Deliverable D5.6
Assessment of potential for new technologies

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Executive summary

The primary objectives of MORE (Multi-modal Optimisation for Road-space in Europe) are to develop and implement procedures for the comprehensive co-design of urban main road corridor infrastructure feeding the European TEN-T (Trans-European Transport Network) network, to accommodate their current and future multi-modal and multi-functional requirements, and to address severe problems of e.g. congestion, emission, noise, air pollution, safety and security, in situations where building new roads is not an option. These objectives are achieved by comprehensively assessing the needs of all road user groups to establish design criteria, defining key performance indicators to set out design requirements, and developing tools to assist the road space reallocation design process. The project tests these tools and procedures through detailed development of street design packages at feeder route corridors in five cities on different TEN-T networks, and on- and off-road trials. Furthermore, MORE believes that the optimisation of the road-space and capacity can be influenced by advanced technologies.

Based on the outcome from analysis of advanced technologies, technology and design trials were performed. Based on the lessons learned from the trials, an assessment has been made regarding the applicability and potential benefits of different forms of technologies in different contexts. The results of the assessments of potential for new technologies are presented in this deliverable. Within the project, two types of assessment methods were applied: 1) technical assessment through traffic simulation studies; and 2) users assessments through group discussions and interviews. Three use cases and a survey study were conducted. Use case 1 investigates the impacts of intelligent traffic control for urban feeder routes in Malmö. Use case 2 explores the impacts of the application of automated vehicles for public transport and city logistics in Helmond. Use case 3 studies dynamic road space allocation through LED (Light-Emitting Diode) road markings and signing. In addition, interviews were conducted to get the views of experts and decision makers of cities about the potential implementation of advanced technologies in European cities.

Based on the results from the use case studies and interviews, it can be concluded that positive impacts of new technologies are convincing, if technologies will be properly implemented. Cites will gain social, economic and environmental benefits by adopting and deploying advanced information and communication technologies and engineering solutions and services.

Abbreviations

Acronyms	**Meaning**
ADAS	Advanced Driver Assistance System
AV	Automated Vehicle
CAV	Connected and Automated Vehicle
C-ITS	Cooperative Intelligent Transport Systems
Covid-19	Corona Virus Disease 2019
FCD	Floating Car Data
GDPR	General Data Protection Regulations
GLOSA	Green Light Optimal Speed Advisory
ICT	Information and Communication Technology
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
LED	Light-emitting diode
LOS	Level-of-service
MaaS	Mobility as a Service
MORE	Multimodal Optimisation of Road-space in Europe
SAE	Society of Automotive Engineers
TEN-T	Trans-European Transport Network
TSC	Traffic Signal Control, also called Traffic Light Control (TLC)
WP	Work Package

Terms and definitions

Term	**Definition**
Cycle time	Time length of a traffic signal in seconds. In one cycle, all signal groups of an intersection have been green at least once.
Gating	*Gating* is a mechanism of restricting traffic entering sensitive areas to prevent the formation of congestion.
Gated link	When referring to *Gating*, a link where *Gating* is applied.
Gating minimum green	When referring to *Gating*, the amount of time used to limit the action of *Gating* on gated links. The *Gating logic* is not able to reduce the green time below this value.
Gating logic	When referring to *Gating*, it provides the necessary restrain and holds the excess vehicles at the *Gating* locations. *Gating* logic takes action at a distance to restrict traffic-entering areas susceptible to congestion.
ImFlow	ImFlow, developed by Dynniq, is a policy-based traffic control that operates at different control modes: 1) Adaptive optimisation - optimises traffic, based on real-time traffic intensity and predicts traffic situations in the immediate future. 2) Local optimisation- optimises flow, based on traffic presence. 3) Green wave optimisation- optimises traffic across a series of intersections to create a green wave for traffic along one or more routes.
Micro-mobility	A term used to indicate transportation devices that allow for personalised mobility, as opposed to transport services on a schedule or a fixed route. Often used in reference to technologies such as dockless bike-share, e-bikes, and e-scooters.
Mobility as a Service	A term describing a move away from the private ownership model of transportation towards platforms that allow mobility to be consumed as a service. It can take the form of a single platform through which users can book multiple different modes, including bike-share, ridehailing and public transport.
Shared Mobility	Concept indicating the move away from the private ownership of mobility assets, like cars, towards accessing transportation through shared assets services such as car share and bike share.

Signal group	A signal group is usually defined to govern a turning movement or a collection of several turning movements and/or signalised cyclist/pedestrian crossing.
Simulation scenario	When referring to traffic simulation, the scenario is an artificial representation of real-world traffic under specific conditions.
Trigger link	When referring to *Gating*, it is the equivalent of a bottleneck link, a link on which traffic congestion is formed.

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1. Introduction

1.1. Overview of the MORE project

The primary aim of MORE is to develop and implement procedures for the comprehensive co-design of urban main road corridor infrastructure feeding the European TEN-T network, to accommodate their current and future multi-modal and multi-functional requirements; and to address severe problems of congestion, sustainability, noise, air pollution, safety, security, etc., in situations where building new roads is not an option. And in such cases to enable city authorities to make the best use of available road-space, by optimally allocating the available capacity dynamically, in space and time, taking advantage of advances in Big data and digital eco-systems, and in new vehicle technologies and operating systems, in materials and construction technologies, and in dynamic traffic signing and lane marking capabilities.

This aim is achieved by comprehensively assessing the needs of all road user groups - and of those who live, work and visit the area – drawing on existing knowledge and extensive stakeholder engagement, to establish design criteria. Key performance indicators will be developed to define and measure the degree to which a road is operating satisfactorily, and to set out design requirements when performance is sub-standard. Four web or computer-based tools will be developed to assist in the road-space reallocation design process, covering: option generation, stakeholder engagement, micro-simulation of road user behavior, and a comprehensive, multi-modal appraisal tool.

The project will test these tools and procedures through the detailed development of street design packages at test sites (feeder route corridors) in five partner cities on different TEN-T networks, and on- and off-road trials will be carried out to test some of the components. Based on these various outputs, MORE will develop new guidelines for optimal urban road-space allocation and disseminate and exploit them and the design tools, widely throughout Europe.

In addition to developing tools and procedures, MORE believes that the optimisation of the road-space and capacity can be influenced by advanced technologies. It is evident that the existing and emerging technology have been affecting and will affect the use of road space. The technical development and possible deployment challenges of the technologies are analysed in MORE, based on which, technology and design trials were conducted through case studies, field trials, and survey. The assessment of the potential for the technologies has been made, and the results are presented in this deliverable.

1.2. The objective of the deliverable

The use of big data and digital eco systems is instrumental in the optimisation of the road-space capacity which will be influenced by advanced technologies. Existing and emerging technology has been affecting this capacity and will continue to do that increasing. In the MORE project, the technical development and possible deployment challenges of the technologies were analysed, and technology and design trials were conducted through case studies, field trials, and interviews. Based on these, assessments of the potential applications and benefits of different new technologies that enhance urban road-space efficiency have been made.

1.3. Scope of the assessment

The assessment covers advanced technologies related to the MORE project. It was carried out through simulation studies, field trials, and users' perspective analysis. The applicability and benefits of certain technologies were assessed in several cities participating in MORE, while in other cities the overall perceptions of a broad range of technologies are covered through interviews.

2. Advanced technologies related to MORE

In order to achieve the necessary improvements in connectivity, performance, productivity, and efficiency of the overall transport system a broad range of new technologies is needed to contribute to the innovation and development in road transport. In “MORE, different aspects of technological advances have been analysed. Based on the analysis this chapter briefly describes a few of the technologies related to the MORE project, such as intelligent traffic management and control systems, connected and automated road transport services, and ICT-based multimodal mobility services.

2.1. Intelligent traffic management and control systems

The increasing traffic flow in urban areas leads to traffic congestions, giving rise to an increase in the cost of transportation as well as affecting the environment and health of people. Intelligent traffic management systems can play a significant role in reducing these issues. Improving them through innovative technologies and new efficient communication systems will increase their use for traffic management and control widely. Modern traffic control methods for example use adjusted signal timing in real-time to accommodate detected changes in traffic patterns as opposed to the fixed timing methods from the past.

In the past years, traffic management systems have been evolved to the level where the system themselves responds to the traffic situation on the transport network. The most modern traffic management systems around the world are relying on adaptive signal control methods where the systems can communicate to road users and provide services according to the need of users. Thanks to intelligent transport systems (ITS) and ICT, intelligent traffic management systems respond to changes in traffic and enable users to be better informed and make safer, and efficient journeys across the transport network. There are several adaptive traffic management systems installed around the world – including but not limited to Urban Traffic Control System (UTCS), Sydney Coordinated Adaptive Traffic System (SCATS), Dynamic Programmed Intersection Control (DYPIC), Optimized Policies for Adaptive Control (OPAC), Real-Time Hierarchical Optimized Distributed Effective System (RHODES), Urban Traffic Optimization by Integrated Automation (UTOPIA), Optimization of Traffic signals In Online controlled Networks (MOTION), ImFlow- traffic signal control optimization application, and Split, Cycle and Offset Optimization Technique (SCOOT). Each of the systems has its own systems design and architecture, problem formulation and solution procedures, and optimization algorithm. Traffic optimization and prediction in the systems rely on real-time traffic data, which requires traffic detection systems to be installed on the roads.

Traffic management systems are implementing both traffic safety and traffic flow optimization. Traffic safety management focuses on the traffic participants and VRUs in particular, whereas traffic flow management focuses on traffic optimisation and environment by assigning the available capacity to the traffic demand in an optimal way meanwhile reducing the number of stops for vehicles with high emissions. With advancements in ITS, C-ITS, and ICT in general, intelligent traffic management and control systems have been equipped with a wide range of functionalities – including smart priority services, speed advice application (e.g., GLOSA), and automated operations. For example, in a cooperative mobility setting, a traffic control system can communicate with vehicles (or buses, trucks) to provide priority service at intersections with the lowest possible disturbance for the general traffic flow.

Despite the huge benefits of intelligent traffic management and control systems, there are technology, human-related, and legal framework challenges. Because of increasing urbanisation the population grows, as is the number of vehicles and the global economy in urban areas and therefore it is getting complex and challenging to control and manage traffic. The limited road space and diverse needs and use of transport services in metropolitan areas are among the other factors requiring optimization of the use of the existing infrastructure and support for modal change.

2.2. Connected and automated road transport and services

Connected and automated vehicles CAVs) are a transformative technology that has great potential for reducing traffic accidents, enhancing the quality of life, and improving transport efficiency [1]. Connected Vehicles (CVs) use communication technologies to establish connections with autonomous and non-autonomous connected vehicles, roadside infrastructures, and other road users to share driving information (see *Figure 1 b*). AVs can move from one place to another using sensors and communication systems without any human intervention (see *Figure 1 a*). CAV incorporates both AV and CV technology, and this combination has more benefits than the individual solutions. The features of automation and connectivity are in the development stage with key infrastructural and technological challenges.

Over the last decades, progressive technological development has brought conventional vehicles to the pilot program stage of fully automated and connected vehicles. This process will have an impact on the usage of road space in the cities, which in turn will have a huge impact on transportation and mobility services.

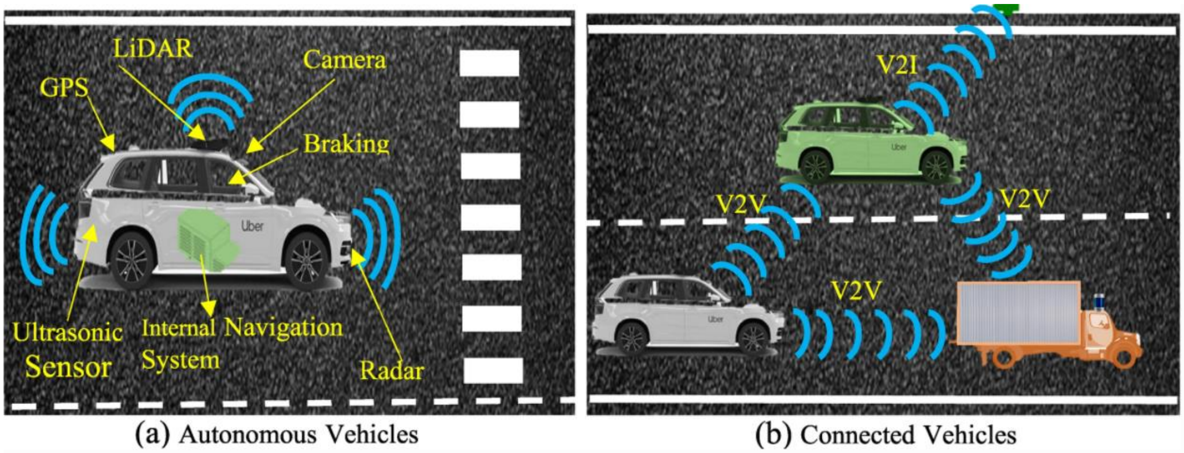


Figure 1: Autonomous vehicle and Connected vehicle [source [2]]

The introduction of new technologies into the CV and AV will bring revolutionary changes in transportation and mobility services in the near future. The features of automation and connectivity are in the development stage, moving towards a higher level of automation. Advanced Driver-Assistant System (ADAS) and cooperative adaptive cruise control (CACC) features will take the CAVs to the next level. Cooperative technology (i.e., V2X technology) will facilitate the automated vehicles to transform into fully connected and will be instrumental in expediting the deployment of CAVs by providing them with environment information (situational awareness) that will supplement the information's from the vehicles sensors to enable it to stay autonomous in complex situations. Advanced digital infrastructure creating a digital twin od the physical infrastructure along with other digital technologies such as Big data, the Internet of Things and Artificial Intelligence provides great potential for developing innovative automated driving functions and mobility solutions for the future [1].

The deployment status of AVs that are functioning at the high level of automation (i.e., SAE levels 3, 4, 5) is still at an early stage. Most vehicles today on the road are at SAE Level 2 (partially driving automation), in which vehicles are equipped with at least one ADAS such as steering or accelerating (adaptive cruise control). The Level 2 autonomous features are commercially available in various vehicles manufactured by Audi, Tesla, GM (Cadillac), Lexus, Porsche, Daimler, BMW, and Volvo [1]. Level 3 vehicles have “environmental detection” capabilities and can make informed decisions for themselves, such as accelerating past a slow-moving vehicle. But they still require a human override. The driver must remain alert and ready to take control of the system it is unable to execute the task. Refer to *Figure 2* for a description of each SAE automation level.

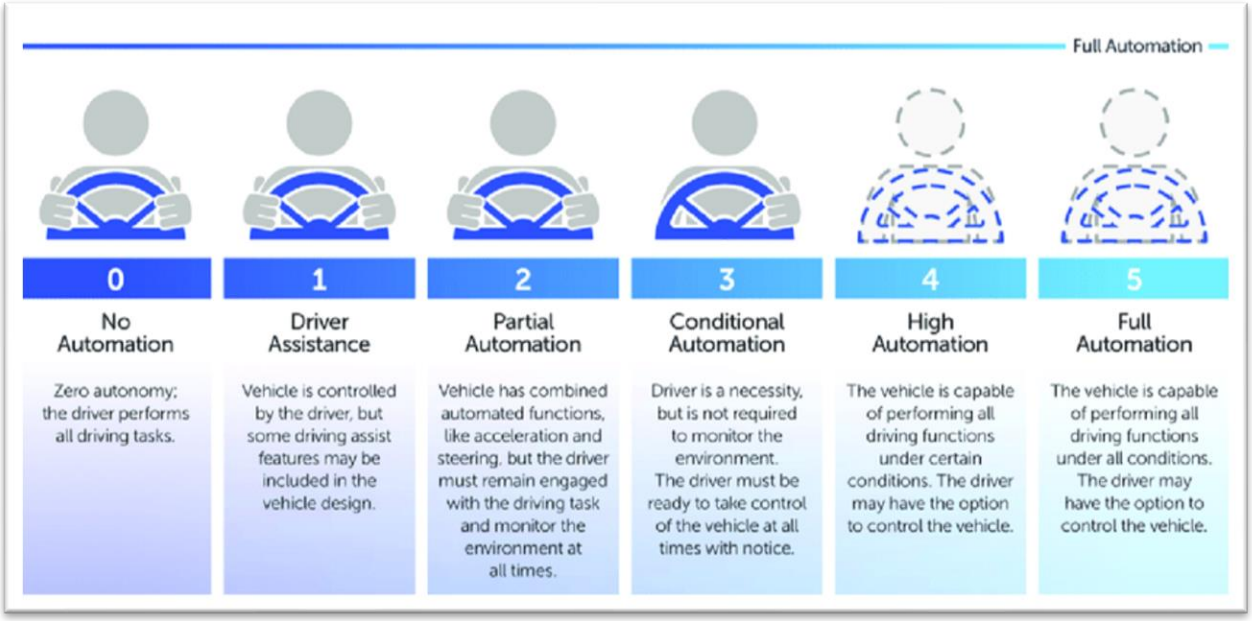


Figure 2: SAE levels of automation [source: SAE J3016 Standard, 2016]

Full deployment of the CAVs has potential benefits in various aspects – including road safety, road capacity, mobility efficiency, environment, and economy. An increase in the number of automated vehicles is expected to result in less injuries and fatalities, less pollution, and less traffic congestion. However, there are several issues related to the implementation and deployment of CAVs that need to be addressed. These include socio-economic and human, privacy and data integrity, communication systems security, infrastructure, and legal framework issues.

The issues related to the operation and maintenance of the physical and digital infrastructures for connected and automated transportation are the most important for cities. As we are moving towards higher levels of automation, the adaptation of physical infrastructure and its link with the digital infrastructure is becoming the key issue for the deployment of CAVs. Physical infrastructure, from roads, junctions and bridges to traffic signals and lamp posts, need to be updated and integrated with digital infrastructures such as static and dynamic geo-referenced traffic information, positioning infrastructure (e.g., GPS, digital mapping), and communication infrastructures. This necessary for an automated vehicle to exactly understand its environment including the legal constraints. For this reason, a classification similar to the automation levels has been defined for infrastructure. This scale comprises of 5 levels, indicating which SAE level of automation is possible in a particular section of infrastructure. This will impact, for example, street design, intersections design, adjacent land use, lane width, kerb management, electrification, and traffic management.

Equally importantly for cities, there is a need to work on seamless and harmonized ethical, legal, environmental, safety legal frameworks that help to handle challenges related to privacy and security, operation and introduction of CAVs to market. Frameworks are also expected to ensure safety, which in turn affect the social acceptance of the technology and business models of mobility services.

To tackle the aforementioned and other challenges related to the implementation and deployment of CAVs, extensive research projects have been established by industries, academia, technology providers, and other stakeholders – including cities and transport organizations. To stimulate this the EU created several funding programs for research projects furthering their strategy in the field of automated road transport and the related field of intelligent transport. A few of the for MPORE relevant projects of one of the EU programs, H2020, are[1]; ADAS&ME, ARCADE, AVENUE, CoEXist, HEADSTART, ICT4CART, INFRAMIX, interact, LEVITATE, MAVEN, and TransAID.

2.3. ICT based multi-modal mobility and services

ITS technologies are aimed at improving road network performance, enhancing safety and environmental quality through the application of advanced computing, electronics, and communication systems. ICT-based ITS is enabler for multi-modal mobility and services. Vehicle communication technologies including cellular networks and wireless vehicular networks are used for communication between vehicles and everything (V2X). Combined with information technology, ICT plays a remarkable role in enhancing mobility services like mobility as a service, shared mobility, last mile logistics, and other modes of mobility.

Mobility as a Service (MaaS) is the provision of transport as a flexible, personalised on-demand service that integrates all types of mobility opportunities and presents them to the user in a completely integrated manner to enable them to travel from A to B as easily an predictable as possible [3]. The future of MaaS is not limited to mobility for people, the approach can also be applied to the movement of consumer goods. Over the long term, rather than having to find, book, and pay for each mode of transport separately, the MaaS platforms will allow users to plan and book end-to-end trips using a single interface. *Whim* in Helsinki, *UbiGo* in the city of Gothenburg, and *Communauto/Bixi* in Toronto are among the commercial MaaS apps in practice. MaaS is an evolving concept of how consumers and businesses move away from vehicle ownership towards service-based transport; however, last-mile problems, regulatory standards, and data-driven inter-modal transport optimisation issues need to be addressed.

Another transport service that continues to grow is shared mobility. Shared mobility provides the users with short-term access to different travel modes to meet the diverse needs of users. In the

[1] https://ec.europa.eu/inea/sites/default/files/art_brochure-2019.pdf (Accessed on 11 January 2022)

cities, shared mobility is shifting trips from being one mode to multi-modal. The wide use of shared mobility will likely result in fewer vehicles on the road, which would benefit the cities to optimally allocate the road space. It may also lead to less pressure on parking space and reduce environmental footprints in the cities. Furthermore, mixing micro-services with public transport and shared mobility gives people a much greater variety of choices. Micro-mobility (e.g., shared bikes and electric scooter services) is one of the fastest-growing services in the cities. However, the complexity of service and the issues of data sharing would challenge the full execution of the service.

Mobility services for goods, particularly logistics, are transformed with the new development in the technologies that are important in production and modes of delivery. Innovations in logistics cover a broad range of technologies - including Big data and advanced analytics, robotics and automation, 3D printing, Augmented and virtual reality, Blockchain, automated vehicles, Cloud and APIs services, and Unmanned Aerial Vehicles. Robotics such as Unmanned Aerial Vehicles (UAV) or drones deliver from point to point and automate the operations. Robotics solutions are entering the logistics delivery service by providing door-to-door delivery. Transformed logistics has numerous advantages, low shipping costs, reduced urban traffic and emission, and faster delivery of goods. World-leading logistics companies such as Amazon have tested UAVs for their delivery service.

In general, ICT ensures communication, data exchange, and automation in the operation of payment systems in transport services, traffic management and control, digital infrastructure, automated driving, and shared micro-mobility services and is therefore an important enabler for all the innovations in ITS deployment.

3. Assessment methods

To assess the potential of new technology implementation, two main assessment methods were applied, technical assessment and users assessment. For the choice of the methods, the feasibility of the assessment and complexity of the technologies was taken into consideration. In the case of the technical assessments, the applicability of intelligent traffic control and automated driving in the MORE cities were evaluated through traffic simulation studies. User assessment was applied to the test of LED technologies in laboratory conditions by collecting user viewpoints form street user groups. Another type of user assessment was used by conducting interviews with the authorities of the MORE cities about the role of technologies.

3.1. Technical assessment

For technical assessment based on traffic simulation studies, a representative model is created of the traffic situation to be exposed to improved methods. By collecting baseline information and actual traffic movement during a certain period the impact of the improved methods can be determined reliably. These traffic simulation studies were conducted to assess the applicability and benefits of technologies in MORE cities. The impacts of advanced technology can be assessed social, economic, and environmental aspects. However, we did not make economic benefits assessment, rather we focus on the usability of the technologies in enhancing mobility. By benchmarking real data, KPIs on traffic efficiency and emission were used in the simulation studies. The actual steps taken in this process are identifying problems, collecting baseline data, defining KPIs, building the model, conducting simulation, and analysing the results compared to the baseline data.

3.2. Users assessment

Users assessment method pertains to exploring the users' reaction and perception regarding the applicability of the new technologies through group discussions and interviews. Group discussions are applied for the assessment of the effects of the use of LED road marking and signing that was carried out at PEARL laboratory in London. The trial was conducted in several phases using the feedback from ordinary road users exposed to the trial conditions. To determine the affinity of the MORE cities concerning the applicability of new technologies interviews were conducted to assess the level of acceptance of non-conventional methods and techniques in the traditional domain. Experts from the transport domain of the cities were addressed to this extent.

4. Use case 1: Intelligent traffic control for urban feeder routes - a case study in Malmö

4.1. Introduction

4.1.1. MORE Urban Feeder Route in the city of Malmö

The urban feeder route in the MORE project is one of three major feeder routes from the north connecting the city of Malmö. The feeder route of Västkustvägen together with adjacent roads defines the study area and streets, connecting the northern parts of the inner city, with the MORE TEN-T corridor, see *Figure 3*. In Malmö, the MORE corridor stretches along the outer ring of the city.

Figure 3: Study area (green) and its relation to the main TEN-T network corridors in Malmö (pink); source **[4]**.

4.1.2. Challenges of the MORE Corridor in the city of Malmö

The corridor stretches from the north part of the city through Spillepengsgatan along Västkustvägen across Carlsgatan up until Universitetsbron in the Nyhamnen area. The city of Malmö wishes to accommodate existing road user demands on the MORE corridor (Carlsgatan –Västkustvägen) with plans for new housing in the Nyhamnen district. The district is located between the sustainable urban district Western harbour and the international TEN-T road network. The city plans to develop Nyhamnen from the existing industrial district to a sustainable urban district including housing, offices, retails, and schools, see *Figure 5*. The area will be employment areas with demand from different road users such as pedestrians and cyclists. Moreover, Västkustvägen is the important road to and through Nyhamnen from the TEN-T network to harbours. It serves as one of the three portals to Västra Hamnen, West of Nyhamnen a district with offices, housing, and retails. An important district for national interests is Malmö Harbour, which is mainly accessible through Spillepengsgatan, refer to *Figure 4*.

The new urban district, Nyhamnen*,* will in the future support up to 9,000 dwellings, 21,000 workplaces, three new schools, and a new green link with parks and recreation. The area is set out to bridge the gap between the central city and the ocean. The future Nyhamnen will be dense, and mobility planning is one of the greatest challenges for the area in general as more pedestrians, bicycles, and cars are expected [5]. Overall, how can the issues of increasing traffic in a fast-growing region be managed to produce a liveable city and not only a transportation link? There are various ways to deal with the challenge. In the MORE project as a development strategy optimised traffic signal control in the district of Nyhamnen is essential. For example, how dense traffic flows can be portioned along the main feeder route corridor and minimize traffic queues in the central city through *Gating*? In this regard, optimisation of traffic signal controls strategies on the corridor can improve traffic efficiency, regulate traffic flow to the Nyhamnen area, and minimize delay along the corridor.

To address these issues, four intersections along Västkustvägen and one intersection in Nyhamnen district are selected to be studied. The intersections are labeled as A, B, C, D, and E as indicated in *Figure 4*. Four intersections are distributed along Västkustvägen, and one intersection is located east of the *Universitetsbron*. The current conditions on the corridor and a detailed description of intersections are presented in *Section 4.1.3*.

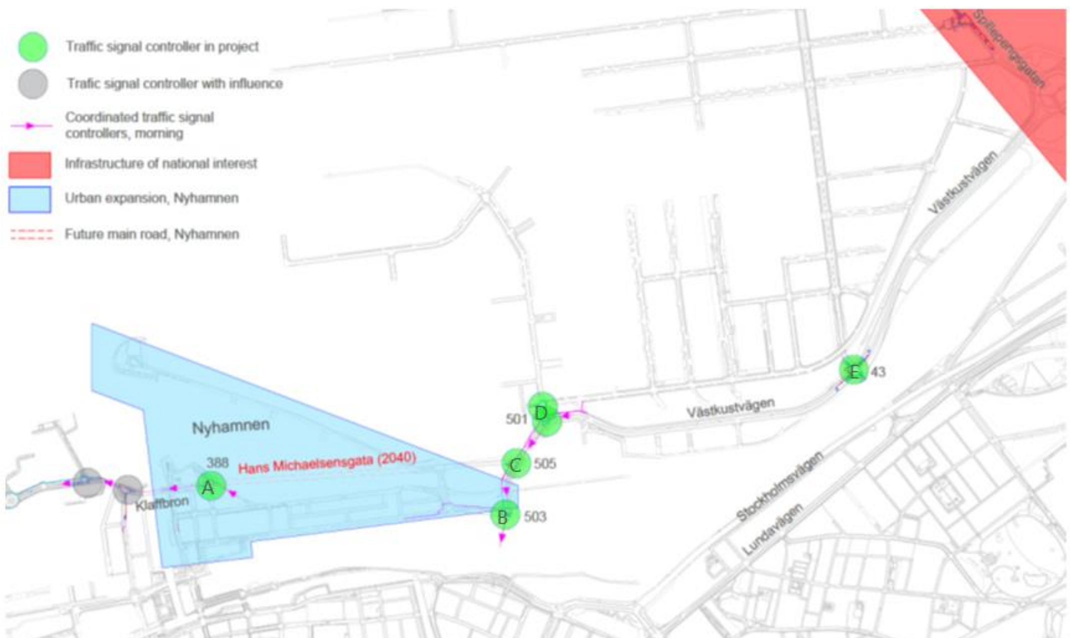


Figure 4: Overview of MORE corridor – city of Malmö, Sweden

Figure 5: The area of Nyhamnen today (left side), and future (right side)[source **[5]**].

4.1.3. The current situation on the Malmö corridor

The study corridor boundary includes both the inner and outer parts of the feed route as presented in *Figure 6*. The outer part stretches through Spillepengen to *intersection-E (*Hans Michelsensgatan/Utstallningsgatan). According to MORE typology, this route is defined as a "road", and not as a "street", where the main character is defined by the mobility of motorised vehicles and non-other functions. A separate bicycle lane is adjacent to parts of the segment but in some cases bicycles priority is not given as the same priority as the motorised vehicles along the corridor. The route is mainly characterised with high speed (70 km/h) and flyover intersection, Spillepengen intersection. Spillepengen is one of the most important intersections for freight and goods traffic in the city, connecting the TEN-T corridor with the major parts of the freight harbour with the traffic flow of 20,700 vehicles per average weekday in 2017 [5].

The inner parts of the corridor stretch along Västkustvägen to the south and west of Carlsgatan to the Nyhamnen area. This section characterised by a number of both signalised and non-signalised intersections as well as crossing for bicycles and pedestrians, surrounding office buildings, and reduced speed limit. The route changes character along with different parts of the corridor (or segments). Along Västkustvägen there are separate bicycle and pedestrian routes on both sides of the road. The southern part of the corridor, Carlsgatan/Frihamnsviadukten characterised by mixed-use buildings and separate facilities for pedestrians and bicycles with a speed limit of 40 km/h.

There are five signalised intersections and three non-signalised intersections along the corridor. The characteristics such as speed limit, traffic composition, traffic flow, intersection layout, and capacity of intersections are changing from place to place. For example, the speed limit along the corridor ranges from 70 km/h to 40 km/h. The posted speed on segment (*intersection-E* to/from *intersection-D)* is 70 km/h where on segment (*intersection-B* to/from *intersection-C*) is 40 km/h. Additional description of intersections is presented in *Table A4.2* in the Appendix.

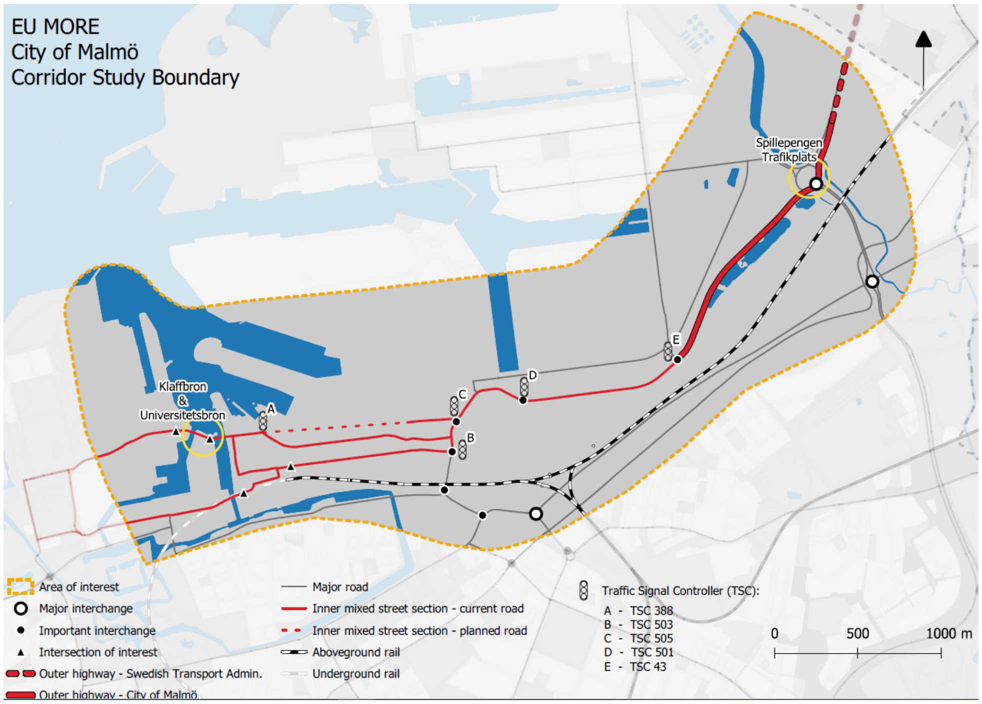


Figure 6: MORE corridor study boundary, city of Malmö, Sweden

4.1.4. The goal of the study

MORE keeps the view that new traffic signal control management strategies, at the transport network level, may substantially increase traffic efficiency, reduce negative environmental impacts, and meet differing policy objectives. The findings from Deliverable D3.1 of the MORE project [6], show that due to the development of a variety of transport modes and dynamics in transport demand a traffic signal control system that accommodates these will be a potential solution to minimise congestion problems on the MORE corridors. For the city of Malmö, investigating the effectiveness of traffic signal control systems is expected to address the current and future traffic challenges described in *section 4.1.2.*

The main aim of the study is to investigate traffic signal control for improving traffic efficiency of the selected part of the corridor, through testing different control algorithms, optimisation approaches, and mechanisms. The development strategy is to optimise traffic signal control strategies, more specifically: 1) to compare and evaluate different traffic signal control methods through simulation studies; and 2) to introduce *Gating* and assess its impact on traffic efficiency across the corridor.

4.2. Method

4.2.1. Traffic modeling methods

To model traffic conditions in the area, the research uses a real-world traffic simulation by employing a microscopic traffic simulation model. This traffic model of the road is based on the characteristics of various vehicle movements such as cars, buses, and heavy goods vehicles. The modelling is focused on car-flow, lane changing, and the gap of individual cars. There are different microscopic traffic simulation software packages such as *VISSIM* [7] multi-modal simulation software and *Simulation of Urban Mobility (SUMO)* open-source simulation software. VISSIM can simulate individual vehicles while they travel through the network, according to car-following and lane-changing theories.

VISSIM is used to simulate traffic conditions by linking to ImFlow [8]. ImFlow is a traffic control system that performs the optimisation of signal timing while VISSIM generates traffic such as cars, pedestrians, and cyclists. It is an adaptive signal control system, but it can also optimize green time using fixed-time and traffic actuated signal control methods. ImFlow adaptive uses the model of approaching and waiting vehicles to evaluate different possible control solutions. The evaluation uses a cost function that minimizes delays and stops for all traffic approaching the intersection. Throughput and delay for this control method are optimal since every cycle can be precisely adjusted to cycle-by-cycle demand fluctuations. In case of congestion, the model knows which stages are most congested or could even cause spillback to other intersections and allocates the most sustainable time there while respecting a maximum cycle time [9].

4.2.2. Signal control methods

Fixed time signal control methods

The fixed time signal control (or called “static signal control”) method minimises network vehicle delay. The signal plans are calculated based on average flow to prevent queues from forming. It provides a fixed amount of green time to each approach during a cycle. This green duration is fixed for each interval for some period, for example, an hour, a rush-hour period, a few days, or indefinitely [10]. The fixed time method is most effective when intersections located along the corridor are coordinated. For sequential intersections stretched along the corridor, configuring them with coordinated fixed time plans minimises the number of stops at each intersection. Currently, on the MORE corridor, three intersections along Västkustvägen have been controlled by coordinated fixed time plans.

A fixed-time control system does not require traffic detection, therefore, has no detection cost. However, the fixed-time control method is not responsive to the change in traffic. Fixed time control methods can be scheduled with alternate timing at a different time of the day to capture regular patterns in the traffic.

Traffic actuated signal control methods

The actuated control method is based on sensors detecting whether traffic is present or not. Stop-line detection is used to check the demand at a signal group and gap detection for extension of green time beyond the minimum duration. The traffic signal provides a minimum length of green time to each approach during a cycle [10]. This time may be incremented based on vehicle arrivals to the approach displaying green as observed by a detection device. The length of every green interval is also constrained by a maximum green time specification.

There are various advantages of actuated signals control, for instance: properly timed actuated signal control can reduce delay; actuated traffic signal control adaptable to short-term fluctuations in traffic flow; and when the traffic flow is low, actuated signal control continuously operates without a problem. The disadvantageous of actuated signal control are, for instance: ineffective when the traffic demand pattern is very regular; very high cost of installation and maintenance, compared to the fixed-time signal installation; and providing a proper operation requires continuous maintenance and inspection.

On the Malmö corridor, one of the isolated intersections is configured with the actuated signal program. This intersection is located on the feeder from the north connecting to the city of Malmö. In the morning rush hours, the intersection handles high traffic flow along Västkustvägen and from the city.

Traffic adaptive signal control methods

The adaptive control method is based on the approach of traffic towards the intersection. The timing of a traffic signal is continuously adjusted based on the changing arrival patterns of vehicles at an intersection [10]. There are few modern traffic management and control systems that are using adaptive signal control methods where signal timing is adjusted in real-time to accommodate detected changes in traffic patterns, for example, ImFlow. The method optimises using stop and delay as the measure of effectiveness to optimise cycle length, green time, or phasing sequences for traffic signals based on the changing traffic volumes collected from the detectors.

The method provides green time to each intersection approach based on anticipated arrivals for a cycle. Generally, as arrivals change from cycle to cycle, the length of green time provided to each approach also changes. Its ability to deal with various traffic conditions makes the adaptive control method most effective in most urban road traffic settings.

Comparing it to other control methods, the adaptive method is robust and stable enough to be able to deal with a wide range of traffic conditions in different locations. A well optimised adaptive signal plan can accommodate the regular daily pattern and changes in traffic due to weather and incidents.

The benefit achieved by adaptive control depends on the base condition of the corridor in question. Drastic improvements are often observed if the base condition is uncoordinated and free running. On the other hand, if adaptive control is applied to a quiet corridor with a set of well-tuned signal timings, benefits, if any, are expected to be small[2].

Furthermore, adaptive signal control is also a state-of-the-art control system not only for today but for future traffic, which can efficiently use cooperative data for priority services for trucks, cyclists, public transport, and emergency vehicles while minimizing disruption of traffic flow. The capability of creating green waves along the route is also another advantage regarding environmental benefits. The specific benefits of the adaptive signal control method are: 1) Use real-time traffic data, allowing them to adjust signals to events that cannot be anticipated by traditional time-of-day plans; 2) Continuously distribute policy-based green light time for all traffic movements such as cyclists and pedestrians; 3) Improve travel time reliability by progressively moving vehicles through green lights; 4) Reduce congestion, excess fuel consumption, delays, and improve traffic safety by creating smoother flow; 5) Maximize the capacity of existing infrastructure, which ultimately reduces costs for both system users and operating agencies; 6) Environmentally friendly by reducing emissions of hydrocarbons and carbon monoxide due to improved traffic flow.

The limitations of adaptive signal control are, e.g. it requires sufficient information to fully exploit its functionality but is gracefully degrading with reduced information; and it brings less improvement for an over-saturated traffic situation.

***Traffic metering* (*Gating*)**

The objective of *Gating* is to control the inflow of traffic into sensitive areas to prevent the formation of long queues or congestion causing gridlock. The *Gating logic* restricts traffic entering areas susceptible to congestion and redistributes queuing vehicles to other roads more suitable for storing traffic [11]. It aims to achieve the reduction of pollutions at the expense of an overall increase in vehicle delay.

The principle of *Gating* is if the degree of saturation or congestion exceeds the threshold on a trigger link, then *Gating* is activated on the gated link(s). The green time for a gated link is reduced (or increased if *Gating* is used to increase the outflow from a region) according to traffic on associated trigger links (s). That means *Gating* can be used to reduce green time on the upstream-gated links or increase the green time on the downstream benefiting links.

For a bottleneck link (or trigger-link), the traffic engineer decides upon a critical degree of saturation above which excessive queuing or congestion is expected. If the level of saturation is

[2] https://www.itsinternational.com/its8/feature/challenges-and-benefits-adaptive-signal-control

less than or equal to the “critical saturation” no action will be taken by the *Gating* logic. If the level exceeds the critical level, the split optimiser will reduce the green time on “gated” links or increase the green time on “benefiting” links downstream of the “bottleneck” link [12].

4.2.3. Design *Gating* method for Malmö corridor

This section is not focused on the theoretical description of the method, but it aims to translate the principles of gating methods described in *section 4.2.2* to the traffic situations on the Malmö corridor. The current and future traffic situation on the Malmö corridor needs a methodological design to employ the principles of gating. In particular, traffic in the area will increase because of new development, and that this threatens to gridlock the area. Thus, the overall goal of designing *Gating* in this study is to limit traffic flow to the Nyhamnen area to address the current and future traffic challenges in the area.

1) The current traffic congestion on the uncontrolled bottleneck in the portal between Nyhamnen and Western harbour at the bridges, Universtatat and Kalfhof. Using *Gating* can minimise the travel time to the bridge that connects the Western harbour with Universitetsholmen.

2) Future congestion in the city’s urban districts of Western harbour and Nyhamnen. With the new development of Nyhamnen, the traffic demand is likely to drastically increase and uncontrolled bottlenecks are likely to expand with the development of Nyhamnen [4]. For future traffic, if the traffic reaches a saturation level, *Gating* will stabilise traffic flow in the area and flow to the west of Nyhamnen. The future traffic in the new district can operate properly; for example, public transport, emergency transport, and other traffic will function without much delay time.

The *Gating* method is designed to withhold (*Gate*) traffic on Frihamnsviadukten and Västkustvägen. In particular, to regulate traffic at *intersection-B* (at signal group 09 left turn from southbound), *intersection-D* (at signal group 09 main direction from eastbound), and *Intersection-E* (at signal group 03 main direction from Northeast bound). Links corresponds to these signal groups are *gated-link B09*, *gated-link D09*, and *gated-link E03* respectively as depicted in *Figure 7*. The gated links were selected because they have sufficient storage capacity to store queue, and a high proportion of traffic to the Nyhamnen area flows through these links. Traffic flow at one or more of these links is gated by triggering congestion at the bottleneck or sensitive area. Although the overall goal of designing *Gating* in this study is preventing gridlock, simulations focus on the particular bottleneck, i.e., the bridges between Nyhamnen and Western harbour as shown in *Figure 7*.

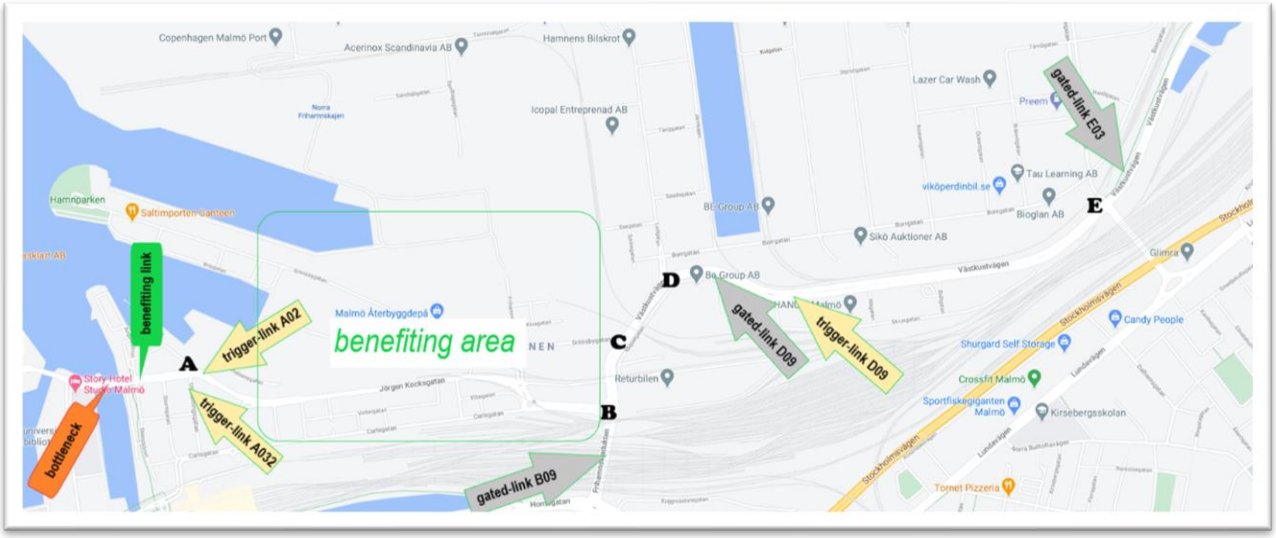


Figure 7: Location of gated links, trigger links, and benefiting links/area along the corridor

Gating on Västkustvägen can be triggered based on the congestion level (and/or saturation flow) at the bottleneck or the appropriate nearest links. To determine the degree of congestion, we used links from the nearest intersection. Traffic congestion on road links corresponding to signal group 02 and signal group 03 of *intersection-A* are used. Analogous to the gated links, these links are *trigger-link A02* and *trigger-link A032* respectively. Trigger links are selected based on current traffic flow because a high proportion of traffic goes to the bottleneck. Approximately 94% of traffic flow on trigger-link A02 and 70% of traffic flow on *trigger-link* A032 flows to the bottleneck.

As outlined in *Table 1*, *Gating* logic at the *intersection-A* initiates *Gating* at one or more gated links, if congestion on a trigger link is greater than critical congestion value(s). The natural upper limit to the critical congestion is the highest degree of saturation normally found at the bottleneck link. For this study, queue length at one or more trigger links is chosen as critical congestion values. For example, for every 5 minutes of simulation, if the sum of queue values from *trigger-link A02* and *trigger link A032* exceeds 50 vehicles, *Gating* will be activated at *gated-link B09* and *gated-link D09.* In practice, excessive *Gating* on these links can form a long queue that blocks other traffic. To overcome the side effects of excessive *Gating*, further *Gating* at the next upstream link(s) or logic that deactivates a *Gating* can be applied. If a queue length on *trigger-link D09* is above a certain critical value (say 100 vehicles), *Gating* will be initiated at g*ated-link E03*. In this way, *Gating* can push away traffic from a sensitive area. When there is no (limited) upstream link for further *Gating*, the degree of *Gating* can be limited to acceptable levels.

Table 1: Possible combinations of trigger-links and gated-links

Trigger link\Gated link	gate-link B09 (1 lane)	gated-link D09 (2 lanes)	gated-link E03 (2 lanes)
trigger-link D09 (2 lanes)			✓
trigger-link A02 (1 lane)	✓	✓	
trigger-link A02 (1 lane)	✓	✓	✓
trigger-link A02 and A032 (2 lanes)	✓	✓	✓

Gating cannot only bring substantial improvements to the traffic in the sensitive area, but it can also impose a side effect on the overall traffic, particularly in the area where traffic is gated. This is expected because traffic flows smoother in the protected area. Therefore, the negative impact has to be balanced to the positive gain obtained from applying *Gating*. The design in this experiment has been made carefully so that it cannot deteriorate the overall traffic flow and cause unnecessary delays and queues on Västkustvägen.

4.3. Data and simulation design

4.3.1. Traffic data collection

All datasets and information used in this study are provided by the city of Malmö. The traffic data were collected according to recommended methods in [13]. Network and signal control data contain the information traffic control system and road network topology files.

Traffic data

Manual counts of traffic flow and turning movements in the morning AM peak are extracted from the city of Malmö. The city was collected data on different standard workdays: on 14-10-2019 from intersections E and D, on 7-3-2019 from intersection B, on 26-2-2019 from intersection A, and 6-3-2019 from intersection C. The data from the morning AM peak are used to undertake the simulations. The dataset comprises: 1) Traffic flow compositions – data of personal vehicles, heavy-duty vehicles, cyclists, and pedestrians; 2) Traffic volumes - hourly count of cars on each segment of the road to the junction/intersection; 3) Turning movement (i.e., static routing decisions) - a relative volume of vehicles drives through left, right, and through at an intersection; 4) Speed data - speed limits posted across the network are used to calibrate simulation, see posted speed from Figure 4A.1 in Appendix 4A.

Network data

Main components are: 1) Network layout - road network in *AutoCAD-dwg* and pdf files, which displays signal heads, stop-lines, bus stop locations, and lane marking arrangements; 2) A VISSIM model of the Nyhamnen area and west of Nyhamnen is collected.

Signal control data

Signal timing data include cycle time, minimum green time, amber time, and minimum red time, red time, green time, and inter green time. Static (or fixed-time) and traffic actuated signal control parameters are currently configured on the road.

4.3.2. Description of simulation scenarios

To conduct simulation experiments multiple real-world scenarios are defined based on different types of traffic signal control methods. These are *scenario-baseline*, *scenario-fixed*, *scenario-actuated*, *scenario-adaptive*, and *scenario-Gating*. *Scenario-baseline* describes the current traffic situation including signal controllers installed across the corridor. *Scenario-adaptive* describes a situation in which all five intersections under study are configured with traffic adaptive signal controllers, refer to *Table 2* for a description of scenarios.

Table 2: Description of simulation scenarios

Scenario	Description
Scenario-baseline	This scenario was used as the benchmark to evaluate other scenarios. It represents the current real traffic situation on the MORE corridor. In this scenario, four of the intersections (A, B, C, and D) are configured with a fixed time signal control program while intersection-E is configured with a traffic actuated signal control program. Morning rush hours traffic of the workday is used.
Scenario-fixed	-The same configuration as scenario-baseline but intersection-E is configured with a fixed time program. Intersection-E is an isolated intersection, which serves traffic from the TEN-T through Splillegetaan. It releases a large volume of traffic to Västkustvägen, which then flows to the Nyhamnen area. This scenario aims to see the impact it has on other intersections and network performance when the entire corridor is controlled by fixed time signal controllers.
Scenario-actuated	-Traffic demand is the same as the scenario-baseline and the intersections are configured with a traffic actuated signal control program. Ideally, the actuated traffic program is used during off-peak; however, well-optimized actuated signal control methods are effectively handling traffic during rush hours. Furthermore, as the traffic nature along the corridor varies, it helps to identify a potential benefit that can be obtained from the actuated method.
Scenario-adaptive	Traffic demand is the same as the scenario-baseline and all intersections are configured with an adaptive signal control program. Although the current design layout in the Nyhamnen area is different, this scenario is defined to solve current and future problems of traffic delay on the corridor.
Scenario-gating	The entire configuration of this scenario is the same as scenario-adaptive but the Gating control strategy is added to the adaptive control program. It is defined to mitigate the traffic congestion problem that exists in urban districts. In the current situation, the city experiences uncontrolled bottlenecks in the portal between Nyhamnen and Western harbour. The uncontrolled bottlenecks are likely to expand with the development of Nyhamnen. The objective is to work with the existing traffic signals along the entire route to reduce the time it takes to get across the bridge that connects the Western harbour with Universitetsholmen.

4.3.3. Traffic Performance KPIs

The level of congestion can be measured in various ways: average speed, flow/density, delay, and travel time [14]. Considering these KPIs, we defined different performance KPIs that are used to evaluate the aforementioned scenarios, refer to *Table 3*. The performance KPIs quantify the efficiency of traffic flow at the network level, intersection level, and road segment (link) level. A scenario that results less delay and travel time, maximum flow rate, and less queue is considered a better solution for the challenges on the corridor.

Table 3: Description of traffic performance KPIs

Traffic performance KPIs	Description	Network-level	Link-level	Intersection-level
Vehicle delay	Delay is measured as the time difference between actual travel time and free-flow travel time. Average delay per vehicle is used.	X	X	X
Number of stops	The average number of stops per vehicle without stops at Public Transport stops and in parking lots.	X		X
Queue length	Average queue length before the intersection	X		X
Travel time	Average travel time of vehicles traveling within the network or that have already left the network.	X	X	
Emission	Emission of the quantity of air pollutants (in grams) including carbon monoxide (CO), nitrogen oxide (NOx), and volatile organic compounds (VOC)			X
Level of Service (LOS) value	KPI indicates the levels of transport quality with levels from A (free flow) to F (breakdown flow). Values of LOS are from 1 (A) to 6 (F)			X
Throughput	The number of vehicles passing a specific location at the exit of an intersection or on the link between two intersections.		X	

4.3.4. Simulation setup

The simulation study adopts a road network with five intersections located along the MORE corridor. The network was configured in both VISSIM and ImFlow. *Figure 8* presents the network developed in the VISSIM. This network is extended to the west and southwest of Nyhamnen but evaluation measurements are collected from the part that belongs to the Malmö corridor.

Figure 8: VISSIM simulation network of the Malmö corridor

VISSIM model parameters and inputs:

As recommended by [13], vehicle inputs and static routes mode of the data input throughout the network is used. The volume of traffic entering the network and relative volume at the signalised and unsignalised intersections were fed into the VISSIM model.

Simulation runs- to get statistically significant KPIs each scenario is simulated in ten runs. Averages of the results from 10 runs are used to evaluate traffic efficiency. Simulation time in seconds: the simulations run for 7200 seconds (2 hrs).

Signal control logic: fixed time and VisVAP add-on logic is used. Signal timing data from the current configuration of traffic signal controls are used to calibrate the model.

Configuration of signal control methods

The configuration of each method is done in different ways and requires parameters specific to each control method. The configuration of the fixed time signal control method is straightforward but actuated and adaptive methods need more parameters to be configured.

To configure the actuated signal control method, stopline detectors, Vehicle Actuated (VA) detectors, and pedestrian and cyclist pushbutton are added to both the VISSIM model and the ImFlow network. Then actuated signal control parameters are configured for each signal group that belongs to the intersections. Parameters such as dynamic minimum green time, dynamic maximum green time, and unit time for extension are set in the adaptive constraint plan. Functional constraints such as common start and prestart are also configured for conflicting signal groups.

The adaptive method is configured for vehicle type signal groups. Stopline detectors and link entry detectors are added to both the VISSIM and the ImFlow network. To optimise signal timing, we used policy-based adaptive signal control methods that exist in ImFlow. Therefore, different policy plans and corresponding policy profiles are configured. Policy plans indicate the level of importance, and policy profiles indicate the cost of each policy profile in the optimisation function. Policy plans in ImFlow are aimed to minimise vehicle delays, stops, queues, or waiting time and to tailor traffic management to the policies of the road authority's philosophy.

Gating logic is programmed for the specified intersections in the DA-logic (virtual machine functions) of ImFlow. Within ImFlow the site-specific conditions and instructions are handled via the DA-logic. User-define parameters and constants such as critical queue values are specified in the logic for different levels of gating.

4.4. Simulation results

First, different traffic signal control strategies were evaluated; second, traffic metering (*Gating*) was implemented in combination with the adaptive signal control method. The two approaches are also with the estimated volume increase resulting from urbanisation in the area. Two hours of the simulation were conducted in two steps. On average a flow of 4,500 motorised vehicles per hour, 320 bicycles per hour, and 325 pedestrians per hour were simulated, refer to datasets in Appendix 4A. We use 10 simulation runs for each defined scenario and sub scenario, and then use average values and standard deviations to make comparisons among scenarios. The results from the first step are presented in *section 4.4.1* and results from the later step are presented in *section 4.4.2.*

4.4.1. Comparison of the scenarios

Currently, during morning rush hour intersections A, B, C, and D are controlled by Traffic Signal Controllers that were programmed with fixed-time control methods, whereas intersection E is controlled by a controller that programmed with fully traffic-actuated control methods. However, signal control methods are not adequately dealing with current congestion on the corridor. Due to these reasons and other possible micro/macro-level factors, the feeder route to the Nyhamnen area suffers from traffic delays for motorised vehicles [4]. Moreover, these signal control methods have originally been designed to optimise unsaturated traffic and might not adapt to change in traffic conditions. To reduce current congestions and most importantly investigate a solution that will address the future traffic challenges, we evaluated different types of traffic signal control methods.

The control methods are evaluated based on the network-level and the intersection level, traffic performance KPIs are extracted from VISSIM simulations. The network-level evaluation KPIs are aimed to assess the impact of optimised signal controllers on the efficiency of traffic flow on the corridor. Whereas intersection-level evaluation KPIs quantify the impact of the methods on the traffic at a specific intersection. Also, the evaluation of scenarios at the intersection-level reveals differences that can be imposed due to variation in capacity and layout of intersections.

Traffic efficiency on the Malmö corridor

Simulations were conducted for four of the scenarios listed in *Table 2*: scenario-baseline, scenario-fixed, scenario-actuated, and scenario-adaptive. The network-level traffic efficiency KPIs have averaged over 10 runs of simulations for each of the scenarios as summarized in *Table 4*. The table presents values of the traffic performance KPIs for scenario-baseline and relative percentages for the rest of the scenarios. The comparison is made between the baseline (current traffic situation on the corridor) and the three scenarios. As defined in *section 4.2.2*, different signal control methods differentiate among the scenarios.

Table 4 presents the simulation results for the four scenarios. For the *scenario-baseline,* the table presents the average measurement of each traffic performance KPIs, and for other scenarios, it presents percentages that show the relative change in values from the *scenario-baseline* measurements. The percentage values are either negative or positive depending on the nature of the traffic performance KPIs, for example, a positive percentage for speed is an improvement but for the delay, it is deterioration.

As expected, configuring the intersections on the corridor with a fixed-time signal method cannot bring improvements in the traffic performance KPIs. This implies replacing the fully actuated signal control installed at *intersection-E* with fixed-time signal control cannot improve traffic efficiency at the network level. For example, when comparing *scenario-fixed* against *scenario-baseline*, network delay and the average number of stops are deteriorated by 7.89% and 5.51% respectively.

For *scenario-actuated,* all traffic performance KPIs listed in the table show significant improvements compared to that summarized from the *scenario-baseline*. When we see the results for HDVs, the average speed and number of stops are improved by 9.70% and 5.60% respectively. The improvements are observed for each vehicle composition and overall average, refer to column six from *Table 4*.

Table 4: Network-level traffic performance KPIs from the simulation of different scenarios (averaged over 10 simulation runs).

Vehicle composition	**Traffic performance KPIs**	**Value**	**Improvement from scenario-baseline**		
		Scenario-baseline	*Scenario-fixed*	*Scenario-actuated*	*Scenario-adaptive*

All (average)	Avg. vehicle delay (seconds)	80.56	7.89%	-25.56%	-30.26%
	Avg. number of stops	2.36	5.51%	-8.50%	-23.30%
	Average speed (Km/h)	29.71	-3.03%	11.70%	14.00%
	Travel time (seconds)	2567178.53	3.08%	-9.92%	-11.82%
Personal vehicles	Avg. vehicle delay (seconds)	99.67	8.53%	-27.53%	-33.73%
	Avg. number of stops	2.90	6.55%	-10.70%	-26.55%
	Average speed (Km/h)	31.72	-3.15%	12.23%	15.26%
	Travel time (seconds)	2145534.32	3.28	-10.40%	-12.80%
Heavy-Duty Vehicles (HDV)	Avg. vehicle delay (seconds)	107.39	13.74%	-21.00%	-29.75%
	Avg. number of stops	2.86	11.54%	-5.60%	-25.87%
	Average speed (Km/h)	30.52	-5.64%	9.70%	14.09%
	Travel time (seconds)	256872.95	5.35%	-8.05%	-12.15%

S*cenario-adaptive* shows a decrease of 30% in average vehicle delay and an approximately 12% decrease in travel time. For the same scenario when we see personal vehicles, there is a decrease of 33.73% and 26.55% in average vehicle delay and the average number of stops respectively. Scenario-adaptive also shows an improvement of 14% in speed on the corridor. When we evaluate this scenario based on the KPIs of Heavy-Duty Vehicles (HDV) and personal vehicles, the improvements are substantial compared to *scenario-fixed* and *scenario-actuated.* Therefore, the results indicate that *scenario-adaptive* has shown significant improvements in all traffic performance KPIs.

When we compare *scenario-actuated* and *scenario-adaptive* to *scenario-baseline*, *scenario-adaptive* shows a relatively large improvement in all kinds of traffic performance KPIs. However, the measurement values from *scenario-actuated* are close to the results from *scenario-adaptive*. For some traffic performance KPIs, there is the lowest difference between the two scenarios. For example, the improvement in the average delay is 25.56% under *scenario-actuated* and 30.26% under *scenario-adaptive*, a difference of 5%. We can see a similar pattern for the rest of the traffic performance KPIs except for the average number of stops. *Scenario-adaptive* shows a major improvement in the average number of stops compared to *scenario-actuated*, which is encouraging results regarding fuel consumption, emission, and traffic safety regarding rear-end collision.

The small differences in some performance KPIs observed between *scenario-actuated* and *scenario-adaptive* could be associated with the nature of the corridor and/or the observed fewer fluctuations of morning peak traffic. We verified that traffic flow during the morning AM peak is less fluctuate, therefore, with well-optimized actuated parameters the results from *scenario-actuated* could be closer to that of *scenario-adaptive*. Overall, the simulation results indicate that adaptive signal control substantially improved the current traffic efficiency on the Malmö corridor. The optimised adaptive traffic signal control does not only improve efficiency but also can efficiently improve the shortcoming of actuated signal control because actuated traffic signal control cannot adapt to the change in traffic flow.

Finally, from an economic point of view, adaptive signal control requires less detection compared to actuated signal controls. In using optimized adaptive signal control for intersections in proximity only stopline detectors can be needed. Because of its capability, adaptive signal control installed on intersections uses exit loop data from neighboring intersections for estimation of arrival and queue model. The most compelling reason to use adaptive control systems over the actuated system is, unlike actuated adaptive needs low maintenance concerning structurally changed conditions because it will automatically adapt. Furthermore, adaptive is capable of using cooperative data for the optimisation of signal timing.

Traffic efficiency across the intersections

Table 5 presents intersection-level simulation results averaged over 10 runs for personal vehicles, HDVs, and all vehicle compositions. It presents the absolute values and relative percentage of intersection-level performance KPIs such as average queue length and Carbon monoxide emission.

When we compare scenarios against the baseline, both *scenario-actuated* and *scenario-adaptive* again show an improvement in almost all traffic performance KPIs. *Scenario-fixed* showed an improvement of 2.38% in average vehicle delay at intersection B and 0.17% in CO emission at intersection A. There are significant improvements in average queue length, CO emission, vehicle delay, and LOS-value at intersections B, C, and D. For example, at *intersection-B* there is an improvement of 27.03% and 57.30% in Carbon monoxide (CO) emission under *scenario-actuated* and *scenario-adaptive* respectively. Similarly, a comparison at the intersection-level can be made from the results summarised in *Table 5*. At these intersections, *scenario-adaptive* showed higher improvement in the KPIs compared to the improvement of KPIs under *scenario-actuated*.

Table 5: Intersection-level traffic performance KPIs from the simulation of different scenarios (averaged over 10 simulation runs).

Vehicle composition	**KPIs**	**Value**	**Improvement compared with Baseline**		
		Baseline	*Fixed*	*Actuated*	*Adaptive*
A	Avg. queue	7	2.86%	-4.00%	-15.63%
	Vehicle delay	18	0.00%	-25.88%	-33.74%
	Emission (CO_2)	226.47	-0.17%	13.39%	8.58%
	LOS-value	2	0,00%	0.00%	0.00%
B	Avg. queue	78.17	-2.39%	-64.32%	-79.78%
	Total delay	64.15	2.10%	-48.73%	-61.05%
	Emission (CO_2)	1692.43	0.87%	-27.03%	-57.30%
	LOS-value	4	0.00%	-25.00%	-25.50%
C	Avg. queue	52	21.21%	-31.62%	-52.08%
	Total delay	56.80	14.98%	-43.86%	-55.59%
	Emission (CO_2)	913.17	9.06%	-21.45%	-24.59%
	LOS-value	4	25.00%	-25.00%	-25.00%
D	Avg. queue	13	26.15%	-51.50%	-61.49%
	Total delay	48.67	8.59%	-43.11%	-32.55%

	Emission (CO_2)	644.45	15.72%	-33.55%	-47.50%
	LOS-value	4	0.00%	-25.00%	-25.00%
E	Avg. queue	15	21.47%	-1.06%	17.01%
	Total delay	35.30	13.31%	-9.66%	14.54%
	Emission (CO_2)	825.82	3.16%	-13.14%	6.59%
	LOS-value	3	0.00%	0,00%	0.00%

Under *scenario-adaptive,* the traffic performance KPIs at intersections A and E have not shown improvements. Particularly there are no improvements in delay, queue, emission, and LOS-value at the intersection E. This could be due to various reasons, e.g.: 1) this could be partially due to a relatively high proportion of slow traffic, cyclists, and pedestrians crossing the intersections; 2) intersections A and E are isolated and located at a far distance from the rest of signalised intersections. As a result, the adaptive configuration might need more adjustments depending on the characteristics of the intersection and intermediate road branches, and parking areas.

On other hand, the observed difference in performances at these intersections could indicate that intersections can be controlled by a combination of adaptive and actuated signal controls. In other words, to achieve the desired level of traffic efficiency at the corridor level, traffic at intersections can be optimised based on the characteristics of intersections.

The intersection-level results indicate that optimisation of signal timing at each intersection depends on the characteristics and capacity of the intersections. The optimisation can be done based on the policy to be attained by the city. The policy could be to minimise network-level delay or improve the capacity of the intersection, or priority for slow traffic and public transport. In this study, the optimisation of signal control methods was related to improving traffic efficiency at the road network level.

Traffic efficiency under high traffic flow

The above results demonstrated that adaptive signal control could control the current traffic situation in the corridor. However, in the future, the traffic condition in the Nyhamnen area is expected to be dynamic and diverse due to the rebuilding of space infrastructure in the Nyhamnen area. For example, a green park corridor for only bicycles and pedestrians will be built along Jörgen Kocksgatan. The southmost street of Carlsgatan will be tighter, though traversing the most densely built-up area in Nyhamnen [5]. To develop a simulation model that replicates the future traffic situation in the area, the demand and supply side of traffic inputs need to be incorporated into the simulation model. Moreover, the simulation network has to be modified according to the new physical road infrastructure; however, the future master plan of Nyhamnen has been under development, and substitute input data is not ready for this study.

We investigated the impact of an increase in traffic demand on traffic efficiency. The optimised *scenario-adaptive* with few modifications in policy profiles was used to evaluate the impact. We assume that with the current infrastructure if there will be an increase in traffic flow up to a certain level, optimised adaptive signal control can still efficiently control the traffic. In other words, if the physical infrastructures of the intersections along the corridor will not be rebuilt, optimised adaptive signal control will be able to control the future traffic, nonetheless. Then, one of the questions is how much traffic the adaptive signal control can handle in the future? The traffic volumes that will be going into and go out of the area can be estimated based on the new development such as houses and schools but for simulation, we increase the current traffic flow by a range of 1% to 20%. The increase in traffic demand was introduced at all the network traffic inputs. Other simulation parameters, including the intersection turning percentages, remained the same as preceding configurations. The capability of the optimized adaptive signal control is evaluated by increasing traffic by 1%, 5%, 10%, 15%, and 20% keep that an increase in traffic demand can also lead to oversaturation at one or multiple intersections.

For different volumes, simulation results are compared to the results obtained from the simulation of current traffic volume.

Figure **9** depicts the percentage change in different traffic KPIs when traffic volume increases by 5%, 10%, and 15%. Labels corresponding to these volumes are *CurrentVolumePlus5%*, *CurrentVolumePlus10%*, and *CurrentVolumePlus15%*. As expected, there are increments in the network-level traffic performance KPIs. For example, vehicle delays and travel times show an increase as traffic volume increases. Travel time increases by 8.7%, 18.92%, and 34.90% as volume increase by 5%, 10%, and 15% respectively. As can be seen from

Figure **9** (a), there are increments in average vehicle delay and number of stops as well.

The impact of an increase in volume on the capacity of each intersection was assessed by intersection-level traffic performance KPIs that were described in *Table 5*Table 3. In

Figure **9** (b), it can be seen that an increase in volume by 15% leads to an increase in the average maximum queue length by 95% and 77% at *intersections-B* and *intersection-C* respectively. According to the results, under *CurrentVolume* if the average maximum queue at the *intersection-B* is 50 meters, then a 95% increase in the average maximum queue under *CurrentVolumePlus15%* is 95 meters. Even though the negative rise in the traffic performance KPIs is expected, it can be improved to an acceptable level by optimising the adaptive signal control parameters for the new volumes.

On average, the traffic performance KPIs from *CurrentVolumePlus15%* are equal to those obtained from *scenario-baseline,* see Table 4B.1 and 4B.2 in Appendix 4B. With current infrastructure when there will be an increase of 15% in traffic flow, the performance of optimized adaptive signal control is equivalent to the current signal control systems on the road. In general, it is observed that optimised adaptive signal control can efficiently manage traffic in the area even when the current traffic volume is increased by up to 15%.

An increase of volume up to 15% have imposed a reasonable negative rise in traffic performance KPIs. From *Figure 10,* we can see that vehicle delay in the area of the Nyhamnen area increase by 12% under *CurrentVolumPlus5%* and 44% under *CurrentVolumPlus15%*. For example, under *CurrentVolume* the average delay time on the road link (B-to-A) starts from *intersection-B* and ends at *intersection-A* is 35.44 seconds. The corresponding increase of 42.15% under *CurrentVolumePlus15%* is 50.03 seconds, refer to the absolute values from *Figure 4B.1* in Appendix 4B. This indicates that the increment in the delay is reasonable, even when traffic volume increases by 15%.

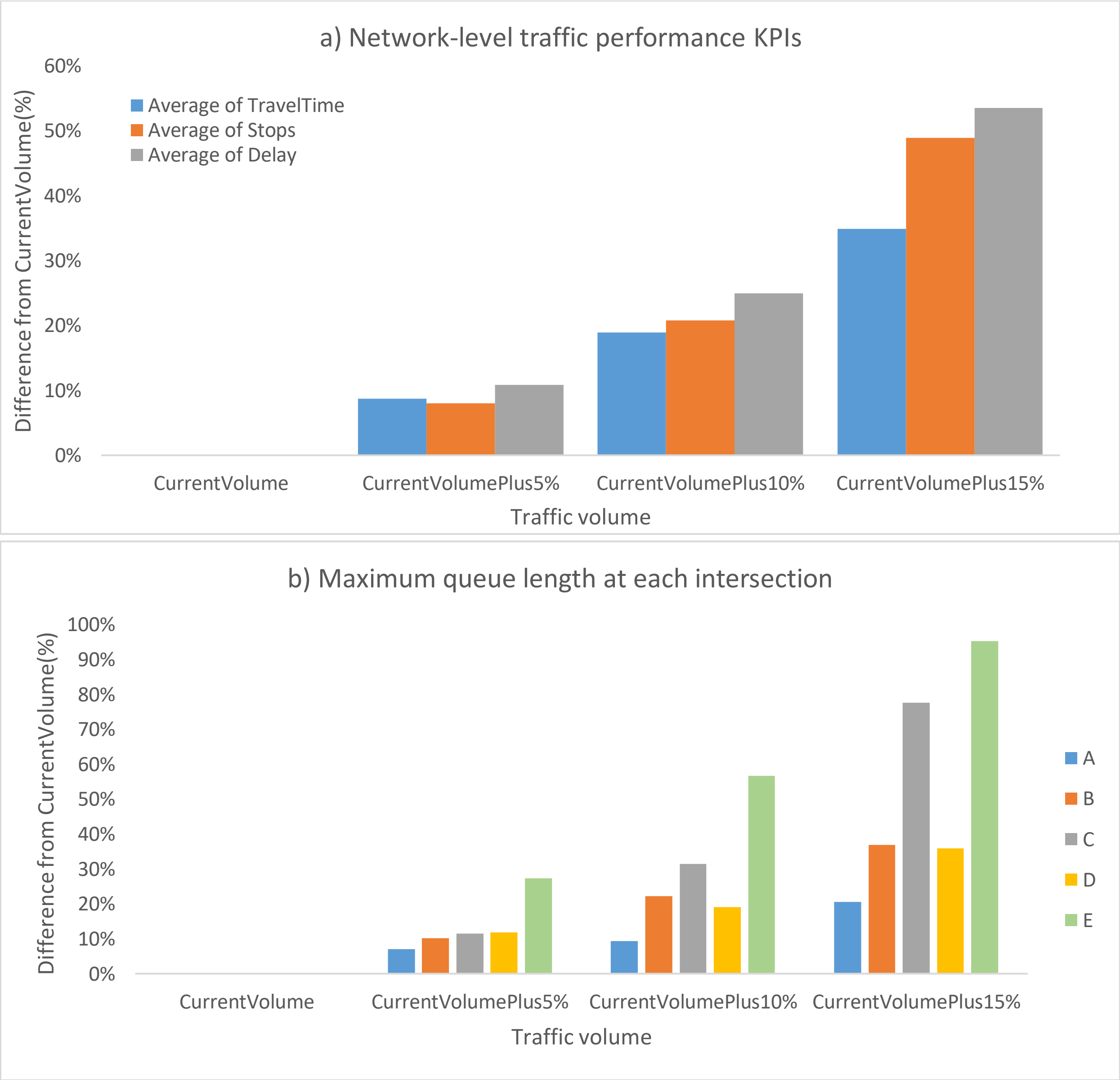


Figure 9: Comparisons of simulation results from the current volume to different traffic volumes

However, an increase of volume greater than 15% causes much delay and queue both at the intersections and in the Nyhamnen area. The queue length at the intersection could be associated with the capacity of the intersections but the delay in the Nyhamnen area could be because of roundabouts in the area, which has an impact on throughput. When there is a continuous flow of traffic from *intersection-B* and *intersection-C,* it blocks traffic coming from the west part of Nyhamnen, and a long queue is forming.

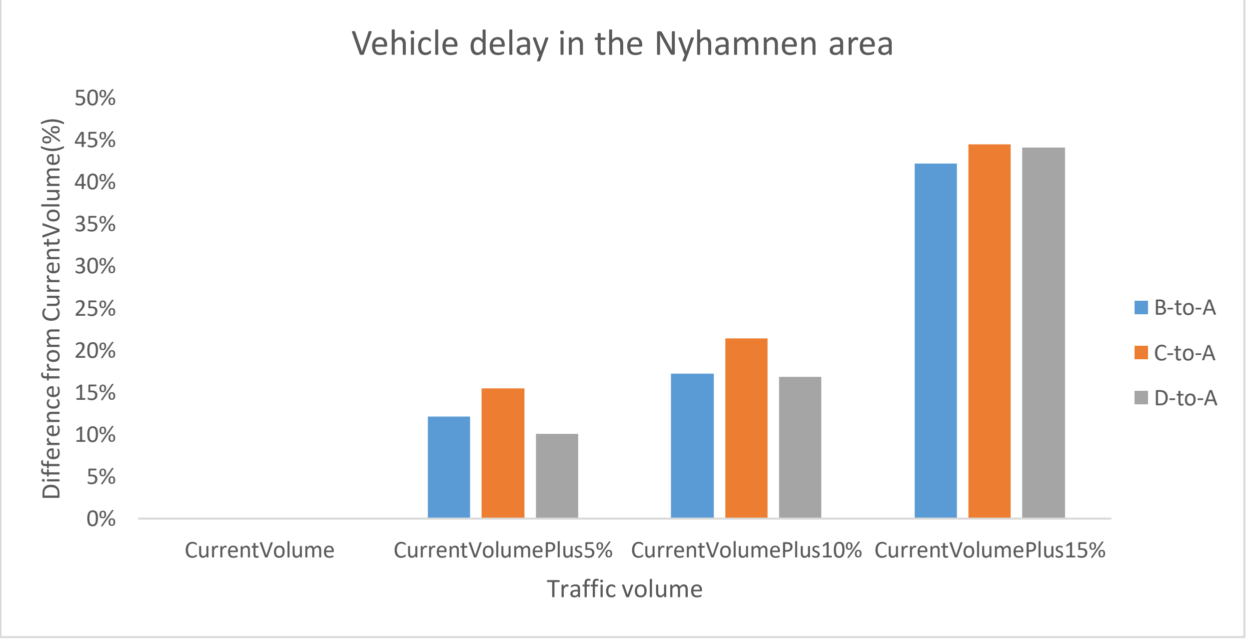


Figure 10: Comparison of different traffic volumes based on delay (averaged over 10 runs)

As mentioned earlier the problem of long queues and delays coming from the increase in traffic volume could be partially improved by further optimisation of the adaptive signal control. Moreover, to bring a considerable improvement in traffic efficiency two measures can be taken: 1) expanding infrastructure in the area, which is planned in the Nyhamnen master plan, 2) implementing traffic metering with adaptive signal control. The first one increases the capacity of infrastructure in the area; the second one regulates traffic entering the area so that the inner part of the area will keep functioning. This approach also solves the challenge of congestion at the bottleneck located to the west of Nyhamnen.

4.4.2. Metering (Gating) traffic to the Nyhamnen area

As described in the method section the goal of *Gating* is to regulate the flow of traffic from the TEN-T network and from Frihamnsviadukten to the city's urban districts of Western harbour and Nyhamnen during morning peak traffic. Taking into consideration the future traffic demand and the capability of the signal control method to be used in the future, a combination of the adaptive signal control program and *Gating* is implemented according to the design.

Setting up the Gating strategy and parameters

Traditionally, *gating* logic is programmed based on the strategy of minimizing green time on gated-link or maximising green time on the bottleneck(s). *Gating minimum green time* provides control by limiting the maximum amount of traffic on the gated-links. A level (degree) of *Gating* on a particular link or a cluster of links is either by minimising or maximising minimum green time(s). We used three different strategies to set up *Gating*; 1) minimising green time of the signal groups on the gated links; 2) reducing cycle time by minimising stage time of signal groups on the gated links; 3) determining minimum stage time for signal groups other than signal groups on gated links.

In practice, *Gating* minimum green time is set below the corresponding peak-hour saturation to flow minimum green time. Here, *Gating* minimum green times are set to the minimum green time from the *scenario-adaptive*. Different values of *Gating* parameters and corresponding *Gating* levels are presented in *Table 6*. *Gating0 (no-gating*) is used as a benchmark to evaluate the impact of *Gating* strategies. *Gating1 (G1G1G1)* represents the first level of *Gating* in which critical queue values at *trigger-link A02 and A032* and *trigger-link D09* are set to 45 and 100 vehicles respectively. In this level, minimum green time and stage times are adjusted compared to *Gating0*. For example, the minimum green time of *gated-link B09* is within a range of [10, 25] and of *gated-link E03* within a range of [15, 18] with maximum stage times of 3 and 8 seconds. Similarly, parameters for the remaining levels of *Gating* are created.

As we go from *Gating1* to *Gating7* the level (degree) of *Gating* is getting stronger. For each *Gating* level, *Gating logic* refers to different values of the configured parameters in the Adaptive Constraint Plan (ACP) of ImFlow.

Each of the strategies in *Table 6* affects the green time of signal groups on the gated links and green times of other signal groups at the intersection. Implementing *Gating* in such a way it creates smooth flow in the area requires a balance between benefit and the negative impact that comes due to the introduction of *Gating*. Too much *Gating* can also cause spillover traffic to parallel roads and/or signal groups. For example, minimising the green time of signal group 09 at *intersection-B* disturbs the traffic from the southeast, at Frihamnsviadukten. Because at gated-link B09, there is no sufficient storage capacity to be able to store a high amount of traffic gated; therefore, *Gating* minimum green time has to be optimally chosen without causing serious extra problems to the Frihamnsviadukten.

In the same way, although there is enough queue storage capacity on *gated-link D09*, minimising the green time for signal group 09 stretches a queue back along Västkustvägen and block the traffic flow through the signal group 08. Moreover, because a large proportion of traffic flows from the TEN-T network through *intersection-E* to harbors passes across Västkustvägen and Nyhamnen, *Gating* at *intersection-D* should consider traffic release from *intersection-E.* That means if *Gating* at intersection D creates a long queue, then *Gating* will be activated at intersection E.

In general, excessive *Gating* (setting low *Gating* minimum green time) can cause problems on the gated links and beyond, and in contrast, inadequate *Gating* (setting maximum critical queue value) cannot respond correctly to conditions at the bottleneck. Hence, values in *Table 6* were selected after careful experiments with a different possible combination of values.

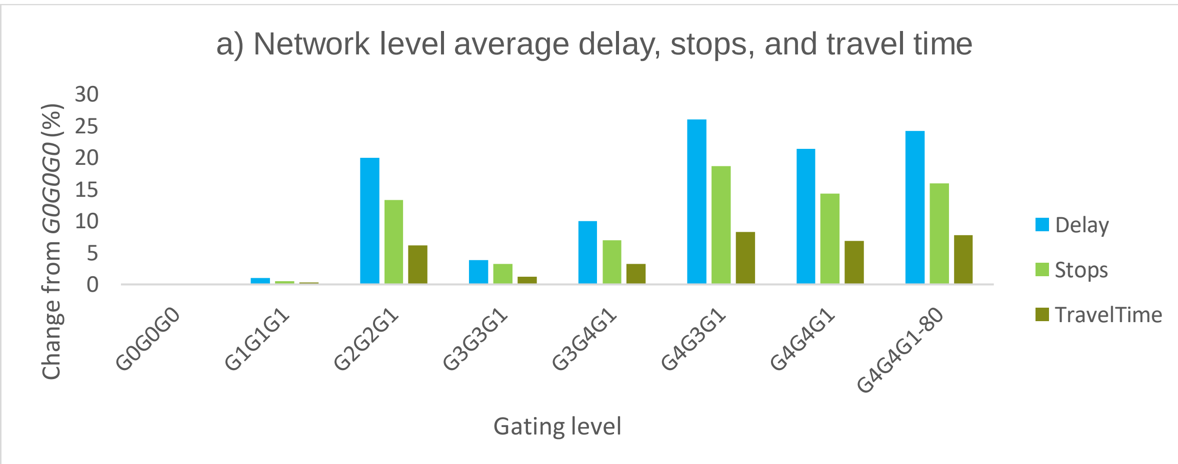
Table 6: Gating strategies and parameters

Gated / trigger links	***Parameter***	***Gating0***	***Gating1***	***Gating2***	***Gating3***	***Gating4***	***Gating5***	***Gating6***	***Gating7***
gated-link B09	*Min green time*	*[10, 30]*	*[10,25]*	*[10,25]*	*[10,25]*	*[10,25]*	*[10,25]*	*[10,25]*	*[10,25]*
	Max stage time	*variable*	*25*	*20*	*15*	*15*	*10*	*10*	*10*
gated-link D09	*Min green time*	*[8, 20]*	*[8, 20]*	*[8, 20]*	*[8, 20]*	*[8, 20]*	*[8, 20]*	*[8, 20]*	*[8, 20]*
	Min stage time	*0*	*0*	*0*	*0*	*15*	*0*	*15*	*15*
	Max stage time	*variable*	*45*	*30*	*20*	*20*	*20*	*20*	*20*
gated-link E03	*Min green time*	*[18, 25]*	*[15, 18]*	*[15, 18]*	*[15, 18]*	*[15, 18]*	*[15, 18]*	*[15, 18]*	*[15, 18]*
	Max stage time	*variable*	*3 and 8*	*3 and 8*	*3 and 8*	*3 and 8*	*3 and 8*	*3 and 8*	*3 and 8*
trigger-link A02 & A032	*Critical queue value*	-	*45*	*45*	*50*	*50*	*50*	*50*	*50*
trigger-link D09	*Critical queue value*	-	*100*	*100*	*100*	*100*	*100*	*100*	*80*

Evaluation of Gating levels

We evaluated each strategy of *Gating* levels by comparing travel time, vehicle delay, and stops at the network level, and by comparing fuel consumption and average maximum queue at the intersection level. As described in *Table 1*, simulations were carried out based on all possible combinations of trigger links and corresponding gated links. Each combination has advantages and disadvantages to the traffic efficiency on the road and in the Nyhamnen area. For example, *Gating* at *gated-link B09* and *gated-link D09* by measuring queue level at *trigger A02* can stabiles traffic possibly go to the bottleneck but traffic from southbound of the intersection still going to the bottleneck. Furthermore, it does not take into account the travel time between gated links and trigger links. Therefore, by assessing the impact of each combination the combination at the bottom row of *Table 1* was found to be reasonable to gate traffic to the area. That means we used the five minutes sum of a queue on *trigger-link A02* and *trigger-link A032* as critical queue values to gate traffic at gated links. Five minutes queue has chosen because on average, it takes five minutes for a vehicle to travel from the closest gated link to the bottleneck.

Simulation results are summarized from all levels of *Gating* that were presented in *Table 6*. Based on the current traffic flow a level of *Gating* which does not impose an unnecessary impact on the network as a whole and particularly on the intersections with gated links would be the best. Looking at the plot in *Figure 11*(a), *Gating* level *G3G3G1* (*Gating*3) has imposed a relatively small increment in network-level average delay, number of stops, and travel time compared to *G0G0G0* (*Gating*0). On average, the measurements are increased by less than 5%, which is acceptable compared to the benefit we expected on the bottleneck. Another level of *Gating* that shows a relatively low increase in traffic performance KPIs is G3G4G1 (*Gating*4). It causes less than a 10% increment in delay, stops, and travel times.



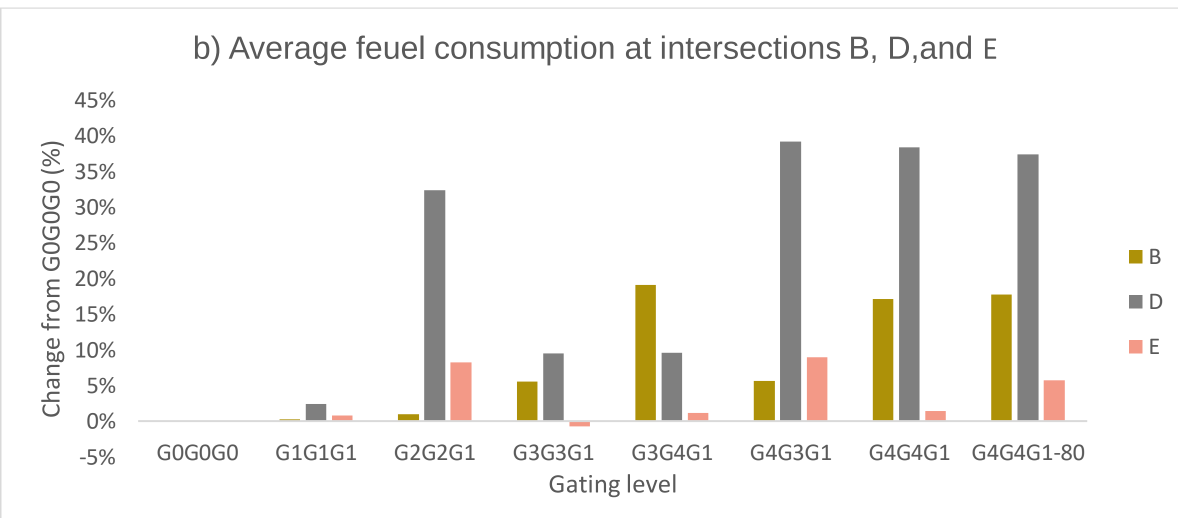


Figure 11: Comparison of Gating levels based on traffic efficiency results at the network level (top figure) and intersection level (bottom figure); averaged over 10 simulation runs.

Comparing the *Gating* levels at the intersections, again *G3G3G1* and *G3G4G1* have relatively small negative changes on each intersection. For example, as we may see from Figure 11 (b), the fuel consumption is increased by 5.5% at *intersection-B* and by 9.5% at *intersection-D*. Based on the other measurements such as average queue length and emission, G3G3G1 followed by *G3G4G1* have imposed little effect on the traffic on the intersection corresponding to gated links.

The results show that *G3G3G1* and *G3G4G1* relatively have benefits over other levels of *Gating*. To verify these results, we also evaluated the levels of *Gating* based on the capacity of gated links. First, we assess the level of the average queue that is formed across the intersections. From intersection level results, it was observed that maximum queue lengths are formed on the gated links. As a result, it is essential to know on average how much maximum traffic queue can be formed on gated the gated link. A *Gating* level that does not form more than an acceptable maximum queue on the gated link is considered the best.

Figure 12 shows the percentage increment in the average maximum queue from each *Gating* level compared to that of *G0G0G0*. It presents summarised results over the simulation time interval for intersections B and D. When we compare *Gating* levels to the *G0G0G0*, we can observe a similar pattern to the pattern observed from previous results. For example, the maximum queue starts forming after 900 simulation seconds and drops around 3300 seconds. The overall pattern shows how often each *Gating* level is activated. Besides that, we need to know how maximum is the maximum-queue because the queue formed due to *Gating* should not be extended and block other traffic.

In this regard, again both *G3G3G1* and *G3G4G1* are producing acceptable levels of the queue at intersections. At intersection B, *G3G4G1* showed a significant increment in queue length around the final simulation minutes. The fact that gated-link B09 has a limited space to store traffic, and then reasonable queue length can be attained by adjusting *Gating* parameters. The increment in percentages depends on the maximum queue length in the reference (*G0G0G0*). If the possible maximum queue length in *G0G0G0* is 50, then an increment of 200% is equivalent to 150, which can block the flow of other traffic. In summary, based on the capacity of gated links, *G3G3G1* and *G3G4G1* form acceptable queues at the intersections.

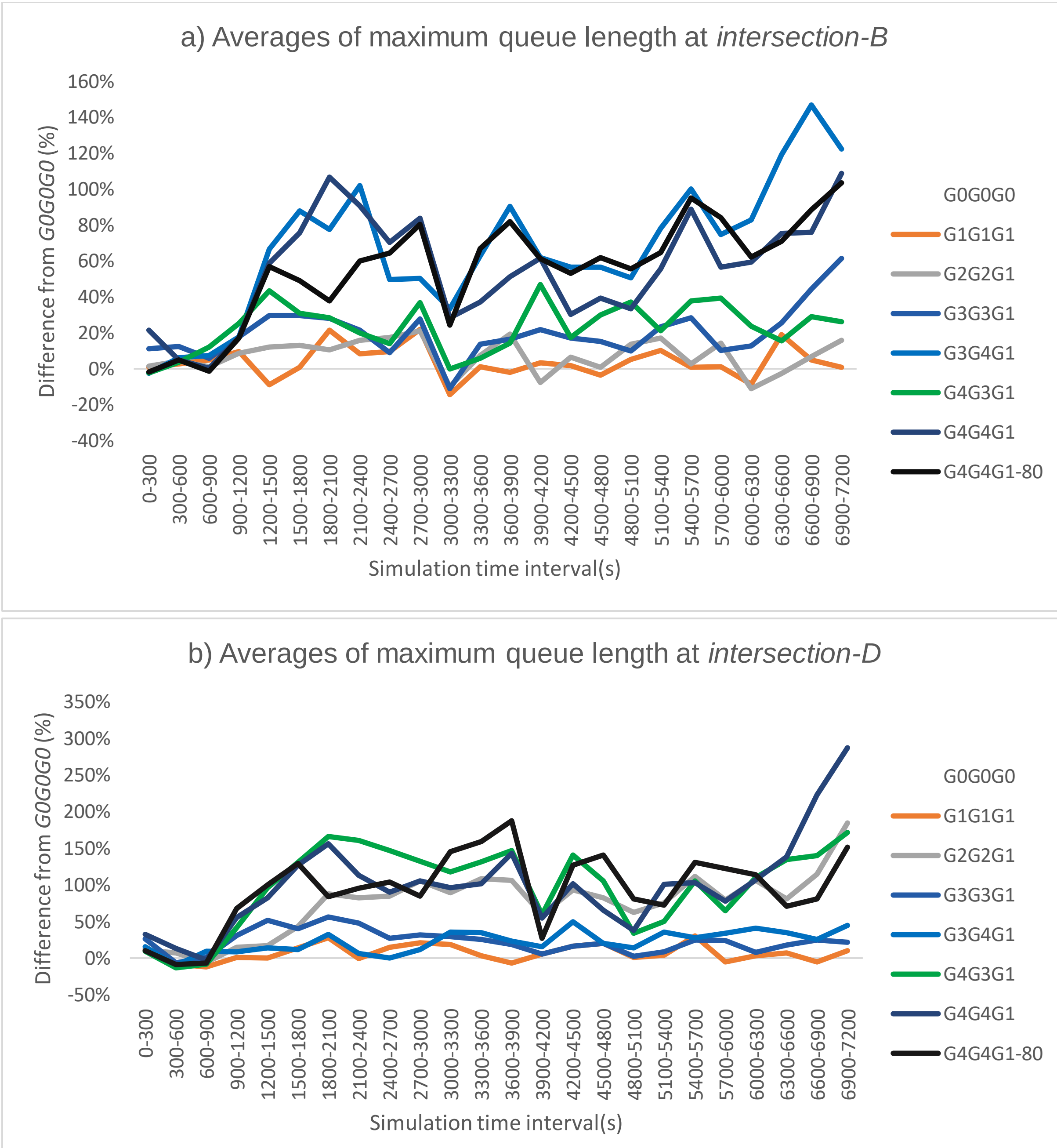


Figure 12: Comparison of Gating levels over simulation time intervals a) at intersection B, and b) at intersection D

Impact of Gating on current traffic

The impact of each *Gating* level was assessed by comparing traffic performance KPIs on the benefiting link (bottleneck), in the benefiting area (Nyhamnen area), and at the intersection corresponding to the trigger link A02 and A032.

Figure *13* presents the percentage of average maximum queue length of each *Gating* level to that of *G0G0G0* at *intersection-A*. There is an improvement of 5.35% in maximum queue length at a *Gating* level *G3G4G1* and an improvement of 2.04% at a *Gating* level *G3G3G1*. The improvement indicates the impact of applying *Gating* on current traffic flow. We also measure average travel time on the benefiting link, a link from *intersection-A* to the bottleneck (the bridge) but it showed an improvement of 1%. This could be because of the free flow of traffic at the end of the network. When the signalised intersection located to the west of the bridge is included in the modelling, it will be clear to measure the impact of *Gating* on the bridge.

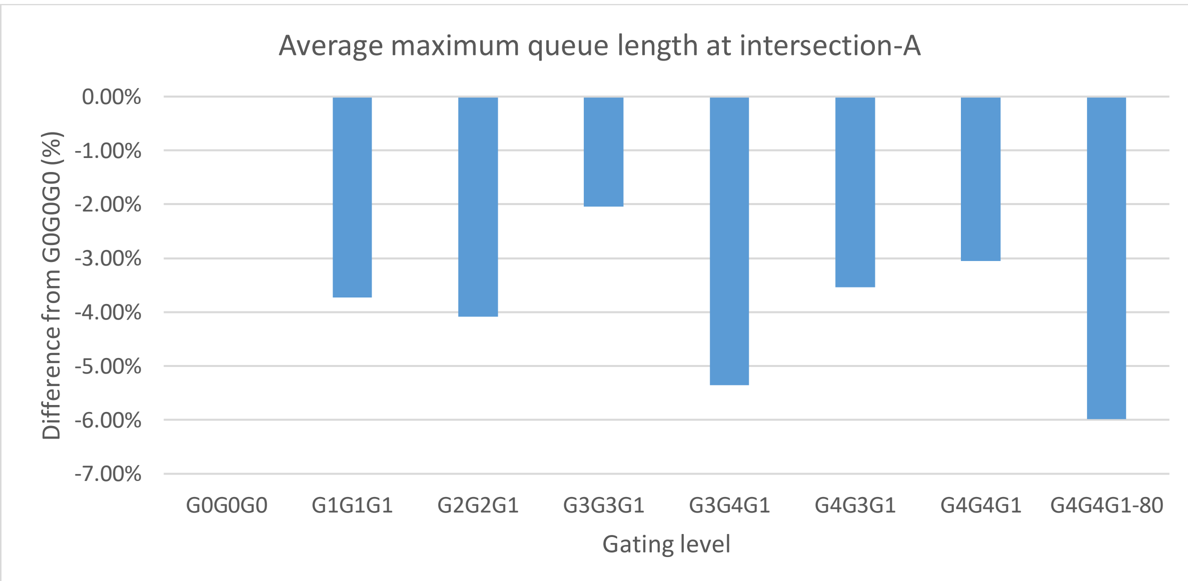


Figure 13: Average maximum queue formed during simulation of different levels of Gating (percentage change from G0G0G0 values)

Figure 14: Average vehicle delay in the benefiting area*Figure 14* shows the average vehicle delay in the benefiting area. As can be seen from the plot, different levels of *Gating* lead to an improvement in average vehicle delay as almost all values are below zero. From *Gating* level *G3G4G1*, the average vehicle delay in the benefiting area is decreased by a minimum of 4% and a maximum of 7% depending on the route length between intersections. For example, *B-to-A* indicates the link (route) stretches from *intersection-B* to *intersection-A*, and vehicle delay is measured on that link.

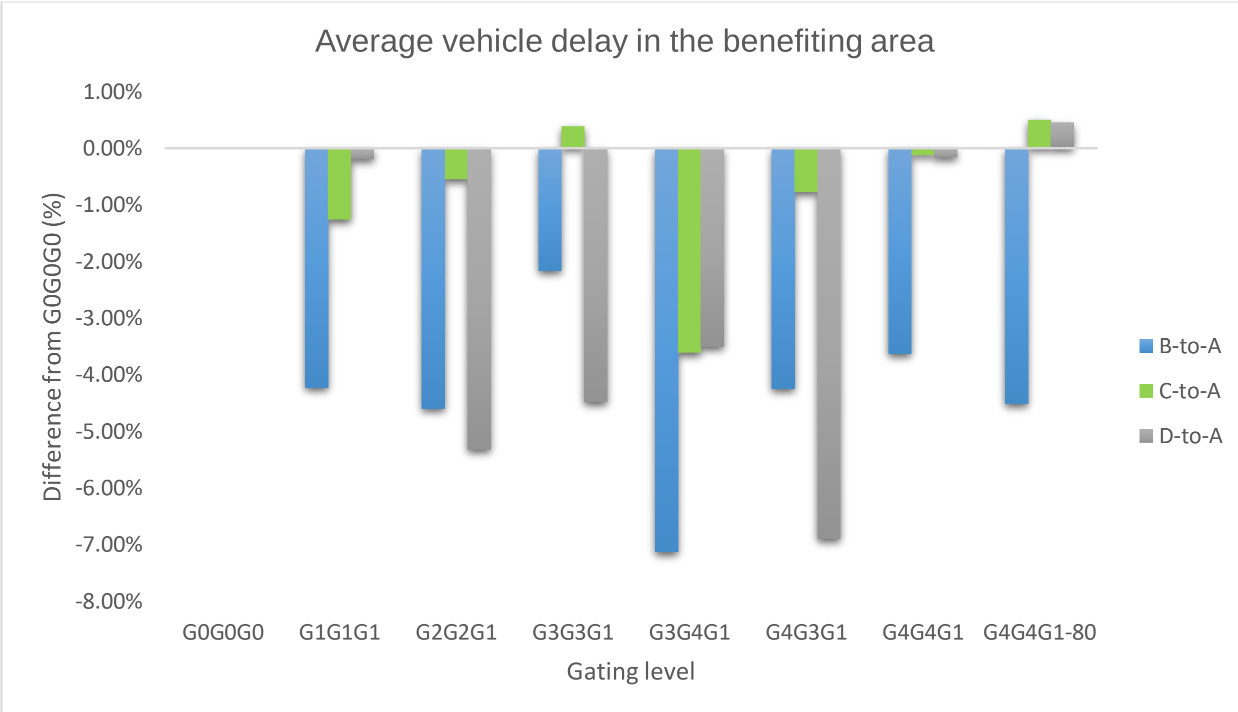


Figure 14: Average vehicle delay in the benefiting area

The impact of Gating on the future traffic flow

As the future traffic will be an increase in volume, *Gating* is essential to regulate traffic to the new city district and harbor. We analysed whether the benefit of *Gating* still exists after the volume of traffic increases. The effectiveness of *Gating* levels that were defined in *Table 6* are evaluated by simulating different traffic volumes: *CurrentVolumePlus5%, CurrentVolumePlus10%, and CurrentVolumePlus15%.* The parameters of each *Gating-level* require fine-tuning and further optimisation for an increase in traffic. Here, we demonstrated the impact of *Gating* when traffic increased by 5% (*CurrentVolumePlus5%*). For this category of volume, the labels of *Gating-levels* are modified as, for example, *G0G0G0-5%* and *G1G1G1-5%. G0G0G0-5%* represents *Gating0* when traffic volume increased by 5%, and *G1G1G1-5%* represents *Gating1* as defined in *Table 6*.

The results show that applying *Gating* improves the average maximum queue at *intersection-A* by a maximum of 5.5% and minimum of 2.23%, refer to *Figure 15*. When *Gating-level G2G2G1-5%* is applied the average maximum queue at *intersection-A* is improved by 5.5%. This improvement is significant because even with a 5% increase of volume the intersection is under capacity but the continuous flow to the bottleneck forms congestion. Travel times and delays measured on the benefiting link, the result of travel time shows that there is an improvement of

2% after applying *G2G2G2-5%*. As we mentioned in previous sections, the measurement on the benefit-link might not reflect the actual reality because the evaluation network ends at the bridge.

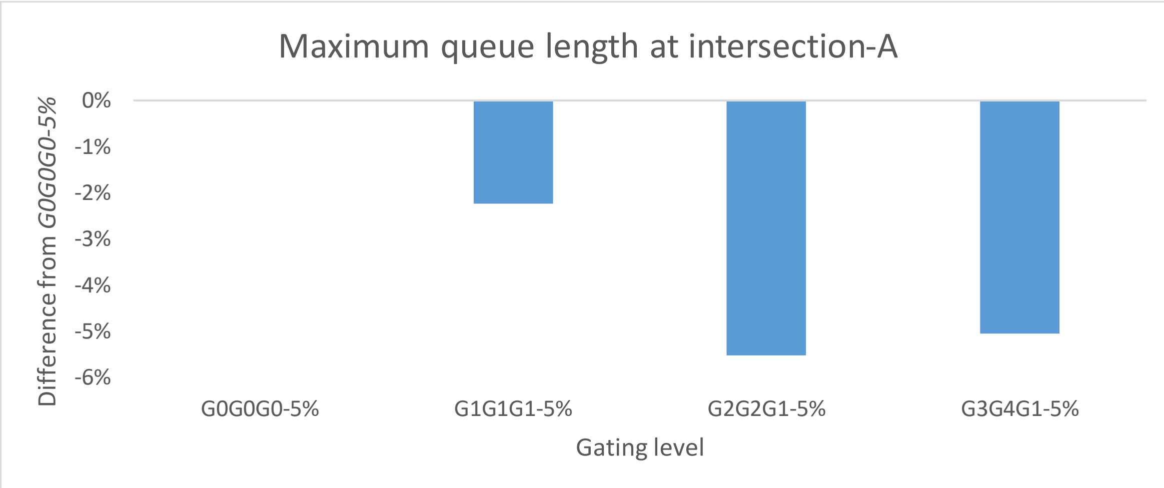


Figure 15: Average maximum queue formed during simulation of different Gating-levels under a 5% increase in traffic.

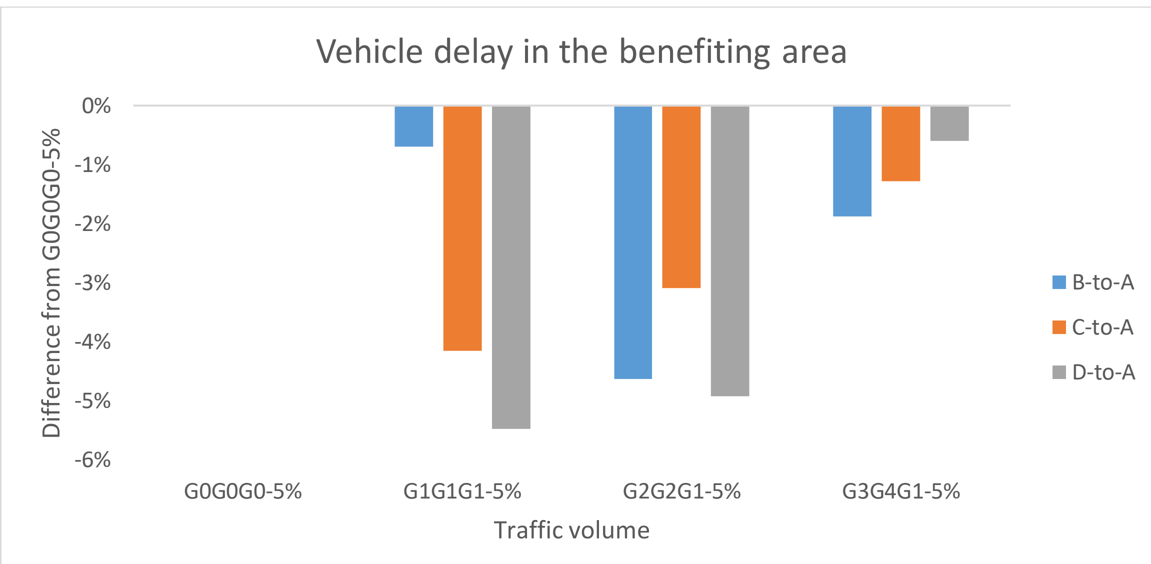


Figure 16: Average vehicle delay in the benefiting area from the simulation of different levels of Gating under 5% increase in traffic

As we can see from *Figure 16*, vehicle delays in the benefiting area also show significant improvement. For instance, when *Gating1 (G1G1G1-5%)* is applied the delay in the benefiting area improved by 5.47%. A vehicle delay is minimised by 5.5% when a vehicle drives from intersection-D to intersection-A. When we compare the result with that obtained from *G1G1G1*, it indicates that *Gating* with adaptive signal control is more effective when future traffic increases by 5%. This implies that *Gating* with optimised adaptive signal control efficiently manages the traffic on the corridor and keeps the function of traffic in the Nyhamnen area.

4.5. Validation of the results

Before concluding the traffic simulation results, checking the extent to which the simulation model replicates reality is necessary. There are two types of simulation model validation: 1) validation of the traffic simulation software package that is used for the study; 2) validation of the facility under consideration to confirm that the simulation model is indeed a representative description of the traffic system that is modelled.

Software validation is not necessary in this case because we used well-established and accepted traffic simulation packages, PTV-Vissim. Furthermore, we validate optimisation methods in ImFlow to that of VISSIM.

In respect of facility validation, there are several ways to assure the reliability of the simulation results. In this study, we did validation based on information from field observation done by the city of Malmö. According to observation, traffic moves slow down west of *intersection-A*, including the bottleneck. This is partially verified based on travel time on these links. Additionally, we used live Google traffic data to validate our model. By comparing, the simulation travel time and queue over simulation time intervals in the area of Västkustvägen, our model replicates the traffic pattern observed during morning rush hours.

4.6. Analysis and discussion

Traffic congestion has been one of the major issues that most cities across Europe are facing. It negatively affects the economies, societies, and environments in the urban setting.

In cities, mobility patterns have been continuously changing, because of several factors such as trends in the economy, and dynamic and diverse demand for transport services.

There are many KPIs that have been taken to mitigate congestion: 1) expanding the capacity of the urban network, 2) optimising the capacity of the urban network through traffic signal controlling, 3) broadening traffic information using software applications, and other KPIs aimed to reduce congestion from demand and supply sides.

The MORE project promotes the redesign of existing urban main roads and streets to accommodate addressing problems of congestion. MORE also believes that identifying new technologies for enhancing the digital and physical transport infrastructure of the corridors is vital for optimal use of road space in the cities [6]. As a MORE partner, the city of Malmö wants to address the challenges of an increasing number of commuters and freight transport and associated congestion along the MORE corridor in the city [15]. In the coming years, the city of

Malmö plans to develop Nyhamnen from an existing industrial district to a sustainable urban district including housing, offices, retails, and schools. As a result, one of the development strategies to address traffic challenges in the district of Nyhamnen is through optimisation of traffic signal controls.

Optimisation of signal control depends on the signal control methods used by traffic signal controllers on the street. According to [9], traffic signal control methods are broadly classified as fixed-time, semi-fixed, actuated, adaptive, and enhanced adaptive methods. The designing and optimisation of the aforementioned methods take into account the road users, motorized vehicles, cyclists, and pedestrians. Different control methods tend to attain certain levels of traffic efficiency on the road based on certain KPIs such as average delay and number of stops. Most of the modern traffic management and control systems are using adaptive signal control algorithms where signal timing is adjusted in real-time to accommodate detected changes in traffic patterns [6]. In this study, we used, adaptive traffic control (ImFlow) but it can optimise signal timing using fixed-time or traffic actuated methods with lesser performance results. A user can switch between different methods once it is installed on the streets.

In the fixed-time control, the duration and the order of all green phases are fixed. The plans are calculated based on average flow and include a margin to cope with cycle-by-cycle demand fluctuations and prevent queues from forming. One of the drawbacks of the fixed time method is it does not react to unexpected changes in the traffic. A traffic responsive system called System Activated Plan Selection (SAPS) often handles this problem [9], or pre optimised different signal timing plans can be scheduled at different times of the day, for example, in the morning or noon or every one-hour. If the intersections are close to each other and the traffic demands between the adjacent intersections are large, then a coordinated fixed time system is effective to control traffic. Fixed time signal controls coordination can provide efficient movements of vehicle platoons through adjacent intersections and reduce delays and the number of stops [16]. Currently, on the MORE corridor, three intersections along Västkustvägen have been controlled by coordinated fixed time plans during the morning peak. From the results, the fixed time signal control method has not shown improvement under the current traffic situation. This could be a little bit improved by coordinated fixed time plan selection that can be executed every short time interval, e.g., around 15 or 30 minutes. The city can benefit from this if there are limited resources to replace fixed time control.

Both actuated and adaptive traffic controllers require detectors. For both control methods, investment costs in detectors are required from the city. Since traditional sensors like inductive loop detectors have significant installation and maintenance costs [17]. Actuated control is more efficient than fixed-time control since provides “actuation” by a vehicle, pedestrian, or cyclist for certain phases or traffic movements to be served. It uses traffic detectors, namely, stop line detectors and gap detection detectors. Adaptive signal control also requires sufficient detector data to fully function. For example, ImFlow at adaptive mode requires stopline detector and link-entry detector data to estimate the queue length and arrival patterns.

Despite the cost related to detectors, the city would get the maximum benefit from using adaptive traffic controls along the corridor. Numerous pieces of literature have shown that adaptive signal control has a benefit over traditional signal control, among these [18], [9], [16]. The primary benefit of adaptive control is it adjusts itself to the momentarily change in traffic but also structurally changes. Under unsaturated flow, the adaptive signal control manages the sudden change in traffic flow that could happen due to the increase in traffic demand and/or special traffic incidents. That means the adaptive signal control is the most effective up to the maximum saturation level. According to [9], adaptive traffic control can efficiently manage mixed traffic of automated driving and cooperative driving. C-ITS applications such as GLOSA and priority management effectively work with adaptive. Also, the significant development in communication and sensor technology Intelligent Transport System (ITS) will provide additional and alternative data that enhance adaptive signal control. For example, data from cooperative and connected mobility from the roadside and on-board units provide richer information for intelligent traffic management [6].

Furthermore, the combination of *Gating* and adaptive signal control is expected to lower network delays and minimise queue at the boundary of the sensitive area (at the bottleneck). According to [19], microsimulation results from a combination of adaptive traffic control and *Gating*, adaptive signal timing can improve the network performance by increasing the maximum flow and increasing the critical accumulation, whereas *Gating* helps to reduce queuing outside the protected network. The paper concludes that a combination of *Gating* and adaptive signal control results in lower delays and on average shorter boundary queues protected network. The conclusion is in line with the results of our simulation results. It indicates that combining ImFlow adaptive control with *Gating* can fully manage traffic in the area as well as along the corridor.

In general, through intelligent management of available road capacity, ImFlow optimises traffic flows and can even postpone the need for major investments. It enables the road authorities to control traffic based on the traffic policies, they can configure requirements such as environmental targets, smooth flows on the key routes, prioritisation of public transport, or stimulating bicycle flows. For example, based on the position of the truck, the ImFlow algorithm calculates how long traffic lights need to be green, and give priority or longer green time depending on the policy objectives configured.

4.7. Summary

The main aim of this case study is to investigate the capability of different types of traffic signal control strategies in controlling current and future traffic on the stressed part of the Malmö corridor without changing the current infrastructure. In addition, the research intends to introduce a congestion mitigation strategy, which regulates traffic flow to the Nyhamnen area. To attain these objectives, traffic simulations were conducted based on real-world morning peak hour data. Traffic simulation software VISSIM and optimised policy-based signal control are coupled to carry out the simulation. The model of the road network was carefully calibrated and validated to resemble the current conditions on the corridor.

Evaluation of different types of signal control methods was carried out based on traffic efficiency KPIs summarised from the simulation results. Comparing each scenario to the baseline, the results indicate that adaptive signal control showed a significant improvement in the network level efficiency of traffic flow. The improvement in average traffic performance KPIs ranged between 12% and 30%. This indicates that adaptive signal control is more effective than other signal control to manage the current traffic flow on the corridor.

The results indicate that fixed time signal control does not show an improvement in either network or intersection level traffic performance KPIs. Actuated traffic signal control has shown significant improvement compared to baseline; however, comparable less to that of improvement by adaptive signal control. Actuated signal control improves the network traffic efficiency between the range of 8.5% to 25%. Comparing the improvements in the number of stops, adaptive signal control has shown a meaningful decrease in the average number of stops, about a 23.30% decrease compared to baseline. Overall, the corridor can benefit significantly from using adaptive signal control. The real benefit of adaptive signal control is in its capability to adapt to the traffic changes and use of traffic data to control traffic at the intersection as well as a large network.

The result from the simulation of high traffic flow shows that optimised adaptive signal control can efficiently manage future traffic. Considering the increase in traffic volume in the future, adaptive signal control can handle the traffic when the current traffic flow on the corridor increases by 15%. This implies, with less investment in sensors and no investment in infrastructure, rush hour traffic situations will not be worse even if the traffic will increase by 15% in the future. However, an increase in traffic flow by more than 15% or possibly to the level of saturation, requires increasing road capacity. To postpone the investment in road capacity the unsaturated operation can be extended by regulating the influx into the network. The capacity can be increased by the development planned in the area of Nyhamnen, and/or by applying traffic metering on the corridor. That means an increase in traffic requires a control strategy that regulates traffic entering the Neymanen area as it causes congestion in the area.

To address the current challenge on the uncontrolled bottleneck and the future expected traffic challenges in the area of Nyhamnen, a congestion mitigation strategy was investigated and designed based on the traffic condition on the corridor. The strategy was implemented by combining optimised adaptive signal control with *Gating*. After experimenting with a different combination of *Gating* parameters and *Gating* links, a degree of *Gating* with a less negative impact on the whole traffic and more positive impact in the sensitive area and on the bottleneck area are selected. Under current traffic conditions, the results of traffic performance KPIs show that *Gating* is successful in reducing the level of congestion in the Nyhamnen area and on the bottleneck. For example, applying a *Gating* strategy improves traffic delay in the Nyhamnen area by 7% compared to results from the optimised adaptive signal control (the benchmark). *Gating* also improves the average queue length on the bottleneck by 5%.

To evaluate the benefit of *Gating* when current traffic increases by 5%, few *Gating* levels are evaluated. Even with adaptive signal control parameters that were optimised on current traffic flow, the results show that *Gating* can improve delay in the Nyhamnen by 4% to 6%. For a 10% or 15% increase, adaptive signal control with Gating strategies would significantly improve the traffic situation in the area.

In conclusion, an adaptive signal control system with *Gating* functionality is a useful means of addressing current and future congestion on the Malmö corridor and in the Nyhamnen area. It improved traffic efficiency not only on the corridor level but also can efficiently improve traffic problems that could happen in the Nyhamnen area and beyond. In other words, it has a high potential to handle diverse and dynamic traffic at a local level as well as a corridor level. Optimised adaptive signal control can improve road network efficiency, largely prevent and mitigate traffic congestion, reduce energy consumption, and emissions at intersections.

5. Use case 2: Impacts of automated vehicles for public transport and city logistics – a case study in Helmond

5.1. Introduction

Enhancing multi-modal transportation and optimal use of road infrastructures are among the objectives of the MORE project. In this regard, the numerous developments in automated driving are expected to enhance the modal shift and transportation logistics on new and existing road infrastructure. For example, automated pods can use bicycle lanes and pedestrian sidewalks where shuttles can use car infrastructure. Automated driving can also be a solution for a last-mile problem and automated shuttles can replace bus areas where there are no dedicated bus lanes.

When looking at traditional public transport, prioritization through dedicated lanes and high priority signal groups at intersections reduces traffic capacity and intersection throughput if not optimally designed. Although this is potentially a problem with adding a larger number of smaller transport vehicles, the demand on the road network will reduce due to the modal shift. Thus, automated shuttles can be a solution for a long distance between stops. On the other hand, logistics transportation is becoming more and more complicated because of the multiple dimensions involved- including its range of physical activities spreads and connects across the whole network. Its highly increasing demand and requirements from customers, and its unpredictable interactions with existing traffic flows on the road worsening traffic congestions with significant effects on the number of road accidents. Automated driving can be used for delivery and especially short distance deliveries of goods.

Another problem in the current urban mobility system is a vast range of transport vehicles that are set out to transport goods and people between specific locations, which are rarely the same as their origin or destination. This misalignment between actual service locations and precise origin-destination is commonly recognized as the “first mile, last mile” problem of the transport network. Automated vehicles can solve these problems: 1) smaller pods can offer efficient last-mile transport because they only need to serve a few destinations, keeping detours at a minimum; 2) More on-demand, comfortable and seamless connections when a trip involves transfers among various forms of transport means.

In this section, we conducted a real-world simulation on the Helmond N270 corridor. The simulation aims to assess the new pattern of transport services based on automated vehicles. Specifically, to study the traffic performance of the Helmond N270 network when the transport services of automated vehicles are integrated into traffic flow and to investigate the impact of infrastructure and intersection signalisation strategies on the performance of the network. The objective of automated shuttles and pods is to manage a barrier-free door-to-door trip, where shuttles serve as intercity travels and pods serve the “first and last mile” of a trip. In the MORE project context, the results from the simulation can indicate the future estimated impact of automated driving on multi-modal demands and traffic demand along the TEN-T Feeder Routes that are under stress.

5.2. Simulation design and setup

The design of the simulation is based on a futuristic design that encompasses automated shuttles and pods that coexist and replace buses in the dense urban environment; automated transport, which uses the same infrastructure as cars, bicycles, pedestrians, and Public Transport in urban areas. For example, with the pods traveling below 25km/hr, using the bicycle lanes on the main roads and parking on pedestrian lanes/sidewalks. The details of the design are:

Shuttles and pods are simulated as level 4/5 automated driving, which utilizing existing road design and infrastructure, such as road surface and signalized intersections. Shuttles are running as mid/long-distance intercity buses using the vehicle lanes while not requiring dedicated bus lanes; pods are running on the vehicle lanes and on the bicycle lanes as a short distance stop bus, which can be also an alternative to bicycles, scooters, etc. It solves the “first mile”/ “last mile” problems and brings goods from door to door. Pods can commute persons or distribute goods through the network. A pod can pass from bicycle lane to pedestrian lane/sidewalks and deliver goods from door to door.

Modal shifts from passenger cars and bicycles to shuttle and pod can be expected. The willingness of acceptance (compliance rate) for the modal shift is presumed to be 68.9% of the available shuttle and pod capacity. The regular line buses are fully replaced by shuttles and pods with a 100% modal shift. The capacity of a shuttle is 20 persons and the capacity of a pod is 5 persons. The goods capacity highly depends on the form factor and weight of the transported objects.

Shuttles and pods travel in a mixed traffic environment with other existing traffic flows, such as non-automated passenger cars, bicycles, and pedestrians. Shuttles run on schedule and use dedicated stops (long-distance between stops, e.g., 5-10km apart approximately). Pods run on-demand and can theoretically stop anywhere, such as shuttle stops, container stops (to deliver goods), charging stations (for self-charge and maintenance) and even ad-hoc locations if deemed necessary. In the simulation, the transfers between shuttles and pods occur at Helmond train station square. Thus, the pods are in practice often synchronized to the shuttles, demonstrating seamless transfers between shuttles and pods.

Simulation set-up

The simulation adopts the N270 corridor network with multiple intersections in Helmond city centre, namely, intersections HEL701, HEL702, HEL704, HEL101, HEL102, HEL103, and HEL104. The main east-west and west-east directions are dominant in terms of traffic demand due to the connection to the A270 to the west and the A73 and A67 motorways to the east. All intersections have pedestrian and bicycle traffic as well. The network is suitable for introducing upcoming automated shuttles and pods. *Figure 17* presents the layout of the simulation network, among which four 100-series intersections: HEL101, HEL102, HEL103, and HEL104 are configured for the simulation experiment. These intersections are controlled with the adaptive controller ImFlow.

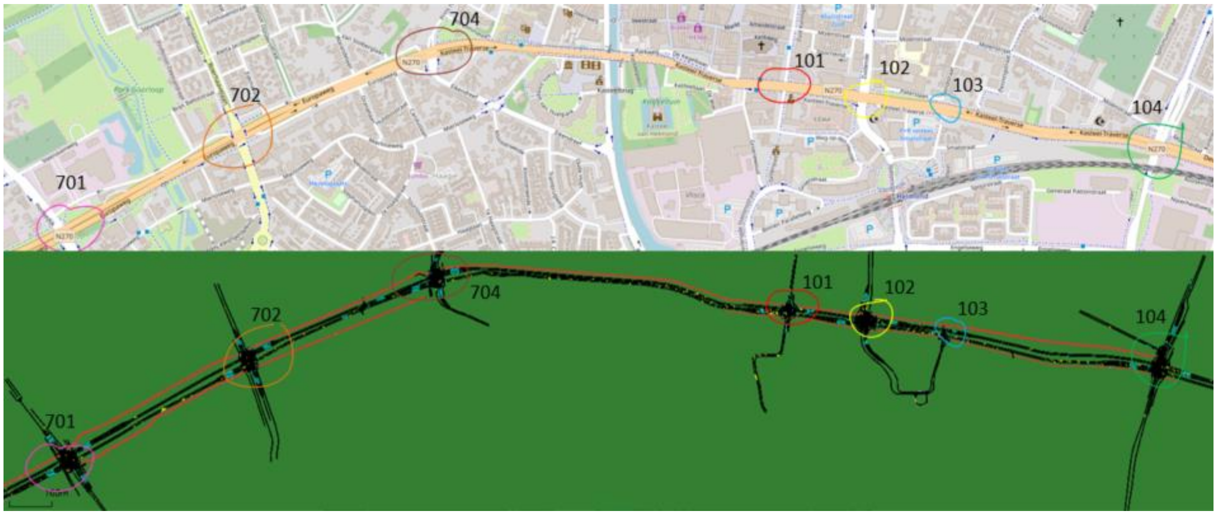


Figure 17: Helmond network (top) and the simulation network in SUMO (bottom)

The current public transport routes and flows are replaced with shuttles and pods, which have a total capacity to carry 320 persons and 64 pods full of goods (only dispatch at a pre-defined container stop in the experiment) across the network (from west of HEL701 to the east of HEL104 and vice versa. Since the amount of passengers is significant, the related traffic flows are recalibrated according to the modal shift mentioned previously according to the OD pairs replaced by the shuttles and pods. The other “normal” traffic, such as passenger car flows (except for the two OD pairs due to modal shift), bicycle flows and pedestrian flows have been kept the same as the current situation.

5.3. Traffic flow and infrastructure

The current traffic flows and infrastructure of Helmond city centre are composed of the following: 1) Existing vehicles: passenger cars and trucks travels on the road surface and use the traffic signal for vehicles; 2) Existing bicycles: bicycles of a generalized bicycle category that travel on the bicycle lanes with a maximum speed of 25km/hr; 3) Existing pedestrians: pedestrians walking on pedestrian lanes/kerbside. Shuttles and pods can perform collision avoidance actions autonomously when they are interacting with pedestrians; 4) ImFlow traffic controllers: Intersections 700-series and 100 series on N270 of Helmond are controlled with ImFlow traffic controllers.

Automated vehicles introduced into the current traffic flow are:

1) Automated shuttles: fully automated vehicles (level 4 or 5) act as automated buses. In this simulation, they are designated to drive on vehicle lanes; follow two pre-defined routes and load/unload passengers at pre-defined shuttle stops; they use the traffic signals of existing vehicles and the PT traffic signals in the PT distribution centre.
2) Automated pods: automated driverless vehicles that can provide rapid transit to persons and goods and they can self-charge (at electric vehicle charging points) during the out-of-service time. With a maximum speed of 25km/hr, they are able to drive on bicycle lanes, vehicle lanes within an exclusive area (such as a PT distribution plaza), and they can ride-on/park on pedestrian lanes or perform kerbside stop. They use mostly the traffic signals of bicycles and the PT traffic signals in the PT distribution centre. The simulation experiment configured features transfers between shuttles and pods at pre-set locations that are concentrated on the PT distribution centre behind Helmond train station.

The stops dedicated to the automated shuttles and pods in the simulation experiment are:

1) **Shuttle stops:** shuttle stops are similar to current bus stops (but longer distances, approximately 5~10 km, between stops). There are in total four shuttle stop locations configured on the simulation network of Helmond. One of the furthest locations on the westernmost link, one of the furthest locations on the easternmost link, and two stopping bays at the PT distribution centre where passengers and goods can change modalities with the most possibilities in a centralized manner.
2) **Pod stops:** there are three types of stops are designed for pods. i) Pod stops: two pod stops are currently set-up in the PT distribution centre, mostly targeting the transfers among modalities. These stops are used to embark and/or disembark for persons and goods; ii) Container stops: one container stop is configured on the pedestrian lane (next to the bicycle lane) between intersection 103 and 104, which is intended to deliver goods to a door; iii) Charging stations: Pods can perform self-charging automatically in the charging station when the electrical power is below a threshold. These pods are in the "on-call" mode, which means they are off to service if needed. One charging station is configured in the PT distribution centre in the simulation network. All pods in this simulation experiment perform a full charge at this station before picking up passengers.

5.4. Routes and schedules

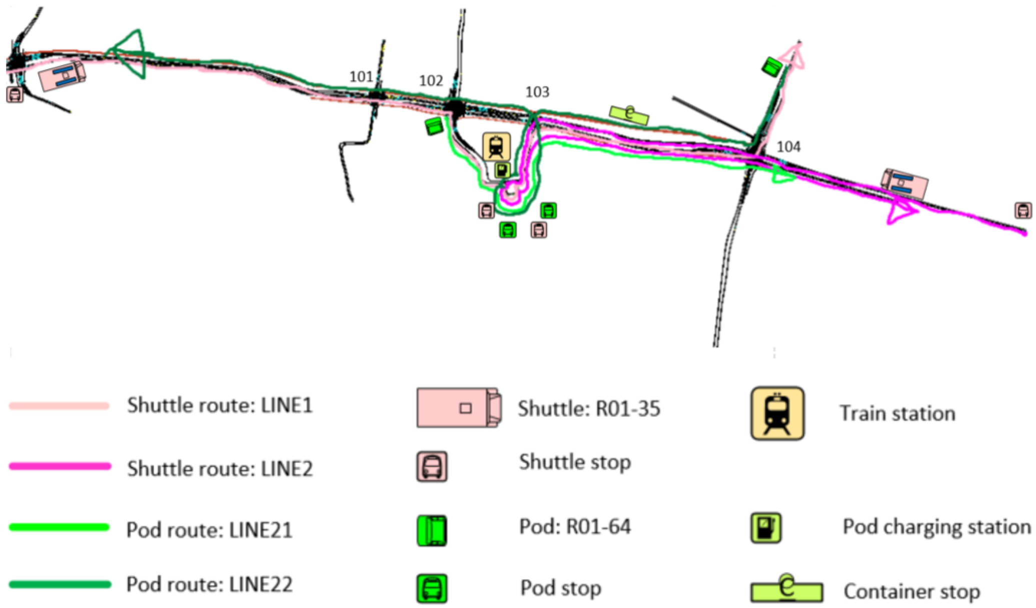


Figure 18: Overview of shuttle routes, pod routes and important POIs

To see the impact of different types of automated public transport units – namely shuttles and pods, 35 shuttles, 64 pods and 320 persons /goods following designated PT routes are simulated. The shuttles and pods are following a pre-configured schedule in a specific timetable with flexile time windows. In the simulation experiment, we expect there should be a high amount of transfers, for example, persons and goods transfer from train to pods/shuttles, from shuttles to pods, and vice versa. *Figure 18* presents the route for the automated shuttles and pods with a detailed description in the legend. This figure shows passengers and goods from potentially long shuttle rides disembark and move to the pods (parked at the pod station east one minute ago) to finish the last short part of the trip to reach their final destinations. The shuttle routes are set to fixed routes, so are the simulated pod routes, in order to deflect from dynamic routing uncertainty. The shuttle schedule has 35 shuttle trips of LINE 1 and LINE 2, departing every 5-10 minutes. The 64 pods of LINE21 and LINE 22, run on-demand. This is implemented by programming every pod to be on time at the pod stop and wait for the arrival of their designated persons or goods to arrive. After embarking the pod will do the last mile delivery.

5.5. Simulation scenarios and KPIs

Two scenarios are set up to perform the simulation experiments:

1) *Scenario baseline*: scenario baseline simulates the current traffic conditions in Helmond. The original ImFlow configuration is used at the traffic lights. The demand is set to the normal workday evening peak hour levels.

2) *Scenario future*: Scenario future paints the same network as the baseline, but with automated shuttles and pods. Intersections are handled as scenario baseline with the same ImFlow configuration on the current road.

The simulation experiments are performed according to the defined scenarios. Based on the objective, the following KPIs are used to measure the impact of automated shuttles and pods on the network. These KPIs measure the network level average to verify the effect of automated shuttles and pods on all users.

Average impact. This KPI indicates the performance of the network in terms of impact. It calculates the average overall impact of overall traffic participants [20]. It can be defined as:

$$Impact = \frac{\sum_{i=0}^{I} Delay_i + 8\ Stops_i}{I}$$

where; *I* indicate all traffic participants (can be vehicle category or a specific signal group of an intersection), the value 8 in the formula is often used as a rule-of-thumb factor by traffic engineers, which is based on CO_2 emissions and road user comfort of not stopping.

CO_2 emission(kg). The average CO_2 emission of all vehicles from the simulation experiment is used to measure the impact of automated shuttles and pods on the emission.

Throughput (vehicles). Throughput is defined by the number of vehicles passing the intersection for a specific (set of) turn direction(s). It can be acquired from the simulation output on the network level and per signal group level.

5.6. Simulation results

In order to ensure the validity of the results, each simulation experiment follows the following approaches:

1) Using real-world data collected in the Helmond network, each simulation scenario was thoughtfully planned, monitored, analysed and calibrated in order to minimize the discrepancies between the real-world and the corresponding simulation experiment.

2) Each simulation scenario (with a configured parameter setting) was performed 10 times with a different random seed (two-hour evening peak simulation each). The results were averaged over these 10 runs to ensure a statistically significant outcome.

3) Out of seven, only four intersections (HEL101, HEL102, HEL103 and HEL104) are evaluated and configured. This is because the signal groups of these four intersections are strategic to use automated shuttles and pods. Besides similar intersection layout, this network cut-out covers the busiest trips (origin-destination pairs) and most POIs, such as central train station (connections to other cities), departure-terminal centre (e.g., public transport distribution plaza) on the south arm of HEL103. Ergo, current public transport routes are also heavily concentrated on this network.

4) Special detectors are added on SUMO and ImFlow. First, the simulated traffic is detected in SUMO, then the information of these detected shuttles and pods are sent back to ImFlow to calculate and optimize the signal timing plan. After deciding on which plan to choose, ImFlow sends back the chosen plan to SUMO to continue the simulation.

The results of both simulations for the two scenarios are exported and results analysis is performed using evaluation scrips. *Figure 19* shows the average impact of all vehicles for the two scenarios: baseline and future. From scenario baseline to scenario future, the average impact decreases by 8.6%. The decrease in the impact is as expected and it confirms the positive effect of automated shuttles and pods on the network performance when the compliance rate of modal shift from passenger car to shuttle/pod is 68.9%

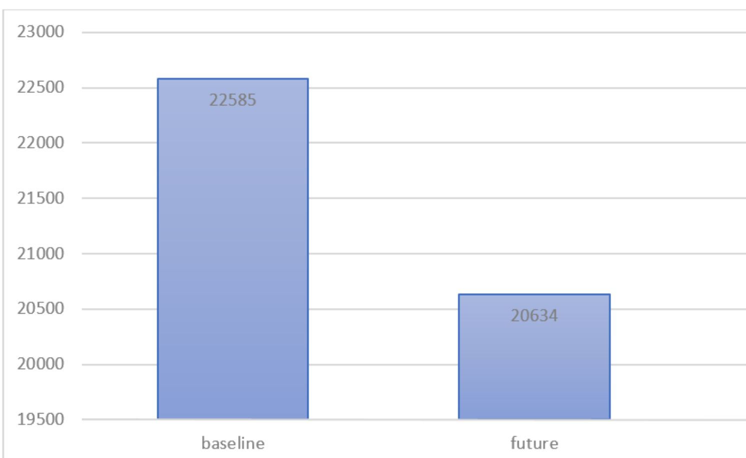


Figure 19: Average impact of all vehicles on the network

CO_2 emission is also compared between the two baselines. From scenario baseline to scenario future, the CO_2 emission decreases by 3.21%. This result is corresponding to the positive average impact exhibited in the previous figure. The decrease of CO_2 emission is quite promising on the network level even with the fact that only Pods are considered fully electrical with zero emissions while shuttles are following the PHEMlight model for the bus in SUMO.

The total throughput is 180 vehicles lower in the future scenario compared to the baseline, which ensures that there is no congestion forming due to replacing buses with automated shuttles and the use of pods for short distance end and start points of the transport.

5.7. Summary

The main aim of this simulation is to analyse the impact of automated vehicles on the performance of traffic on a network. In the simulation experiments, automated shuttles are used as the long-distance-stop buses and automated pods are used as start-point and end-point transportation of goods and people. The performance of the network was assessed using overall impact and average CO_2 emissions. The average impact and the CO_2 emissions on the network level (all vehicles) are significantly decreased with 8.6% and 3.21% respectively. This shows that a 68% compliance rate for the modal shift from private vehicles to automated shuttles and pods would be realistic. At the same time, the overall performance is still better than in the baseline, which is promising in making this solution beneficial for all traffic participants. In general, the results indicate the realistic direction of future automated based transport services such as public transport and transport of goods is promising. However, further research regarding the logistics organisation for pods and strategies for combining goods with people in one transport, and other requirements related to the delivery of goods can be conducted.

6. Use case 3: Dynamic road space allocation – a role for LED road markings and signing

6.1. Introduction

6.1.1. Study context

Street user demands for capacity and provision vary by time of day, day of week and seasonally, so it makes sense to vary traffic regulations in time, to use the available space/capacity in the most efficient way. There is a long history of doing this, using two strategies: 1) Allowing space to be used by multiple users, at the same time, possibly for different durations (e.g., a 20-minute loading bay also accessible to disabled, blue badge holders for up to 3 hours); and 2) Varying space allocation, by time of day (e.g., a peak period, kerbside bus lane, uses in the off-peak for kerbside loading)

Currently, these regulations are conveyed to street users through a combination of kerbside traffic signs and on-carriageway road markings, but there are limits as to how far this method for communicating traffic regulations can be taken, in two respects: 1) The amount of information about permitted uses at different times of day that can be displayed on a fixed sign in a meaningful way; and 2) The inability to vary regulations in a dynamic way, to reflect changing patterns of demand, in real time.

There is growing interest in the dynamic use of street space, from the 'Flexi-kerb' concept developed by Arup, to the trials of real-time loading bay allocation, developed by companies such as Grid Smart Cities. All designed to squeeze more out of the limited street space and capacity, by better aligning patterns of demand with supply, in a more agile and dynamic manner.

A substantial application of this more flexible approach to traffic regulation would require a form of dynamic signing and lining, most obviously through using LED technologies. But, to date, there have been very few tests exploring the potential format or feasibility of using LED signing and road markings, either in laboratory settings, or on street.

This report sets out to address this gap, in a limited way. It describes some tests that were carried out to compare LED signs and road markings with conventional physical signs and painted road markings, in controlled laboratory conditions, with groups of motorists and professional drivers, at UCL's new PEARL facility, in East London.

The focus was on kerbside access regulations, and the allocation of the carriageway to particular road user groups, in particular, buses and cycles.

6.1.2. Role of the trail in the MORE project

This trial forms part of Work Package 5: ‘City corridor case studies: design brief, package generation, option appraisal and overall assessment’, and forms part of Task 5.3.1 (‘Technology and design trials) and Deliverable 5.6 (‘Assessment of potential for new technologies’).

In particular, the trials have been influenced by the outcomes of Work Package 3, in particular Deliverable 3.1 ‘Analysis of technological advances’, which identifies, describes and assesses the contribution that new technological advances could make to the provision of the supply on main roads in cities. Within the deliverable, it was identified that the conveyance of information (for example LED road signs and lane markings) could be a key contributor of new technologies enhancing the use of road transport infrastructure.

More specifically, the trials aim to “test new dynamic signing and lining concepts – and the transitions from one ‘plan’ to another - based around LED technologies, in laboratory conditions with a wide range of street user groups”.

6.1.3. Brief introduction to the PEARL laboratory and its capabilities

Developed by Professor Nick Tyler, PEARL (Person-Environment-Activity Research Laboratory) is a unique facility, designed to explore the ways in which people interact with their physical environment. It is a massive space (around 4,000m_2 in floor area and 10m high), in which UCL scientists can create life-sized environments – such as a railway station, a high street, or town square – so that they can examine how people interact with the environment and other people in these types of places, under controlled conditions.

Much of our understanding about how cities work is based on assumptions about how people perceive, respond to, use and act in the physical environment. Many of these assumptions are based on practical experience over many years, but precise relationships cannot be established in the real world, as there are too many confounding variables. PEARL enables the scientific community to study in detail how people actually interact with the environment under controlled conditions, so that we can obtain rich insights that facilitate improved designs of real urban systems.

The laboratory allows for a change of profile, type and texture of material used on the floor area; it can simulate lighting of any colour and intensity, create sounds from the tiniest bird song to the most massive explosion, and includes other senses, such as smell - and much more.

PEARL’s vision is to create a better world for a future in which people and the environment can thrive together in a mutually beneficial, safe, equitable and healthy way. It aims to improve the quality of life, health and wellbeing of all, within the context of a more sustainable environment.

PEARL is a dynamic, integrated and interdisciplinary organisation comprising Researchers, Academics, Makers, Producers, Enablers and Students, who together can make an important contribution to the study of People-and-Environment interactions.

Its organisational structure can thus be likened to that of an Atom: we are more than the sum of our individual parts, as we all work together towards the creation of a better world.

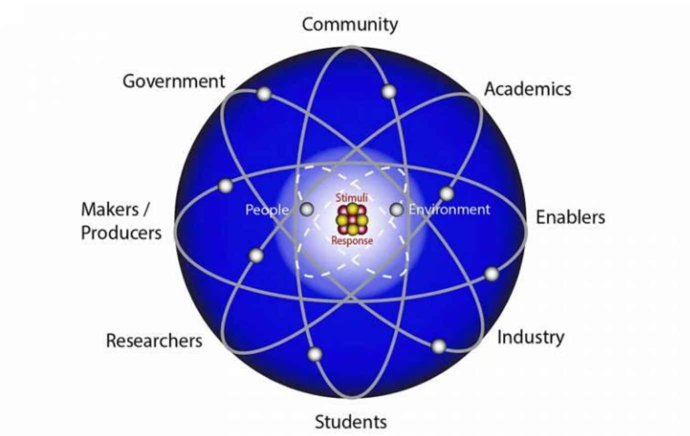


Figure 20: PEARL organisation structure

6.2. Planning the LED trails

Planning involved the flowing stages:

1) Identifying issues to be addressed during the trials
2) Determining the sample (composition & size) of participants
3) Selecting stimulus materials and scenarios to be presented to participants
4) Obtaining UCL ethics approvals
5) Obtaining hardware to simulate LED traffic signs and road markings
6) Programming and testing the hardware and software
7) Conducting the trials
8) Analysis and writing up

The key issues that were to be addressed by the trials included:

Understanding of existing signs and markings, e.g. What do they mean? Do they make sense?

Reactions to new types of signs, e.g. What do they mean? Do they make sense?

LED vs conventional signs & markings, e.g. How well do they compare under different lighting conditions? Reactions to scope for flexibility? General reactions to use of LED?

LED road surfaces and transitions, e.g. Methods of signalling transitions, and Reactions to the idea?

Overall reflections? It was decided to carry out the trials with groups of motor vehicle drivers, rather than through individual interviews. Cyclists were not included as, in general, kerbside traffic regulations do not affect where they can stop and park. Since the topic was a novel one, it was felt that discussions among the group members would be a valuable part of the exercise.

Three groups of participants were planned

Group 1: Younger car drivers (18 – 44)	Age range; Male/female balance; Ethnic representation Infrequent car driver trips/low mileage vs Frequent car driver trips/high mileage
Group 2: Older car drivers (45+)	Age range; Male/female balance; Ethnic representation Infrequent car driver trips/low mileage vs Frequent car driver trips/high mileage
Group 3: Professional passenger and freight vehicle drivers	Taxis, Private hire, etc; buses and coaches Vans (delivery), vans (servicing – e.g., plumbers), medium goods, HGVs Age range; Male/female and ethnic representation

The recruitment and on-site greeting of the three groups were managed by Accent Marketing and Research. Participants were offered a financial incentive.

Considerable effort went into selecting stimulus materials and the scenarios to be presented to participants, as illustrated in Chapter 4. They comprised a variety of traffic sign layouts, road marking bay shapes and colours, and coloured carriageway surfaces to reserve space for specific types of vehicles.

The UCL ethics committee required a detailed description of the sample composition and sampling method, the questions to be asked/topics to be addressed, and the visual stimuli to be presented. Information sheets and consent forms were developed and approved by the committee, as shown in Annexes A1 and A2.

Two traffic signs were commissioned from RBLI of Aylesham, Kent via Simon Morgan at Buchanan Computing (a MORE partner). These depicted two ways of showing peak period stopping restrictions, with off-peak loading permitted; one showing the Red Route version of the signs and the other the standard UK version. LED strips and studs were obtained from commercial suppliers. Most LED signs were shown on high-quality monitors and high quality, ceiling-mounted data projectors were hired, to depict different coloured road surfaces.

Templates for the LED versions of existing traffic signs were provided by Buchanan Computing, using their SignPlot software. Grid Smarter Cities provided one of their their-sided traffic signs for the trials. Background lighting, the sequence of LED sign and marking displays, and the sequence of carriageway surfaces were programmed by the PEARL team.

A section of a footway and carriageway were constructed, so that LED markings could be embedded in the carriageway and the kerb.

Planning commenced in July 2021, with the discussion groups taking place in late October 2021. The original intention had been to run the trials in spring/summer 2021, with support from an MSc student, but due to COVID restrictions on group meetings, the work had to be delayed until the late summer/autumn.

6.3. Conducting the trails

The trials took place between the 26th – 28th October 2021. Each group session lasted 1.5 hours, and refreshments were provided. The groups were moderated by Peter Jones, with other CTS staff (Luciano Pana Tronca and Paulo Anciaes) assisting and taking notes. The activities were videoed and audio recorded.

The PEARL technical team managed the lights and projections. Two members of the technical crew were behind the cabin ensuring the correct functioning of the lights, while one crew member was on the platform listening to the discussion and communicating with the crew when it was time to display the next sequence.

6.3.1. Participants profiles

Younger car drivers' group (Tuesday 26th October 2021)

Nine young car drivers were recruited. The average age was 34 years old. Five out of nine drove their cars for 5+ days a week; three drove their cars between 2 and 5 days a week and only one drove their car once a week or less. Six drivers used a small or medium sized car, two use a large car and one uses a 4-wheel drive vehicle. Four out of nine were female and five males.

Older car drivers' group (Wednesday 27th October 2021)

This group included nine participants. The average age was 57 years old. Older drivers in this group mostly used their cars between 2-4 days a week (6 participants), one used their car between 2-3 days a week, and two participants used their cars more than 5 days a week. Six participants drove a small or mid-sized car (not a 4-wheel drive vehicle), one used a large car, one a mid-size vehicle and one a small or mid-sized car. This group included 4 women and 5 men.

Professional drivers (Thursday 28th October 2021)

This group also included nine participants. The average age was 40 years old, with ages ranging between 27 and 68. Three participants drove either a taxi or private hire car, two drove buses, one drove a van, one a coach or funeral car and one drove a delivery or service van. Eight participants were male and one female.

6.3.2. Phases of the trails

Participants arrived at PEARL between 17:00-17:30hrs and were greeted by the Accent host. They were asked to read the information sheet (if they hadn't done so before) and to sign in and complete the consent form. They were provided with refreshments. A copy of the information sheet and consent form can be found in the annexes.

The trials consisted of four phases.

Phase 1 (seminar room): Welcoming of participants, introductions around the table, overview of MORE and the LED trails, and an on-screen exercise involving exploring participants' comprehension of some existing traffic signs and markings.

Phase 2 (PEARL platform): Participants were first shown four signs, two normal signs and their LED equivalents; lighting levels were then varied, to assess participants' reactions. They were then shown carriageway markings on the floor of the platform, both in painted and LED forms – and, in the latter case, in different colours; again, lighting levels were varied, to simulate day and night times. Finally, participants were presented with a dynamic parking sign, provided by Grid Smarter Cities.

Phase 3 (PEARL Floor area): Participants were shown different projections onto a grey road surface, depicting different types of pedestrian crossings, plus cycle and bus lanes. In each case, issues around transitions were explored.

Phase 4 (seminar room): Participants returned to the seminar room, for final around-the-table reflections on what they had seen and heard, before departing.

6.3.3. Acknowledgements

Most of the photographs shown in this report were extracted from the videos or from camera images taken by the PEARL crew; we thank and acknowledge, in particular, Joe Boxshall and Richard Burton for their help in setting up the trials and with follow up activities associated with this trial. Paulo Anciaes assisted with some of the groups and Grid Smarter Cities contributed several photographs used in this report.

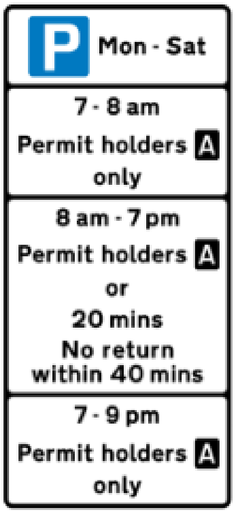
6.4. Key findings

This section displays what people were shown and then summarises their reactions.

NOTE that, in some cases, the digital camera images displayed here do not accurately capture lighting levels and the brightness of the LED road markings, in particular, due to a combination of the limited colour range of the camera chips and the tendency to auto-adjust to give the best exposure

6.4.1. Phase 1 (existing signs/markings – seminar room)

Residential parking sign



It took participants some while to read and process the information provided in this sign.

Younger car drivers generally agreed the sign was confusing. In particular, they were not sure what happened on Sundays:

> *"Is it free to park after 7pm?"*
> *"There is too much information in one sign"*

Older car drivers agreed that the sign meant that vehicles owned by non-residents couldn't park at certain times, but there were different opinions about which times the sign referred to. In general, they agreed in a similar way as younger drivers, that the sign had too much information and it was somewhat complicated.

In contrast, the sign was clearly understood by professional drivers:

> *"Permit holders can park anytime" "Non-permit holders (can park) only for 20 minutes between 8-7".*

High street kerbside activity sign

The majority of younger drivers didn't understand this sign. They mentioned that it was confusing, in particular about the meaning of "No waiting", and whether that included "No stopping". Referring to the white section of the sign, participants said:

> "*It's free to load on Sundays*" and
> "*You can do anything after 5pm*".

In general, those participants felt that they could park there.

Older car drivers took some time to come to an understanding about the meaning of the sign. They agreed that the sign applied in areas where people are picked up by taxis. However, they mentioned the word "waiting" is ambiguous and raised doubts about the application of restrictions on every day of the week.

Again, most professional drivers had a good understanding of the sign:

> *"Taxis can't park between 11 to 5"*
> *"Taxis can't use it between 10-4pm"*
> *"Sunday is free to park"*

However, some felt it was not clear if the "no waiting" section was only from Monday to Saturday. Additionally, they raised the issue that mini cabs are not considered taxis.

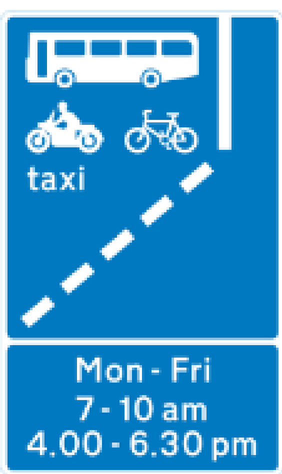
High street kerbside activity sign – Red Route

Younger car drivers generally correctly understood this sign; however, they expressed reservations about stopping even during what they perceived to be permitted times, due to fears they could be fined (given a reputation for strong enforcement on Red Routes).

However, some were unsure whether the bottom part applies from Monday to Saturday, as the top part indicates, or if it applies every day. Additionally, a question was raised as to whether loading can only be carried out by lorries and vans, or could apply to private cats too.

For older drivers and professional drivers, the sign was generally easy to understand. Yet, some older drivers were not sure if they could stop between 4pm and 7am; this group also mentioned they would need to stop in order to read the sign, which meant "it's self-defeating".

Blue bus lane sign

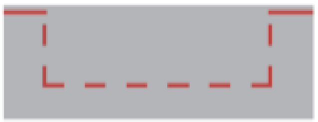


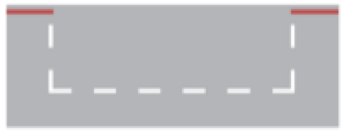
Younger drivers identified the sign as being related to bus lanes; however, a few were not sure if the hours referred to the period when the bus lane was in operation or could be used by cars.

Some noted that other drivers did not read these signs and so did not use them during permitted hours – giving them an advantage.

Both older drivers and professional drivers had a good understanding of the sign. Older drivers also had the impression that cars rarely use the bus lanes outside the operating hours.

High street kerbside road markings





Younger drivers had a relatively poor understanding of the markings. In particular, they were unsure about the meaning of the dashed line. They didn't know if it was related to parking or loading [this would be evident from the accompanying traffic sign, not shown to participants] - and were unaware that the colours denoted hours of operation: red line – part of Red Route hours only; white line – throughout Red Route hours.

Older drivers also didn't understand the difference between the red and white dotted lines. Some professional drivers, but not all, knew about the difference between the red and white dotted lines.

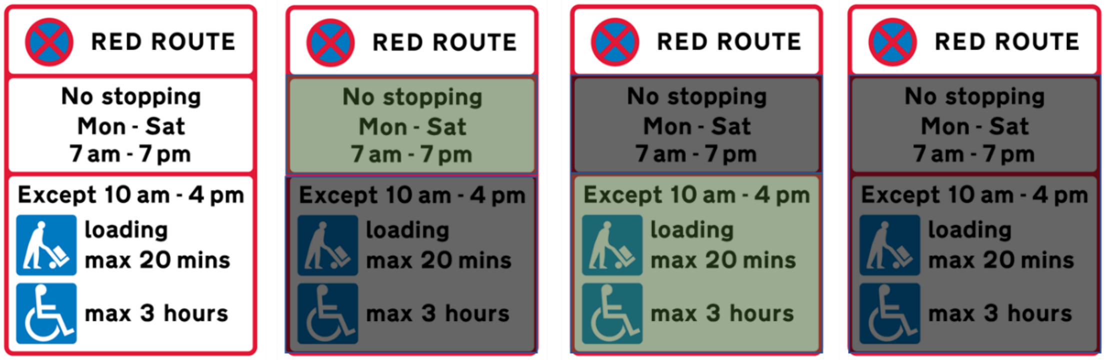
Younger drivers displayed a good understanding of the yellow lines (i.e., double yellow = no waiting/parking at any time; single yellow = restrictions apply during limited hours – see traffic sign). But they did not know about the meaning of the kerb 'blip' – which indicates that loading is not permitted at any time.

Older drivers had similar understandings concerning the double yellow lines and the single yellow line, however they were less clear about the rules for loading. Some recognised and understood the kerb 'blip', but most didn't.

The best comprehension was displayed by professional drivers, who generally understood the meaning of both the kerbside lines and the kerb blips. They recognised that the blip meant that you can't park, even with a disabled badge – although participants hadn't seen this marking very often.

Participants generally complained about a lack of training about the meaning of signs and markings, as these keep changing without proper communication.

Highlighting time-specific information on signs



This set of signs was designed to obtain reactions to the possibility of highlighting the regulations that applied at a specific time of day, on LED signs (grey = not applicable).

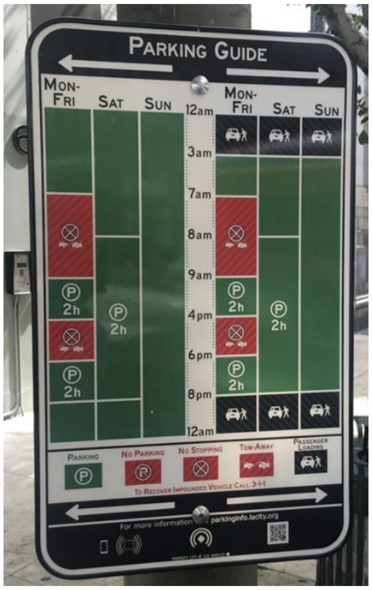
Younger drivers considered that "blacking out" the information that didn't apply could be helpful, in particular along Red Routes, as it is generally (incorrectly) understood that motorists can't park there. However, some participants raised the issue that all information should be visible, to enable drivers to plan ahead and be aware of regulations at different times of day. They also raised concerns about possible power failures or technical issues around incorrect displays on LED signs - which could result in them getting fined incorrectly.

Several older drivers worried about the cost: "*where will the money come from*". But, in general, participants liked the idea and regarded it as simple and less confusing to highlight what applies at that particular time of day. When considering the colour of the highlighted area, all said that using green was fine - but that this should be checked in related to colour blind people. They also suggested having a white light around the box that applies at the time.

The professional drivers all had a good understanding of the signs and supported the idea of using some form of highlighting. Some suggested that it should be clear when there are no restrictions in operation:

> *"Don't use different colours (for highlighting what is in operation), just white [showing what applies] and no colour [i.e., blank out the parts that don't apply]"*

Unconventional parking sign from the US



Among the younger drivers' group, only one person understood the sign. Most mentioned it could be dangerous to try to read it when driving.

Older drivers found the sign confusing too and said that people might opt to ignore it. In particular they dislike "*too many symbols and colours*", and they were confused by the need for two different tables [representing different regulations in the two directions]. Some disagreed and were positive:

> *"I could get used to it, diagrams like this are better than words".*
> *"It's like a puzzle, I need to spend time understanding it, then it becomes obvious".*

Professional drivers really liked the sign:

> *"Once you get used to, its useful"*
> *"It's simpler"*
> *"I would understand something like this better*
> *Its self-explanatory"*
> *"It's one instruction without exceptions, so you find your slot and that's it"*

6.4.2. Phase 2 (Comparing LED vs conventional sign and markings on the PEARL platform)

Conventional signs

Participants were first shown two conventional kerbside regulation signs, one used on Red Routes (right hand sign) and the other on other roads, and asked to comment on/compare them (an extension of the Phase 1 exercise).

People generally understood both signs, that are largely different ways of conveying the same information (although the left-hand sign does not indicate the maximum loading duration). Younger drivers noted that the left-hand sign contained more information, and in that sense was more 'complete', but it took longer to grasp the meaning.

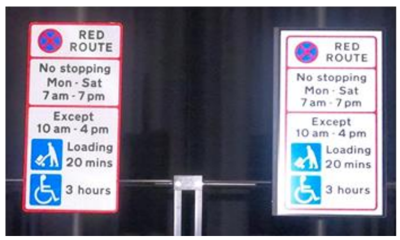
Physical vs LED signs

For each of the above signs, in turn, participants were shown the conventional sign and an LED equivalent alongside, under different lighting conditions (NOTE the earlier caveat about the limited ability of digital cameras to capture lighting level differences).

Participants were first shown each set of designs, in turn, under normal lighting conditions. The background lighting was then lowered to simulate night time conditions, followed by right and left angle lighting and, finally, a strong front spotlight to simulate maximum sunlight face-on to the signs.

Normal light

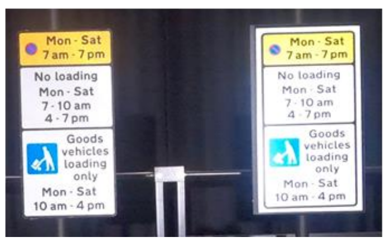
Bright light



Low light

Normal light

Bright light



Low light

There were no major differences in the appreciation of the signs by the different groups. In general, all the groups considered the LED signs to be clearer and brighter than the conventional physical signs – and were pleasantly surprised by this. There was an exception, when the front spotlight was illuminating the signs, which showed that the LED signs couldn't cope with the strong, direct strong light and the glare. However, moving only a few degrees either way removed the problem.

On the negative side, participants raised issues around cost, maintenance, malfunctioning, vandalism and accessibility (colour blindness, dyslexia). Comments included:

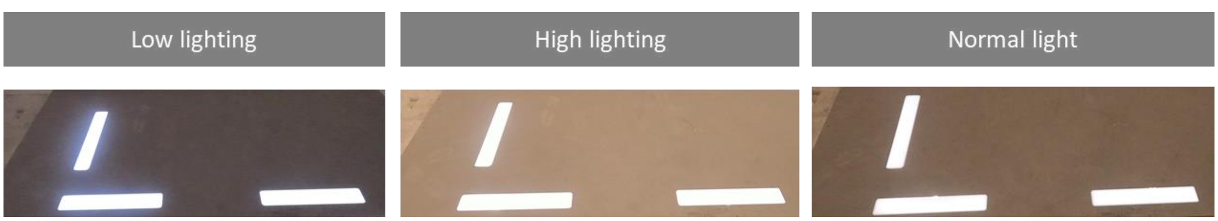
> *"In daylight it might be difficult but in night time is perfect".*
> *"I would be worry if there are not working"*
> *Low light: "Its brighter but better to see (the LED signs)"*
> *"Would the light annoy residents?"*

“My son has dyslexia, and he reads better with a non-white background”

White bay dashed lines (Red Routes)

Participants were first shown a Red Route all-day parking/loading bay, with half the bay represented by a painted white dashed line and the other half using LED strips.

Under normal and strong lighting conditions, the LED and painted lines were largely indistinguishable, but under low lighting conditions the LED markings were much brighter and clearer.



Younger and older drivers raised concerns about the cost and funding for this measure. Younger drivers also didn’t understand why this needed to change, as the painted lines worked fine – it was explained that this could allow for more flexibility.

Older drivers considered the LED better and clearer than the painted lines. They specifically mentioned that LED wouldn’t wear out – unlike paint - and could be replaced when necessary.

Professional drivers considered the benefits of LED under different weather conditions, as they perform better, especially at night or under rainy conditions.

“It’s a no brainer, the LED is much better. The normal signs wear out easily”

Scope for using other coloured dashed lines

The adoption of LED markings would provide for the possibility of using different colours on the same set of markings, to depict variations in regulations at different times of day. So, next participants discussed the benefits of using different coloured dashed lines, and their suitability under different lighting conditions.

Younger drivers considered that the LED lights and, in particular, the colours would work better at night. However, they were concerned that changes between colours (and the restrictions that would apply with each colour) would compromise advanced trip planning and provide no predictability, if applied dynamically:

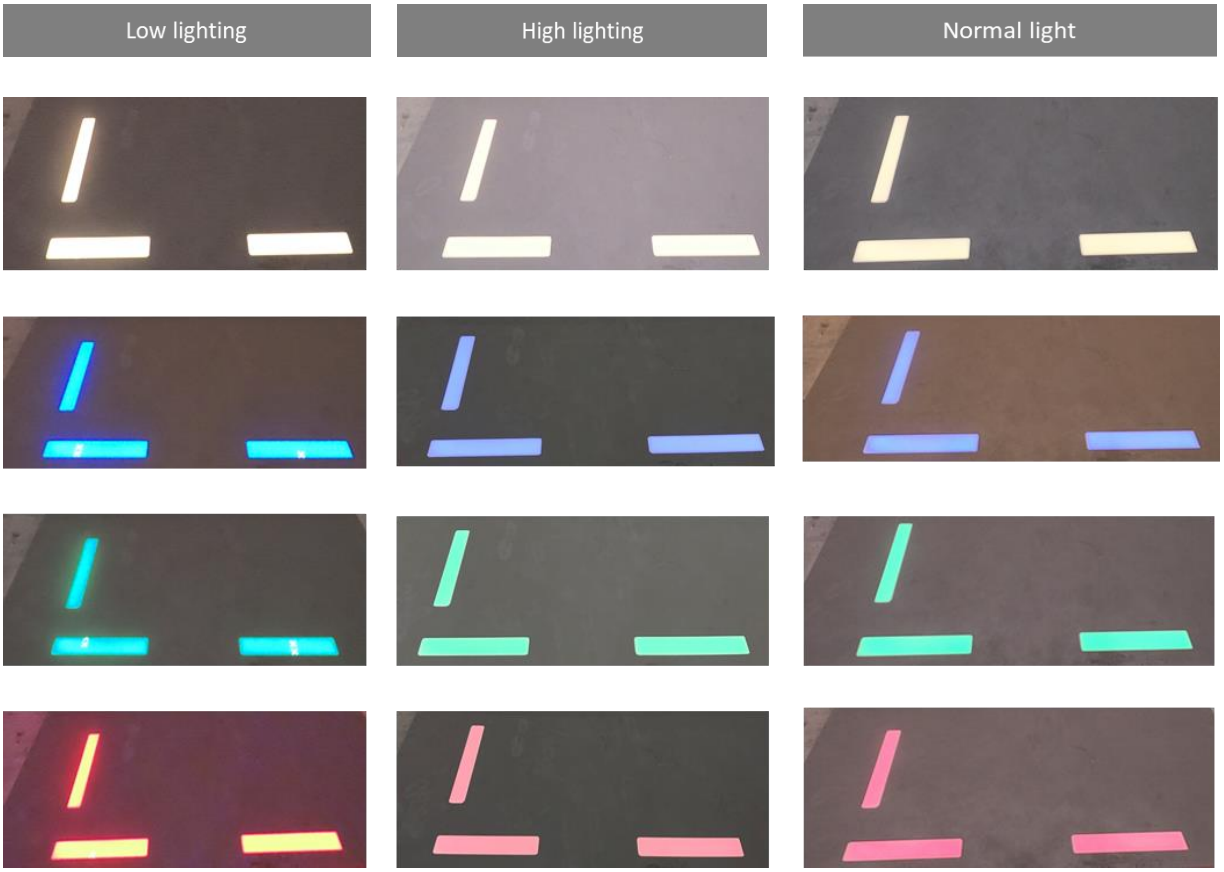
> *"As long as you don't get so many colours, the traffic lights system works"*
> *"What about for colour blind drivers?" You would need some sign to show them it's changing"*
> *"The idea that you can change it from a laptop I like, it keeps the road moving – it's a smart way of going, [compared to] when things are statutory and you can't change them. Sometimes there are roads that are empty - you just waste space"*

Younger drivers also commented on the risk of malfunction. In terms of colour coding, they considered green and red better suited for general parking (showing permitted and non-permitted times, respectively) and blue for cars with blue badges; they did not see a value in using an amber colour – which was also the least clear under different lighting conditions.

Older drivers agreed they didn't like the amber colour – what would it mean? - and preferred that the markings should be green and red only; although some participants found any mixing of colours confusing. They would prefer to stick to painted lines and using signing to indicate current conditions.

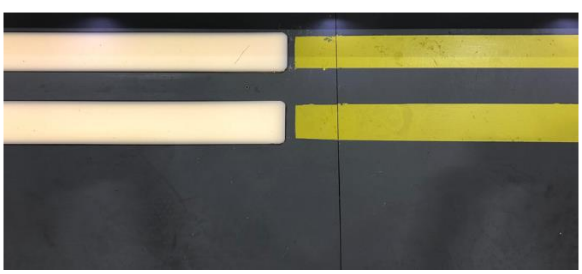
Professional drivers responded positively to flexible colour coding, and focused on situations that would provide the best use for the new technology:

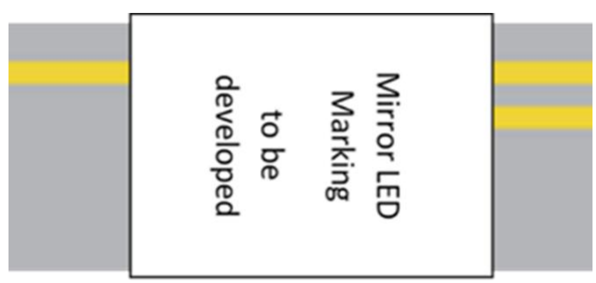
> *"Something like this could be beneficial near Wembley" "For example, on match days you couldn't park [in some areas where] normally you would"*
> *"Blue use… "for electric vehicles"*



Kerbside yellow lines

As with the Red Route markings, participants were shown a section of single and double yellow line, contrasting pained and LED strip versions. Here the visual differences between the two media tended to be greater.





The main advantage of using LED line markings would be that they could be changed, by time of day, but younger drivers were very concerned about making such a transition:

> *"I feel there should be a sign that says 'In this road signage can be swap (referring to the yellow lines) for them to be aware'"*

“A lot of people plan ahead of their journey and (changing the lines) could be a problem, changing from a single to a double yellow line”

“If you incorporate set times, then people would know”

Older drivers considered that the LEDs looked better and stand out in low lighting. However, they were concerned the cost of installation and operation, and issues regarding any utilities under the road.

Professional drivers considered the yellow LED to be too pale, and were concerned about leaves covering the LEDs on rainy days.

Studs in the kerb upright

Using LED dashed lines in the carriageway would be expensive to install and would need to be very robust to take the weight of HGVs and well insulated to be protected from heavy rains. As an alternative, Simon Morgan (from Buchanan Computing) suggested using a white dashed line on the carriageway to demark a parking or loading bay, to show current regulations by using coloured studs located in the upright kerbstones – along with conventional traffic signs.

The same range of colours was shown, as for the dashed lines described above.

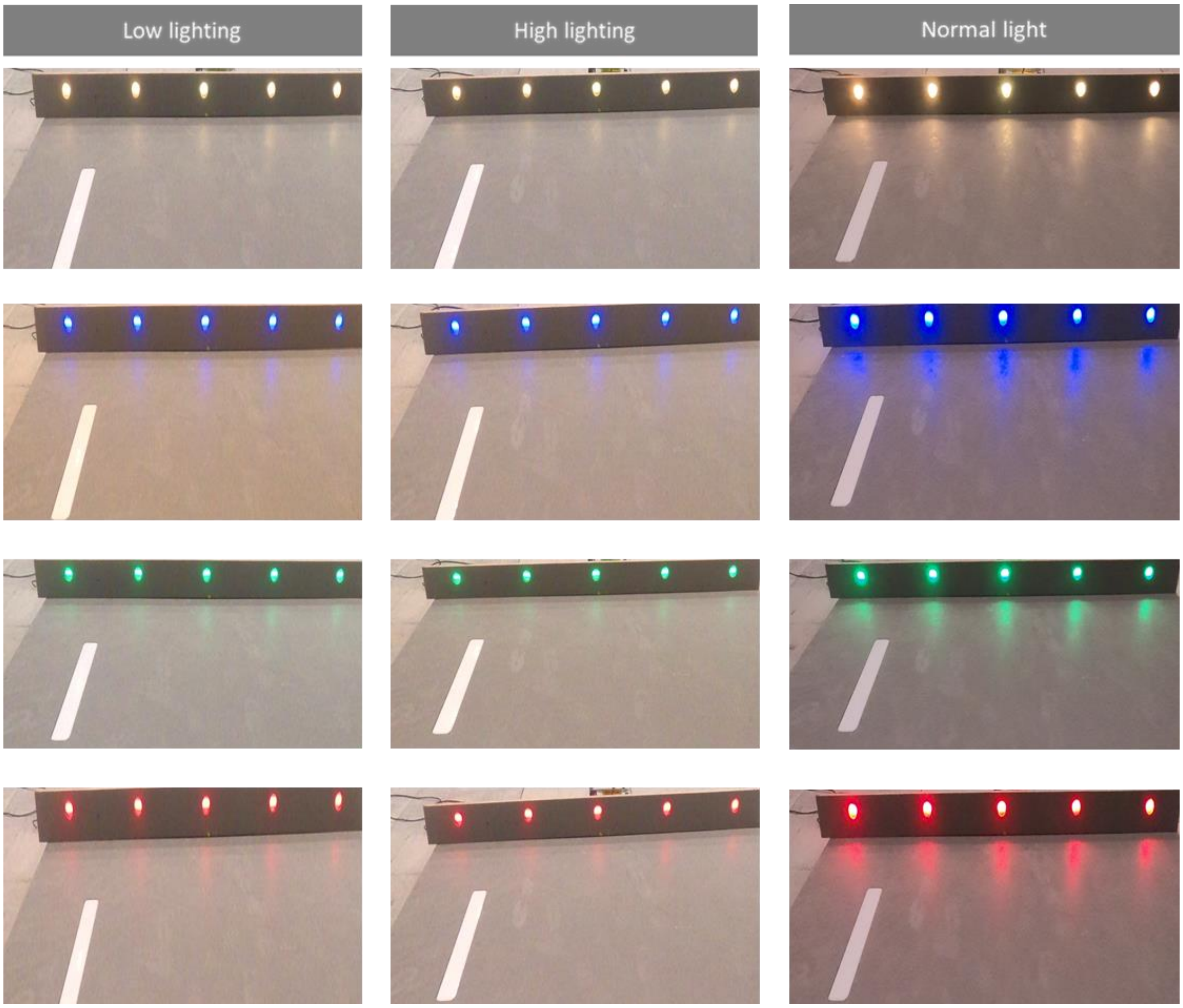
There were very mixed views among the younger driver group. They thought that the studs were clear, but questioned the need for them. Views on colours were similar to the dashed LEDs: yellow/amber is seen as confusing; they preferred red/green and maybe blue for police or ambulance.

There was also a concern that drivers might be distracted from concentrating on the road:

“You would have to look at the kerb to actually see the lights”

“I like the way it looks, but I agree that you might not be able to see it (the lights)”

“I’m not convinced by these lights”



On the other hand, older drivers were very positive; they felt that you wouldn't need to slow down to understand the regulations and that it was generally easy to understand. However, they considered potential problems such as maintenance (rubbish, leaves), vandalism and big vehicles such as lorries parked on the road and obstructing the light. As regards colours, older drivers said that amber was not needed and that people associate green with "go" and red with "don't go". The issue of colour blindness was brought up.

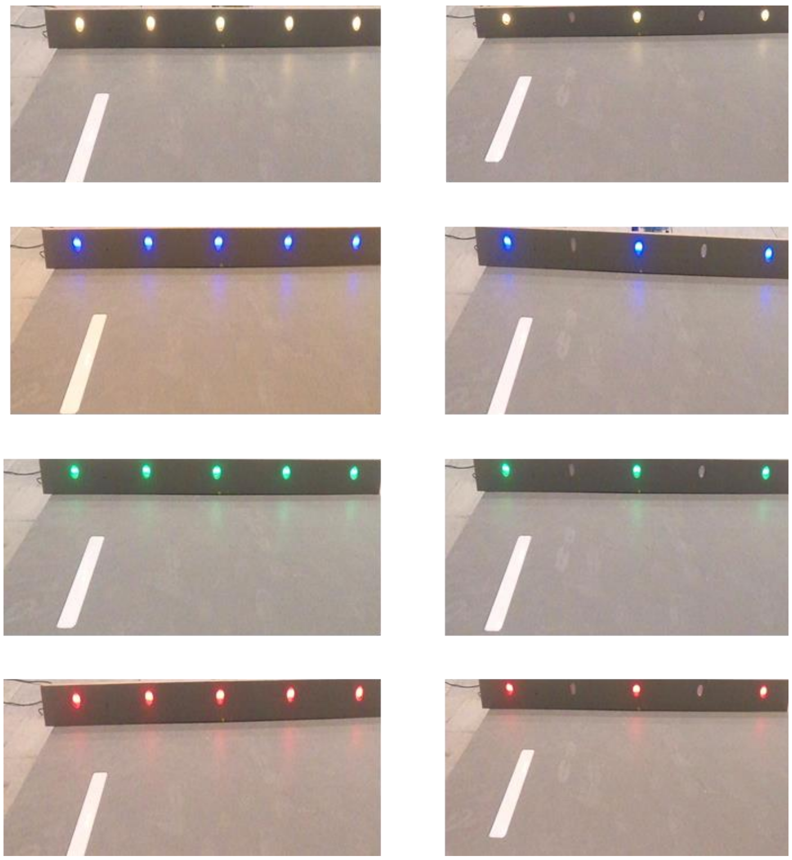
Professional drivers again discussed specific uses for the lights. They mentioned in particular that red could work for stadiums on match days. Amber had no clear connotation, although it could work in a specific area with a specific rule. Green was considered for ambulances or to denote where someone could park. One participant mentioned that blue could be for electric vehicles. In general, they considered this type of technology to be very practical and the next step forward, and related the kerb lights to the sorts of signing on smart motorways.

Professional drivers were also more positive about the cost, noting that in-kerb studs would be cheaper than the in-carriageway dashed lines, and have less possibility of being damaged as they are not installed in the carriageway.

> *“Maybe (with the studs) you don’t even need the signs”*

> *“That’s more affordable” “I would me more visible when driving” (studs kerb)*

Frequency of studs

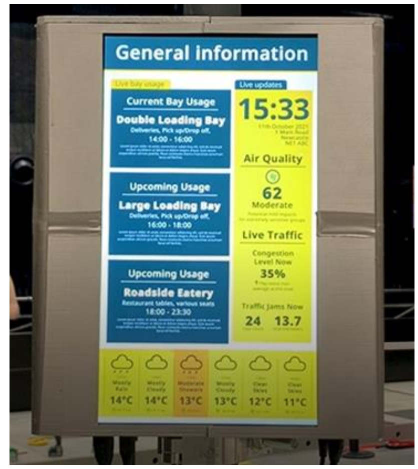


The cost of installation and maintenance would be reduced if studs were installed less densely. In the examples shown on the left alongside, studs were installed at 0.5m frequency. Next, alternate studs were switched off, to simulate a 1.0 metre spacing, and participants were asked if they thought that this would be sufficient.

All the groups considered that installing this reduced frequency of lights would still work effectively:

“You don’t need as many” (talking about reducing the frequency)

Dynamic kerbside loading reservations: a triangular LED sign



Drivers were shown an experimental three-sided LED sign, under development by Grid Smarter City, to be used in conjunction with their dynamic loading booking system. The first sign face warns drivers that this section of the kerbside is reserved for drivers with bookings only. The second face records details of each booking (i.e., booking reference and time slot booked), while the third face is used for public service information, such as weather conditions, or local public events.

This part of the exercise generated much interest and many comments and questions.

Younger drivers asked how someone could extend their time, if they arrived a bit late or underestimated how long they would need. They raised concerns that the system is not flexible enough.:

> *"The problem is extending your time, I find when I rented and extend its already booked by someone else and you need to move. It's not flexible enough for me, its stuck on that time"*
>
> *"There is no guarantee"*

Some also mentioned that general information would better suit bus stops, not parking.

> *"I think that should be on a bus stop, it would be good to have them (there)"*
>
> *"It's not needed, maybe in a busy area for tourists"*

Older drivers asked:

“*What if there are delays and I can’t use the booked space?”*

They were concerned that large companies could make block bookings for long periods of time – just in case it is need – and leaving booked, but unused, space for much of the time.

Older drivers would prefer a larger sign, to be readable when driving. The community information was considered useful. Using the sign to display commercial adverts was seen as a solution to offset costs. They advised that bays should be numbered in order to be better identifiable. They also asked what would happen if you arrive late.

“Good idea but some details don’t work”

Professional drivers were particularly interested in time management:

“How do you manage the time….?”

As previously, professional drivers explored the potential practical uses of the technology. They mentioned it could work if spaces are reserved only for loading bookings (in comparison with many normal loading bays, where disabled people can also park) in busy areas. Some people would like to be able to use it for parking, for example when going to the theatre. Discussing the type of deliveries, they felt it would work for freight deliveries on busy streets, but not in residential areas.

As regards the “local information” displayed on one face, they asked what kind of information was shown and whether advertising could be included. They suggested that it would be useful to display local traffic updates. To mitigate the risk of malfunctioning, they proposed the installation of a physical QR code on the post, to be read if the screen was not working:

“I would be game changing, you won’t even need the LED signs”

“I think for business purposes this would work, but for personal purposes it won’t”

“This is probably for those business who have massive deliveries, but not for deliveries in residential areas”

6.4.3. Phase 3: Modifying the carriageway

Participants next moved to the edge of the raised PEARL platform, to view various projections from overhead data projectors, displayed on the grey floor surface, alongside.

In this section of the report, we show the images that were input to the data projectors and some examples of them as they appeared when projected onto the floor.

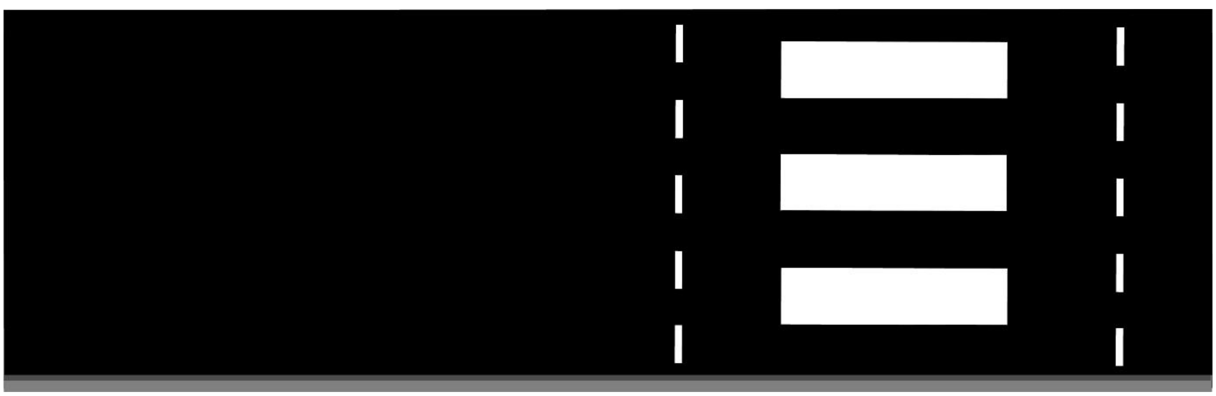
Pearl floor

First, for orientation purposes, participants were shown a simple representation of part of a carriageway, with a double yellow line next to the kerb and a single dashed line at a distance of 3 metres, to represent a single traffic lane for general traffic.

This was well recognised by all the road user groups.

Pedestrain crossing: Zebra crossing

A simplified zebra crossing was projected onto the floor, showing the zebra markings and the dashed while line demarcating the edge of the crossing area.



The lighting of the zebra markings was then lowered and raised, with the suggestion that the lights would be intensified when a pedestrian approached the crossing, to alert drivers to their presence.

Some younger drivers felt that it would be dangerous to change the lighting levels, as drivers might not know what it means. They also questioned what would be the appropriate timing/distance between a person about to cross the road and the lights turning brighter – and, could you be sure that they were about to cross the road?

But, others thought changing the colour intensity could be beneficial:

> *“If it’s possible to make it whiter when (the pedestrian) is approaching”*

Older drivers mentioned that having the lights increasing in intensity when pedestrians are crossing would be confusing for them as:

> *“Drivers learn the roads. Like this, it’s always changing”.*

It could also mean drivers would come rely on the lights and might not notice if something else is happening on or around the crossing area. They raised the issue that the LED markings would have a ‘glass’ top which could be a danger for cyclists riding over them.

Professional drivers said it could be useful in the evenings, when light levels are low, but if it malfunctioned and people had come to rely on it, then this situation could be dangerous.

> *“It’s good if there is a sensor and the lights get brighter. Depends on the speed limit and how much time to react the driver will have”*

> *“At the moment lots of zebra crossings are fading down”*

> *“It would work only at night “If it doesn’t work and people get used to and all of the sudden, someone crosses…”*

Pedestrain crossing: Signalised crossing

The surface studs showing the limits of the carriageway crossing area were projected onto the floor, along with a grey line representation of the kerb line.

Then, a colour was added to the kerb within the crossing area, successively showing red (indicating don’t cross), amber (prepare to cross) and green (safe to cross). The traffic signal head was not represented.

[redacted]

[redacted]

[redacted]

[redacted]

Younger drivers had mixed views. They wondered whether people would look down, or be able to see the coloured kerb if they were not at the front of the queue? Several preferred the TfL ‘countdown’ display.

Older drivers saw it as a good, extra safety measure. However, they were concerned that, if pedestrians were texting, they wouldn’t see the red line it would be less effective. They mentioned this as adding cost to providing crossings, as the pedestrian traffic signals already serve this purpose. They considered including amber to not be a good option as people:

> “….*push their luck, take risks with amber”.*

Some professional drivers had seen a similar approach in New York, where a red line on the footway flashes when the green period for pedestrians is coming to an end. In particular, they said it was:

> “*Fantastic for children.”*

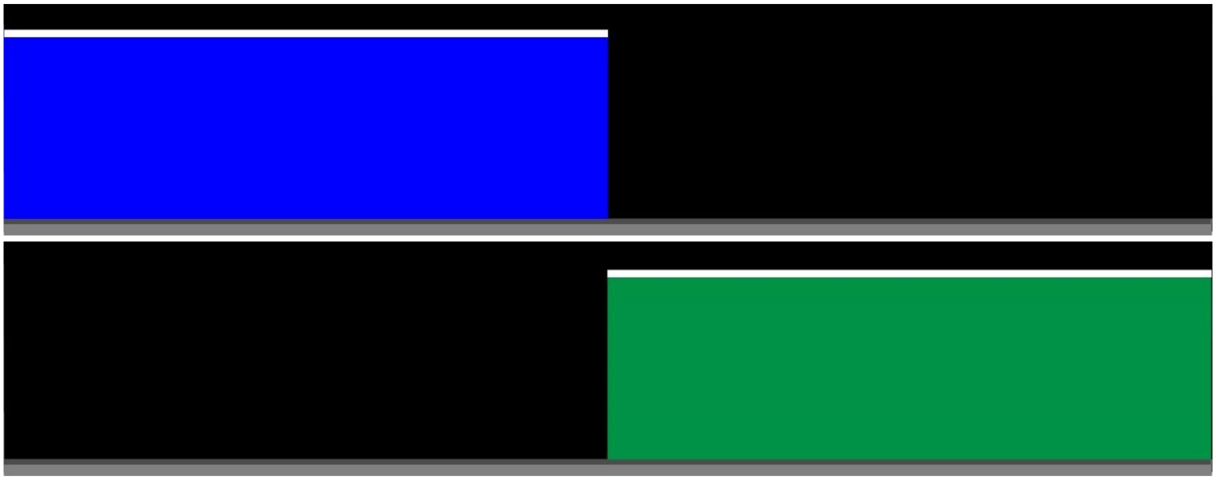
They also suggested that the red line on the kerb should be linked to the dots on either side of the crossing, so that when the kerb colour turns green, then the dots should change colour to red.

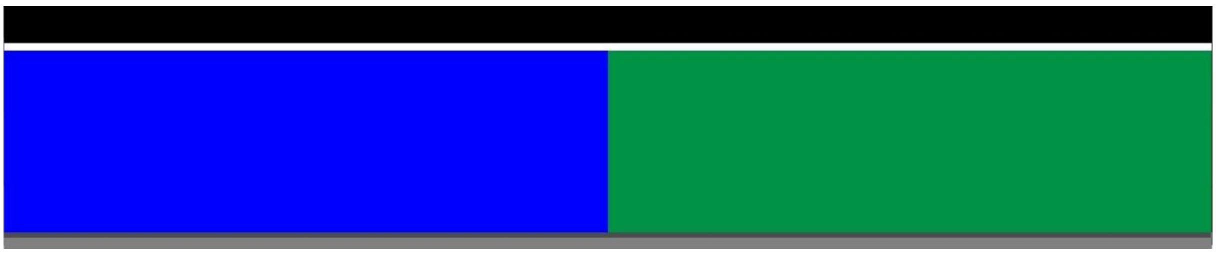
Depicting a cycle lane

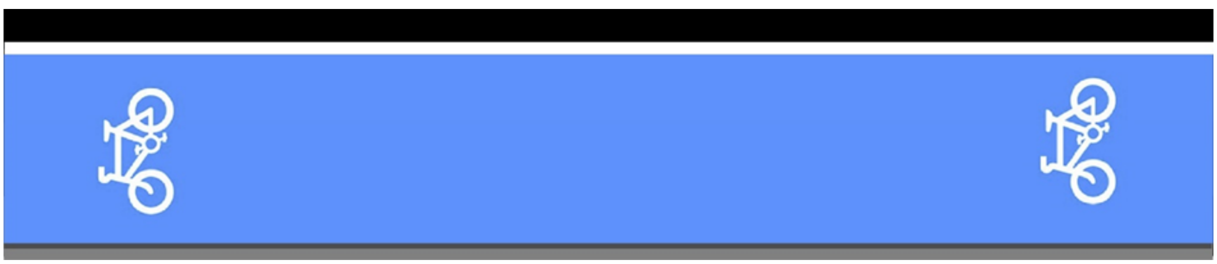
Participants were shown two colours depicting a cycle lane - a blue lane and a green lane, both with a white line edge marking on the far side from the kerb – and asked which colour they preferred. As the TfL super cycle highways are denoted by a blue surface, then most motorists opted for that colour.

Professional drivers also preferred blue, and not everyone recognised green as an existing option. They proposed that there should be one standard colour for all priority cycle lanes and not two, as is currently the case in the UK.

A standard cycle image was ten projected onto the surface of a blue cycle lane. Most drivers thought that adding the cycled symbol aided comprehension of the marking and an awareness of cyclists.





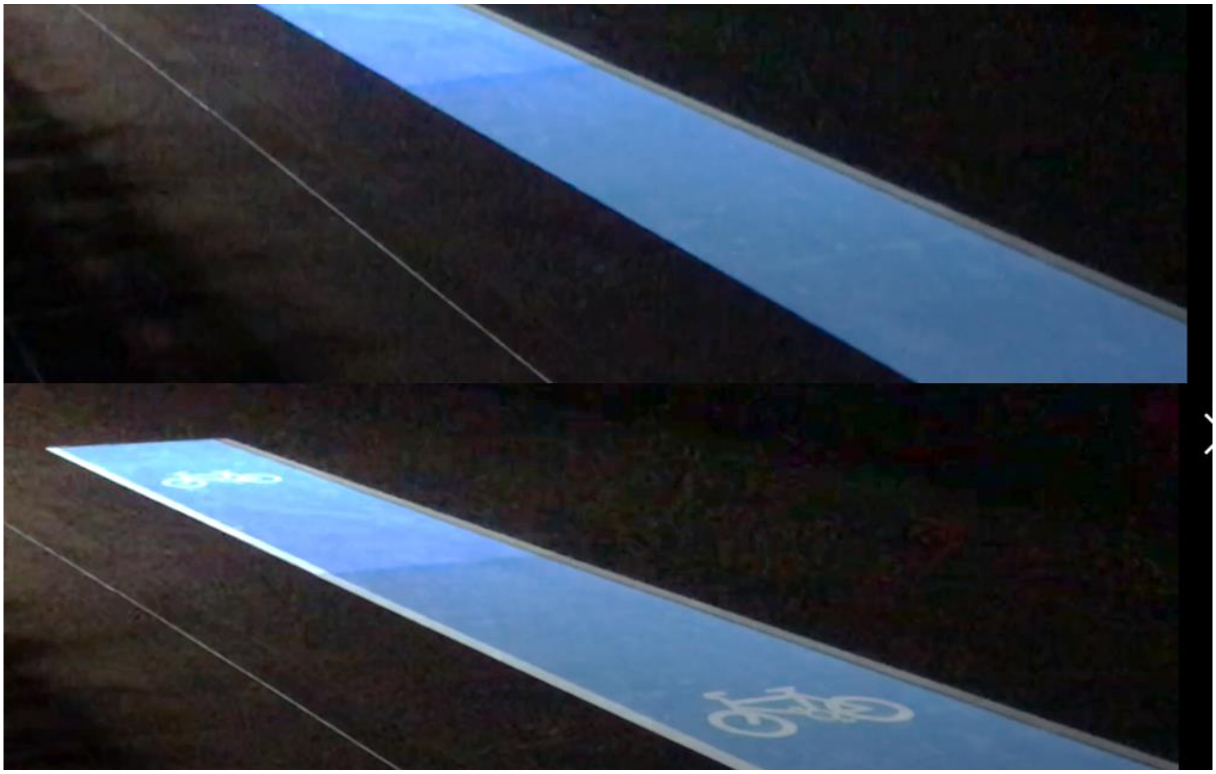


Cycle lane transition

In cases where a cycle lane does not operate for 24 hours per day, then the question would arise of how to mark the transition from the starting and ending of the period of operation.

To indicate the commencement of operation of the cycle lane, respondents were shown a sequence of events, starting with a grey carriageway:

- Blue carriageway shading appears, to denote the area of the cycle lane
- A white edge line is added
- Completed by the appearance of cycle symbols at regular intervals.



This led to a - sometimes heated – debate about whether cycle lanes should be time limited, or only operate on a 24-hour basis.

Young drivers in particular considered that:

> *"(Changing the cycle lanes) could endanger the cyclists"*

Older drivers were divided on the issue. Some thought cycle lanes should be 24 hours:

> *Should be either a cycle lane or a parking"*

> *"(Part-time cycle lane) puts cyclists' lives at risk".*

> *"it's safer not to have a cycle lane at all (than a part-time one)"*

But others were OK with the idea of a part-time cycle lane. Some considered that bicycles should be on pavement, not on the road – but cyclists and pedestrians sharing space is also dangerous.

Professional drivers also considered a part-time cycle lane to be problematic for cyclists; however, at quiet times it could be more beneficial to allocate the kerbside space for parking and loading, or even general traffic, when no one is using the cycle lane.

Given the majority prefererence for 24 hour cycle lanes, most were not interested in the transition process, although one participant noted that:

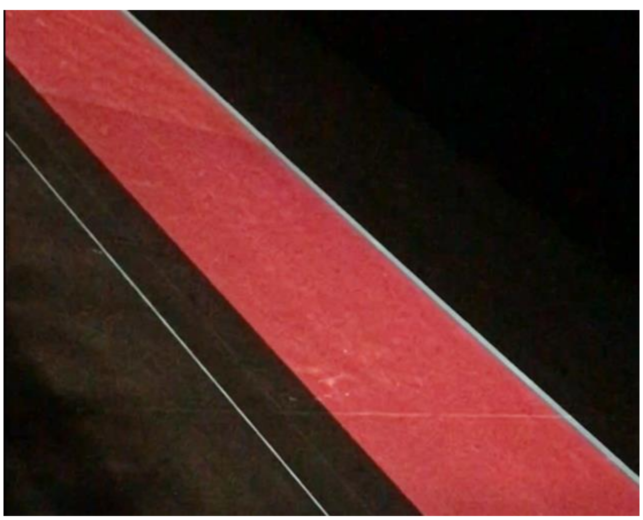
> *"If I'm cycling in the lane, if I see there is a change as a cyclist I could be more careful and understand that there is no more special lane".*

Depicting a bus lane

In a similar way to the depiction of a cycle lane, participants were first shown a red area projected onto the grey road surface, followed by a white edge line on the side away from the kerb, and the addition of wording saying 'BUS LANE'. There was also an LED sign depicting a standard bus lane operation sign, but with no hours of operation indicated. When the lane was not in operation, a red diagonal line appeared across the sign.

Everyone understood what was being represented and was comfortable with it. When the issue of a limited-hours bus lane was introduced, most people were much more supportive of this than a limited hours cycle lane.

For example, older drivers were in agreement that bus lanes should not be in operation 24 hours a day (since they do not face the same safety risks as with cycle lanes) and that their use should depend on the different requirements on that road at different times of day. They thought also that that colouring the bus lane only during its periods of operation might encourage more cars to use bus lanes outside their operating hours.



As regards adding a red diagonal line through the LED sign when the bus lane is not in operation, some participants suggested that it should be thicker but not everyone liked the addition of a line. Some thought it would be better to switch the sign off all together outside the hours of operation – but others pointed out that drivers could not be certain whether the bus lane was not operating, or that the LED sign had failed.

Professional drivers thought it was better to have the red line, specially until people understand that the bus lanes can be turned on and off. They stressed that people will need to time to get used to the idea that bus lanes might vary, by time of day. Some suggested that the hours of operation should be displayed on the carriageway surface too.

Bus lane transition

Two types of transition were demonstrated. First, a simple fading in and fading out of the bus lane, as described above, namely:

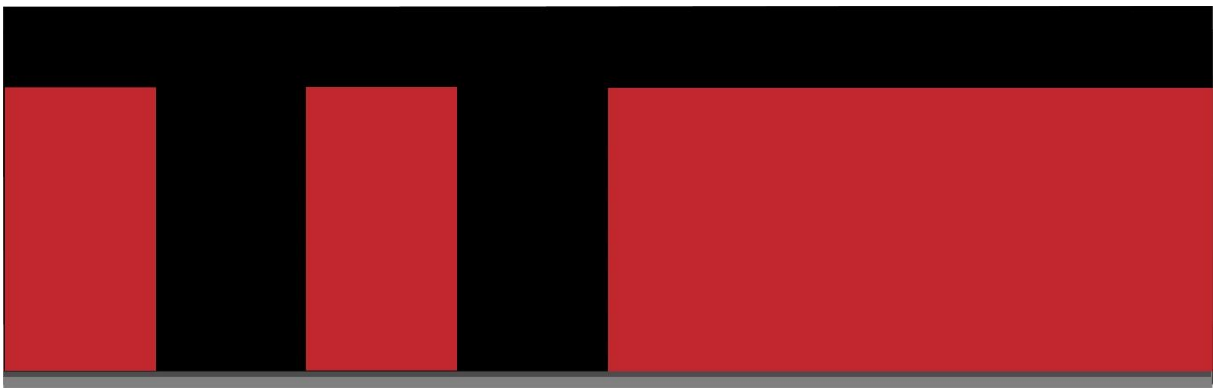
- First, the full bus lane with a white line and the words “BUS LANE”
- Removing the white line and wording and reducing the red light by 50%.
- Finally, all light was removed, revealing the grey carriageway

Many participants were concerned about phasing in and phasing out lighting levels, as their visibility would vary by weather and lighting conditions. Didn’t like change in colour intensity – would prefer to rely on the sign. They were also concerned about the cost of this type of system.

Second, a more incremental transition at the start of a bus lane was illustrated, comprising:

- First, a grey road surface
- Next, the fading in a set of narrow red stripes
- Then increasing to double-sized red stripes and

- Finally, the full bus lane surface covered in red light, with the white edge line and the words “BUS LANE” added.



Younger drivers said: *"Having the transition is confusing"*

A few participants found it confusing and asked themselves if this would encourage speeding. But most younger drivers liked the idea of building up blocks, but just at the start of the bus lane; although they were concerned about the expensive and would be happy to rely on the sign

Older drivers agreed that if the transition hours change from day to day, this would cause uncertainty. They were concerned about the surface material and the impact it might have on surfaces and on cyclists' and motorcyclists' safety.

Professional drivers liked the idea of having a pre-warning and asked about the possibility of having an interaction between the bus lane and the stud kerb lights (shown in the previous phase) to enhance the transition. They preferred the 'stepped' introduction of the part-time bus lane, over a transition based on a change in lighting intensity, as the former would be more robust to different ambient lighting conditions.

6.4.4. Phase 4 (Reflections and conclusions – seminar room)

Finally, participants were escorted back to the room where the session began, and were asked about their overall impressions about what they had seen, and any implications for future traffic management and signing.

When asked about their overall impressions, younger drivers were succinct in their responses. They recognised the advantages of introducing greater flexibility in the ways in which busier streets are designed, managed and operated. They also agreed that LED signs and markings could help to achieve this greater flexibility and dynamism, while improving legibility and comprehension. But they were concerned about the costs of installation and operation of LED systems, and the risk of malfunctions: could there be a physical sign behind the LED that would act as a fall-back?

Older drivers concluded that the new signs and markings could be useful, especially in busy areas. Safety might improve, because signs/markings are lit and so highly visible, especially on overcast days. They considered LED signs as 'the future' and were excited to participate in the trials. They regarded this new technology as a "young baby" that will grow up and mature. They saw it as complementing new forms of in-car information – so supporting, not substitute information.

As regards potential downsides, they mentioned costs, vandalism (vandals could destroy LEDs, but not metal) and the need to take into account colour-blindness.

Colours should be used in a simple and self-evident way, with green (go/available) and red (stop/not authorised) preferred over amber and other shades. They stressed the need to simplify parking restrictions, and standardize signs, so that they are easy to see by moving vehicles. This would reduce delays caused by hesitant drivers and increase safety.

Finally, older drivers put a greater emphasis on the signs, with the marking providing supporting information. In general, they wanted simplicity, standardisation and certainty – so need to be careful when introducing any dynamic element: people need to know what to expect

Professional drivers very much liked the use of LED lighting (both signs and road markings), being especially bright at night and under poor weather conditions – although the glare issue in bright sunshine requires more attention. The embedded kerb lights, used in conjunction with standard painted bay markings, were considered a ‘game changer’, enabling them to spot at a glance empty bays where they would be eligible to load or park.

In general, they were less concerned about costs: they agreed that it doesn’t matter how much it costs, that costs will drop over time as schemes are rolled out, and that change that supports future demands and aspirations always happens. Vandalism and malfunctions are also issues that would need addressing.

They generally supported 24-hour cycle lanes, but only peak period bus lanes.

6.5. Conclusion and recommendations

All participants were fully engaged in the discussion groups and the displays presented to respondents in the PEARL laboratory setting provided an ideal stimulus for exploring the future potential of LED traffic signing and road markings.

Everyone was impressed by the brightness, sharpness and general visibility of the LED displays, in all but the strongest glare under head-on lighting conditions. They addressed concerns about the existing fading of signs and road markings, and provided opportunities to make signs both more comprehensive – highlighting the applicable regulations at a specific time – flexible and responsive to changing conditions.

Some of the displays were seen as being more attractive and realisable than others. The LED signs were generally well received, including the Grid Smarter Cities triangular sign. While participants were generally impressed with the LED dashed road markings, in terms of clarity and versatility, many questioned the need for a wide range of colours, which could confuse drivers; and questioned the cost of installation within the road surface and the robustness needed to withstand the weight of the heaviest vehicles. In contrast, the use of coloured LED studs built into the kerbsides was seen as a ‘game changer’, being very versatile and adaptable, while giving a clear and easily recognisable message to motorists while driving, in conjunction with adjacent LED traffic signs.

While the main application of these technologies is likely to be on our busiest urban streets, some specialist applications were suggested, such as around major football stadia and other major occasional trip attractors, where kerbside regulations are very different on certain days.

All groups brought up the cost of installing and maintaining such new technologies, but it was the younger and older car drivers that were more concerned about this, while professional drivers saw the cost as an investment. All groups expressed some concern about potential vandalism and malfunction of the LEDs; but most participant regarded what they saw as being ‘the future’; several saw the technology as being beneficial on busy, mixed up urban streets, and used as an analogy the introduction of ‘smart’ motorways on the national road network.

The last two years during the Covid-19 pandemic was mentioned (particularly by professional drivers) as a time when many, quite radical changes were introduced very quickly – with very little warning and information about those changes. If more flexible and dynamic management of roadspace is to become more common, then it is vital that the signing and markings accurately display current information. But there was a warning in all the groups that drivers often plan ahead and so there is a desire for stability and regularity; at least providing some information on conditions at other times of day.

Professional drivers took a distinctive approach when looking at the LED displays as a form of innovation. They tried to see how to adapt the technology to their needs, personally or professionally, while young and older drivers were much more focused on looking for problems.

7. The overall perception of cities about the potential for implementation of advanced technologies

7.1. Introduction

In the previous chapters 4, 5, 6, assessments of the applicability of new technologies are presented. However, many advanced technologies are not covered. In this section, a survey of the general perspective of cities about whether the use cases and other advanced technologies are applicable in their city is presented. The interview survey is expected to provide a general overview of the potential for new technologies.

7.2. Interview survey planning and execution

The survey was planned and carried out in the following steps: 1) Defining the objective of the survey; 2) Identifying different technologies related to the MORE project based on Deliverable 3.1, Analysis of Technological Advances; 3) Designing a questionnaire with a list of questions for the interview; 4) Planning interviews by selecting suitable candidates to interview and scheduling the interviews; 5) Conducting the interviews online in a one-to-one setting with participants from each of the MORE cities, experts and users over the period of 3 weeks; 6) Processing the interview transcripts and performing qualitative analysis; 7) Report the key findings and summarise the interview outcomes.

7.3. Interview participants

The interview involves participants from five countries in Europe. Two groups, a group of ten participants from MORE cities (London, Constanta, Malmö, Lisbon, Budapest) and a group of two experts, one from Dynniq Netherlands and one from UCL participated in the interview. The group from the MORE cities comprises individuals active in urban transport related areas: mobility planning and operation, mobility solutions and innovation, traffic and network management, traffic panning and traffic engineering. For each city, at least two representatives with different professional backgrounds were involved. The group of experts consists of individuals who have decades of extensive experience in the domain of urban planning, transportation, and ITS and smart mobility.

7.4. Topics addressed

Nearly similar questionnaires (interview guides) were designed for each interview group, but with a slightly different focus. The guide for representatives from the MORE cities has more focus on the current activities related to the technologies and the possibilities of implementing them in the cities, while the guide for the expert group has more focus on the applicability of new technologies in general and in some cases on specific users' perspectives.

Application and use of the following technologies are directly or indirectly covered in the interview: 1) Automated driving – including autonomous buses, shuttles, vehicles, pods, and trucks; 2) Intelligent traffic management and control systems – including intelligent traffic signal control, adaptive traffic management, and traffic data collection technologies; 3) Big data and AI – including data acquisition, AI for data collection and analytics, and information provision; 4) ICT and digitalisation – including IT, communication technology, and internet-based applications; 5) Alternative advanced transport modes – including delivery robots, delivery drones and air taxis; 6) Mobility services – including shared mobility, MaaS, and micro-mobility.

7.5. Results

7.5.1. Analysis of interview transcripts

The interview transcripts were processed through the following steps: 1) Familiarising to data and assigning code (description) to data – this phase allows us to get a preliminary idea and assign code to the data; 2) Searching patterns and assigning to themes (topics); 3) Reviewing the themes and naming them; and 4) Producing a summary report.

7.5.2. Perspective of MORE cities

The outcome from interviews with participants of the MORE cities is briefly summarised with different themes that are defined during the interview data processing. The themes (topics) include automated mobility services, mobility based on advanced transport modes, intelligent urban traffic management and control, mobility services for people and goods, data-driven urban mobility services, dynamic road space allocation, and challenges of implementing new technologies.

Before we present the themes, first the general perceptions of participants regarding the application of technology are summarised. The participants are presented with a question about whether they think the advanced technologies have been changing the transportation of people and goods. All participants responded ‘Yes’, and they also elaborate why they think so. Few examples of responses are:

> *IT and digitalization allow us to use apps on our phones to book mobility services, check availability of service, use navigation apps, use shared micro-mobility.*

> *In transport technologies, ITS plays a great role in serving as a tool to handle road infrastructure and traffic effectively. However, the technology itself is not a solution.*

> *We are digitalized society, and we get information through apps incorporated in mobile phones, and then use the information for what we want to do. With information, we can cost-effectively make a correct decision.*

We should not think that technology will solve all problems, but the development and deployment of the technologies have to be human-centric.

Technology is changing a lot, what is right for the future of cities matters. Cities should be careful with what they let in and what should not, and think out of the box regarding how they can use new technologies with the existing problems.

Below is the summary of the aggregated responses of all the cities to the thematic questions in the interviews:

Automated mobility services

In the future, mobility of people and goods will be more sustainable, smart, and automated. The introduction of automated vehicles (AVs) for public transport, logistics, and personal trips will transform future mobility. Summary of the general feelings of participants from the MORE cities about the potential for application of automated driving is that overall, the participants believe that certain levels of automation could be beneficial for optimization and efficiency, but higher-level or full autonomy is quite far. In most cities, the implementation has not yet started, and only in a few cities pilot tests have been executed. In cities like London for example several pilot projects have already been facilitated for automotive companies, whereas in cities like Constanta and Budapest, there is a need (at discussion) to test AVs and their impacts, but the opportunity has not emerged yet. For example, in Constanta, the aim of the city administration in this case is to implement automated driving (i.e., automated public transport) in the city center where currently only pedestrians are using the space. In Budapest, there are discussions on the way to look possibility for autonomous minibuses, for example, between university campuses.

Some participants described that although we do not see AVs in our cities at a moment, the future of AVs is now because the technology is already tested in various cities around the world; therefore, we need to embrace it and prepare for it, and this goes not only local authorities but also the public who is expected to use it. For this reason, pilot tests of AVs should be widely available for people to understand and experience the potential and challenges associated with automated driving.

Participants also suggested what could be done in order to prepare for the implementation of high-level automated driving: 1) political decision making is required to regulate and standardize to allows AVs to drive on certain routes, with certain functionality, 2) at intersections above-ground detection like lidar can help if the automotive industry combines them with the detection of the AVs to increase the situational awareness, 3) traffic data collection needs to be hybrid (loop, lidar, camera), 4) traffic management and control systems have to be able to accommodate AVs and handle mixed traffic in a complex network, 5) infrastructure for AVs needs to have joint strategies.

Transport service based on advanced transport modes

In this theme, the interview results related to the application of advanced transport modes such as autonomous robots, delivery drones, and air taxies is compiled. The participants were asked whether drones for delivery of goods, autonomous robots for delivery of goods, and urban air taxis for transporting people have been used in their cities. Almost all participants feel that their cities are not ready for delivery drones and air tax applications. However, some of them believe that the operation of delivery drones between logistical nodes will not cause problems but in mixed traffic, there might be safety issues. In mixed traffic and residential areas, delivery drones require regulations to allow them to land in a specific area, and they need to have an alert to warn people while landing. Under these conditions drones could be deployed sooner than air taxis which require a more elaborate regulation as a result of the involvement of human beings.

One of the perspectives raised during an interview is that we need make more efficient use of space rather than looking for the third dimension (urban air mobility) if sustainability and environmental benefits and associated risks of these modes are not worthwhile compared to surface transport modes. However, drones can be used for other purposes – including surveillance, data collection, emergency services for example delivery of medicine and marking and collecting car accident locations, fire extinguishing, if the operating environment is facilitated.

Regarding the deployment of robots, in one city pilot trials were conducted but did not yet produce practical results. Overall, it was mentioned that the main challenges regarding the deployment of delivery robots in the cities could be public acceptance regarding safety and security, and possibly the behavior of people interacting with robots on the streets. Moreover, as delivery robots may lack a cognitive ability for interaction with the environment, particularly people, they could cause security issues and delay in deliveries.

Intelligent urban traffic management and control

Traffic in cities is likely to become more diverse and denser in the future. With the growing use of smart traffic detection sensors, C-ITS, and computing power the result is traffic signal management and control systems communicating with road users and to control traffic intelligently have been emerging. The implementation of these kind of systems and associated technologies in the MORE cities are assessed based on participants’ views and have resulted in three different city groups.

Cities that do not have intelligent traffic management and control systems deployed on the roads, and who are working to change/improve the current systems. These cities are in transition to prepare the infrastructure for intelligent traffic management and control systems. For example, in this group it was mentioned that using of above-ground sensors is considered, to collect traffic data for signal timing and to get an overview of the traffic detecting all road users, and not just part of the road users.

Cities that are in the middle of changing/improving traffic management and control systems to more advanced ones. Some of the cities are upgrading the systems to more intelligent and smarter TLCs, and a traffic management system that manages all subsystems in a centralized way. Furthermore, they have a cooperative mobility-based project in progress on improving V2X, although these developments have not yet been deployed on a large scale. Other cities in this group, have shown an improvement in traffic management (e.g., dedicated bus lane); however, they think there is a lot to do regarding TLCs.

Cities that already have advanced traffic management and control systems and in the process of making them more intelligent. These cities have traffic management systems that are well advanced in terms of technology. These traffic management systems can accommodate AVs, and regarding preparation for cooperative and connected driving, these cities have pilot tests in progress. They are in the process of creating much better traffic management systems that have better optimization, and more resilient intelligent traffic management.

Some believe that the cities as a node need to be protected from car-centric technologies. If we want to keep the city on a human scale, we do not believe in equipping the city with resilient sensors and intelligent systems because if we have it everywhere then we will have cars everywhere no matter whether it is AVs or others. Therefore, all the automation of infrastructures and making them intelligent would be useful probably in rural areas, outside the cities on highways for example.

Mobility services for people and goods

Regarding mobility services, people want safe, comfortable, and fast services. In this theme, the status of mobility services – including mobility as a service, shared mobility, micro-mobility, public transport, and logistics in the cities was assessed. In most cities, there is a wide application of micro-mobility services. For example, in cities like Constanta, there is a tendency towards green mobility services such as electric bicycles, e-scooters, EVs, and ridesharing. The national government produces safety rules on how to use micro-mobility systems. In Lisbon, concerning public transport, everything is integrated into a single ticket. The city has also included micro-mobility in the shared payment systems and is planning to include bike-sharing. So tremendous progress in improving mobility services for people including public transport shared mobility, and micro-mobility but mobility for goods (i.e., urban logistics) lacks behind.

Regarding MaaS, some participants believe that there is a delay in the implementation of the service. MaaS has already been existing for years but did not come into practice in the anticipated scale. In Budapest, on-demand services for public transport can be mentioned regarding share mobility, where different kinds of mobility options (e.g., bike-sharing, care-sharing) are physically put in relatively small space around the stations and be accessed on-demand, which means the vehicles only be on streets (or roads) when some one call to use them. This has two dimensions in it: 1) shared mobility services, 2) optimal use of road space.

Data-driven urban mobility services

As new mobility services continue to evolve and change the urban mobility landscape, it is critical, to leverage existing and new mobility data to enhance transport services, road safety, and the environment. Data from People through their phones, sensors, assets and other devices in the cities is generated in vast amounts – Big data. Integrating and analyzing this data using predictive analytics and Artificial Intelligence (AI) methods allow cities to provide real-time information and data-driven mobility services. To assess the position of the MORE cities, participants were asked to express their perspectives about the implementation of data-driven mobility services.

Participants believe that data analytics enables the cities to make informed decisions, structure plans, identify trends and predict future signals. Based on the respondents' assessment, more than half of the cities have started using data for certain purposes in some form. For example, some cities use car and bicycle counts for better planning regarding traffic demand, and some use real-time data that comes from road systems to identify trends and signals to improve the flow better and understand road network. Some participant mentioned that their cities are bit far from a situation where infrastructure equipped with sensors, and they can provide data in real time or provide detail information road network.

Furthermore, cities like Malmö and Lisbon have their plans to integrate data/information to provide real-time information access, and London wishes to use information in automated ways that help to make decisions on network performance. However, a few participants mentioned their concerns regarding the challenges related data sharing between organizations. Regarding utilizing Big data, the city of Malmö has a subscription to FCD aiming to supplement other data sources. When we come to applying AI, London has it in its road map to apply machine learning to improve transport services.

Dynamic road space allocation

With advanced technologies – including ICT and digitalization, the management and use of road space in cities are expected to be flexible and automatic for different uses over time and target different mobility services. In this regard, participants are presented with questions about how advanced technology supports the flexible use of road space and the practice of dynamic space allocation in their cities. The participants mentioned that there are limited practices of flexible use of road space. Some mentioned that there are areas where their city uses parking for shared vehicles during the day, loading in the early morning, and for residents during evening and night. In some cities, there are dynamic road-space practices, for example, in London trials were conducted to dynamically assign bus lanes, but in terms of hard implementation is not yet there.

Some cities are in a phase of implementing parking regulation and looking to develop alternative parking payment methods and build new infrastructure, where some already have areas where parking availability and rates have been provided to users. When we come to redesigning road space, it was mentioned that all streets need to be redesigned to accommodate all types of road users, and speed may be the main indicator to allocate road space for different transport modes. For example, the city of Lisbon is investing in public space through its program “plaza in each neighborhood” to build around 100 places where people can connect, cycle, and walk. Participants from other cities have similar opinions regarding this. For example, health streets towards sustainable transport agenda in London were also mentioned.

Few of the participants have mentioned that we do not have time and resources to change everything as fast as technology changes but still we can operate with existing infrastructures. For example, automated driving can help to pick-up trashes or delivery of goods during the night taking into account that road is not dedicated to specific transport modes. Often projects are successful but maintains and operations are not. For that, we have huge assets, which are not 100% used, and we do not need more assets, more technology, and more infrastructures to maintain and operate. However, we need to find the right combinations of technology, existing assets, peoples’ needs, and problems to focus on.

Challenges of implementing advanced technologies

The participants think that multiple challenges could contribute to the delay in the full implementation of the advanced technologies in their cities. Among the main challenges, a few are listed below. Note that, the factors are specific to the technology and city, and have different causes.

Infrastructure-related challenges – readiness of both physical and digital road infrastructures, for example, to implement CAVs in the cities; lack of integrated and updated transport data to facilitate smart mobility services; lack of skillset and knowledge about the technologies and their implementation.

Social dimensions – lack of public awareness, for example, perception of people that the implementation of AVs will be in the future because they do not see and understand it in their cities; the car-centric mentality of the people is one of the challenges affecting the introduction alternative transport modes; technology acceptance and behavior of people, for example, the reaction of people may show to the delivery robots on the streets.

Legal framework and regulatory issues – lack of EU-level legislation and standards for implementation of automated driving; legal framework regarding how to manage micro-mobility with other traffic.

Organizational related challenges – lack of cross-sectors human willingness to collaborate, for example, data sharing between different stakeholders; sometimes lack of plan or political motive, for example, to facilitate prerequisites for new technology implementations.

Technology-related issues – technical maturity of the technology itself, for example, issue related to how autonomous robots for delivery can function in a traffic jam or places where road accidents happened; security and vulnerability of the technology.

7.5.3. Perspective of experts

Based on the same procedures used in the previous section, the interview with experts is briefly summarised with different themes – including automated mobility services, intelligent urban traffic management and control, mobility services for people and goods, data-driven urban mobility services, dynamic road space allocation, and challenges of implementing new technologies.

At the beginning of the interview, the participants are presented with a question about whether they think advanced technologies have been changing the transportation of people and goods. All participants responded 'Yes' and elaborate why they think so with examples. A few examples are:

> *Technology helps to create an overview of the activity of every object in the mobility domain based on which mobility policies can be changed. We cannot continue trying to optimize let say mobility and not run into a problem sometime in the future. Because the level of urbanization through the world is so extensive that the simple conventional ways in which mobility is organized will not be able to handle that anymore. That is also the reason why modal shift is a buzz word right now. Current experience distinguishes two phases, 1) technology has helps us to make more efficient use of available infrastructure so that we can prolong the time that it works in more balanced way; 2) it provides us data which allows us to extrapolate which provides us an insight that there is an end to the improvements and that we need to do something rigorously to make it future proof.*

> *If you take the urban areas the most obvious one is initiatives like uber having a big impact on travel. Same goes for micro-mobility through e-scooter and e-bikes in terms of passenger modes and cargo-bicycle for last mile transport on the freight side. In the traditional ITS systems obviously, there are more advanced traffic control systems that affect the efficiency of the network; advanced information systems including roadside messaging systems on parking availability and navigation systems as an example for new technologies. In addition, internet-based applications that facilitate reduction of trips and travelling can be considered.*

Automated mobility services

The experts were asked to provide their perception regarding the use of automated driving for transport of people and goods. They provide views on the potential benefits of automated driving, challenges associated with the implementations and measures to be taken.

Automated driving can change current mobility, but predicting the outcome is difficult. For delivery of goods, AVs relieve the pressure on the infrastructure by the vans driving around in large numbers a bit. In general, AVs will be expected to reduce congestion resulting from accidents because AVs are expected to prevent accidents from happening. There is a lot of potential, but it depends on how we organize AVs. For example, if everybody keeps having personal cars as it is now, then wide introduction of AVs will increase number of cars, which leads to parking and congestion problems. According to the expert, this even could be worse it if we get through to the 4^{th} and 5^{th} level of automation because then people do not care about how long they stay in a traffic jam. People may be tempted to travel longer distances by car and work or sleep. So, in order for AVs to work properly, we need to have some sort of demand management for example by stimulating car sharing and possibly even integrate them into MaaS transport. In this case, one car can be used by many people during the rush hours and then be used for delivery or other purposes during off-peak hours. There should be an attempt to use the vehicle more in first and last mile of the journey and shift to mass transport for the majority of the journey, which can also be based on AVs. These are some of the conditions that need to be arranged for automated driving to make a contribution to future mobility according to the participant.

The expert gives his view on the deployment of automated buses with existing infrastructure and situations. On inter urban roads, it is already a possibility to use them, but in the cities, they will meet the same challenges as the other automated vehicles. AVs still need to have an improvement in situational awareness, sensors of AVs are good, but in urban conditions occlusion is a problem. This can either be solved by cooperative perception through 100% penetration of other AVs or additional detection in the infrastructure. Some specific industries are already more advanced in using AVs, for example mining industry trucks, light rail, and underground systems partly already don't have drivers anymore. An intermediate form of driverless vehicles is using a platoon as is done in a project like ENSEMBLE[3] where hybrid platooning of trucks is designed and tested. Once a platoon is formed and in operation, basically we have automated driving for logistics services.

Regarding autonomous robots and pods for delivery, several trials are going on, but there are potential issues that if you have a lot of them deployed in the city, they could start congesting the footways. To avoid this, the initiative going forward to develop the new international standard of how delivery robots on the footways should behave is a prerequisite.

[3] https://platooningensemble.eu/project [Accessed on 21 January 2022]

Intelligent traffic management and control for future mobility

Intelligent traffic management and control systems for future mobility are expected to use cooperative data, sensors and camera data, and data from other sources to intelligently handle mixed traffic in a more complex network. Mixed traffic comprises AVs, motorised vehicles, and slow transport modes. Experts were asked to provide their perspectives regarding the development of intelligent traffic management and control systems and the systems potential for future mobility.

Intelligent traffic management and control systems are a prerequisite for automated mobility on short notice, said the participant. I see a very important role for the traffic management industry to provide information and do orchestration of AVs for at least in the next 10 -15 years. Because in the urban domain knowledge of direct environment is insufficient for seamless operation of an AV and even if that situational awareness is provided to it there still will be exceptions it will need help with. So apart from additional detection either coming from other vehicles or detection at intersections, but an individual vehicle can also be targeted with instructions like a temporary allowance to use an otherwise prohibited lane to circumnavigate an obstacle.

Another topic mentioned in the interview is AI-based traffic control systems. AI-based applications coupled with cameras installed at the traffic junctions, detecting and identifying vehicles, have been paving the way for application of AI in traffic management and control systems. A participant, asked for his opinion, mentioned that mostly AI and particularly machine learning seems to bring improvements, but a worry is that as humans, we get used to a particular behavior and act upon it. If the algorithm controlling something can be unpredictable it may cause accidents because of acting on expected behavior.

Mobility services for people

Experts’ perspectives about the enhancement of mobility services are summarized in this theme; MaaS is prominently discussed. A participant mentioned that one of the most important conditions for modal shift to MaaS transport is that the travel experience becomes better. The mean the reasons why people are not using moving to public transport right now is because it is too full, not comfortable, and it is not private enough.

Another participant mentioned that MaaS has been discussed for many years, and we are now getting to a point that one can book door to door journey by using different modes with one payment, but the problem emerges when things go wrong during the journey. In that case there should be alternatives available like for example, if you miss a connection for some reason, will it automatically generate you the next quickest route or do you get a refund?

Data-driven urban mobility services

With advancements in computing power, emergence of Big data framework, AI methods such as machine learning, it is quite feasible to leverage mobility data for improving mobility services. In this regard, the participants were asked to express their views about the potential of data and data analytics in the field of mobility. One of the participants said I think data and data analytics can help in improving transport services because the more information you have the better you can make predictions and decisions. It is more or less the same as with what we do in cooperative mobility, but the difference is that in cooperative the time horizon is shorter. If we would structurally make all information available, then it is probably most beneficial for the use cases with slightly longer horizons. Initiatives like Data Space for mobility that is envisioned to create generic data lakes that store all the data directly (or indirectly) related to mobility and offer general access will be a base for data-driven mobility.

Regarding data analytics, a participant said that AI (i.e., machine learning) for data analytics is relatively young in the mobility area but obviously, it has a huge potential for both minute-by-minute management of transport systems and strategic planning. AI crunching huge amounts of data and extracting signals that will be used for public policy decisions and assessments, and even feedback to the drivers. One of the problems in this area is that except for companies like Google, many companies, and certainly local authorities do not know how to harvest Big data, crunch the data to get signals.

Dynamic road space allocation

In this theme, reflections of the participants on how advanced technology supports flexible use of road space are presented. One of the participants shared that there is still a long way to go on optimizing the existing infrastructure and we are postponing to have to do something drastic. And that is a missed opportunity because we only need to analyze the occupancy of space and based on that analysis consider if using dynamic use of road space will be beneficial. Of course, having accurate real-time monitoring for this is important.

Another participant replied it in this way, I think in moving traffic it is not so difficult in the sense that technology basic dynamic road space allocation like tidal waves is close to the current traffic management technology. But when we come to using of kerb side, booking of loading or parking space it becomes more difficult. The basics are using the space efficiently and recognizing the conditions are varying from time to time. Network, traffic can be changing over time, and having much better intelligence about that could allow to change the use of bus lane or if you have a problem on one route to divert traffic/ loading temporarily to alternative road space is vital. I think there is a huge potential there in the application of AI. If you got a better algorithm to predict traffic conditions, you should be able to estimate travel time accurately, and having some strategies in advance allows us to allocate space dynamically.

At junctions, signal control dynamically adjusts the flow in real-time, but when we come to kerb side management, I think we do not go far enough there yet. For that, we need to create plans like we used to have for traffic signals and use them depending on the time of day. Eventually, if all vehicles have in-vehicle equipment the whole process can be done dynamically but I don't expect that to happen in very near future.

On the other hand, to ensure the benefits road users get from the dynamic use of road space, we must look at this from the big picture, if we succeed in finding a balanced solution there in the end the individual road user will benefit as well. The road infrastructure owner (particularly the cities) should avoid gridlock at all times, otherwise the whole infrastructure cannot provide the intended services.

Challenges of implementing new technologies

According to the experts some of the challenges hindering the wide deployment of advanced technologies are;

> *The progress in MaaS is lacking behind because of legislation, platforms and modes of the transport not yet included and payment systems.*
>
> *The readiness of technology needs to be proven. For example, the readiness of AI and AVs for scale deployment under different circumstances.*
>
> *Confidence in convenience and safety of the new technology.*
>
> *Regulatory issues and infrastructure compliance.*

7.6. Summary

This survey endeavoured to have a helicopter view at the advanced technologies and assess their potential through a survey. The main purpose of the survey is to gather the general perception of representatives from the cities and experts from the field of transportation. The survey was carried out through online one-to-one online interviews where participants were asked to provide their general opinion regarding the applicability of the advanced technologies. A total of 12 participants of which ten are from the MORE cities and two are senior experts in the domain of transportation were interviewed. The applications of automated driving, intelligent traffic management and control systems, ICT and digitalisation, Big data and AI, advanced transport modes, and micro-mobility vehicles are the themes that were covered by interviews.

The outcome from the interview can be summarised as follows:

The participants think that AVs can change current mobility; however, the application of automated driving is not beyond the pilot trials in a few of the cities. There is a lot needed to be done to realise wide implementations of automated mobility in the cities. Preparing infrastructure that accommodates AVs and delivery robots, increasing public awareness through wide pilot tests, working on strategies that allow AVs in shared mobility and MaaS transport, and preparing a legal framework and standards could speed up the wide use of automated driving. Regarding urban air mobility – including air taxis and delivery drones, participants indicated that the implementation of these services may take even more time than the implementation of automated driving because they probably need extra safety and solid regulations.

The deployment of intelligent traffic management and control systems in the MORE cities varies from city to city. The interview outcome indicates that there are some cities that are in transition of making the infrastructure ready for deployment; cities that have partly upgraded their systems and expanded in scale; cities that have already used advanced traffic management and control systems and are currently working to make the systems more intelligent. This confirms that cities are in different phases regarding road infrastructure that is aimed to handle mixed traffic.

Participants believe that data and data analytics can help improving transport services; for example, enabling the cities to make informed decisions, structuring plans, identifying trends and predicting future signals. In terms of practice, there is promising progress by the cities. For example, some cities use traffic counts for planning and some use real-time data for identifying trends and insights regarding traffic flow efficiency. Some cities are envisioned to use Big data from existing sources and various other sources such as FCD and air quality data sources to provide real-time information for users.

The practices of dynamic allocation of road space in the cities are limited to, for example, using parking places for different transport modes and pilot trials of assigning bus lanes dynamically. This indicates that there is still a long way to go when we come to optimization of the existing road space and kerbs for different purposes. It was mentioned that having some strategies partly based on Big data and application of AI methods can help cities to make a thorough analysis of available space, and then consider using flexible use of it.

Interview participants have mentioned that road infrastructure and human capital, social dimension including public awareness and behavior, legal framework and regulatory issues, organizational challenges, and maturity of the technology are challenges that hinder the applicability of the new technologies.

8. Conclusion and recommendetions

The MORE project believes that the optimisation of the road-space and capacity can be influenced by the advanced technologies. It is evident that the existing and emerging technology have been affecting and will affect the use of road space in urban areas. Based on the outcome from Task 3.1, technology and design trials were conducted in WP5 Task 5.3 through case studies, field trials, and surveys. Based on the experience and knowledge gained from these tasks, the assessment of the potential for applicability and potential benefits of new technologies that enhance urban road-space efficiency was made. To assess the potential of new technology implementation, two main assessment methods were applied, technical- and users assessments. Technical assessments – through traffic simulation studies of the applicability of intelligent traffic control and automated driving, and user assessment – through groups discussions to test application LED technologies and survey by interviewing authorities of MORE cities to assess the role of advanced technologies in improving mobility services.

The increase in vehicles, the growth of population, and lack of enough road space in the urban areas lead to traffic congestion and creates several negative concerns for the environment, economy, and society. In cities, the emerging intelligent traffic management and control systems allow the use of limited physical infrastructure more efficiently and adjust the traffic flow over time. In this regard, the simulation case study was conducted in the city of Malmö to investigate traffic signal control for improving traffic efficiency of the selected part of the corridor, through testing different control algorithms, optimisation approaches, and mechanisms. By benchmarking the morning peak hour data collected from the corridor, different traffic control strategies were evaluated based on the traffic efficiency KPIs. The results indicate that adaptive signal control with gating functionality has a high potential to handle diverse and dynamic traffic at a local level as well as a corridor level.

The wide application of automated mobility, particularly AVs has potential benefits in various aspects – including road safety, road capacity, mobility efficiency, environment, and economy. AVs are expected to contribute to the first and last mile transport of people and goods, and play a great role in multi-modal transportation. Using the Helmond N270 network, a new pattern of transport services based on automated vehicles was simulated. In the simulation, automated shuttles serve intercity transport of people and automated pods serve the first and last mile transport of goods. In particular, the impacts of automated vehicles for public transport and city logistics on traffic network efficiency and infrastructure were simulated. The performance of the network was assessed using overall impact and average CO_2 emissions. The results indicate the realistic direction of future automated mobility services such as public transport and transport of goods is promising. However, further research regarding the logistics organisation for pods and strategies for combining goods with people in one transport is needed.

In WP3-D3.1 'Analysis of technological advances,' it was identified that the conveyance of information could be a key contributor to new technologies enhancing the use of road space.

Street user demands for capacity and provision vary by time, therefore, to use the available space/capacity most efficiently, it makes sense to vary traffic regulations in time. Currently, these regulations are conveyed to street users through a combination of kerbside traffic signs and on-carriageway road markings. However, there are limitations regarding the amount of information conveyed on a fixed sign, and the inability to vary the regulations dynamically. To address this gap, trial tests were carried out to test new dynamic signing and lining concepts – and the transitions from one 'plan' to another - based around LED technologies, in laboratory conditions with a wide range of street user groups at UCL's PEARL facility, in East London. After a full engagement in the discussion and the displays presented, participants were generally impressed with the LED dashed road markings, in terms of clarity and versatility but many questioned the need for a wide range of colours, cost of installation, and the robustness needed to withstand the weight of the heaviest vehicles. The use of coloured LED studs built into the kerbsides was seen as a 'game changer', being very versatile and adaptable, while giving a clear and easily recognisable message to motorists while driving, in conjunction with adjacent LED traffic signs.

In addition to the simulation studies and the trial test, a survey was conducted to gather general perspectives of representatives from MORE cities about whether advanced technologies are (will be) applicable. The survey was conducted through online one-to-one interviews, in which participants provided their point of view about advanced technologies, application of the technologies in cities, and challenges. Various technologies were covered by the interview – including AVs, delivery drones and autonomous robots, intelligent traffic management and control systems, Big data and AI, micro-mobility vehicles, ICT, and smart mobility services. Based on the outcomes, it can be concluded that the applicability of advanced technologies related to automated driving and urban air mobility may take a while because of many reasons related to road infrastructure and human capital, a social dimension that includes public awareness and behavior, legal framework and regulatory issues, organizational challenges, and maturity of the technology. On the other hand, there are good signs towards regarding the implementation of intelligent traffic management and control systems and utilization of data for improving transport services and making informed decisions.

In conclusion, the assessment based on real traffic data and information from users and representatives of the MORE cities and applied generic methodology has revealed the potential for the new technologies. The deliverable provides detailed information regarding the applicability and potential benefits of different forms of technologies in different contexts. Cities can be benefited from this by adopting procedures and using the information for wider implementation.

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10. Appendices

Appendix 4A: Input data

Table 4A.1: Traffic volume, turning percentages, and vehicle composition (Source: City of Malmö)

Date	Time	Intersection	Link name	Direction	Head	Cars	Cars(%)	HvB	HvB(%)	Veh/Hr(no.)	Left(no.)	Left(%)	Striaght(no.)	Striaght(%)	Right(no.)	Right(%)	Bike (no.)	Pedestrain (no.)
14-10-2019	AM peak (8-9)	E	Västkustvägen-East	East-E	←	1075	86,00	175	14,00	1250	250	20,00	875	70,00	125	10,00	50	25
14-10-2019	AM peak (8-9)	E	Västkustvägen-West	West-E	→	609	87,00	91	13,00	700	105	15,00	420	60,00	175	25,00	50	25
14-10-2019	AM peak (8-9)	E	Flinträmnegatan-North	North-E	↓	198	79,00	53	21,00	250	75	30,00	75	30,00	100	40,00	50	25
14-10-2019	AM peak (8-9)	E	Sjölundaviadukten-South	South-E	↑	395	79,00	105	21,00	500	200	40,00	250	50,00	51	10,20	50	25
14-10-2019	AM peak (8-9)	D	Borrgatan-East	East-Borrgatan	←	156	78,00	44	22,00	200	160	80,00	10	5,00	30	15,00	0	25
14-10-2019	AM peak (8-9)	D	Borrgatan-West	West-Borrgatan	→	28	79,00	7	21,00	35	4	11,43	11	31,43	21	60,00	0	25
14-10-2019	AM peak (8-9)	D	Lodgatan-North	North-Lodgatan	↓	83	83,00	17	17,00	100	40	40,00	55	55,00	5	5,00	0	25
14-10-2019	AM peak (8-9)	D	Lodgatan-South	South-Lodgatan	↑	203	81,00	48	19,00	250	13	5,20	100	40,00	138	55,20	0	0
14-10-2019	AM peak (8-9)	D	Västkustvägen-South	South-D	↑	516	86,00	84	14,00	600	90	15,00	0	0,00	510	85,00	0	0
14-10-2019	AM peak (8-9)	D	Västkustvägen-North	North-D	↓	208	83,00	43	17,00	250	175	70,00	0	0,00	75	30,00	0	25
14-10-2019	AM peak (8-9)	D	Västkustvägen-East	East-D	←	1001	87,00	150	13,00	1150	978	85,04	0	0,00	173	15,04	50	25
7-3-2019	AM peak (8-9)	B	Västkustvägen-Frihamnsviadukten	South-B	↑	876	97,88	19	2,12	895	470	52,51	425	47,49	0	0,00	1	0
7-3-2019	AM peak (8-9)	B	Västkustvägen-North	North-B	↓	777	97,13	23	2,88	800	0	0,00	211	26,38	589	73,63	0	0
7-3-2019	AM peak (8-9)	B	Carlsgatan-East	West-B	→	647	94,45	38	5,55	685	332	48,47	0	0,00	353	51,53	35	3
26-2-2019	AM peak (8-9)	A	H.Michelsensg East	East-A	←	634	97,24	18	2,76	652	0	0,00	613	94,02	39	5,98		
26-2-2019	AM peak (8-9)	A	H.Michelsensg West	West-A	→	477	95,02	25	4,98	502	32	6,37	436	86,85	9	1,79	1	27
26-2-2019	AM peak (8-9)	A	Kristianiagatan-North	North-A	↓	10	90,91	1	9,09	11	7	63,64	0	0,00	4	36,36	12	52
26-2-2019	AM peak (8-9)	A	Utställningsgatan-South	South-A	↑	209	97,21	6	2,79	215	139	64,65	52	24,19	24	11,16	0	20
6-3-2019	AM peak (8-9)	C	Västkustvägen-South	South-C	↑	450	93,75	30	6,25	480	88	18,33	392	81,67	0	0,00		
6-3-2019	AM peak (8-9)	C	Västkustvägen-North	North-C	↓	1085	94,43	64	5,57	1149	0	0,00	679	59,09	470	40,91		
6-3-2019	AM peak (8-9)	C	Grimsbygatan-East	West-C	→	171	81,04	40	18,96	211	206	97,63	0	0,00	5	2,37	24	1

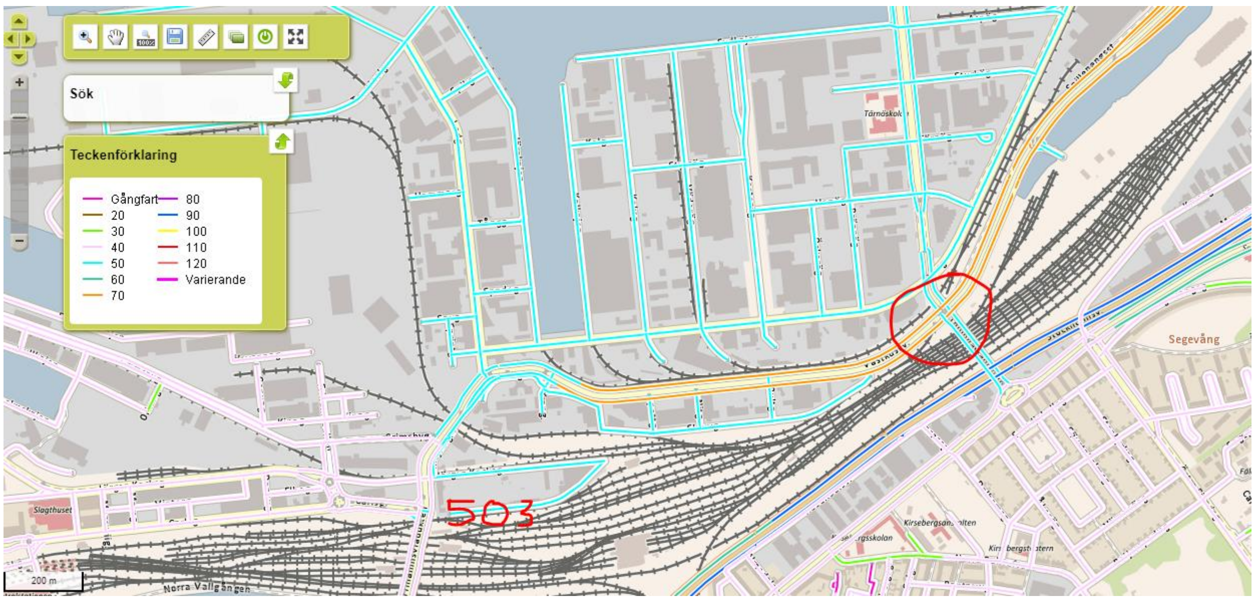
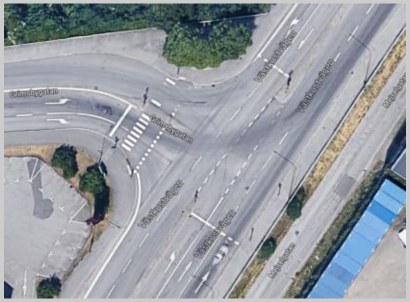
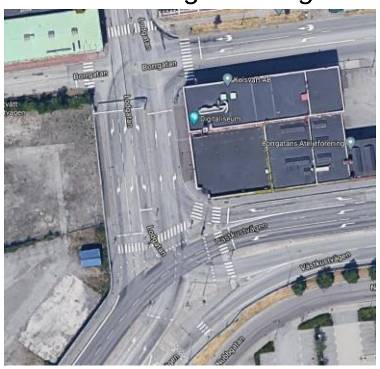


Figure 4A.1: Speed along the corridor (Source: City of Malmö)

Table 4A.2: Description of intersection and corresponding traffic signal controls

Intersection name and layout	Description of the intersection	Traffic signal control (TSC)
A : Hans Michelsensgatan/Utstallningsgatan 	-The intersection is located to the east of Universitetsbron in the Nyhamnen area. - Sided by a mix of street-level parking lots and high-rise office and commercial buildings. - Has pedestrian crossing and curbs found on both sides of the road. -The current traffic flow is approximately 11, 300 vehicles per average weekday. - The intersection is equipped with detector type inductive loops and radars. - Radar to count traffic	- *TSC-388* controls the traffic on this intersection. - The TSC is programmed with the principle of *fixed-time* with coordination to the two intersections west of Universitetsbron. - TSC is of the model ITC-2 from SWARCO with a standard SWARCO interface for the ITC-2. -During off-peak hours, the TSC switches to the *vehicle-actuated* program.
B : Västkustvägen/ Carlsgatan 	- This intersection is located on the southern segment of the MORE corridor to the northwest of Frihamnsviadukten. - The intersection is not equipped with detectors. - The traffic flow is approximately 16,500 vehicles per average weekday. - Has fewer pedestrians and bicycle crossing Carlsgatan.	-*TSC-503* controls the traffic on this intersection. -The TSC is programmed with the principle of *fixed-time* with coordination to the two intersections, namely C and D. -The TSC is of the model EC-1 from PEEK (Dynniq) with a standard PEEK interface for the EC-1. - *A fixed-time* program has been used during rush hours

C: Västkustvägen/ Grimsbygatan 	-The intersection is located between intersections B and D in the proximity of 150 meters from intersection B and 180 meters from intersection D. - The intersection is not equipped with detectors. -The intersection has pedestrians and bicycles crossing across Grimsbygatan.	-*TSC-505* controls the traffic on this intersection. -TSC is programmed with the principle of *fixed-time* with coordination to the two intersections B and D. -TSC is of the model EC-1 from PEEK (Dynniq) with a standard PEEK interface for the EC-1. - *A fixed-time* program has been used during rush hours.
D: Västkustvägen /Lodgatan 	-The layout of this is different from the rest of the intersections. It has two separate intersections that are nearby. - Both intersections are controlled by one TSC. -On the Lodgatan part, there are pedestrian crossings on both sides of the road. -On Västkustvägen part of the intersection, there are bicycle and pedestrian crossings. -This intersection is not equipped with detectors, except for two approaches from Lodgatan to Västkustvägen.	-TSC-501 controls the traffic. -The TSC is programmed with the principle of *fixed-time* with coordination to the two intersections B and C. -The TSC is of the model EC-1 from PEEK (Dynniq) with a standard PEEK interface for the EC-1. -The *fixed-time* program controls the intersection but during off-peak hour a vehicle-actuated program controls two of the signal groups that drive from Lodgatan to Västkustvägen.
E:Västkustvägen/Sjölundaviadukten	-The intersection is an important node connecting the inner parts of the harbour area and the eastern parts of Malmö. -It connected to Spillepengen, through which traffic flow comes from TEN-T. -It is isolated from other intersections.	-TSC-43 controls traffic on this intersection. -The intersection is programmed with the principle of *fully-traffic-actuated* intersection signal control with all red as the rest stages.

	- -It is equipped with detectors type inductive loops. - -The intersection has both pedestrians and bicycle crossings.	-The TSC is of the model ITC-2 from SWARCO with a standard SWARCO interface for the ITC-2. -The *traffic-actuated* program has been run during rush hours.

Appendix 4B: Additional results

Table 4B.1: Average (standard deviation) from the simulation of from different control scenarios

Vehicle Composition	Traffic performance KPIs	Scenario-baseline	Scenario-fixed	Scenario-actuated	Scenario-adaptive
All (Average)	Avg. vehicle delay (seconds)	80,56	86,92	59,97	56,18
All (Average)	Avg. number of stops	2,36	2,49	2,16	1,81
All (Average)	Average speed (Km/h)	29,71	28,81	33,18	33,87
All (Average)	Travel time (seconds)	2567178,53	2646322,49	2312522,55	2263644,62
Personal Vehicles	Avg. vehicle delay (seconds)	99,67	108,17	72,23	66,05
Personal Vehicles	Avg. number of stops	2,9	3,09	2,59	2,13
Personal Vehicles	Average speed (Km/h)	31,72	30,72	35,6	36,56
Personal Vehicles	Travel time (seconds)	2145534,32	2215875,08	1922421,84	1871195,55
Heavy-Duty Vehicles (HDV)	Avg. vehicle delay (seconds)	107,39	122,15	84,89	75,44
Heavy-Duty Vehicles (HDV)	Avg. number of stops	2,86	3,19	2,7	2,12
Heavy-Duty Vehicles (HDV)	Average speed (Km/h)	30,52	28,8	33,48	34,82
Heavy-Duty Vehicles (HDV)	Travel time (seconds)	256872,95	270608,13	236190,33	225667,75

Table 4B.2: Average (standard deviation) from the simulation of optimised adaptive TSC with different traffic volumes

Performance measure\Volume	CurrentVolume	CurrentVolume Plus5%	CurrentVolume Plus10%	CurrentVolume Plus15%
Delay	58.25 (0.67)	64.58 (2.37)	72.77(3.4)	89.45(9.55)
Stops	1.88(0.03)	2.03(0.08)	2,27(0.11)	2.8(0.35)
Speed	33.39(0.14)	32.23(0.42)	30.8(0.58)	28.3(1.41)
Travel time	2280659.97 (110.63)	2479298.74 (40614.92)	2712146.81 (57505.97)	3076649.45 (45941.09)

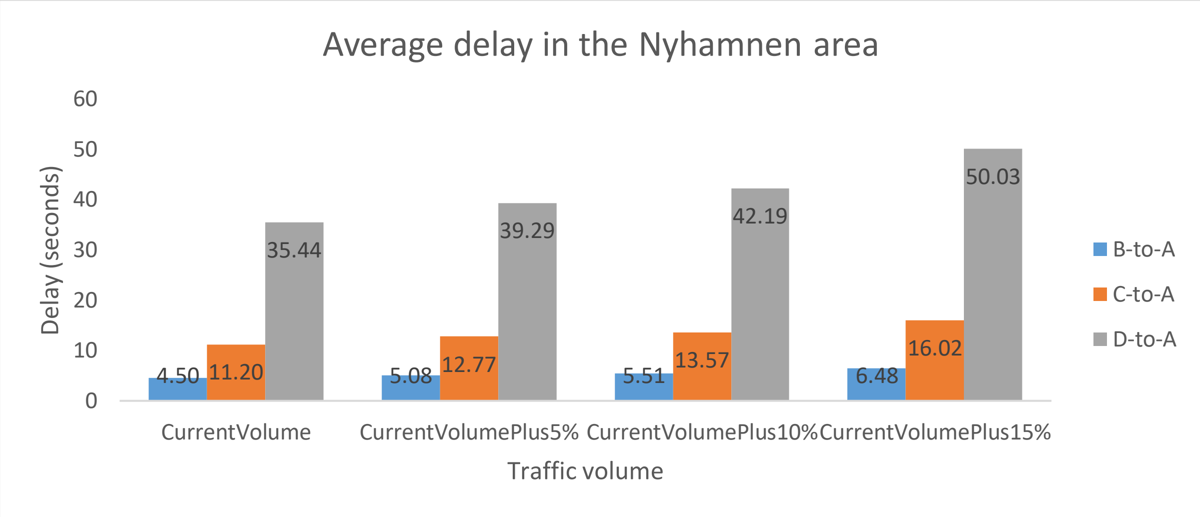
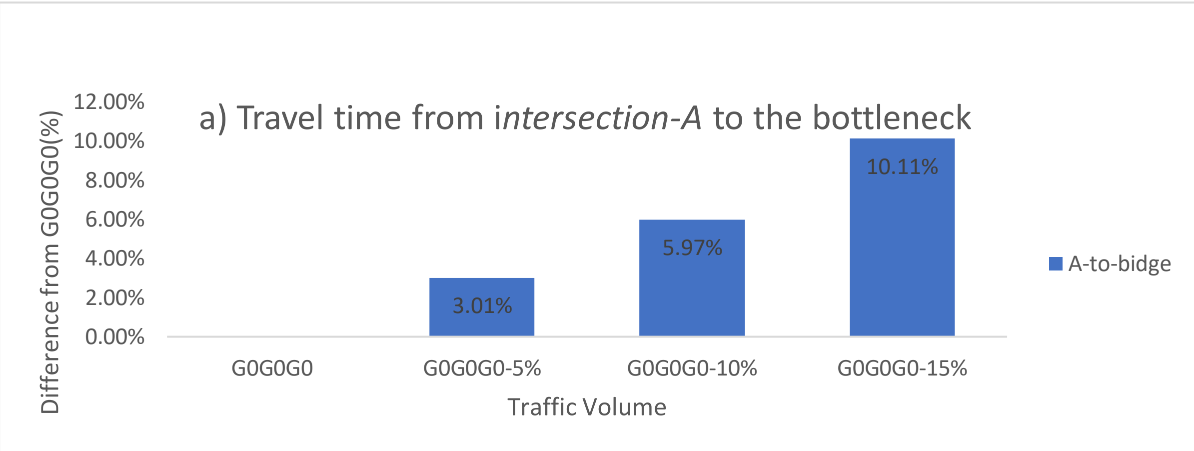


Figure 4B.1: Comparison of delays from the simulation of different traffic volumes (averaged over 10 runs)



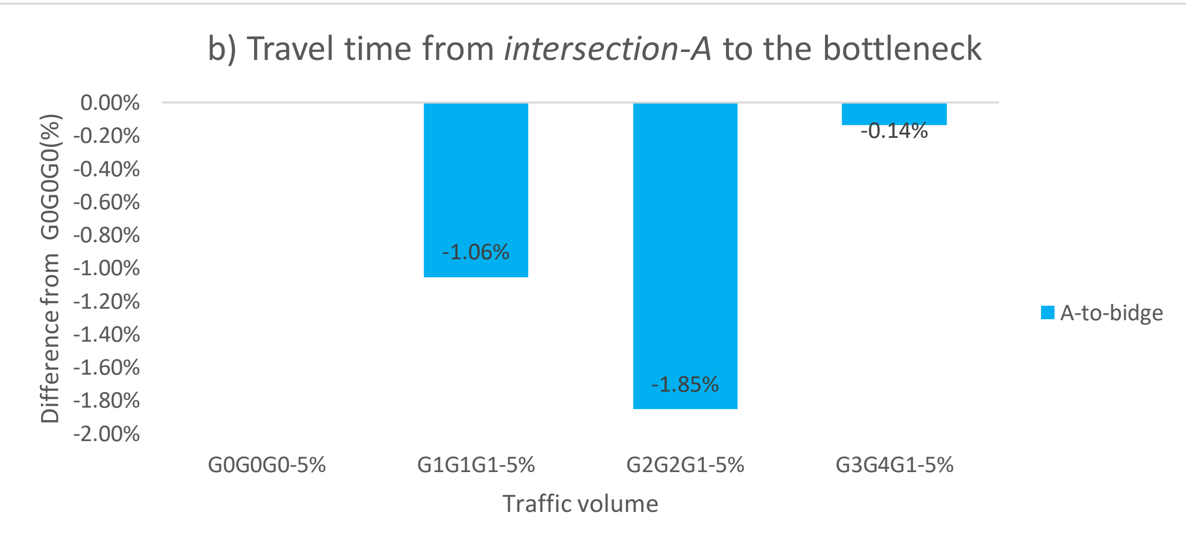


Figure 4B.2: Comparison of travel time on the link from the intersection-A to the bottleneck: a) before Gating applied, b) after Gating applied (only a 5% increase)

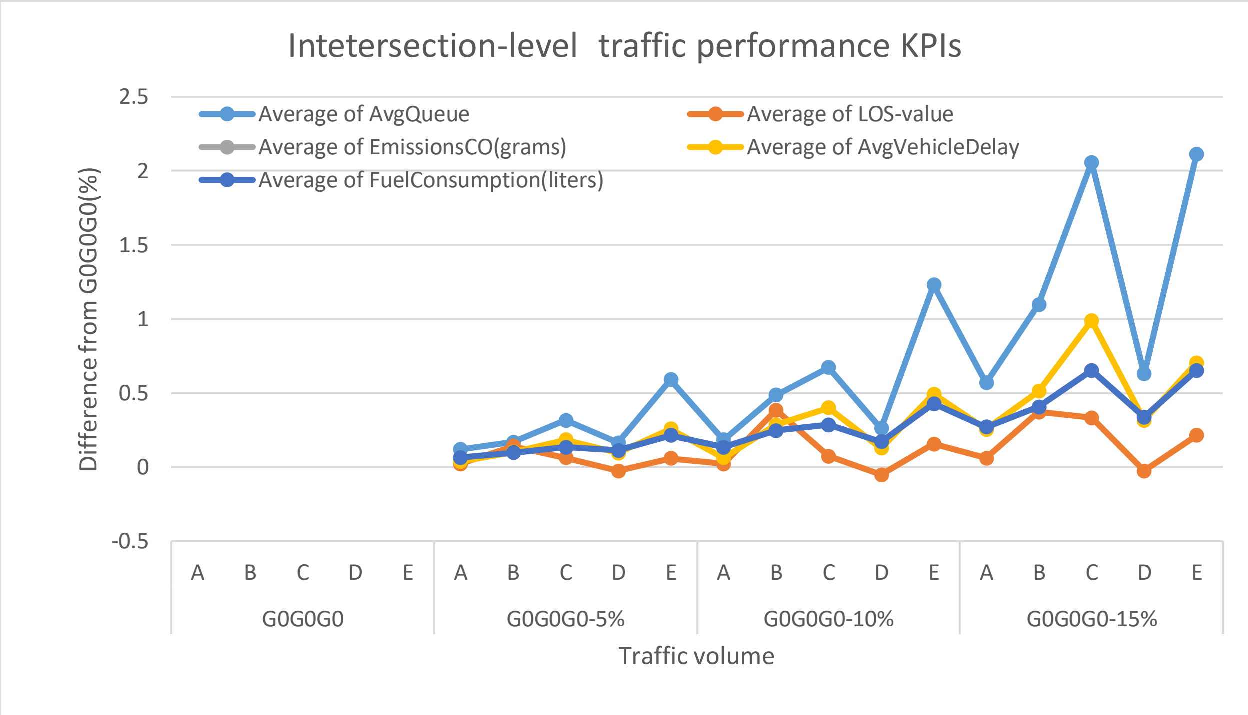


Figure 4B.3: The impact of an increase in traffic volume on each intersection

Appendix 6A: Participant information sheet for adults

PARTICIPANT INFORMATION SHEET FOR ADULTS

UCL Research Ethics Committee Approval ID Number: 0718/001

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Title of Study: Dynamic LED road signs and markings

Department: Civil, Environmental and Geomatic Engineering

Name and Contact Details of the Researcher(s): Professor Peter Jones: peter.jones@ucl.ac.uk

Name and Contact Details of the Principal Researcher: As above

You are being invited to take part in a research project. Before you decided it is important for you to understand why the research us being done and what participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

1. What is the project's purpose?

The objective of this study is to explore how we can vary the displays of traffic signs and road markings to manage traffic at different times of the day. To do that, we would need to replace fixed signs and painted road markings with LED versions. We are inviting you to join in a discussion, to share your thoughts on the ways in which we might use traffic signs and road markings to better inform drivers about the regulations.

2. Why have I been chosen?

We are inviting a random sample of drivers to take part in a series of discussion groups, each with around eight to ten participants. Across the groups, we are aiming to reflect the diversity of people who drive, both for personal and business purposes

3. Do I have to take part?

It is up to you to decide whether to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form.

4. What will happen to me if I take part?

You will join a group of other drivers, in a discussion lasting about 90 minutes, during which refreshments will be provided. You can leave at any time, should you wish to do so. You will be paid an incentive, to cover travel and other costs. The discussion will be audio and video recorded and transcribed. No personal data will be held on the transcription and this will be stored on a password protected file and computer at UCL**.**

5. Will I be recorded and how will the recorded media be used?

The audio recordings of the discussion and the video recording of the signs and markings you will be shown will be used only for analysis. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

6. What are the possible disadvantages and risks of taking part?

We do not foresee any risks being involved in this research.

7. What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will help to improve traffic signing for drivers in the future.

8. If you feel you wish to make a complaint to an independent person please contact Chair of the UCL Research Ethics Committee – ethics@ucl.ac.uk

9. Will my taking part in this project be kept confidential?

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified in any ensuing reports or publications.

10. Limits to confidentiality

Confidentiality will be respected subject to legal constraints and professional guidelines.

11. What will happen to the results of the research project?

Following the discussion groups, a report will be written to summarise the various views expressed, illustrating the various signs and road markings that people will have commented on. This will be published in February 2022.

12. Who is organising and funding the research?

This research is being conducted by UCL with funding from the European Commission.

13. Contact for further information

Please contact Peter Jones: peter.jones@ucl.ac.uk

Notice:

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our 'general' privacy notice. For participants in research studies, click here

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices.

The lawful basis that will be used to process your personal data are: 'Public task' for personal data.

Your personal data will be processed so long as it is required for the research project. We will anonymise or pseudonymise the personal data you provide and will endeavour to minimise the processing of personal data wherever possible.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Thank you for reading this information sheet and for considering taking part in this research study.

Appendix 6B: Consent form for adults in research studies

CONSENT FORM FOR ADULTS IN RESEARCH STUDIES

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: Dynamic LED road signs and markings

Department: Civil, Environmental and Geomatic Engineering

Name and Contact Details of the Researcher(s): Professor Peter Jones: peter.jones@ucl.ac.uk

Name and Contact Details of the Principal Researcher: As above

This study has been approved by the UCL Research Ethics Committee Project ID number: 0718/001

Thank you for considering taking part in this research. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study.

		Tick Box
	I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of me. I have also had the opportunity to ask questions which have been answered to my satisfaction. I am happy to be involved in an individual interview.	☐
	I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified. I understand that my data gathered in this study will be stored anonymously and securely. It will not be possible to identify me in any publications.	☐
	I understand the direct/indirect benefits of participating.	☐
	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.	☐
	I understand that the information I have submitted will be published as a report.	☐

	I consent to the discussion being audio recorded and the signs we are being shown being videoed, and understand that the recordings will be stored anonymously, using password-protected software and will be used for specific research purposes	☐
	I voluntarily agree to take part in this study.	☐

Name of participant Date Signature

Appendix 7A: Interview guide – MORE cities

Introduction

MORE is a European-funded project aiming to develop and implement procedures for the design of urban corridor roads and streets. In the process, technology and methods play a vital role. Analysis of advancement in technology and trials of some advanced technologies were conducted in MORE cities. Furthermore, the assessment of potentials for new technology is planned under WP5 T5.3. Accordingly, there is a need to conduct assessments regarding the applicability of the new technologies. The perspective from the MORE cities is therefore of the utmost important to assess the potentials.

This interview guide with a list of questions is designed to collect general perspectives of MORE cities regarding the potential for implementation of new technologies. The interview will take us about 45 minutes as indicated in the schedule.

Consent

The collected information will be kept confidential and only be used in the MORE project deliverable, and then after that will be erased. Would you give me a permission to record the interview, please? Thank you!

1) Personal information.
   - Company/organization/city----------------------Country------------------Role----------------------
2) Do you think advanced technologies have been changing the transport of people and goods? Please, explain how-------------------------
3) How do you find your city, regarding the use of automated driving for transport for people and goods? Please, explain ---
   - In your point of view, what are the factors that delay the full implementation of automated driving in your city?--
   - Would you tell me how realistic is the use of autonomous buses and shuttles for public transport services in your city? Please elaborate with the use case if any------------------
   - What is your perception regarding the use of autonomous pods and robots for the transport of goods in your city? How do you think the implementation can be realised?--
4) Traffic in cities is likely to become more diverse and denser in the future. Recently, intelligent traffic control systems that communicate with road users and control traffic dynamically have been emerging.
   - Do you think intelligent traffic control for feeder routes (adaptive traffic control with gating functionality) can be applied for traffic situations on MORE corridor in your city? Please, describe how it can contribute positively ---
   - What do you think is needed to fully deploy the system in your city? ------------------------
   - Which technology do you think would accelerate the innovation in traffic management area?

- How do you express the role of 5G in accelerating traffic management?
- What do you think policy makers need to consider while designing road spaces?

5) People, sensors, assets, and other devices in the cities are generating a huge amount of data – Big data. Integrating and analyzing these data using predictive analytics and Artificial Intelligence (AI) methods allow cities to provide real-time information and data-driven services to their citizens through mobile apps or other information provision techniques such as LED signs and websites.

   - How do you express your perspective regarding the implementation of data-driven mobility services in your city? ---
   - How do you think providing real-time information to road-space users would contribute to the flexible use of kerbs and road-space? ---
   - Would you mention a few of the areas where Big data-driven applications and operations could improve the current mobility services in your city? How? -----------------

6) With advanced technologies – including ICT and digitalisation, the management and use of road space in cities are expected to be flexible and automatic for different uses over time and target different mobility services.

   - Would you tell me how advanced technology supports flexible use of kerb-space and dynamic allocation of road space? ---
   - Flexible use of kerb-space and dynamic allocation of road space to accommodate different functions can be widely implemented in my city. How strongly do you agree? Why? ---

7) Is your city ready for wide use of delivery drones and air-taxi? If no what do you think are the barriers?---

   - Would you describe how these technologies would affect public services? ----------------

Thank you for your time and information!

Appendix 7B: Interview guide – Experts/users

Introduction

MORE is a European-funded project aiming to develop and implement procedures for the design of urban corridor roads and streets. In the process, technology and methods play a vital role. Analysis of advancement in technology and trials of some advanced technologies were conducted in MORE cities. Furthermore, the assessment of potentials for new technology is planned under WP5 T5.3. Accordingly, there is a need to conduct assessments regarding the applicability of the new technologies. The perspective of the users/experts is therefore of the utmost important to assess the potentials.

This interview guide with a list of questions is designed to collect general perspectives of technology users/experts regarding the potential for implementation of new technologies.

Consent

The collected information will be kept confidential and only be used in the MORE project deliverable, and then after that will be erased. Would you give me a permission to record the interview, please? Thank you!

1) Personal information.
   - Company/organization/city----------------------Country------------------Role----------------------
2) Do you think advanced technologies have been changing the transport of people and goods? Please, explain how------------------------
3) What is your perception regarding the use of automated driving for transport for people and goods? Please, explain ---
   a. How comfortable do you feel traveling by autonomous bus? Why? ------------------------
   b. Logistics operators and e-retail companies are testing autonomous pods and robots for door-to-door delivery services and last-mile transport in cities. Would you explain how ready you are to be served by these technologies? If not, why? -----------------------
4) Traffic in cities is likely to become more diverse and denser in the future. Recently, intelligent traffic control systems that be able to cooperate with road users and control traffic dynamically have been emerging.
   a. Do you think the wide deployment of such systems would contribute to a reduction in traffic congestion? How? ---
   b. What kind of traffic control systems you would like to see on the road in the future? Why? ---
   c. There have been many experiments with AI for traffic management system, how do you evaluate its applicability on road/streets?
5) People, sensors, assets, and other devices in the cities are generating a huge amount of data – Big data. Integrating and analysing these data using predictive analytics and Artificial Intelligence (AI) methods allow cities and transport service providers to offer

real-time information and data-driven services to users through mobile apps or other information provision techniques such as LED signs and websites.

a. Would you explain how do providing real-time information to road-space users can stimulate the flexible use of kerbs and road-space? --

b. How do you express your perspective regarding the potential for implementation of data-driven mobility services? For example, flexible parking, loading, peak-off, and EV-charging areas--

6) With advanced technologies – including ICT and digitalisation, the management and use of road space in cities are expected to be flexible and automatic for different uses over time and target different mobility services.

a. Would you tell me how advanced technology supports flexible use of kerb-space and dynamic allocation of road space? --

b. Do you think road-space users benefit from the dynamic use of road-space? How? ----

7) In your view, to what extent do you agree or disagree with using the 5G network in C-ITS? Please, explain--

8) In general, what are the major factors do you think hinder the full implementation of advanced technologies?

Thank you for your time and information!