployed further.

1 Background

1.1 Introduction

SPOT/UTOPIA is a traffic signal control strategy developed by Mizar Automazione in Turin, Italy. After the systems initial introduction in Sweden, Peek Traffic achieved the licence to sell SPOT/UTOPIA outside Italy. (The licence is primarily for Scandinavia, Netherlands, USA, and Eastern Europe.)

As part of the licence agreement, PEEK Traffic has been financing some development of SPOT/UTOPIA. The focus has mainly been hardware oriented, but also some software development has been undertaken.

PEEK Traffic is currently in the process of improving the SPOT algorithms. This project is called SPOTNordic and it consists of hardware adaptation, software development and testing of resulting changes.

The progress in computer technology gives possibilities that were excluded some years ago. New functions and schemes can now be implemented. This work embraces both old schemes, that previous hardware could not support, as well as new initiatives. A distributed system is normally limited by the local computing power. As the possible computing power increase will also the potential benefits from the system increase. This is an advantage with a distributed compared to a central system. A centrally based system is mainly limited by communication capacity.

1.2 Goal

SINTEF Road and Transport has been a participant in the Norwegian SPOT/UTOPIA installations since 1996, and we have been responsible for evaluations of the SPOT/UTOPIA system in several Scandinavian cities. As a support to installations, SINTEF has simulated the traffic flow under different priority schemes for the public transport. SINTEF has recently been assisting PEEK Traffic by testing the new SPOT algorithm compared to the older version.

The cooperation has showed that the lessons learned through the different assessments, should be made available for both existing as well as potentially users. This report summarises the joint work done by PEEK Traffic and SINTEF within the area of adaptive signalling. The report is a part of a development project called SPOT Nordic where Peek Traffic engaged SINTEF supported by the Norwegian SkatteFUNN scheme.

Most of the cases are only briefly presented to give the reader an overview of the work done. One on-street test (Grünerløkka, chapter 4.1.1) as well as one simulation case (Chicago, chapter 5.3.6) is presented in more depth. In depth documentation for the other cases exist only in Norwegian.

This report is divided in the following chapters:

- *Background*. This chapter
- *SPOT/UTOPIA layout*. A brief description of the adaptive system.
- *Methodology*. A description of the different methods that are used in the investigation of the effects.
- *Review of installations.* Presentations of three on-street installations were the effects are described. The Grünerløkka case is covered more in depth.
  - Grünerløkka, Oslo
  - Christies gate, Bergen
  - Ila, Trondheim
- *Review of simulations*. Presentation of computer simulations where the effects are described. The Chicago case is covered in more depth.
  - Christies gate, Bergen
  - Tampere, Finland
  - Ila, Trondheim
  - Bystasjonen, Bergen
  - Chicago Avenue
  - Kvadraturen, Oslo
  - Fredriks gate, Oslo
  - Kvadraturen, Oslo
- *Summary*. Conclusions and recommendations from the installations and simulations.

The aim of this report is to provide the readers with enough confidence in the system to evaluate if SPOT/UTOPIA is worth implementing in their city without taking the detour through small local test cases.

2 SPOT/UTOPIA layout

2.1 Introduction

SPOT/UTOPIA is a traffic signal control strategy developed by Mizar Automazione in Turin, Italy. It was first installed in intersections in Turin. SPOT/UTOPIA is now installed in several cities in Italy and also in the Netherlands, Poland, USA, Norway, Sweden, Finland and Denmark. Some of the installations are to be regarded as test areas.

The idea with SPOT/UTOPIA is to do calculations of the signal settings in real time in order to minimise the total socio economic cost of the traffic system. The main costs are vehicle delays and vehicle stops. In order to give priority to buses and trams higher costs are given to these vehicles.

SPOT/UTOPIA does in principal the same adjustments (changes green time distribution and offset in real time) as older adaptive systems. but it differs in some important aspects. The main differences are that the intelligence is decentralised, that SPOT/UTOPIA can make bigger changes during a short time and that SPOT/UTOPIA is originally designed for public transport priority. The most prominent of the older adaptive systems are the British SCOOT and the Australian SCATS systems. The French PRODYN system is more similar to SPOT/UTOPIA, but has not been used outside France. The German MOTION system has some similarities to SPOT/UTOPIA, but it is not based on a mathematical optimisation.

SPOT/UTOPIA requires detectors at the beginning of each link counting vehicles in each lane. SPOT/UTOPIA is a special program that operates on a separate CPU connected to the traffic signal controller by a special interface. The CPU can be on a single card or be in a complete industrial PC. The Spot units in each intersection exchange information with neighbours, with the automatic vehicle location system for public transport and also with a software at a central level.

The SPOT/UTOPIA concept distinguishes three layers;
- A central computer named UTOPIA, primary used for supervising and monitoring
- Industrial computers, SPOT units, that are integrated in the traffic controllers and takes care of the local optimisation.
- Traffic controllers that execute the signalling strategy.

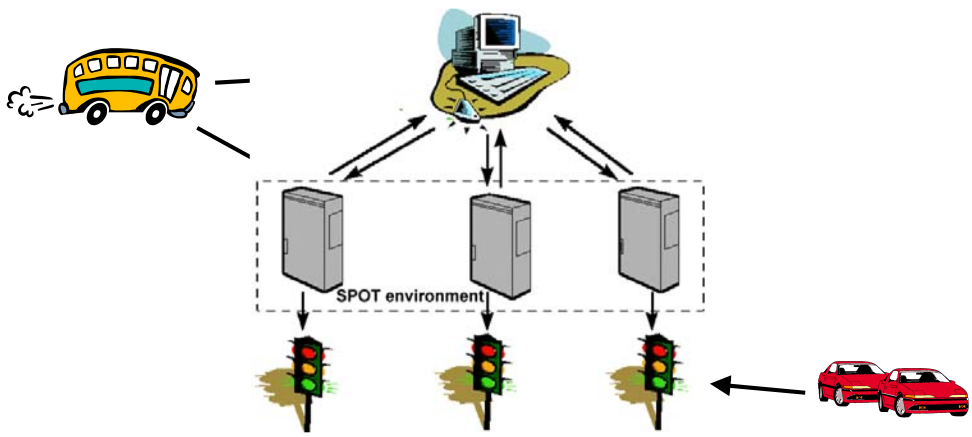


Figure 2-1 Layout of SPOT/UTOPIA concept

Figure 2-1 shows the three layers in the SPOT/UTOPIA concept. Unlike most other UTC-systems SPOT/UTOPIA focus on the traffic that are actually approaching each intersection. The SPOT units utilise loops in the road's surface or video counts to adjust the signalling strategy for the next two minutes. Also push buttons may be used to detect waiting road-user or pedestrians. The signalling strategy, based on vehicular traffic, public transport and pedestrian traffic, is adjusted every 3 seconds.

Furthermore, the SPOT units exchange forecast information with their neighbours about signalling strategy and expected platoons. The SPOT units will thereby make a signalling strategy that should fit the whole area.

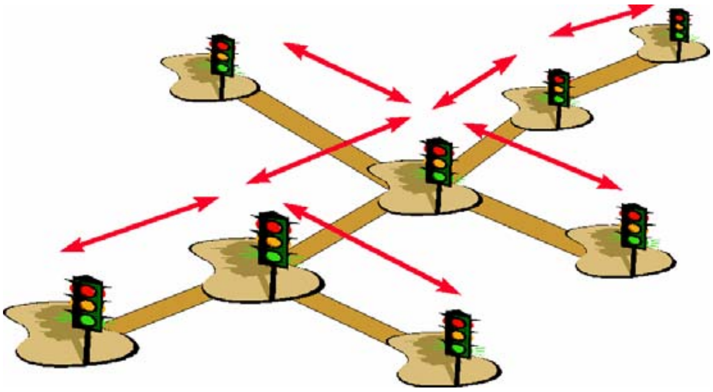


Figure 2-2 Exchanging of information

Figure 2-2 shows the internal network in the SPOT/UTOPIA concept. Each unit is communicating with its immediate neighbours. This makes a total network based on local units.

2.2 A more detailed theoretical description

The SPOT/UTOPIA system aims to minimise the total time lost by private vehicles during their trips, subject to the constraint that public vehicles (for which weighted priority has been requested) shall not be stopped at signalised intersections.

Decomposition is done following a topological rule: a sub-problem is defined for each intersection in the controlled network. Then a robust feedback control for the intersection and consistent rules for the interaction between intersections are created. In order to guarantee stability and robustness at the network level, interactions can be defined with an upper level or a reference time plan.

A local control operates for each traffic light intersection or zone (a zone consisting of several connected junctions) interacting with the neighbour local controls and the area level. The intersection is regarded as a discrete dynamic system where time is subdivided into three-second steps and the topology is modelled by the junction model described below. At the intersection level, the road network is represented by a set of controlled junctions and carriageways, a carriageway being an oriented stretch of road between two junctions.

The elementary component of the model is the "link": the link is a logical entity defined by grouping the carriageway turns which have the same favourable traffic light stages and which allow traffic movements with the same conflicts at the junction. Each link belongs to a carriageway and a carriageway can generate several links according to the possible carriageway turns, the signal setting and the junction traffic regulation.

For each quantity or parameter relating to the carriageway a corresponding quantity or parameter is defined for the link together with the correspondence rule. As a result, the junction model used by the local control consists essentially of links corresponding to the incoming carriageways. The elements involved in the model are:

- Allowed turns
- Saturation flows (per turn)
- Private traffic travel time (per link)
- Private traffic crossing time (per turn)
- Link capacity
- Carriageway/link correspondence rules
- Connection to the adjacent controlled junctions

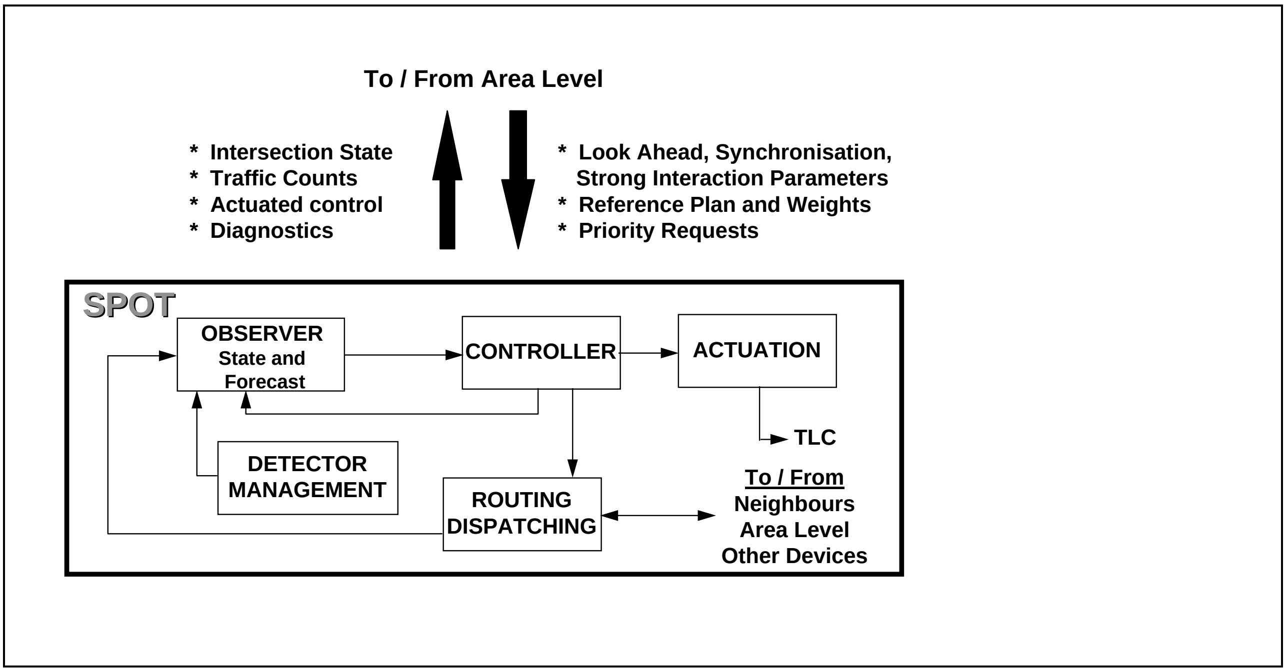


Figure 2-3 Area level provide timings and weights

Figure 2-3 shows the modules of the SPOT program. The modules are run once every 3 seconds. This limits the possible alternatives the unit can consider.

The local control consists of two main interacting modules: the "intersection state observer" and the "intersection control" (hereafter referred to as respectively as "observer" and "controller"). The observer updates the best estimate of the intersection state based on all the available data: traffic counts and signal group status. The intersection state elements are vehicles to be served for every incoming link, grouped by three-second steps. In this intersection state definition public transport vehicles are considered in the same way as private vehicles.

Forecasts of arrivals of public transport vehicles to be prioritised are managed directly by the controller. At the end of each traffic light cycle (here defined as a sequence of stages and not as a

fixed time) a balance is made of all incoming links together, with the aim of checking the state estimation performed and, if necessary, updating the final state, and improving the estimation of the intersection parameter (turning percentages, saturation flows, sources and sinks).
The controller determines the signal settings to be applied to the traffic lights. The start and stop orders are given for each signal group, including pedestrian signal groups. It operates by optimising a suitable function adapted to the current intersection traffic situation. Optimisation is done on a time horizon for the next 120 seconds and is repeated every three seconds. The resulting optimal signal settings are actually in operation only for three seconds. The closed loop control thus obtained can be viewed as an "Open Loop Feedback Control" or as an application of a "Rolling Horizon” concept.

In order to guarantee the optimisation and the robustness of the control at the network level, the functional (i.e. the cost function) optimised by the controller has been designed by adopting the "strong interaction" concept: the functional takes into account the state of the neighbouring intersections, thus keeping a closed loop capability of building a dynamic signal co-ordination, and is constrained by limits given by the area level control (while remaining sensitive to traffic dependent criteria).

The cost elements are:
1. Time lost by vehicles on the incoming links.
2. Stops on the incoming links. Stops are defined as vehicles that arrive at the stop line when queues are present.
3. Excess queuing on the incoming links (this term takes into account queues exceeding safety thresholds which are proportional to the maximum capacity of the links).
4. Time lost on the outgoing links by vehicles leaving the intersection. (These terms actuate the "strong interaction" principle at the intersection level. They provide for intersection control co-ordination and control stability at the area level).
5. Time lost by public transport vehicles to be prioritised at the intersection.
6. Deviation from the reference plan provided by the central level (this element actuates "strong interaction" with the area level and allows the degree of interaction between the two levels to be dynamically changed).
7. Deviation from the signal setting decided at the previous iteration (this element contributes to the smoothness of the area control).

Cost elements 1, 2, 3 and 5 are normally used in Norway. We have less experience with the other cost elements.

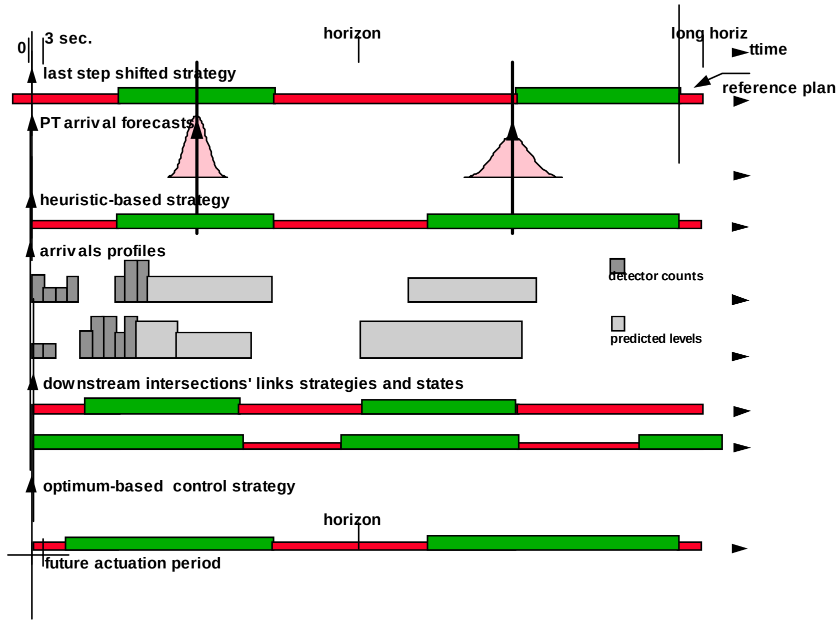


Figure 2-4 Buses and trams are often given weights >200 vehicles

Figure 2-4 shows the decision basis for the signalling in one SPOT unit. For each approach of the intersection, SPOT receives information about the arrival of possible public transport units, the arrival of private traffic and the planed signal status of downstream links.

If used, the algorithm tries to adapt the control strategy to the reference plan. The control strategy decided at the previous iteration is shifted on the horizon according to the elapsed time from the previous computation (normally 3 seconds). The algorithm treats the public transport vehicles in the horizon. The control strategy thus obtained is then adapted to create a green window covering the predicted arrival times. A heuristic method is applied which minimises the time lost for the public transport vehicles.

The last step is an analytical optimisation; a branch and bound algorithm modifies the heuristic strategy on the first part of the horizon (the "closed loop horizon") minimising the functional incremented by a "look ahead" cost. This added term assigns a cost to the modifications that may occur in the strategy already defined in the second part of the horizon (the "open loop horizon") in order to join the closed loop strategy and comply with all the constraints. Moreover it takes account of the intersection state (queues) left at the end of the closed loop horizon.

The closed loop horizon is normally thirty to fifty seconds and is defined to be as long as possible according to the complexity of the intersection problem. In any case it is long enough to contain the arrivals predicted on the basis of the actual traffic counts. In order to introduce further stability in the global control scheme, local controls operate following a priority order decided at the area level.

2.3 New SPOT algorithm

As a part of the development in the SPOT Nordic project, a new SPOT algorithm is developed. The new algorithm has two important improvements compared to the original SPOT algorithm:

- SPOT Nordic takes account of the traffic state the rolling horizon leaves after the closed loop period with regards to both queues and arriving traffic. The difference in the arriving traffic is that SPOT used an average flow while SPOT Nordic use the actual platoon information. This leads to a better fit for upcoming traffic.

- SPOT Nordic enables an SPOT intersection to decide to which upstream intersection it should adapt its the signalling. This makes the basis for ensuring green waves.

A fully description of the algorithms can be found in the upcoming PhD report by Gunnar Arveland. The new algorithm is however already the new official SPOT algorithm from Mizar (SPOT version 8.2.4 and newer).

3 Methodology

We have used two different methods to evaluate the cases depending on the nature of the case. In on-street tests we have deployed a registration crew that have monitored the traffic flow under different regulations. In simulation test we are fortunate to obtain all the information needed from computers.

3.1 Methods for evaluation of on-street tests

In the cases we have evaluated in Norway, we have been focusing on three different sets of parameters for comparison. These are

- Travel time for public transport
- Travel time for private traffic
- Waiting time for pedestrians

We have used different techniques to evaluate the findings. The techniques are described in the following subchapters.

3.1.1 Public transport

The overall frequency of the buses and trams are not influenced by the local fluctuations in the traffic flow. Therefore the main interest for the public transport is to reduce the travel time for each unit.

The travel time for public transport is registered manually by personnel travelling by the buses or trams. They register the passing times for intersections as well as arrivals and departures from bus stops. By registrations both before and after the changes in the signalling, this method gives a direct comparison of how the new systems perform.

3.1.2 Private cars

When we introduce an improved traffic flow in an area, drivers have a tendency to choose routes that utilize that area. The area attracts more traffic. To evaluate how the new traffic regulation is compared to the original traffic regulation, we must compare the travel times at equal traffic work. (Total number of km travelled in one period).

In the Norwegian cases we have used a technique promoted by TRL (Holroyd & Owens, 1971). This method is based on a series of observations with different traffic work. By making a regression plot of the observations we get a relationship between travel time and traffic work in an area. It is also possible to estimate the confidence interval of the regression line.

The technique states the regression line describing the relationship between travel time and traffic work of the new regulation should be compared to the regression line based on the original regulation.

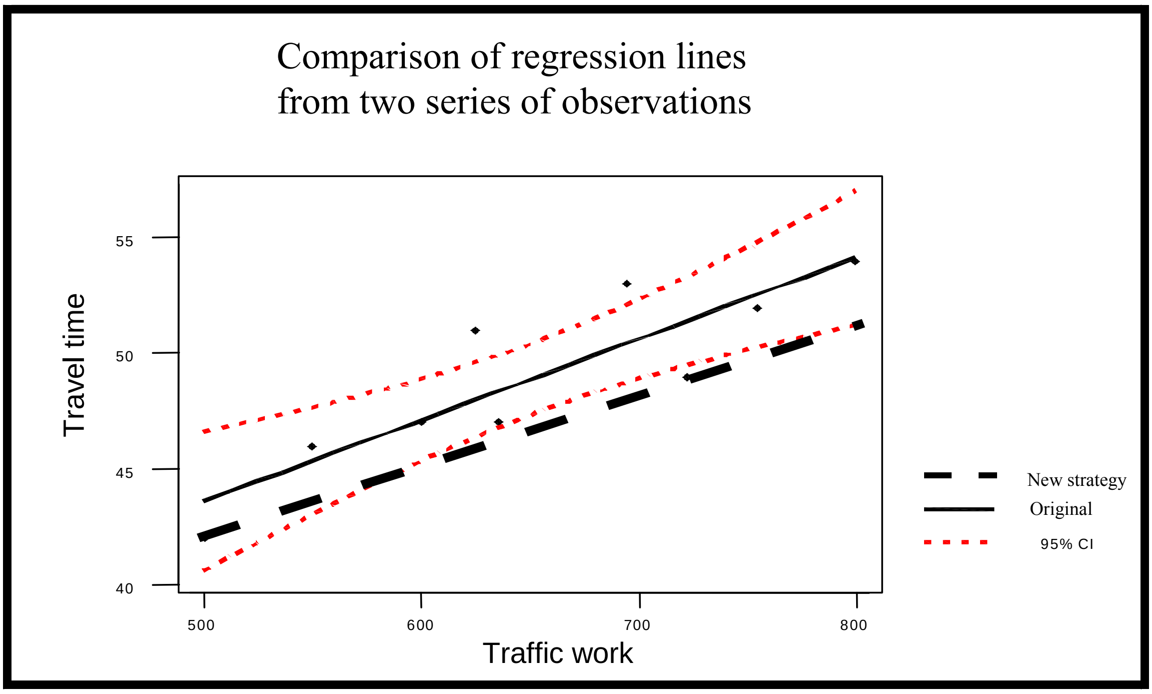


Figure 3-1 Method for comparing different traffic schemes

Figure 3-1 shows that the new strategy gives an improved traffic flow compared to the original strategy. The confidence interval shows the probable variation for the original regulation. The difference between the lines describes the improvements. In parts of the interval we also can state that the new strategy in this theoretical example is better than the old strategy at a 95 % confidence level.

3.1.3 Pedestrians and cycle time

In the SPOT/UTOPIA concept the average cycle time tends to be lower than in the normal fixed time system. This is partially true due to fact that SPOT/UTOPIA has a different average cycle time for each intersection.

This means that the pedestrians at an average must wait less time before they receive green signal. The lower average waiting time is however not a fixed reduction that each pedestrian experience. SPOT/UTOPIA adjusts the green time to the arriving traffic from each direction.

Although the UTOPIA system can promote a certain common cycle time, the SPOT units as we use them in Norway have no concept of a cycle time. The different adjustments for each direction add up to a resulting cycle time without any specific restrictions. If the pedestrians have a push bottom, they can compete with the arriving cars for priority. Otherwise the pedestrian waiting time is a result of the platoons in arriving traffic.

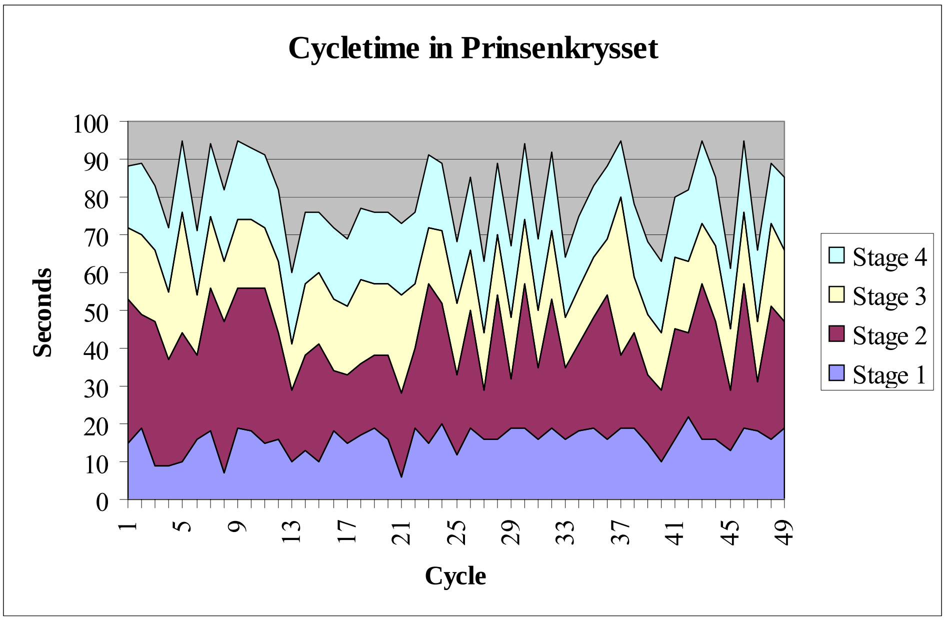


Figure 3-2 Variation in cycle time

Figure 3-2 shows the variation in cycle time we obtain with SPOT regulation. The green time for each stage is based on the traffic flow. Fixed time signalling utilized a cycle time of 100 seconds in Prinsenkrysset. The reduction in waiting time for each cycle can be read directly in the figure.

In the on-street cases we have assessed the waiting time for the pedestrians based on the average cycle time for each intersection. This means that we believe that the arrival times for the pedestrians at the intersections are random.

3.2 Methods for evaluation of simulations

In the simulation cases we can control the occurring traffic at each inbound lane. Both the arrivals of private and public transport can be repeated identically several times to obtain similar traffic situations. The changes in the traffic flow can therefore fully be related to the adjustments in the regulation.

The results for simulation are based upon directly comparison of results for public transport, private transport and pedestrians within similar settings. The settings are then changed and the simulations repeated to make the basis valid for all normally occurring traffic situations. The average changes are reported as the results of the simulation.

For simulations the result extraction is not the only challenge. Another important task is to make the model reflect the actual network and traffic situation.

4 Review of installations

The basis for the Norwegian installations in Oslo and Trondheim are an aim to assist the public transport. Adaptive signal control is used to improve the progression for buses and trams. There is a common understanding about the problems we are confronting when public transport is sharing lanes with private traffic. This necessarily leads to improved progression for the private traffic along the corridor for public transport.

However, since the new signalling is mainly financed by found for public transport, there is demand for avoiding a distortion of competition between private and public transport. Therefore the traffic engineers are not always requested to take the additional benefit for private traffic to the maximum.

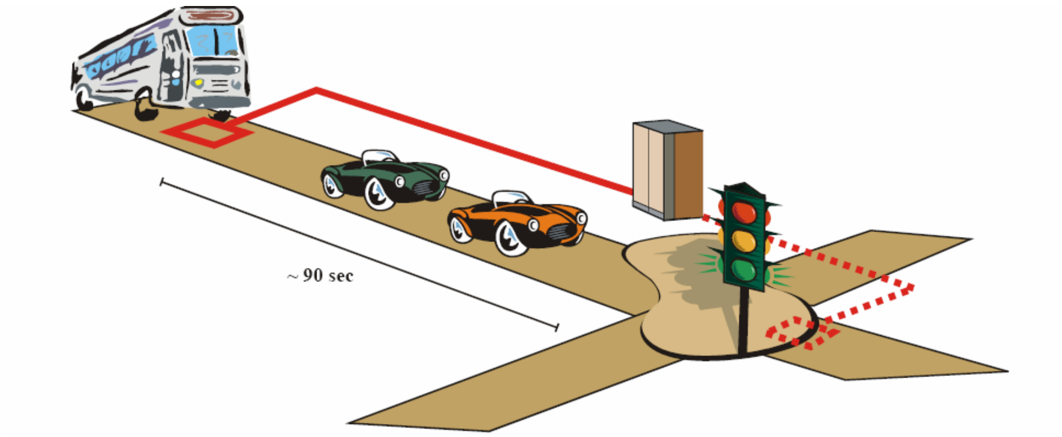


Figure 4-1 Priority of public transport

Figure 4-1 focus on an important aspect of priority. Since the bus and the private traffic are using the same lane, the cars must drive before the bus can pass the stop line. Reduction in delay for public transport will also give advantages for private traffic in the same direction.

4.1 Study cases

There are three study cases based upon on-street surveys.

- Grünerløkka (1998)
- Christies gate (1998)
- Ila (1999)

The studies show results for an early SPOT/UTOPIA version. Resent changes are not implemented in these studies. An on-street survey has been planed for some years at Majorstua. However, it has been delayed due to ongoing construction work in the area. This survey will give a valuable evaluation of both the resent software improvements as well as validate the simulation work described in chapter 5.3.4.

4.1.1 Grünerløkka, Oslo

The Norwegian utilization of SPOT/UTOPIA started at Grünerløkka in Oslo in 1996. Firstly there were four intersections equipped with SPOT. These intersections are marked with a red circle in figure 2-4.

The area was not controlled by a UTOPIA central. The concept has therefore always been called SPOT in Norway instead of UTOPIA as Mizar is labelling the adaptive system.

Figure 4-2 SPOT area at Grünerløkka

The results from the first test were positive. The system gave good progression for the trams. This test gave the initiative for a larger area at Grünerløkka. In 1998 totally 14 intersections was controlled by SPOT.

City	Comparison of SPOT with original signalling	Changes in morning rush - travel time		Changes in afternoon rush - travel time	
		Tram	Private traffic	Tram	Private traffic
Oslo	SPOT with priority of public transport	- 25 %	- 5 %	- 35 %	- 15 %

Table 4-1 Results from first installation with 4 intersections

In the first installation there was only a study of the travel time in the main road. The study can therefore not conclude that the total travel time in the area was reduced.

In the autumn of 1998 there was a larger travel time study for the whole area. The study was organised with two registration intervals.

- Morning rush 0700 – 0900
- Afternoon rush 1500 – 1700

The public transport was monitored by onboard registration crew that observed the passing time for stop lines in intersections as well as the time for arrival and leaving at bus stops. In the study we monitored 6 traffic directions travelled by bus or trams.

The private traffic was monitored by floating car studies. Equipped cars were travelling along 6 different routes to observe the travelling time in the network. Passing of stop lines were recorded. Both the partial and total travel time were analysed.

Since the floating car studies monitored the main roads, we supplemented the study by registrations of queue lengths and delay estimation on four important minor roads. These registrations did not give any results that indicated that SPOT favoured the main road on the expense for the minor roads. In contrary, at all the additional sites both the queue length and delay was reduced.

The study was undertaken once for fixed time signals and once for SPOT in the autumn of 1998.

- Fixed time signals week 38 / 1998
- SPOT week 46 / 1998

Thereby we had one registration period for each signalling technique.

Traffic volumes were recorded automatically by UTOPIA. In the adaptive signalling concept there are detectors for each lane. These data were recorded each 3 seconds. The cycle time for each intersection were also recorded by UTOPIA.

Travel time for public transport was evaluated by directly comparing the travel times under fixed time signals and with SPOT.

The volumes and travel time studies made the basis for comparing the relationship between total travel time and traffic work (distance travelled) for sub periods of 10 minutes. The registrations were used as a basis for evaluating the resulting traffic flow for private traffic under different regulations.

Pedestrians must in principle wait until next time they receive green signal. With shorter cycle time we also experience shorter waiting time. The changes for the pedestrians were based on the changes in cycle time.

In this documentation we have used the term fixed time signals. This is not entirely true for Grünerløkka. Some of the intersections had green modification of signals to give priority to public transport. This did however not affect the cycle time or reduce the waiting time for the pedestrians. The extra green time for a bus lane was taken directly from the next stage.

The results from the test shows overall good results, but not at the same level as in the first test. We now had conflicting bus routes as well as trams crossing the bus routes. This gives situations where one of the public vehicles must yield.

SPOT offers a better capacity. In the morning rush, the fixed time system had a minor breakdown. The adaptive system did not have the same problems. At the time of the breakdown, SPOT offered a 50 % reduction in travel time for private traffic.

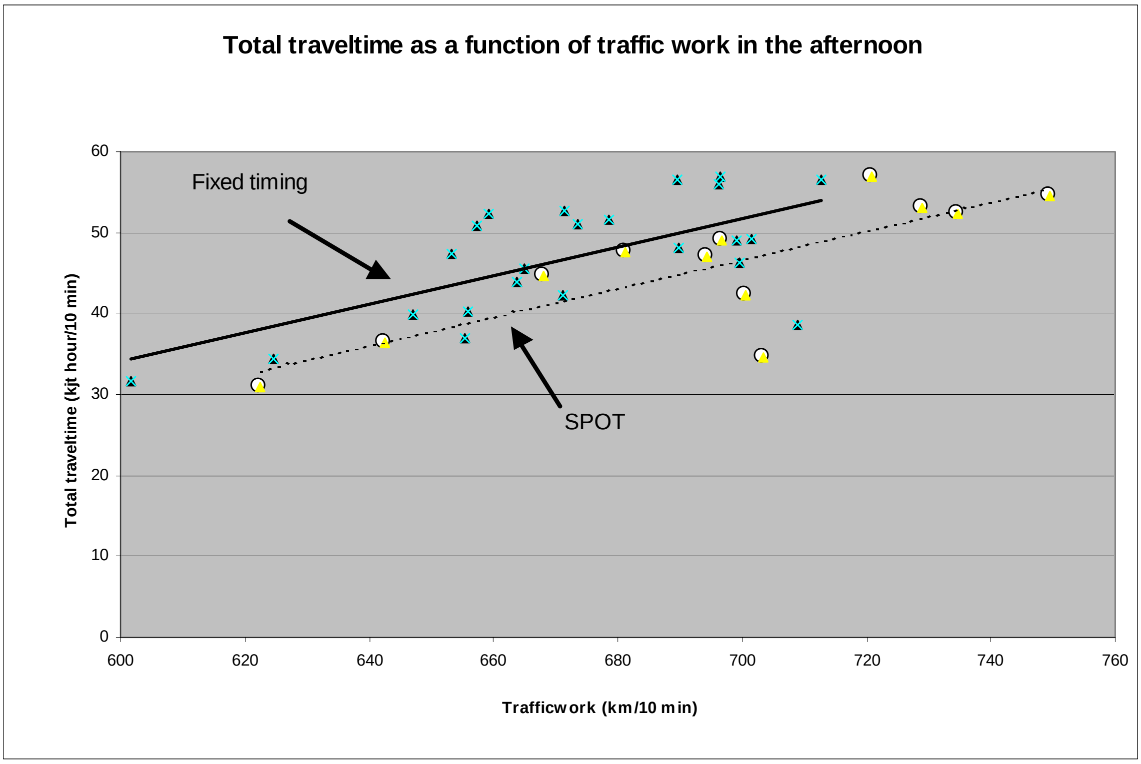


Figure 4-2 Improvement in travel time at Grünerløkka

Figure 4-2 shows that SPOT performs better than the fixed time system at all periods of the afternoon rush. SPOT improved the travel time for private traffic by 15 %. The results are not statistical significant at an appropriate level. This is linked with the possible resources used in the survey. With more registrations we could have obtained statistical significant results.

City	Comparison of SPOT/UTOPIA with original signalling	Changes Travel time for public transport	Travel time for private traffic	Waiting time for pedestrian
Oslo	SPOT with priority of public transport	- 15 %	- 15 %	- 30 %

Table 4-3 Changes for the large SPOT area

The changes in travel time made SPOT the Norwegian centre of attention for future priority of public transport. This has lead to a significant expansion of SPOT in Oslo.

4.1.2 Christies gate, Bergen

In Bergen the Public Road Administration wanted to test if SPOT/UTOPIA could perform better than the existing fixed time system. The network that was chosen was mainly a one way road with distinct platoons due to upstream intersections. Priority of public transport was not included in the test. Therefore one of SPOT/UTOPIA greatest assets was not included.

One might say that the intent from the Public Road Administration was that if SPOT/UTOPIA could perform well under such limitations, it would perform well anywhere in Bergen.

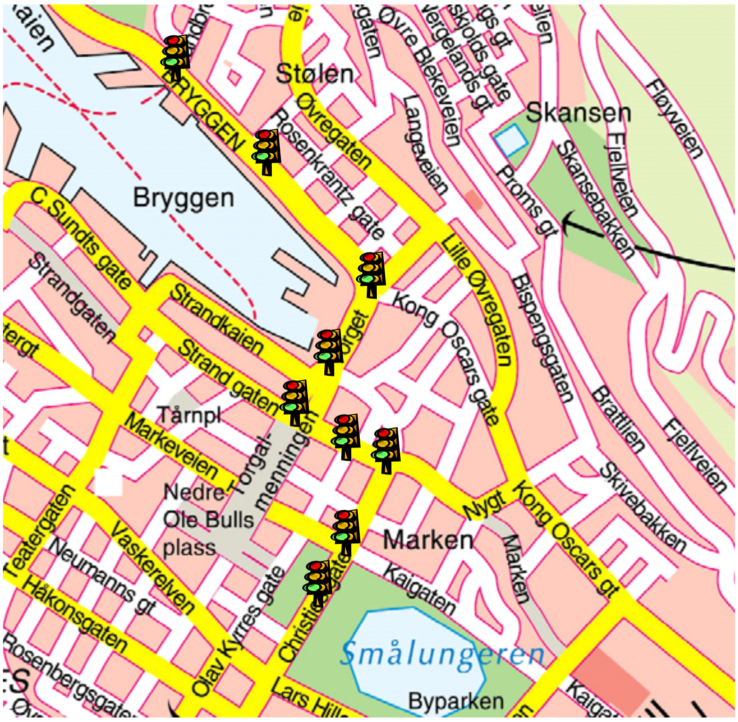


Figure 4-3 SPOT/UTOPIA network in Bergen

Figure 4-3 shows the nine SPOT intersections in the Bergen case. The main traffic flow is from Christies gate (lowest intersection marked in the figure) towards Torget. At Bryggen there is more spacing between the intersections, and the traffic flow is below the capacity limit. The main issue here is coordination.

Unfortunately, we soon encountered problems with the adaptive system. The three intersections in Strandgaten are very narrow spaced. The main traffic flow here is going from Christies gate towards Torget. There is nearly no queue magazines. If the intersections are coordinated they can function very well. Since the intersections are free to choose their own green times for each stage, they can however in some cases choose differently.

And this was exactly what happened in some cycles with heavy traffic flow. We got a extensive queues upstream in Christies gate. The total performance of the network dropped.

Figure 4-4 First test in Bergen

Figure 4-4 shows that the initial test in Bergen was not according to our expectations. The case had revealed a hidden shortcoming in the concept. To evaluate further what went wrong, we used simulations to study the problems.

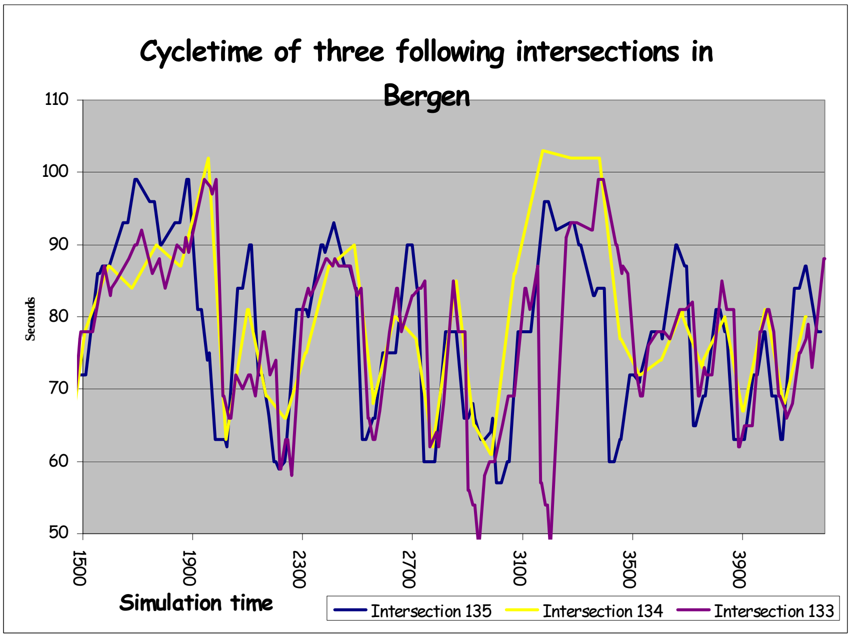


Figure 4-5 Tests in Bergen

The first simulations showed how the narrow intersections mainly changed the green time coherently, but also how they sometimes failed. The solution for the problem was a new SPOT version with possibilities for coordination, or linking, for closely spaced intersections. This solution also was needed for some installations in Italy. The simulations are described further in chapter 5.3.1.

4.1.3 Ila, Trondheim

In Trondheim the Public Road Administration started tests with detection of public transport by using electronic tags. The information about delay and passenger levels was used to give priority to the buses and trams along the inbound corridor from west (Kongens gate).

Evaluations showed that the normal signalling was not able to utilize the information in a coherent manner. This initiated an interest for installing a new signalling system. The aim was to improve the progression for the public transport.

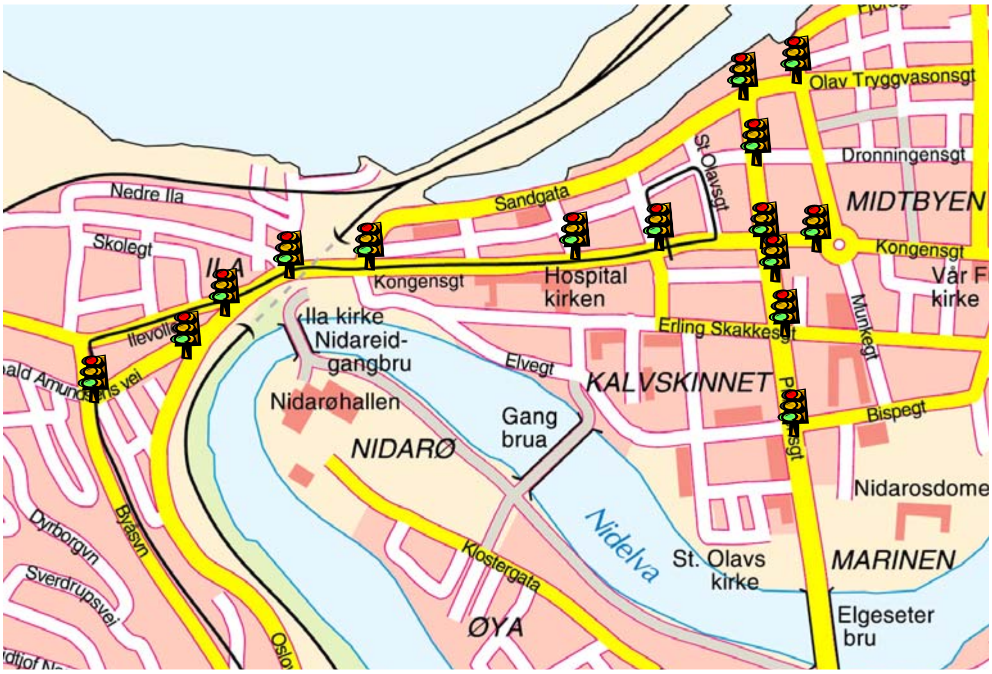


Figure 4-6 First SPOT/UTOPIA area in Trondheim

As figure 4-7 shows there were 15 intersections in the first SPOT/UTOPIA area in Trondheim. The area covered both Kongens gate, were the Public Road Administration used electronic tags, and Prinsens gate which is another major corridor for public transport. In Prinsens gate there were 70-80 buses per hour in the rush hours.

Due to the large numbers of public transport units in both Kongens gate and Prinsesgate, the intersection between them controlled the overall performance in the area. The intersection (Prinsenkrysset) was oversaturated in the rush hours. This limited the possible adjustments to give priority to public transport.

In the first installation the existing stage settings were continued. This created problems in the priority of public transport. Even if we gained time in the upstream intersections, the delay in Prinsenkrysset reduced the overall improvement along the corridor for the public transport.

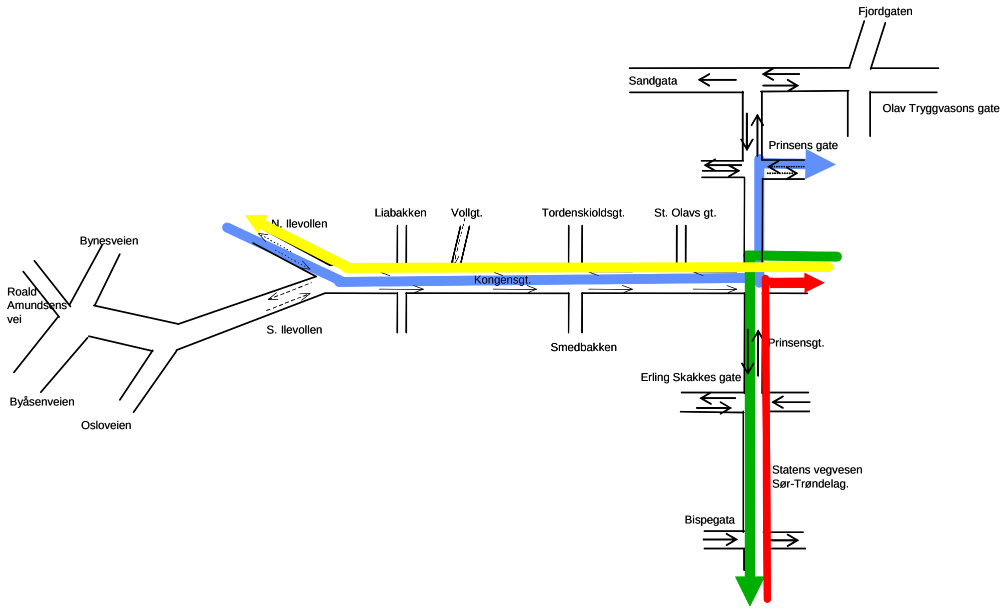


Figure 4-7 Public transport lines in the case area

Figure 4-7 shows how the public transport lines are all sharing the same space in Prinsenskrysset.

City	Comparison of SPOT with original signalling	Changes in morning rush - travel time		Changes in afternoon rush - travel time	
		Public transport	Private traffic	Public transport	Private traffic
Trondheim	SPOT with priority of public transport	- 10 %	- 1 %	- 10 %	- 9 %

Table 4-2 Results from on-street test in Trondheim

The installation of SPOT/UTOPIA gave a positive improvement for the public transport. The travel time in the corridors towards Prinsenkrysset was reduced significantly.

When we analysed the data, we did however believe that it was possible to improve these results substantially. The SPOT installation was based on the stage settings brought forward form the fixed time system. The different signalling schemes may require different settings to perform the best way possible.

This is described further in chapter 5.3.3.

5 Review of simulations

5.1 Simulation set-up

A simulation model is used together with SPOT/UTOPIA to simulate the traffic flow that will occur with SPOT/UTOPIA. Both European and American simulation models are possible to integrate with SPOT/UTOPIA. This is done with HUTSIM, NEMIS, NETSIM and AIMSUN.

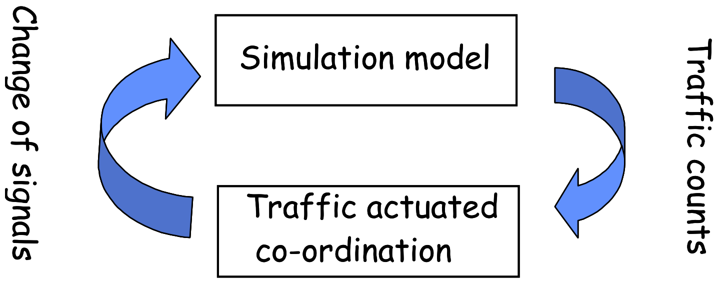


Figure 5-1 Simulations set-up

In the simulation model the vehicles are generated and shipped through the network. When a vehicle is passing a detector a message is generated towards SPOT/UTOPIA. SPOT/UTOPIA is treating the incoming traffic information to set-up the best signal setting according to the present traffic situation. The chosen strategy is shifted back towards the simulation model which is changing its signal according to the SPOT/UTOPIA strategy. This exchange of information between the simulation model and SPOT/UTOPIA is a continuous process with several message interchanges each second.

5.2 Simulation models

When SINTEF started its involvement in SPOT/UTOPIA simulations, HUTSIM was the only commercial simulation model possible to combine with SPOT/UTOPIA. NEMIS is an Italian simulation model that was poorly documented with respect to new users.

After a few cases with HUTSIM, we realised that the simulation model was too limited with respect to possible external intersections. This led to a development towards NETSIM, which at that time was the leading simulation model.

A successful implementation gave a new platform for simulations. This platform gave us the opportunity to study several important cases. Normally the focus was on how to give maximum priority to the public transport. When essential detectors were not present, the studies focused on how a reduced standard on the detection system would impact on the progression for public transport.

Any simulation model will only last as long as the models are being maintained and necessary developments are being done. The FHWA has stopped the development of NETSIM. The model was therefore no longer a reliable model to focus on.

In 2003 two separate simulation models were linked with SPOT/UTOPIA. There were some major differences in the interactions, which lead to a rather easy decision about our future progression.

- Peek Traffic Netherlands established cooperation with TSS, the producer of AIMSUN. This interface was similar to the interfaces that previously were made between respectively HUTSIM and NETSIM towards SPOT/UTOPIA.

- A Swedish initiative towards VISSIM made it possible to utilize this model in simulation of SPOT intersections. However, this initiative used the software for the intersection controller as a media that the traffic counts and signalling changes should be shifted through.

  This leads to an extra link that needs attention. If you are about to study one ore two intersections this approach may be valid. But if you are about to study the interaction of 15 – 20 intersections, this approach is time consuming without added value.

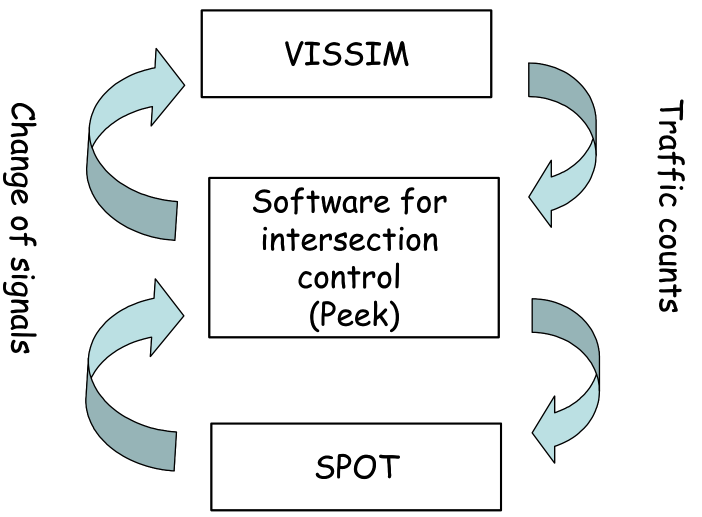


Figure 5-2 Information interchange with VISSIM

Both AIMSUN and VISSIM are regarded to be equally good simulation models. It is the interface that separates the different alternatives. Since we in Norway are mainly focusing on priority of public transport in medium to large network, AIMSUN seemed to be the only natural path.

5.3 Simulation cases

SINTEF has together with Peek Traffic Norway been involved in 10 different simulation evaluations. Use of simulation has been a valuable tool in the pursuit of the best settings for SPOT/UTOPIA. In the first simulation cases we were focusing on interactions between close spaced intersections. Later the focus has shifted towards how we can assist the public transport.

The different simulation cases are listed below. They are sorted by time and simulation model. The simulations in Bergen and Chicago have so far only been elucidations of possible installations, while the other cases have given valuable answers to real installations.

HUTSIM (1997 – 1998)
- Christies gate, Bergen
- Tampere

NETSIM (1999 – 2002)
- Ila, Trondheim (two laps)
- Majorstua, Oslo
- Bystasjonen, Bergen
- Chicago Avenue, Chicago
- Kvadraturen, Oslo

AIMSUN (2003 →)
- Fredriks gate, Oslo
- Kvadraturen, Oslo

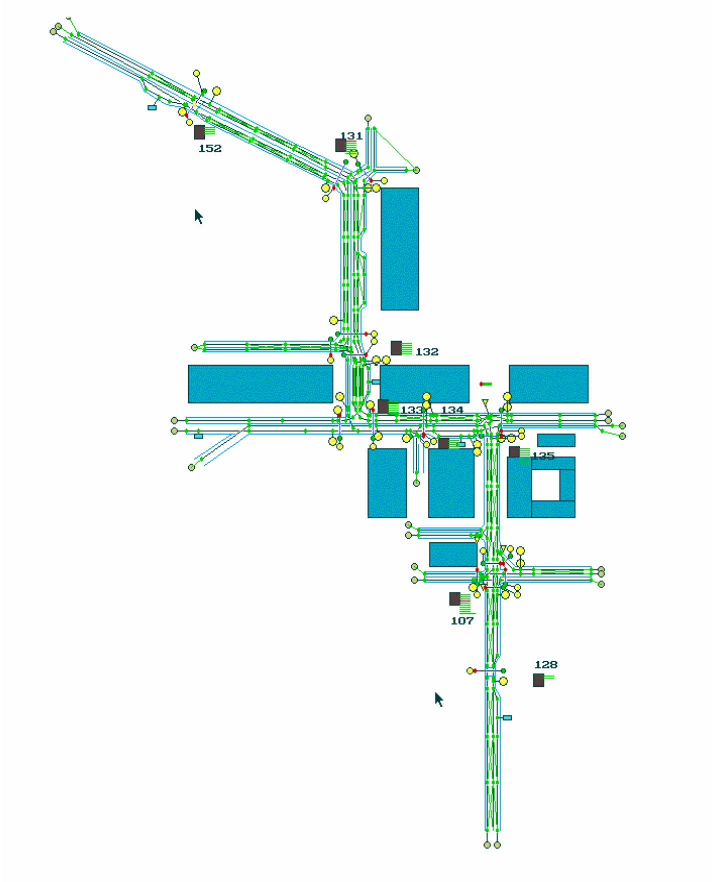
The new algorithms based on the SPOT Nordic project were used in the AIMSUN simulations.

5.3.1 Christies gate, Bergen (HUTSIM)

Background for simulation
After a serial of negative on-street tests in Christies gate in Bergen, there was a need to prove that SPOT/UTOPIA could perform better than the fixed signalling that existed in the area (See chapter 4.1.2).

As a response to the problems with SPOT in Bergen, Mizar developed a new SPOT version. The new version had a cost element that put a cost on stopping a group of vehicles. This was an attempt to link closely spaced intersections together to create a "green wave".

It was not desirable to progress with manual collection of travel time measurements by the floating-car technique. We needed a more cost-effective method. This was solved by using simulation to evaluate different SPOT/UTOPIA settings.



Description of area
From the south there is a primary road that leads into an area with four closely spaced intersections. The distances between the intersections are 50-55 meters.

From the north there is a major traffic flow into the centre of Bergen. Here the traffic is regulated in a four lane arterial. From east here is mainly minor traffic flow, but some platoons may disturb the flow in the main road.

From west there is a link with low capacity that tends to block upstream intersections.

The public transport is present in nearly all the approaches in the area, but the main public traffic is south / north bound.

Figure 5-3 Network in Bergen

Results

City	**Comparison of SPOT/UTOPIA with original signalling**	**Changes in morning rush - normal traffic slow**		**Changes in morning rush - 20 % increased traffic flow**	
		Delay	**Travel time**	**Delay**	**Travel time**
Bergen	SPOT/UTOPIA without priority of public transport	-8 %	-4 %	-20 %	-14 %

Table 5-1 Results from Bergen

By changing to the new SPOT version, we were able to show that SPOT/UTOPIA had a potential for improving the traffic flow in Bergen. This verified that the newer SPOT version was able to cope with the narrow spaced intersections.

However, the previous challenges with the on-street tests resulted in a negative conclusion for the project. SPOT/UTOPIA was consequently not chosen to manage the traffic flow in Christies gate.

5.3.2 Tampere (HUSTIM)

Background for simulation
In Tampere the Public road Authority started an installation with 6 intersections in 1998. They were soon experiencing quite similar problems to what we experienced in Bergen.

The SPOT/UTOPIA expert in Scandinavia was an employee at Peek Traffic Norway. He got the responsibility for mending the signalling in the area. SINTEF got involved in the case in order to verify that SPOT/UTOPIA could give positive results.

The simulations were focusing on the traffic flow without any special considerations for public transport. The simulations in the area were completed in 1998.

Description of area

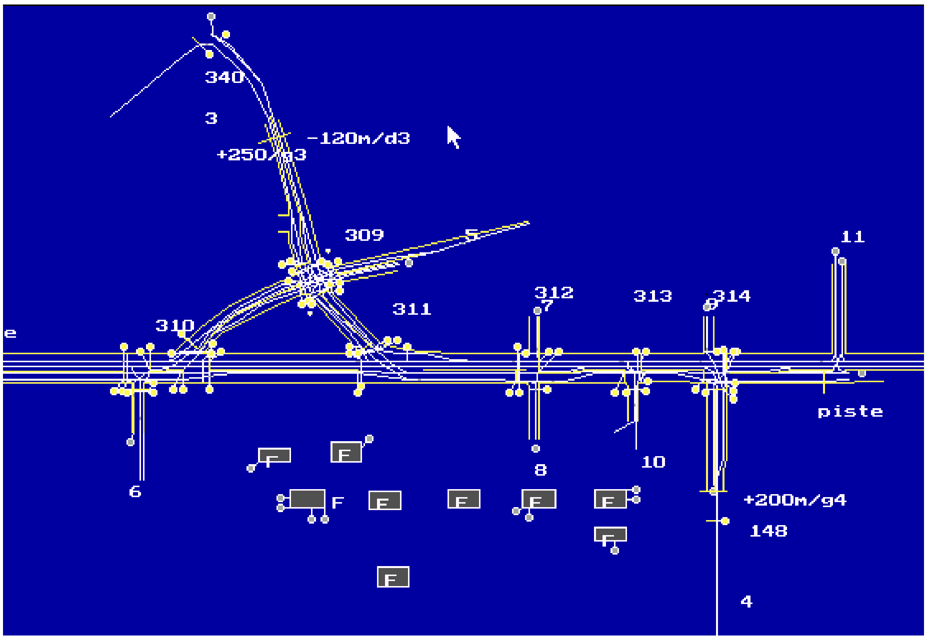


Figure 5-4 HUTSIM network for Tampere

The SPOT/UTOPIA network in Tampere is situated in an area between the motorway system (at the top of Figure 5-4) and the centre of the city (at the right of Figure 5-4). There is high traffic flow in the rush hours, and an amusement park close to the area gives large platoons in some intervals.

As Figure 5-4 shows, intersection 312, 313 and 314 must be working together and make green waves for the main road in order to get a good traffic flow in the area. Also the triangle 309, 310 and 311 must function together.

Results
The simulations were done in Trondheim by SINTEF. The city of Tampere provided the HUTSIM network. There is no specific report from the simulations, they were merely used as an element in the ongoing process to improve the installation. The focus in the case test was to examine if it was possible to get positive results for the area. There were none attempt to analyse if the obtained results were based on the best possible settings.

City	Comparison of SPOT/UTOPIA with original signalling	Changes in morning rush - levels of traffic work		
		Low	Normal	High
Tampere	Travel time	-6 %	-9 %	-16 %
	Delay	-12 %	-16 %	-23 %
	Stops	-14 %	-6 %	-15 %

Table 5-2 Results from Tampere

The simulations showed that the area should give better progression for the traffic when the Public Road Authority used SPOT/UTOPIA. After a new set-up of the system, the settings from simulation study were implemented in the area.

An on-street test verified that SPOT/UTOPIA were favourable. A Finnish study in year 2000 gave an 11,5 % improvement in the overall travel time for the morning rush. There was however some problems in the afternoon rush.

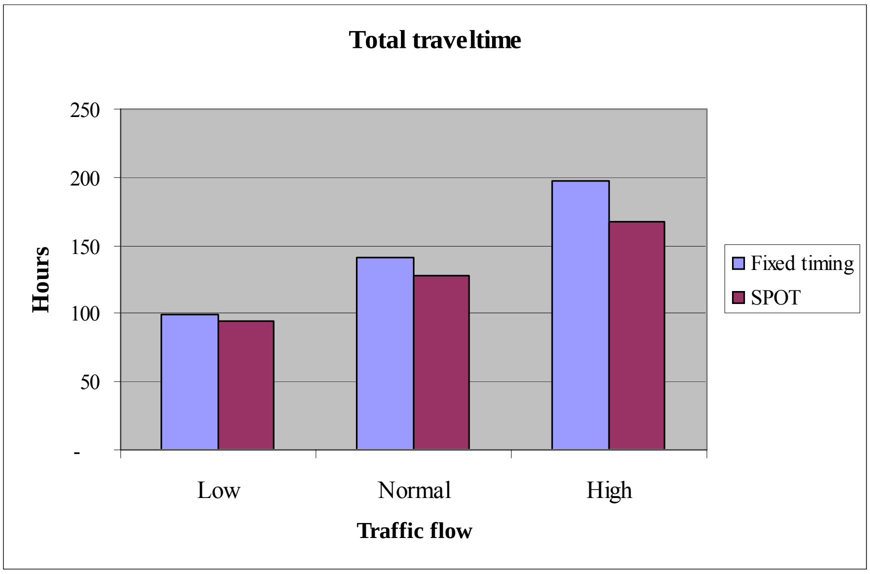


Figure 5-5 Changes in travel time - Tampere

The simulations show that SPOT/UTOPIA offered better conditions with higher traffic flow compared with fixed signalling. This is quite naturally since an adoptive signalling should adjust its green times and thereby its capacity according to the demand.

5.3.3 Ila, Trondheim (NETSIM, two versions)

Background for simulation
The aim of the simulation was to improve the travel time for the public transport in an already implemented area with SPOT/UTOPIA. By introducing more detectors for the buses in the simulation model, we had the opportunity to evaluate the effects before a full installation. We also made some adjustments in the signalling in two of the intersections.

Simulation is a normal procedure before implementing for many types of installations that effect the traffic flow, but so far traffic responsive systems have not normally utilised such possibilities.

Description of area

The simulation area was reduced to the nine inner SPOT/UTOPIA intersections due to limitations in the NETSIM set-up. The focus of the simulations was Prinsenkrysset, marked with a red circle in Figure 5-6.

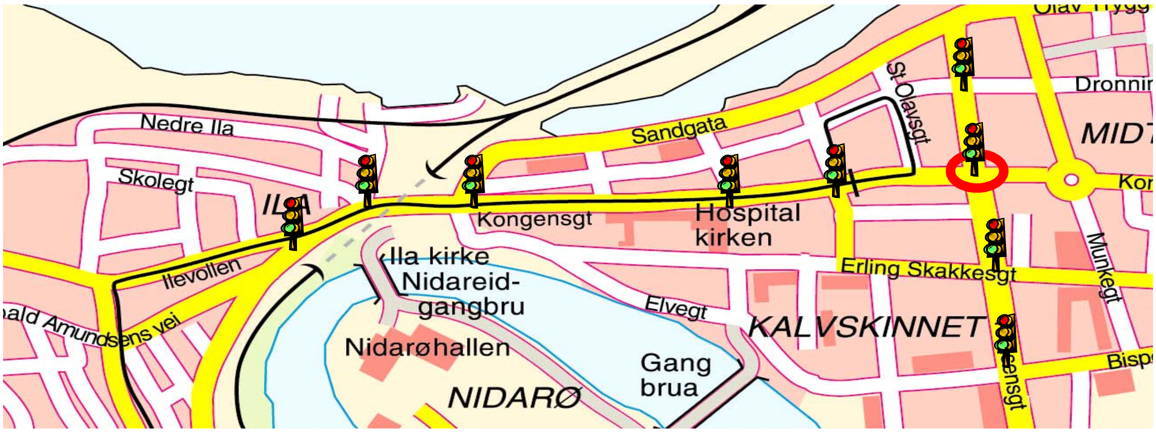


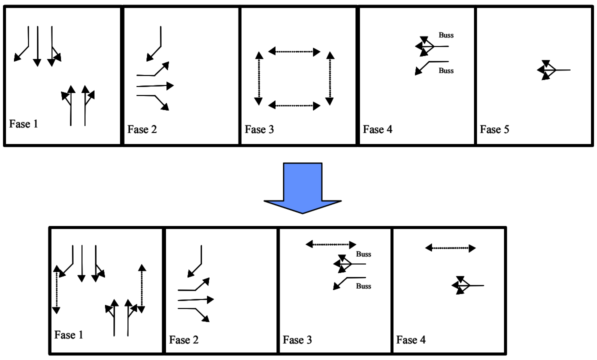
Figure 5-6 Simulation area for the Ila case, Trondheim

Results
The Ila case have been simulated two different times:

- Firstly we used the case in a study of how aggressive priority of public transport would affect the overall traffic flow. The results from this study showed the potential for improvements.

- Secondly we tried a revised stage setting for signalling in Prinsenkrysset. In the simulations we tested four different settings with regard to the signalling in the main intersections. The layouts showed considerable differences in the results. These differences were not easy to predict in advance. The preferred setting allowed for two separate stages for public transport in each cycle.

Alternative 1:



The signalling is changed by removing the pedestrian stage. Some of the pedestrian movements are introduced in other stages.

The overall movement for pedestrians are however maintained by possibilities in adjacent intersections.

Figure 5-7 Changed stage setting in Prinsenkrysset – aggressive priority

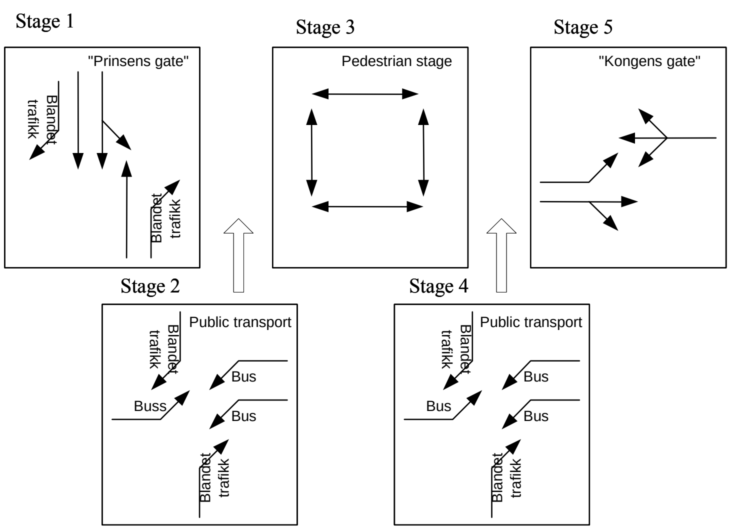
City	Comparison of different signalling schemes with original signalling	Changes in travel time - morning rush		Changes in travel time - afternoon rush	
		Public transport	Private traffic	Public transport	Private traffic
Trondheim	SPOT/UTOPIA with aggressive priority of public transport	-34 %	-10 %	-32 %	-17 %

Table 5-3 Results from Ila – aggressive signalling

The results in Table 5-3 show that it is possible to give the public transport large improvements in the travel time. These results are included the original improvements by SPOT/UTOPIA with reductions in the travel time for both public transport and the other traffic.

The proposed signal plan does however have some drawbacks for the pedestrians. A reviewed signalling scheme is investigated in Alternative 2.

Alternative 2:



The second alternative is not reducing the total number of possible stages. The traffic movements in Kongens gate are however combined into one stage.

This gives the traffic engineer the possibility to introduce two similar stages for public transport. The stages is only activated when there is detection of public transport units.

Figure 5-8 Final signalling plan

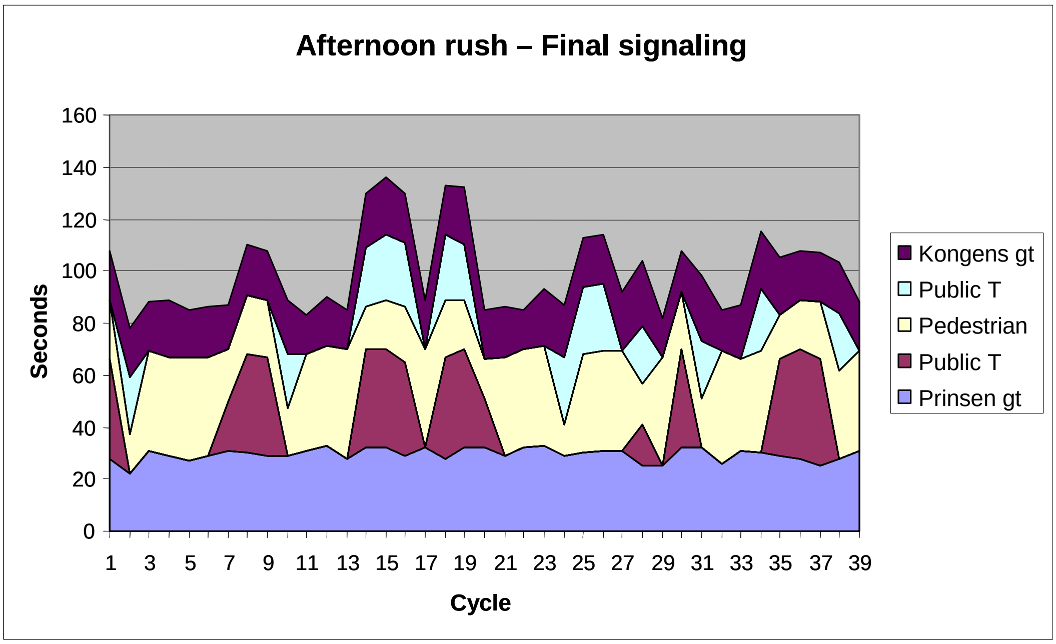


Figure 5-9 Cycle time - Prinsenkrysset

Figure 5-9 shows that the public traffic is not present in all cycles. In some of the cycles the public transport gets two stages.

The stage length for the public transport can be up to 30 seconds. If both possible stages for public transport is in use, both the pedestrian and the private traffic must wait longer than normally in Norway.

City	**Comparison of different signalling schemes with original signalling**	**Changes in travel time - morning rush**		**Changes in travel time - afternoon rush**	
		Public transport	**Private traffic**	**Public transport**	**Private traffic**
Trondheim	SPOT/UTOPIA with priority of public transport	-40 %	-20 %	-40 %	-25 %

Table 5-4 Results from Ila – final signalling

The changes in the signalling are currently implemented in the installation. The SPOT/UTOPIA system is expanded and is now covering nearly all the central area of Trondheim.

5.3.4 Majorstua, Oslo (NETSIM)

Background for simulation
At Majorstua in Oslo the Public Road Authority has installed a new SPOT/UTOPIA area. The aim of this project is to give priority to the public transport. The priority schemes are supported by information from selective loops.

As a support to the installation SINTEF has simulated the traffic flow under different priority schemes for the public transport. This gives the Public Road Authority an opportunity to be certain on the effects of the set-up they implement. A full physical installation is delayed due to construction work in the area.

Description of area
In Oslo there are several ring roads around the centre. The Ring road 2 is an important traffic artery in the system that is crossing the area through Kirkeveien. Six of the SPOT intersections are located at Ring road 2.

The intersections were Kirkeveien are crossed by Bogstadveien and Valkyrie gata are connecting two major traffic streams. In these intersections there are also many crossing public transport lines.

The installation at Majorstua consists of totally 12 SPOT/UTOPIA intersections. In the simulations we have implemented 10 intersections. This is due to restrictions in the simulation setup.

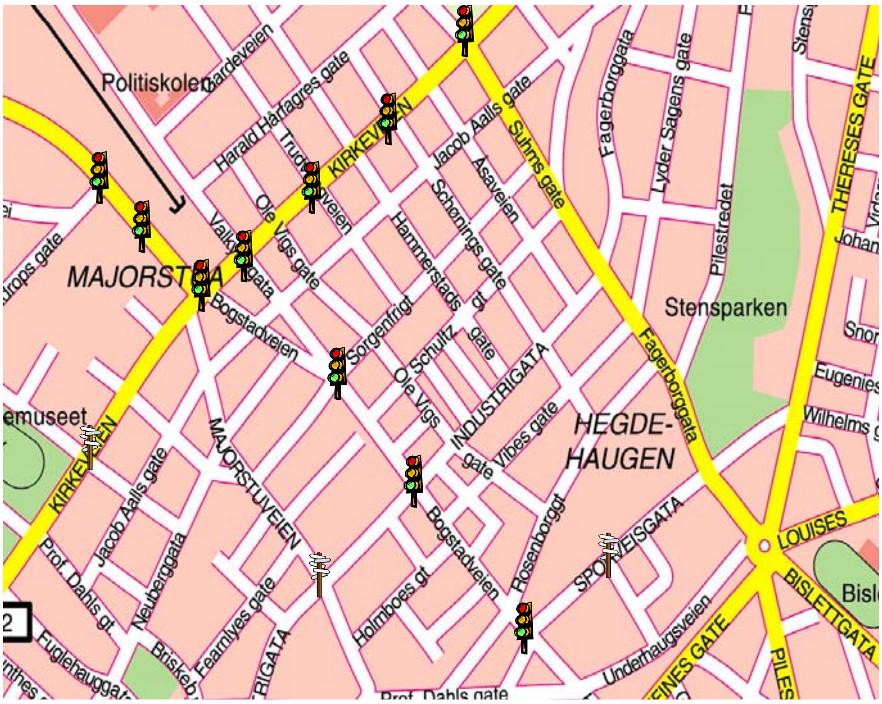


Figure 5-10 SPOT area at Majorstua, Oslo

Figure 5-10 show that the area mainly builds around two crossing arterials.

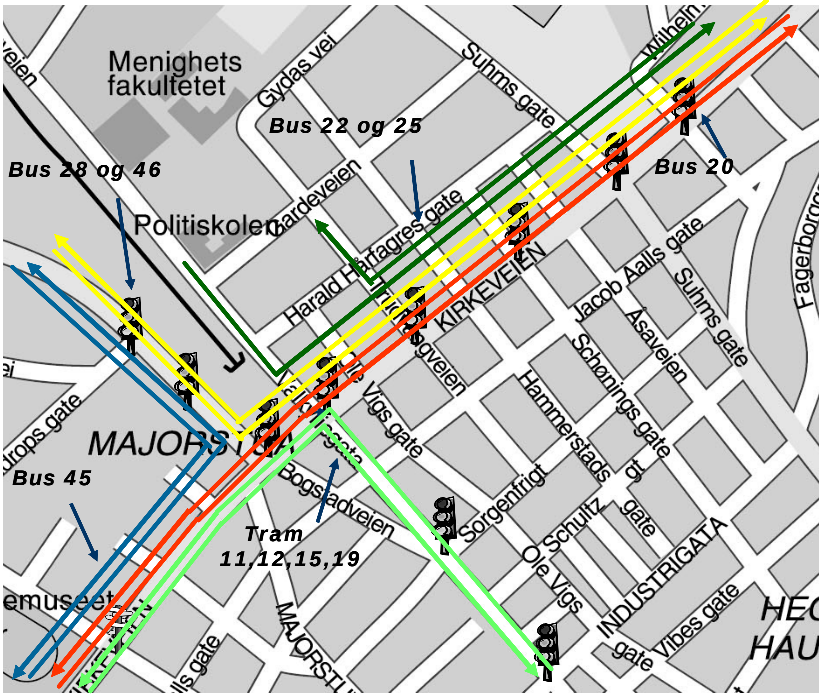


Figure 5-11 Buses and trams at Majorstua

Results

When an adoptive signal control system is introduced in an area, the traffic flow will normally increase. This is also the case in Oslo. We have estimated that the traffic will increase with 10 % after the installation as a basis for the simulations. The simulations also show how different levels of priority to the public transport will impact on the overall traffic flow.

City	Comparison of different signalling schemes with original signalling	Changes in travel time - morning rush		Changes in travel time - afternoon rush	
		Public transport	Other traffic	Public transport	Other traffic
Oslo	SPOT/UTOPIA with 10 % increase in traffic	-37 %	-21 %	-28 %	-11 %
	SPOT/UTPOIA with 10 % increase in traffic and aggressive priority of public transport	-33 %	-36 %	-6 %	14 %

Table 5-5 Changes in travel time for Majorstua

Our recommendation is that the Public Roads Authority deploys a normal SPOT/UTOPIA installation. This is due to the inaccuracy that will occur without possibilities to track the public transport towards the stop line in the intersections. If the public transport unit stops prolonged to pick up passengers and the intersection is holding the green light for the direction of the public transport unit, we may be wasting the capacity in the intersection. This was the case in Oslo. If we had an automatic positioning system for the public transport, the case may have been different.

Never the less, the results of implementing SPOT/UTOPIA are quite substantial.

5.3.5 Bystasjonen, Bergen (NETSIM)

Background for simulation

The Public Road Authority is in the process of evaluating SPOT/UTOPIA in the area around the central bus station in Bergen. The aim of the project is to give priority to the public transport. The priority schemes are supported by information from selective loops.

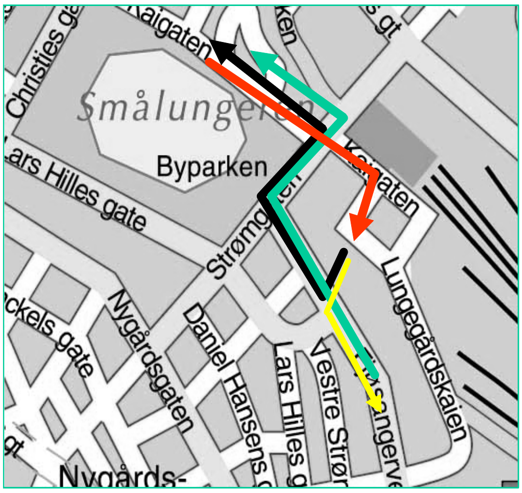
SINTEF was firstly engaged to evaluate how adaptive signal control would affect both the buses as well as the rest of the traffic. As an extension of the project, SINTEF has also reviewed a possible rebuild of the bus station. This takes the buses away form the most congested roads and allows the adaptive system to remove nearly all the queues.

Description of area

The area in Bergen consists of an arterial road towards the centre of the city. The arterial passes the bus station on its way toward the centre. There are several conflicting movements in and out of the bus station. Also the close spaced intersections in Strømgaten are a challenge for the fixed time system.

Figure 5-12 SPOT area in Bergen

Figure 5-12 shows the layout of the SPOT area with totally 10 SPOT intersections. The area consists mainly of crossing one way roads.



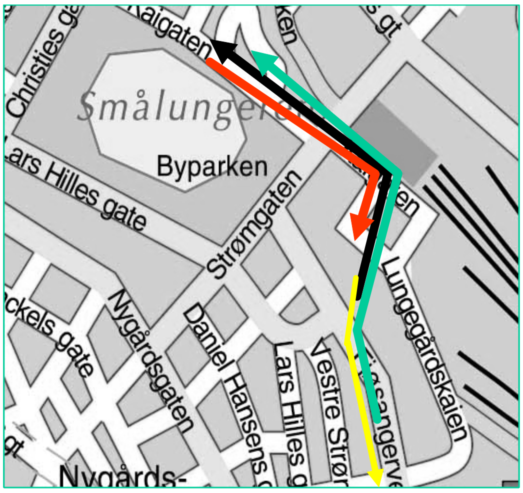


Figure 5-13 Changes in public transport lines

Figure 5-13 shows that by moving the public transport lines to an alternative route, we avoid problems with crossing lines. This gives the possibility give priority to one bus without stopping another. All buses are travelling in the same stage.

Results

Since the public transport is travelling along the same roads as the private traffic, the improvements for the public transport will also benefit the private traffic. When we separate the public transport from the corridors for private traffic, it is easier to give priority to public transport. The improvements for the public transport with respect to private traffic in such settings are easily recognised in Table 5-6

City	Comparison of different signalling schemes with original signalling	Changes in travel time - morning rush		Changes in travel time - afternoon rush	
		Public transport	Private traffic	Public transport	Private traffic
Bergen	SPOT/UTOPIA with priority of public transport	-31 %	-29 %	-26 %	-23 %
	SPOT/UTOPIA with priority of public transport and rebuild of bus station	-40 %	-31 %	-42 %	-27 %

Table 5-6 Changes in travel time in Bergen

A probable payback time for the costs of the project is estimated to be 2 months. A sensitivity study showed that SPOT/UTOPIA more or less could maintain the improvements even with a 10 % increase in the traffic flow.

5.3.6 Chicago Avenue, Chicago (NETSIM)

Background for simulation

SINTEF has together with Peek Traffic Norway been working with a development scheme for SPOT/UTOPIA from a Nordic perspective. The Regional Transit Authority (RTA) in Chicago has through a Transit Signal Priority Simulation Study evaluated operational impacts of TSP in 17 different corridors. In this project RTA has collected data for simulation of the areas.

SINTEF and Peek Traffic Norway were fortunate to get access to the data and used them as basis for a case study of SPOT/UTOPIA. This was a part of the development scheme for SPOT/UTOPIA.

Description of area

12 intersections in Chicago Avenue were selected to test adaptive signalling by the SPOT system. All intersections are located along Chicago Avenue, an important arterial for both private and public transport. This is not a typical SPOT/UTOPIA case, because adaptive systems normally functions best in a grid.

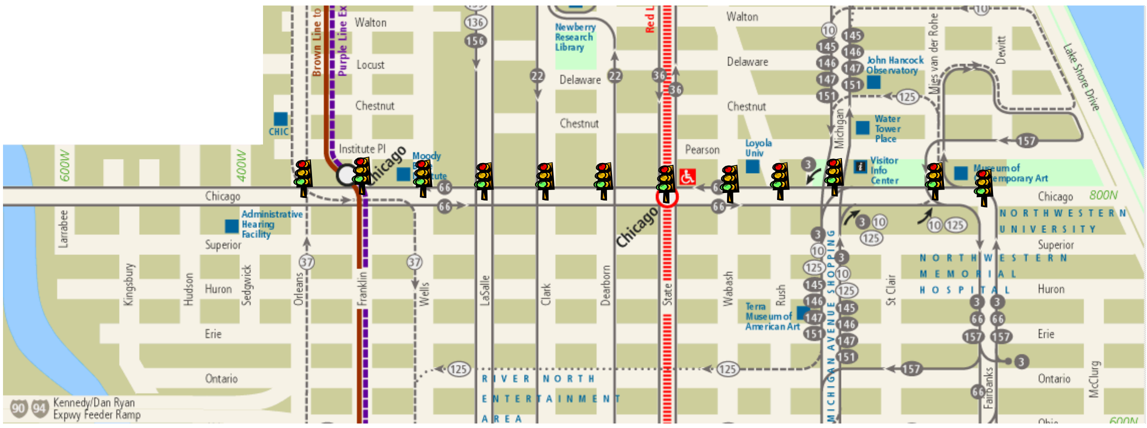


Figure 5-14 SPOT network in Chicago

Figure 5-14 shows the 12 SPOT units used in this test. The intersections in Chicago Avenue are relatively evenly spaced with approximately 110 – 130 meters between them.

SINTEF received all the information regarding the geometry, fixed signalling and traffic demand from the study undertaken by RTA. We also obtained bus schedules in the area. The information included an initial travel time study for the buses along the avenue.

The information was used to build a NETSIM model that represented the area and the traffic flow in a realistic manner. The NETSIM model was the basis for the SPOT implementations. SINTEF only changed the signalling. All the geometric layout and traffic demand were kept.

The avenue is an important corridor for public transport. Therefore, RTA is searching for a signalling scheme to secure a good progression for the public transport. The SPOT simulation functioned as an additional alternative for the new signalling.

Figure 5-15 Bus lines along Chicago Avenue

Figure 5-15 shows that there is heavy bus traffic especially in the inner parts of the avenue. Figure 5-14 shows the bus routes travelling along the corridor.

If SPOT/UTOPIA was to be implemented in the area it would be better to incorporate some of the crossing corridors as well. This is due to the fact that some of the crossing corridors have larger traffic flow than Chicago Avenue.

Results

In the simulations we tried two different approaches. In the morning rush we focused on optimising the traffic flow for all traffic categories. In the afternoon rush we tried to improve traffic flow for public transport without giving advantages to the ordinary traffic.

City	**Comparison of different signalling schemes with original signalling**	**Changes in travel time - morning rush**		**Changes in travel time - afternoon rush**	
		Public transport	**Private traffic**	**Public transport**	**Private traffic**
Chicago	SPOT/UTOPIA with priority of public transport	-13 %	-15 %	-15 %	-3 %

Table 5-7 Changes in travel time – Chicago

Table 5-7 shows that it is possible to give improved traffic conditions to a selected group as long as the detection system are able to distinguish the selected group. The changes in travel time is obtained by directly comparing the total travel time for the public and private transport on links influenced by SPOT.

One limitation in the simulation was however that the rush traffic was way bellow the system capacity for the fixed system. Therefore the possible reduction in the travel time was lower than the results we have experienced in other simulation cases.

Especially in the morning rush the progression for the public transport is bellow what we expected. This is mainly due to the irregularities in the travel time for the public transport when it is approaching the stop line. Sometime the bus stops at the bus stop just before the stop line, and sometimes they pass the bus stop. This make a large window of needed green time to ensure that all buses pass inhibited. Since such a large green time is not possible to combine with optimisation of the traffic flow, only some of the buses get priority.

In an attempt to give higher priority to the public transport we have tried to relocate the bus stops from the near side to the far side of the intersections. We have also reduced the number of bus stops.

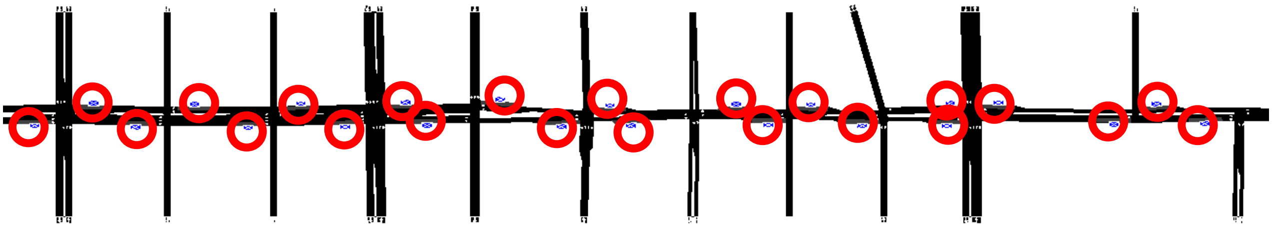


Figure 5-16 Original location of bus stops

Figure 5-16 shows that there is a bus stop at nearly all the intersections. The bus stop is close to the intersection at the upstream side. This means that it is difficult to determine when the bus needs green signal at the stop line.

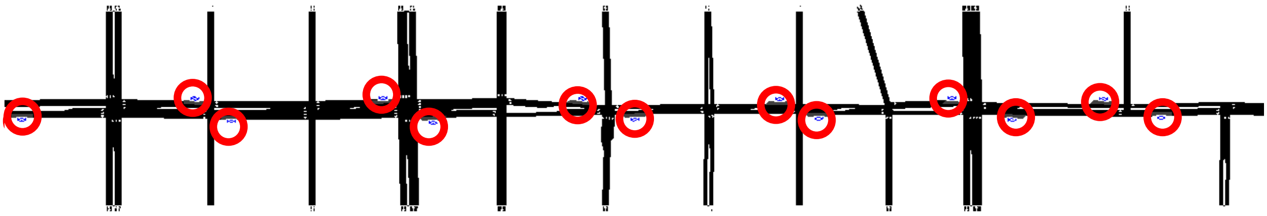


Figure 5-17 Proposed relocations of bus stops

The proposed new setting in figure 5-17 is not well funded in the utilisation of the different bus stops. It is just an example on how one could relocate the bus stops to make a system that is more predictive with regards to the travel time towards the stop lines. The bus stops are now located to the fare side of the intersections. This will give the buses a travel time between the bus stop and stop line. This travel time can be utilized to change the signals if needed.

The proposed system gives no changes when we simulate it with fixed signal timings. In this case it is the signalling and not the bus stops that determine how the progression for the public transport should be.

When we simulate the area with SPOT/UTOPIA settings, we get results more in line with our previous European experiences. The buses were getting priority in a manner that allowed more of the gains canalized toward the public transport.

City	**Comparison of different signalling schemes with original signalling**	**Changes in travel time - morning rush**	
		Public transport	**Private traffic**
Chicago	SPOT/UTOPIA with revised priority of public transport	-22 %	-14 %

Table 5-8 Changes in travel time – Chicago, revised priority

Table 5-8 shows the resulting from the simulations with revised priority. Now the priority scheme are used to give priority instead of waiting for a bus that may and may not arrive on time.

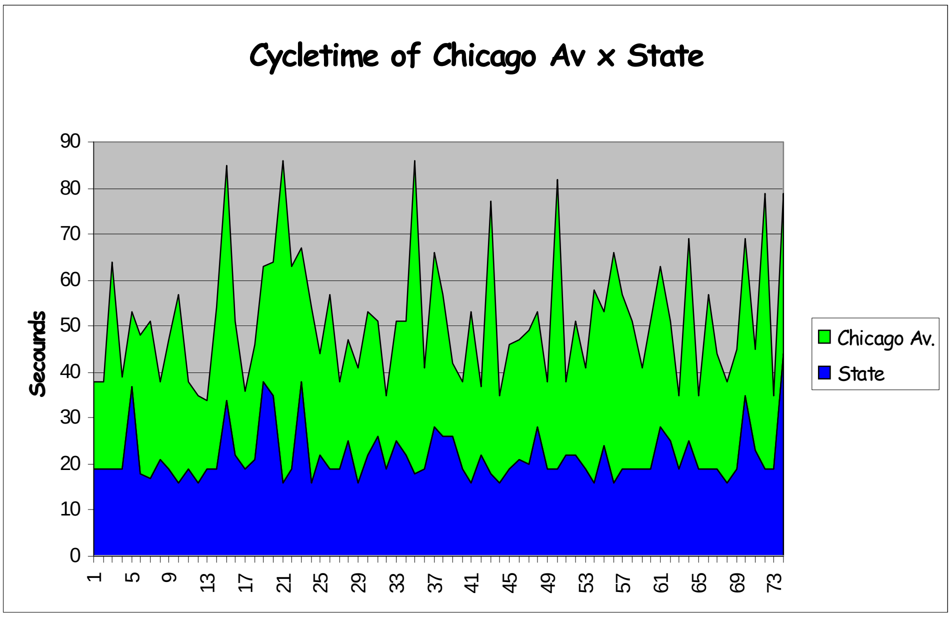


Figure 5-18 Variation in cycle time – case Chicago

Figure 5-18 shows that the cycle time for one of the intersections. At this intersection there is crossing bus routes that may need priority at the same period. The extended stages for Chicago Avenue shows when there were buses needing priority.

The simulations showed further that the average cycle time in the area decreased by 15 %. This gives benefits to the pedestrians.

5.3.7 Kvadraturen, Oslo (NETSIM)

Background for simulation

After a series of positive cases in Oslo, the Public Road Administration and the City of Oslo, Road and Transport Authority have together decided to progress with SPOT/UTOPIA in several other areas as well.

The aim of the installation is to give better priority to the public traffic. The installation is financed by founds for public transport in Oslo. The simulation was done as a preparation before the new signalling was started.

Description of area

Kvadraturen is an area with mixed functions. There are both offices and shopping centres in the area. It is also an area with heavy bus and tram routes along Prinsens gate and Tollbugate. Both buses and trams use the area as a connection between the inner city and the outer arterials. At the same time the public authorities have set the cycle time for the fixed time signalling in the area low to accommodate the pedestrians in the area.

In the simulations we have limited the focus towards Prinsens gate and Tollbugate. This is the important routes for the public transport. The limitation is also based on the possible network size we could implement in our simulation setup.

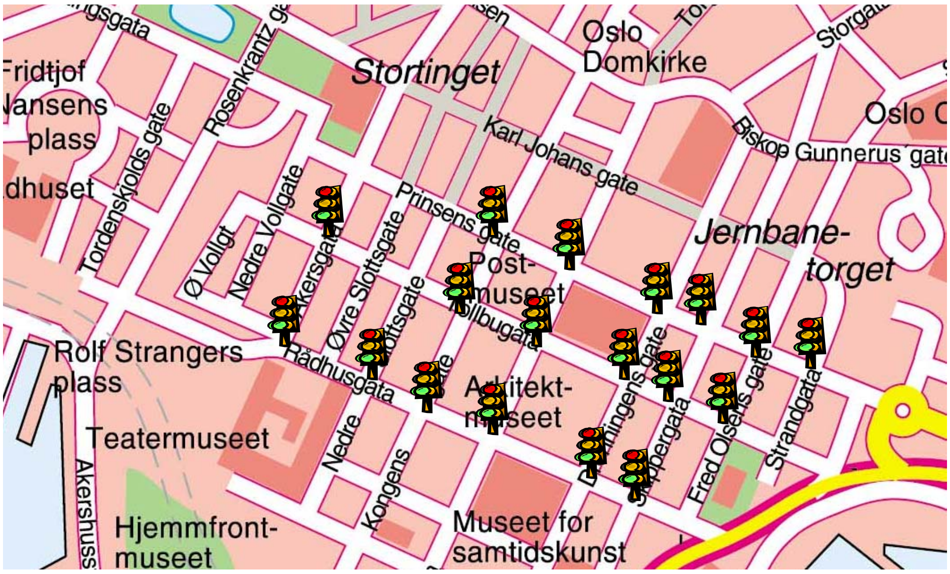


Figure 5-19 SPOT implementation in Kvadraturen

Figure 5-19 shows the implementation of SPOT in Kvadraturen. This case is rather large compared to other Norwegian first time installations.

The public transport travels mainly along the main roads in Kvadraturen. Previously there has been a passive priority of the buses and trams. The fixed time traffic signals have given more green time to the main roads than the traffic actually demanded.

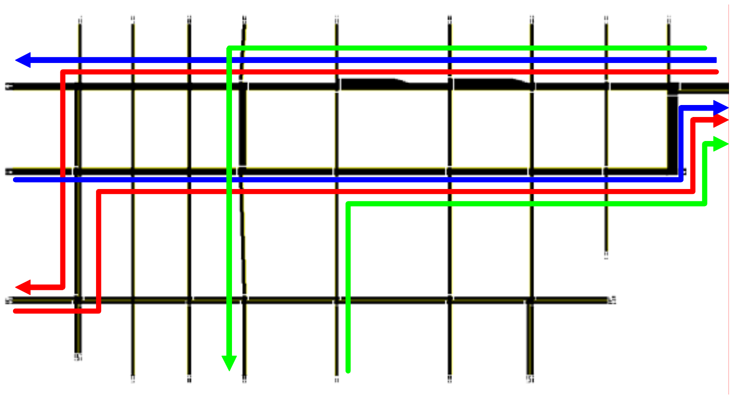


Figure 5-20 Bus and tram routes in Kvadraturen

The installations are based on a desire to give priority to the public transport. One problem is however that the detection does not accommodate this desire. There are none specific detectors or detection systems for public transport. The old detection system based on Sarasota detector was not available for further expansions.

The Public Road Administration and the City of Oslo, Road and Transport Authority are working with a new detection system for public transport in Oslo. This system is to be combined with a passenger information system. The new detection system will be active from 2005/2006. Therefore the priority of public transport is difficult in an intermediate period.

Results

In the simulations we focused on both how we could assist the public transport within a default SPOT/UTOPIA system, as well as how we could give priority to public transport when a new detection system were installed.

City	**Comparison of different signalling schemes with original signalling**	**Changes in travel time - morning rush**		**Changes in travel time - afternoon rush**	
		Public transport	**Private traffic**	**Public transport**	**Private traffic**
Oslo	SPOT/UTOPIA without priority of public transport	-13 %	-34 %	-12 %	-21 %
	SPOT/UTOPIA with priority of public transport	-33 %	-36 %	-21 %	-20 %

Table 5-9 Results from Kvadraturen

The simulations show that there are a large potential for improvements in the traffic flow in the area. We can also see that without a detection system for public transport, the private traffic will get most of the improvements. This is not according to the intentions for the installation. However this can not be avoided for a transition period. The average cycle time was reduced by 20 %. This gives a reduced waiting time for the pedestrians.

5.3.8 Fredriks gate, Oslo (AIMSUN)

Background for simulation

The case in Fredriks gate is one of several upcoming SPOT/UTOPIA installations in Oslo. The Public Road Administration and the City of Oslo, Road and Transport Authority have together decided to progress with SPOT/UTOPIA in several other areas as well.

The aim of the installation is to give better priority to the public traffic. The installation is financed by founds for public transport in Oslo. The simulation was done as a preparation before the new signalling was started.

Description of area

The area around Fredriks gate is an area with medium traffic flow. A new political scheme regarding the routes for buses in Oslo, implicate that most of the regional buses will travel through this area. The bus routes marked on Figure 5-22 are new for the area.

It is initially not a question whether SPOT/UTOPIA will perform better that the original signalling, but more a question on how to setup the priority scheme in SPOT/UTPIA.

Figure 5-21 Signalling in the SPOT case in Fredriks gate

The simulation case in Fredriks gate is small. It was however a good starting case since we had changed the simulation model from NETSIM to AIMSUN.

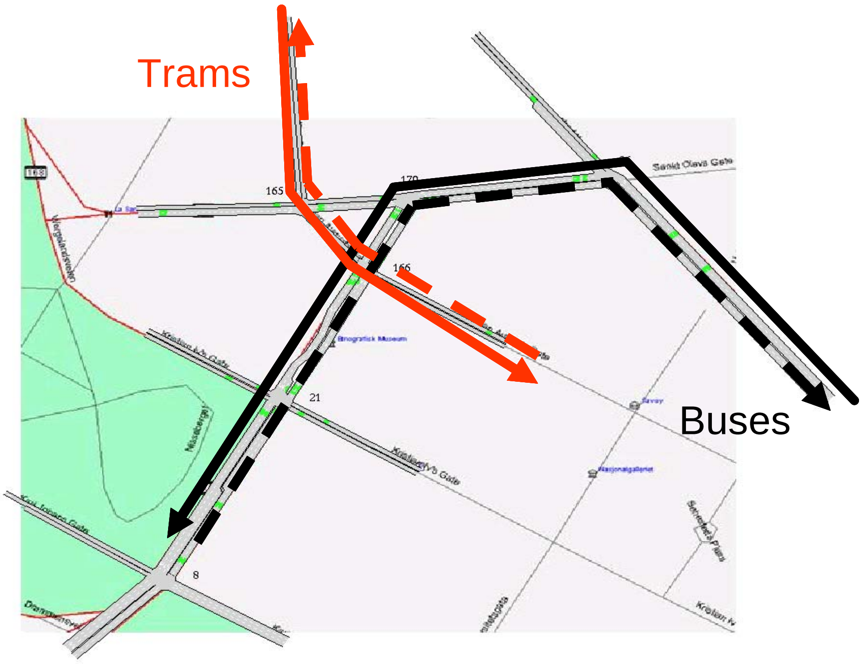


Figure 5-22 Bus and tram routes – case in Fredriks gate

Results

The original signalling was not prepared for the traffic flow used in this simulation. The delay time was reduced nearly by 35 - 40 % for private traffic when we compared the original signalling with standard SPOT/UTOPIA setting. We have therefore focused on the differences between the different SPOT alternatives.

City	Comparison of different signalling schemes with default SPOT/UTOPIA settings	Changes in delay - morning rush			Changes in delay - afternoon rush		
		Private traffic	Buses	Trams	Private traffic	Buses	Trams
Oslo	SPOT/UTOPIA with priority of trams	4 %	-4 %	-75 %	-2 %	-5 %	-74 %
	SPOT/UTOPIA with priority of trams and buses	10 %	-41 %	-68 %	-0 %	-48 %	-67 %

Table 5-10 Results for Fredriks gate

Table 5-10 shows that with only priority for trams, they achieve an imprecise reduction in the travel time. Buses and private traffic is affected by the changes in the signalling as well. The best overall results for the public transport are achieved when both buses and trams are detected and given priority. Buses will not be detected before the Public Road Administration and the City of Oslo, Road and Transport Authority have installed the new detection system.

5.3.9 Kvadraturen, Oslo (AIMSUN)

Background for simulation

After changing from a simulation model to another simulation model, we normally ask ourselves – is the results we obtain with the different model comparable? Does AIMSUN give the same results as NETSIM when both models use external processes for adaptive signalling?

In an attempt to investigate these questions, we have repeated the simulation for Kvadraturen in Oslo. There are naturally some minor differences. The development of SPOT has progressed, and AIMSUN is therefore using a newer SPOT version than we could use with NETSIM.

Also there might be some model differences due to the way traffic is generated and shipped through the network. General differences are however hopefully discovered by the other scientifics that are using the models. We have focused on the possibilities that there are differences in the way SPOT/UTOPIA modules are implemented.

Adjustments in the models

In both NETSIM and AIMSUN a bus stop can be assigned to a route. The average stop time and stop time variation are to be stated. There are however a big difference between the models. NETSIM can state a bypass percent for each bus stop while in AIMSUN all the buses are supposed to stop at an assigned bus stop.

The problems with this aspect of AIMSUN are therefore to get the buses to behave in a similar manner as in the original NETSIM simulation. In AIMSUN we therefore had to divide the different routes into two sub routes. One that passed the bus stops and one that stopped. This secured that we had similar conditions in both simulation cases.

Results

City	**Comparison of SPOT/UTOPIA simulations**	**Changes in travel time - morning rush**	
		Public transport	**Private traffic**
Oslo	New AIMSUN simulations compared to original NETSIM simulations	-3,4 %	-2,2 %

Table 5-11 Comparison of NETSIM and AIMSUN simulations

Table 5-11 shows that the simulation models make quite similar results. The AIMSUN simulation of the area gives a little better travel time than we experienced with NETSIM simulations. The improvements we obtained with AIMSUN are expected. With a newer SPOT model, we anticipate advancements.

5.4 Distribution of cycle time

In most types of signalling the concepts for an area, are based upon a common cycle time for all intersections. This is true for fixed time systems as well as systems based on the fixed time systems like SCOOT and SCATS. This ensures that the planed progression in the system is maintained throughout the entire period.

In the SPOT/UTOPIA concept like we use it in Norway, there is no fixed cycle time. The logic is based on an individual green time for each link. This gives a flexible cycle time that varies with traffic flow.

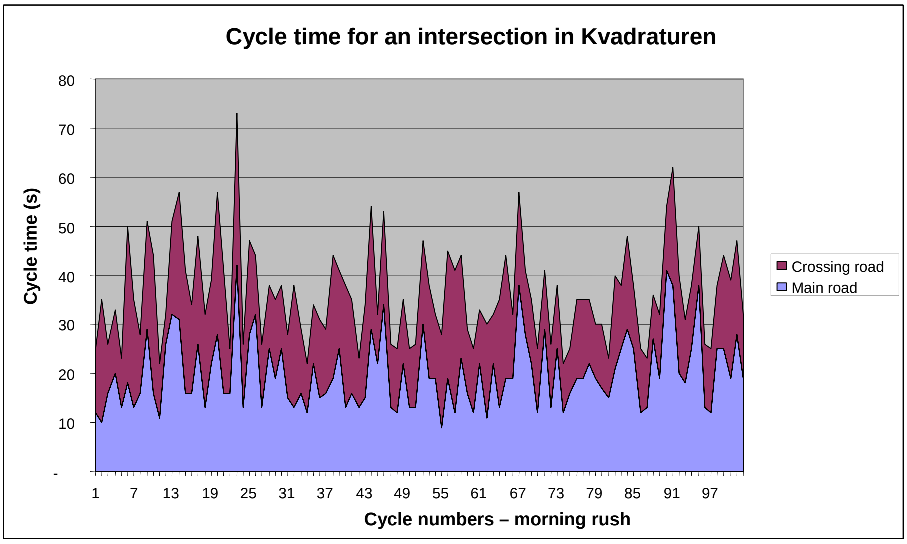


Figure 5-23 Variation in cycle time – an intersection in Kvadraturen

Figure 5-23 shows how green times for each of the two roads are changing constantly. Consequently, the cycle time is also changing with each cycle.

In most of the cycles the downstream intersections are changing their cycle time coherent. This ensures green waves adjusted to the size of the platoons. If there is a larger platoon in the crossing road, or there is a public transport unit that need priority, the green wave is broken.

One of the advantages of a distributed adaptive system like SPOT is that the units can make up for the previous short green time. A new green wave can be started.

In both Figure 5-23 and Figure 5-24 we have used the morning rush to illustrate the differences between SPOT and systems that focus on common cycle time.

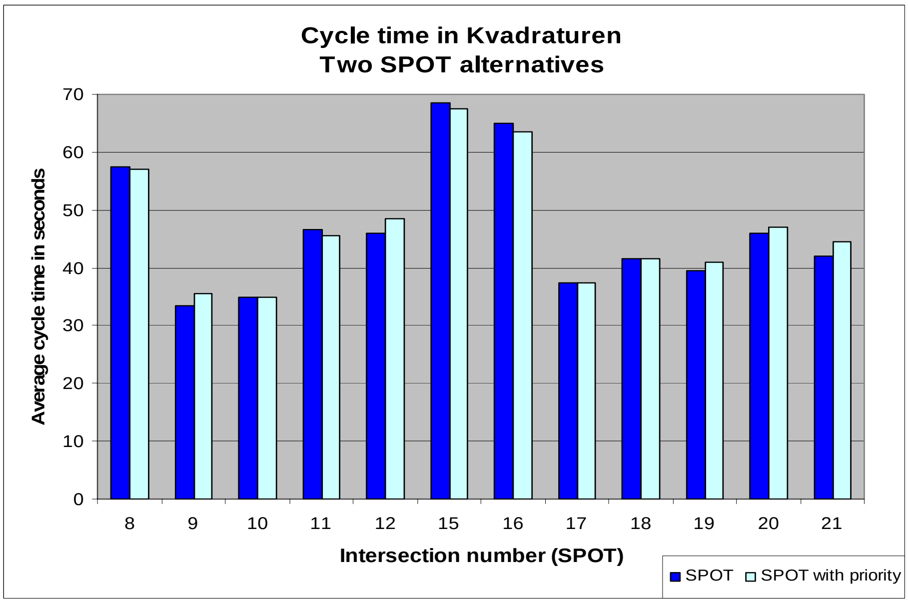


Figure 5-24 Average cycle time in Kvadraturen

Figure 5-24 shows that the mean cycle time is different in each intersection. As Figure 5-23 show this does not mean that one lane gets a fixed offset that secure the progression, while another link gets just stops. The linking is adjusted depending on the size of the platoons and the needs of the public transport.

Especially the pedestrians will benefit from the lower cycle times in the intersections. The average cycle time is different for each case, but normally it is lower than the cycle time of the fixed time signals.

We can also observe another common familiarity of SPOT areas. In the fixed time signalling the cycle time was set to 60 seconds. In most cases we have analysed, SPOT tends to increase the cycle time slightly in the intersections with higher traffic flow. Normally 2-3 out of 12-15 intersections gets a slightly higher cycle time. These intersections is normally limiting the possible cycle time we can choose with fixed time systems.

The rest of the intersections in the area get benefits. They can adjustment more freely to the occurring traffic flow.

6 Results and recommendations

In Norway the Public Road Administration are implementing the Italian SPOT/UTOPIA signal system in several areas. The aim of the installations is to give priority to public transport. Therefore the installations are founded by grants reserved for public transport.

SINTEF has been responsible for evaluations of the SPOT/UTOPIA system in several Scandinavian cities. As a support to the installation SINTEF has simulated the traffic flow under different priority schemes for public transport.

This report offers a summary of the results from the SPOT/UTOPIA cases SINTEF has undertaken.

6.1 Summary of installations

SINTEF has been involved in three on-street travel time studies. In the installations we have seen different schemes been tested. It is clearly that the most successful installations have been focusing on priority for public transport in a grid area.

City	Comparison of different signalling schemes with original signalling	Changes in travel time		Change in waiting time for pedestrians	Survey year
		Public transport	Private traffic		
Oslo, Grünerløkka	SPOT/UTOPIA with priority of public transport	-15 %	-15 %	-30 %	1998
Bergen, Christies gt	SPOT/UTOPIA without priority of public transport	-	-5 %	-10 %	1998
Trondheim Ila	SPOT/UTOPIA with priority of public transport	-10 %	-10 %	-	1999

Table 6-1 Summary of results from on-street travel time studies

SPOT/UTOPIA has been installed and partially tested in several countries. In Norway the tests from on-street surveys are dated a few years back. This influences the results compared to the results from the simulations. Resent developments in the SPOT algorithms have improved the performance of the adaptive system.

An on-street survey has been planed for some years at Majorstua. However, it has been delayed due to ongoing construction work in the area. This survey will give a valuable evaluation of both the resent software improvements as well as validate the simulation work.

6.2 Summary of simulations

The simulations have been a valuable tool for the installations in Norway. In the first projects SPOT/UTOPIA seemed like a black box technology. After working with SPOT/UTOPIA through both simulations and installations it is easier to understand both the advantages and disadvantages for the adaptive model.

Positive expectations have grown into practical visualization of how to utilize the system. The results speak for it self with regard to a comparison to fixed time systems. SPOT/UTOPIA has proven to give better traffic flow for all investigated cases.

Another lesson learned is that public transport needs special attentions and a good detection system if this group is to achieve better results than private traffic. Normally both private traffic and public transport are sharing the same lanes. Therefore it is difficult to give advantages to public transport and not to private traffic.

City	Comparison of different signalling schemes with original signalling	Changes in travel time - morning rush		Changes in travel time - afternoon rush	
		Public transport	Private traffic	Public transport	Private traffic
Bergen Christies gt	SPOT/UTOPIA without priority of public transport		-4 %		
Tampere, Finland	SPOT/UTOPIA without priority of public transport		-9 %		
Trondheim Ila	SPOT/UTOPIA with aggressive priority of public transport	-34 %	-10 %	-32 %	-17 %
Trondheim Ila	SPOT/UTOPIA with priority of public transport	-40 %	-20 %	-40 %	-25 %
Oslo Majorstua	SPOT/UTOPIA with 10 % increase in traffic	-37 %	-21 %	-28 %	-11 %
Bergen Bystasjonen	SPOT/UTOPIA with priority of public transport	-31 %	-29 %	-26 %	-27 %
Chicago, USA	SPOT/UTOPIA with priority of public transport	-13 %	-15 %	-15 %	-3 %
Chicago, USA	SPOT/UTOPIA with revised priority of public transport	-22 %	-14 %		
Oslo Kvadraturen	SPOT/UTOPIA with priority of public transport	-33 %	-36 %	-21 %	-20 %
Oslo Fredriks gt	SPOT/UTOPIA with priority of public transport	- 63 %	- 36 %	- 50 %	- 35 %

Table 6-2 Summary of results from simulations

6.3 Sensitivity studies

The *on-street cases* contain a sensitivity aspect when we divide the traffic flow into sub groups for 10 minutes intervals. The sensitivity testing is done by assessing the regression lines for fixed time signals and SPOT. In the cases at Grünerløkka, Oslo and Ila, Trondheim the regression lines for both signalling schemes are parallel. This shows that SPOT is able to maintain the improved traffic flow at all levels of traffic flow.

In the *simulation cases* sensitivity studies have been added at two different levels.

- Firstly the arriving traffic is adjusted according to a normal traffic profile. The average traffic flow is based on both manually and automatic traffic counts. The counts are normally valid for the whole rush period. If the simulation time covers one hour of traffic, the traffic profile may be implemented by firstly one period with 85 % traffic demand, secondly by one period with 110 % traffic and finally by one period with 100 % demand. Other combinations may also be valid.

- Secondly the average traffic flow has been increased by 10 - 20 % in the simulation cases for Christies gate, Tampere, Majorstua and Busstasjonen. In these cases SPOT has maintained its advantage to the fixed time signals.

6.4 Priority of public transport

In Europe there is a tendency to co-ordinate the traffic signals when we are providing priority to public transport. This approach secures that the benefits that are achieved in one intersection are maintained in the next intersection. *The detection system for public transport is the key to a good priority scheme.*

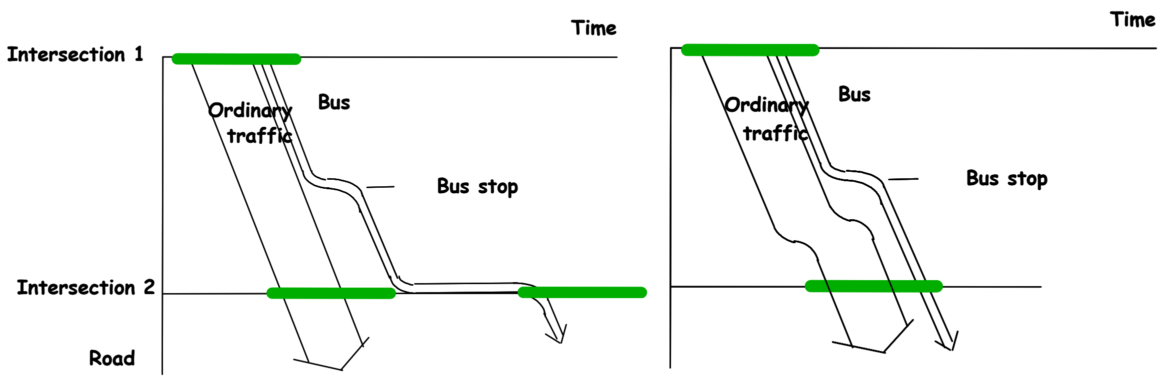


Figure 6-1 Priority of public transport

We have especially studied the priority and progression for the public transport in the simulation cases. The conclusions are that the detection system must be able to both give priority messages and modify the scheduled arrival time if there is delay. This will ensure that, if possible, the adaptive system gives priority.

Normally we would like a confirmation message once the public transport unit has passed the stop line. This message can shut down the current stage and enable other traffic flows in the intersection to get priority. This confirmation message may also serve as a request massage for a downstream intersection.

SPOT/UTOPIA has proven to give advantages for the public transport in both the simulation cases and in the on-street cases. The studies in Oslo, Bergen and Trondheim are very favourable. *If we use the Payback method to evaluate the economic effects of the installations, we normally get a payback time of less then 6 months.* Therefore these types of installations are highly recommended in Norway.

The status for SPOT/UTOPIA in Norway for 2004/2005 is expected to be:

- Trondheim – Totality of 44 SPOT intersections (10 new)
- Oslo – Totality of 80 SPOT intersections (32 new)

SPOT/UTOPIA will continue to be an important tool in priority of public transport for Oslo and Trondheim. We now have the knowledge to utilize the technique further in other Norwegian installations.

6.5 Further work

Still there are possibilities for improvements in the SPOT/UTOPIA concept. The progress in computer technologies gives possibilities that were excluded some years ago. New functions and schemes can now be implemented. This work embraces both old schemes, that previous hardware could not support, as well as new initiatives. A distributed system is normally limited by the local computing power. As the possible computing power increase the potential benefits from the system will also increase. This is an advantage with a distributed compared to a central system. A centrally based system is mainly limited by communication capacity.

In Norway the simulation work is accepted as a scheme to obtain the expected results from SPOT/UTOPIA installations. The simulations give valuable information on how to setup the system. One of key element that simulations can demonstrate is the differences in the signalling schemes between an adaptive system and a fixed time system. This is demonstrated in the cases for Trondheim and Chicago. Another key element in the evaluation process is the possible priority for public transport. The aims for priority may be high, but the actual results will always be linked with the characteristics of the detection system. The simulations can therefore demonstrate the differences obtained with various technical levels for the detection system.

Simulations of SPOT/UTOPIA areas will continue to be a valuable tool for both new and existing installations. The system has proven its assets and should be deployed further.

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