

GUIDELINE TO ASSESS SOCIETAL IMPACT OF C-ITS ON SIGNALIZED INTERSECTIONS



Title report

Guideline to assess societal impact of C-ITS on signalized intersections

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Client

Research Institutes of Sweden (RISE)

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Table of content

Executive summary	4	4. Explore societal benefits in simulation environment	18
Purpose	7	4.1 Why simulation?	18
1. Introduction: How to read this guideline?	8	4.2 Connect C-ITS to city-goals regarding mobility and sustainability	19
2. From societal objectives to measurable indicators	10	4.3 Design C-ITS implementation in simulation environment	20
2.1 Challenge: Quantifying the potential of C-ITS	10	4.4 Experiment with different settings	23
2.2 Breakdown of KPI's	11	5. Cost versus benefits	26
3. Potential of C-ITS in general	12	5.1 Cost collection	26
3.1 Impact of C-ITS on signalized intersections	12	5.2 Benefits calculation	27
3.2 Impact of C-ITS on a city level	16	6. Results	28
		6.1 Societal benefits of C-ITS (results from simulation)	28
		6.2 Impact of C-ITS on soft KPI's	32
		6.3 Process with road authorities	32
		6.4 Conclusions and Next step: Towards C-ITS implementation	34

Executive summary

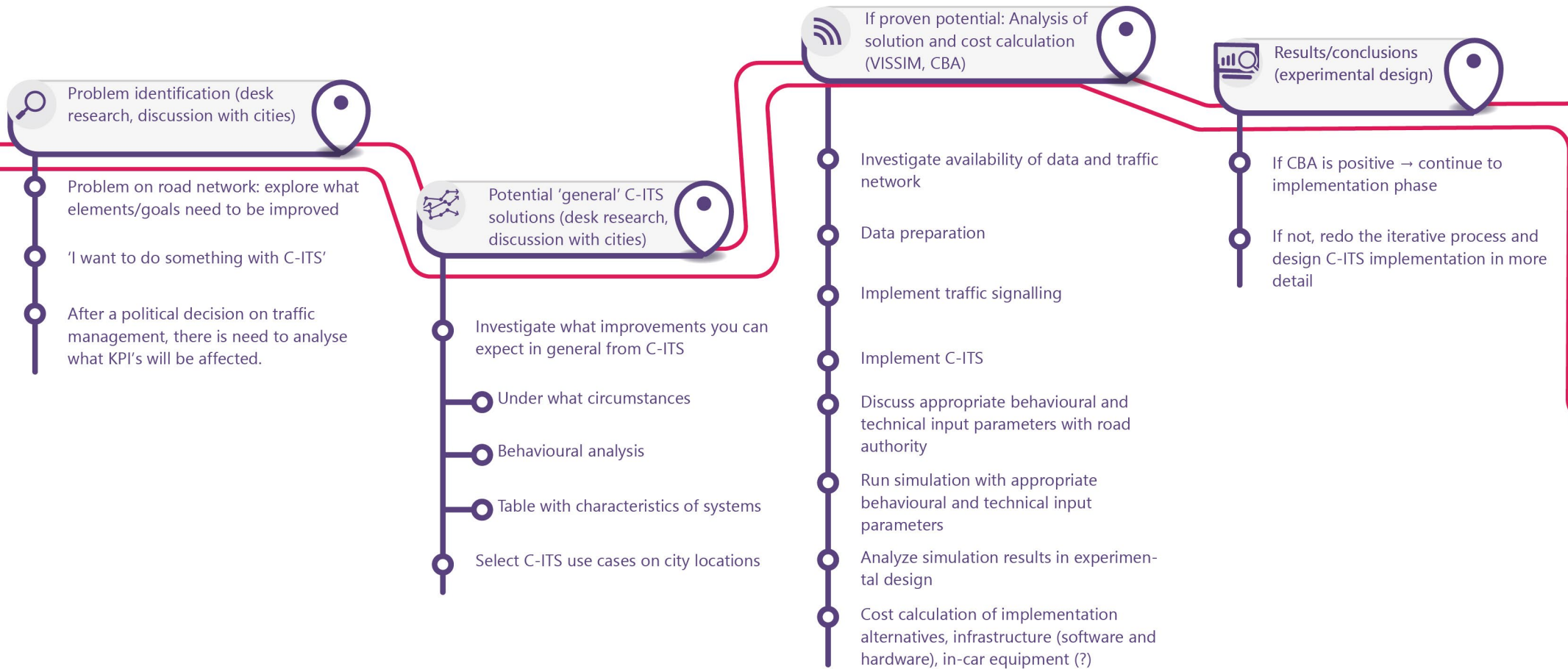
Cooperative Intelligent Transport Systems (C-ITS) promises to bring societal benefits. The lack of large-scale implementations and real traffic conditions, however, present a challenge in quantifying the impact of C-ITS services. Road authorities are in need of information about the necessary conditions and options required to achieve a successful implementation of C-ITS

This guide serves as a tool for road authorities and cities to support investment decisions regarding C-ITS on signalized intersections. It provides a step-by-step process for the assessment of the (potential) effectiveness of C-ITS applications in its own specific setting. Next to obtaining realistic expectations on the benefits from implementing C-ITS on various types of signalized intersections, this document guides in the process on how to investigate the impact of C-ITS on signalized intersections. This process is summarized in the figure below.

The simulations help to explain how different variables, such as the traffic load, type of traffic signalling, the given advice and follow-up behaviour impact the functioning of C-ITS. They do, however, not explore the impact on softer KPIs, such as lane changes, red light negation, smart routing and the attention and safety of road users. To give an indication on the direction of the impact, we used causal diagramming to explore what factors impact these KPI's.



PROCESS WITH ROAD AUTHORITIES



Cooperative Intelligent Transport Systems (C-ITS)

ASSESSMENT OF SOCIETAL BENEFITS

Potential of C-ITS in general

Understand the general potential of C-ITS applications in terms of KPI's

From societal objectives to measurable indicators

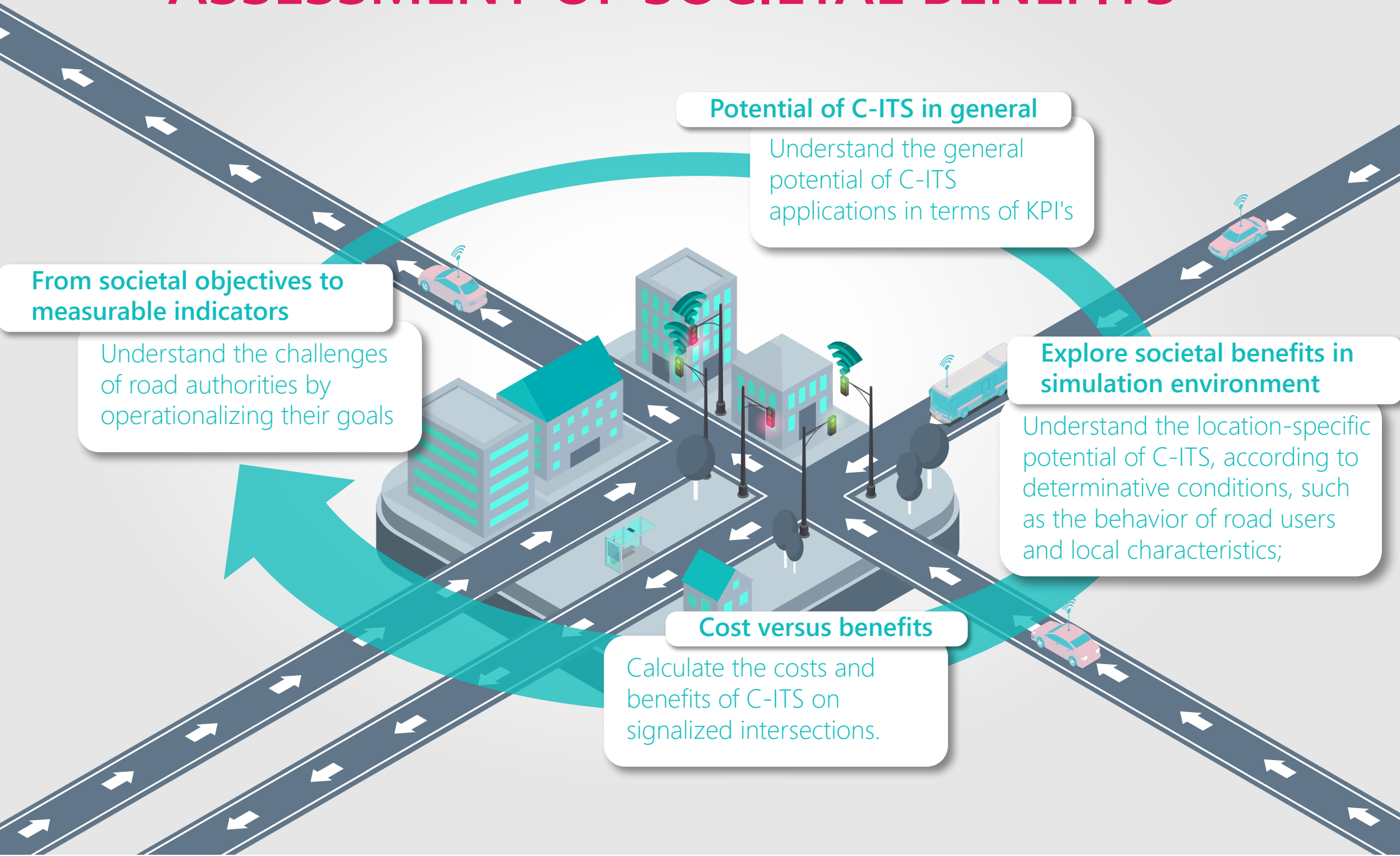
Understand the challenges of road authorities by operationalizing their goals

Explore societal benefits in simulation environment

Understand the location-specific potential of C-ITS, according to determinative conditions, such as the behavior of road users and local characteristics;

Cost versus benefits

Calculate the costs and benefits of C-ITS on signalized intersections.



0

Purpose

This project is carried out on behalf of the Research Institutes of Sweden (RISE) as part of the NordicWay 3 project (<https://www.nordicway.net/>), co-financed by the European Union within the Connecting Europe Facility programme. NordicWay 3 involves cities to develop sustainable business models and ecosystems for a realistic implementation of C-ITS. As part of the project and with a focus on traffic signals, this study develops a method to evaluate societal benefits related to traffic signals, which has been applied to use cases in the municipalities of Gothenburg, Uppsala and Stockholm.

This document should be seen as a guide where you are led in a process where different tools and input values may need to be used, e.g. simulation, the municipality's traffic policy to reach a result. A result can either be a basis for a decision in a political traffic committee or part of a follow-up of a previously made investment or other C-ITS related issues to be solved.



1

Introduction: How to read this guideline?

It is generally agreed that Cooperative Intelligent Transport Systems (C-ITS) could bring societal benefits. C-ITS allows vehicles and infrastructure to communicate with each other to provide real-time information, optimize traffic flow or prioritize targeted road users. This can improve road safety, reduce congestion, and enhance the overall efficiency of the transport system. However, it is also acknowledged that the lack of large-scale implementations and real traffic conditions present a challenge in quantifying the impact of C-ITS services.

This guide serves as a tool for road authorities and cities to support investment decisions regarding C-ITS on signalized intersections. It provides a step-by-step process for the assessment of the (potential) effectiveness of C-ITS applications in its own specific setting:

- Understand the challenges of road authorities by operationalizing their goals;
- Understand the general potential of C-ITS applications in terms of Key Performance Indicators (KPIs);
- Understand the location-specific potential of C-ITS, according to determinative conditions, such as the behaviour of road users and local characteristics;
- Calculate the costs and benefits of C-ITS on signalized intersections.





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Welkom!

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100% Stampot vangedreven

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From societal objectives to measurable indicators

2.1 Challenge: Quantifying the potential of C-ITS

Understanding the impact of C-ITS applications on signalized intersections may be driven by various motives. For instance, if a municipality faces issues related to environmental conditions, road safety or congestion, they may consider implementing C-ITS as a solution. To get insights into the issue or problem, we need to explore what elements need to be improved. Road authorities are in need of information about the necessary conditions and options required to achieve a successful implementation of C-ITS. Additionally, they are in need of a tool in which they can learn and share the needed requirements towards autonomous driving with stakeholders.

Due to a lack of understanding of what factors influence the effects it remains difficult to quantify the impact of C-ITS on a large scale. Some benefit evidence of C-ITS is found in pilots and demonstration results, but when comparing pilot studies, aspects that are found as positive in some studies are not observed or are even seen as negative in others. For example, real life has no constant conditions, which makes it difficult to compare the situations before and after a measurement is taken. Pilots in which use cases of new technology are tested are often localized experiments with low user penetration rates. In such pilots, use cases are often combined, and it can be difficult to isolate the effects of independent applications, particularly when the impacts are relatively small.



2.2 Breakdown of KPI's

Authorities set goals to improve the overall wealth level of society. These goals can be decomposed into a wide variety of societal goals regarding numerous elements with respect to overall wealth. A broad range of Key Performance Indicators (KPIs) needs to be included to evaluate an application in traffic control thoroughly. This is important, because accessibility and travel times are no longer the only important factors in mobility policies. Even through travel time saving could be small, impact could be gained on other aspects, such as safety, energy consumption, emissions and traffic noise, as shown in Figure 1.

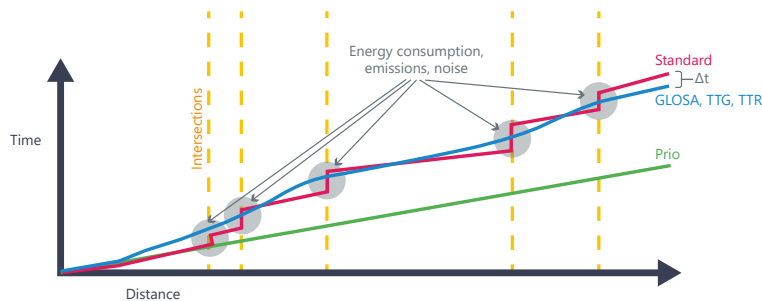


Figure 1: Impact of C-ITS: more than accessibility.

C-ITS use cases are assessed on their contribution to policy goals. To make these goals more concrete, we convert them into measurable KPIs as seen in Figure 2. The KPIs under accessibility, liveability and safety match the KPIs from C-ROADS (2020).

SOCIETAL OBJECTIVES

Accessibility

Delay, travel time (seconds)

Travel time reliability (sd seconds)

Average speed (km/h)

Queueing, waiting time (seconds)

Number of stops (#)

Throughput or traffic flow (# vehicles)

Liveability/sustainability

Fuel/Energy consumption (J)

Emissions (grams, i.e. NO_x, CO₂ or PM₁₀)

Noise level (dB)

Safety

Risk of accidents (%)

Potential impact of accidents (# casualties)

Potential conflicts (SSAM)

Figure 2: Breakdown from societal objectives to measurable KPI's



3

Potential of C-ITS in general

Based on the general findings on the C-ITS applications in Chapter 2, we determine bandwidths with plausible system settings and resulting behavioural changes. The effects and correlations between different settings within these bandwidths are analysed by using various different settings in a design, as explained in section 4.4.

3.1 Impact of C-ITS on signalized intersections

C-ITS provides an enhanced quality of information and service level for road users, transport operators, road authorities, and policymakers. To understand what aspects of our mobility system are changed by C-ITS, we need to describe C-ITS in terms of behaviour. This starts with the measurement and its follow-up behaviour and through the Unified Theory of Acceptance and Use of Technology (UTAUT). Firstly, not all of the road users are able to receive the information. If they do receive the information, follow up behaviour depends largely on the perceived – and expected - usefulness and the perceived ease of use of the advice. Drivers usually prefer having additional information about upcoming traffic signals. It is, however, not guaranteed that the user is always willing to follow the given advice. In some cases, the driver cannot follow the advice, for example because of other traffic in between. From the group that uses the advice, a part uses it in the intended way and another part ‘misuses’ the information.

Figure 3 shows the process from adjusting the green phases and enhancing the information given to road users, to the follow-up of intended use, misuse and possible (negative) side effects of C-ITS



Aspects that play an important role in the follow up behaviour are experience with C-ITS, personal characteristics (also stress, hurry, attention span), complexity of the driving task, surroundings, other traffic and the quality of information.

Other green phases,
information to road
users



Drivers behave differ-
ently when being
informed or instructed

Users, non-users,
misusers are
affected differently



Travel time, comfort,
number of stops,
energy use, emissions

Speed control, lane
choice, reaction time,
headways, risky behavior,
breaking, accelerating



Route choice,
mode choice

Traffic flows are
affected differently

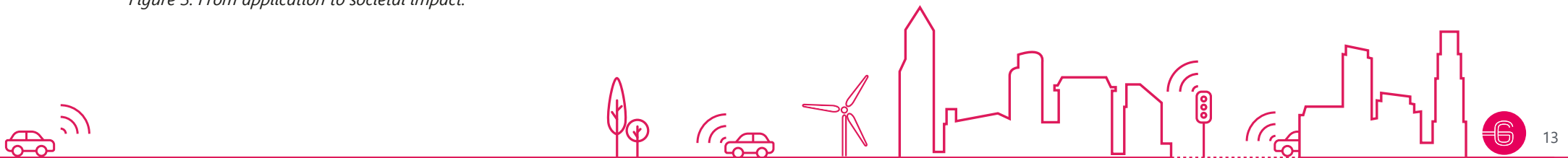


Societal impact

It is highlighted that the activation distance plays a significant role in the response behaviour and, depending on the cycle duration of the traffic light. A short activation distance might be completely inefficient, while the social threshold of following up the advice, caused by the feeling of bothering others, might be present when the assistant recommended a lower speed at far distances to the traffic light.

The ideal situation for the user, likely causing a high follow-up is the case without traffic in front of you and no one behind you. Drivers can slow down quietly to get and stay in the green zone, reducing unnecessary breaking.

Figure 3: From application to societal impact.



This research explores the impact of Green Light Optimal Speed Advisory (GLOSA), Time to Green (TTG), Time to Red (TTR) and priority on signalized intersections. See Table 1 for an overview of the potential impact for each of these applications.

Table 1: Potential impact of C-ITS applications

C-ITS application	Functioning of application	Expected behavioural change	Expected improvements
GLOSA	In car information about predicted green phases.	Less speeding, less stops, more smooth driving. Vehicle platoons.	Improved traffic flow, increased comfort, reduced emissions. More efficient cycle times.
TTG, TTR	Countdown timers inform when traffic lights will turn green or red.	Quicker reaction time, reduction of (heavy) breaking. Possible additional speeding in amber/yellow light.	Shorter cycle time of intersections. Reduction of energy spent by vehicles causes reduced emissions. Possible increased number of conflicts.
Priority ¹	Individual priority requests by giving green to 'their' direction.	Reduced number of stops for priority vehicles. Increased number of stops for conflicting vehicles. Increased attractiveness impacts use of prioritized modes or routes.	Decreased travel time for prioritized groups.

¹ Priority is distinguished in two categories:

- Absolute priority (direct green, pass without delay). This is often applied for buses.
- Conditional priority (green under specific condition). Priority when arriving during (end of) green. Green can be maintained to ensure passing without breaking. No priority when arriving during red.





3.2 Impact of C-ITS on a city level

It is not straight-forward to compare studies to determine the impact of C-ITS yet. Reasons for the variations are a lack of understanding of what factors influence the effects. Regarding the big picture and the impact of C-ITS when scaling up, and to obtain more insight into causes and effects, we mapped all relevant variables into causal diagrams. We collaborated with Kungl Tekniska Högskolan and interviewed experts in Stockholm to investigate how and under which circumstances C-ITS applications and policy objectives interact, highlighting C-ITS' contribution to the development of a sustainable society.

The result is seen in Figure 4 and distinguishes the impact and explanatory variables of three use cases GLOSA, TTG/TTR and Priority on the usage of different modes of transport. Arrows are used to show the relationships between different variables. These arrows include visual features: plus (+) signs, minus (-) signs, or delays. An arrow with a (+) sign indicates a positive relationship, meaning that the variables in the origin and the destination of the

arrow change in the same direction. An arrow with a (-) sign shows a negative correlation, meaning that the two variables it connects change in opposite directions (an increase in one variable results in a decrease of the next). Lastly, a delay mark (||) on an arrow represents a time lag between the input and output variables. This indicates that a change to the input variable has an effect on the output variable that is not immediately apparent.

Findings demonstrate that C-ITS has the capacity to support policies aimed at improving transport systems and mobility in the cities. C-ITS usage has enormous potential for influencing society and mobility. C-ITS reduces accidents while enhancing road safety through real-time communication. By enhancing traffic flow and promoting alternative modes of transport, it supports environmental sustainability. It also has secondary effects such as reducing pollutants and improving air and noise quality. Through the integration of numerous mobility choices and the provision of real-time information, C-ITS improves accessibility.



C-ITS's success is dependent on several important factors. Efficient communication and interaction between C-ITS systems and other devices depend on standardization, interoperability between systems and devices, and collaboration between stakeholders. Sufficient geographic and road coverage, user acceptance via user-friendly technology, positive awareness are essential aspects in realizing the benefits of C-ITS. Its growth may be impacted by economic factors, which includes the expenses of installing and maintaining C-ITS systems. To achieve successful implementation, cooperation amongst parties, administrative tasks, and legal considerations must all be handled.

Figure 4: Causal diagram of impact of C-ITS on mobility.

Make this picture bigger by clicking on it



4

Explore societal benefits in simulation environment

4.1 Why simulation ?

Pros

+ Simulation allows to scale up effects

- Stable conditions, external effects can be 'switched off'
- Effects of applications can be isolated
- Easy to experiment with penetration rates and follow up behavior
- Possible to evaluate broad range of KPI's
- Translate theoretical insights into practical and realistic effects
- Fair comparison before and after C-ITS
- Possible to simulate a situation that does not yet exist: vary with uncertain factors of which we do not yet know its functionality

Cons

- Simulation considers a 'perfect' world

- Simulation is not identical to the real world
- Unwanted traffic behavior is arbitrary process
- Arbitrary process to illustrate effects of unwanted factors, e.g. red light negation, speeding, tailgating

"Simulation is an efficient tool to support decision-makers to understand the potential of C-ITS under different implementation scenarios".

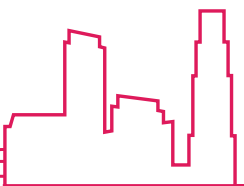


4.2 Connect C-ITS to city-goals regarding mobility and sustainability

To connect C-ITS to societal objectives, it is important to check what type of solutions can help to improve the situation, as described in the cities' goals in Chapter 2. To define the C-ITS applications with the most potential, we include the local characteristics of the intended use case in the following steps:

1. Identify the problem: Are there issues with congestion, safety, liveability or something else that requires attention or improvement?
2. Define the scale of the issue and the use case location: Is it a local intersection, a unimodal or multimodal corridor, or a customized intersection? And: Is the potential element of improvement limited to a particular time of the day or is it persistent throughout the day?
3. Not all issues can be resolved with C-ITS in traffic signalling. Other measures, such as redesign of infrastructure, or other types of C-ITS such as Road Works Warning, are left out of scope in this guideline. Therefore we add the step: Match the issue with C-ITS functionalities to inform or prioritize traffic (Talking Traffic, 2023):
 - a. **Inform:** In-car information informs road users about the predicted green or red phases of traffic lights. Drivers can adapt their driving behaviour according to the information to increase efficiency and comfort of driving and improve traffic flow.
 - b. **Prioritize:** Prioritization refers to the process of giving precedence to certain type of vehicles or modes of transport over others. This is typically done to improve safety, reduce congestion, or facilitate the movement of high-priority vehicles, such as emergency vehicles, public transport or slow modes of traffic.

² Optimization is out of the scope of this guideline because the C-ITS applications addressed in the guideline are not fundamental applications for traffic optimization.



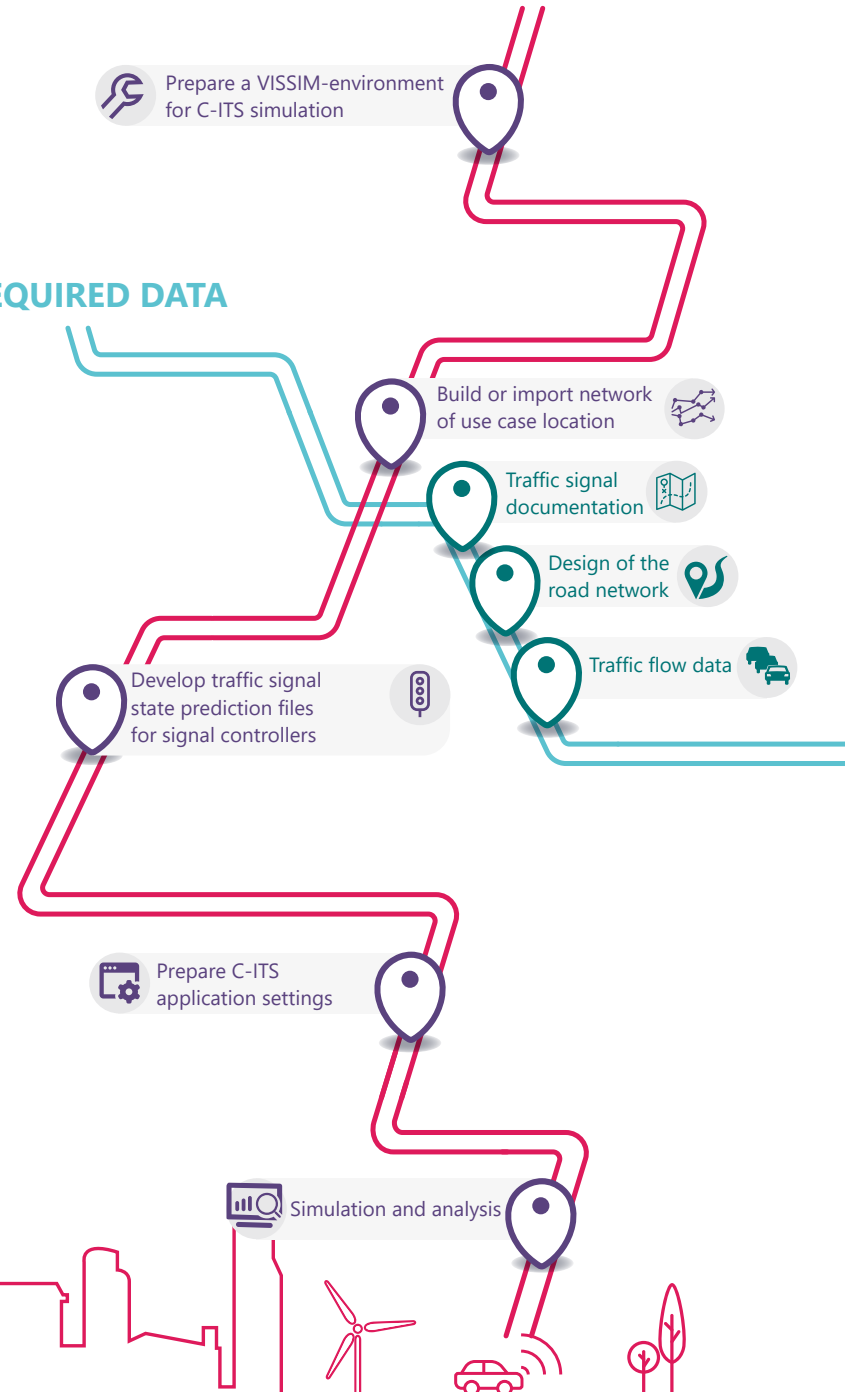
PROCESS TO IMPLEMENT C-ITS IN SIMULATION

4.3 Design C-ITS implementation in simulation environment

To research the impact of C-ITS on mobility, behavioural changes and system variables of the application need to be translated into model variables. Therefore, a digital twin has been developed that combines real world traffic signalling software and added C-ITS functionalities to investigate the selected intersections. The realistic traffic signal software and additional C-ITS functionalities (being not part of the current practice) are programmed within this model environment.

The behavioural aspects found in the chapter 3 are translated into penetration rates and into behavioural parameters that are varied in simulation software VISSIM. Information about the signal timings is shared with the road users in the simulation, with expected time-to-green and time-to-red calculated and communicated to vehicle, which then leads to speed-advice to road users. As a result, road users behave accordingly (i.e., smooth deceleration, faster reaction time, or the ability to follow specific speed advice). This section describes the steps to create a simulation environment for new use cases:

REQUIRED DATA





- 1.** Prepare a VISSIM-environment for C-ITS simulation
 - a.** Import functionalities for user defined attributes and scripts, specifically developed within this project to support communication between road users and traffic signals.
 - b.** Prepare vehicle settings (types, classes compositions) in order to differentiate between C-ITS and non C-ITS equipped vehicles.
 - c.** Prepare evaluation settings in order to evaluate desired KPI's (i.e. emission class setting)
 - d.** Steps a-c are also required for existing VISSIM networks. The settings need to match the prescribed format in order to use C-ITS communication application in VISSIM.



- 2.** Build or import network of use case location

In case of a new network:

- a.** Insert network objects regarding road infrastructure (link, speeds, priority rules etc.). Required data: Designs of the road network.
- b.** Insert network objects regarding traffic signalling

(traffic signals, signal heads, detection) following the required numbering for communication protocol in order to allow communication between road users and traffic signals. Required data: Documentation of the traffic signal software/plan and intersection design (location and numbering of signals and detection).

- c.** Insert network objects regarding traffic flow using vehicle inputs and routing or dynamic assignment. Required data: Traffic flow data for road traffic, slow modes and public transport (preferably either modelled or measured).
- d.** Insert network objects regarding evaluation of the network (KPI's).
- e.** In case of an existing network: Network objects regarding road infrastructure, traffic signalling, traffic flow and evaluation need to match the communication protocol.





3. Develop traffic signals state prediction files for signal controllers

- a.** The model needs to be fed with predictive TTG/TTR information. This is done by reading a .txt-file (including TTG/TTR information per signal head following the layout of the communication protocol). This information is read once every second during simulation.
- b.** For static traffic signals, reliable prediction can be made following its fixed signalling scheme. For dynamic traffic signals, a prediction module is required. This study applies a Dutch state of the art prediction algorithm. Note: There is no prediction module included for signal controllers of any kind. This needs to be provided by the applier of the simulation environment.



4. Prepare C-ITS application settings

- a.** The enhanced VISSIM environment (following

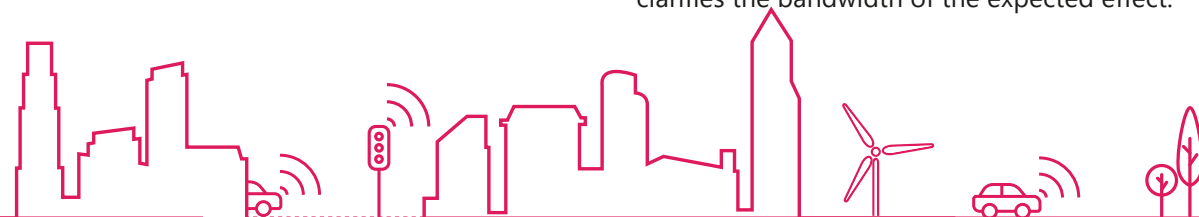
from step 1) allows to vary in application settings (information or advise strategies), behavioural changes (acceleration or reaction time) and environmental conditions (penetration rate or coverage).

- b.** These can be set to a preferred setting (one set of variables), or an experimental design can be prepared in order to identify a bandwidth of the expected impact on the KPI's. Experimental design scenario's need to be configured following related schemes as explained in section 4.4.



5. Simulation and analysis

- a.** Simulation of variants needs to be performed multiple times. In case of experimental design, all scenario's from the scheme are run.
- b.** VISSIM output needs to be evaluated for each of the required KPI's. Regression analysis helps to identify the explaining variables (causes) and clarifies the bandwidth of the expected effect.



4.4 Experiment with different settings

To identify which variables have societal impacts, and what determines the success of C-ITS, an experimental design is used to vary different settings systematically. This methodology, is considered efficient as it selects smart combinations of input variables instead of exploring all possible input combinations, which could result in thousands of model runs. The experimental design helps to explain how different variables, the advice and follow-up behaviour impact the functioning of a C-ITS application. It is important to mention that some variables might also have negative effects for specific KPIs. Some variables have no influence at all and can be left out of future calculations. Before starting simulation works, we determined which variables are taken into account².

To find out which variables have the most effect, we distinguished 2, 3 or 4 options, as described below:

- % of vehicles with C-ITS connection GLOSA (10/40/70/100%), 4 options
- Traffic load (morning traffic, rest day, night), 3 options
- Traffic signaling (Fixed or Vehicle Actuated), 2 options
- Directions of the intersection (main or all), 2 options
- Maximum speed limit of cars (max 40 or max 60), 2 options
- Minimum speed limit of cars (min 20 or min 30), 2 options
- Distance from intersection where advice is shared (100 – 500m), 2 options
- Continuity of advice (once or every second), 2 options
- Level of intermediate cars (0 or all), 2 options, only GLOSA
- Buffertime (0.5 or 2 seconds), 2 options, only GLOSA
- Reduction of reaction time startgreen (0.5 or 2 seconds), 2 options, only TTG/TTR

² in case of very limited number of variables a more regular approach (simulating all combinations) might be more time efficient than an experimental design.



Experimental design allows for an optimal combination of variable values given a certain number of simulations. To determine the amount of simulation runs and the corresponding settings, the application of experimental design uses a basic plan, as presented below. Using a basic plan allows to perform statistical analysis on the results of simulations and to identify the magnitude of each of the variables on the KPI's. A basic plan can be implemented within the model environment using modifications and scenario's. With the amount and settings of the variables above, the experimental design needs 16 different simulation runs, with settings as described in the columns in the basic plan.

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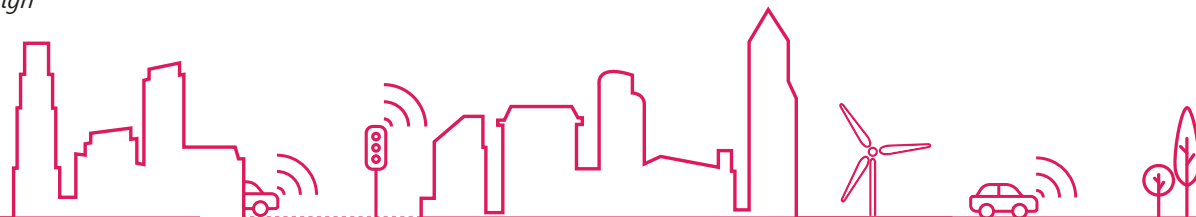
BASIC PLAN 3: 42; 33; 215; 16 trials
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Figure 5: Basic plan for experimental design

As a result of each simulation, we obtain a set of environmental and accessibility indicators. After the simulations of the complete experimental design have been performed, their results are statistically analysed to investigate a relationship between variables and to explore how they correlate to the outcomes of the application of C-ITS. We applied regression analysis, which in theory explains changes in a 'dependent variable' based on a number of 'independent variables'. The result of each regression analysis tells us numerically what would happen to the dependent variable, if one of the independent variables changes in one way or another. A regression analysis is therefore performed for each of the indicators resulting from the simulations, which identifies the most important variables that affect C-ITS and allows for a more focused impact analysis.





5

Costs versus benefits

To justify the investment that is needed for a large-scale introduction of C-ITS, a cost-benefit analysis (CBA) is necessary. A CBA quantifies the costs and benefits to support decision-making. This is done through a comparative study of the current situation with and without the introduction of C-ITS services. A CBA can be done in four steps, consisting of:

- Collecting and estimating the cost;
- Calculating the benefits;
- Comparing one or more implementation scenarios with the status quo;
- Calculating the quantified indicators.

The CBA considers changes in monetary value over time through a discount rate and typically spans a period of 20-30 years for traffic lights.

The key output indicators of a CBA include the Net Present Value (NPV), which assesses project profitability, the Internal Return Rate (IRR), which gauges profitability potential, and the Benefit-Cost Ratio (BCR), which determines whether a project is worth investing in. A previous C-ITS Platform analysis projected a BCR of 3:1 by 2030, considering the introduction of C-ITS services in bundles from 2015 to 2030.

This analysis was conducted at the EU level and encompassed multiple C-ITS services. At the city level, local infrastructure characteristics, mobility patterns, labour-related costs, and other factors must be taken into account.



5.1 Cost collection

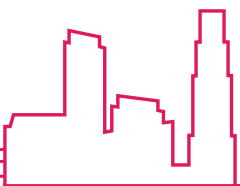
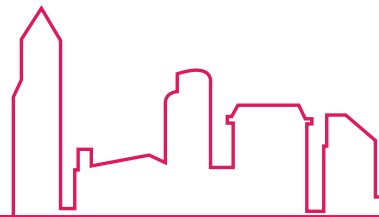
The costs associated with implementing C-ITS services can be broadly categorized into two segments: Costs related to city infrastructure including Roadside Units (RSUs), backhaul communications, infrastructure upgrades, traffic management center upgrades, and data costs; and costs related to onboard units in vehicles. Each cost segment comprises investment costs and operational costs. To estimate these costs effectively, valuable cost information can be obtained from various sources such as the 5GAA, US Department of Transport (DOT), and NordicWay 2 (NW2) analyses.

Most cities in Sweden already have connected traffic controllers, but the level of digitalization varies. Therefore, the recommended approach for Swedish cities is to implement C-ITS services using existing infrastructure while enhancing digitalization and data delivery. For traffic light-related services, the cost segments are generally well-defined, although more precise cost information requires specific iterations. It is important to consider the digitalization strategies of each city, as infrastructure costs are often shared, and data provision is often part of the investment strategy in many cities.

5.2 Benefits calculation

This document discusses some of the benefits and explains how to study them through simulation. It is crucial to understand these benefits at the city level before introducing them on a larger scale. Once the benefits are identified, they need to be quantified in monetary terms using national economic statistics, such as the costs associated with accidents, travel times, emissions, and other relevant factors.

The Swedish Road Administration has developed the ASEK (a Swedish abbreviation) tool that provides monetization factors for accurately calculating the benefits. To ensure precise benefits calculations at the city level, it is vital for cities to provide local information, including the specific areas where C-ITS services will be implemented, as well as local mobility patterns and traffic statistics. Incorporating such information is essential for a comprehensive and accurate assessment of the benefits of C-ITS services in each city.



6

Results

6.1 Societal benefits of C-ITS (results from simulation)

In simulation, there are several possibilities to set up variables to create the most realistic situation. This model environment is used to examine if and to what extent a C-ITS application contributes to societal goals by measuring KPIs related to these goals. Since most C-ITS applications are under development with high uncertainties about their exact future functionalities and behavioural response, we used reasonable bandwidths for realistic simulation.

Results on a solitary intersection

The figures below show bandwidths of the impact of TTG/TTR and GLOSA on a solitary intersection on between the Kungsängsleden and Dag Hammarskjölds Väg in the south of Uppsala. The bandwidth is biggest on the number of stops, meaning that, especially GLOSA could impact the number of stops significantly (ranging from -28% to +8% stops). TTG/TTR has lower impact on the number of stops.

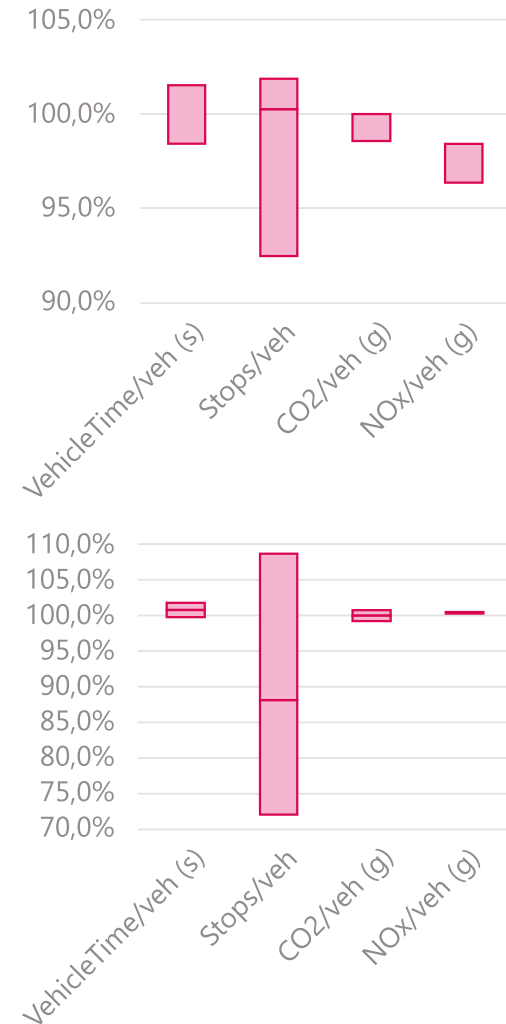


Figure 6: Impact TTG/TTR (top) and GLOSA (bottom) on solitary intersection



The diagram also shows no to limited (significant) impact on travel time or environmental KPIs. The negative impact is caused by the fact that the added information by C-ITS on a solitary intersection can only slow down cars. Speeding them up would encourage speeding, which is not desirable. A small reduction of travel time is possible because added knowledge about start time of green phase reduces reaction time. This could result in approximately 0.5 seconds travel time gain per intersection for the first vehicle(s). What is striking is that fewer stops not necessarily lead to lower environmental impact. The fact that vehicles do not need to stop does not mean that the average vehicle speed increases. Lower average speeds are less emission friendly, which limits the benefits on environmental KPIs.

Results on a corridor

On a solitary intersection there was almost no environmental impact observed. On a corridor, as investigated on Uppsala's Tycho Hedéns Väg, emissions could reduce, meaning there is potential to scale up C-ITS applications. However, as seen in the diagram below, no significant effect on travel time is seen. Also, a slight increase in the number of stops (+1%) is possible. This could

be caused by shorter cycle time, or an increase of stops for the side-directions, crossing the green wave.

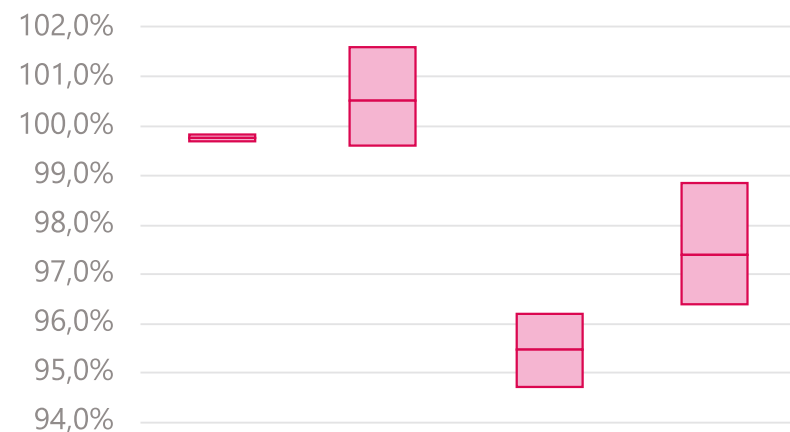
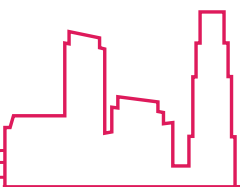
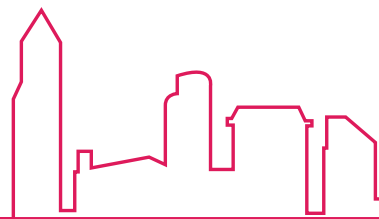


Figure 6: Impact GLOSA on green wave corridor



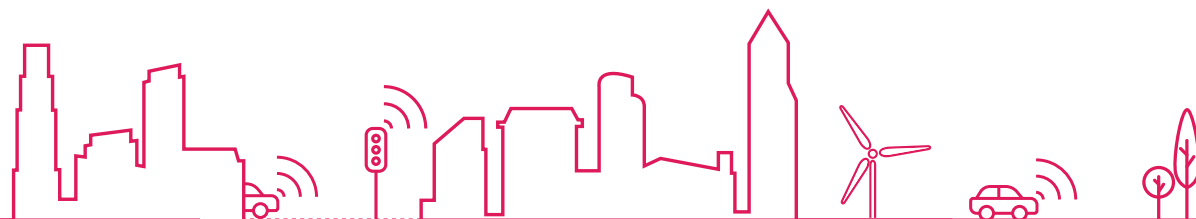
Results on mixed traffic intersections with priority for public transport

Bus priority can significantly improve traffic flow of public transport, with minimal negative impact for other road users. With priority for buses, as investigated on the Kungsgatan around Uppsala Central Station, the travel time loss per intersection could be reduced to up to 50% compared to the current situation. This means on average a reduction of 10% of the travel time for buses. Such a reduction in travel time has a big impact on reducing the costs for exploitation. An important precondition in achieving the positive impact for public transport, is to not create additional delays for bikes and pedestrians. Depending on the load and presence of public transport, the delays for cars could increase from +1% to +18% (average +6%).

Priority has limited (negative) impact on the number of stops (+3%) for other road users which might lead to reduced comfort of road users. Nevertheless environmental KPIs show a small decrease as a result of priority for public transport (<-1%).

This means that the improved traffic flow for public transport has higher positive impact regarding emission than the slightly decreased traffic flow for other road users. This however is highly depending of the number of public transport in the network in relation to other road traffic.

Since most impact is seen on travel time for public transport, C-ITS is most promising on locations where an improvement of travel time and exploitation costs for public transport is desired. If travel time can be reduced for public transport, public transport becomes more attractive, which means more people will use it. If the use of public transport increases, car use decreases, which contributes positively to environmental KPI's.



Factors that have a significant impact on the success of C-ITS

From our exploration with different technical and behavioural settings we found factors that influence the success of C-ITS, and factors that have no significant impact. Factors that have a significant impact on a variation in the results are the type of traffic signalling, the percentage of vehicles that is connected with C-ITS and on a corridor also the distance over which the advice is given plays a significant role.

By varying different signalling settings, it has been found that the impact of GLOSA is most significant when it is implemented in combination with predictable phase durations (fixed-time signalling plans). Vehicle-actuated signal operations have uncertain signal timings, which means that the needed reliable timing is not available. Therefore, on current signal operations, GLOSA likely will not bring a positive impact, and may even worsen traffic performance.

The percentage of vehicles with C-ITS connection has a positive impact on all KPIs. In general, the more vehicles that are equipped, the higher the benefits. Also, there might be a threshold that requires some level of penetration from which significant impact is observed. The distance from which the advice is given plays a significant role as well. The longer the distance of advice, the more vehicles are given the option to use this advice to create positive effects.

In addition to factors that significantly impact the success of C-ITS on KPIs, we also found variables that do not seem to have any influence. The continuity of advice (informing only once, or every second) and the buffertime (time to anticipate leaving the intersection) seem to play no role in impacting the societal benefits of C-ITS. Contrary to the impact on a corridor, the distance from where the advice is given does not play a significant role on a solitary intersection.



6.2 Impact of C-ITS on soft KPI's

In our simulations of intersections, it is not possible to include all (soft) indicators with relevance to society. We can, however, extend the results by comparing the results to literature and logically reasoning what the expected impact on these soft indicators could be. Further studies should focus in more detail on KPI's such as user experience, traffic safety and environmental factors that are difficult to measure.

C-Roads WG3 – Evaluation and Assessment Final Report (2022) states results from other European countries: Users in Spain and in the United Kingdom stated that where services operated reliably, users felt at ease because of the service. The fact drivers knew when lights would change appeared to have a positive effect on their feeling when approaching traffic signals. It was also found when waiting at red lights that GLOSA had a positive effect on a driver's preparedness and awareness. This improves driving experience and comfort. Cities should also investigate the possibilities to benefit bikes and public transport with C-ITS.

C-ITS could reduce nuisance for residents close to intersections.

Calmer driving and fewer stops lead to less acceleration and deceleration, which leads to less noise pollution around intersections.

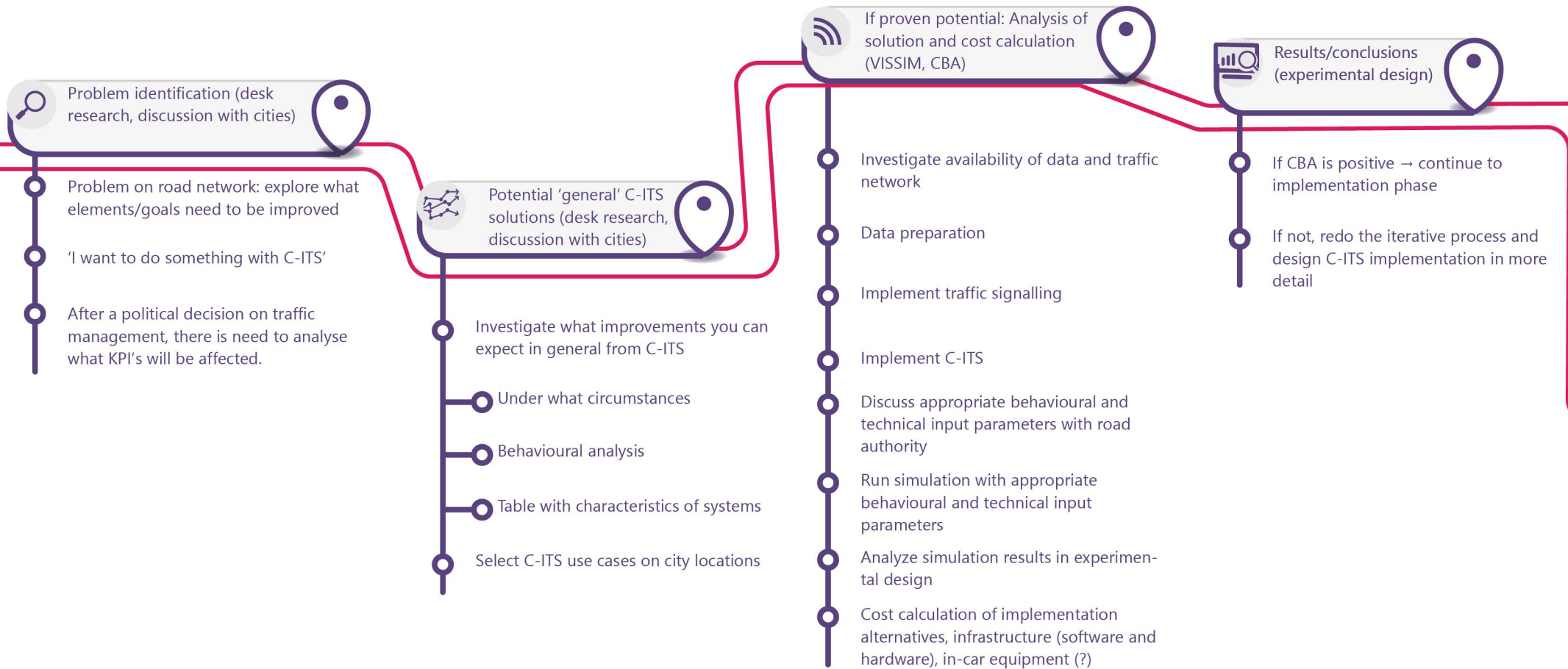
More reliable information leads to better anticipation, improved reaction times and a reduced likelihood of incidents/accidents. Regarding behavior of road users, both decrease of speed and increase of speed were seen to avoid stopping (C-Roads, 2022). The first could result in more harmonized traffic, less speed differences, less overtaking and fewer conflicts on intersections. The latter could result in more unsafe situations, because of speeding, larger speed differences between road users and possible red-light negotiations.

6.3 Process with road authorities

During the NordicWay 3 project, we collaborated with road authorities to co-create an assessment method to explore the societal impact of C-ITS. Close collaboration with road authorities plays a crucial role to create a better understanding of the potential of C-ITS to solve societal issues. The following process serves as a guide in order to pay the needed attention to understand societal objectives, the potential of C-ITS and its preconditions.



PROCESS WITH ROAD AUTHORITIES

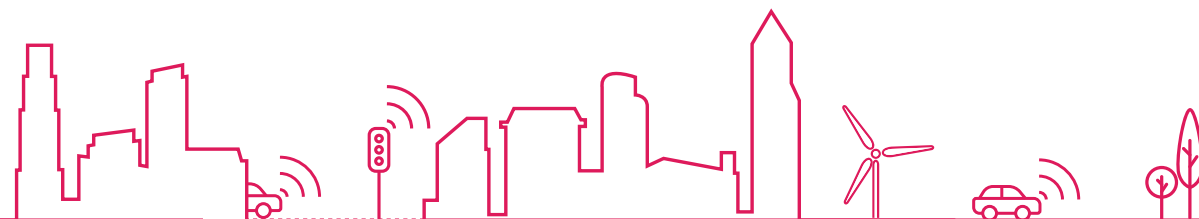


6.4 Conclusions and Next step: Towards C-ITS implementation

The impact of C-ITS is limited on a solitary intersection. On a corridor, the impact is strengthened, which is promising when planning to scale up the applications. Most impact is expected on the number of stops at intersections. The number of stops is, however, not the most important KPI. In relation to the potential benefits on environmental KPI's, as shown in section 2.2, this study proves that fewer stops not necessarily lead to higher sustainability. With fewer stops, the average speed could still reduce, meaning that cars drive slower but do not come to a full stop. A lower average speed is less emission efficient when driving a car powered by fossil fuel.

The limited impact of C-ITS is generally explained by the comparison to a well-functioning current situation. These analyses are carried out assuming the current vehicle fleet. To create a better understanding of the energy use, we advise to explore different compositions of the vehicle fleet. Lower average speeds are for example promising for hybrid cars, where vehicles drive electrically at lower speeds, which has a huge impact on the reduction of fossil fuel.

The results of this study also highlight the limitations of C-ITS. Providing information to road user comes with a cost of flexibility and efficiency of green phases. In order to provide trustworthy information, the length of green phases needs to be fixated. Vehicle actuated traffic signalling is, however, far more efficient than fixed traffic handling. Vehicle actuated traffic signalling results in 10-20% better traffic flow and 2-3% less emissions compared to fixed traffic signalling. In some cases, the current situation could perform better than a situation where C-ITS is implemented. Therefore it is important to compare the success of C-ITS to a (well-functioning) current situation, which could result in concluding that C-ITS is not desirable under certain circumstances.



Further research should be done to explore the impact of softer KPIs, such as lane changes, red light negation, smart routing and the attention and safety of road users. Also, C-ITS could decrease operational costs for the infrastructure and possibly decrease exploitation costs for public transport. Smart routing additionally benefits the operational costs for logistics. Even if the C-ITS services do not show great advantages, you can get support for other services, such as autonomous driving.

Deliberate abuse of the system should be further researched as well. If no information is given, the road user could draw the conclusion that reaching the green light is no longer feasible. Perhaps with a small speeding violation it is. The road user may accelerate in combination with lane change. Lastly, it is important to understand how non-users behave when users of C-ITS around them adapt their behaviour. Differences in knowledge levels between non-users and users may lead to interpersonal issues and unexpected events.



