Intelligent Traffic Light Controllers in Sustainable Urban Mobility Plans

The role of intelligent Traffic Light Controllers (iTLC) in Sustainable Urban Mobility Plans (SUMP)

About CROW

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CROW is an independent not-for-profit knowledge organisation that invests in knowledge for the present and future. We aim to find the best solutions to issues from policy to management in infrastructure, public space, traffic and transport, and work and safety. In addition, we are procurement and contracting experts.

Disclaimer

*T*his paper contains a projection of the Dutch iTLC system and governance, based on the SUMP methods of the European Platform of Sustainable Urban Mobility Plans.

European Platform on Sustainable Urban Mobility Plans

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iVRI

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1 Introduction

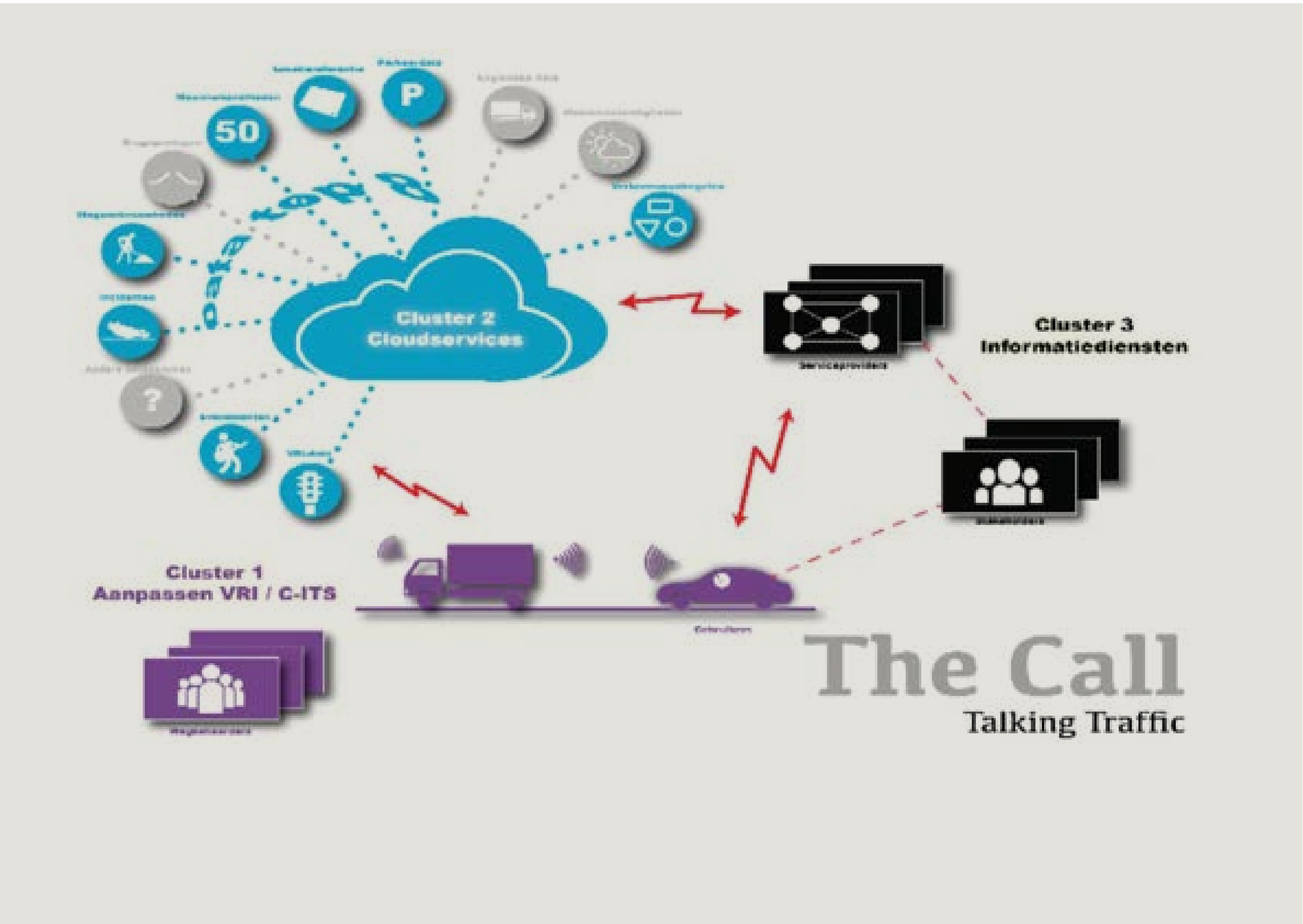
1.1 About iTLC and Talking Traffic [1]

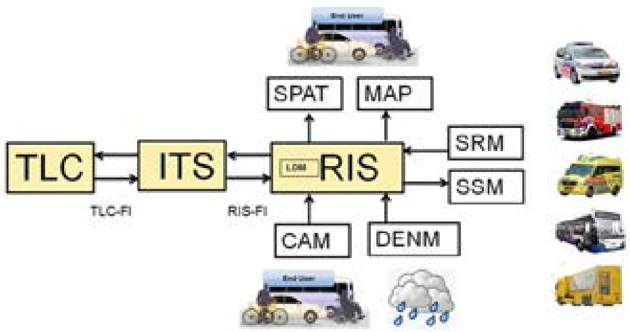
Intelligent Traffic Light Control Systems (iTLCs) have an important role in the deployment of C-ITS and traffic management. The iTLC can be beneficial to various SUMP goals. Therefore, and because of the recent large-scale deployment of iTLC's in the Netherlands and Flanders, we focus on this document specifically on iTLC. In the Netherlands and Flanders over a thousand iTLC's are connected to the national data platform "Urban Data Access Platform" (UDAP). Connected vehicles and iTLC's exchange data in real time via UDAP using standardized data formats. Based on the data, iTLC's can, among other things, give priority to certain types of vehicles such as ambulances and vehicles; receive information about time to green; or speed advice with which can be assessed whether a vehicle can still make it to green safely.

The figures below show the architecture and standardized data streams which are needed to make the use cases work.

The key features of the iTLC architecture, data streams and usecases are:

- Open Eco System: automotive, telecom, cloud service providers, fleet management system providers, iTLC suppliers.
- Three redundant clouds for data merging and distribution.
- Merging & distribution of public and private data: not just traffic lights, but also freight vehicle data, logistic processes, events and so forth.
- Latency under 1 second and end-to-end via telecom networks: 4G/LTE.
- Partly technical (e.g. standards, interfaces), but primarily conditional (privacy, security, data use, business rules) with a joint governance.
- For all types of road users: cars, trucks, buses, trams, cyclists, and pedestrians.
- iTLC related usecases: Green Light Optimization Speed Advice (GLOSA), priority for target groups and optimization traffic control by using data of connected vehicles.





Talking Traffic and Mobilidata

Talking Traffic and Mobilidata are smart mobility projects in the Netherlands and Flanders. The project involves collaboration between government agencies, private companies, and knowledge institutions to develop and implement new smart mobility solutions. At its core, Talking Traffic uses real-time data and cellular communication technologies to provide drivers and traffic managers with better insights into traffic conditions and potential hazards. This includes a range of solutions such as intelligent traffic lights, dynamic route guidance, and in-vehicle information systems that provide real-time updates on traffic conditions and road safety. The project is designed to improve safety, reduce congestion, and optimize mobility by integrating different transport modes and enabling more efficient use of the existing infrastructure. It also provides a platform for testing and deploying new mobility innovations.

Communication technologies [2]

The two main technologies for communication between connected vehicles and iTLC are:

1. ITS-G5, the European standard for short range V2X communication.
2. 4G, also called LTE Uu, long range cellular network based communication.

This publication is mainly based on the experiences with 4G/LTE in the Netherlands and Flanders. Nonetheless a thorough analyses of the pros and cons of both should be part of the feasibility study in advance of deployment of iTLC solutions in the context of SUMP.

1.2 Why to integrate an iTLC approach in SUMP? [3]

iTLC can be considered to have three roles related to sustainable urban mobility planning:

1 **Tools to implement transport measures and achieve policy goals**

iTLC enables quick implementation of innovative measures. Current examples include Green Light Optimization Speed Advice (GLOSA), priority for various modes such as emergency vehicles and the guidance of freight transport. This helps reduce CO_2 and NO_x emissions by preventing stop and go traffic. By providing tools to prioritize certain groups of vehicles, specific policy objectives within the municipality or region can be integrated in the local traffic management scheme. For instance, by prioritizing groups of cyclists at traffic lights, the city can further promote the use of active modes for commuting. Another example is the ability to support incident management, enabling the traffic manager to clear specific road segments after an incident has occurred in the network. While traffic lights can already be considered to be the city's gatekeepers that regulate and prioritise transport modes according to policy objectives, the next generation iTLC and its potential to deliver new types of measures, bring the game to a new level, making integration in SUMPs more feasible and versatile.

2 **City infrastructure**

iTLC enables cities to build on existing infrastructure to deliver innovative mobility policies to accomplish more sustainable and cost- effective objectives, tackling urban transport challenges for passengers and freight effectively and efficiently. Depending on the iTLC level-of-readiness and implementational maturity in a city, this technology offers tailor-made support which complies to policy objectives, technological readiness and local implementation plans. This way, cities can play an important role by providing open data for re-use through smart city/urban mobility data portals, which is supported by the open iTLC architecture, which are accompanied by public-private contractual arrangements that promote the exchange of data.

3 **Data provider for developing, monitoring, assessing and evaluating SUMPs**

iTLC combines several data sources that support SUMP development, implementation and monitoring. For example, iTLC enables the collection and storage, the exchange and processing of digital information, e.g., real-time data on multimodal traffic flows. Therefore, iTLC can be used as a tool in the different steps of the SUMP development process (e.g. baseline- analysis, modelling, scenario-development, monitoring, user/stakeholder involvement, etc.).

1.3 Opportunities and challenges

1.3.1 Opportunities

As the availability of city data increases, new opportunities arise to deploy new use cases on a large scale. An example of a usecase delivering environmental benefits is the Green Light Optimum Speed Advisory (GLOSA), which allows drivers to have in-vehicle information on the best speed to adopt while approaching a signalized intersection in order to avoid having to stop due to a red light, or even to slow down and then accelerate back to cruise speed, thus reducing fuel consumption and increasing comfort.

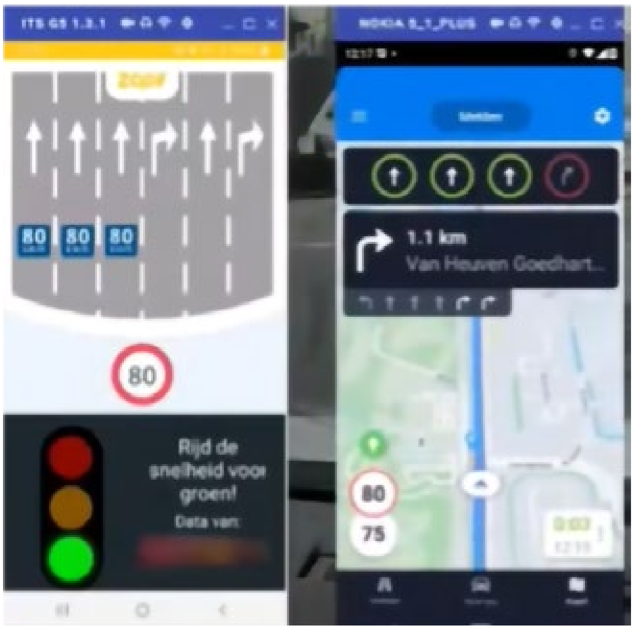
More generally, C-ITS and iTLC can increase the transport system efficiency and operational excellence. Examples are the Green Priority at signalized intersections for emergency services or public transport vehicles. Further developments could promote shared mobility concepts by giving shared vehicles a subtle form of priority. Ultimately the iTLC concept makes more data sources available to regulate traffic in a smarter and more efficient way then before. From data of connected vehicles, data of opening of bridges and loop detector data to smart data fusion and smart control algorithms, iTLC forms the basis for next generation traffic management which paves the way to optimised use of existing infrastructure.

1.3.2 Challenges

A key aspect to maximise the societal impact lies in the standardisation of data streams, using a centralised data hub. With this, a variety of service providers can make feasible business cases with sufficient customers for use cases like freight priority on connected transport corridors. Keeping initiatives and innovations local is, in the long run, not interesting enough to service providers, who seek to deliver high-quality information and guidance to a large customer group. This economy-of-scale requires nationwide deployment at a minimum. However, European-wide deployment is considered to be preconditional to create significant impacts on SUMP objectives. In this perspective the choice between ITS-G5 and 4G or a hybrid combination of both is a significant challenge to be met before making steps towards largescale deployment.

The Netherlands and Flanders have pioneered through a phase of transition, having learned valuable lessons. The first one is that a public-private partnership is needed to develop and maintain nationwide standards, including a governance structure to administer the required changes in the standards. Secondly, the business-to-business impact on the success of iTLC solutions is only realised with a bit of help from public road authorities. Otherwise, road users will not buy or adapt iTLC solutions as GLOSA or freight priority, however obvious the societal and individual benefits turn out to be.

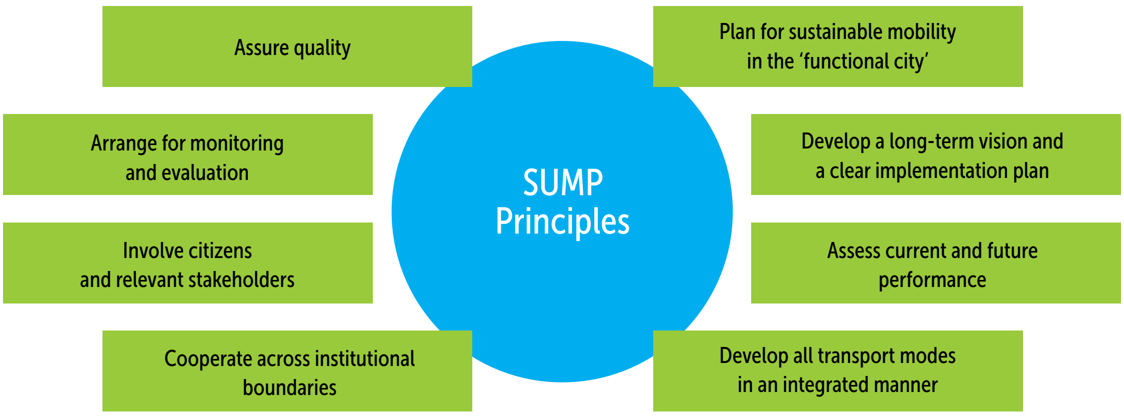
Another big challenge is to prepare road authorities and iTLC suppliers to perform new and different tasks. The roles of both parties have changed from a one-off government procurement process to an ongoing co-operation of parties within in an ecosystem, consisting of several interfaces and interdependencies. This requires all parties to redefine their roles and responsibilities, including the need for ong-term financing, needed to safeguard the permanent availability of the use cases.



2 The 8 SUMP principles and the relevance of iTLC [3]

Building on existing practices and regulatory frameworks, the basic characteristics of a Sustainable

Urban Mobility planning can be summarised in the following 8 principles according to the 2013 Urban Mobility Package.



The 8 SUMP principles will be addressed through an introduction of the specific key challenges posed by the deployment of iTLC.

2.1 Plan of sustainable mobility for the "functional urban area"

From the user's perspective, the transport network is one entity with trips not stopping at administrative geographical boundaries. iTLC implementations must envision beyond municipal, or even regional borders, thus enabling, or even forcing local governments to co-operate on sustainable mobility planning in metropolitan areas, or even at national or European levels where necessary. For example, freight will go from city to city and from country to country, so their priority service at iTLC's should be interoperable across the continent, underlining the need for European standardization. The precondition of a well-governed national plan for implementing iTLC architecture and publicly available data streams is, in this aspect, somewhat different from the preferred bottom-up approach that is associated with the SUMP methodology.

The iTLC architecture, and the data ecosystem associated with it, enable governments to create multimodal frameworks to guide traffic along the network in a safe, healthy and sustainable way. Various guidelines for the setup of such frameworks are available across Europe. In chapter three examples can be found.

2.2 Develop a long-term vision and a clear implementation plan

iTLC solutions should be objective-oriented; the technology is a means to policy ends. SUMP, combined with multimodal network frameworks, will help align these objectives. This can enable transitions for traffic management: municipalities can move on, not only prioritising among different multimodal networks, but defining key performance indicators to make the quality of service for each transport mode explicit. The prioritisation is needed in case a quality of service for a particular transport mode cannot be met. As an example, when a regional bike corridor crosses the main access road for cars through a signalized intersection, choices will have to be made: which level of service is more important? It is often impossible to give both modes a free flow quality, so the long-term vision and implementation plan should provide explicit goals and methods to identify short- and long-term measures.
The other aspect in this matter is the readiness level of adopting new technologies to serve the long-term vision. It is for example much simpler to introduce new services when the city or region has an open data architecture, living up to legal compliance rules, to make integration possible.

2.3 Asses current and future performance

iTLC can offer significant added value to urban authorities in assessing the current, as well as the future performance of the transport system. It can explicitly show the impact of implemented mobility policies. iTLC can provide digital information on efficiency and sustainability of the urban mobility system and in particular can:

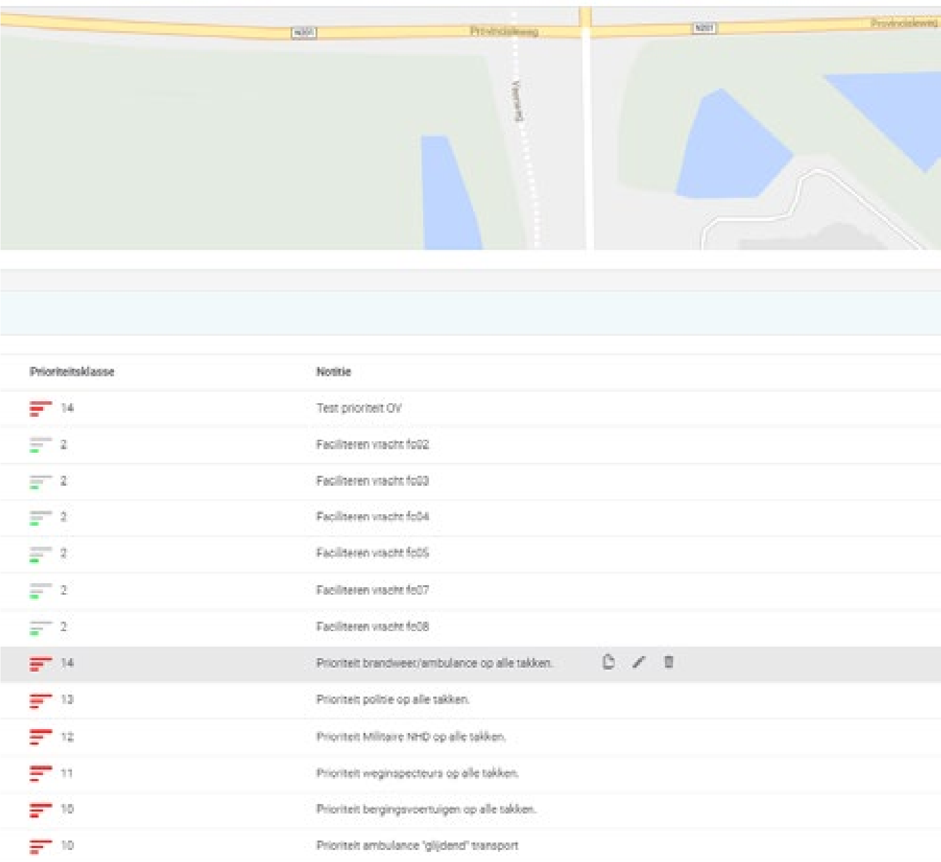
a collect real-time information through continuous monitoring and produce data through analyses and simulation techniques.
b implement policies at different levels of the urban area.
c offer tools and methods that help to reach policy objectives dynamically and within a limited amount of time.
d directly feed information on SUMP performance indicators, as defined by the city. They allow common performance indicator content, also valid for verification, assessment and comparison across Europe.

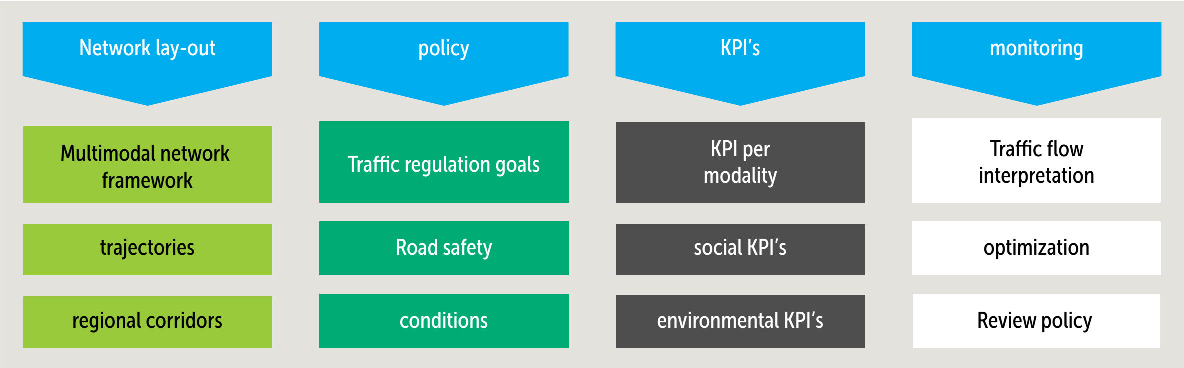
The figure shows the possibility to implement priority classes for various modalities which are fit to policy goals of the city.

2.4 Support all transport modes in an integrated manner [4]

The primary function of an iTLC is to handle all traffic at intersections that require interventions from the viewpoints of capacity management, and sometimes solely for the purpose of traffic safety, such as pedestrian or bicycle crossings. In that matter, an iTLC is still a TLC. iTLC's, however, allow for more intelligent controls, being increasingly used as a tool to deliver more sophisticated transport policy measures. These measures do not necessarily reflect the traditional traffic engineering point of view, but can integrate environmental, health, sustainability and other potential dimensions of community wellbeing policies into the system.

Making traffic lights more intelligent offers opportunities but also complicates the task of traffic management. Road authorities can either outsource this task, or, if the human capital is available in their own organization, develop policies in such a way that integrated policy objectives are made explicit.





Since many policy indicators need to be monitored and dynamically managed, and since the margins to influence the situation through local traffic light algorithms on a single intersection are often small, it is time to transcend from this local control to routes, corridors or even network control strategies. This enables the road authority to assess the quality of a whole journey instead of adding up individual intersection performances. Still, at the intersection level it remains necessary to set basic requirements for road safety (credibility, avoiding back spills, et cetera). Hard and explicit tactical choices are important; the clearer an authority is on preferred routes, the more effective it can support regional main connections. In order to do this, KPI's need to be developed that clearly reflect the extent to which basic levels of service are being met. These should be standardised, enabling road authorities to make them available in digital format for use by service providers (item circulation plans RTTI).

Within the Netherlands, several guidelines enable road authorities to formulate abstract, high-end policy objectives, and translating them towards concrete iTLC measures, key performance indicators and a monitoring scheme. More details are available in paragraph 3.2.

2.5 Co-operate across institutional boundaries

A truck driver, cyclist or any road user does not really care which road authority runs the iTLC that she is passing. Only the quality of the journey itself is relevant. Setting up and reaching agreement on what main corridors correspond to what modalities in a certain region is therefore essential. After that, a hierarchy could be set to determine what should be done if a certain level of service can't be met. If, for example, a corridor for public transport underperforms, is it acceptable to introduce longer waiting times for cyclist on their corridor? Having regional agreements, it is possible to formulate specific iTLC measures that are both tailormade – accounting for political and local preferences – and still contribute to regional objectives.

In particular, the CROW Multimodal Network Framework (MNK) [5] methodology enables co-operation among road authorities to co-ordinating the management of urban and regional accessibility. Through translating societal policy objectives into hierarchies of multimodal corridors, it is possible to formulate performance indicators, that can be fed by iTLC measurements and a monitoring scheme.

2.6 Involve citizens and relevant stakeholders

Involvement of citizens and relevant stakeholders is needed in various stages of the process. This includes representatives of road authorities, emergency services, public transport, freight, road operators, cyclists, pedestrians, individual car drivers, disabled road users, shared mobility providers, navigational service providers, traffic management operators, to name a few. All of them have a role in the different steps to integrative account for all transport modes, fulfilling the objectives from the perspectives of accessibility, health, safety and the living environment of all citizens. The involvement of these stakeholders assures that the iTLC configuration not only meets the objectives of the traffic engineer, but also ensures that the iTLC meets the societal demands. For example, minimising the stop/go instances of freight trucks can meet the objective to improve air quality by nudging transport companies and their drivers to take the preferred route around the city centre instead of following an undesirable route straight through this densely populated area. For this, all relevant stakeholders should be able to take notice of the preferred route, as well as access to the available iTLC enabling them to use them to their benefits. This requires that traffic engineers configure the iTLC appropriately, and that navigational service providers for transport companies implement the associated services within their fleet management systems. Finally, transport companies, as well as the individual truck drivers need to use the priority service in the vehicle, ideally driven by positive effects on their operating costs and comfort. This shows that active involvement and commitment of parties is necessary to achieve a well-working priority service.

2.7 Set up monitoring and evaluation

The first step for proper monitoring and evaluation is the definition of the desired level of service through key performance indicators (KPIs) for all transport modes. For example, on the main freight corridor a composite KPI could be calculated for the average freight traffic speed being over 40 km/h, while the waiting time for crossing cyclists does not exceed 40 seconds per cycle. Of course, KPI's need to consist of measurable data. The availability of reliable data and accurate tooling should be checked as a part of this step. iTLC uses the v-log data format [6], containing the logging data of loop detectors and all signal phases. Using specific software, waiting times for all the phases can be calculated. Furthermore, CAM, SRM and SSM data [6], can be used, informing the traffic engineer about speed, type of vehicles and the extent to which certain types of vehicles received priority at an intersection. Finally, the floating car data, collected by fleet management providers, can be used for the purpose of monitoring and evaluation on corridor and network levels.

2.8 Assure quality [3]

Through the execution phase of a SUMP, process quality, as well as compliance with the chosen objectives, should be examined periodically. The quality assurance process of a SUMP is usually done by external reviewers or higher levels of government. Still, forms of self-evaluation can inform local governments, if the appropriate evaluation criteria are applied in the SUMP process. The standards for the quality assurance process (i.e. in terms of number of participating stakeholders, quality of documents used for decision making, level of feedback expected or required from the citizens etc.) should be set by the stakeholders. This is ideally governed by the municipality. Analogously, the quality of the SUMP content can be aligned within this process by checking the compliance of the priorities and individual measures with existing technical guidelines. This can in particular be the case for the iTLC related components of the SUMP, where openness and interoperability must be assured.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3 Considering iTLC in SUMP implementation [3]

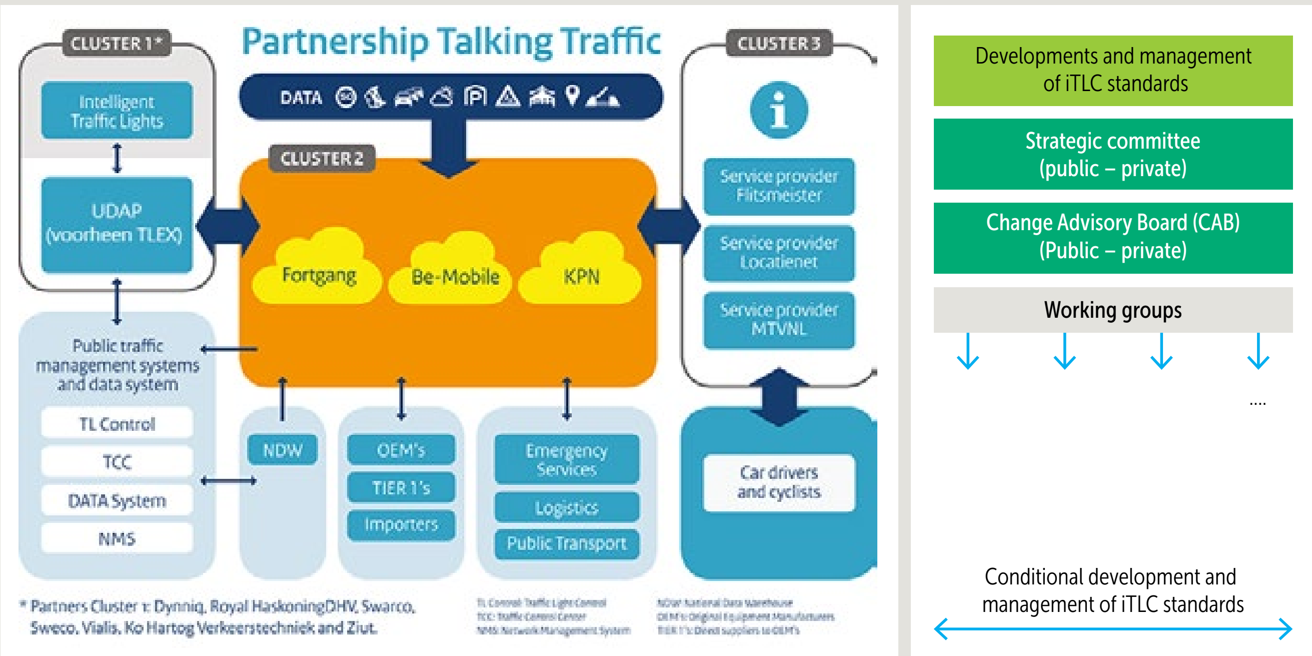
This chapter introduces the essential activities required, as well as considerations for urban planners, traffic engineers and decisionmakers when integrating iTLC in the SUMP process presented in the figure below.

iTLC planning is a multilevel endeavour: iTLC implementation in urban areas usually concerns the management of interconnected transport and mobility systems which extend beyond the municipal level. The impact of iTLC measures increases with the scale of deployment. Therefore, we start this chapter with an explanation of the importance of large-scale deployment. After that we describe the essential actions and considerations of an iTLC integrated approach in the SUMP implementation.

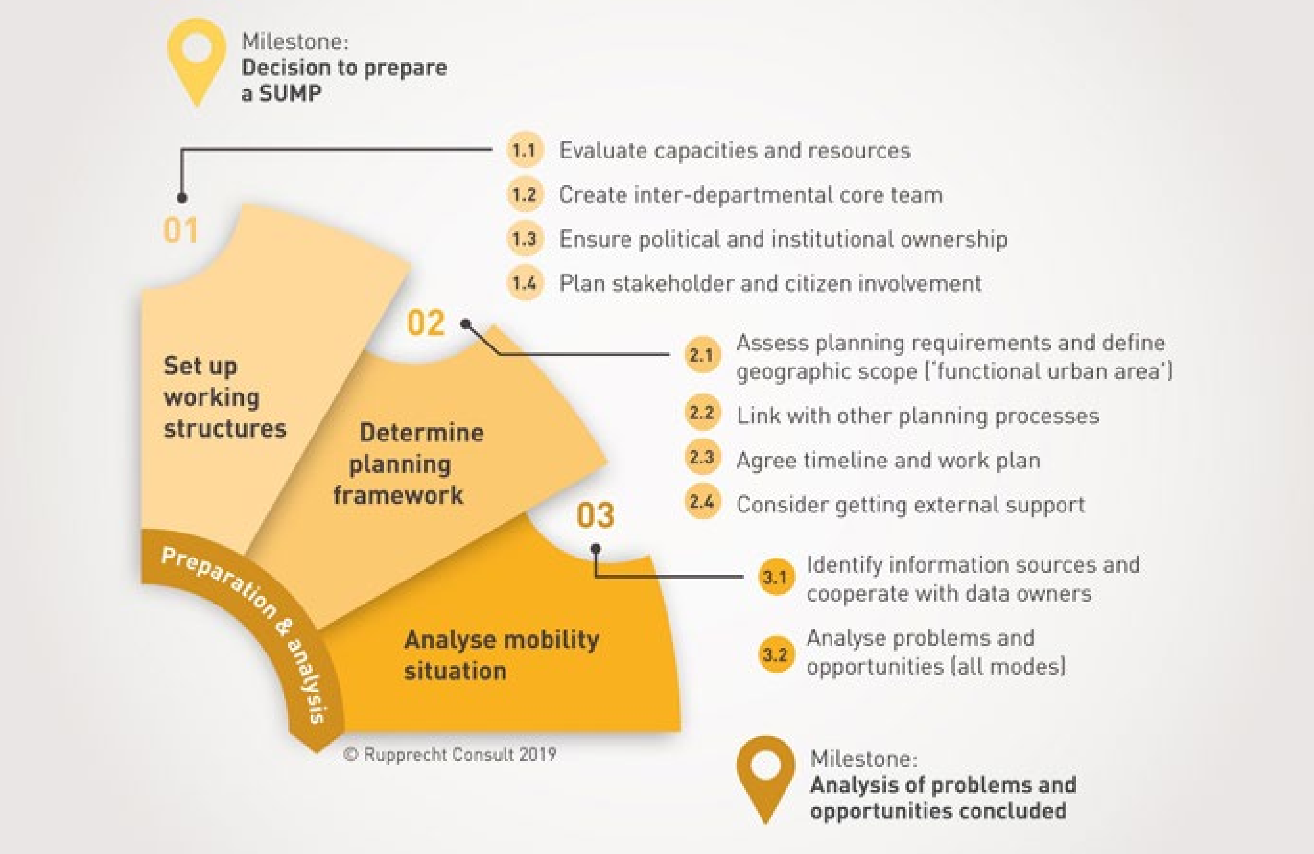
Large-scale deployment as a prerequisite for maximum impact

The effectiveness and added value of iTLC applications depends on its scale of deployment. A priority service for freight, for instance, should at least function on a national, or perhaps a European scale. If not, road users and service providers will not see the benefits of the use case. A nationwide deployment of the iTLC architecture and data streams is therefore essential. This includes the requirement to create a governance structure to maintain and improve the standards. Current examples are the Dutch and Belgian approach with Talking Traffic and Mobilidata [8], as well as Nordic Way [9], in Scandinavia. Essential for this approach is that both public and private partners engage in a collective effort to develop and maintain standards for data exchange and interfaces, based on European standards. This precondition is a major difference compared to the traditional SUMP methodology in which a city or a region can work in some degree of isolation.

Having gone through the developmental phase, called Talking Traffic, the low countries developed a governance structure that maintains, defines, and implements changes within the entire ecosystem in a highly controlled manner [7]. This governance structure is illustrated in the figure above on the right. . The Strategic Committee (SC) makes all final decisions regarding the adoption of changes in the ecosystem. Participants are a mix of public and private partners, appointed by the Minister of Infrastructure and Waterworks. The Change Advisory Board (CAB) is the preparatory entity, which is open to all stakeholders, seeking support and involvement for improvements and bug fixing. Working groups perform the actual task of preparing, specifying, and processing the needed alterations to the standardisation scheme. These (temporary) working groups recruit from the group of experts within the field, mostly on a voluntary basis.



3.1 Phase I: Preparation and analysis of mobility situation [10]



This phase consists of three steps: set up working structures, determine planning framework and analyse mobility situation.

01 Set up working structures

1.1 *Evaluate capacities and resources*

In this first step, the project team develops an understanding of: a) the availability and quality of current (i)TLC systems and technologies; b) the maturity of the local administration to adopt iTLC solutions; and c) the actors involved in the iTLC ecosystem, including their roles and responsibilities towards systems development and implementation.

1.2 *Create inter-departmental core team*

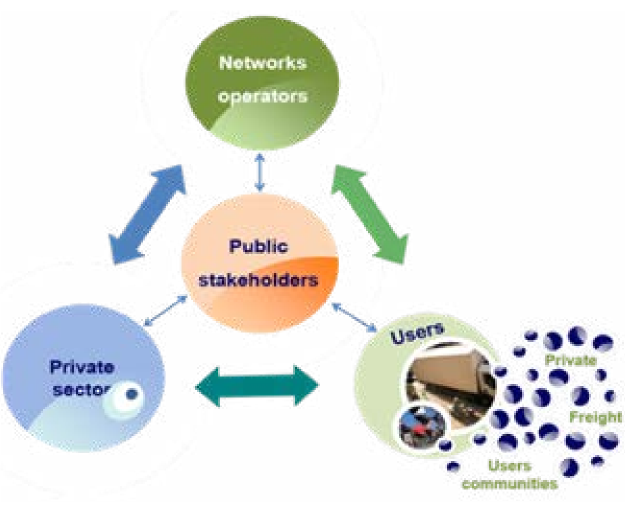
An interdepartmental core team ideally consists of representatives several departments, such as asset management/public works, traffic management, transport policies, sustainability, and social inclusion. These expertise will be influenced by, or can benefit from the implementation of iTLC related SUMP objectives.

1.3 *Ensure political and institutional ownership*

For iTLC services, it is elementary that resources and estimated budgets are clearly specified to the ones politically involved, since this technology is less dependent on the single procurement of technical installations, but on long-term contracts and service level agreements. A steering committee, consisting of different political representatives could ensure political ownership and understanding of the possibilities and limitations of iTLC based traffic management.

1.4 *Plan stakeholder and citizen involvement*

Although relying on data services, an iTLC is still an asset for a city which should perform according to the functional and operational specifications. Therefore, the asset management department should be involved, often being the responsible party to oversee the maintenance task of new iTLC solutions. Functionally, iTLC serves societal goals such as the improvement of traffic flow for different transport modes, which need to be aligned with SUMP goals. Involving representatives of different road user types is therefore evident. Usually this includes emergency services, public transport operators, goods transports, cyclists, (visually) impaired road users, elderly and children. On the other end of the spectrum, the private sector, such as iTLC vendors, navigational and cloud service providers, communication network providers, fleet management operators and in-car ITS suppliers could be involved. Good stakeholder management will require some form of regional or national private-partnership to support successful implementation, as shown in figure below [3].



02 Determine planning framework

2.1 *Asses planning requirements and define geographic scope ("functional urban area")*

Defining the geographical scope, often called the daily urban system, is crucial for SUMPs because it allows for analyses and measures that account for complete door-to-door trips, enabling policymakers to identify viable and sustainable alternatives. It accounts for the fact that transportation networks, commuting patterns, and mobility needs often extend beyond the city limits, requiring collaboration among different municipalities and jurisdictions to effectively address urban mobility challenges.
It all start by understanding the characteristics of the city and its surrounding areas. Analyses of demographic data, economic activities, commuting patterns, and existing transportation infrastructure help identify the areas that are functionally connected to the city and contribute to its urban mobility.
This step is a general step to be taken in the SUMP process and requires a minimum of specific iTLC considerations. For example:

- iTLC can be a source of relevant information in terms of traffic counts and waiting times for various transport modes as an input for analyses of commuting patterns,
- the actual control strategy can be of help to give insight into the use of existing transportation corridors.

2.2 *Link with other planning processes*

In sustainable urban mobility planning, it is important to integrate various planning processes to ensure a coordinated approach. To connect the mobility expertise to other policy fields, it is required to identify relevant other planning processes, establish coordination mechanisms and define common goals and objectives. For iTLC solutions there are various aspect to be taken into account such as:

- The defined functional area mostly covers more municipalities, thus a link should be made with the planning process across the different municipalities and their iTLC contractors.
- Within the own municipality, there are more stakeholders involved in planning iTLC solutions. This can relate to replacement activities because of its age or road reconstructions. In those cases different departments are responsible for planning of iTLC solutions.
- Also, co-ordination with policy plans for other policy fields, such as air quality plans and spatial planning might be of influence on how iTLC might be needed in the future.

2.3 *Agree timeline and work plan*

The work plan should define milestones and estimates of activities to deliver the eventual sustainable urban mobility plan. For this, a specific scope, timeframe and the phase breakdown structure is elementary. Discussing the specific consequences that relate to potential iTLC solutions is advised to include in this plan, since these require detailed planning and project management efforts, as well as specific knowledge on both the technology and the subject matter of network-based traffic management strategies.

2.4 *Consider getting external support*

The work plan will give an estimate of necessary resources to work on the next phases of SUMP. This will give insight into the level of need for external support.

Typical iTLC considerations in this perspective are to get external support from specialized iTLC and traffic management consultants who are able to make the crossover between strategic SUMP goals and iTLC solutions.

03 Analyze mobility situation

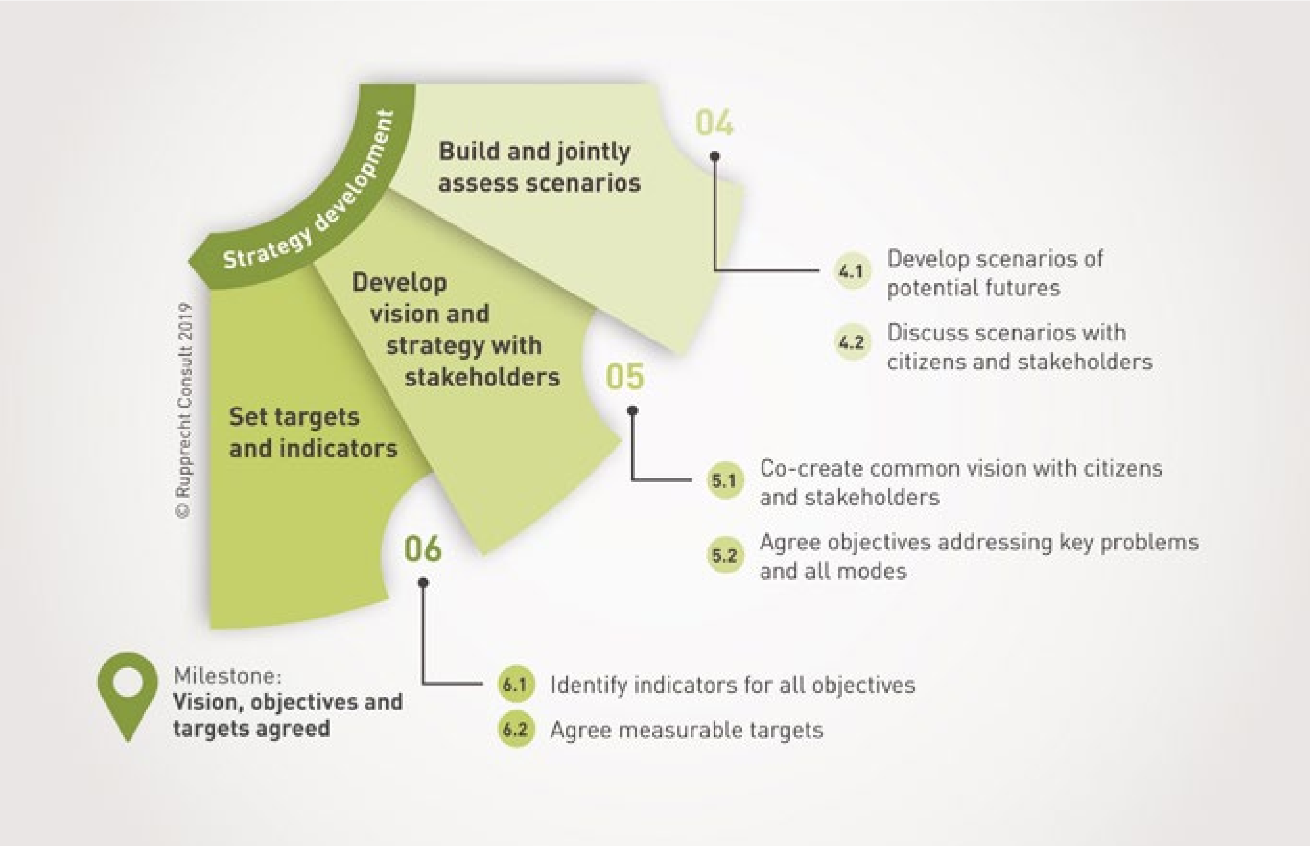
3.1 *Identify information sources and co-operate with data owners*

When working on Sustainable Urban Mobility Plans (SUMPs), it is essential to gather information from reliable sources and co-operate with relevant data owners. These can be public and private iTLC stakeholders. Data from traditional traffic light controllers typically includes information about the current state of the traffic lights, timing parameters and vehicle detection. With these data items, it is possible to gather information about traffic flows on the signalized intersections. Also waiting times or red light negation can be gathered from traditional TLCs.
With iTLCs, so-called CAM, SRM and SSM data is available which holds extra information in comparison to traditional TLC data. As CAM data is delivered every second to the iTLC controller it gives detailed information about for example position, heading, speed and type of vehicles. In the images above there is an example shown about what can be done with data analyses of CAM data [11]. In the image you can see speed analyses to compare two control strategies.

3.2 *Analyse problems and opportunities (all modes)*

Sustainable urban mobility plans (SUMPs) aim to create more efficient and environmentally friendly transportation systems in cities. So to make a contribution to the SUMP goals we need to gain insight into problems and opportunities on the use of public transport, walking and cycling, shared mobility and efficient freight transport and cars. In relation to iTLC the analyses of problems can be focused on getting insight in on which trajectories and intersections we see congestion or high waiting times. Typical iTLC opportunities and solutions are: prioritization of public transport and (groups) of pedestrians and/or cyclists and freight transport on corridors to reduce emission. Optimizing the efficiency of traffic controllers and implementation of state of the art adaptive control system can be a part of the solution as well. With modern iTLC the integration with connected vehicles and traffic management systems can be made. This integration allows for real-time communication between vehicles and traffic infrastructure, enabling features like traffic signal pre-emption for all types of modes and dynamic traffic rerouting to minimize congestion.

3.2 Phase II: Strategy Development [12]



04 Build and jointly assess scenarios

4.1 *Develop scenarios of potential futures*

Developing scenarios of potential futures in relation to traffic light controllers combines an understanding of emerging technologies with an understanding of societal trends. In regard of iTLC implementations, possible scenarios could be:

1 Fully connected and autonomous vehicles dominate the road, and traffic light controllers communicate directly with these vehicles, optimizing traffic flow and minimizing congestion.

2 Traffic light controllers incorporate advanced AI algorithms [13] that continuously analyse real-time data to adapt signal timings based on traffic patterns, weather conditions, and events, resulting in more efficient and safer intersections.

3 Traffic light controllers integrate with smart city infrastructure [14], allowing them to share data with other systems like public transportation, emergency services, air quality monitoring, and pedestrians, enabling synchronized mobility across different modes.

In all of these potential future scenarios traditional traffic light control systems won't be fit for purpose anymore. iTLC is in a way preconditional to work towards these scenarios of potential futures.

4.2 *Discuss scenarios with citizens and stakeholders*

When discussing scenarios with citizens and stakeholders on SUMP and iTLC, it's important to organise an inclusive and participatory environment. To effectively engage and discuss scenarios with citizens and stakeholders, it is imperative to:

1 Define the objectives:
Clearly establish the purpose of the discussion and the desired outcomes. Are you seeking input on traffic light

timings, intersection design, or other related aspects? Define the scope and communicate it to the participants.

2 Identify key stakeholders:
Identify and invite the stakeholders who have a interest in the topic, such as community groups, transportation experts, urban planners, businesses, and representatives from relevant government departments, public transport, freight organizations, ambulances, fire brigades, police force, representatives from special interest groups, such as environmental working groups, the physically and mentally disabled, low-income groups, et cetera.

3 Provide background information:
Share relevant information about the SUMP, its goals, and the specific focus on iTLC. This helps participants understand the context and make informed contributions.

4 Present different scenarios:
Develop a range of scenarios related to iTLC that address the identified objectives. These scenarios can include different traffic signal timings, adaptive corridor oriented signal control systems, prioritization of emergency vehicles, public transport or groups of bikes. Present the scenarios clearly, using visual aids like maps, diagrams, or simulations to aid understanding.

Furthermore, there are more general steps in order to come effectively engage and discuss scenarios with citizens and stakeholders: consider impacts and trade-offs, analyse feasibility and costs, seek consensus and prioritize, document and communicate the outcomes and incorporate feedback and re-iterate.

05 Develop a vision and strategy with stakeholders

5.1 *Co-create common vision with citizens and stakeholders*

A common vision in the context of Sustainable Urban Mobility Plans (SUMP) regarding traffic light controllers could be to prioritize the efficient and safe movement of pedestrians, cyclists, and public transportation while reducing congestion and emissions. This vision aims to create a more sustainable and inclusive urban transportation system.

Creating a common vision with citizens and stakeholders in the context of Sustainable Urban Mobility Plans (SUMP) regarding iTLC involves a participatory and inclusive approach. Steps to be made are: develop a common vision statement, refine and finalize the vision, communicate and implement the vision among all stakeholders.

5.2 *Agree objectives addressing key problems and all modes*

When it comes to SUMP and iTLC, it is essential to agree on objectives that address key problems and consider all modes of transportation. Here are some points to consider:

1 Key Problems:
Identify and prioritise the key problems related to urban mobility. This could include traffic congestion, air pollution, queueing times for pedestrian and cyclists infrastructure, inadequate public transport, or safety concerns.

2 Multi-Modal Approach [5]:
Recognize that urban mobility involves multiple modes of transportation, such as cars, bicycles, pedestrians, buses, and trams. Develop objectives that consider the needs and challenges of each mode and promote an integrated, efficient, and sustainable transportation system.

3 Safety and Accessibility:
Focus on objectives that increase safety for all road users, including (and maybe prioritising) pedestrians and cyclists. Ensure that traffic light controllers are designed to provide adequate crossing times, prioritise pedestrian and cyclist movements, and create safe conditions at intersections. Additionally, make sure that the system complies to national legislation and international treaties, concerning accessibility for the disabled, such as audible signals or tactile surfaces.

4 Sustainable Transport:
Promote objectives that encourage sustainable modes of transportation, such as walking, cycling, and public transport. Traffic light controllers can support these objectives by providing shorter waiting times for pedestrians and cyclists, prioritising public transport movements, and creating a favourable environment for active modes.

5 Data-Driven Decision Making:
Utilise real-time traffic data and advanced control algorithms to optimize signal timing, dynamically adapting to changing traffic conditions. This can improve the overall performance of traffic light controllers.

Main cycle corridors Copenhagen

Multi-Modal approach [4]:
An example of a Multi-Modal approach is to shift attention from controlling single intersections to managing routes or even whole corridors. In this approach, the quality of a journey needs to be assessed, making the traffic regulation at a specific intersection a subordinate task. However, at the intersection level, it remains necessary to safeguard the local safety requirements (credibility, avoiding blockages, et cetera). The challenge is to solve these local issues by optimising on a route or corridor level. Copenhagen does this by setting objectives in terms of level-of-service on the most important corridors for the specific modes. For example: the prioritized bike lanes are to realise a 15% drop in travel times in 2025, compared to 2019. These objectives are set for all modes and with constraints on intersection level. This way, the policy goals are translated to multi-modal objectives on corridor and intersection level.

06 Set targets and indicators [4]

6.1 *Identify indicators for all objectives:*

1 Reduce traffic congestion on preferred routes selected in the Multi-Modal approach:
- Target: Decrease average travel time during peak hours by 10% on main bike or public transport or freight transport or car corridors.
- Indicator: Measure the average travel time on key routes during peak hours and track changes over time.

2 Enhance pedestrian and cyclist safety:
- Target: Decrease the number of red light violations at intersections by 15%.
- Indicator: Monitor and record the number of red light violations at signalized intersections and track improvements.

3 Optimize traffic signal efficiency on preferred routes selected in the Multi-Modal approach:
- Target: Improve signal co-ordination and reduce vehicle stops at intersections by 20%.
- Indicator: Measure the average number of vehicle stops per intersection per day and track the reduction achieved.

4 Reduce greenhouse gas emissions:
- Target: Decrease vehicle emissions at signalized intersections by 15%.
- Indicator: Monitor and record the emissions levels (e.g., CO_2, NO_x) at selected signalized intersections and track reductions achieved.

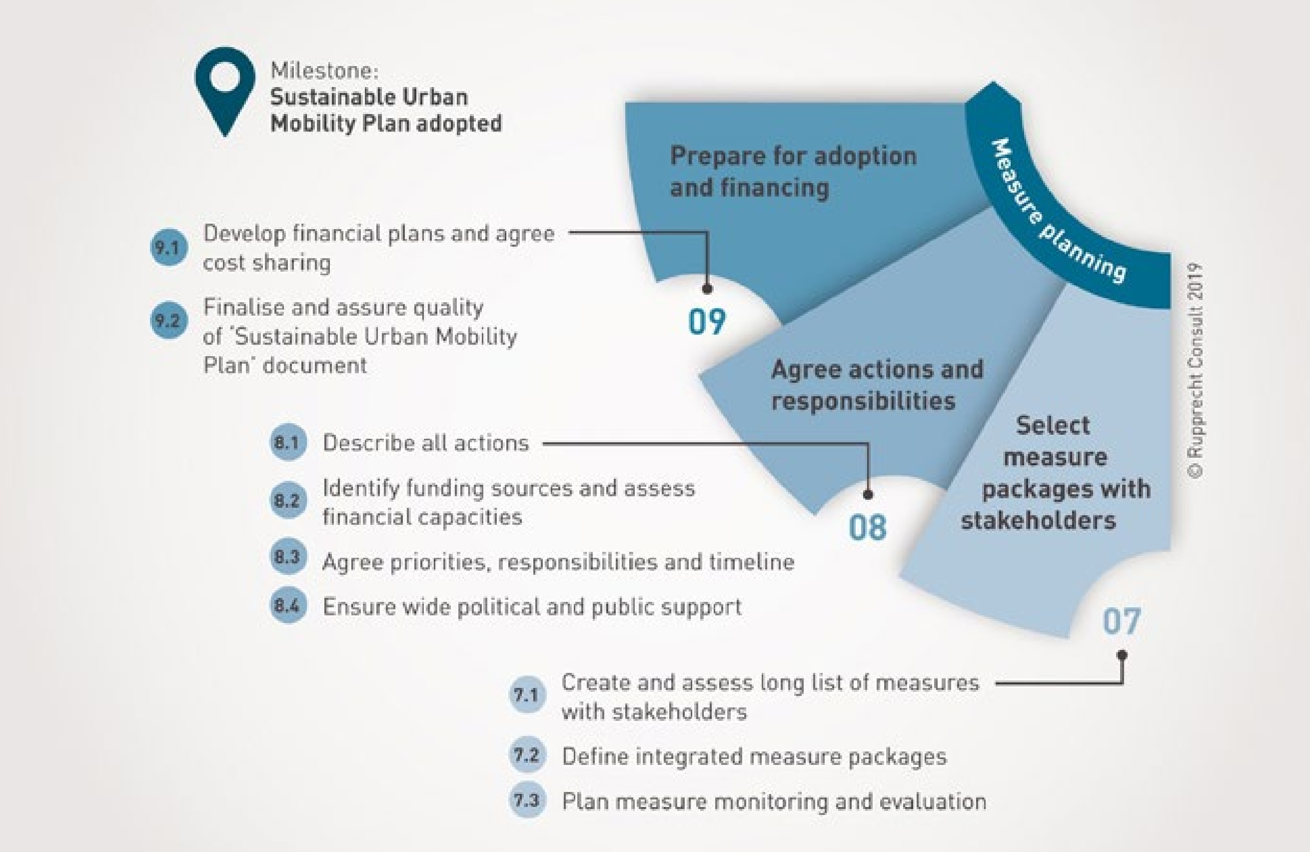
5 Improve accessibility for people with disabilities:
- Target: Ensure 100% compliance with accessibility standards at signalized intersections.
- Indicator: Conduct regular audits to assess the level of accessibility compliance and track improvements achieved, or take surveys among the interest group members.

6 Enhance data collection and analysis:
- Target: Implement a real-time traffic monitoring system at 90% of signalized intersections.
- Indicator: Monitor the percentage of signalized intersections equipped with real-time traffic monitoring systems and track progress

6.2 *Agree measurable targets*

- Decide on a set of measurable targets for each of the agreed-upon strategic indicators (see Activity 6.1), covering all of your objectives.
- Make sure that the agreed-upon targets can assess the achievement of desired outcomes.
- Express feasible, but ambitious targets.
- Ensure that the targets are mutually compatible.
- Involve key stakeholders in target setting, as this will ensure that targets are widely supported and realistic. However, be careful not to let lobby groups block ambitious change that serves the majority of people. Prepare, conduct, and follow-up working group meetings.

3.3 Phase III: Measures planning [15]



07 Select measure packages with stakeholders

7.1 *Create and asses long list of measures with stakeholders*

When developing sustainable urban mobility plans in relation to iTLC, it is essential to involve stakeholders and consider a wide range of measures. These measures can address various aspects of urban sustainability, including reducing traffic congestion, improving air quality, promoting active transportation, and enhancing overall liveability. A long list of measures and its estimated impact on SUMP goals can be found in chapter 4 of this document.

7.2 *Define integrated measure packages*

Integrated measure packages refer to a set of coordinated measures or actions implemented within sustainable urban mobility plans (SUMPs) to address transportation challenges and promote sustainable mobility.

In the context of iTLC and connected vehicles, integrated measure packages focus on technologies and data exchange to optimize traffic signal operations and improve the interaction between vehicles and the traffic infrastructure.

7.3 *Plan measure monitoring and evaluation*

A set of objectives and KPI's are preconditional for a thorough monitoring and evaluation plan that looks to traffic light controller measures. Once those are clear the following steps can be taken:

1 Collect baseline data:
Gather baseline data on the current traffic conditions, including traffic volumes, congestion patterns, and existing traffic light controller performance. This data will serve as a reference point for evaluating the effectiveness of your measures.

2 Define data collection methods:
Organize a system for collecting relevant data to monitor the performance of your measures. This may involve deploying sensors, cameras, or connected vehicle technologies to capture real-time traffic data, including vehicle counts, speeds, and queue lengths.

3 Implement monitoring mechanisms:
Set up a monitoring system to collect and analyze the data collected. This can involve integrating data from iTLCs, connected vehicles, and other sources into a centralized platform or traffic management system. Consider using data analytics tools to obtain insights and identify trends or areas for improvement.

4 Regular reporting:
Develop a reporting framework to communicate the progress and outcomes of the policy measures. This could involve creating periodic reports or dashboards that highlight the performance of KPIs, identify bottlenecks, and provide recommendations for adjustments or improvements.

08 Agree actions and responsibilities

8.1 *Describe all actions*

Actions that could be included in a SUMP and iTLC context:

1 Deployment of connected vehicle infrastructure:
Installation of infrastructure to support connected vehicles, such as dedicated short-range communication (DSRC) or cellular vehicle-to-everything (C-V2X) technology. This enables vehicles to communicate with traffic lights and other infrastructure elements.

2 Prioritisation of connected vehicles:
Facilities to prioritize connected vehicles at iTLC. For example, emergency vehicles or public transport buses equipped with connected technology can be given priority to improve the efficiency of emergency and public transport services.

3 Intelligent traffic signal control:
Promote the use of intelligent traffic signal control systems that can analyse real-time traffic data received from connected vehicles. These systems can optimize signal timings and adapt to changing traffic patterns, reducing delays and improving overall traffic efficiency.

4 Data collection and analysis:
Utilize the collection and analysis of data from connected vehicles and iTLC. This data can be used to understand traffic patterns, identify congestion hotspots, and inform decision-making for further improvements in traffic management and infrastructure planning.

5 Collaboration with stakeholders:
SUMP encourages collaboration among various stakeholders, including local authorities, transport operators, vehicle manufacturers, and technology providers. This collaboration is crucial for the successful implementation of connected vehicle initiatives and ensuring compatibility between vehicles and iTLC infrastructure. By actively promoting the use of open standards, and by cultivating an open government attitude, external stakeholders can integrate the available information from the iTLC system safely into their own operations.

6 Evaluation and continuous improvement:
Organize ongoing evaluation and monitoring of connected vehicle initiatives. This involves assessing the effectiveness of implemented measures, identifying aspects for improvement of connected vehicle and iTLC.

By optimizing the possibilities of interaction between connected vehicles and iTLC in real-time, traffic efficiency, traffic safety and sustainability can be significantly improved.

8.2 *Identify funding sources and asses financial capacities*

When it comes to funding sources and assessing financial capacities for implementing iTLC and connected vehicles in a SUMP, several options can be considered. Here are some potential funding sources and methods:

1 Government funding:
Local, regional, or national government bodies may have grants or programs dedicated to improving transportation infrastructure or promoting smart city initiatives. Research and apply for relevant funding opportunities from transportation or urban development departments.

2 Public-Private Partnerships (PPPs) [16]:
Collaborating with private companies, such as technology providers, automotive manufacturers, or telecommunication companies, can help secure funding and expertise. PPPs often involve sharing financial responsibilities, risks, and rewards between the public and private sectors.

3 Municipal budgets:
Allocate funds from the municipal budget to support traffic management and smart city projects. It is important to consider that iTLC budgets are only partially a one-off investment in technical roadside systems. Be aware that the exploitation of the system in terms of maintaining the digital ecosystem and the development of additional services requires a yearly budget. If managed well, the total cost of ownership is well outweighed by the societal benefits of an iTLC ecosystem.

4 Research and Development (R&D) grants:
Look for grants offered by government agencies or research institutions to support R&D efforts in the field of traffic management and connected vehicles. These grants can help cover the costs of developing and testing of innovative solutions.

8.3 *Agree priorities, responsibilities and timeline*

For an iTLC implementation in SUMP, the following items are recommended:

1 Priorities
Prioritise the implementation of measures that have the highest potential for positive impact and align with the overall goals of the SUMP.

2 Responsibilities:
a Identify the key stakeholders involved in the implementation of intelligent traffic light controllers and connected vehicles.
b Clearly define the roles and responsibilities of each stakeholder in the planning, implementation, and maintenance of the iTLC and connected vehicle systems. Aim for longer-lasting contracts and manage these well.
c Organize collaboration and coordination among stakeholders to ensure effective implementation and smooth operation of the systems. Attend extra attention to the data privacy and security aspects involved.

3 Timeline:
a Develop a realistic timeline that considers the complexity of implementing iTLC and connected vehicle systems. Consider factors such as technical feasibility, necessary infrastructure upgrades, regulatory requirements, and financial resources.
b Set specific timelines for key activities, such as procurement, installation, testing, and integration with existing infrastructure and vehicles.
c Regularly review and update the timeline to accommodate any changes or unforeseen circumstances that may arise during the implementation process.

8.4 *Ensure wide political and public support*

To ensure wide political and public support, you can consider the following strategies:

1 Public awareness campaigns:
Launch a comprehensive public awareness campaign to educate the public and political stakeholders about the benefits of iTLC and connected vehicles. Show how these technologies can improve traffic flow, reduce congestion, enhance safety, and lower emissions.

2 Stakeholder engagement:
Engage with local politicians, community leaders, and key stakeholders throughout the planning process. Seek their input, address their concerns, and involve them in decision making. This collaborative approach will help build trust and support for the measures. Actively discuss the data privacy and security concerns with citizens and other stakeholder groups.

3 Demonstrations and pilot projects:
Conduct small-scale demonstrations and pilot projects to showcase the effectiveness of iTLC and connected vehicles in real-world scenarios. Invite politicians, community members, and the media to witness the positive impact of these technologies first hand. Do consider the scaling up process from these experiments to real-life implementations.

4 Economic benefits:
Highlight the economic benefits associated with implementing iTLC and connected vehicles. Show how these technologies can attract investment, create jobs, and stimulate local economies, thus appealing to politicians and business communities.

5 Environmental benefits:
Show the environmental advantages of iTLC and connected vehicles, such as reduced emissions and improved air quality. Make sure to communicate these benefits to both politicians and the general public.

09 Prepare for adoption and financing

9.1 *Develop financial plans and agree cost sharing*

Considerations for financial plans and cost sharing in SUMP and iTLC are for example:

1. Cost allocation for infrastructure:
   Divide the costs of installing iTLC among the relevant stakeholders. This may involve negotiations and agreements between the municipality, transportation authorities, and private entities, such as technology providers or vehicle manufacturers. Consider factors such as the benefits for each stakeholder and their respective budgets.

2. Shared funding for connected vehicles:
   Determine the financial contributions required from connected vehicle owners or operators. This could be through subscription fees, usage-based charges, public funding, or other models.

3. Cost-sharing agreements:
   Develop formal agreements between stakeholders outlining the cost-sharing arrangements. These agreements should clearly define each party's financial obligations.

4. Establish a financial management plan:
   Set up a system for managing the funds allocated to the SUMP project. This may involve appointing a dedicated financial officer or team to handle budgeting and financial reporting.

5. Consider long-term funding for maintenance [17]:
   Define how ongoing costs for maintenance, software updates, and system upgrades will be covered.

9.2 *Finalize and assure quality of "Sustainable Urban Mobility Plan" document*

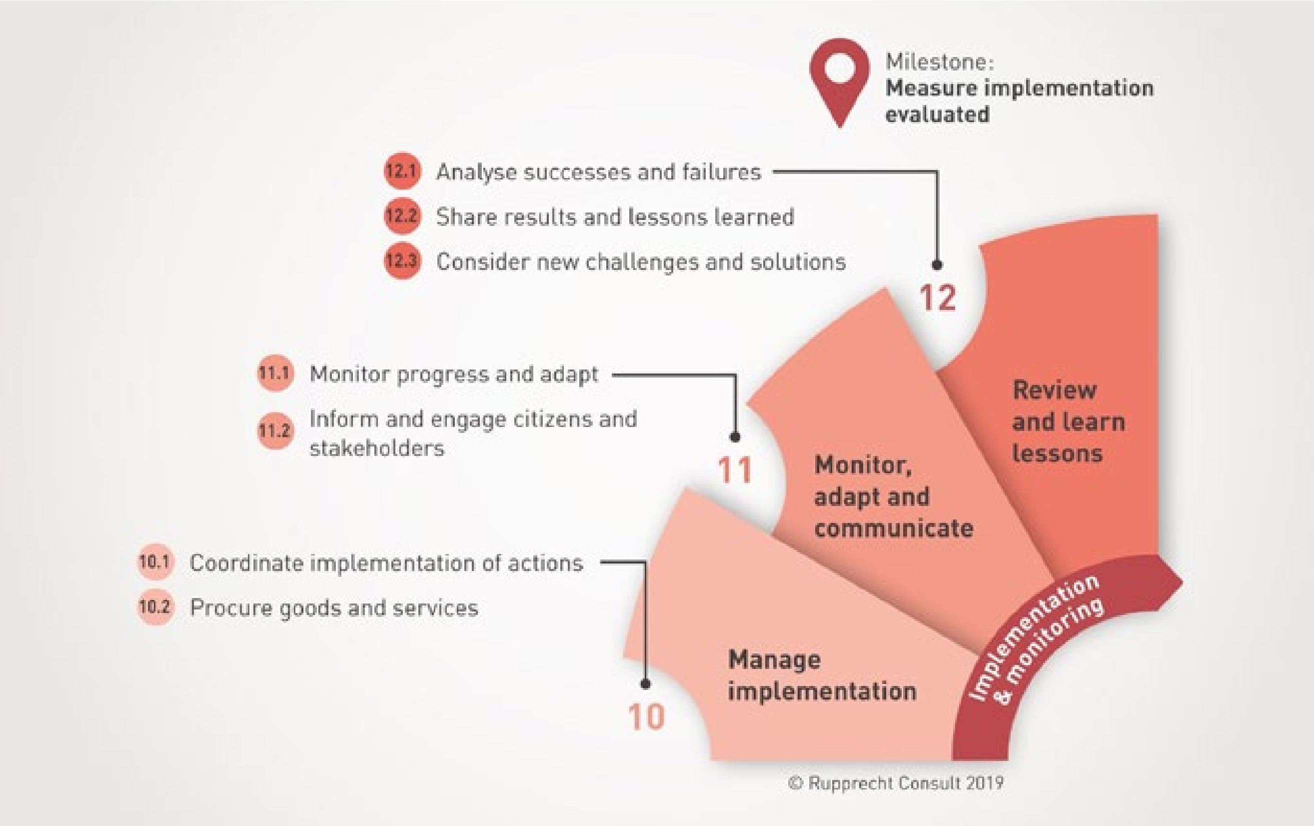
Here's a suggested approach on finalize and assure quality of a SUMP and iTLC document:

1. Review and revise the content:
   Ensure that the document includes all relevant information about sustainable urban mobility, iTLC, and connected vehicles. Review the content for accuracy, coherence, and consistency.

2. Check compliance with regulations and standards:
   Verify that the plan aligns with local and national regulations, transportation standards, and guidelines for sustainable urban mobility. This could include considerations such as emission reduction targets, traffic management policies, and safety regulations, as well as GDPR and RTTI compliance.

3. Ensure clarity and readability:
   Make sure the document is clear, concise, and easily understandable by various stakeholders, including policymakers, urban planners, transportation experts, and the general public. Use plain language and avoid unnecessary technical jargon.

3.4 Phase IV: Implementation and monitoring [18]



10 Manage implementation

10.1 *Coordinate implementation of actions*

The key steps to consider for successful implementation of iTLC and connected vehicles in SUMP are:

1. Check infrastructure requirements [19]:
   Evaluate the existing infrastructure to determine if it can support iTLC and connected vehicles. Identify any necessary upgrades, such as communication networks and data management systems. These investments are not only beneficial to the traffic management task, but could also improve the implementation of other smart city technologies.

2. Engage stakeholders:
   Involve relevant stakeholders throughout the planning and implementation process. Consider organizing workshops, focus groups, or consultations to gather input and build consensus.

3. Develop a roadmap:
   Create a detailed roadmap outlining the actions, timelines, and responsibilities for implementing iTLC and integrating connected vehicles. Identify specific projects, pilot initiatives, and deployment strategies.

4. Cooperate with technology providers:
   Work with technology providers specializing in iTLC and connected vehicle systems. Engage in partnerships to develop and deploy the required hardware and software. Ensure interoperability and compatibility among different systems.

5. Implement pilot projects:
   Start with small-scale pilot projects to test and validate the effectiveness of iTLC and connected vehicles. Monitor and evaluate their impact on traffic flow, emissions reduction, and overall transportation efficiency. Report the results not only within the own organisation, but share them with other parties, both nationally as internationally. Find alliances to co-ordinate the research agenda.

6 Regulatory and policy considerations:
Review and update existing regulations and policies to accommodate iTLC and connected vehicles. Address issues such as data privacy, cybersecurity, liability, and vehicle-to-infrastructure communication protocols.

10.2 *Procure goods and services [16]*

General outline of the procurement process of iTLC:

1 Define requirements:
Clearly define the requirements for iTLC and connected vehicles based on the specific needs of your sustainable urban mobility plan. Consider factors such as compatibility with existing infrastructure, connectivity standards, energy efficiency, and environmental impact.

2 Start market research:
Research and identify suppliers or manufacturers that offer iTLC and connected vehicles aligned with your requirements.

3 Request for Information (RFI):
Issue an RFI to potential suppliers to gather information about their products, services, and capabilities. Include specific questions regarding sustainability features, energy efficiency, connectivity standards, and any other relevant criteria.

4 Request for Proposals (RFP):
Prepare a detailed RFP document that outlines your requirements and evaluation criteria.

5 Evaluation and selection:
Evaluate the received proposals based on criteria such as sustainability, technical capabilities, compatibility, and cost-effectiveness. Depending on the investment volume, this process is usually governed by the EU procurement act.

11 Monitor, adapt and communicate

11.1 *Monitor progress and adapt*

Key points to consider with iTLC in SUMP related to monitoring progress and adaptation:

1 Data collection:
Implement a data collection system to gather information from iTLC and connected vehicles. This data should include traffic patterns, vehicle speeds, congestion levels, and environmental conditions. Strive for maximum openness, so third parties can benefit from this public data source.

2 Real-time monitoring:
Realize real-time monitoring tools to continuously check the performance of iTLC and the usecases with connected vehicles. This can help identify bottlenecks, optimize signal timings, and detect any malfunctions or connectivity issues.

3 Adaptive strategies:
Based on the insights gained develop adaptive strategies to improve the performance of iTLC and the usecases with connected vehicles. This may involve adjusting signal timings or optimizing priority services.

4 Continuous improvement:
Establish a feedback loop to continuously improve the system.

11.2 *Inform and engage citizens and stakeholders*

In this step the following strategies should be considered:

1 Public surveys and feedback mechanisms:
Conduct surveys and organise feedback mechanisms to gather opinions, suggestions, and concerns from stakeholders regarding the effectiveness of iTLC in relation to SUMP goals.

2 Case studies and success stories:
Highlight successful implementations of iTLC and connected vehicles usecases in other cities or regions. Share case studies and success stories through various communication channels to inspire citizens and stakeholders.

12 Review and learn lessons.

12.1 *Analyse successes and failures*

Successes and failures related to iTLC and connected vehicles use cases should be reported, feeding into the international research and development agenda:

1 Level of impact on traffic flow, emissions and safety [20]:
Intelligent traffic light controllers can use real-time data from connected vehicles to optimize traffic signal timings. This can lead to smoother traffic flow, reduced congestion, and shorter travel times for commuters.
The analysis should focus on the level of improved traffic flow, reduced emissions and improved safety.

2 Level of standardization [2]:
The integration of intelligent traffic light controllers and connected vehicles requires standardized communica-

tion protocols and data formats. In the absence of such standards, interoperability becomes a challenge.

3 Data privacy and security [19]:
Connected vehicles generate and transmit a significant amount of data, including location and behavioural patterns. Ensuring the privacy and security of this data is crucial to gain public trust and prevent potential misuse or unauthorized access.

4 Infrastructure requirements [19]:
Implementing iTLC and connecting vehicles needs infrastructure fit for purpose, including perfect communication networks. Deploying and maintaining this infrastructure can be costly, especially for cities with limited resources.

5 Technological limitations:
While iTLC and connected vehicles have great potential, there may be technological limitations that affect their effectiveness. For instance, unreliable connectivity or inaccurate data from sensors can lead to suboptimal traffic control.

12.2 *Share results and lessons learned*

The results and lessons learned of the analyses of successes and failures should be shared. Steps to be undertaken could include:

1 Finding opportunities to share your lessons learnt with other cities in your country, region or language area (and beyond, if possible).

2 Finding opportunities to learn from the experience of others in your country or region or country (and beyond, if possible). This could be on the SUMP content, process or iTLC measures.

3 Being willing to share less positive experiences openly as well as - importantly - what you learned from them and how you would do things differently the next time.

12.3 *Consider new challenges and solutions*

This final phase of the SUMP process is to reflect on experiences in the current planning cycle with a view to new challenges ahead. Tasks related to iTLC could be:

1 Consider new challenges for the future that could have an impact on the planning cycle and the SUMP implementation. Especially new developments of technologies and data usage might lead to major changes in the near future.

2 Identify how policies in other areas could create synergies with iTLC (smart city access or smart routing).

3 Be prepared to develop the next generation of your Sustainable Urban Mobility Plan.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4 What iTLC solutions can serve your SUMP goals?

This section presents a description of key iTLC solutions that can contribute to urban sustainable mobility objectives.

The table below is an indicative tool for planners and decision-makers to choose their measures according to the goals and priorities they pursuit. In the rows, there are 13 objectives that are common in SUMP, from the general such as improving liveability to the more specific such as gathering better data [3]. The more 'X', the higher the potential contribution of the measure to the objectives. SUMP goals may be monitored by Sustainable Urban Mobility Indicators (SUMI) [21].

The following paragraph describes the essential difference of iTLC solutions versus traditional traffic light solutions. The paragraphs following give definitions of the iTLC solutions as named in the solutions table.

SUMP goals / iTLC measures	GLOSA	Priority: Emergency vehicles	Priority: Public Transport	Priority: Road operator	Early detection: Freight	Early detection: Cyclists	Early detection: shared mobility	Next generation adaptive multimodel control scheme	SUMI indicators *
Improve city liveability	X	XX	XX	X	XX	XX	XX	X	#4 Noise hindrance #14 Quality of public spaces
Reduce CO_2 and improve air quality	XX	X	XX	X	XX	XX	XX	X	#3 Air pollutant emissions #7 Greenhouse gas emissions (GHG)
Reduce noise emissions	XX	X	XX	X	XX	XX	XX	X	
Improve safety	X	XX	X	XX	X	X	X	X	#5 Road deaths
Reduce congestion	X	-	X	X	XX	XX	X	X	#7 Congestion and delays #15 Commuting travel time (all modes
Unlock spacial opportunities	X	-	X	-	X	-	X	X	
Boost economic growth	X	X	X	X	XX	XX	-	X	
Smoother, seamless journeys	XXX	XXX	XXX	XX	XX	XX	XX	X	#9 Energy efficiency
Boost public transport	-	-	XXX	-	-	-	-	X	#12 Satisfaction with public transport
Boost active travel	-	-	-	-	-	XXX	X	X	#10 Opportunity for active mobility
Boost electromobility	-	-	-	-	-	-	X	X	
Better transport data	X	X	X	X	X	X	X	X	
									#1 Affordability of public transport for the poorest group
									#2 Accessibility of public transport for mobility-impaired groups
									#6 Access to mobility services
							X	X	#11 Multimodal integration
						X			#13 Traffic safety active modes
									#14 Urban functional divers
									#15 Mobility space usage
									#16 security crime an d passanger)

*) SUMI indicators description: https://transport.ec.europa.eu/system/files/2020-09/sumi_wp1_harmonisation_guidelines.pdf

4.1 Essential differences between iTLC solutions and traditional traffic light solutions

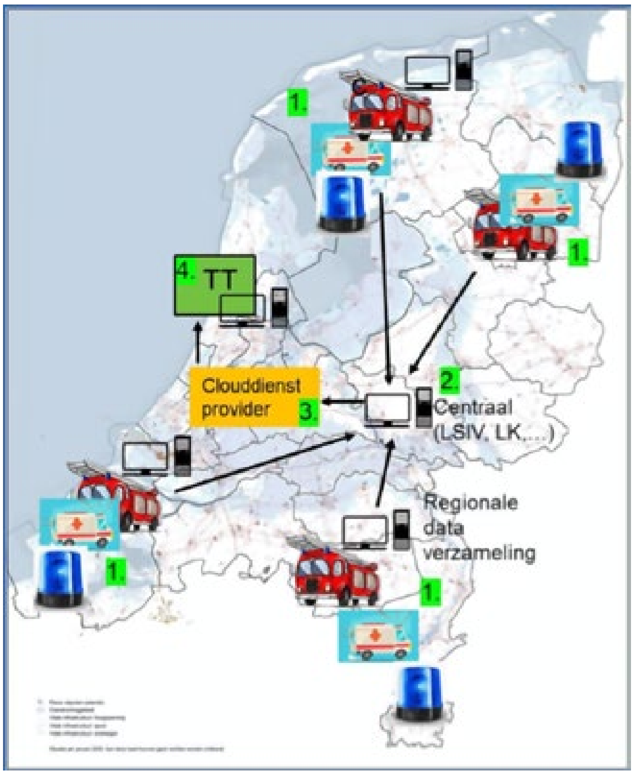
Most of all, iTLC is capable of receiving standardized data from all types connected vehicles and neighbouring intersection via the iTLC cloud and via the cellular network. The other way around it can also send standardized data towards connected vehicles and neighbouring intersections. The architectural setup provides the possibility of cloud-based solutions. Thus, already connected vehicles via fleet management systems can instantly connect to iTLC by interfacing to a cloud service provider which already is certified to connect to iTLC. The major advantage, compared to traditional traffic light services, is that additional hardware in or on the traffic light and in vehicles is not needed. Once connected by a cloud solution there is no need for additional hardware. Being independent from expensive cable architecture, this can be cost effective, as well as more versatile under ever changing conditions. Off course iTLC can function as well with ITS-G5 short range communication. As mentioned in the introduction a choice for ITS-G5 or 4G long range cellular network based combination or hybrid communication is to be done up front. And preferred on a national or European scale.

4.2 Green Light Optimization Speed Advise (GLOSA)

What and how? [9]
The usecase GLOSA provides information about the upcoming phase of the traffic lights ahead of the road user. It gives in-car information about time to green, time to red and in addition it can provide a speed advice to reach the intersection at the right time to prevent a stop at the stopping line. The standardized data which are used for this use case are called: SPAT and MAP.

Benefits?
The main benefits are: less stops, thus reducing emissions and noise emissions and a smoother and seamless journey.

Challenges? [2]
The main challenge is to send accurate information about time to green and time to red. Especially where dynamic, traffic actuated control systems are used it is hard to give the exact time to green and time to red. This is due to the fact that the green timeframes are not fixed.



Example: cloudbased solution to deploy rapidly nationwide priority for firetrucks.

4.3 Emergency Vehicle Priority

What and how? [16]
The use case "priority for emergency vehicles" makes that ambulances, firetrucks and police on their way to incidents send priority requests to the iTLC and the iTLC provides green light on the lights the vehicles are approaching. The standardize data which are used for this usecase are CAM, SRM and SSM.

Benefits?
The main benefits are: less stops and shorter travel times towards an incident. Also it provides a more comfortable and safer journey as the driver doesn't have to make risky manoeuvres at signalized intersections to pass queues before a red light.

Challenges?
Some countries already have other hardware like special loop detection or short distance radio communications to make the use case possible. However, these solutions are often implemented only locally or regionally, prohibiting interoperability. As COVID-19 has shown, and also when looking at the increased risk of large-scale incidents from climate change, such as floodings or natural fires, the deployment of emergency services will increasingly be cross-border. Therefore a well substantiated transition strategy is needed to make the transition to an iTLC architecture is needed.

4.4 Road operator vehicle Priority

What and how? [22]
The use case "priority for road operator vehicles" facilitates road operator vehicles on their way to incidents. This particular solution can be combined with technologies to alert the nearest roadwork vehicle to a particular incident. From the traffic management centre, a traffic operator is informed about the location of the incident and the real time locations of the available road operator. The nearest operator is then sent to the incident, automatically sending priority requests to the iTLC en route to the incident. The standardize data which are used for this usecase are CAM, SRM and SSM.

Benefits?
The main benefits are: less stops and shorter travel times towards an incident, earlier clearance, resulting in shorter and less congestion due to the incident. Also it provides a more comfortable and safer journey as the professional driver doesn't have to make risky manoeuvres at signalised intersections to pass the queues.

Challenges?
Standardization of the level of priority which is given by the iTLC may differ for one and the next road authority. On a national or regional level agreements should be made on this subject.

4.5 Public Transport Priority

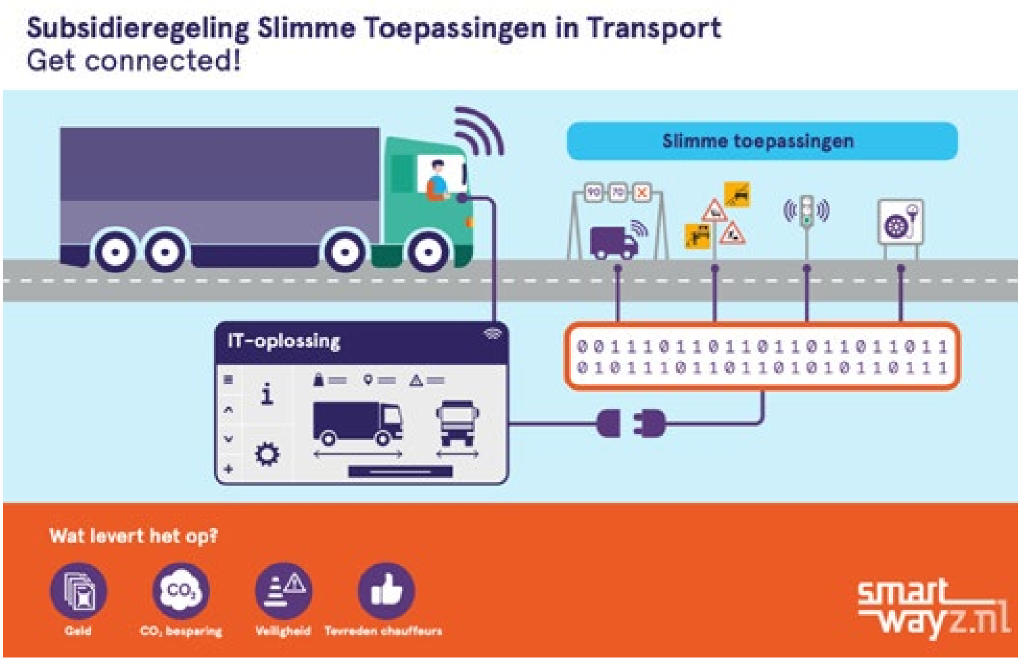
What and how? [24]
Public transport sends priority requests to the iTLC and the iTLC provides green light on the specific connection and direction of the bus or tram. The standardized data which are used for this use case are CAM, SRM and SSM.

Benefits?
The main benefits are: less stops and shorter travel times for public transport. Which results in a boost for public transport as it will be more attractive as an alternative for a journey by car.

Challenges?
Some countries already have other hardware like special loop detection or short distance radio communications to make the use case possible. Therefore a well substantiated transition strategy is needed to make the transition to an iTLC architecture. Co-ordinating these efforts with potential lower costs for bus manufacturers, integrating this technology might speed up this development.

4.6 Early Detection of Freight

What and how? [24]
In the use case "early detection of freight" a truck sends its position, speed and direction to the upcoming iTLC. The iTLC makes sure, if possible, that once the light ahead is



Example: public funding scheme to connect FMS to iTLC.

already keeps green until the truck has passed the intersection. In addition it is possible to combine this with GLOSA to prevent stops for trucks. The combination with fleet management systems is promising because it efficiently makes use of the position, destination and route information. This way, the early detection can be sent automatically to the right iTLC, conveying the turn direction on the intersection. The standardised data which are used for this usecase are CAM, SRM and SSM.

Benefits?
The main benefits are: less stops, shorter travel times, reducing CO_2 and sound emissions and fuel use. Nevertheless, always take into account that giving priority to one mode will have negative side effects for other conflicting modes.

Challenges?
The interface with existing fleet management systems (FMS) in freight vehicles is essential for large scale deployment. Public funding schemes [25] seem to needed to convince FMS suppliers and transport companies to connect their vehicles to iTLC.

4.7 Early Detection of Cyclists

What and how? [26]
When a cyclist approaches an intersection, their connected bicycle or wearable device can transmit their presence to the iTLC or to nearby connected vehicles. This data exchange can occur through wireless communication protocols such as Cellular Vehicle-to-Everything (C-V2X) technology. The intelligent traffic light system uses advanced algorithms to process the data received from the connected vehicles. These algorithms can analyze the information, including the speed, direction, and location of the approaching cyclists, to determine their proximity to the intersection. Based on the analysed data, the intelligent traffic light can prioritize the detection of cyclists and adjust the signal timing accordingly. For example, if a cyclist is approaching the intersection, the traffic light can extend the green signal to allow the cyclist to cross safely. The standardized data which are used for this use case are CAM.

Benefits?
The main benefits are: less stops and shorter travel times for cyclists. Which results in a boost of active travel.

Challenges?
Priority for groups of bikes would be a beneficial solution on SUMP goals. The degree of connected bikes are too small to identify groups of bikes. Therefore connectivity of bikes should increase more rapidly, so priority schemes can be implemented as well for connected bikes.

4.8 Shared Mobility vehicles Early Detection

What and how?
Shared mobility vehicles, such as ride-sharing cars or electric scooters, need to be equipped with connected devices that allow them to communicate with the iTLC. Based on the data received from the shared mobility vehicles and other traffic conditions, the iTLC can optimize the traffic light timings to accommodate the shared mobility vehicles more effectively. This may include giving priority to certain types of vehicles and adjusting signal timing.

Example: Early Detection of Cyclists with Schwung app.

Benefits?
The main benefits are: minimizing stops and delays for connected shared mobility vehicles, early detection can help reduce unnecessary idling and fuel consumption. This leads to lower emissions, contributing to improved air quality and reduced environmental impact. Also, it gives these services a little advantage over privately owned cars, increasing the attractiveness of these services, ultimately contributing to lower car ownership.

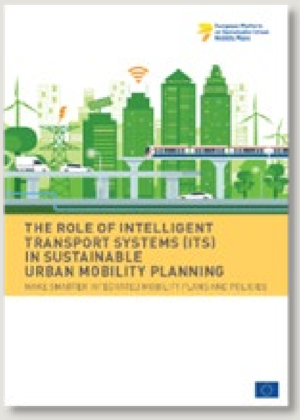
Challenges?
Shared mobility services often include a diverse fleet of vehicles, including cars, bikes, scooters, and more. Each type of vehicle may have different communication capabilities and sensors, making it difficult to ensure consistent and standardized early detection across the entire fleet.

4.9 Next generation adaptive multimodal traffic control

What and how?
Adaptive traffic signal control systems use real-time data from sensors, cameras, and connected vehicles to dynamically adjust traffic signal timings based on traffic conditions.

Benefits?
These systems optimize traffic flow, reducing congestion, travel times, and emissions.

Challenges?
Adaptive traffic signal control systems rely on accurate traffic prediction models to anticipate traffic conditions and adjust signal timings accordingly. Developing reliable prediction models that can account for various factors such as weather conditions, special events, and unexpected incidents is a challenging task, and inaccuracies in predictions can lead to suboptimal signal control decisions.



Further guidance on the role of Intelligent Transport Systems (ITS) can be found in the *Practitioner Briefing The role of Intelligent Transport Systems (ITS) in sustainable urban mobility planning.*

https://www.eltis.org

Further guidance on SUMP in Dutch can be found in the *Richtlijnen voor de ontwikkeling van een duurzaam stedelijk mobiliteitsplan (2021).*

https://www.eltis.org

and bij CROW at:
https://www.crow.nl/duurzame-mobiliteit/home/regionaal-mobiliteitsprogramma-rmp/1-regionaal-mobiliteitsprogramma-rmp/duurzaamheidsscore

The intelligent trafficlight controller

iTLC info- graphic

Sustainability

The iTLC enables the quick implementation of novel and more efficient algorithms to handle traffic dynamically, ultimately decreasing the emissions of CO_2, particulate matter, and traffic noise.

prioritization of special vehicles

Priority for public transport, emergency vehicles, and future modes requiring this can be easily implemented and adjusted

promoting active modalities

Cyclists and pedestrians, especially in large groups, that frequently use the same route, can profit from more timely green lights.

Use case development

The presence of the open communication platform enables service providers to develop new, yet unimagined use cases. Scaling up the iTLC within Europe will speed up this process.

Governance

The public-private standards, developed by parties in The Netherlands and Flanders, are free to use.

Find out more at:

https://www.crow.nl/thema-s/smart-mobility/landelijke-ivri-standaarden

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Colophon

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