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UTILIZING DATA TO OPTIMIZE ROAD NETWORK OPERATIONS

A PIARC COLLECTION OF CASE STUDIES

TECHNICAL COMMITTEE 2.4 *ROAD NETWORK OPERATIONS AND ITS*

PIARC

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020– 2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were appointed by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

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EXECUTIVE SUMMARY

2022R09EN

UTILIZING DATA TO OPTIMIZE ROAD NETWORK OPERATIONS

Road network operators are increasingly making use of technology and developing digital infrastructure to manage road networks. Road users are making use of technology to efficiently and safely complete trips. Vehicle manufacturers and fleet managers are utilizing an increasing amount of technology to manage fleets, improve safety, and advance toward automated operations. Sensor and data analytics technologies are continuing to increase in capability. All of these trends are increasing the amount of data available to road network operators to support improved decision making. Applications include use of data for monitoring the performance of the system and making decisions about project investments. They also include use of data sources for real time road network operations to optimize the operation of the road network.

This work builds on the “Big Data for Road Network Operations” report from the 2016-2019 PIARC work cycle by providing current, real world examples of current application of big data concepts. The case studies included in this report represent the current state of practice and highlight the progress being made by road network operators to utilize the growing amount of data available for road network operations.

CONTENTS

1. INTRODUCTION

PIARC Technical Committee 2.4, Road Network Operations and ITS, work group 2.4.2 (Optimizing Road Network Operation Decision-Making Through New Technologies and Digitalization), has been tasked with investigating how new technologies and new forms of data are revolutionizing Road Network Operations. Specifically the work group is investigating the impact that these new technologies have on the availability and use of data for decision making. This work builds on the work done by the Road Network Operations and ITS Technical Committee in the 2016-2019 PIARC committee cycle and the "Big Data for Road Network Operations" technical report.

The previous technical report discusses a number of topics related to data technologies and data sources that have the potential to transform road network operations. Topics covered include discussion of the digital transformation within the transportation sector and the advances in data technologies to deal with the increasing volume and velocity of data. This includes both the increasing amount of data available to road network operators through their own systems and sensors as well as the rapid growth in probe data and crowd sourced data. This expanding data access combined with advanced data processing methods and automation present new opportunities for improving road network operations and decision making.

The work in the 2020-2023 cycle is focused on identifying real world applications of these technologies to road network operations, assessing the current state of the industry, and capturing best practices as these technologies begin to be implemented. The questions to be addressed include:

- How have road network operators begun to harness the growing amount of data available and implement solutions that facilitate informed decision making?
- How have the big data technologies discussed in the "Big Data for Road Network Operations" begun to be utilized for road network operations?
- How are these technologies driving improvements in decision making and optimizing road network operations?
- Are any new challenges emerging related to using data for road network operations?

This initial deliverable is a collection of case studies illustrating various data applications for road network operations that have been implemented around the globe. This effort has been divided into the following two categories.

1.1. System Performance Monitoring and Planning

This category seeks to identify opportunities and best practices related to the application of data related technologies and data driven decision-making in order to monitor and improve the performance of the road network. This approach typically utilizes archived data to report key performance indicators and visualizations that provide road network operators with a detailed understanding of system performance. These indicators can be utilized for resource and investment decisions. Sample use cases include the following:

- Project Evaluation – Use of data to perform before and after evaluations of projects.

- Road System Performance – Use of data for key performance measures related to system performance, comparisons between corridors, and identification of problem areas.
- Public Transport System Performance – Use of data related to public transport system operations and performance.
- Performance for other transport modes – Use of data for measuring system performance related to freight, bicycles, or pedestrians.
- COVID-19 Pandemic Response – use of data to evaluate public response to the pandemic and the effectiveness of policy decisions.

1.2. REAL-TIME OPERATIONS

Case studies in this category investigate the use of data to support and optimize real-time traffic management strategies and techniques related to ITS systems. Typically these applications utilize data in algorithms and incorporate some automation to process data and react to changing operating conditions in real-time or near real-time. Real-time operations applications include the following:

- Traffic Operations – Use of data from traditional or emerging sources in algorithms for real time traffic management applications.
- Incident and Emergency Management – Real time applications of data to identify incidents or provide situational awareness for responding to and managing incidents and emergencies
- Safety and Hazard Warning – Identification of hazards and providing notification to transportation system users and operations staff.
- Weather Event Response – Situational awareness of weather events for winter maintenance decision making and traffic management.
- Public Transport Operations – Use of data for real time management of public transport.
- Traveler Information – Innovative approaches to sharing real time road status information with travelers.
- Other – Other innovative approaches for real time use of data for road network operations that don’t fit in the previous categories.

2. METHODOLOGY

These case studies were gathered through distribution of a call for case studies to the members of the PIARC Road Network Operations technical committee. Members of the committee either drafted case studies or worked with other experts in their country to draft case studies that were then peer reviewed by other members of the technical committee. The peer review process reviewed the case studies for alignment with the topic of utilizing data for optimizing road network operations as well as providing editorial and content review. Case study authors were given the opportunity to address the review comments and edit the case studies to arrive at the final 21 case studies included in this report.

3. CASE STUDIES

A total of 21 case studies were received from 10 countries. These case studies represent applications for both system monitoring and planning applications as well as real time applications. A summary of the topics addressed by each case study is included in the table below.

		System Performance Planning						Real-Time Operations						
	Case Study Title	Project Evaluation	Road System Performance	Public Transportation System	Performance for Other Modes	COVID-19 Pandemic Response	Other	Traffic Operations	Incident and Emergency Management	Safety and Hazard Warning	Weather Event Response	Public Transit Operations	Traveler Information	Other
1	Real-time and Archived Transportation Operations Data sharing and Analytics (RITIS) (USA)	•	•	•	•	•		•	•	•	•	•		
2	Hybrid Data Model and Cost of Congestion Evaluation (Australia)	•	•					•						
3	Using BIG DATA to monitor the impact of measures against COVID-19 (Czech Republic)	•				•								
4	Artificial Intelligence to Optimize Traffic Flow at Signalized Intersections (Germany)							•						
5	Victoria Department of Transportation – Data Fusion Prototype (Australia)	•	•	•				•						
6	Island-wide Heat map Analysis of Traffic Trends during COVID (Singapore)		•			•								

		System Performance Planning						Real-Time Operations						
	Case Study Title	Project Evaluation	Road System Performance	Public Transportation System	Performance for Other Modes	COVID-19 Pandemic Response	Other	Traffic Operations	Incident and Emergency Management	Safety and Hazard Warning	Weather Event Response	Public Transit Operations	Traveler Information	Other
7	Mobility management in the COVID-19 crisis during the State of Alarm in Spain (Spain)		•			•								
8	Congestion Hot Spot Identification for Optimized Traffic Management Using Automated Pattern Recognition (Germany)		•					•						
9	Oregon Department of Transportation Performance Management Plan (USA)	•	•				•							
10	Road Database based on Artificial Intelligence (Tunisia)		•				•							
11	Identifying bottleneck and traffic congestion using ETC 2.0 probe data (Japan)		•											
12	Automated diversion system for trucks in adverse weather conditions (Spain)									•	•			
13	Brisa-Waze collaboration to improve traffic operations and traveler information (Portugal)		•					•	•	•	•		•	
14	DGT 3.0 Connected Vehicle Data Platform (Spain)							•	•	•			•	•

		System Performance Planning						Real-Time Operations						
	Case Study Title	Project Evaluation	Road System Performance	Public Transportation System	Performance for Other Modes	COVID-19 Pandemic Response	Other	Traffic Operations	Incident and Emergency Management	Safety and Hazard Warning	Weather Event Response	Public Transit Operations	Traveler Information	Other
15	Use of Bluetooth data to estimate travel times on HWY 30 on the south shore of Montreal (Canada-Quebec)		•				•							
16	Real-Time Network Awareness Platform (Australia)							•	•	•	•	•	•	•
17	Automatic Classification of Road Visibility Conditions by AI (Canada-Quebec)									•	•			
18	System That Uses Big Data to Identify Passable Roads After Disaster (Japan)								•				•	
1 9	Automated Diversion System for Wind and Fog (Spain)							•		•	•		•	
20	Connected Vehicle Data Ecosystem for Roadway Safety (USA)							•	•	•	•	•	•	
21	Washington State DOT Truck Parking Information Management System (USA)												•	•

3.1. Case Study 1 – Real-time and Archived Transportation Operations Data Sharing and Analytics (RITIS) (United States of America)

3.1.1. Description

Introduction to RITIS

The Regional Integrated Transportation Information System (RITIS) is an automated data platform that provides real-time and archived status of the transportation network. RITIS ingests thousands of data types from hundreds of agencies and data feeds. The system constantly evolves to include the latest transportation data from the public and private sectors. RITIS combines these data sets in different ways to support real-time situational awareness and coordination applications, along with archived data analytics to support planning and performance management efforts. Public safety officials can access transportation and emergency management information, such as live video feeds, radio scanners, cameras, and weather maps through the system. RITIS allows authorized users to access this information through a secure web-based portal.

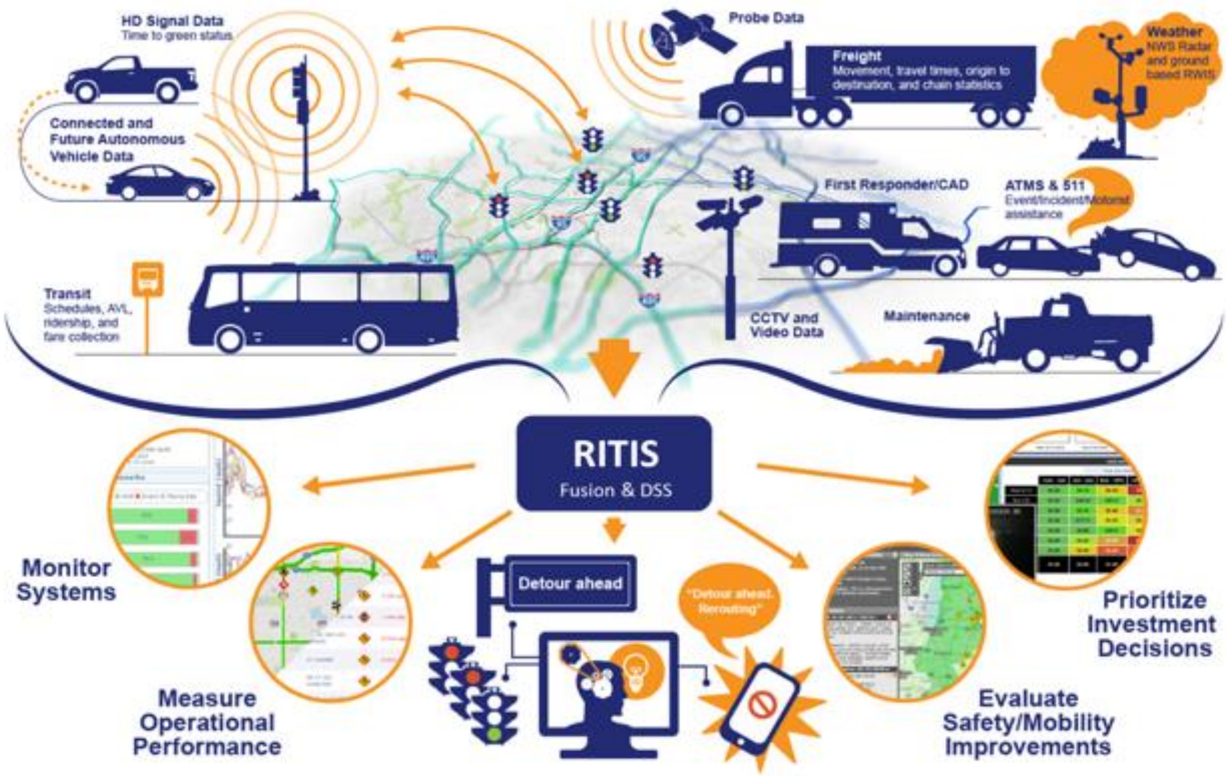

Figure 1: RITIS consolidates, fuses, visualizes, and disseminates information related to the transportation system.

Improving Traffic Operations with Real-Time Data

Figure 2: zoomed view of the RITIS map where first responders (orange dots) are shown positioning themselves in response to an event on the roadway.

RITIS provides comprehensive real-time situational awareness —combining traffic, weather, video, incident information, law enforcement dispatch information, transit, and more—in a web-based user interface that includes maps and other interactive visualizations. The system quickly identifies where speeds are abnormally slow, measures queue lengths, and identifies the location of potential safety issues. During significant events, RITIS helps first responders understand how their actions affect roadway clearance times and commerce. RITIS works across jurisdictional boundaries to allow coordinated responses across entire regions. It has been used to manage and respond to extreme weather events, large-scale events (Presidential inaugurations, Papal visits to Philadelphia and Washington DC) and major traffic disruptions (like long-term, unplanned bridge closures). Additional tools in RITIS can forecast travel conditions, identify signal timing issues, and can compare the effectiveness of first responders over a variety of time periods.

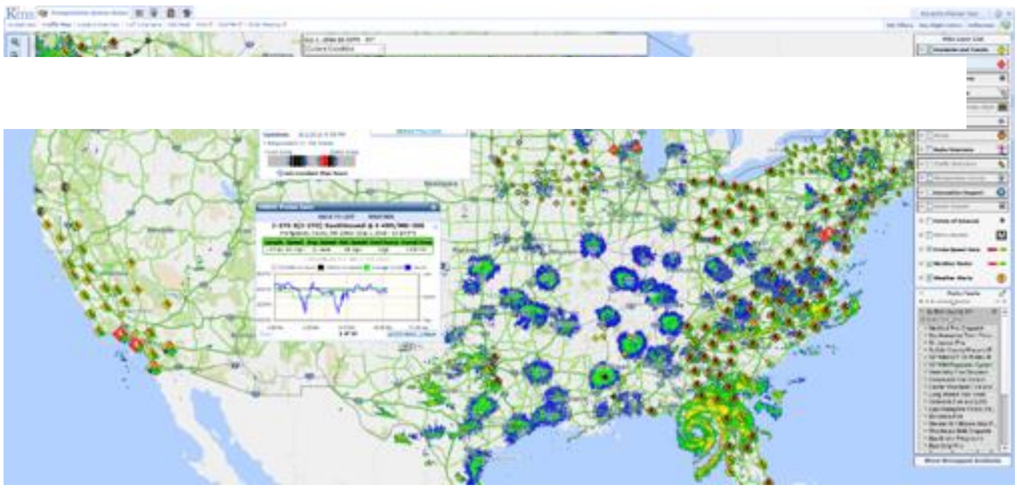

Figure 3: The RITIS Transportation System Status Traffic Map showing real-time data of the continental US with multiple layers of real-time data that can be turned on or off to focus in on what's important. Clicking on an icon will bring up additional information.

The platform is also used by operations and planning professionals to determine the travel patterns and movement of vehicles and other transportation modes to identify safety hotspots and prioritize where to invest in traffic safety measures.

Elected officials and emergency managers need to make decisions quickly that are based on real data—not just models and simulations. Before RITIS, answering even the simplest questions about traffic congestion during a winter storm or a holiday would have taken months. These types of questions include: where is the worst congested location in my state, and what is the economic cost of that congestion to industry and the public? What is the energy-use impact of congestion? Where are the locations with most significant fatal crash rates across the nation? How much of the congestion in my district was a result of winter weather vs. construction vs. bad infrastructure vs. collisions? Military officials can plan the safe movement of supplies in minutes. Emergency managers can understand the impact of their decisions to evacuate a region or request to shelter in place. And all the answers to these questions are securely provided to officials over the web, in a matter of minutes. The RITIS platform is the world's largest transportation data archive – visualized.

The RITIS platform is also integrating third-party connected vehicle data into its situational awareness capabilities. Real-time CV safety measure data include heavy breaking events, traction control engagement, hazard warning engagement, rollover events, and more. This third-party CV data, along with other CV/AV data, has the potential to significantly improve safety assessments and response, improved mobility, and more efficient management of congestion. The RITIS software engineering team continues to architect the platform to support the agile integration of additional CV/AV data as it becomes available.

Better Planning using Archived Historical Traffic Data

While RITIS is extremely useful for real-time situational awareness, multi-agency collaboration, and emergency management, the true power of RITIS is in the archiving or operations and planning data, and the visualization and analysis tools that are built into the platform. These tools make accessing data, downloading data, and deep-dive analytics incredibly easy for engineers, researchers, and even the public. Examples of these tools include:

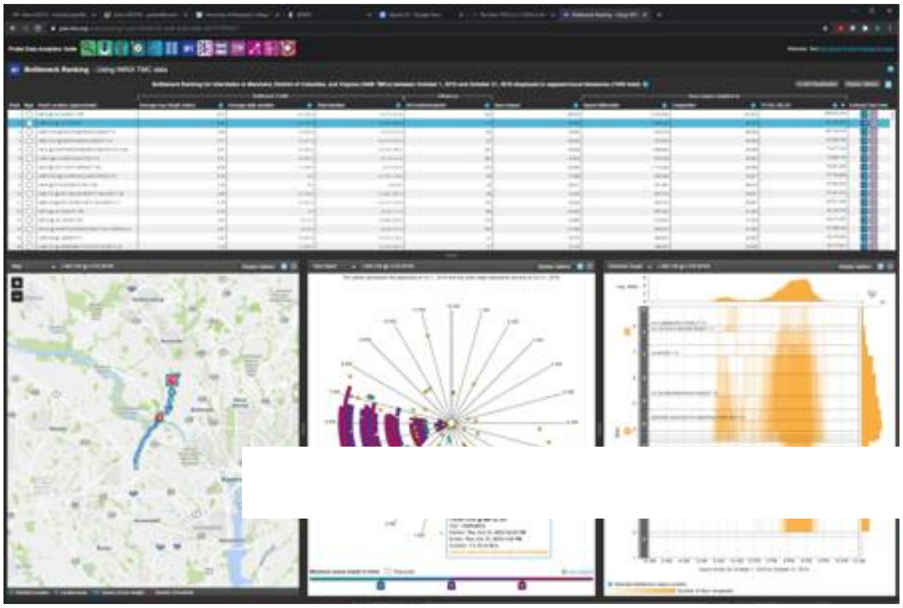

Figure 4: The bottleneck ranking tool uses probe-based speed data fused with volumes and event data to rank and quantify the worst congested locations in any geography and date range.

Probe Data Analytics is a true big-data analytics platform that archives over 10 billion cellular-phone and automated vehicle location (AVL) data points per day. Our analytics enable agencies to directly measure the economic impacts of congestion, discern people and goods movements, and more.

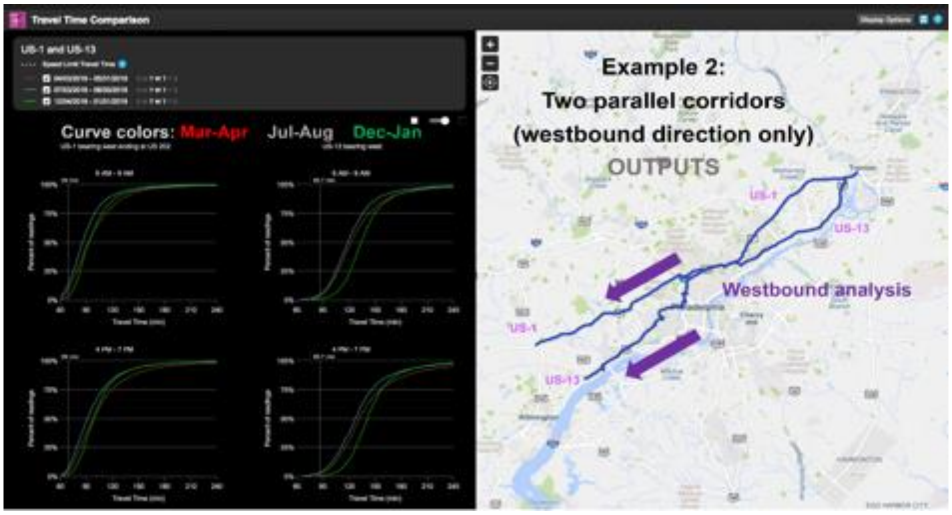

Figure 5: Cumulative frequency diagrams provide insights into signalized corridors--visualizing changes in reliability and travel times.

Arterial Signal Analytics provides the ability to analyse signal performance over time—including the ranking of signalized corridors at the state-wide level to see where the agency needs to invest resources. You can also analyse how congestion and reliability change after retiming.

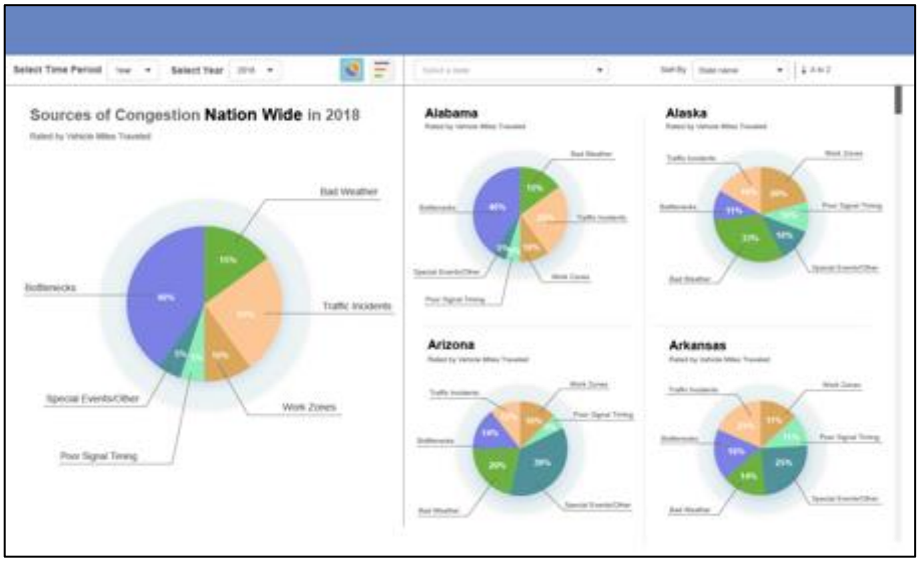

Figure 6: RITIS allows agencies to choose a geography and date range, and then the amount of and causes of congestion are displayed in bar and pie charts.

Causes of Congestion Pie Charts provides the ability to analyse an entire state, or a smaller region, to determine the amount of congestion and what caused it—weather, construction, incidents, poor signal timing, etc. This tool is funded by the Bureau of Transportation Statistics and is replacing the 14+ year-old national causes of congestion pie chart. The tool uses real data from agencies and private sector probe data to inform agencies about the causes of congestion in their region, enabling them to make better investment decisions.

Evaluating Incidents and Work Zones

RITIS contains specialized tools that make it easier for agencies to evaluate how effectively they respond to incidents and how efficiently they manage work zones. These tools are described below.

Incident Timelines visualize real-time incident response and provides a detailed history of a traffic event in a graphical, one-screen overview. Intuitive graphics summarize data that would normally take multiple pages and large tables to understand. The Incident Timeline reduces the chance of missing critical information and clarifies the many simultaneous events that occur during the management of an incident. The timeline can also be used by an agency during after action reviews.

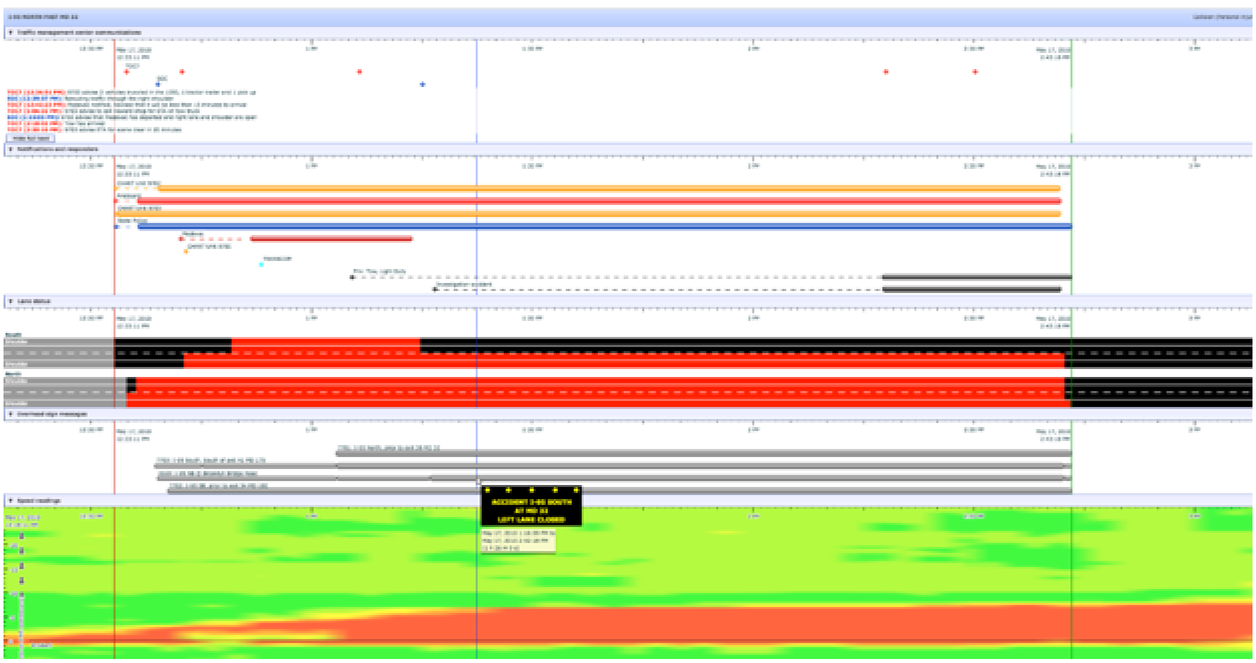

Figure 7: A sample incident timeline depicting responder actions, vehicles involved, event severity, weather, land status, queues, and more. View this interactive event timeline at: https://timeline.ritis.org/demo

Figure 8: real-time and historic work zone performance is displayed in the work zone performance monitoring application.

Work Zone Performance Monitoring provides regional and individual work zone dashboard-style analytics to monitor and manage work zones, and evaluate the impacts through a variety of performance charts and widgets showing cost and delay.

Enabling Better Communication through Reporting Templates

Reporting templates are integrated within RITIS to make it easier for state and local agencies to "tell their story" and communicate both internally and with the public. These templates include step-by-step instructions for how to produce fliers, pamphlets, press releases, and other materials to assist with incident after action reviews, holiday travel forecasts, before and after studies, corridor performance reports, work zone audits, and more.

Figure 9: Example reporting templates within RITIS.

A Solid Platform for a Growing User Community

RITIS is supported, maintained, and improved by nearly 100 full- and part-time software developers, program managers, data scientists, and art and UI/UX professionals. There is also an established community for outreach and feedback via the *RITIS User Group*, which meets regularly so agencies can share best practices, hear about and understand the latest features, and suggest improvements to the RITIS platform to meet their specific needs.

Third parties, such as Waze, Google Maps, TomTom, Sirius XM Satellite radio, the media, and other travel information services also redistribute non-sensitive RITIS data to their users. All data shared with RITIS is archived, and a large suite of data analytics and information visualization tools have been developed.

RITIS is widely used by nearly 14,000 users and hundreds of public safety, government, law enforcement, military, defense, and transportation agencies in the United States

3.1.2. Objectives

Through early stakeholder meetings, we determined that RITIS would emphasize data fusion, data sharing, data collection, regional transportation systems management, regional traveler information dissemination, and systems evaluation. RITIS would attempt to enhance ongoing activities performed by individual agencies, companies, and the public by providing each with real-time, regional information in an electronic, standardized format.

By consolidating, disseminating, and archiving transportation-related data from various agencies in the Washington, D.C., area, RITIS would:

- provide improved information for a variety of purposes, including regional transportation management, traveler information, and emergency response
- provide regional data fusion to allow an overall view of the region's transportation network
- support and complement activities of participating agencies in data collection related to regional transportation systems
- support and complement transportation systems management efforts of the member jurisdictions for regional transportation operations
- support and complement traveler information and 511 activities related to regional traveler information
- support and complement the region's emergency preparedness activities
- provide the means to produce regional performance measures and access regional transportation data from a single location.

Additionally, RITIS was designed to support individual agencies in:

- Transportation Planning
- Congestion Reporting and Analysis for:
    - System Performance Reporting
    - Problem Identification
    - Project Prioritization
    - Before & After Studies
    - Emissions and Energy Consumption
- Conduction After Action Reviews (AARs) of incidents
- Work Zone Monitoring
- Responding to federally mandated performance measures reporting
- Travel behavior analysis (O-D analytics, select-link analysis, route analysis, model calibration, etc.)

3.1.3. Technical challenges

The greatest technical challenges associated with building out RITIS included:

- **Standardization**: Every agency classifies incidents and events differently. Some call crashes "collisions" while others call them "accidents" or "incidents" or something else. Others assign detailed attributes to incidents. For example, an incident could involve a vehicle fire, a medical emergency, and a fatality all at the same time. Each agency provides this information in different formats—either as a text description or an attribute. We wanted to ensure that users see consistent, universal terminology when using our tool, so we created a working group with participants from each agency to make sure individual agency terms were translated to universal terminology in a way that was agreeable and consistent.

- **Overlapping/Conflicting Data**: It is common to receive data from three or more agencies (State DOT, Local DOT, state police, local police, and/or the private sector) who are all attempting to describe the same incident. RITIS must identify overlapping and conflicting information and attempt to present a single, fused description of the event to users. This is particularly challenging when agencies have conflicting accounts of what is happening at the scene of the incident.
- **Latency**: every agency provides data at different intervals. Some agencies provide incident/event data in near real-time, while others may send data once every minute or five-minutes. Some detectors are configured to report speeds and volume data every 10 seconds, while others report data every 30-seconds, one minute, or five minutes. Ensuring that we present a "real-time" view of traffic conditions that don't conflict with one another or confuse the user is a significant challenge—especially when multiple agencies are providing data at different time intervals in the same general area.
- **Credentialing and User Management**: Not all data in RITIS is accessible to all users. Some agencies have restrictions on what can be shared with other users inside and outside of their own agency. Private sector data sources are governed by data sharing agreements and 3rd party contracts. There may be restrictions on who is allowed to see 3rd party data and on which dates data can be accessed (real-time or historical). It was challenging to define a credentialing and user management database that could account for all of the needs of data providers.
- **Modernization**: RITIS has existed in some form since 2005. Technologies have changed significantly over the past 15 years. Some of the original technologies used to develop RITIS tools are no longer supported. This means that RITIS software developers must be constantly rewriting and rebuilding the system to ensure it is modern, secure, and compatible with current browser technologies. This has been one of the greatest long-term challenges as it requires significant resources to manage each year.

3.1.4. Non-technical challenges

The most significant non-technical challenges associated with RITIS include:

- **Quantifying the Value of Sharing.** Convincing agencies of the value of data sharing and regionalization has been a challenge—especially with agencies who have traditionally been hesitant to share data for fear of being compared to others, judged, open to liability, etc. These issues have been well documented in NCHRP Synthesis Report 460: Sharing Operations Data Among Agencies[9]. Once RITIS began to provide extremely compelling data analytics tools, most agencies found it hard to say "no" to sharing their data, since the capabilities that were provided in return for sharing their data were too good to pass up.
- **Pooled-fund approach to funding:** RITIS is unusual because no single agency can claim ownership of the project and, by extension, pay all of the recurring costs. Participating

[9] https://www.nap.edu/catalog/22372/sharing-operations-data-among-agencies

agencies must commit to working collaboratively to ensure that RITIS is properly operated and maintained. Many agencies still want to "own" their own systems and technology. This can be wasteful as each agency has to recreate capabilities. The RITIS approach shares the cost of the system between agencies. Also, when each agency pays for new features or functionality, those features are freely shared with all other agencies. This has proven to be compelling to many agencies as they essentially get more for their investment than they would building a system on their own.

- **Sharing "raw" data instead of public data:** Many agencies had already invested in some form of public data portal or data feed. However, these data feeds were scrubbed of any sensitive data elements. These agencies wanted to use these public portals for sharing data with RITIS. However, these data gave few insights into operations and operational strategies since they were missing key information required for truly understanding the performance of the agency and the road network. Because RITIS is a platform used by many agencies and states, we were able to show agencies with limited data availability what they were going to miss out on by showing them what was possible with other agencies who provide significantly more data.
- **One pays, all use.** In most cases, State DOTs fund the RITIS platform, and local agencies (including MPOs, cities, and first responders) all get free access. This means that it is possible to have significantly more "local" users than users from the agency who is paying their way. This can sometimes create problems when executive leadership at the State DOT changes, and they begin to question expenses. Convincing the leaders the value of this business model remains a challenge today. Some understand the Return on Investment (ROI) of supporting the locals who ultimately help the state (we're all trying to solve transportation mobility issues together), while others are a harder sell. In a perfect world, the Federal government would fund RITIS for everyone. This would remove funding challenges and costs associated with managing dozens of contracts. It would also free up other funds for system capability expansion.

Additionally, RITIS developers made many assumptions, as described previously, during the conception and build-out of the original RITIS system. However, many of these assumptions were incorrect or have evolved over time. These include things such as:

- **Users:** While it was always envisioned that third parties and travelers may want access to RITIS, the extent to which it would be adopted by non-transportation agencies has been astonishing. Less than 50% of current RITIS users are transportation agencies. The bulk of RITIS users are governmental agencies that want to maintain situational awareness, need help with decision support, or have logistical concerns that can be addressed by the data found within RITIS.
- **Growth Potential:** The number of agencies and users signing up for access to RITIS is growing well beyond what was originally imagined. The number of RITIS website users has tripled in the last year and a half. The number of agencies that want to provide their data to RITIS so that they can better meet their data sharing objectives continues to grow with dozens of agencies now providing their real-time data to the program.

- **Reliance:** RITIS is now viewed as the primary source for transportation data on the Eastern Seaboard and much of the rest of the country. As such, many agencies are beginning to rely on RITIS significantly more than was ever expected. Critical data sources for regional evacuation plans and emergency management information are now stored within RITIS and agencies now know that in an emergency RITIS is where they need to look. This has increased the perceived worth of the system; however, it places a significant operational burden on the support staff who are constantly answering questions about data, capabilities, and providing training.
- **Performance Measures and Planning Applications:** While real-time operations remains the primary focus of RITIS, the number of users who request access solely for the purpose of historical data retrieval and analysis is beginning to advance. Hundreds of individuals access RITIS daily for the sake of studying traffic patterns, identifying congested corridors, developing performance measures, developing reports for the media and decision makers, prioritizing projects, etc. While the data archive was always at the front of developers' minds, the success of the RITIS data visualization and performance measurement tools has been a true driving force in continued funding and development.

3.1.5. Evaluation

No formal evaluation of the entirety of RITIS has been conducted. Instead, agencies tend to evaluate individual components of the platform to showcase return on their investment. For example:

- One agency evaluated RITIS's ability to help it produce before and after studies of projects. They noted that similar studies would have cost approximately $45k USD leveraging consultant support. Using RITIS, the agency is now able to produce higher quality project assessments at less than $1k USD each. Annually, they can save over $1M in using RITIS for this one specific purpose.
- Another transportation operations entity operating in the Washington, D.C. region used RITIS as part of its regional coordination program—noting that RITIS helped them to respond and clear incidents on the roadway much faster. They made fewer mistakes and were able to provide better information to the public which redirected traffic to other roads and decreased secondary incidents, congestion, etc. This was considered a conservative analysis as it did not account for rubbernecking delays, emissions, or secondary queues. The results showed a savings of $380k per major crash and $30k per minor incidents. Given the number of incidents in the region, this amounted to tens of millions in savings each year.

In addition to the above enumerated evaluations, the following are direct quotes from RITIS users:

- "Analysis that used to take an entire year to accomplish with one or two full-time employees now takes only 10-minutes, and I don't need an entire IT staff to support it." ~MPO Senior Transp. Analyst
- "The RITIS Probe Data Congestion Analytics Suite represents a quantum leap in capabilities for problem identification, problem confirmation, and communicating with the public." ~DOT Planner

- “The amount of funding we have to ask for from our DOT program manager has decreased as a result of access to these tools. They are saving money, and we are more nimble.” ~DOT Consultant
- “We are making better informed decisions about which ops centers to keep open, where to deploy patrols, and what type of economic impact we are having on the traveling public. We’ve never had this type of insight into operations before.” ~DOT Ops Mgr.
- “This is amazing! We can tell some really compelling stories to the public about our impact, and it’s so easy!” ~Private Sector Public Information Officer and Media Relations for a DOT

3.1.6. Future

RITIS is now branching out into more multi-modal areas—integrating seaport, airport, bike, and pedestrian data. RITIS is introducing new real-time and historical analytics to further facilitate operations management and inter-agency collaboration. This new dashboard in RITIS provides real-time multi-modal impact information on all current disruptions, including those on both bus and rail public transportation, roadways, seaports, and airports. The dashboard makes linkages between each mode to show how disruptions to one mode can impact others.

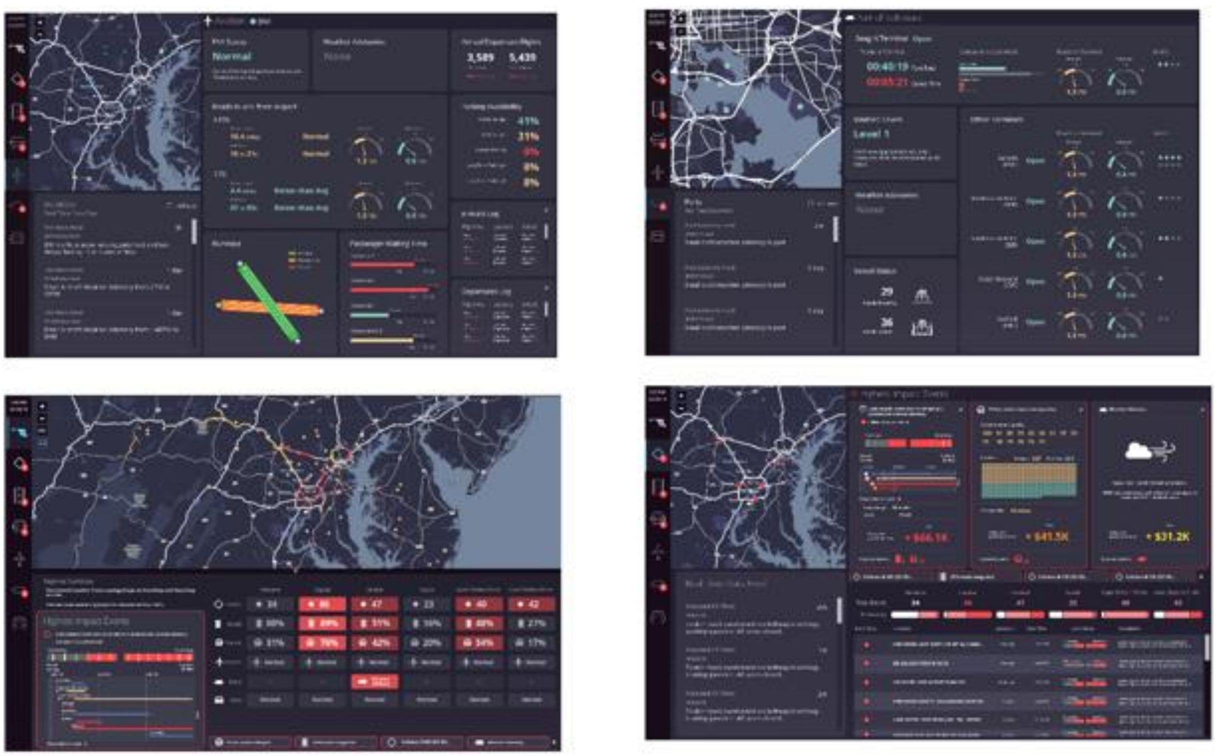

Figure 10: Clockwise from top left (Baltimore-Washington International Airport dashboard panel, Port of Baltimore, MD Overview, and Severe Impact Dashboards.

In 2020, a nationwide people movement and social distancing analytics engine was also deployed to RITIS. This COVID-19 Impact Analysis Platform provides insight on COVID-19’s impact on mobility, health, economy and society for all states and counties with daily data updates. A Society and Economy Reopening Index were also added to help states and counties understand how well they were meeting the CDC’s guidelines for safe reopening.

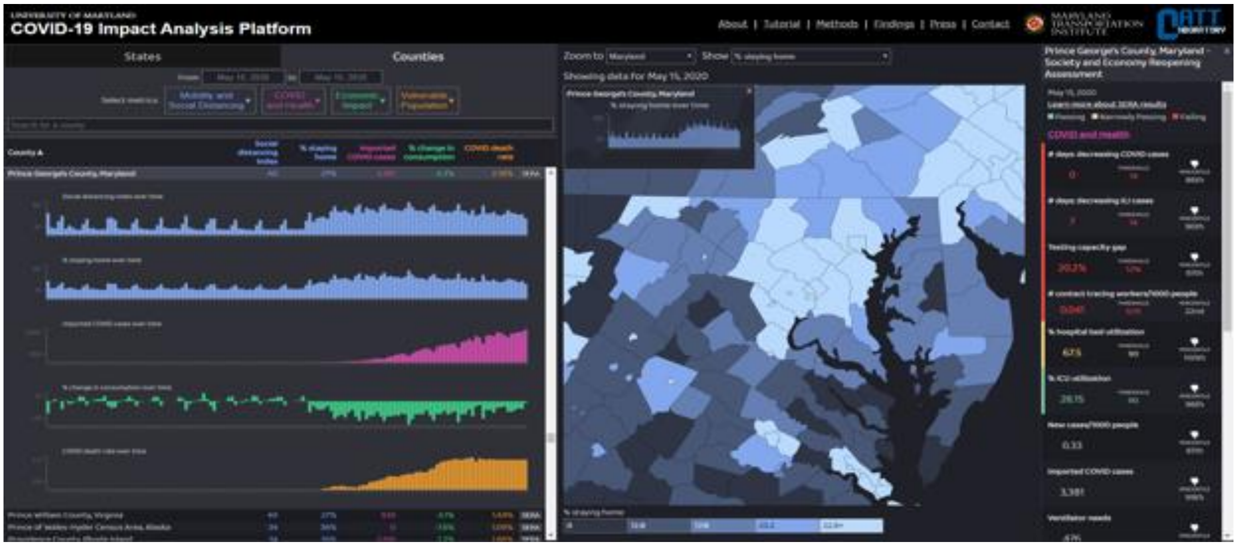

Figure 11: A screenshot of the interactive COVID-19 Impact Analysis Platform that provides historic mobility, health, and social distancing stats for every county in the United States starting Jan 1, 2020 through today.

A new Trip Analytics suite of tools within RITIS is being significantly enhanced to enable route analytics, cordon and screen line analytics, and other Origin-Destination studies—furthering the ability to monitor people and freight movement to help with planning, analysis, and security operations. These tools will enable agencies to review and analyze origin-destination data and provide insight into routes taken– where they begin, where they end, and the segment-by-segment routes that were taken along the way.

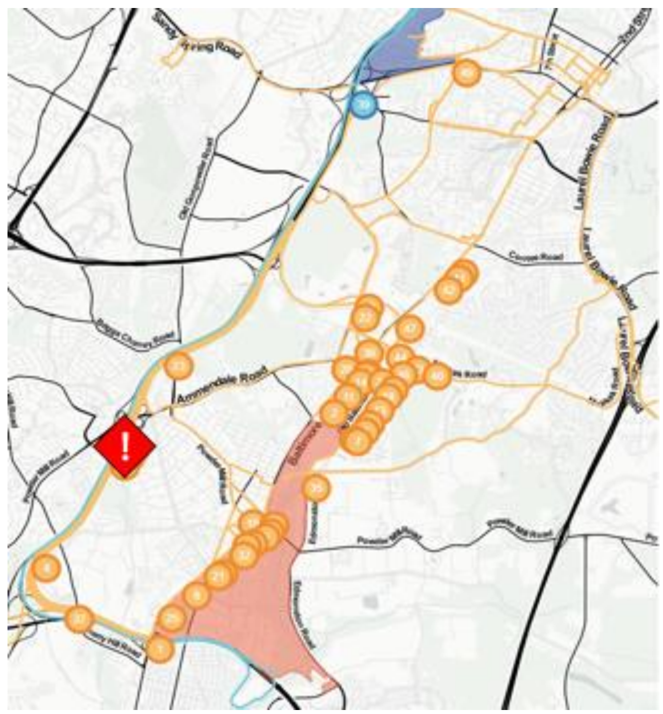

Figure 12: map showing the routes that travelers used to detour around an incident on I-95 just north of the Beltway.

RITIS has also added several new historical data tools to RITIS's Probe Data Analytics (PDA) to enhance agency capabilities for planning, analysis, and after-action review. These include a new "Temporal Comparison Mapping" tool that enables users to visualize changes in congestion and travel speeds between multiple date ranges on a map. Several new Energy Analytics dashboards were also deployed that show road-by-road real-time and predicted energy consumption, emissions, and vehicle registration details.

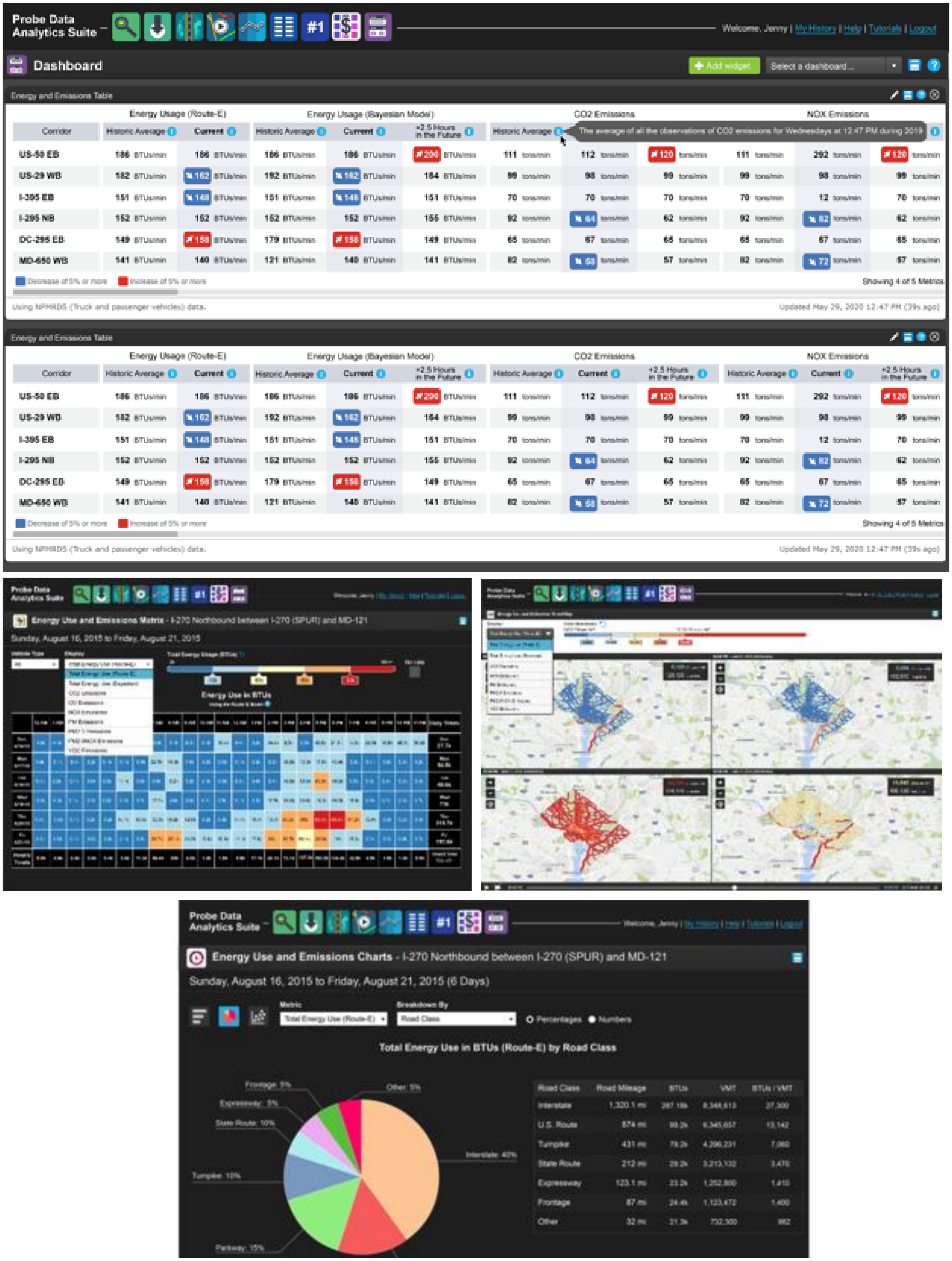

Figure 13: Several screenshots from the RITIS Transportation Energy Analytics Dashboards

Further information:

CATT Laboratory Director & RITIS Program Manager, please contact Michael L. Pack at PackML@umd.edu or visit https://www.ritis.org

3.2. Case Study 2 – Hybrid Data Model and Cost of Congestion Evaluation (Australia)

3.2.1. Description

Department of Transport and Main Roads (TMR) in Queensland, Australia, in collaboration with the Australian Road Research Board (ARRB) are developing the methodology and an automatic system to report the cost of excessive congestion (CoC) of a network with roads from different jurisdictions (e.g. TMR and local governments) and different data sources. A hybrid data model, which blends in traffic data from different data collection methods is considered as the ultimate data source. A web-based prototype system has been built that can test the main functions of the automatic system before the product implementation. The cost of excessive congestion as a measure for project evaluation and network performance monitoring covers the cost of excessive delay, travel time reliability cost and cost of externalities such as increased emission and vehicle operation cost due to the excessive delay.

The calculation of the cost of excessive congestion was originally limited to the state-controlled roads with the loop detectors that are fully functional. To improve the spatial and temporal coverage of traffic data for the entire road network, TMR initiated a data fusion project which combined three datasets – loops from the TMR traffic management platform STREAMS, Bluetooth travel time data and probe speed data. The fusion method intelligently selected the data from one or a combination of the data sources that had a strength under the historical traffic conditions.

The web-based CoC prototype has been tested and is able to assist TMR in testing the hybrid data and evaluating its impact on the cost of excessive congestion calculation using data collected from the City of Gold Coast, Queensland. To date the prototype has processed 16 months of data from multiple data sources as well as the hybrid dataset. The project made use of an agile software design and development process. The prototype provides a modern and interactive visualisation function for users to select links, routes or networks, defines the data source and time range and automatically produces CoC-related results in both table view and map visualisation view on the same screen.

The map visualisation tool conveniently provides a traffic performance snapshot for the comparison between data sources (Figure 1). Generally, the hybrid data map showed more map links, more moderately slow links (as highlighted in yellow in the map display), and less extremely slow links (as highlighted in black on the map), when compared to the STREAMS loop data map. Users can zoom in to more detailed view for observing the difference between the four data sources at network, route and link level.

By using the prototype, a detailed dashboard for CoC-related KPIs for different date ranges on a selected route or link can be easily generated and compared between the four data sources (Figure 2). The prototype scenario testing results using the hybrid data also suggested a significant improvement in the data coverage and data quality, hence enabling a more accurate evaluation of network congestion cost to inform investment decisions.

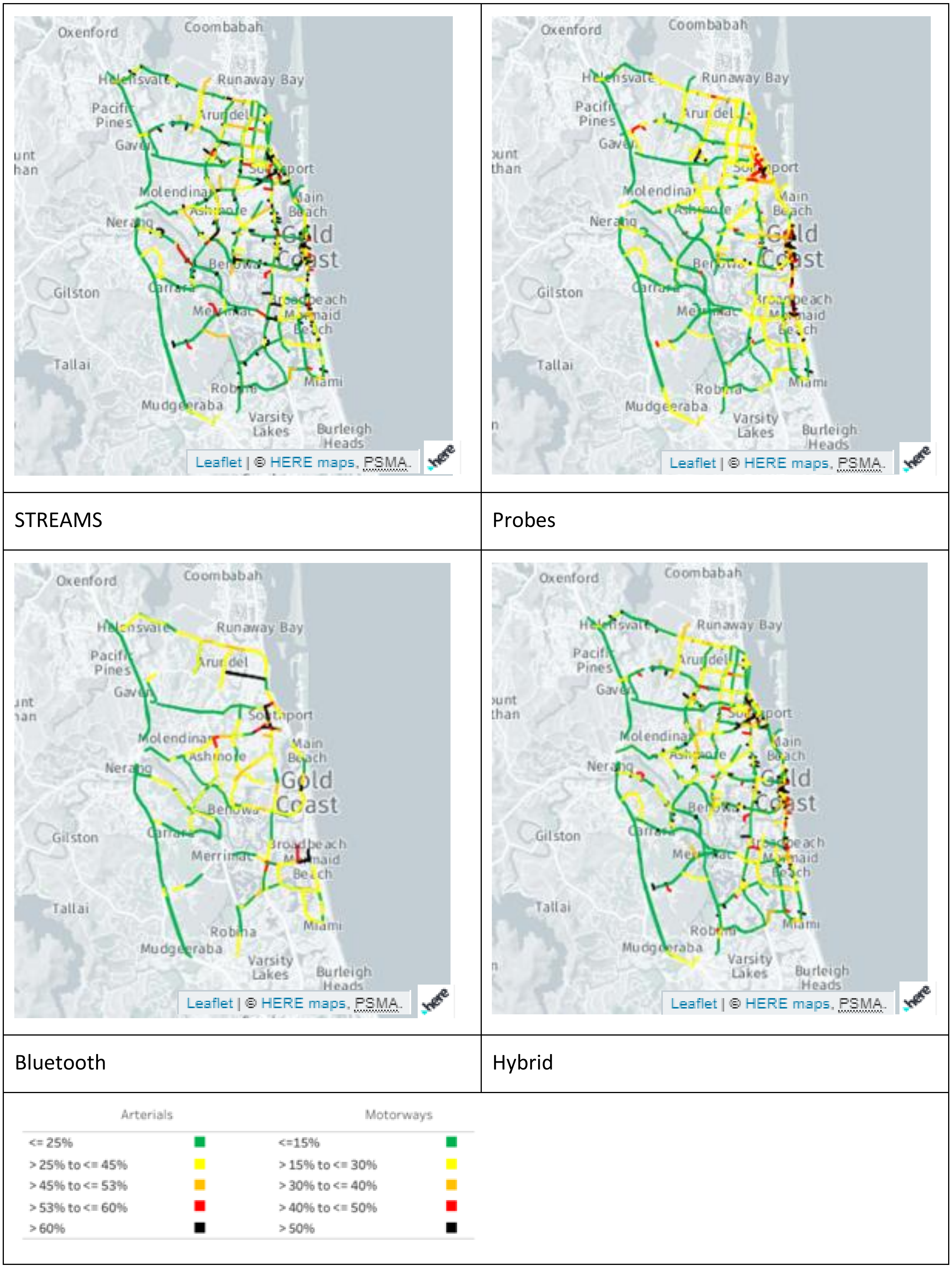

Figure 1: Screen shot of prototype output - Variation from posted speed for entire study period visualized by different data sources.

Note: both variation from posted speed and variation from free-flow speed can be used to visualize the comparison.

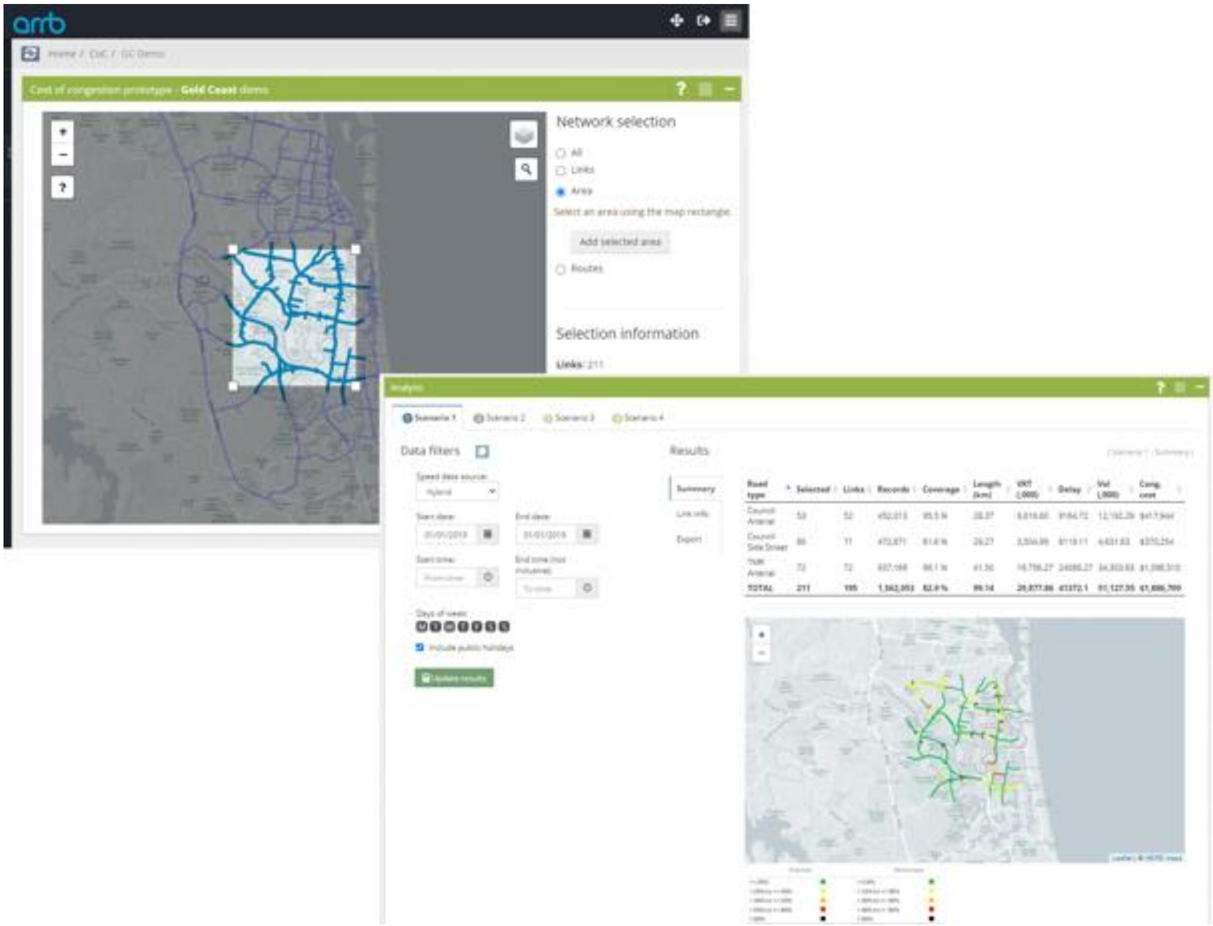

Figure 2: A snapshot of prototype output – link selection and CoC reporting

3.2.2. Objectives

The key objectives of the research work are:

- to develop a web-based prototype that could incorporate both the hybrid data model and the enhanced CoC methodology into one platform for testing. Ultimately, the aim is to provide an automatic system to report the CoC of a network with different types of roads. The CoC should be reported on a regular basis for network performance monitoring purpose or per request for project evaluation. The CoC reporting would serve different business needs for TMR users including network performance evaluation, before-and-after study for major projects, incident impact analysis, etc.
- to further refine and validate the hybrid data model business rules in order to improve the quality and coverage using the prototype and analytical assessment
- to develop a set of sample hybrid datasets that can demonstrate the key functions of the CoC reporting system.

3.2.3. Technical challenges

- The prototype utilises the TMR STREAMS network as the reference network (Figure 3). Therefore the Bluetooth and probe data needs to be mapped on to the STREAMS reference network before data fusion, data patching, and CoC calculation were performed and reported. The map-matching process was proven to be quite a significant amount of effort due to the differences in spatial granularity and accuracy.

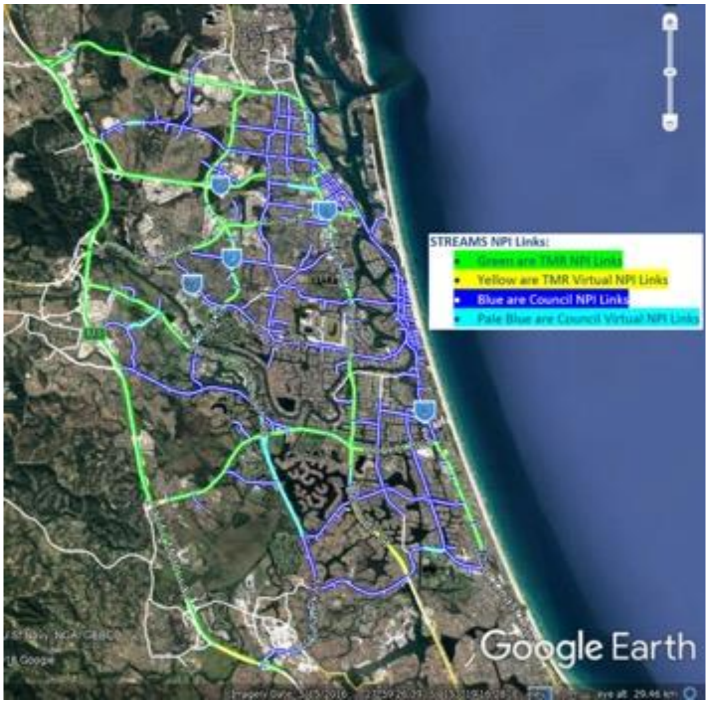

Figure 3: Data coverage of the Gold Coast testing network

Source: Google Earth (2020), ‘Gold Coast’, map data, Google, California, USA.

- A data behaviour investigation was conducted to understand the variability among data sources and to ensure the probe data does not introduce unnecessary volatility in the hybrid model. The speed variability was compared between different data sources using the speed distribution via Whisker Charts, standard deviation and coefficient of variation of selected links in different road categories.

3.2.4. Non-technical challenges

- Collaboration of public and private sectors was required to ensure the permission of data sharing for different data sources was obtained for the use of the project.
- Implementation of the hybrid data model and the enhanced CoC methodology across TMR at current stage remains a challenge although the idea is understood and supported. While TMR has invested a lot of effort in the research and development of the CoC measure, it is not reported externally as TMR does not have a standardised view on how to communicate this perceived cost to the community. The concept of blending multiple data sources to improve data quality and coverage is recognised by TMR, however the hybrid data model is

not implemented due to capacity and limitations of existing systems. It is expected that the outcome of this project will help users in road agencies to gain more confidence in the hybrid data quality and for the CoC methodology to be implemented at a broader network level.

3.2.5. Evaluation

- The STREAMS loops data and Bluetooth data, that were used to develop the hybrid data model, were further used in the Australian Transport Assessment and Planning (ATAP) '*Road reliability measurement for ATAP TAP6234*' project to assist the development of ATAP travel time reliability model and national guidelines (ATAP 2021).
- This project of using hybrid data model for the CoC reporting prototype system have been presented as a technical paper at a few conferences, such as ITS Asia Pacific Forum, Australian Institute of Traffic Planning and Management (AITPM). Positive feedback and broader interest were received from the transport and technology professionals.
- Austroads Guide to Traffic Management Part 3 Traffic Studies and Analysis have included the TMR hybrid data model and the enhanced CoC methodology model as case studies of emerging traffic study data initiatives. This demonstrates the project was built on a high quality standard with the acceptance of Austroads guideline.

3.2.6. Future

- The prototype developed in this project is intended as a starting point to enable TMR to apply the CoC methodology at a state network level.
- The prototype system can be expanded, in terms of data coverage, if it is connected to TMR's Transport Data Exchange in future.
- Since the current prototype system only focuses on the Gold Coast area, this can potentially be expanded to include other major cities within Queensland or Australia.

Further information:

- TMR – Dr Merle Wood
- ARRB – Dr Clarissa Han
- CoC prototype system: http://toolbox.atlab-arrb.com/coc/cocmain (permission required for access)

3.3. CASE STUDY 3 – USING BIG DATA TO MONITOR THE IMPACT OF MEASURES AGAINST COVID-19 (CZECH REPUBLIC)

3.3.1. Description

Mobility Atlas is a system for monitoring population mobility in the Czech Republic. During 2020, a module for monitoring the impact of measures against the spread of COVID-19 was created. It is the primary transmission interface of data on population mobility in the Czech Republic. The system processed anonymized operational data of T-Mobile CZ using the services of the National Supercomputer Centre at VŠB - Technical University in Ostrava.

Selected data from the Mobility atlas (result of the RODOS project) are made available for the needs of the country and state of emergency for territorial code lists "State", "Region", "Municipality" (over 50 thousand inhabitants according to the Czech Statistical Office). The system is based on the processing of location data of mobile operators where the data of two independent mobile networks are processed.

The development of the modules included the following steps:

- Mobile network data time series cleaning and calibration.
- As part of the development of the mobility indicator from the COVID-19 Community Mobility reports and database, the module analysed and showed trends in the movement of people in residential areas and residential buildings. Other indicators covering more locations were gradually added, such as establishment and recreational areas, which focuses on places such as restaurants, cafes, shopping malls, amusement parks, museums, libraries, and cinemas.
- Thanks to the connection to the public data lake database for COVID-19 research and development operated by Amazon. An indicator of the number of newly registered cases in the Czech Republic and neighbouring countries was added to the comparison. By using additional and valid data sources, an interesting international comparison of mobility trends is possible.

Qualitative criteria checks involve the deployment of automatic calculation methods, where the processor checks the content and consistency of data on the mobility of the population from the mobile network. Based on this inspection, days that do not meet the quality criteria may be excluded from processing. Days in which the qualitative criteria for the input data were not met, with the consequence of their exclusion from processing, are evident by a gap in the time series.

3.3.2. Data for the Czech Republic

The Czech Republic domestic data and results are presented through three dashboards.

- The Czech Republic summary is a view of the overall saturation in the Czech Republic in terms of non-exits and the number of new cases.
- The change comparison uses 3 independent data sources to verify the dependency of the sub-indicators.
- The change in non-commuters allows to compare the change in non-commuters (via mobile data) in selected municipalities and in all regions of the country. Dashboard has two further

parts, subsets of (i) the actual analysis of total change and (ii) the analysis of total change in the first wave, which allow to compare regions using the key indicator change in non-commuters.

- **International comparison**
- The international comparison is based on data available for neighbouring countries, i.e. Austria, Germany, Slovakia and Poland.

The international comparison works with the following data sources:

- Google Data are updated daily between 12:30 PM - 1:30 PM.
- Data from the Ministry of Foreign Affairs of the Czech Republic are updated daily between 12:30 PM - 1:30 PM.
- AWS data is updated when the report is processed.
- T-Mobile CR mobile network data are processed continuously. The mobile network penetration is approximately 42%.

Unless otherwise stated, the data used for comparison include Czech SIMs, i.e., users connected to the network of a mobile operator licensed to operate a mobile network in the Czech Republic, and foreign (SIMs), i.e., users of a mobile operator licensed to operate a mobile network outside the Czech Republic connected to the network of a mobile operator licensed to operate a mobile network in the Czech Republic, so-called Roaming.

Link to the Atlas Mobility portal:

https://atlas-mobility.danse.tech/zme-sou.html

Figure below illustrates the highest share of movement of persons in the Czech Republic. Note that the colors in the map are not essential for the purpose of this article.

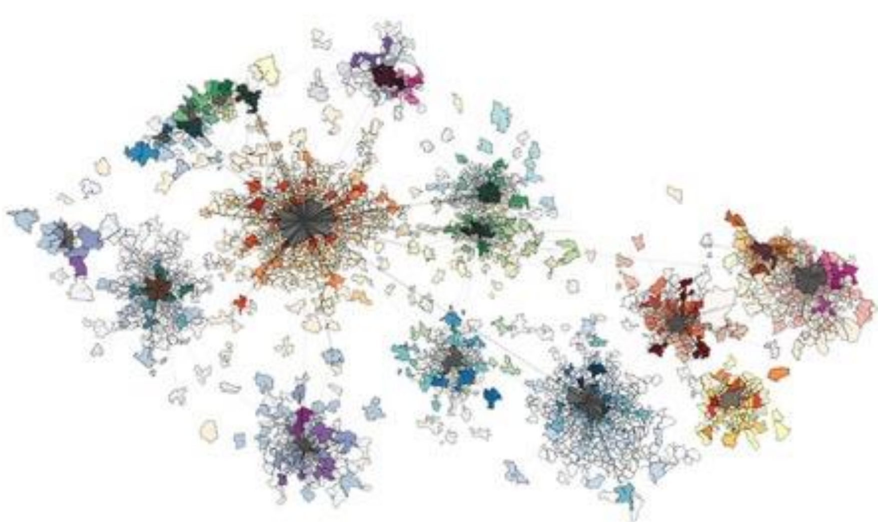

Figure 14: Map of Czech Republic from atlas – mobility (SIM movements)

3.3.3. Objectives

The main objective of the system development was to use the full power of the Supercomputer installed at IT4Innovations research infrastructure at the VŠB - Technical University of Ostrava for processing anonymized records from the mobile network and to provide information on population movements in aggregated form with granularity down to the basic territorial units.

The most important aspects in the development of this system were to meet the following requirements:

- To provide a simple environment for monitoring changes in population behaviour and mobility following the issued COVID-19 disease control measures.
- Provide access to such an application to the entire professional community, the press, as well as the political representation.
- Create accesses to a mobility portal where different reports can be created according to the assigned roles.
- Fully autonomous operation of the system on a daily/hourly basis with the capability of manual inputs and gradual upgrades and expansion of use cases.
- Enable to compare different periods and specifically selected territories according to user priorities.
- Define roles and method of data aggregation to distinguish between outbound and non-outbound movement in the context of a defined territory.

3.3.4. Technical challenges

The main technical challenge is the correct setting of the measured parameters and the setup of the entire system and data handling. It is necessary to work with a supercomputer for continuous calculations. Further aspects for the correct setup of the system are the definition of the individual terms and the assignment of rules for the computing system to process. A few examples to demonstrate the challenges are discussed below.

A classification of the number of SIMs is performed in a daily cycle. In the daily cycle, it is evaluated whether the occurrence location in the morning time window (00:00:00 - 04:59:59) remains the same for the rest of the daily cycle (05:00:00 - 23:59:59). If the location of occurrence remains the same throughout the daily cycle, then a classification the **Not Outgoing** is applied to the SIM.

The Commuter classification is used for a SIM if the location changes, i.e., the SIM left the location in the morning window and stayed in another location for a minimum of 30 min.

The assignment to a territorial unit is made based on the maximum cumulative time spent in the territory. In the case of **Commuters**, this is the time in the time-of-day window (05:00:00 - 18:59:59). **The Commuter** is defined geographically by the terminal logging on to a different transmitter. Transmitter distances vary by location type and are related to the population density of the area. In general, transmitter distances decrease with increasing population density and vice versa. It is not decisive whether Commuters have left the administratively defined area. **The fact of leaving the administrative area is captured in the 'Commuting from' and 'Commuting to' indicators**. Depending on the chosen territorial code, this is leaving the territory of the region or municipality. The share of non-commuters and the sum of non-commuters and leavers from the place of occurrence is denoted as the Share of non-commuters. The number of registered and/or classified SIMs varies slightly from day to day. Thus, the indicators are not calculated on the same basis.

Non-commuters are users who did not leave the place of occurrence where they rested in the daily cycle from the previous to the current day (place of residence). The point of occurrence is defined by the functional area of the mobile network; any cell on the same transmitter. In this context, **Non-commuters** should be interpreted to mean that they did not travel a distance in the territory longer than twice the radius of the transmitter's range. This varies according to the type of territory (urban, rural) see the Distances section below for classification.

Assignment of a record to a territory

On top of the territory map and the mobile signal propagation map (coverage map), a formula for the transfer of information from the functional area of the mobile network to the administrative or transport subdivision of the territory is used to record the information on the use of the territory, in particular the housing stock and the expected population.

Place of residence in the daily cycle

The so-called home cell of the mobile network (home cell) is used to determine the place of residence. The morning and evening window is used.

Commuting location in the daily cycle

The mobile network commuter cell (commuter cell) is used to determine the commuting location. Here only the daily time window is used. The specific base station (BTS, NodeB or eNodeB) where the user spent the longest time in the daily window is determined.

Distance for classification

The approximate distances of the area covered by individual transmitters (BTS) are based on the maps of the expected signal propagation of **T-Mobile mobile networks** (the so-called dominance maps) in the month of October 2019. The distances are based on the matrix of distances of all registered transmitters in the Czech Republic (matrix approx. 7.3 thousand X 7.3 thousand).

The condition of existence of minimum 3 additional transmitters within the maximum distance is verified for each transmitter, which assigns the type of territory and the expected size of the radius of transmitters in the territory, according to the following rules: urban density area: 0 to 500 m, urban area: 0 to 1000 m, suburban: 0 to 2000 m and rural area: 0 greater than 2000 m. The values of the radii of the transmitters' range in meters (rounded) are then determined for each type of area. The simplifying assumption of circular transmitter coverage is used in the model. The average distances (radii) for each territory type are as follows: densely populated urban 300 m, urban 600 m, suburban 1300 m, and rural 2800 m.

The proposed methodology have been experimentally tested by the contractors and developers over the past 4 years prior to the development of this system.

3.3.5. Non-technical challenges

The most significant non-technical challenge is ensuring consent to datasets and respecting all data protection contexts.

One of the important aspects of the success of the application was gaining confidence in the veracity of the data provided. Only after repeatedly providing evaluated data that demonstrated sufficient accuracy and reliability did the application gain trust. Consequently, secure access for top political representatives was also created.

3.3.6. Evaluation

On-going evaluations were conducted. The most outstanding assessment and comparison results were from the followed three aspects:

A. Total number of non-commuters for the entire pandemic period and new cases of COVID 19
B. Mobility during the district closures
C. International comparison.

Total number of non-commuters for the entire pandemic period and new cases of COVID 19.

The non-commuters did not leave their home cell during the day (200m to 1km depending on the settlement). The difference is compared to the normal 5 weeks before the epidemic. Figure 2 below shows the change of the non-commuters in relation to the average of the new cases of COVID-19. In the first wave around March 29 20120 compared to normal, around 50% more people did not leave their home cell (stayed at home during the day). Currently this is only around 15%.

In the 2nd and 3rd waves a recurring trend can be seen. From the date when the peak of non-commuters occurs (the 5th Nov 2020) in about 3 weeks the number of new cases drops (the 26th Nov 2020). The next peak in non-commuters is the 7th Jan 2021 and the number of new cases is lowest at 31st Jan 2021.

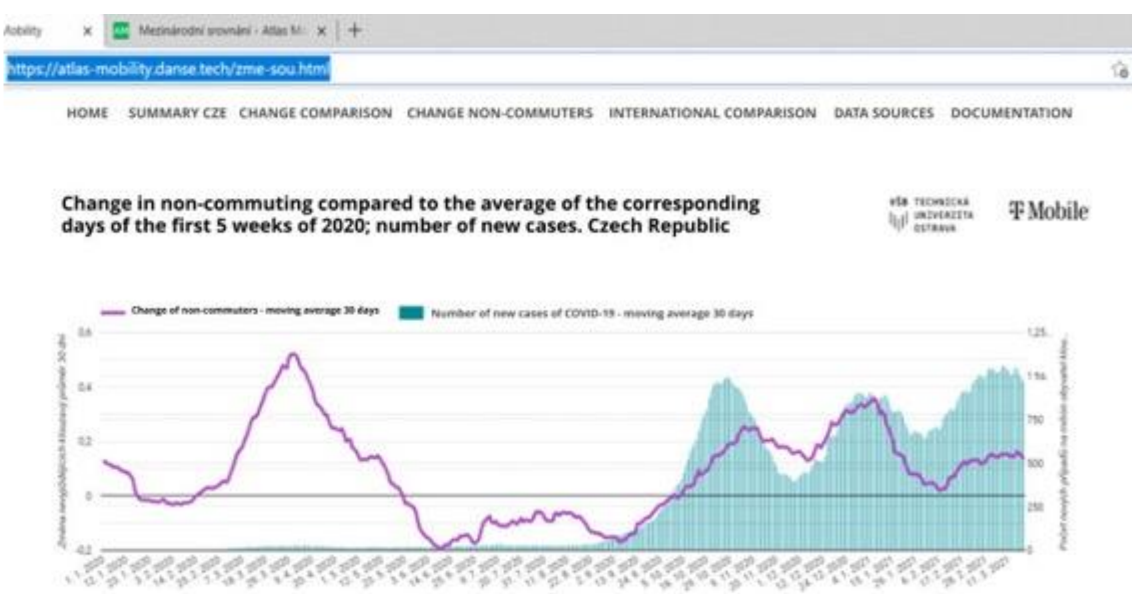

Figure 2: Change of the non-commuters in relation to the average of the new cases of COVID-19

Mobility during district closures

We count how many people left the district on a given day to reach their commuting destination (the place outside their own district where they spent the most time and more than 30 minutes). All relative again to a baseline of 5 normal weeks before the pandemic. A summary is produced separately for weekdays and weekends. Example: -20% of out-commuters therefore means that compared to normal weeks before the epidemic, 20% fewer people are leaving the district.

The graphs are broken down by county and show inter-district mobility within districts within the county and outside the county. Thus, both those who left Ostrava for e.g. Frýdek-Místek and those who left Ostrava for e.g. Prague East are counted in one graph. Intra-district mobility is not captured in these graphs.

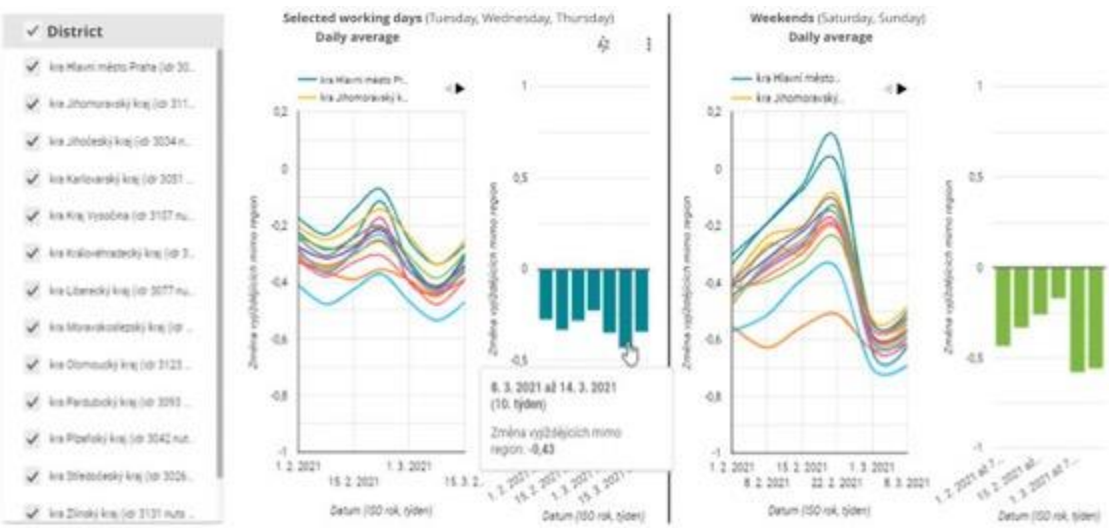

Figure 3: The graphs of inter district mobility within districts

International comparison

There is also an interesting international comparison tab at this link https://atlas-mobility.danse.tech/mez-sro.html. There users can clearly see to the comparison between Czech Republic people and Germany after the release of measures before the Christmas holidays (Change in residential areas - similar to our non-commuters). For example, Figure 4 below shows that since the 10th Nov 2020, we have slacked off for a month (people stopped staying at home) and our non-commuters have not recovered. During the same time period, the Germans have consistently stayed at home and the number of people not leaving the house increased.

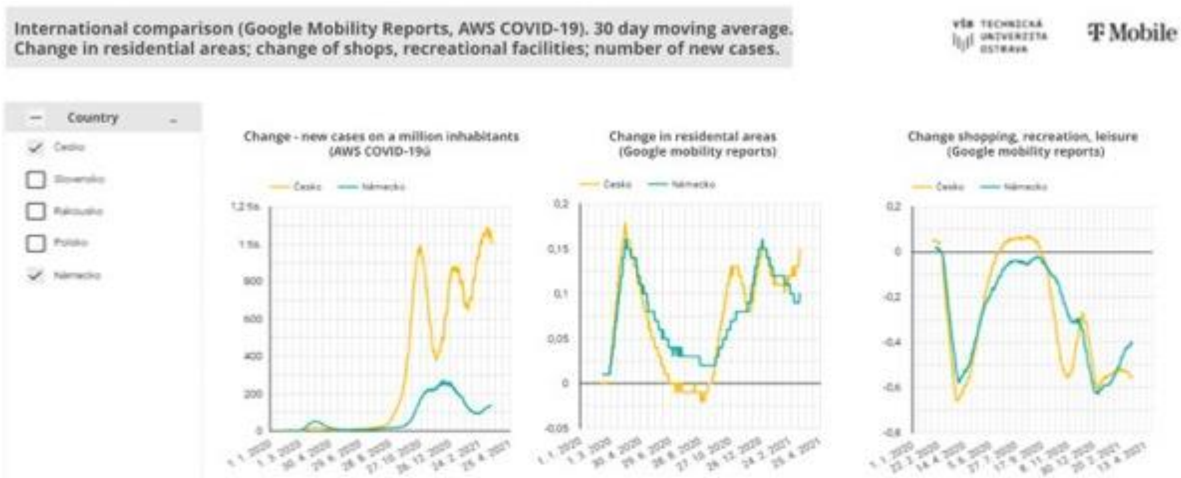

Figure 4: The graphs of international comparison

3.3.7. Future

Further use of the module is expected in the future, especially with the evaluation of the mobility of people from different perspectives. In particular, the following use cases are currently under development:

- A comparison of the use of public transport versus traffic;
- Modification of population mobility trends in response to various stimuli (local rule changes, new timetables, major transport infrastructure repairs, etc.);
- Integration of traffic detector data to investigate the potential of virtual detection techniques in individual traffic;
- Counting passengers in public passenger transport.

Further information:

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3.4. Case Study 4 – Artificial Intelligence to Optimize Traffic Flow at Signalized Intersections (Germany)

3.4.1. Description

The German KIVI (artificial intelligence in the traffic system of the city of Ingolstadt) project aims at a multimodal optimization of the traffic control as well as traffic safety in Ingolstadt (Germany) using AI approaches with high-precision traffic detection via stationary and mobile sensor systems. The stationary sensing consists of LIDAR and camera detectors as well as inductive loops, whereas the mobile sensing is mainly done my floating car and floating bus data, cyclists and pedestrians equipped with a tracking app as well as several camera drones as high observers for trajectories. For the multimodal optimization of traffic flow, local signal plans at intersections as well as the coordination of consecutive intersections will be adapted according to the city-wide traffic state. In Ingolstadt, the considered multimodal traffic consists of cars, buses, bicycles, and pedestrians. The project runs from Q4 2020 until Q4 2023 and is meant to bring the multimodal traffic control in Ingolstadt onto a new level using the potential of artificial intelligence.

3.4.2. Objectives

- Demonstration and enhancement of the potential of AI for multimodal traffic control and traffic safety at signalized urban intersections.
- Evaluating the potential of AI for traffic data fusion as well as traffic state estimation and prediction for traffic control.
- Extending the range of AI methods applied in traffic engineering (network planning, traffic management).
- Expected benefits of this project are an enhanced traffic efficiency and traffic safety for all modes of urban transportation compared to common traffic control methods.
- Transferability of the proposed methods to other cities and municipalities.

3.4.3. Technical challenges

- Planning and implementation of a high-definition test field, which comprises three heavily loaded intersections, which are located in the planned 5G test field in the city of Ingolstadt.
- Real-time fusion of various data types (stationary and mobile sensor systems) and different traffic modes / road users.

3.4.4. Non-technical challenges

- Fulfilment of the European and German legal requirements concerning data protection and safety.

3.4.5. Evaluation

Survey about objectives for network control that authorities usually apply in practice.

- Evaluation using simulation (simulating multi-objective and multimodal traffic control).
- Implementation of the proposed methods in a field test.
- Offsite and onsite implementation of traffic pattern recognition algorithms.

- Expected results are a multimodal, AI-based network control system for traffic harmonization and early warning systems for the occurrence of critical traffic safety situations (especially for vulnerable road users).

3.4.6. Future

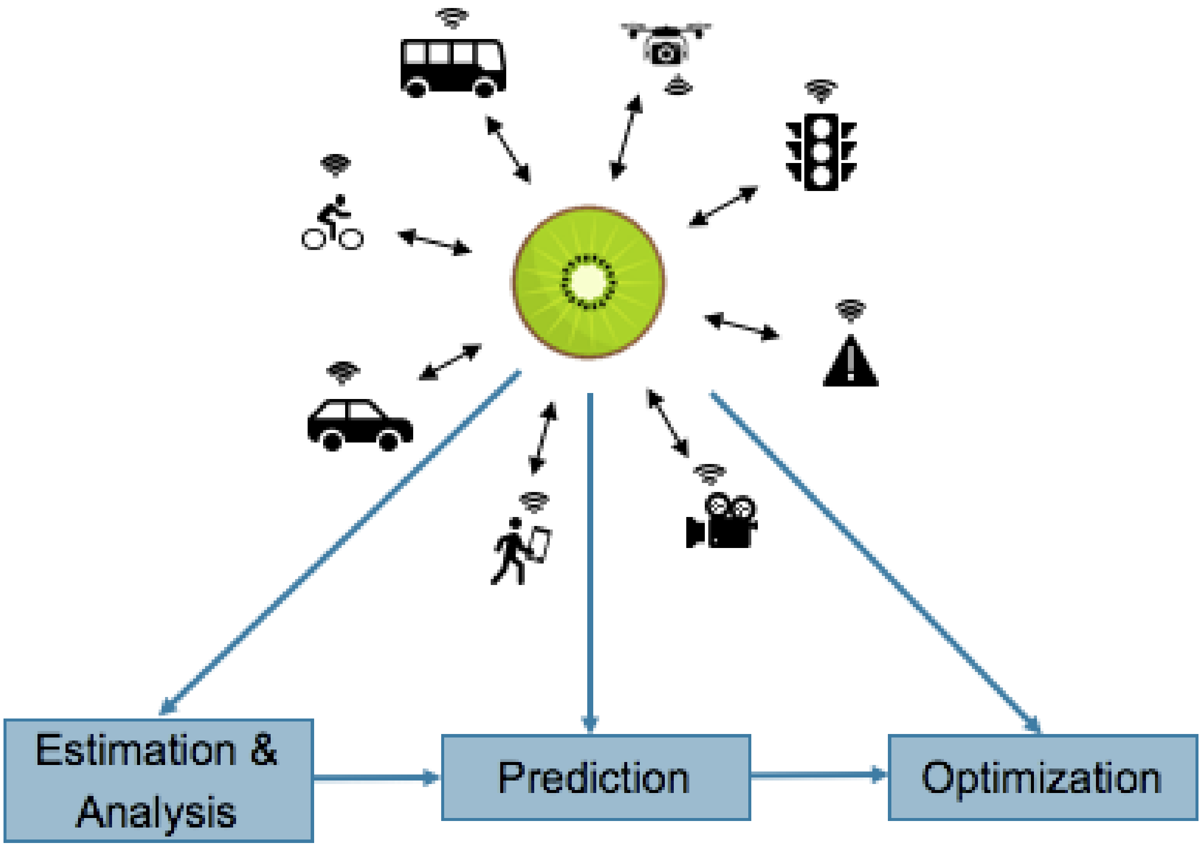
- Derivation of recommendations for cities and municipalities:
- to implement AI methods into local and network-wide traffic control tasks.
- to coordinate control actions for different transport modes.
- to plan detection equipment upgrades with applications of AI methods in mind.

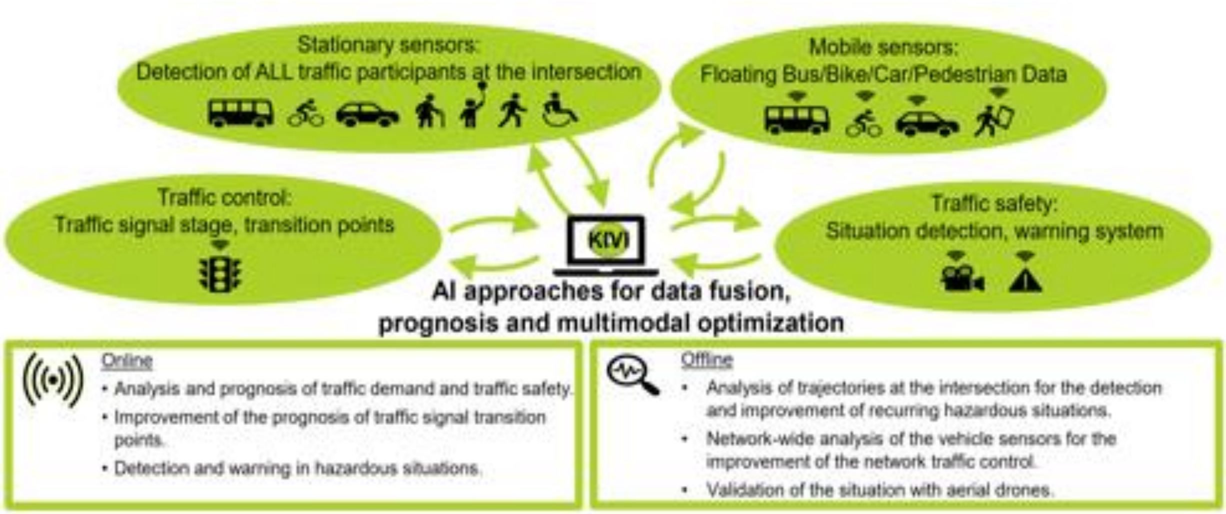
Further information

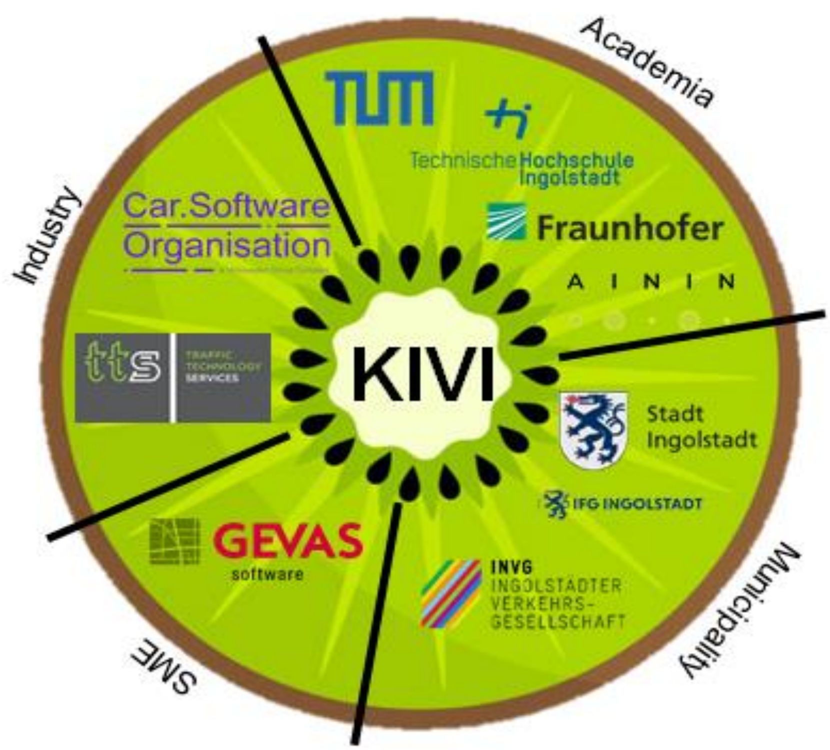
Contact: https://www.bgu.tum.de/en/vt/staff/mitarbeiter/margreiter-martin/

Further read: https://www.bgu.tum.de/en/vt/home/

Visual Content




Stationary sensors:
Detection of ALL traffic participants at the intersection
Mobile sensors:
Floating Bus/Bike/Car/Pedestrian Data
Traffic control:
Traffic signal stage, transition points
KIVI
Traffic safety:
Situation detection, warning system
AI approaches for data fusion, prognosis and multimodal optimization
Online
• Analysis and prognosis of traffic demand and traffic safety.
• Improvement of the prognosis of traffic signal transition points.
• Detection and warning in hazardous situations.
Offline
• Analysis of trajectories at the intersection for the detection and improvement of recurring hazardous situations.
• Network-wide analysis of the vehicle sensors for the improvement of the network traffic control.
• Validation of the situation with aerial drones.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Fraunhofer
AININ
Industry
Car.Software Organisation
tts
TRAFFIC TECHNOLOGY SERVICES
KIVI
Stadt Ingolstadt
IFG INGOLSTADT
GEVAS software
INVG INGOLSTÄDTER VERKEHRS-GESELLSCHAFT
SME
Municipality

3.5. Case Study 5 – Victoria Department of Transportation Data Fusion Prototype (Australia)

3.5.1. Description

The Victorian Department of Transport (DoT) is developing a Data Fusion Model to support the development of a sustainable road network performance reporting system. Data fusion will involve several processes to map STREAMS, SCATS, Bluetooth and other traffic data sources to a baseline road network model, perform data quality and sanity checks and select the best data sources to measure performance under varying traffic conditions.

These data fusion processes will ensure the best data is used to develop performance metrics, based on traffic speed, flow and travel time, and provide confidence in the measures reported in the sustainable network performance reporting system. The latest data from all sources will be imported into the data fusion model on an on-going basis to sustain near real-time performance reporting across the network. This data will then be archived for historic analysis and reporting.

[STREAMS is the Automated Traffic Management System (ATMS) used in Victoria to manage all freeway ITS devices and sub-systems as well as other ITS sub-systems across the broader arterial road network. SCATS is the central, automated and adaptive traffic signals system used to operate all traffic signals across Victoria. STREAMS and SCATS collect, use and store traffic metrics and system operations data. Organisation owned Bluetooth travel time data and 3rd party probe data is also available.]

3.5.2. Objectives

Current State of Practice

Victoria DoT currently has a lack of consistent network-wide situational awareness, limiting means for measuring and prioritising performance issues for intervention treatments. This is impeding DoT's ability to respond effectively and efficiently to sub-optimal network performance. Limited dashboards make use of some available data but are impacted by sub-optimal data quality (accuracy and completeness).

Large amounts of data are collected and stored from various operational and monitoring systems, however their full potential for monitoring RNO has not been fully pursued. Many processes for using available data has often required development of single or limited purpose tools or processes that may not be available or exposed to groups that may have similar needs. This has often resulted in duplication of efforts and inconsistency in data usage.

Due to the current state of data collection, storage and processing, there has been a lack of a single, reliable source of truth. Data across different systems is not necessarily related or comparable. There has been a standing risk that assessments, advice, or actions by different parties using different data for the same intended purpose, could result in different or potentially even conflicting outcomes, although legitimately based on the data utilised.

Proposed Future State

Development of a sustainable network performance reporting system, reporting on high integrity data that has been passed through processes within a data fusion model to ensure data quality, completeness and fit for purpose, should provide VicDoT with the ability to monitor current and past performance across all parts of the road network, thus providing the network-wide situational awareness VicDoT needs to effectively and efficiently manage the state road network.

Data fusion goes a step further than data integration. While data integration is the process of combining data from different sources into a single, unified view, data fusion is the process of integrating multiple data sources of similar metrics to produce more consistent, accurate and useful information.

Initial scope of the project is to principally support reports requiring Speed and Volume measures. Extended scope for future requirements would enable support for other data / measures. At all stages of development, the system would not constrain the ability to combine data automatically from a range of different sources.

The proposed system would provide a more reliable source of truth that is available across all business units to ensure consistent use of a common data set. The system would also form the basis for analysis to be undertaken in combination with other related data sets (e.g. traffic assets, maintenance records, public transport data etc.) to get a full understanding of cause and potential effect.

Key Proposed Outcomes

- Reports using the data model are more accurate and have better coverage than any other single data source.
- Improved quality of traffic status reports supports:
- Better management of road network
- Better measurement of benefits of operations
- Better measurement of impacts of projects – before, during and after implementation
- Methods developed could also be used for real-time data, leading to:
- Better operations and traveller information (Variable Message Signs (VMS), navigation systems, etc.)
- Better incident identification and management
- Data traceability features inform investment in data sources for optimal data quality and coverage outcomes.

Key System Principles

- Sustainable – able to provide reporting on an on-going basis
- Scalable – able to expand from minimum viable product area to entire metropolitan network
- Extensible – able to iteratively add on new functionality and reporting features
- Reliable – quality data inputs producing quality reporting outputs
- Robust – system computes fast and does not break

Key Reporting Principles

- Interpretable – able to evaluate all measures as either poor, acceptable or good
- Comparable – able to compare with previous reporting periods to assess change in performance

- Meaningful – able to provide insights on performance issues to inform interventions
- Fit for purpose – strategic, tactical or operational purposes

Key Input Considerations

(Identified through findings from other jurisdictions and internal investigations)

- There is no single "best" traffic data source – all sources have strengths and weaknesses, in accuracy and reliability, based on the way the data is collected and the conditions at the time it was collected
- The "best" data measure is determined from an intelligent fusion of multiple sources using different technologies
- Different sources reporting differing speeds can be legitimate. Understanding strengths, weaknesses and measurement bias of different technologies helps to resolve these differences.
- The best data sources for fusion include quality measures and are not pre-filtered.
- Intelligent data fusion needs traffic flow and density data. Currently this needs roadside sensors.
- Cooperative-ITS (C-ITS) data offers the potential as a superior data source for some purposes, but critical mass will need to be achieved before it can replace roadside sensors.
- Evaluating and using data quality measures will be increasingly important to resolve differences in measures to determine a "ground truth".
- Probe data sources that include 'confidence' or 'sample count' are more useful and have better coverage than those that exclude low sample count data.

Key Steps in Data Fusion

Table 1: Steps in the Data Fusion Model

Step	Description	Activity
1	Establish baseline road network	Chose a network model to be used as the foundation of the reporting system. All data collected by the system will be "attached" to the objects in this model.
2	Import data	Import the raw data from various sources into the data fusion system.
3	Map each measurement onto baseline network	Identify the relationship between the section of road that each source system measured and how it is represented in the baseline network.
4	Perform data quality / sanity checks	Check all imported data to ensure that the data is of suitable quality. Only data of acceptable quality is used in the data fusion process.

5	Identify strengths, weaknesses & bias of each source	Seek to understand the specific nature of each data source so that understanding is gained on when each is the most accurate source of data. This informs the business rules used in the data fusion process.
6	Fuse available data that passes all quality tests	Determine the measures which most accurately represent the traffic conditions present on each
7	Patch missing data by deriving a "best estimate" value.	Fill in the gaps in the data by derive a value using data from adjacent links, adjacent time periods and statistical profiles.
8	Log method used to derive all data.	Provide full traceability of the data published, identifying which data sources and algorithms contributed to the results.

Figures 1 - 3 below illustrate some of these steps and key data input considerations.

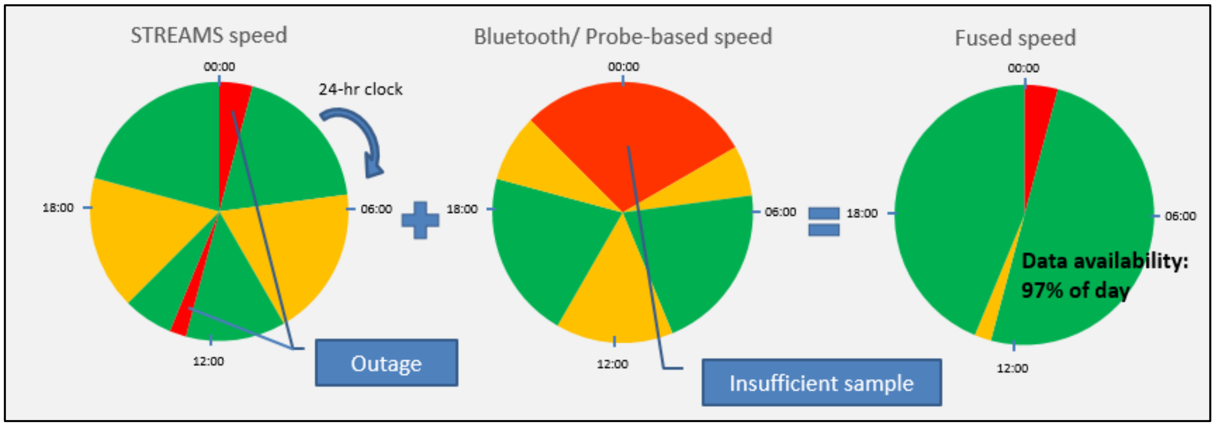
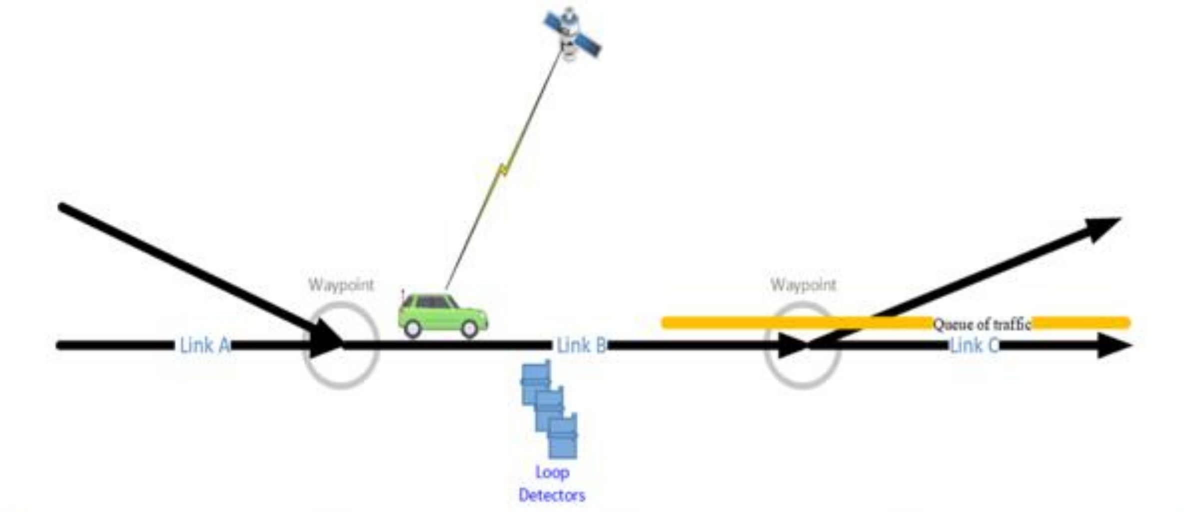
- 

Figure 1: Overlaying Multiple Datasets Improves Data Coverage and Quality



Data source / Traffic conditions	Roadside sensor data	Point-to-point sensor data	GPS-tracked vehicle data
No traffic	Best data	No data	No data
Light traffic	Best data	High risk data	High risk data
Medium traffic	Good data	Good data	Good data
Heavy traffic	Good data	Good but delayed data	Best data
Jammed traffic	Limited data	No data	Best data
Rapidly varying traffic	Good data	Good but delayed data	Best data

Figure 2: Selection Matrix for Identifying "Best" Data

Within Figure 2, speed and flow measures can both be impacted and assessment of data quality is based on a few considerations including:

- the sample size (or vehicle count) available within measurement periods due to the measurement method,
- the timeliness of receiving the data and its representativeness of the measurement period (or real-time condition) due to the measurement method, and
- the impact of the prevailing traffic state on measurement accuracy due to the measurement method.

For example, when traffic is jammed:

- the accuracy of roadside sensors can be impacted by undercounting (sensor detection zones remain constantly occupied due to small gaps between vehicles)
- point-to-point sensors do not measure sufficient completed trips within the measurement period due to lack of vehicle progression across the measurement segment.

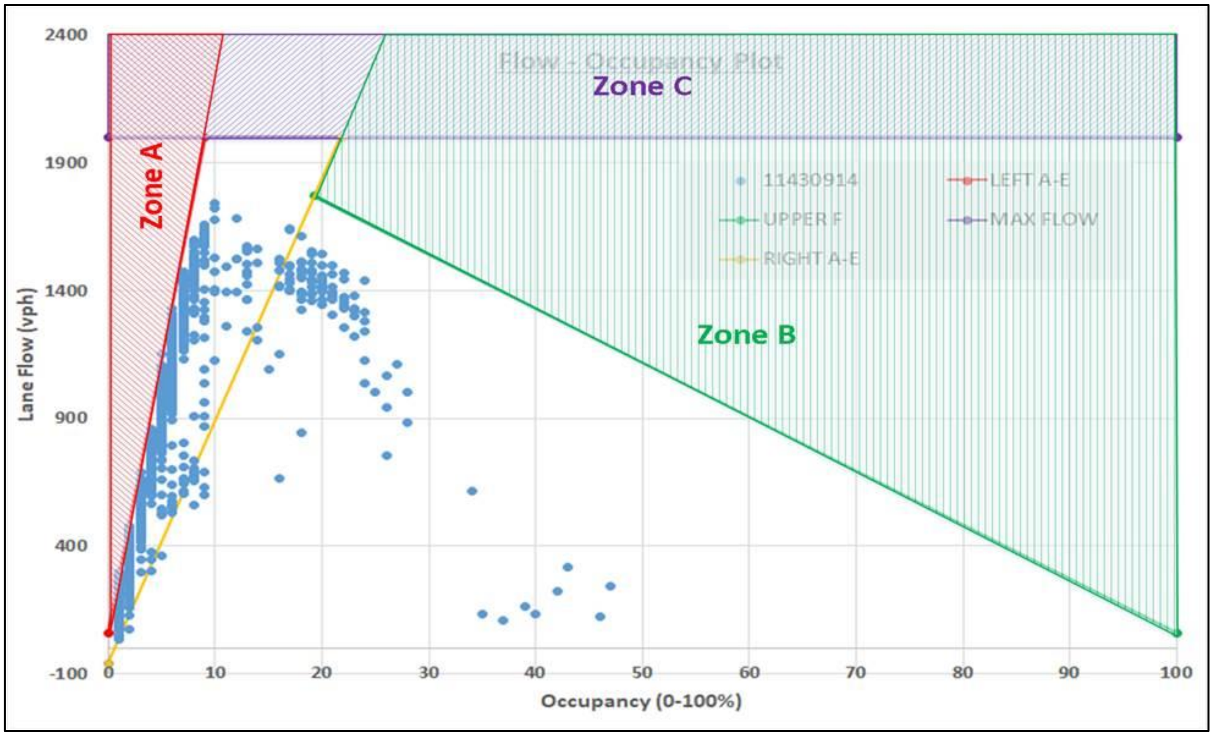


Figure 3: Example of Data Filtering in the Fusion Process to Remove "Bad" Data for Freeways

Prototype Development

At the time of developing this case study, a prototype implementation utilising historic data had been pursued.

- The prototype represented a sub-section of the road network. This area of the network was representative of the wider network, containing samples of all road types to cover all scenarios.
- The prototype was developed on the existing Azure based "Traffic Analytics Platform (TAP)" to enable access to data from the various pre-existing systems.
- The prototype utilised 3 months of historic data.

While the fully featured reporting system is envisaged to report on a wide range of performance indicators, including public transport and safety, the prototype initially tested the ability to use the SCATS, STREAMS and AddInsight Bluetooth data to report the following key network demand and operational performance indicators:

- Vehicle Kilometres Travelled (VKT)
- Average travel speeds
- Average travel times
- Travel time reliability
- Productivity (flow x speed)
- Traveller efficiency
- Congestion indicators

Refer to Figures 4 and 5 below for illustrations of the data fusion and flow concepts and methodology for incorporating them into the prototype.

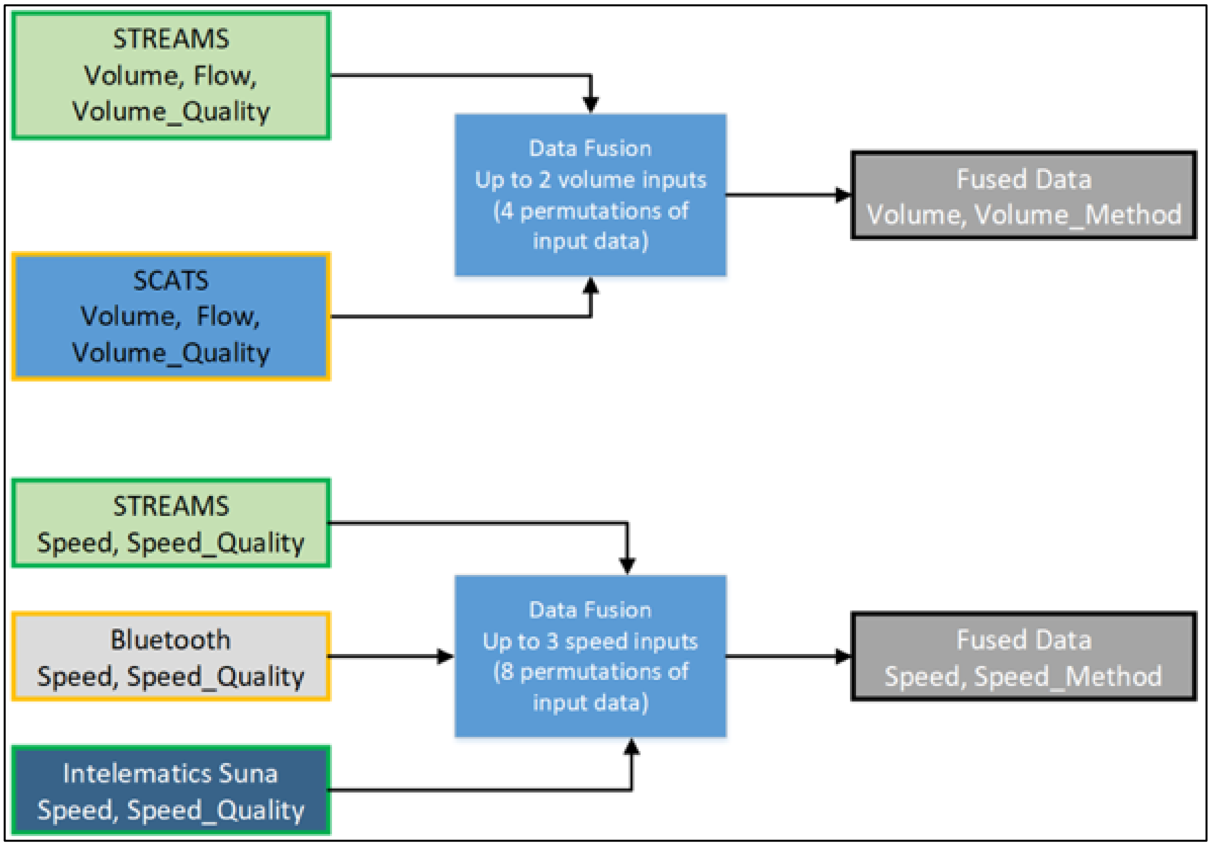


Figure 4: Concept Diagram for data fusion path to produce Speed and Volume measures

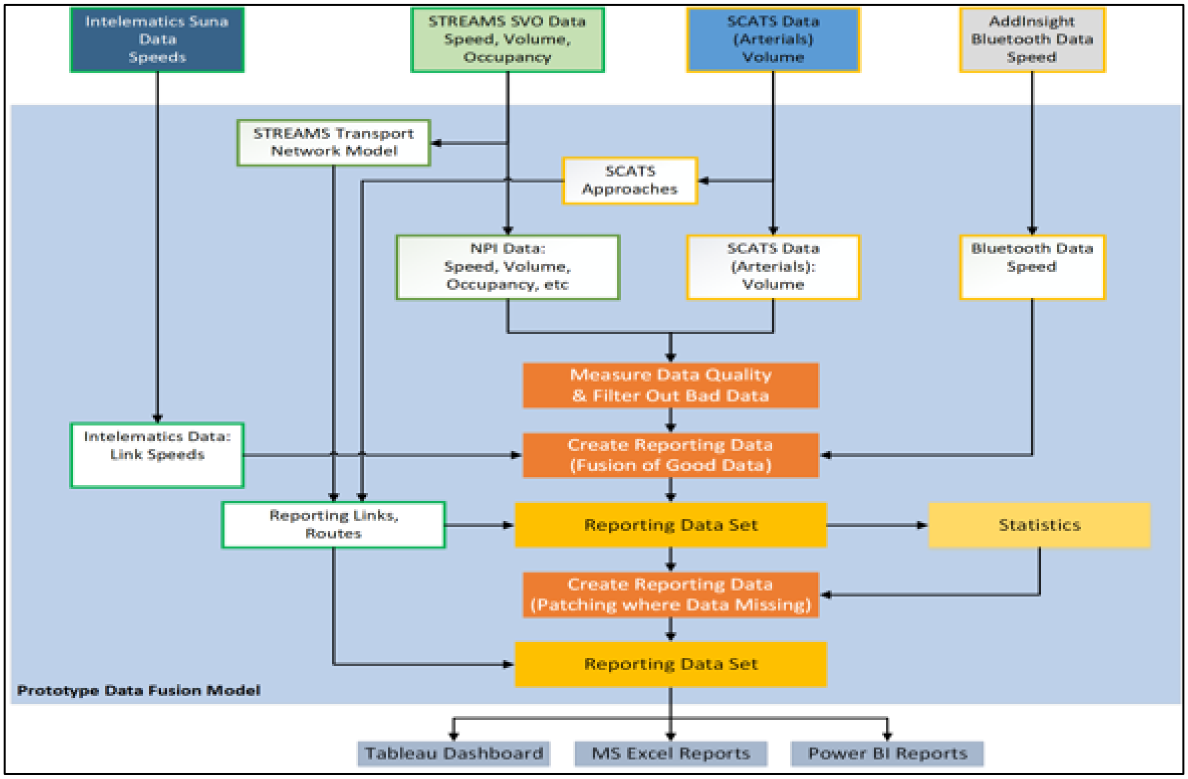


Figure 5: Prototype Data Fusion Model – Data Flows

3.5.3. Technical challenges

Variations in Data from Various Data Sources

Table 2: Difference in some of the characteristics in the data utilized in the Data Fusion Model

	STREAMS (Freeway)	SCATS (Arterial)	Bluetooth Point to Point (Arterial, Fwy)	SUNA GPS Probe (All Road Types)
Measures	Speed, Volume	Volume	Travel Time - Speed	Travel Time - Speed
Granularity	Lane	Lane / Movement	Intersection	3rd party defined waypoints
Frequency	20sec	5-15min	5min	15min

[10] SUNA GPS Probe Data is provided by Intelematics, an Australian based company collecting GPS probe data across major Australian and New Zealand urban centers. Real-time and historic travel times and speed data on road links are available. SUNA Data is also published to various in-vehicle navigation systems to provide real-time traffic information.

Sample	All detected	All detected	> 3 / period	Unknown
Bias	Nil	Nil	Unknown	Fleet Veh
Transparency of aggregation	Open	Open	Known methods that can be adjusted	Unknown – some exclusions suspected
Quality assessment at Source	Limited	Nil	Some clustering / filtering	Unknown

Varying Spatial References and Network Alignment

All data sources have independent underlying dedicated network models. As a result, the locations / reference points of measures are not consistent. This requires a process of remapping locational information to a standardised base network model.

Remapping and interpretation of locational information in separate spatial systems can result in errors and misalignment of data to the base network model, requiring cross checking and validation of references and data to ensure sensible results.

Changes to the data source network reference systems can create issues for consistency and robustness of translation processes over time.

Resource costs and efforts are required to maintain and update the base network model. Leveraging a common base network model for multiple uses, with the necessary level of detail, is advantageous.

Other technical challenges

Cloud based computing is required for large scale network fusion – this often comes with cost implications for operating the system. The adopted approach needs to be efficient but without incurring significant costs.

3.5.4. Non-technical challenges

Ownership and access: Access to pre-existing systems – organisational restructuring, system compatibility and system access, especially during transition processes. Some legacy / cultural practices or expectations can carryover through change processes that block or slow necessary access rights and ability to interact with core data systems.

Data procurement: fused model for internal applications is likely to include 3rd party data which can have licencing arrangements between the provider and the purchasing agency. This can limit sharing and transparency. This could result in two branches of outputs from the fusion process (to comply with 3rd party requirements) to enable external sharing which may result in different reported network outcomes being available in comparison to what is utilised internally.

Data Governance - defining and empowering owners / custodians: Who owns and is responsible for the fused output if compiled from data sources owned and maintained by different groups and external parties? It can be difficult to address the challenges as the potential options may not be clear or simple to implement.

Ways of working: The project will result in data solutions for operational practitioners being lead from outside the traditional data management structures within the organisation. This is likely to require additional buy-in from stakeholders to understand and progress unfamiliar changes – extra flexibility and understanding. This also influences the system resources and architecture to suit the operational needs that still have to comply with broader data and system policies etc.

3.5.5. Evaluation

Pre-existing data validation processes were found to be relatively immature. They were able to be applied at broader time scales (e.g. daily timeframes); but dealing in smaller time resolutions (e.g. 15-minute) requires different approaches.

Older methods of aggregation and validation for traffic data were reasonable for understanding typical traffic profiles – e.g. longer time scales for daily, weekly, seasonal purposes. However, it was identified that it was much more difficult for more certainty to be assigned to more detailed data where atypical conditions may be present or data quality is poor. Is the cause of a data anomaly due to atypical traffic condition in the network or due to a system or related technology anomaly?

The processes were found to be good for freeway data but many more challenges were identified when dealing with data from arterial / surface roads.

It was found that although data could be flagged as “valid” it does not imply (and it can’t be assumed) that the data is accurate.

Due to the primary purpose and nature of data sourced from the SCATS traffic signal system, there was little to no data validation associated with the raw input data.

There was limited ability to go straight to production. It was identified that more refinement was required, and the prototype could not just be expanded to a production system.

When fusing, patching and assessing the reliability of flow data, three different levels of remedial action have been identified that need to be developed – each subsequent level being more complex than the preceding ones.

First – substitute missing or poor data with historic data. It is noted that this approach may not be as reliable as desired especially for periods impacted by atypical traffic conditions.

Second – adopt common sense logic rules to patch or correct, such as considering nearby data in space and / or time or utilise complementary data sets with appropriate reliability under the prevailing traffic conditions. There is an underlying assumption that there is no bias in the data utilised.

Third – more complex and/or sophisticated approaches such as using machine learning / specialised algorithms / other more complex processes for both validity and comparison with other sources.

3.5.6. Future

- Adoption of a Data Fusion Model into the production environment based on learnings from the prototype exercise
- Expansion to full Metropolitan Network
- Undertake input data quality assessment to understand confidence limits and correct for data bias (ultimately)
- Segment / re-architect fusion model to provided analysis ready forms of each input data source
- Collection / purchase of additional data to improve quality
- Ongoing refinement of data processing algorithms
- Creation of reporting outputs

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Source: David Johnston, Independent Consultant (davej@its.net.au)

3.6. Case Study 6 – Island-wide Heatmap Analysis of Traffic Trends During COVID (Singapore)

3.6.1. Description

This technical report was a response to the call for case studies to illustrate uses of data from emerging technologies or the merging of new data sources with traditional data sources to measure performance of system and plan improvements to the system. It's submitted under the category of "Road System Performance", to discuss data used for key performance measures related to system performance, comparisons between corridors, and identification of problem areas. This report detailed the traffic trend study of the changes in trip patterns during the various phases of COVID-19 tightening and easing of restrictions in Singapore, through visual representation using an island-wide heatmap.

Data was collected from Intelligent Transport Systems scattered throughout the Singapore road network and provides an insightful understanding of mobility patterns across the island. This study was done across 5 COVID-19 phases (those marked by "*", starting from Circuit Breaker, as illustrated below in Figure).

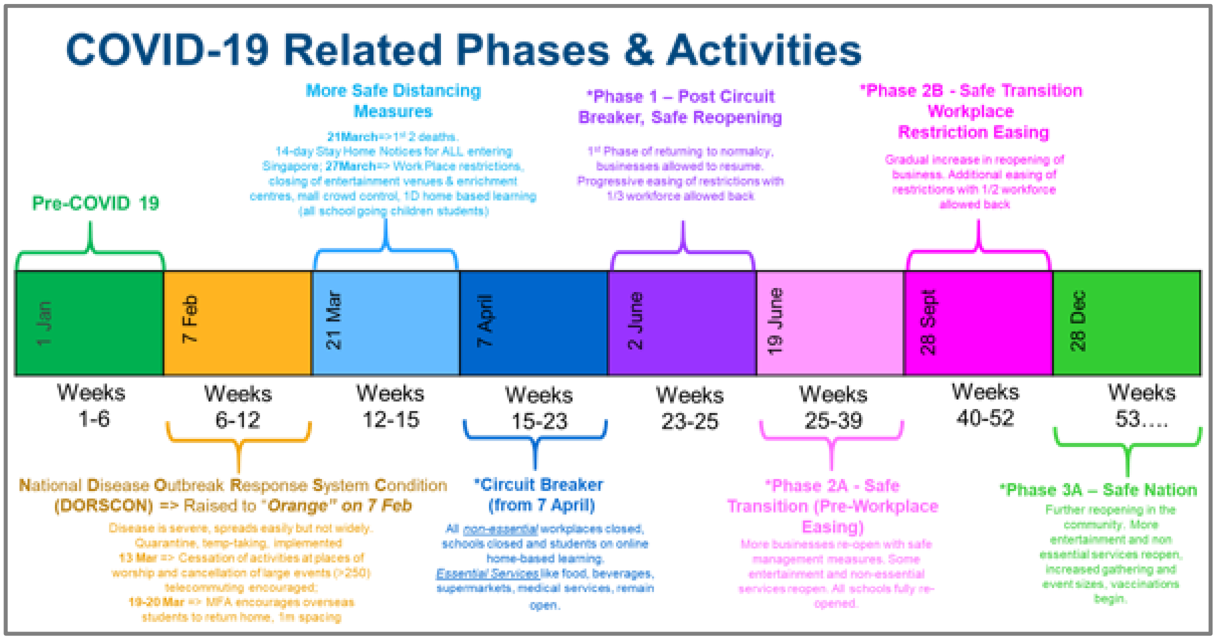


Figure 1: Phases of Measures during COVID

3.6.2. Objectives

When COVID-19 started to impact cities in early 2020, many policy and operational decisions had to be made almost overnight. Strict measures were introduced in Singapore to minimise transmission, and these measures include imposing on companies to restructure their business processes to allow working from home, except for essential services like medical care, specific F&B establishments, supermarkets, public transport etc. Retail malls were closed, and dine-ins were prohibited at the F&B establishments that were allowed to remain open (i.e. take-outs and/or delivery only). In addition, personal trips were also restricted to only essential trips, and the international airport in Singapore, Changi Airport, suffered a huge impact due to global travel restrictions.

This unprecedented COVID-19 situation presented us with valuable opportunities to use ITS to derive traffic insights. We therefore monitored the traffic trends through some of the phases of COVID-19 in Singapore, comparing the various phases of safe distancing measures against the base pre-COVID-19 situation, starting with the phase called Circuit Breaker, which involved the closure of all non-essential workplaces, schools, with all students on home-based learning.

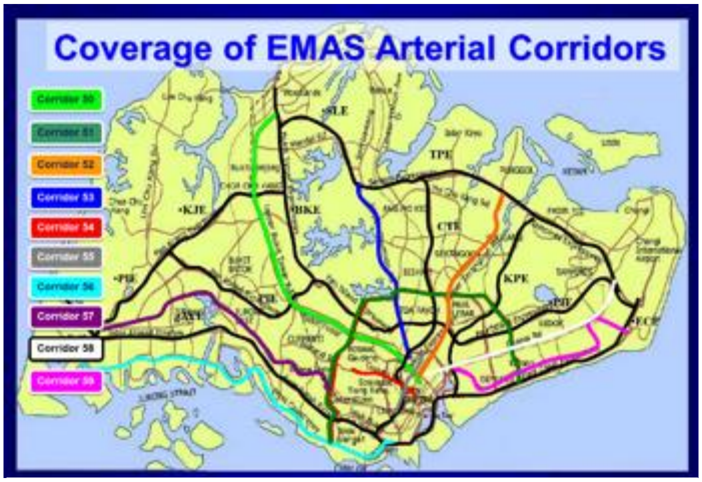


Figure 2. Coverage of the EA system

This level of island-wide visualisation was done for the first time during COVID. This was because Singapore went through several level of Safe Management Measures (SMM), as illustrated by the various phases in Figure 1 above. Each SMM had varying degrees of mobility restrictions, which subsequently had different levels of traffic impact on every part of the island. For example, one can expect that the city centre may have less traffic, but the Authority is also interested to understand the mobility impacts on other parts of the island. To do that, regular charts and line graphs no longer suffice, since those will only capture a snapshot of the average values across the country, or can only reflect a particular road or road category. Visualising the data in an island-wide heatmap, one for each SMM phase, was an ideal representation of the changing mobility trends across the country.

3.6.3. Technical challenges

Integration of Different Data Sources

Our data source for this study comes from 2 main sources:

- **Expressways** data from – Expressway Monitoring & Advisory System (EMAS)
- The EMAS system was implemented as an incident management system, which comprises real-time video surveillance, incident detection and traffic advisory functions. The incident detection function was made possible through a network of detection cameras that have also been programmed to collect traffic data for monitoring and future road planning purposes.
- **Arterial Roads** data from – EMAS Arterial (EA) System, which is the arterial road equivalent of the above mentioned EMAS system. The EA system was implemented on around 142km of arterial roads (**Erreur ! Source du renvoi introuvable.**), at routes of strategic importance within the road network e.g. trunk roads, outer ring road system or linkage to expressways.

- Both the EMAS and EA data was derived through automatic backend video analytics in the central computer system. The source video images come from a total of more than 1700 detection camera from the expressways and major arterial roads. These detection cameras are interfaced to intelligent analytics software which enable the system to derive lane occupancy and presence of stationary/incident vehicles via the virtual loops illustrated in Figure 3 below. These virtual loops are placed on each lane, and focused on strategic locations in the road network. The incident detection ability helps greatly in facilitating the operational work and responses in the Operations Control Centre. As incidents get detected automatically, operators are alerted and can tap into the images of the closest surveillance camera to monitor the accident and assess the impact. This also allows them to speedily deploy special recovery vehicles to remove these disabled vehicles, which served to minimise duration of con gestion to the expressway or arterial road.

Figure 3. Detection Cameras and Virtual Loops of EMAS and EA Systems

- The cameras actually have multiple purposes; in addition to the above-mentioned capability of incident detection and incident recovery, the detection cameras also count the number of vehicles passing through and perform vehicle classification. The system is calibrated regularly to ensure it meets the accuracy and performance standards.
- All of this data is sent at real-time time into a central ITS system, named the i-transport platform. This i-transport platform collects data from the various ITS systems in Singapore, and interfaces with various other applications to serve the various needs of traffic operations, monitoring, maintenance etc. These aggregated vehicle counts (not classified into vehicle types) are the source of the volume data that is being used in this case study.

Methodology

- The traffic volume data from above was therefore accessed through a data portal within the i-transport platform. The data is then further processed and analysed via a custom data processing and visualisation tool. Using this tool, data was aggregated into 24-hourly counts across each of the COVID SMM periods.
- The volume collected from each of the systems was presented in different formats, data dimensions and different levels of aggregation. The study premise was to combine the 2

data sources so as to present the trends as a holistic island-wide impact across the 2 road categories. Whilst this was eventually achieved, there are 2 challenges in the journey:

Data size

- The amount of data being studied was across each phase of COVID-19 restriction measures, where some phases could span across 3 months of data. The data sets being downloaded thus had to be split up into different smaller data parcels so as to work within the constraint of the download bandwidths, then later union-ed. Processing time took longer than usual, especially since team also went through a data verification process to ensure table unions were done accurately.

Reduced Volume-Band Resolutions

- As the traffic demand on expressways were way higher than on arterial roads, a combined heatmap integrating both expressway and arterial traffic together may not provide an equally representative indication of changes across the road categories. Even though we use percentage (%) change in volume as a measurement indicator, a percentage change of say 10% on an arterial was not equivalent to the magnitude of demand changes corresponding to the same 10% of changes on an expressway. This has to be taken into context when interpreting the data.

3.6.4. Evaluation

These heatmaps were used to trace back the expressways and arterial roads of Singapore as the country moves through the various phases of COVID-19, starting from the Circuit Breaker period (which resembles lockdowns in other parts of the world) to the cautious re-opening in Phase 1, through to the Phase 2 and Phase 3 which was named Safe Transition and Safe Nation respectively. For this case study, we will only selectively focus on Circuit Breaker, Phase 1 and Phase 3, which will cover sufficient variations in the heatmaps and COVID phases to illustrate and showcase their usefulness. Readers will see from the heatmaps how the key areas of Singapore responded in terms of traffic demand, and how this varied across city centres, residential areas, borders and even across arterial roads and expressways. For each map, the colours of the stretches indicated the traffic volume of that phase as a *percentage (%) of the pre-COVID-19 volume*. The specific areas/zones on the map being discussed were boxed out and labelled to correspond to the numbering within this report. Arterial data points were in clear dots, whilst expressway data points were represented in smoother links.

Circuit Breaker Period (7 April – 1 June 2020)

The general traffic volume on the roads dropped island-wide, as denoted by extensive dark green segments on the heatmap (Figure) as there was large volume reduction compared to Pre-COVID-19 situation. As Singapore entered the Circuit Breaker, both commuting trips and leisure trips were kept

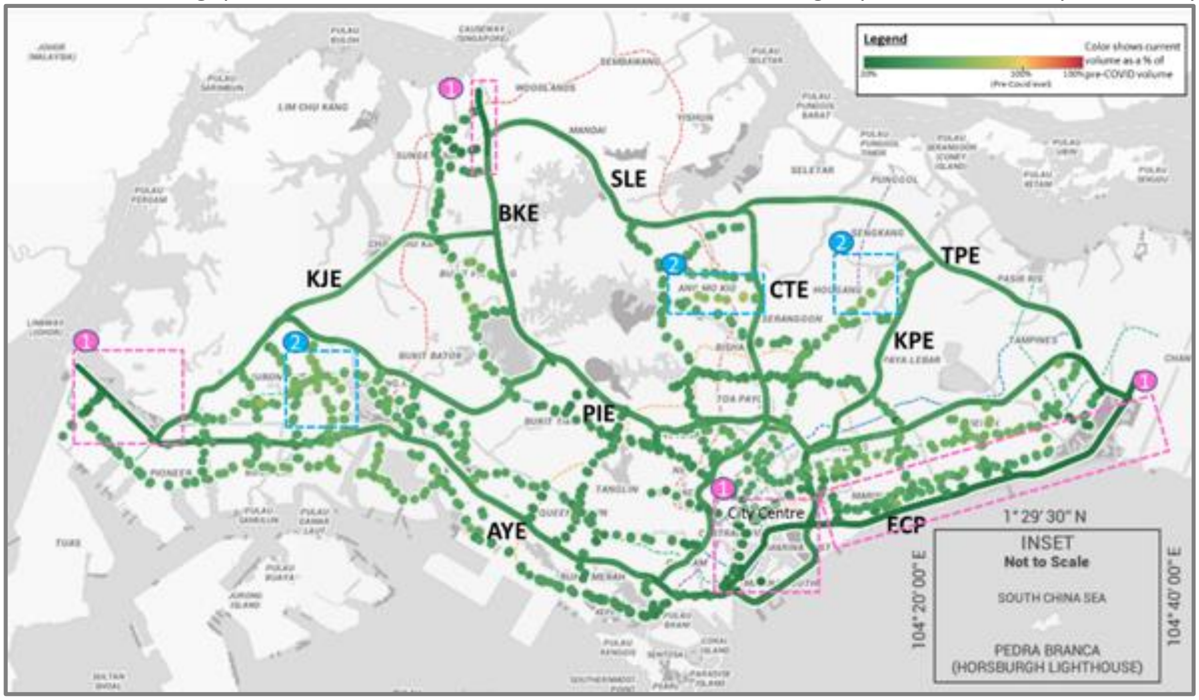


Figure 4. Heatmap of Circuit Breaker (zone numbers in the map correspond to the numbered paragraphs below)

to the minimal. We saw on average, a 58% and 51% volume reduction on expressways and arterial roads respectively, compared to pre-COVID. This meant that expressways and arterials was only carrying 42-49% of the traffic levels it used to before COVID-19 happened and suppressed the trips.

The arterial roads in the city centre experienced large volume reductions as companies implement business continuity plans and the work force started to telecommute and work from home, seeing only 20-40% of the usual pre-COVID-19 volume. The expressways leading to city centre, industrial roads in the west and east also experienced large volume reductions. The % of traffic using expressways ranged from as low as 6% on AYE segments leading to Tuas (western industrial zone) to only as high as 22% of pre-COVID-19 levels. As roads in the Woodlands (north) and Tuas (west) areas were also near border with Malaysia, another reason for the lower traffic volume in these 2 areas were due to restriction of border crossings between Singapore and Malaysia; both Singapore and Malaysia had imposed border control and restrict trips between the 2 countries except for logistics vehicles. Malaysia had also imposed their movement control order since mid-March 2020. Global restrictions on air travel and Singapore's entry restrictions still affect the Changi area where the country's international Airport is, with the large drop in air traffic resulting in lower road traffic in the area.

Residential areas such as Ang Mo Kio, Hougang and Jurong area saw the least reduction; but traffic was still considered low at 77-85% of usual levels; this showed up as light green dots. This represents the essential trips that were permissible, where people circulate and move within their respective residential neighbourhoods. This could be particularly because most of these residential towns in Singapore were largely self-sufficient, equipped with extensive neighbourhood amenities, and essential trips were to purchase meals, grocery run, or by food delivery drivers. The latter had experienced a surge in demand during this phase. In some areas, a few generations of families were also living in close proximity so some of the trips could be care-giving trips to deliver food to elderly parents since this vulnerable group was encouraged to stay home during this period.

Phase 1 Re-opening (2 -18 June 2020)

This was a much-awaited phase after 2 months of Circuit Breaker, with very cautious and slow easing of restrictions where a very small proportion of workforce was allowed to return to work.

As Singapore moved from Circuit Breaker into the Phase 1 of the phased reopening approach, more employees returning to offices and gradual re-opening of schools had resulted in some traffic demand returning. The general expressway traffic volume reduction was still denoted by green stretches (Figure 5) and on average, the traffic levels on expressways and arterial roads were now around 65% of pre-COVID-19 traffic levels.

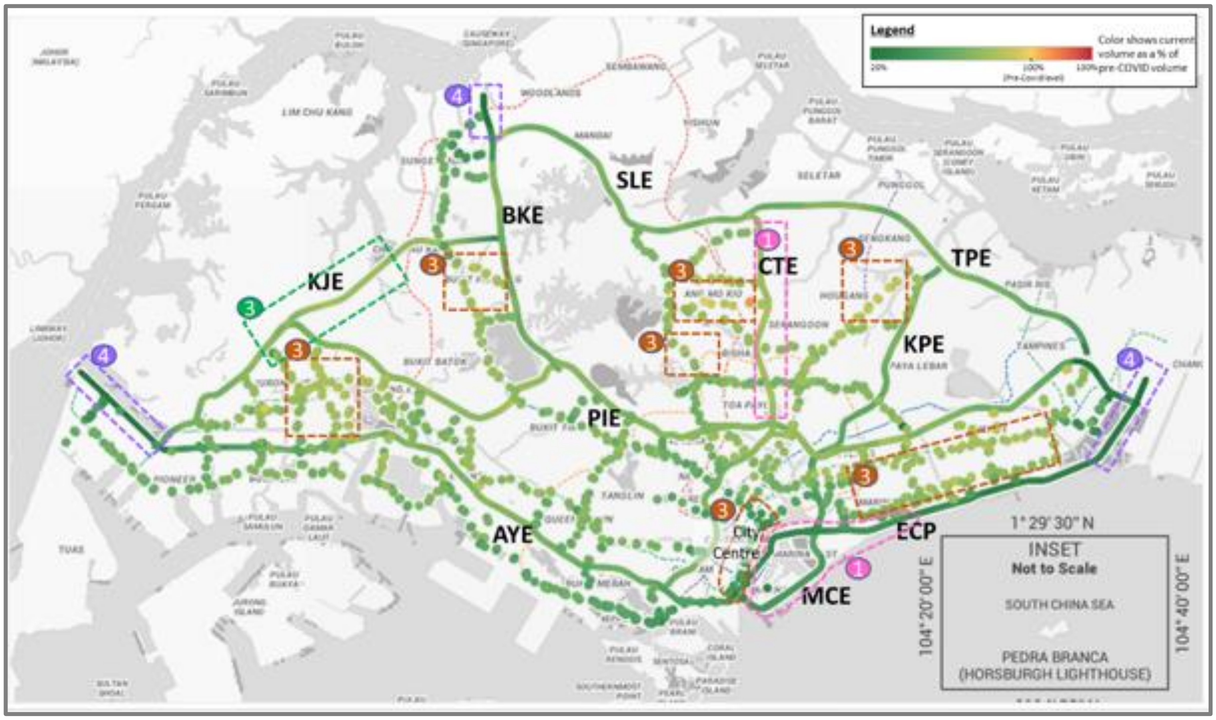


Figure 5: Heatmap of Phase 1 Re-Opening

Expressways heading to the city centre however, such as the MCE and ECP, were still at 30% of pre-COVID-19 volume, denoted by dark green stretches leading to the CBD. The CTE being a major expressway serving the majority of the north-south trips through the island had attracted significant traffic demand, and was now already 70-90% of pre-COVID-19, because traffic demand returned to this expressway very quickly the moment some parts of the economy were allowed to re-open.

The city centre, denoted by dark green points, still only experience 20-50% of its usual traffic, with only a small portion of the workforce returning. This was due to the fact that many organisations still encouraged telecommuting and the majority of employees had adapted to working from home and were able to continue doing so. This applied to even some parts of the banking sector.

Areas further away from the city centre, nearer to residential areas like Bukit Panjang, Boon Lay, Upper Serangoon Rd, Clementi Rd, New Upper Changi Rd were denoted by lighter green dots showing smaller volume reduction compared to pre-COVID-19, representing more trips that are being made in the residential areas compared to the strict Circuit Breaker period. The roads within Ang Mo Kio residential area in particular seemed to remain attractive and had a smaller volume reduction vs Pre COVID compared to other areas. This was denoted by lighter green, almost yellow dots. This represents more trips being made in the Ang Mo Kio Area, possibly because Ang Mo Kio was a relatively large and dense residential zone and generates more essential trips than others.

The expressway stretches leading to the Tuas (west), Woodlands (north) and Changi areas (east) were still denoted by dark green stretches. As mentioned above, these areas are both industrial and near borders with neighbouring country or near international Airport. As such, they still see a large reduction in volume due to crossing restrictions between Singapore and Malaysia, as well as the global restrictions on air travel.

Phase 3A – Safe Nation (28 December to 4 April)

This was the phase where vaccinations started, more entertainment and non-essential services were allowed to resume operations, and the size of allowable social gatherings was increased from 5 to 8, with households able to receive up to 8 visitors. Religious services and live arts/cultural performances could now allowed up to 250 attendees. Capacity limit for malls also increased.

The general island-wide heatmap (Figure) was now denoted by very light green, more yellow and some orange dots as Singapore moved into Phase 3 of reopening, which contributed to higher traffic demand. We saw on average, that arterial roads had reached 92% of pre-COVID-19, and expressways 97%. More areas have returned to pre-COVID-19 traffic volumes and have slightly increased traffic volumes compared to pre-COVID-19, showing up as more orange dots.

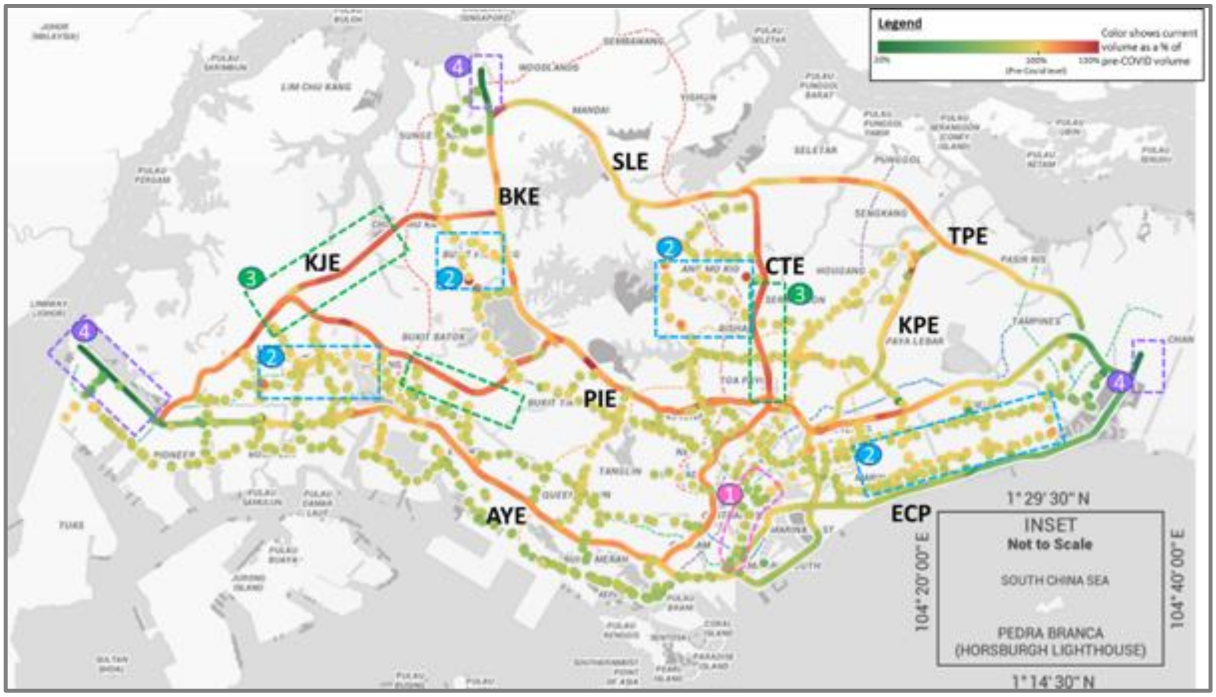


Figure 6. Heatmap of Phase 3A

The city centre traffic volume still had yet to return to normal, with up to 30% traffic volume still missing even as more of the workforce gradually return. There was still a portion of the workforce adhering to remote working and telecommuting as a default rather than travelling back to their workplaces, and the city centre showing up mostly as light green dots.

Roads in residential areas like Bukit Panjang, Boon Lay, AMK, Thomson Rd, Upper Serangoon Rd, and Upper East Coast Rd are denoted by a mostly yellow and a few orange dots showing that the local traffic volume seemed to be returning to the norms experienced pre COVID-19.

Expressways heading to the industrial area in the west and city centres such as KJE and PIE, with traffic increase denoted by dark orange stretches. This is likely due to the workplace restriction easing with more of the workforce gradually returning. The CTE continues to attract significant traffic demand, with volume continuing to surpass pre-COVID-19 levels, showing up as dark red and orange stretches with traffic increase**.** ERP operations are continually adjusted on the CTE to better manage traffic demand, while ERP was resumed on the AYE.

The expressways stretches leading to the Tuas and Woodlands checkpoint area was still denoted with dark green dots as it still saw a large number of trips yet to return, due to reduced border crossing between Singapore and Malaysia and associated activities. Similarly for the Changi area, which was still low despite the progressive lifting of global travel restrictions.

3.6.5. Future

This type of heatmaps allow us to understand the evolvement of travel patterns in the country and how the transport needs of our residents change during COVID-19. This can form a valuable reference for traffic engineers for problem solving and when implementing schemes, as well as for planners to facilitate drawer plans in preparation for any scenario planning down the road.

Further information

For more information about Singapore's Government's response to COVID: www.gov.sg

For more information about the LTA EMAS system please go to the following links:

https://www.lta.gov.sg/content/ltagov/en/getting_around/driving_in_singapore/intelligent_transport_systems/expressway_monitoring_advisory_system.html

https://eresources.nlb.gov.sg/infopedia/articles/SIP_507_2005-01-05.html

For more information about where the EMAS Arterial have been installed on Singapore's Arterial Road corridors:
https://www.lta.gov.sg/content/dam/ltagov/getting_around/driving_in_singapore/pdf/list_of_major_arterial_road_corridors_with_emas_r2.pdf

For more information about Electronic Road Pricing (ERP)
https://onemotoring.lta.gov.sg/content/onemotoring/home/driving/ERP.html

For more information about i-transport platform, the Operations Control Centre and the various ITS

https://www.lta.gov.sg/content/ltagov/en/getting_around/driving_in_singapore/intelligent_transport_systems.html

3.7. Case Study 7 – Mobility Management in the COVID-19 Crisis During the State of Alarm in Spain (Spain)

3.7.1. Description

The declaration of the State of Alarm[1] in Spain on 14 March 2020, to manage the public health crisis caused by COVID-19, had an unprecedented impact on mobility.

To deal with this emergency situation, extraordinary management measures had to be taken that affected the free movement of people throughout the national territory. During the duration of the State of Alarm, the movement of private vehicles on public roads was restricted to certain activities.

The Directorate General for Traffic established a strategy to guarantee the permitted and appropriate circulation of people and freight transport vehicles. The latter were a priority to avoid shortages of basic goods, health equipment and personal protection.

3.7.2. Objectives

- To fulfil the required tasks, specific objectives and measures were defined:
- Reduce the number of trips made in private cars - State Security Forces and Corps set up controls throughout the road network to enforce compliance with the imposed mobility restrictions and to ensure that journeys in private cars were limited to those permitted: procurement of basic needs; assistance to health centers and the workplace; return to place of habitual residence; assistance and care for the elderly and dependents; and other situations of need or force majeure.
- Guarantee the circulation of freight transport vehicles - Even though the country was virtually paralyzed, it was extremely important to ensure that supply chains continued to operate as normal as possible.
- Preserve citizen support activities - Certain vehicles that contributed to ensure the provision of essential services to the public were exempted from traffic restrictions: roadside assistance vehicles, collection of urban solid waste, or fuel transport; among others.
- Facilitate the smooth transit of freight transport across borders - Border control measures could not jeopardize the continuity of economic activity, more than the emergency situation itself caused. For this reason, the European Commission called for coordinated action to ensure the free movement of food, medicines and protective equipment throughout Europe[2].

3.7.3. Technical challenges

The following are the measures implemented during the period of the State of Alarm and which were adapted to the circumstances, from the initial intensification to the gradual reduction of extraordinary measures in the transitional phases to the new normality.

Mobility management measures

Suspension of movement restrictions for freight transport vehicles

In order to ensure the supply of basic goods, special traffic regulation measures for freight transportation, for certain dangerous goods and for special vehicles were suspended.

Suspension of special traffic control and surveillance campaigns

During the State of Alarm, programmed[3] special traffic control and surveillance campaigns were suspended and efforts focused on monitoring compliance with mobility restrictions.

Internal mobility control

State Security Forces and Corps carried out controls at various road points to monitor compliance with the traffic restrictions imposed. These controls were intensified during periods that, under normal conditions, have a higher number of journeys: weekends, Easter and other festivities.

In order to adequately control the movements of private vehicles on high capacity roads in safe conditions, the Directorate General for Traffic made its resources available to those Security Forces and applied more than 120 support measures daily during periods of greatest restrictions. The measures included signaling material, beaconing, traffic cones and specialized personnel for their deployment.

Image 1. Security Forces and Corps controlling internal mobility

Border traffic control

The necessary mechanisms were put in place to ensure that border controls did not obstruct supply chains. To this end, the monitoring of border traffic was strengthened, and instructions were given to the Traffic Management Centers to alert if retentions were longer than 15 minutes, in order to speed up the established controls and ensure the fluidity of freight transport.

Operational coordination measures and information to citizens

CECOR (Operational Coordination Centre)

Actions related to road mobility were coordinated through the Operational Coordination Center (CECOR), which served as the sole command center for the Civil Guard, National Police, regional and local police, and coordinated with other areas of the Ministry for Home Affairs.

The Directorate General for Traffic actively participated in CECOR meetings and provided information on the evolution, updates and relevant forecasts related to mobility and road safety.

Dissemination of information to the public

During the State of Alarm, the state, regional and local authorities responsible for transport matters had to ensure the dissemination of the measures taken by the Ministry for Home Affairs.

For this purpose, the Directorate General for Traffic used all the available means: more than 2400 Variable Message Signs, radio stations, social networks, the website www.dgt.es and the telephone number 011. Likewise, the information was provided to service providers through the National Traffic and Mobility Access Point (http://nap.dgt.es/).

Image 2. Variable display boards

Mobility evolution indicators

In order to know and understand the traffic evolution as an indicator of social and economic developments, and its possible relationship with the probability of infection, the Directorate General for Traffic carried out continuous monitoring of road mobility using equipment deployed on the roads. As a result of this monitoring, it was able to establish indicators related to road mobility and to track them: the total long-distance movements; the differentiation between light and heavy vehicles; or the evolution of mobility at the approaches to the main cities and at the borders, among others.

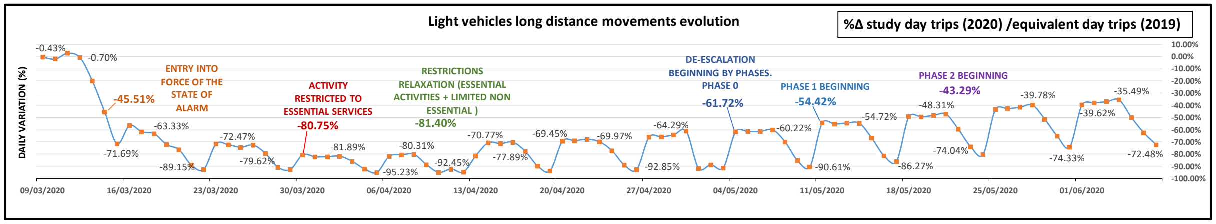


Image 3. Light vehicles long-distance movements evolution

Other mobility evolution indicators

In a parallel and complementary manner, the Ministry of Transport, Mobility and Urban Agenda considered it necessary to analyze the changes that were taking place in the mobility of Spaniards during the COVID-19 crisis, with the aim of generating information that would serve both to evaluate the effect of the mobility restriction measures imposed on citizens and for other analysis and studies that would help in the management and subsequent exit from the crisis.

For this purpose, solutions based on the analyses of massive data were used, using anonymous records from mobile telephone networks as the main source of data. The information from mobile phone networks was merged with other data sources to generate origin-destination matrices and other indicators of mobility and population presence, all of them anonymous and aggregated, ensuring strict compliance with the requirements of LO 3/2018, of December 5, 2018 on Personal Data Protection and Guarantee of Digital Rights (LOPD-GDD)[4].

The main data sources used were:

- Anonymous mobile phone records. The study was based on a data sample of more than 13 million records provided by a mobile operator.
- Land use. Land use data were also used to improve the characterisation and spatial location of the activities identified from the mobile phone data.
- Population data. For the sample elevation processes.
- Transport network data. The algorithms used for trip identification also used information from the transport network (e.g. location of airports, rail network, etc.), in order to refine the distinction between activities and intermediate stops between stages of the same trip.

3.7.4. Non-technical challenges

The collaboration within the different state levels has been crucial during the pandemic crisis:

- Coordination between State Ministries, mainly: Ministry of Transportation, Ministry for Home Affairs and Ministry of Health.
- Coordination between city councils.
- Collaboration between local and state security forces.

There has been a fast coordination and well-defined responses in different pandemic situations.

Safety protocols for state servant personnel have been in place at all times.

3.7.5. Evaluation

The measures listed above achieved decreases of up to 82% in light vehicle traffic on weekdays, reaching 95% on weekends. In addition, until May 31, 2020, the number of traffic fatalities fell by 61% compared to the same period in 2019, and in the period between March 15 and May 31, there were 27 days with 0 deaths (24 hours monitoring indicator).

From May 2020, Spain began a process of gradual reduction of the extraordinary measures to restrict mobility and social contact established in the declaration of the State of Alarm. As this process evolved and mobility restrictions were gradually reduced, some recovery in the number of trips was observed.

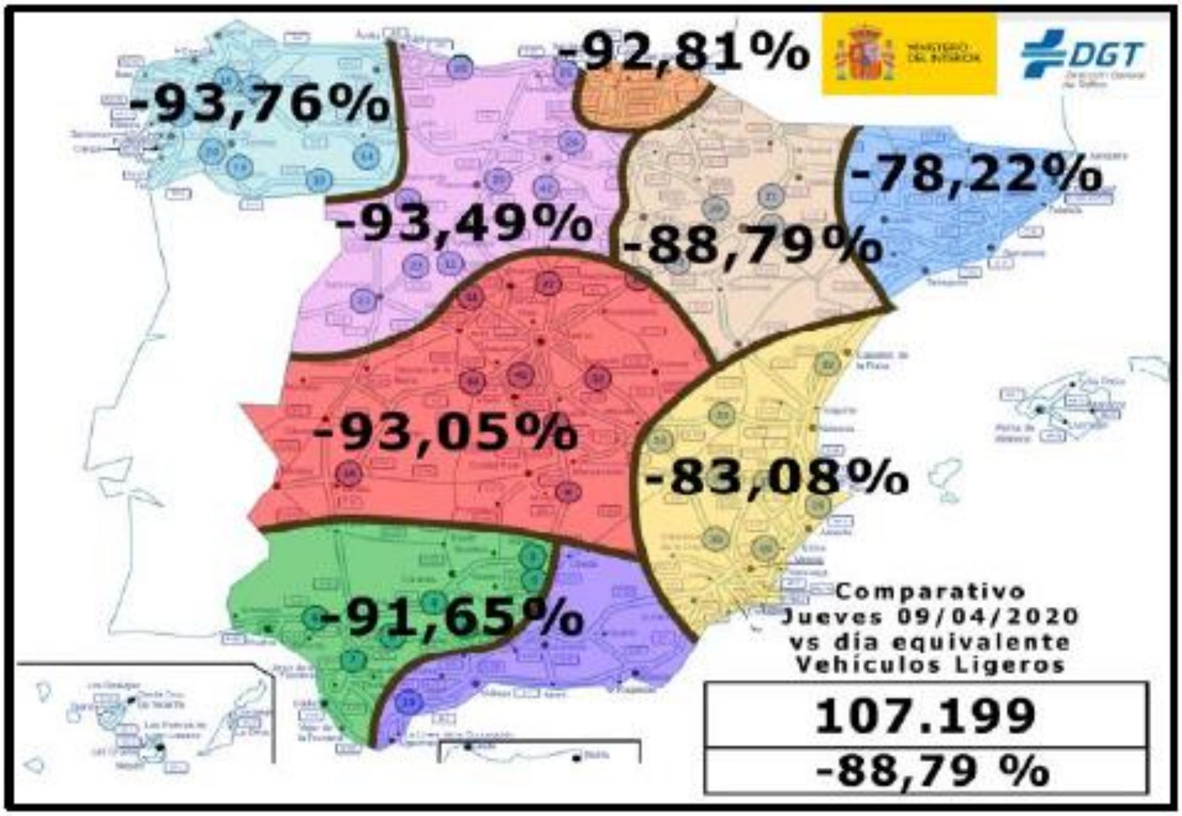


Image 4. Comparison of LIGHT vehicles long-distance movements with an equivalent day

*Including information provided by traffic authorities of **Gobierno Vasco** and **Generalitat de Catalunya.**

During this complicated period, the Spanish population has complied with the necessary restrictions to slow down the progression of the disease, showing an exemplary attitude in terms of responsibility and discipline against very strict measures to limit mobility.

The Directorate General for Traffic has provided all the means available to ensure fluidity and safety on the roads and to assist in the implementation of the measures established during the State of Alarm. The eight Traffic Management Centres with their officers and specialized technical staff provided an essential service 24 hours a day, 7 days a week.

3.7.6. Future

Comparison of long-distance vehicle movements with an equivalent day has been consolidated as a mobility indicator. It is presented as a main indicator for economic post-pandemic evolution process.

This new tool indicator allows governments to predict traffic trends in city accesses, long-distance movements, and the increase of light and heavy vehicles percentage in comparison with the previous year.

References:

[1] *Real decreto 463/2020, de 14 de marzo, por el que se declara el estado de alarma para la gestión de la situación de crisis sanitaria ocasionada por el covid-19.*

[2] *Covid-19 Guidelines for border management measures to protect health and ensure the availability of goods and essential services.*

[3] *Orden int/262/2020, de 20 de marzo, por la que se desarrolla el real decreto 463/2020, de 14 de marzo, por el que se declara el estado de alarma para la gestión de la situación de crisis sanitaria ocasionada por el covid-19, en materia de tráfico y circulación de vehículos a motor.*

[4] *BOE.es - BOE-A-2018-16673 Ley Orgánica 3/2018, de 5 de diciembre, de Protección de Datos Personales y garantía de los derechos digitales.*

3.8. Case Study 8 – Congestion Hot Spot Identification for Optimized Traffic Management Using Automated Pattern Recognition (Germany)

3.8.1. Description

Not only traffic scientists and experts know about the fact that certain sections of roads, specifically freeways, are frequently, even regularly, affected by congestion depending on the time of day. Also, people traveling regularly in individual traffic are familiar with these congestion accumulation points. There are certain time windows – rush hours – when one should avoid being on an arterial road, and also certain regions where the probability of congestion is usually high.

This paper presents an approach that increases the resilience of a freeway network while differentiating patterns of freeway congestion events and investigating hot spots of each pattern both spatially and temporally. Based on an automated pattern recognition, an emerging congestion event can be identified and classified into one of four predefined congestion patterns: “Jam Wave”, “Stop&Go”, “Wide Jam”, and “Mega Jam”. Determining the spatial and temporal extensions of several congestion events, hot spots of each pattern can be localized. Additionally, possible traffic management and control measures are compiled and evaluated by expert statements to mitigate or dissolve the found congestion hot spots.

3.8.2. Objectives

This approach provides a helpful toolbox for freeway operators to classify occurring congestion into predefined categories and to select appropriate countermeasures based on the hot spot analysis to increase the resilience of the overall system. By applying the presented methodology, optimized traffic information is provided to the operator in time-critical situations, which enables an improved decision-making process in traffic management. The data base is large-scale data sets from stationary detectors, vehicle re-identification sensors (Bluetooth) and floating car data collected on a German freeway.

3.8.3. Technical challenges

The methodology works in three steps. First, a spatio-temporally discretized speed distribution is created out of measured data, with grid cells of constant speed values. Coherent cells with a speed value below a threshold, and hence indicate congestion, are combined into a congestion cluster.

Second, virtual trajectories representing simulated vehicles are created, that drive through the space-time domain. Their experienced speed profiles are analyzed according to several parameters. If there is a single short speed reduction, the trajectory is categorized as “Jam Wave”, whereas a long-term stable speed reduction is said to be a “Mega Jam”. If it is neither of these, the number of speed drops below the threshold is counted. A higher number of speed reductions imply “Stop&Go” traffic; a lower number “Wide Jam”. Finally, the congestion patterns of all trajectories are combined in order to assign an overall cluster congestion pattern. Third, the spatial and temporal starting points of each cluster are identified. Analyzing multiple similar time frames, e.g., days of a month, hot spot of emerging congestion can be investigated. The fourth and last point of our investigation involves the search and analysis of different traffic engineering or management measures to resolve the congestion hot spots.

The technical difficulties in the first three steps were that the congestion patterns are not so easy to find in the speed plots. The human eye recognizes our differentiation excellently, in a speed distribution of a day - but to automatize this recognition was not easy. The criteria by which the congestion patterns are assigned must be very well evaluated. For this purpose, we applied a sensitivity analysis of the individual parameters. In the last point, the possible measures against the congestion hot spots, the current difficulty is that: to the best of our knowledge, there are hardly any real-life tests in which various traffic management measures have been tested and analyzed on a road section. We have to look for ideas and possible effects from a multitude of literature and thus from simulative and empirical studies.

3.8.4. Non-technical challenges

The biggest challenge that has emerged in this study is the high-quality data availability. Unfortunately, there are not many freely available datasets that meet the qualitative requirements. It is a benefit to examine several larger data sets from different regions. The methodology is proven to work with the following types of data:

- Speeds from loop detection.
- Floating-car data (FCD).
- Segment speeds derived from low-resolution travel times such as Bluetooth.

3.8.5. Evaluation

Data from one road stretch and several detection technologies are compared with respect to their suitability of identifying congestion pattern. Results show “Jam Wave” hot spots in metropolitan areas, “Stop&Go” occurrences upstream of large interchanges, “Wide Jam” hot spots rather rarely, among other. Further, low-resolution travel time measurements are barely able to detect “Jam Wave” because of their upstream jam front propagation in contrast to downstream travel time matchings. FCD and loop data can be classified reliably. A typical classification of congestion patterns for a German freeway is provided in the visual content.

The TUM Chair of Traffic Engineering and Control is always looking for new data sets to evaluate congestion patterns from different freeways and different countries.

3.8.6. Future

Based on the classification of congestion, the freeway operators will be able to activate tailored traffic operation measures such as detailed dynamic traffic information and early warnings of incidents to drivers.

The analysis of spatial and temporal characteristics of recurring congestion patterns allows for a better understanding, control or even permanent technical or infrastructural measures to prevent or reduce the negative effects of congestion.

Based on the evaluation of congestion patterns, a standardized catalogue of applicable and situation-dependent measures can be developed to be used in a semi-automated or even fully automated control strategy for typical congestion patterns.

Further information

Contact: https://www.bgu.tum.de/en/vt/staff/mitarbeiter/margreiter-martin/

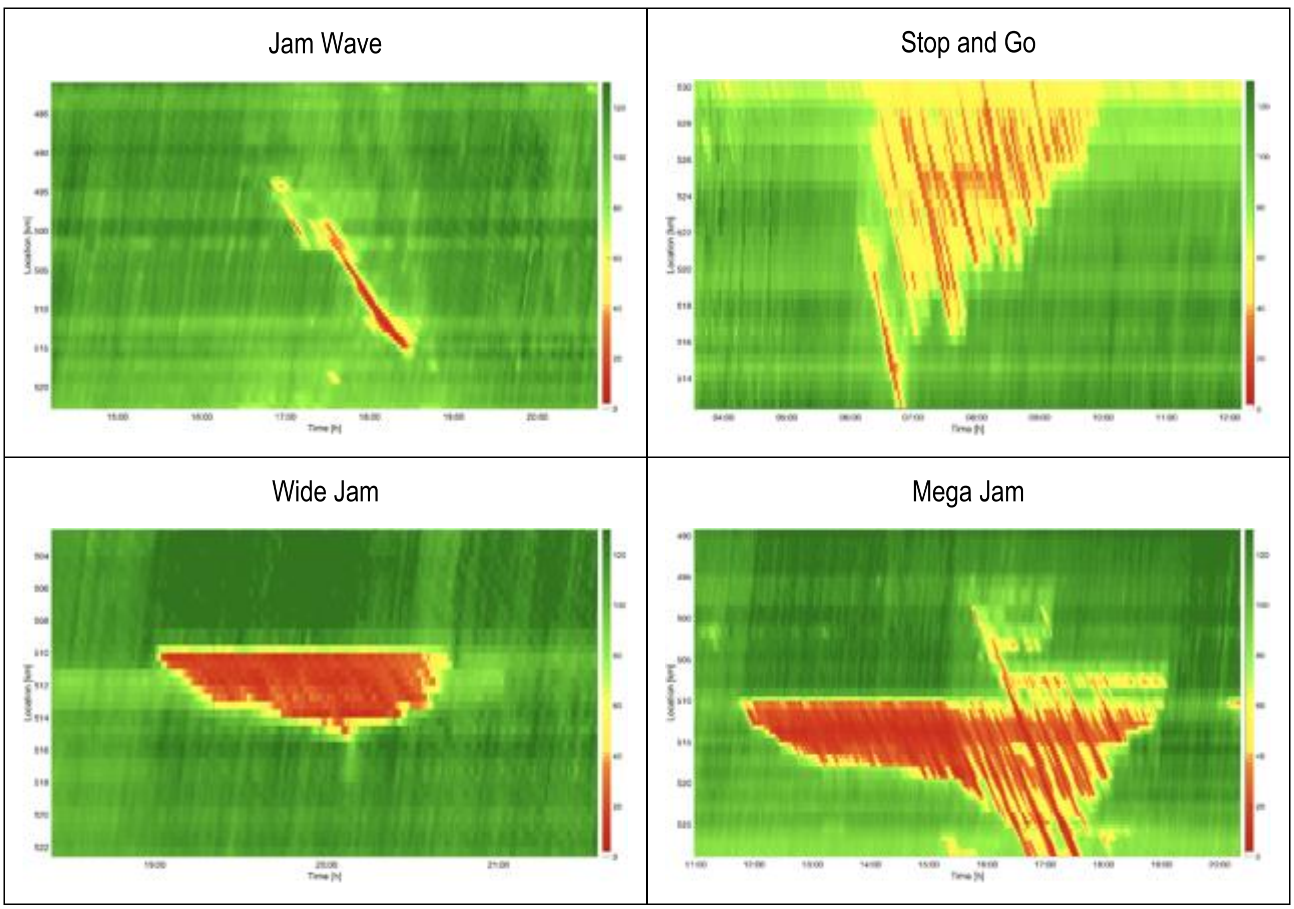
Further read: https://www.bgu.tum.de/en/vt/home/

Publications:

https://ieeexplore.ieee.org/document/8917410

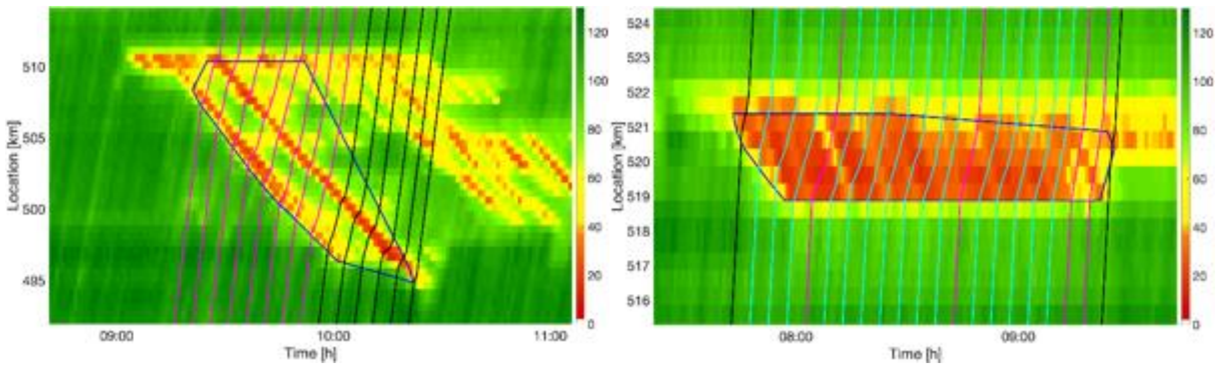
https://ieeexplore.ieee.org/document/9294598

Visual Content Speed contour plots of the four congestion patterns: A Jam Wave corresponds to a single congestion wave, a thin stripe implying a temporarily low velocity. Stop and Go waves are several narrow stripes representing congestion waves separated by free-flow sections. A Wide Jam is a broad area with predominant congestion velocity. An extensive area with the domination of speed values below a velocity threshold is called Mega Jam. It represents a widely spread traffic breakdown. The characteristics can be seen in the following pictures:

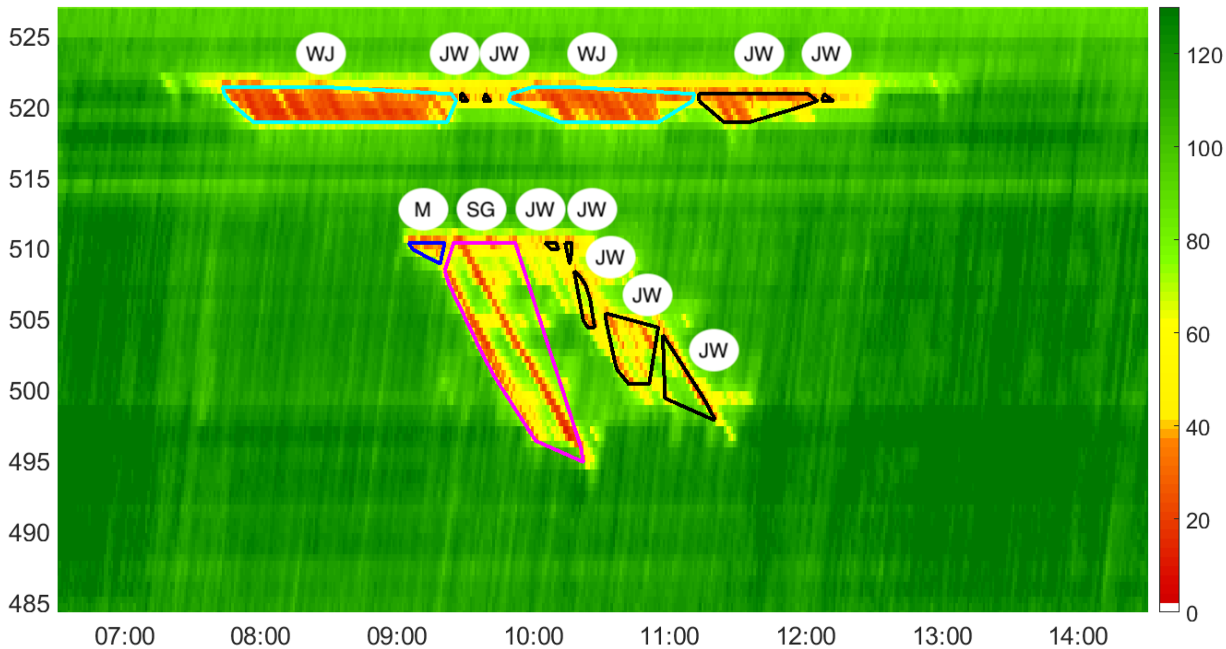


Traversing of virtual trajectories:

In these two figures, the auxiliary step for assigning the congestion pattern to a congestion can be seen as an example. The individual generated trajectories can be seen as pink, blue and black lines. These trajectories are automatically generated and routed through the individual congestion clusters and subsequently their velocity progression over time is analyzed. Depending on the duration and frequency of the velocity breakdown, a congestion pattern is assigned to each trajectory. The entire congestion cluster is then assigned to the congestion pattern that occurred most frequently.

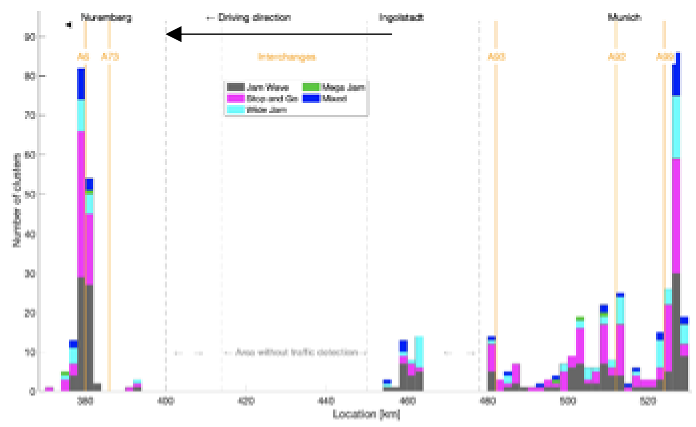


Identification of congestion pattern per cluster in a space-time diagram: In the following figures, the detection and assignment of the congestion patterns can be seen as an example for a part of one day and the examined section of road. Short explanation of the abbreviations: WJ=Wide Jam; JW=Jam Wave; SG=Stop and Go; M=Mixed (not clearly assignable to a congestion pattern).

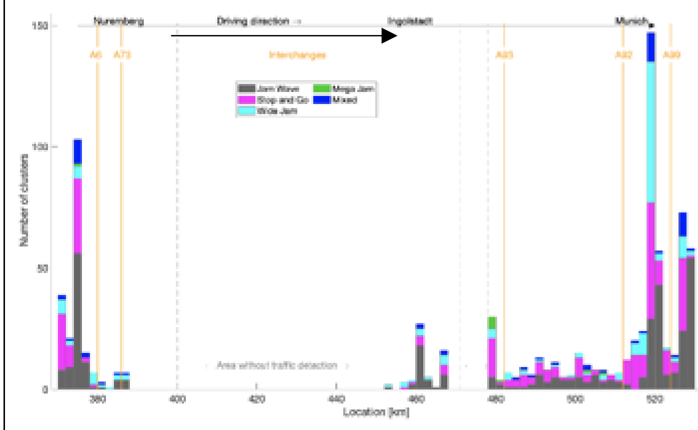


Hot spots of congestion pattern in a space-time domain of the different data sources: Stationary Detector Data (SDD); Floating Car Data (FCD); Bluetooth Data (BT):

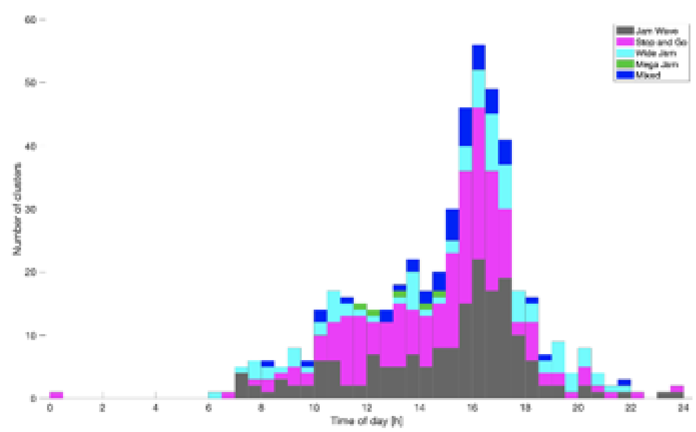
SDD – Spatial Hot Spots (NB)



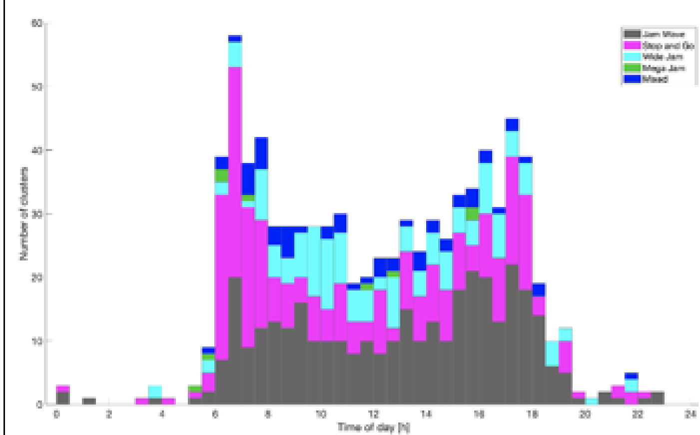
SDD – Spatial Hot Spots (SB)



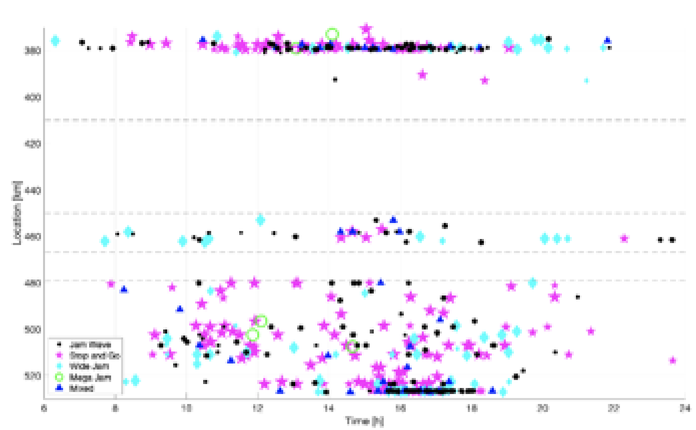
SDD – Temporal Hot Spots (NB)



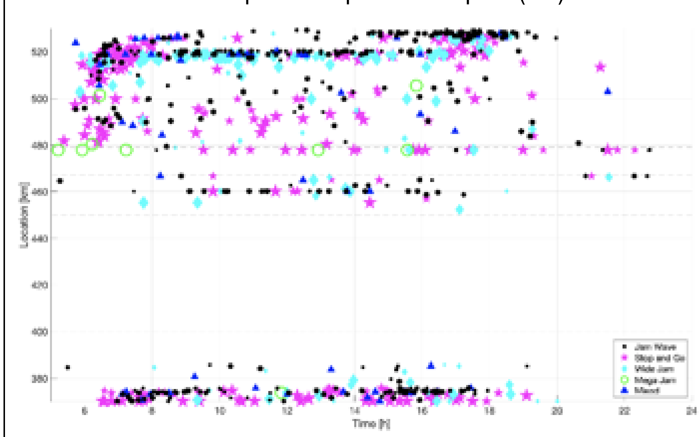
SDD – Temporal Hot Spots (SB)



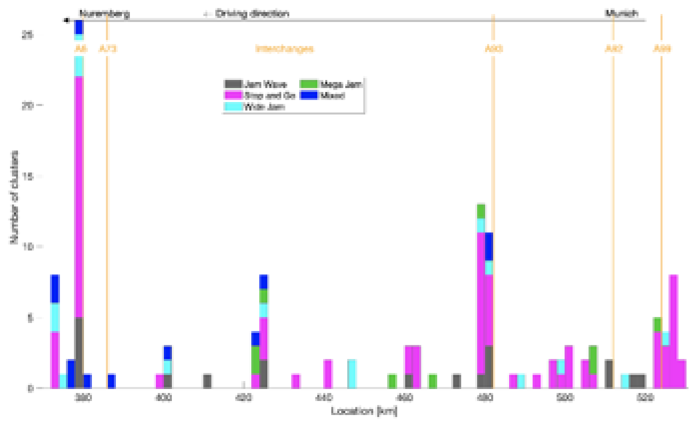
SDD – Spatio-temporal Hot Spots (NB)



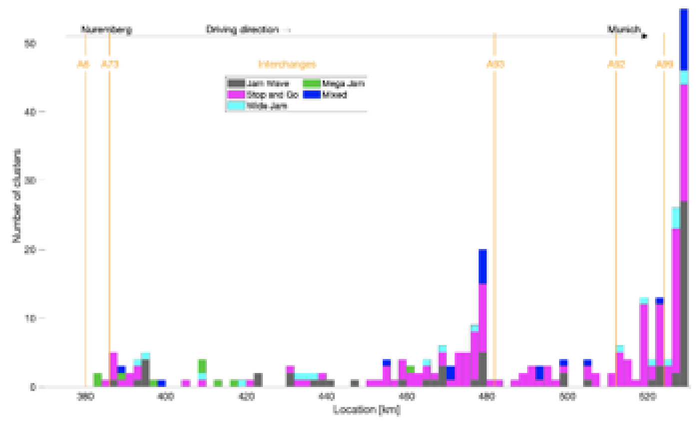
SDD – Spatio-temporal Hot Spots (SB)



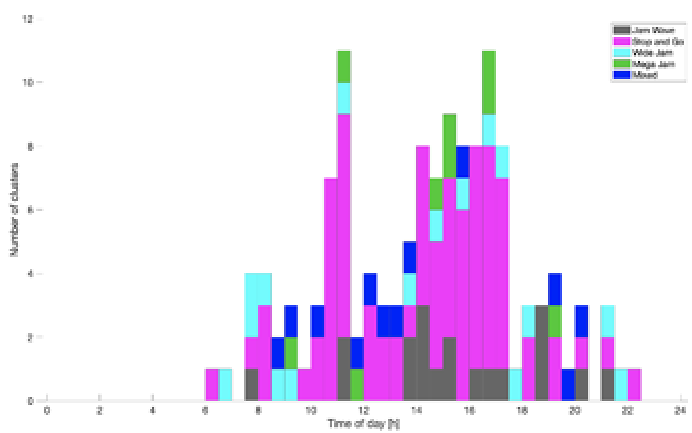
FCD – Spatial Hot Spots (NB)



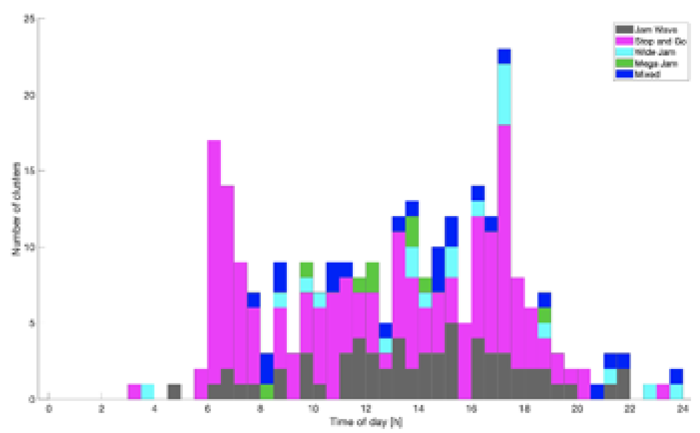
FCD – Spatial Hot Spots (SB)



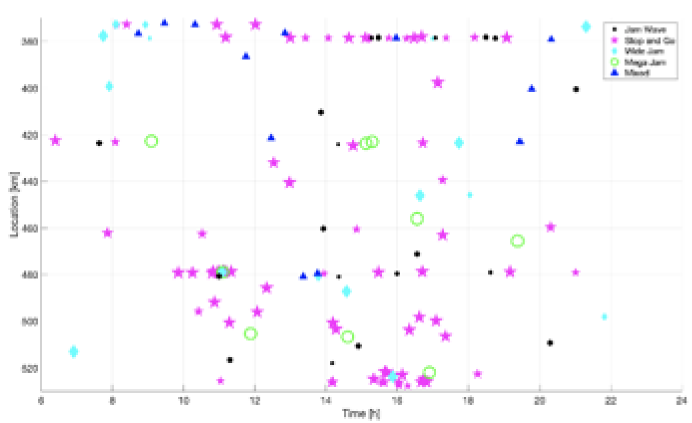
FCD – Temporal Hot Spots (NB)



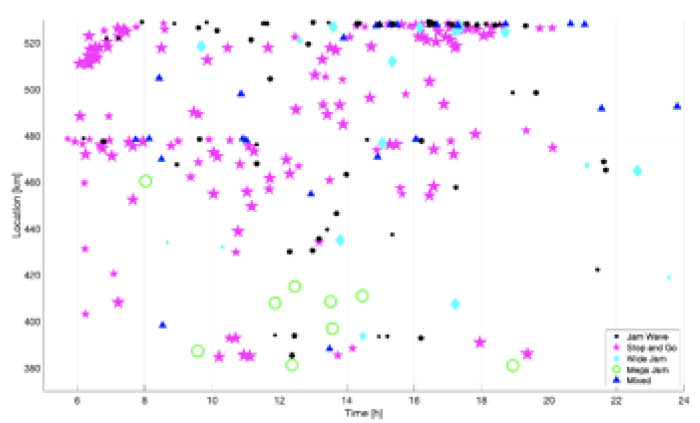
FCD – Temporal Hot Spots (SB)

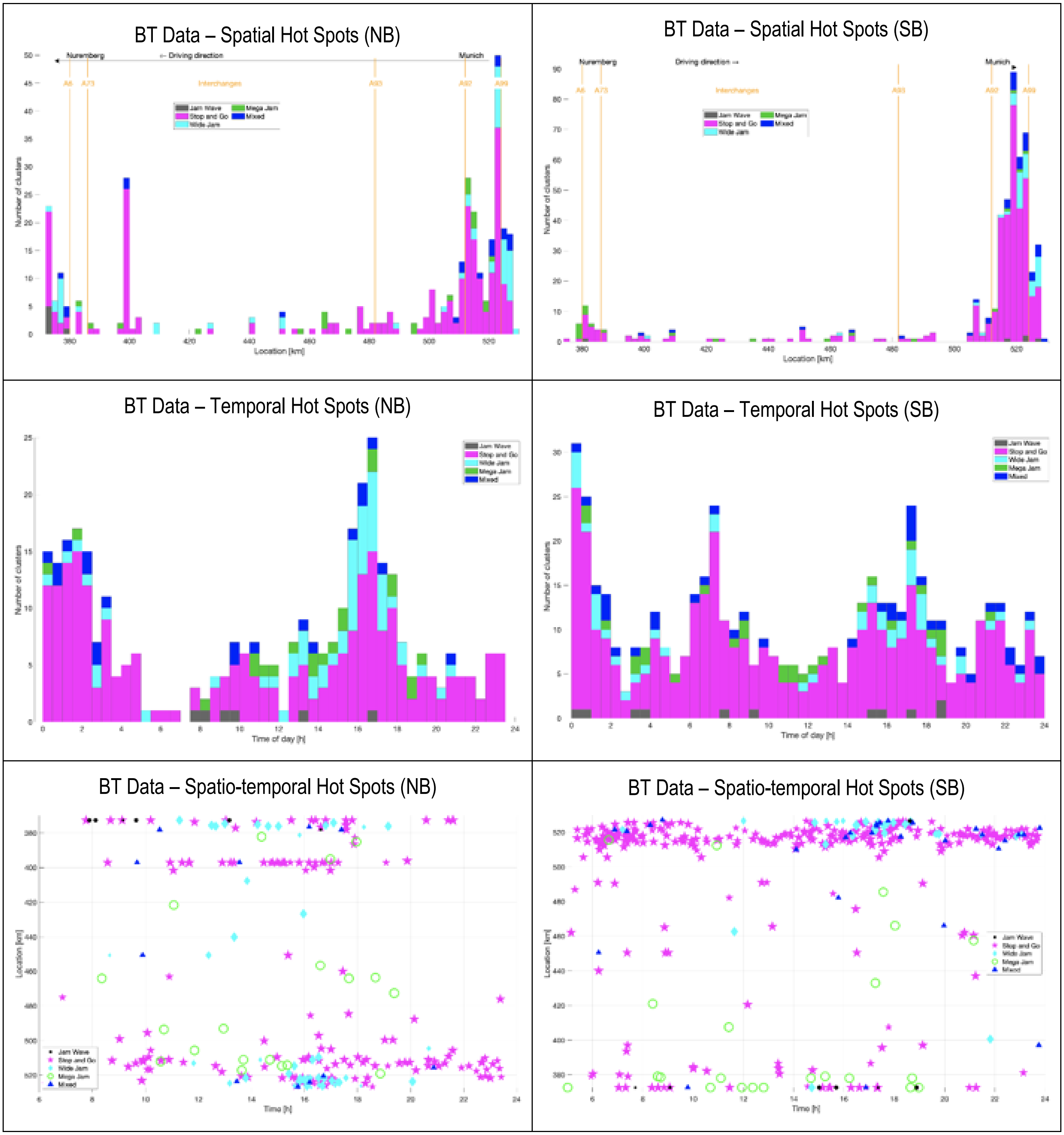


FCD – Spatio-temporal Hot Spots (NB)



FCD – Spatio-temporal Hot Spots (SB)




BT Data – Spatial Hot Spots (NB)
Nuremberg
Driving direction
Munich
A6
A73
Interchanges
A93
A92
A99
Jam Wave
Stop and Go
Wide Jam
Mega Jam
Mixed
Number of clusters
Location [km]
BT Data – Spatial Hot Spots (SB)
BT Data – Temporal Hot Spots (NB)
Time of day [h]
BT Data – Temporal Hot Spots (SB)
BT Data – Spatio-temporal Hot Spots (NB)
Location [km]
Time [h]
BT Data – Spatio-temporal Hot Spots (SB)

3.9. Case Study 9 – Oregon Department of Transportation Performance Management Plan (United States of America)

3.9.1. Description

The United States Federal Highway Administration has implemented a self-assessment, capability maturity framework for evaluating the effectiveness of Transportation System Management and Operations (Road Network Operations and ITS) programs (http://aashtotsmoguidance.org/). The framework allows an agency to evaluate its Road Network Operations against six dimensions of performance – Business Processes, Systems and Technology, Performance Measurement, Workforce, Culture, and Collaboration. The Oregon Department of Transportation, after completing the self-evaluation process, recognized the need improve capability related to performance measurement.

This led to the development of performance management plan (ODOT TSMO Performance Management Plan) to identify the opportunities to leverage both agency data and private sector data to implement key performance measures across various aspects of the Operations Program. The topics covered in the plan include:

- Mobility/Transportation System Performance Monitoring
- Asset Management
- Traffic Incident Management
- Transportation Operations Center (TOC) Management
- Traffic Signal Management
- Traveler Information
- Work Management

Implementation of the plan has resulted in integration of data from various agency ITS and operation software systems into the agency data warehouse. Automated extract, transform, and load processes copy needed data from operating systems into the data warehouse. The advantages of a data warehouse include:

- Improves data availability for reporting and dashboards.
- Pre-processing of data in cubes simplifies report building and allows implementation of business rules for how data is used.
- Simplifies aggregation of data from multiple source systems.
- Boosts security by only making non-sensitive data available for reporting and sharing.
- Ability to implement data cleaning and quality checks to ensure data quality for reporting.
- Increases use of data for road network operations decision making and planning efforts by simplifying and expediting access to data and data visualizations (See example in Figure 1).

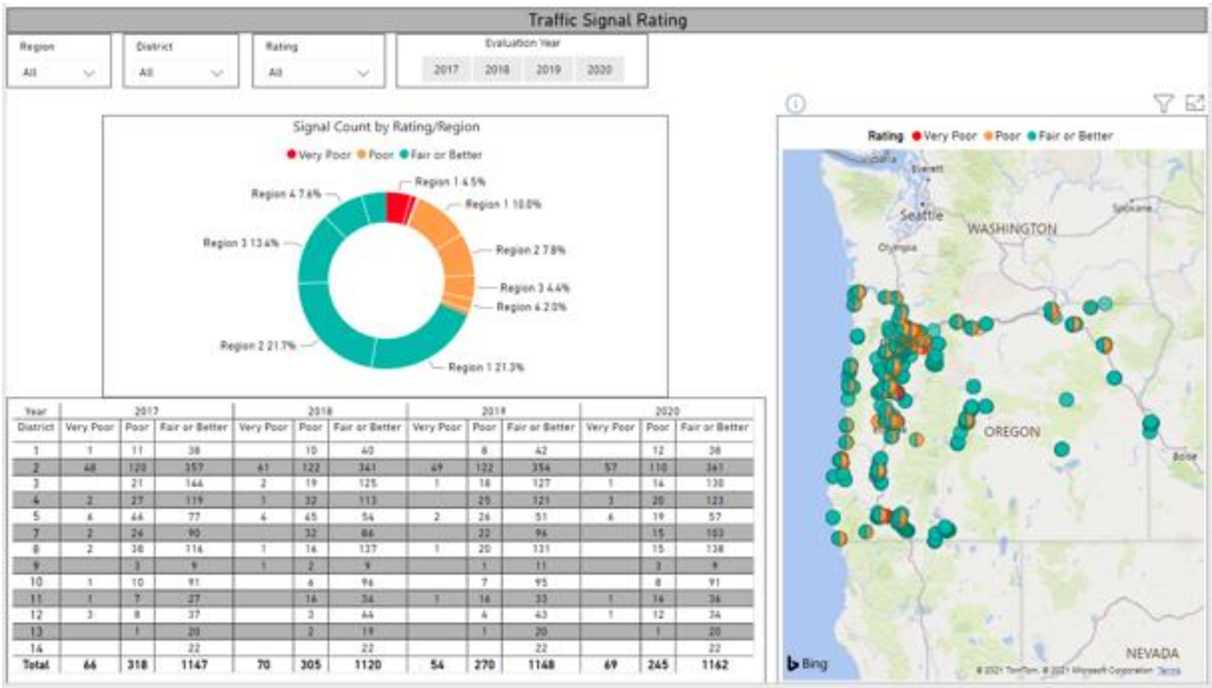


Figure 1 Example Traffic Signal Asset Condition Power BI Report

Figure 2 shows the variety of data sources that are currently integrated into ODOT's Enterprise Data Warehouse. To illustrate the capabilities that the data warehouse provides, data from ODOT's ITS maintenance management system can be combined with data from ODOT's accounting system to merge maintenance data with cost data.

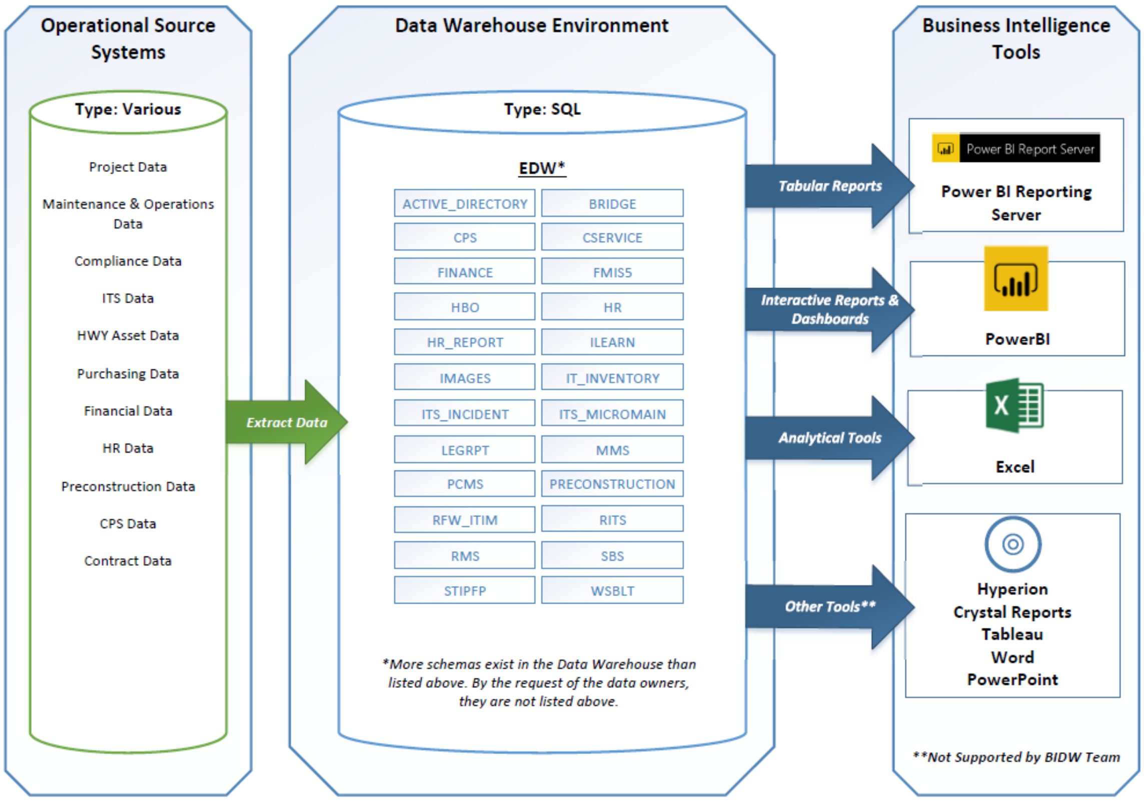


Figure 15 ODOT Enterprise Data Warehouse

ODOT utilizes the Microsoft Power BI tool for developing reports utilizing data in the data warehouse. These reports, which align with the sections of the TSMO Performance Management Plan, are available to anyone in the agency through an internal report portal shown in figure 3.

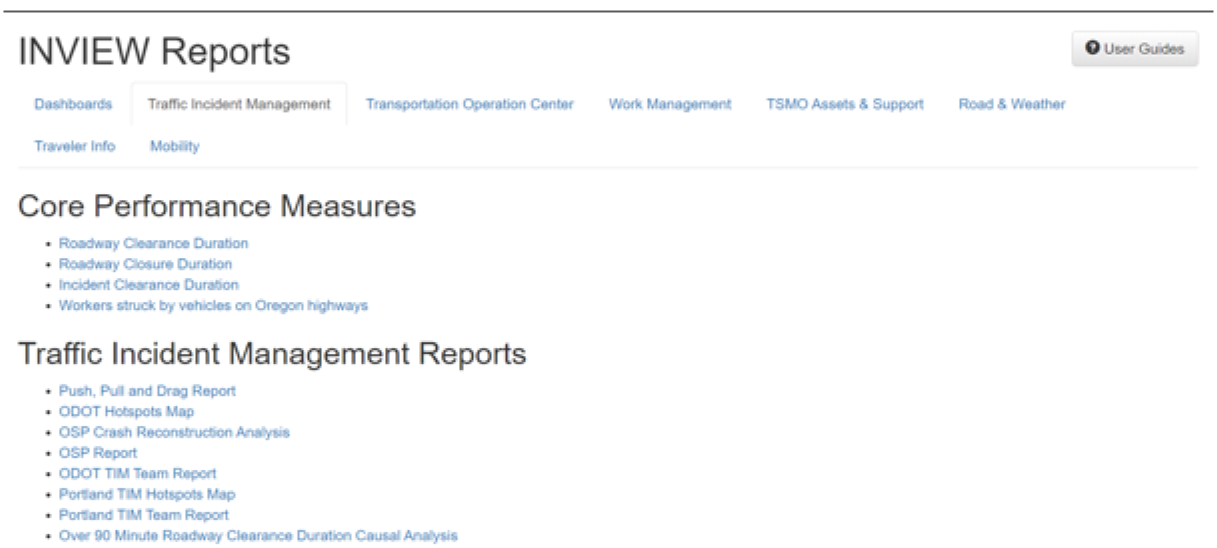


Figure 3 ODOT Operations Report Portal

While the data warehouse is an important tool for developing reports and dashboards utilizing data from agency systems, private sector provided probe data has grown in importance for use in measuring and monitoring system performance. ODOT currently purchases probe data for the entire road network in the State of Oregon. This very large data set is ingested into the Regional Integrated Transportation Information System (RITIS) operated by the University of Maryland (for more information about the RITIS system see the separate RITIS case study). ODOT utilizes the analytic tools within the RITIS platform for numerous applications and performance measures related to travel times, delay, and reliability. An example of the use of probe data to evaluate project investment needs is the Corridor Bottleneck Operation Study which utilized probe data to evaluate and rank bottleneck locations in the Portland metropolitan area (Corridor Bottleneck Operations Study).

3.9.2. Objectives

The objectives of this project include the following:

- Develop a comprehensive approach for utilizing data across the agency Operations Program.
- Use performance measures to influence resource decisions, investment decisions and policy development.
- Shift agency culture toward a performance management approach.
- Utilize existing data analysis resources to efficiently implement the TSMO Performance Management Plan.

3.9.3. Technical challenges

There are many challenges associated with integrating data into data warehouse systems including the following:

- Determine how much history is needed. Storage costs for large data sets can add up, so having a clear idea of how long data needs to be stored and a clear data purging process is necessary.
- Few data sets are perfect. There are usually numerous quality issues in any data set, so having a clear understanding of the business processes and gaps associated with business processes associated with the data gathering process is important for understanding what the data can reliably be used for.
- When bringing data together from multiple data sources, it is important to have some type of data key (e.g. specific location, date/time, etc…) to be able to combine the data for meaningful analysis.
- When purchasing private sector data, it can be difficult to know many of the details related to the data source(s) and analysis procedures behind the data product. While the quality and coverage of private sector data products is continually improving, it is still important to gather as much information as possible about the data and to investigate the quality of the data sufficiently to understand the appropriate uses for the data.

3.9.4. Non-technical challenges

There are also some non-technical challenges in implementing this type of data and performance measures program.

- Individuals responsible for systems tend to have a lot of ownership in the data from their system. This is for good reason. The technical issue listed above discusses that each data set can have its own quality issues or unique characteristics where an understanding of how it was gathered becomes important. People with expertise with a certain data set have concerns with how others with less experience may misinterpret the data. We worked around this issue by implementing data sharing agreements. These agreements provide transparency about how data will be used and provides the data experts the ability to review and provide recommendations related to the proposed use.
- Shifting to a more data driven decision making organization culture requires effort over time. It is very helpful to have executive level support within the organization. Clear and consistent communication about performance over time helps improve awareness of performance and the factors influencing performance.

3.9.5. Evaluation

ODOT is already realizing the benefits of implementing a true Enterprise Data Warehouse. Some of these benefits include:

- Having a single curated source of data for performance measures and reporting.
- Limiting the duplication of data across the warehouse, saving space on the server, and eliminating the time and the effort that goes into maintaining various copies of almost the exact same data.
- Better focus on data security resulting from a consistent understanding of what users need access to, not sharing sensitive data in the data warehouse environment, and developing data sharing agreements.
- Staff efficiency from supporting a single data warehouse environment for use for multiple applications across the agency.
- Improved access to data and ease in building relationships across data through bringing agency data together utilizing consistent data structures and documentation.
- Improving the ability to make data driven decisions to improve road network operations in Oregon.

3.9.6. Future

Oregon DOT has made excellent progress implementing the TSMO Performance Management Plan since it was published in 2017. An update to the plan was published in June 2021. Additional work will be done to integrate more data sets into the data warehouse and to integrate ODOT data with probe data in the RITIS platform. Work to continue to promote and utilize the existing reports and analytics tools is ongoing.

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3.10. Case Study 10 – Road Database Based on Artificial Intelligence (Tunisia)

3.10.1. Description

Given the traditional method of road management, the Ministry of Equipment, Housing and Infrastructure (MEHI) through the General Department of Bridges and Roads aims to develop a Road database (for 20.000 km roads and 4000 bridges) using Artificial Intelligence (AI) for data collection. Indeed, the road database used nowadays is traditional and doesn't allow rood infrastructure projects (Construction and Maintenance) to be planned in a scientific manner like for example using HDM-4 or similar. For this reason, taking into account the limited budget, the MEHI plans to implement a Road database based on AI that will allow to manage road assets with the optimization of the budget and prioritization of investments and works in short, medium and long term.

In this case study we aim to use some new techniques and technologies of equipment to collect Data from the road network and compare the outputs with the current methodology and conclude with the efficiency of the new methodology.

3.10.2. Objectives

The main goal is to improve the management of the road network under the responsibility of the MEHI.

Database based on AI will allow the manager of roads:

- Collect data on site using high precision equipment based on AI
- Plan maintenance operations works using data recorded on Site
- Plan construction of new roads
- Plan the programs of reinforcement and rehabilitation of roads through scientific methods
- Plan programs of Bridge maintenance
- Real time Traffic Control (number of vehicles, accidents, statistics, …)
- Optimizing budgetary and using resources on a rational way using HDM-4 or similar
- Set priorities according to the available budget
- Establish multi-year programs

3.10.3. Technical challenges

Data feeding the Database will be collected by equipment based on Artificial Intelligence such as:

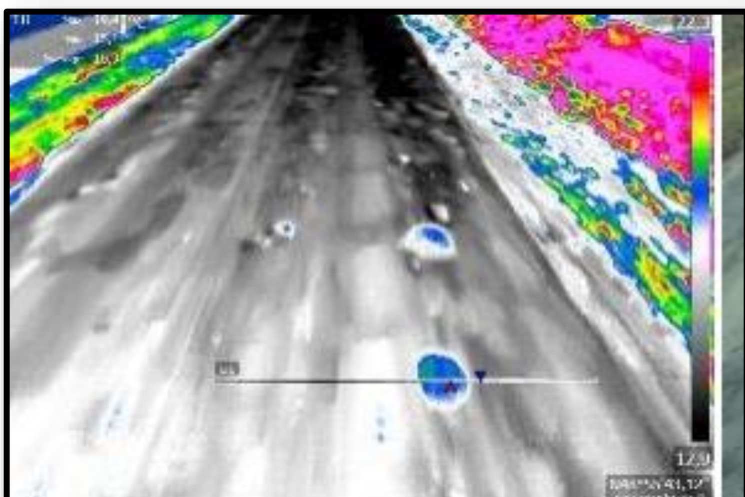
- Laser " Lidar" to detect the pavement surface condition (IRI),
- Intelligent Camera with thermal technology to detect the state of the pavement
- Ground penetrating radar to detect the composition of the pavement layers
- Camera based on AI for Road traffic ,
- Camera based on AI with Optical Character Recognition (OCR) technology to detect all road equipment and symbols
- Drones for bridge inspection

These equipments have to be equipped in a professional car and cross the entire road network in order to record all the data that will constitute the database

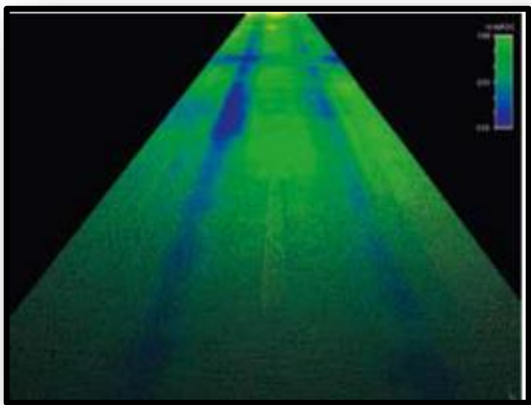
In addition, there is a challenge of having a real time answer of equipment which needs a high internet connection (5G).

Below are pictures of some equipment we plan to use:

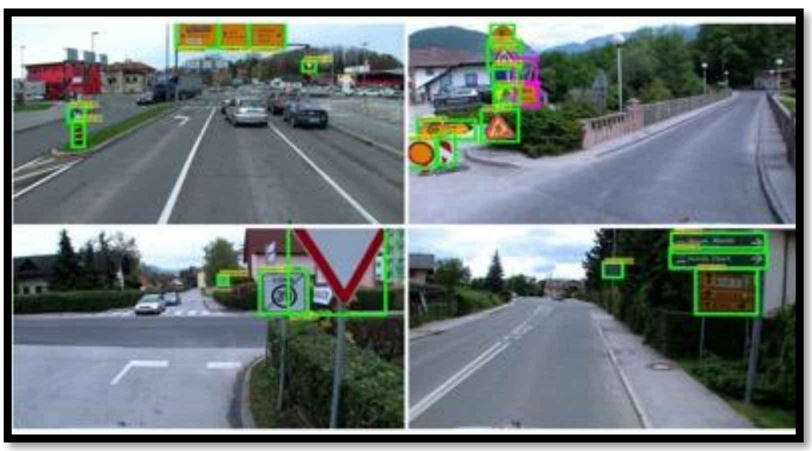
Infrared Camera



Thermal Technology - High-precision detection of the surface condition of the roadway (storming, potholes, cracking, etc.)



3D Pavement Profile Scanner (PPS) – Teledetection by LiDAR laser of the condition of the pavement (IRI of longitudinal and transversal)



OCR Technology Camera – Reading road equipment (traffic signs, guardrail, traffic, etc…) through camera equipped with AI.

Camera AI for road traffic counting and speed

3.10.4. Non-technical challenges

- Authorization to use cameras and drones on the road network (Authorization from Ministry of interior and defense)
- Define the organism which will be in charge of data collection on site
- Creation of a department in the MEHI in charge of database management
- Train people who will be in charge of using new equipment for data collection on site
- Train people who will be in charge of using the road database (regional and central users)
- Transition from the traditional methodologies of planning to developed technologies
- Coordination with other institutions to use camera in order to control traffic congestion and counting vehicles
- Assistance from experienced consultants to implement this project
- The funds to finance the project of implementing this database

3.10.5. Evaluation

- Evaluation of the current database and the content of its functionalities
- Possibility of extending the existing database over the entire road network
- Evaluation of the current methodology for planning roads and bridges interventions
- Compare the current database results to the new database based on AI results.
- Evaluation of the efficiency of the new database based on AI
- Compare with other countries experiences (benchmarking)

3.10.6. Future

- Extending this road data base to municipalities roads
- Coordinate with other institutions in order to have a rational territory planning
- Decentralization of investment programs related to roads and bridges

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3.11. Case Study 11 – Identifying Bottleneck and Traffic Congestion Using ETC 2.0 Probe Data (Japan)

3.11.1. Description

National Institute for Land and Infrastructure Management (NILIM) of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan develops methods for finding road traffic issues and evaluating the effects of various measures using road traffic data such as the ETC2.0 probe data. One is the development of a bottleneck index to identify "bottlenecks"- the origin of congestion in the traffic network. This analyses the travel speed of ETC2.0 probe data and evaluates as scores by distinguishing between "whether it is at the starting point of congestion" and "whether it is affected by congestion ahead". It also quantifies the frequency of occurrence during the measurement period.

The conventional speed contour plot is a simple and effective way to capture bottlenecks, but it usually deals with the average speed during the period of analysis. However, in road sections at where the frequency of speed reduction is relatively low, the effect of speed reduction in a slight traffic jam during the analysis period cannot be shown, so a “bottleneck point” cannot be identified accurately. Since distinguishing the influence of traffic congestion ahead is not possible, it is difficult to determine intersections with bottleneck where vehicles keep running at low speed.

In conventional analysis, probe data is aggregated for individual Digital Road Map (DRM) section to calculate the travel time (speed). DRM sections are designed mainly for car navigation systems, and these sections are basically divided at intersections, in an average of about 200 to 400m. It is therefore impossible to capture more detailed traffic congestion than in DRM sections, and this low spatial resolution of conventional analysis remains as an issue in identifying bottleneck accurately.

In addition, since DRM sections are basically divided at intersection, the distance differs for each evaluation section. Hence, it is a problem that evaluation might not be appropriate due to various length of the road section.

Basic Concept of Bottleneck Index

The bottleneck index is a congestion head value (Bottleneck (BN) value), which is the "likelihood to be a starting point of traffic congestion" in certain road sections. It is also a congestion influence value (Affected Queue (AQ) value) reflecting the “susceptibility to congestion ahead". First, the route is divided into unit sections in equal distance for analysis, and "congestion" and "non-congestion" are determined by the travel speed for daily hours for individual sections. Then, scores are given according to the combination of the "congestion" and "non-congestion" in the target section and its adjacent sections (Figure 1). If the target section is "congested" and its front adjacent section is "non-congested", this particular section is considered the starting point, and "BN point +1" is given. On the other hand, "AQ points +1" is given if both the target section and the section ahead is “congested”. The BN value is then calculated by adding up the "BN points +1" during the analysis period and dividing by the number of days that data was acquired. The AQ value is also calculated in the same way.

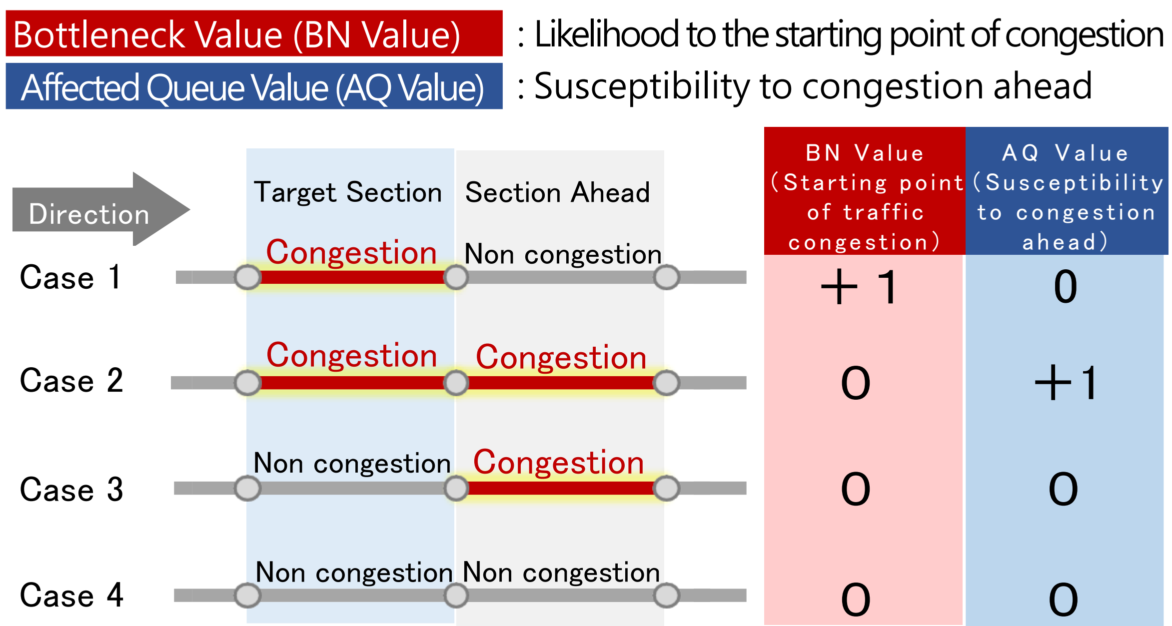

Figure 1- Basic Concept of the Bottleneck Index

Comparison of Bottleneck Index Value and Speed Contour Plot

As shown in Figure 2, the conventional "speed contour plot" analysis had difficulties in identifying bottleneck in continuous congestion sections (bottleneck intersections confirmed by road administrators by visual inspection based on their expertise are the intersections B, F, L, and P). Yet, the Bottleneck (BN) value indicates that the section is where the congestion starts, and the Affected Queue (AQ) value, on the other hand, indicates the affected sections (non-bottleneck sections). It is thus possible to identify bottlenecks with these indexes.

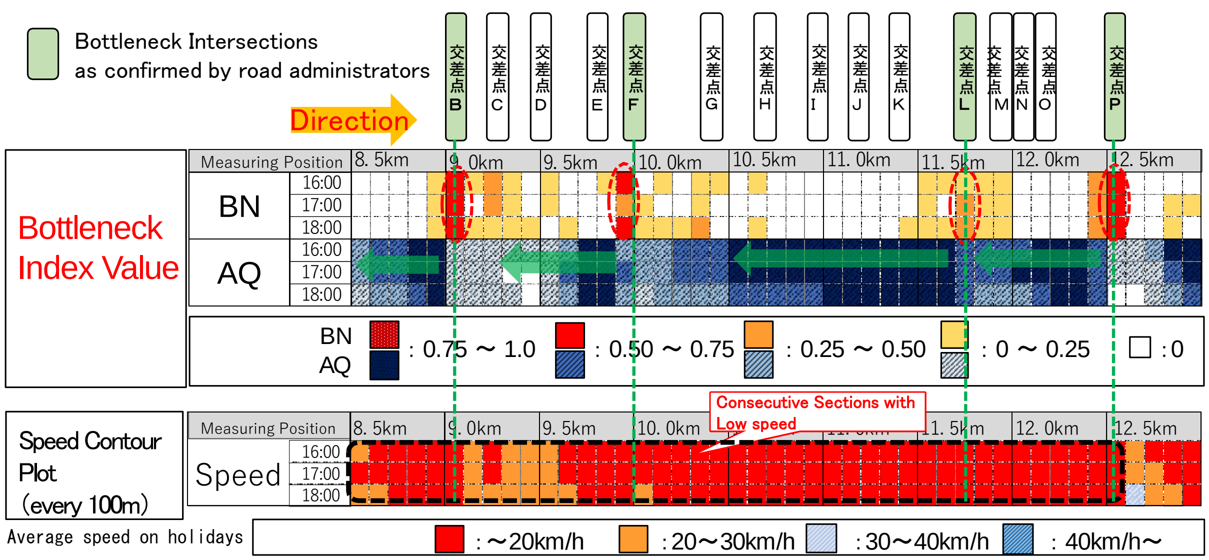

Figure 2 - Comparison of Bottleneck Index Value and Speed Contour Plot

3.11.2. Objectives

Effective, accurate measures should be implemented against congestion, and the identification method of local congestion factors should also be further improved. In order to implement effective and appropriate traffic congestion countermeasures, it is necessary to identify bottleneck locations, so the development of more accurate analysis methods is necessary.

3.11.3. Technical challenges

The conventional way to identify the bottleneck section is the manual “field survey” with visual inspection at specific locations only on a specific day due to financial and labor restrictions. Nevertheless, the survey date may not have the typical traffic condition throughout the year as conditions vary every day. Moreover, as traffic congestion may affect multiple road sections, it may also have multiple bottlenecks close to each other. It is, in fact, difficult to determine the actual bottleneck by investigating a limited number of locations.

To tackle the issue, along with advancing ICT technologies, the use of probe data that reflects the road traffic conditions 24 hours a day and 365 days a year have been underway. Specifically, MLIT collects ETC2.0 probe data including travel speed and time aggregated for DRM sections, and it also collects travel history data of vehicles by vehicle locations so as to capture the congestion conditions efficiently and effectively with these data.

The travel history data of individual vehicles in the ETC2.0 probe data includes time, latitude, and longitude; it’s measured when a vehicle travels 200m from the point where the data was previously accumulated or when it turns the driving direction more than 45 degrees.

In this study, the travel time of vehicles is divided proportionally at 100m interval, in which basically recorded every 200m as the travel history data of individual vehicles in the ETC2.0 probe data. In addition, as the threshold for judging "congestion" and "non congestion", the judgment speed for congestion at major congested locations is adopted: 40km/h for motorways and 20km/h for ordinary roads.

3.11.4. Non-technical challenges

ETC2.0 probe data have issues such as the limited number of samples in some routes. However, it can be used not only in traffic congestion measures, but also in safety measures, natural disaster prevention, etc., as well as in road development projects.

3.11.5. Evaluation

- This method has been able to properly identify bottleneck locations and is considered to be effective in identifying bottleneck locations accurately.
- This method is applicable in ordinary roads, as well as motorways.
- It may be possible to identify bottleneck locations with infrequent congestion that cannot be captured in the speed contour plot.

3.11.6. Future

In the future, we plan to develop a manual, and thus, bottleneck index value can be implemented to identify bottleneck locations in practice.

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3.12. Case Study 12 – Automated Diversion System for Trucks in Adverse Weather Conditions (Spain)

Adverse weather conditions have a strong impact on road safety, decreasing the traffic flow and increasing the risk of accidents. Within these adverse conditions, the presence of ice and snow on the road is especially relevant, which tend to occur, with greater intensity, at certain times of the year and in high mountain areas.

Currently, the level of service (LOS) in the roads of Spain is categorised by a colour codes, which indicate the possible traffic restrictions that may be placed on the road. Therefore, during episodes of adverse weather, the protocol establishes the following levels:

- White level to indicate the absence of restrictions
- Green level to indicate the presence of snow on the road, light vehicles must drive at a maximum speed of 100 km/h on high-capacity roads or 80 km/h on conventional roads. (Heavy vehicles are not allowed to overtake others)
- Yellow level: restriction for heavy goods vehicles
- Red level: obligation to use chains or winter tyres for light vehicles
- Black level: impassable road

Therefore, in periods of winter conditions, in which driving restrictions for heavy goods vehicles have been placed, the execution of roadblocks or diversions for trucks towards stabling areas is the common mechanism to avoid situations that can cause safety risks for traffic.

The usual methodology to establish these diversions is based on the traffic regulation through beacon using traffic cones and direct management by road authority agents. The role of these agents is to filter the vehicles which have to go to stabling areas, and those vehicles which can continue along the affected road.

This way of managing traffic has led to the following conclusion: there is an inefficient use of the human resources deployed in these situations, which can bring a possible road and labour safety hazard for these workers.

The need to implement a beacon system in adverse weather conditions leads to a potential risk for the workers who install the diversion and the use of police resources for filtering vehicles. These aspects prompted a study by the Directorate General of Traffic to investigate an automated system for lorries which, by means of variable road signs, would divert heavy goods vehicles without the need of use human resources.

This system needed to address, on one hand how to encourage compliance with the diversion, and on the other hand how to identify vehicles that breach the restriction issue a penalty due to the default. To address these aspects, the system included the implementation of license plate recognition systems, before and after the diversion, to enable penalties to be issued to heavy goods vehicles that failed to comply with the diversion requirements.

For this reason, in 2018 a pilot program was implemented on A-1 highway kilometre point 119+000 close to Boceguillas village. This location was chosen because it has a winter road parking area and it is an enclave before the Somosierra pass, where snow restrictions are common.

The result obtained during the 2018-2019 winter season was a 96% success rate in the second restriction period of the season, achieving the outcome of releasing the previously associated road crew to other road locations and attend other incidents.

3.12.1. Technical challenges

Equipment incorporated to the automated diversion

For the mentioned pilot program in Boceguillas, the following equipment was installed:

- One variable message sign (VMS) at the advance warning section.
- One variable message sign (VMS) and one installation of license plate recognition (LPR) equipment at the start control section.
- One installation of license plate recognition (LPR) equipment at the end control section.

The following picture shows the location of the different equipment.

Procedure for action and proposed signalling

When restrictions are put in place, Traffic Management Centres (TMCs) will launch the signaling messages on the Variable Messaging Panels, in advance warning zones and control zones. The proposed signage is as follows:

Advance Warning Signage

Title: “ADVANCE WARNING SIGNAGE - NEARBY – DISTANCE <5KM”

First picture message: “TRUCKS > 7500 KG WITHIN X KM”

Second picture message: “> 7500 KG COMPULSORY TAKE EXIT XX”

Diversion point. Start of control and reading point 1

Title: “READING POINT NUMBER 1. START CONTROLLED SECTION”

First picture message: “> 7500 KG TAKE NEXT EXIT”

Second picture message: *“CHECKPOINT OVERSEEN”*

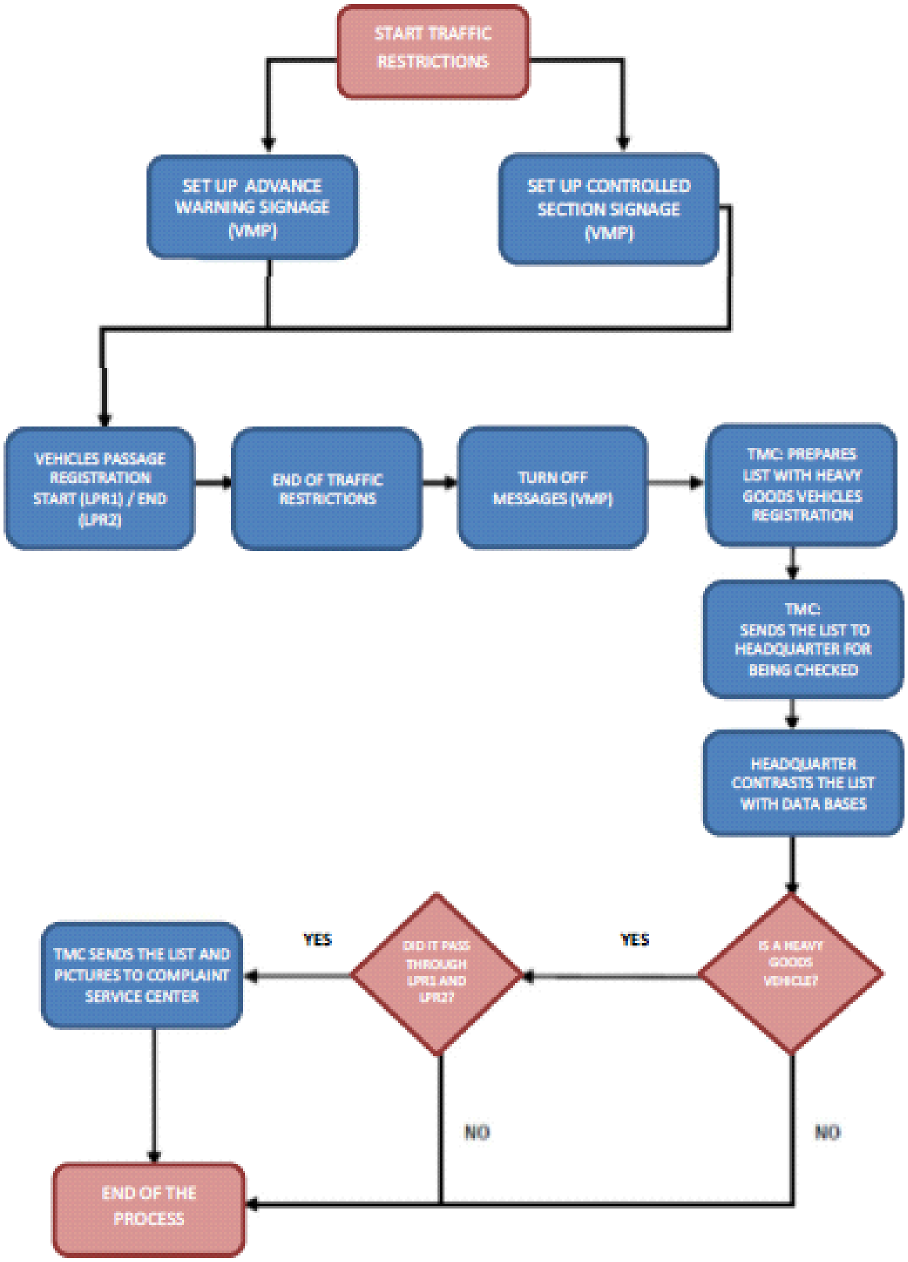
Reading point 2. End controlled section

Title: “READING POINT NUMBER 2. END CONTROLLED SECTION”

First picture message: *“TRUCKS > 7500 KG”*

Second picture message: *“CHECKPOINT OVERSEEN”*

Once the signaling plan has been activated, the registration of the passage of vehicles by the initial and final license plate recognition (LPR) equipment of the control section begins. At the end of the period of restrictions for heavy goods vehicles, the registration of trucks is terminated. At the end of the automation process, lists of vehicles that have not respected the signaling are generated to be proposed for compliance checks. The flowchart of the whole procedure is detailed below.



3.12.2. Non-technical challenges

The main barrier of this pilot program was the need to change the way of thinking and operations of the road crews, as it was initially inconceivable to leave an automated system without the support of maintenance staff and the traffic authority during adverse weather conditions.

Gradually, drivers and road maintenance crews will get used to this new system, in which it is not necessary to have the presence of police to comply with the restrictions set by the traffic authority.

3.12.3. Evaluation

The pilot program was deployed during the 2018-2019 winter season. During this time, traffic restrictions with yellow level were set twice, achieving the following results:

		A-1 110+250D		
19/01/2019 17:00 - 20/01/2019 00:00		Ligeros / Light Vehicles	Pesados / Heavy Goods Vehicles	Intensidad total / Total Traffic Intensity
19/01/2019	17:00:00 - 18:00:00	319	7	326
	18:00:00 - 19:00:00	284	17	301
	19:00:00 - 20:00:00	233	9	242
	20:00:00 - 21:00:00	154	6	160
	21:00:00 - 22:00:00	125	6	131
	22:00:00 - 23:00:00	68	4	72
20/01/2019	23:00:00 - 00:00:00	40	8	48
	Total / Total	1.223	57	1.280
Coincidencia ambos LPRs / Coincidence in both LPRs			11	
Porcentaje sobre pesados / Percentage over heavy goods vehicles			19,30%	

		A-1 110+250D		

01/02/2019 19:30 - 02/02/2019 02:15		Ligeros / Light Vehicles	Pesados / Heavy Goods Vehicles	Intensidad total / Total Traffic Intensity
01/02/2019	19:00:00 - 20:00:00	584	95	679
	20:00:00 - 21:00:00	356	30	386
	21:00:00 - 22:00:00	250	8	258
	22:00:00 - 23:00:00	112	16	128
02/02/2019	23:00:00 - 00:00:00	93	28	121
	00:00:00 - 01:00:00	59	13	72
	01:00:00 - 02:00:00	34	2	36
	02:00:00 - 03:00:00	31	163	194
	Total	1.519	355	1.874
Coincidencia ambos LPRs / Coincidence in both LPRs			12	
Porcentaje sobre pesados / Percentage over heavy goods vehicles			3,38%	

During the first period of restrictions (19/01/2019), a total of 1280 vehicles were affected of which 57 were heavy goods vehicles and only 11 vehicles of >7500kg class vehicles illegally used the restricted section.

During the second period of restrictions (01/02/2019), a total of 1874 vehicles were affected and there was a further decrease to 3.38% of heavy goods vehicles that illegally used the restricted section.

Lessons Learned

The main lesson learned from this pilot program was that it confirmed the effectiveness and benefits of rapidly activating stabling areas dynamically, decreasing the possibility of heavy goods vehicles getting caught in the restricted zone.

In this sense, having localised real-time information about weather conditions, the system was able to apply the restrictions within a few minutes.

Costs

The cost of installing the automated diversion elements was covered by the maintenance contract budget of the zone and amounted to €143,470.

3.12.4. Future

Currently, eight more automated diversion systems are being installed in different locations in Spain and studies are underway to determine inclusion of pavement beacons, helping trucks to use the next exit.

3.13. Case Study 13 – Brisa-Waze Collaboration to Improve Traffic Operations and Traveler Information (Portugal)

3.13.1. Description

Brisa tollway concession strongly believes that successful development of effective real-time traffic management and information systems requires high quality traffic information in real-time. To that end, Brisa has worked together with Waze to get strategic and operational travel time forecasts to combine with data gathered from road sensors and data about incidents to inform drivers about estimated travel time data during major traffic events (MTE). This is accomplished by updating strategic variable message signs (VMS) along the highways. The effect of this collaboration is notable during major events where traffic demand increases significantly.

Figure 1 - VMS display of estimated travel time

Besides the active collaboration for short-term travel time forecasts, Brisa and Waze also cooperate in sharing information about road events. The Brisa traffic control center (TCC) updates the Waze traffic map with road incidents under its management. These updates include road works, lane and road closures, traffic congestion, and abnormal weather conditions among other things. Those alerts are particularly crucial during large-scale incidents, such as wildfires, to provide warnings and guidance for drivers both in-route and pre-trip.

Figure 2 - Brisa's Traffic Control Centre

Brisa also gets Waze alerts reported by the application users. Alerts that intersect the concession network are combined with existing road incidents and, according to specific rules related to location, time and type on incident. Such alerts are presented to traffic operators for confirmation using video-surveillance or patrolling services. For alerts with a high level of confidence and criticality, the TCC can implement automatic alerts for road users through the VMS panels.

3.13.2. Objectives

- The objectives for the Brisa-Waze collaboration include the following:
- Disseminate real-time travel time forecasts for in-route or pre-trip users
- Disseminate alerts related to accessibility or road safety
- Consolidate road network condition information to improve traffic operations

3.13.3. Technical challenges

- The technical challenges in implementing the collaboration with Waze include:
- On-line data fusion to combine Waze traces and alerts with Brisa's road metering, alerts and incidents to reach the objectives in a consistent and reliable way.
- Normalizing the level of importance and level of trust for alert entries from heterogeneous sources spanning from police forces to social media users.

3.13.4. Non-technical challenges

- The primary non-technical challenge has been developing the organizational procedures and external commitment to integrate, adopt and make use of the entire set of available data and resources.

3.13.5. Evaluation

The evaluation of this project is performed at different levels and includes the following:

- Reliability of travel time forecasts published.
- Traffic demand changes during planned events or special holidays resulting from strategic communication of information.
- Level of dissemination of Brisa network alerts through the existing channels
- Incident reporting time improvements, based on Wazers' alerts

3.13.6. Future

Plans for future improvements include:

- Implementation of network performance monitoring, powered by WAZE
- Applying advanced analytics to all of the data gathered from road sensors, tolling, the traffic control centre, C-ITS services, and WAZE feeds to provide real-time network conditions and alerts and to provide short-term predictions and operational tasks to be performed by road assistants and the field service task force.

This phase will implement a big data architecture supported by ELT (extract, load, and transform) pipelines for data ingestion adopting the best practices for sharing data securely with partners and for data privacy compliance.

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3.14. Case Study 14 – DGT 3.0 Connected Vehicle Data Platform (Spain)

3.14.1. Description

The DGT 3.0 platform is the Internet of Things (IOT) platform of the DGT (General Directorate of Traffic) that allows the different road users to be connected in real time, offering them real-time traffic information at all times and thus allowing them to achieve safer and more intelligent mobility. The objective is to build a road user platform that allows all the actors who make use of the roads to be connected anonymously, both to provide valuable information to the connected community, and to consume it in order to detect and be notified of dangerous situations that occur during the exercise of our mobility. This platform will be an access point of unique, free, and accurate real time information about what is happening on the roads -- information of great value for the entire mobility ecosystem in the national territory.

In this sense, the General Directorate of Traffic has the ultimate goal of reaching 0 deaths, 0 injured, no congestion and no emissions.

The platform has passed the halfway point of its development and is expected to be finished in May 2022. The project began just three years ago and is a pioneer in Europe. It is one of the most advanced technological initiatives in terms of improving road safety and providing smart, connected, and safe mobility. It is a new way of tackling the reduction in the number of accidents based on the collaboration among the entire mobility ecosystem to achieve a “Zero” vision by 2050 -- zero victims of traffic accidents (deaths or injuries).

To make the DGT 3.0 platform a reality as a unique information reference point, the participation and collaboration of all the actors that are part of the traffic and mobility ecosystem is required. For this reason, different diffusion actions have been implemented during the project at various levels. The main objective of these actions has been, and is, the participation and integration in DGT 3.0 of vehicle manufacturers, signalling devices manufacturers, public transport platforms, city halls, insurance companies, and application providers.

Participation varies depending on the type of actor who is integrated into the platform. Among the actors, some are oriented to collaborate by feeding mobility information to the DGT 3.0 platform, whether provided by their technological solutions as in the case of device manufacturers or through open data information as is the case for city halls. Others are oriented to consume the information contained in the DGT 3.0 platform as in the case of mobility application providers. And others could provide and consume information from the platform as would be the case for vehicle manufacturers.

During the time that the project has been in progress, a total of 40 actors have been contacted including 10 vehicle manufacturers, 4 signalling device manufacturers, 6 mobility service providers, 5 public entities and city councils, 6 transport companies and concessionaires, 5 associations / federations, 3 technology centres and 1 insurance company.

In order to attract the actors, personalized and specific workshops have been carried out with each one including a presentation of a project overview and the objectives and benefits that their integration with the platform could bring to their business, to end users that use mobility services, and to the environment in general. Once the integration acceptance to the platform is achieved, new technical workshops are held where each technical team is instructed with the necessary information for feeding and consumption of information contained within the platform. After the integration is done, end-to-end tests are planned and coordinated to cover sending information through the actor's cloud to the DGT 3.0 platform. Tests include all the processes that feed, process, enrich, and publish information on DGT 3.0 platform, and also the consumption by consumer actors who provide mobility services to end users.

Use cases

The users of the platform can access information related to:

Road Work and incident

DGT 3.0 includes details of the road work in progress in real time and work planned in the future. The data provided identifies the section of road and the lane or lanes that are affected at all times by the execution of the work.

Any operator of road infrastructure must inform DGT about the planned work that will be carried out on the infrastructure. In addition, the kilometre points where the work that is being executed begins and ends must be provided and updated in real time. DGT has a system called RENO in which it houses this information. DGT 3.0, integrates with this DGT system to be able to position in real time the active planned work with the real start and end data, as well as affected lanes.

With this information, users will be able to know the existence of these events prior to encountering them on the road. This is complementary to the visual signs that exist on the road, and it allows users to plan their routes and minimize the surprise effect on the road, thus avoiding possible accidents.

V-16 devices

This integration into the platform arises from the need to receive Road Safety information from events whose origin is not the vehicles manufacturers. The device incorporates a geolocation system that allows the user to activate it and alert the rest of drivers through the DGT 3.0.

The integration into the DGT 3.0 platform of information from the V-16 devices allows:

- A greater ability to distribute the warning beyond the visual area.
- The possibility of reaching a greater number of vehicles to warn that there is a vehicle on the road and therefore there is an incident or danger to traffic.
- Increase driver safety.
- Publish the incident in the first person.
- Increase the quality of information.

Environmental Protocols

Information related to the activation of **environmental protocols** and low emission zones, which in Spain, will be mandatory for cities with more than 50,000 inhabitants.

Virtual Variable Message Panel

Information that DGT publishes at any point on a road through the **Virtual Variable Message Panel**, which allows communication with road users at any time.

Traffic Light Information

In addition to the real time information previously described, the DGT 3.0 platform will **integrate real time traffic light information** for the urban traffic light phases for the entire national territory and will include topology of the intersection. This application will help to make driving more relaxed and efficient, with greater protection of vulnerable users. The DGT 3.0 platform will be the central point of publication of traffic light information in Spain in such a way that the different brands and third parties who want to consume information find it under the same protocols and interfaces regardless of the municipality to which the traffic light information belongs. DGT 3.0 is working with different traffic light information providers and the City Council for the publication of traffic light information in real time from the intersection.

Safety information from vehicle

One of the great advantages of the DGT3.0 platform is to turn each vehicle into a set of sensors. Currently vehicles are composed of systems that make decisions to help drive them better, based on the sensors they have on board. Examples include the use of the Electronic Stability Program (ESP) or the use of windshield wipers. This information is collected, and some of it is sent to the platform from the manufacturer itself once it has been anonymized.

The use of the raw sensor data is not useful by itself. It is the logic and analysis provided by the platform that transforms the data to useful information. For example, if a vehicle has the windshield wipers activated this event, along with intensity of use, is received on the platform. Logic can determine that there is a certain intensity of rain at that location. Receiving several messages from different vehicles in the area allows the platform to calculate the area affected by rain and communicate this event to drivers who approach it. In the same way, if an anti-slip system is activated, when it is sent to the platform, it calculates the area affected and also communicates it to other drivers.

The Data Task Force group was created in February 2017, which currently goes by the name of Data For Road Safety. The objective of this group is to implement Delegated Act 889/2013 and define data models and interfaces for the communication of information related to road safety, in addition to supporting collaboration between vehicle manufacturers and Member States. As a result of this collaboration, a proof of concept was launched that allowed communication between different brands using different national platforms.

In Spain, the reception of this information is being promoted in two ways. Through an intermediate service, such as HERE and directly from the manufacturer itself. For the latter, conversations have been started with various manufacturers such as Volvo, Daimler or Nira Dynamics aimed at establishing a channel for direct and real-time reception of the information generated by their vehicles.

The main advantage of this initiative and collaboration is the standardization of data models and protocols. In this way, manufacturers can build their vehicles without worrying if they are going to circulate anywhere in Europe. In any of them they will have the same information at their disposal and can connect in the same way, and as a result, save resources. This is an interoperable and cross-border solution that allows a car to be connected from Lisbon to Vienna, without changing technology.

New Use Cases

Throughout 2021 the platform will provide the following information through the implementation of **new use cases**:

- Special vehicle information (dynamic events)
- Perimeter beaconing of sporting events.
- Information for real-time protection of workers performing road maintenance work
- Reception and publication of information in real time for cyclists.
- Information on points of interest. Mobility map
- Dynamic management of parking capacity data.
- Identification of loading and unloading zones
- Real-time crane location information

All of them involve collecting information anonymously from on-board devices in different types of vehicles and sending it to the platform. Within the platform, logic is applied that allows it to be enriched with information from other systems and, finally, to be published.

Likewise, we will work on the concentration and standardization of urban information generated in the different city councils to facilitate the development of mobility solutions that favour the decongestion of cities and reduction of pollution. This includes Information such as the real time availability of parking spaces in park-and-ride lots and the occupation of loading and unloading zones.

All this information is published in real time, with a maximum latency well below 1 second, allowing any customer to consume information efficiently.

3.14.2. Objectives

The General Directorate of Traffic has been working for years with the aim of reducing the number of accidents and mortality on our roads. In recent years, work has been done on different strategies, from collaboration with other Administrations in improving infrastructure in line with the safe system approach, to awareness campaigns on misconduct while driving. However, accidents that could be avoided in the road network continue to occur because the different actors involved in the circulation (motorists, motorcyclists, cyclists, pedestrians, etc.) lack the necessary tools to know in real time the hazards on with their route. With sufficient information in advance to make decisions and improve awareness, the risk of suffering an accident can be minimized. This strategy supports meeting the General Directorate of Traffic's ultimate goal of **0 deaths, 0 injuries, no congestion and no emissions.**

The intelligent mobility platform has successfully passed the halfway point of its development, with a year and a half remaining for the completion of this project; it is one of the most technologically advanced initiatives, and a pioneer in Europe, for improving road safety and intelligent mobility.

DGT 3.0 is an IoT platform in the public cloud with high capacity for scalability, availability, security, and portability to allow the interconnection between all the actors that are part of the traffic and mobility ecosystem. These actors include vehicle manufacturers, leasing companies, rental companies, public transport platforms, municipalities, insurers, manufacturers of connectivity devices, providers of applications related to safe and intelligent mobility and the different road users.

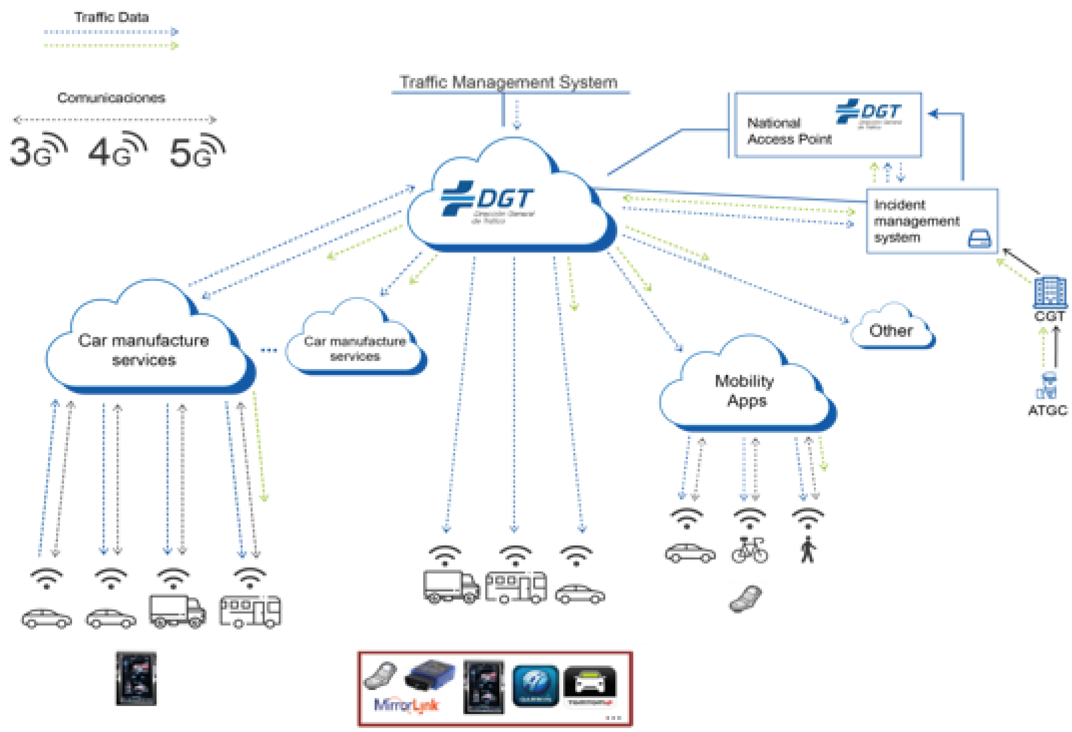
DGT 3.0 provides a new way of tackling the reduction in the number of accidents based on the collaboration among the entire mobility ecosystem around a "Zero" vision to be achieved by 2050 -- zero victims of traffic accidents (deaths or injuries). Currently the connected vehicle is facing great challenges and varied scenarios derived from the constant emergence of new technologies and the needs and expectations of citizens who demand more information and security when traveling.

It is estimated that by the year 2025 more than 81 million vehicles will be connected, and within 10-15 years, 100% of the vehicles will have some connectivity system implemented.

The connected vehicle will have the capacity to store and process a high volume of information and data about its users and the operating environment. This opens up endless possibilities for all the actors involved in mobility, proposing new paradigms for the industry and the actors involved.

On the one hand, the exploitation of the data generated may be used by manufacturers to adapt to the needs of consumers and to collect information on their own vehicles and offer new services. It will generate new relationships within the industry, with innovation and technology as the main driving force.

In terms of user impacts, connected vehicles are expected to increase efficiency in terms of fuel consumption and time use, contributing to emissions reduction and sustainability. These communications to connected vehicles will not only help with the driving task, but will also offer new services (e.g., internet connection, content delivery, trip planning, smart parking, preventive maintenance, etc.). The mobility of the future will be increasingly personalized, efficient and sustainable.



3.14.3. Technical challenges

The main challenge for the Directorate General of Traffic to meet the project objectives has been to design it in such a way that any of the actors / clients can integrate with the platform in a simple and attractive way to achieve the goal of incorporating the largest number of subscribers possible. The success of the platform largely depends on this point.

To facilitate the integration of a client system to the platform at the software development level, some connection libraries have been developed and are available within the platform. User authentication and authorization are configured within the platform. Along with these libraries, documentation is provided to guide participants through the integration process.

To expedite implementation, developers are provided with integration documentation via a Wiki in standard Markdown format along with the development source code. All material is provided in an open and constant GitLab compliant format.

To arrive at the design of the technical solution, a study of the functional and technical requirements for this platform was carried out.

These requirements have been obtained from the analysis of:

- DGT's strategy to reach the goal of 0 deaths, 0 injured, no congestion and no emissions
- DGT’s connected car strategy and autonomous car strategy.
- The state of technology and market trends.
- Use cases which will provide added value for road users regarding safety and contribute to useful information in their trips.

- The existing legal regulations on road safety. The identification of the legal and normative principles on which the new model of traffic information to users of the DGT is based.

Within the world of V2x communications there are two clearly differentiated models. The short-range ones, based on ITS G5 technology, and the long-range ones, which make use of traditional mobile data networks. In the case of the DGT3.0 platform, the second of these approaches has been chosen, as cellular networks provide convenient communication for the use cases and also in order to avoid an extra deployment of dedicated communication infrastructure which wouldn´t be feasible for giving services across Spain’s entire road network. Currently the coverage of 4G in Spain is 99.5% according to MINECO

The combination of these two elements, coverage and use of existing networks, allows the DGT3.0 project to have the ability to obtain information from any point of the country's road network, without having to deploy a network of sensors on it. Likewise, it is possible to send the information, following this scheme, to any vehicle at any point on the road network.

Through the different tests that have been carried out during the execution of this project, it has also been possible to verify that the use of these networks does not introduce a latency that prevents implementation of the use cases. As an example, tests of the dissemination of traffic light information dissemination showed that latencies of less than 300 milliseconds have been obtained from the generation of the SPAT messages from the source with the regulators until the arrival at the vehicles on the road. Therefore, current networks have demonstrated their ability to be used in all use cases of the DGT3.0 platform, without the need to resort to future infrastructure installations.

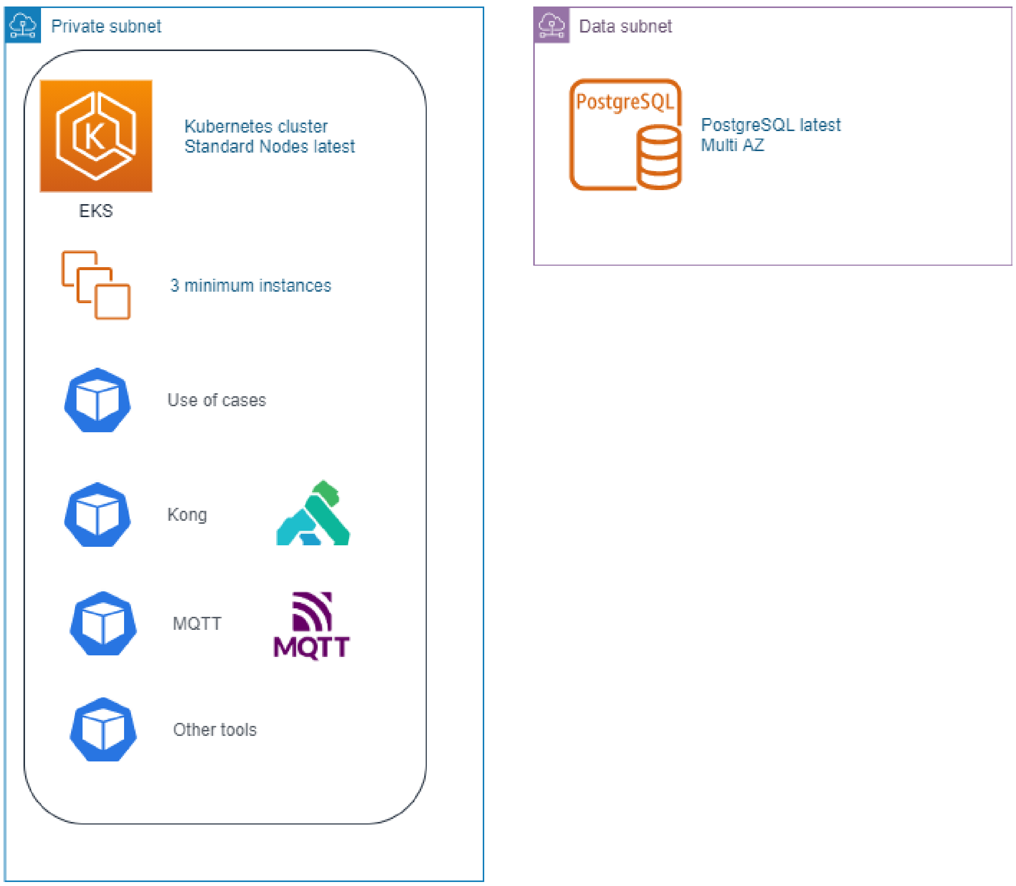
Looking to the future with the deployment of 5G networks, the possibilities for the platform are further improved. In this scenario, not only does it improve in terms of the micro latency provided by the network, but the use of distributed computing through the MECs (Multi-access Edge Computing) will enable new use cases that require greater intelligence and computing load.

The objective of the DGT3.0 platform infrastructure is to create a highly available, scalable, resilient, and replicable environment, providing the best possible service to the use cases that are deployed on it. To achieve this goal, KPMG's provider cloud team has designed an architecture of nested layers, relying on dozens of technologies, which are integrated properly.

All components in the architecture are deployed on the Amazon cloud (AWS) which offers the best resources in multiple regions across Europe and globally. This allows services to be operated and provided from anywhere on the planet if necessary. Another highlight is speed and agility when it comes to being deployed and having the services operational, allowing resources to be increased and decreased according to demand, needs, or the project stage.

The use cases are deployed on a Kubernetes cluster. Using these container-based technologies (Docker), high availability, scalability, and fault tolerance can be achieved, because the micro services can be up and running in few seconds. In addition, using other technologies such as Jenkins and Helm, and agile for the deployment of improvements and new cases, developers are able to test their code immediately. And finally, as a result of all of these technologies, the possibility of production problems is minimized and nearly eliminated.

All infrastructure used, such as the Kubernetes cluster, databases, use cases, etc.; are deployed through code, using Terraform, and other tools. This allows having identical and fully functional environments to be deployed in less than an hour greatly improving the deployment time compared to traditional architectures that could take weeks or months.



3.14.4. Non-technical challenges

Looking at the state of the art of the connected vehicle regulation in the EU, it can be concluded that the DGT 3.0 Platform is not only in line with EU mobility, road safety and traffic priorities, but also ahead of other countries, both within and outside the EU.

This is a new initiative within the EU and will set a precedent for other Member States. One of the biggest legal challenges is due to the novelty of this project, as it will force to lead, prioritize and simplify the different use cases that can be developed within the framework of connected vehicles, because despite the collection of a list of priorities in Europe and minimum information to be communicated, no officially closed or prioritized unified list has been established to indicate how they should be addressed, only the generic lines of the framework for action have been established.

Since this is a multi-party agreement, new parties can in principle only join the agreement if all parties to the agreement have given their consent. This creates an administrative burden and, moreover, carries the risk that it will take a long time for new parties to be able to join the SRTI Ecosystem.

However, by including a third-party clause or an authorization in the agreement, the negative impact of this disadvantage in our opinion can be limited.

The low-threshold entry of new parties is also important to guarantee the open nature of the SRTI Ecosystem and the equal treatment of market parties. If that open nature disappears, there are risks of violations of competition law and/or state aid law.

The European legislation that will have the greatest impact on the framework of the DGT 3.0 Platform will be that concerning data protection and privacy. The European Data Protection Committee has produced one of the most important guides when it comes to covering the connected vehicle and the DGT 3.0 Platform (Guidelines 01/2020 on processing personal data in the context of connected vehicles and mobility related applications), because it focuses on personal data relating to data processed inside the vehicle, data exchanged between the vehicle and the personal devices connected to it, as well as data collected inside the vehicle that is communicated to external entities for further processing.

3.14.5. Evaluation

Real-time systems aimed at processing large volumes of mobility data must be equipped with specific technologies and characteristics from the start. It is for this reason that when designing and developing a platform tailored to the current needs of the DGT, the design considerations included the current state of art and the ability to evolve over time to respond to the appearance of new communication technologies, new devices, new sources of information, new processing technologies including high speed or new spatial data processing techniques. These items are key consideration for mobility platforms.

The objective of all these technological advances is to improve road safety and reduce the number of accidents and accident victims. The intelligent mobility platform is expected to have a great impact on reducing accidents, reducing traffic, and therefore, a positive impact on the environment.

In this sense, the main challenge for the DGT so that this platform can meet the objectives for which it has been designed is that any of the actors that are part of this ecosystem can integrate with the platform in a simple and attractive way, allowing DGT to incorporate as many subscribers as possible. The success of the platform depends largely on this point.

The DGT 3.0 platform is part of the safe system approach, where technology is a fundamental pillar to achieve the goal of zero victims in traffic accidents by 2050. Connected vehicles are being deployed on our roads and we must take advantage of this opportunity to provide the user with maximum information that will undoubtedly save lives.

3.14.6. Future

The future of developments within the platform is highly conditioned by two aspects. On the one hand, the state of the art, which undergoes constant modifications and new technologies appear that can help to improve the use cases available until now and the design of the new ones. On the other, the needs detected by the different actors of road safety. Taking this into account the emergence of new technologies such as 5g, and with it the availability of new functionalities and increased transmission speed, will make it possible to implement solutions based on image analysis and load distribution using MEC technology.

Another important aspect is the improvement of geopositioning solutions that will allow knowing the location of vehicles with sub-metric precision and the use of updated cartography in real time.

3.15. Case Study 15 – Use of Bluetooth Data to Estimate Travel Times on HWY 30 on the South Shore of Montreal (Canada-Quebec)

3.15.1. Description

When it comes to modelling road flows on networks, travel time data are very useful, especially in the step of model calibration. Indeed, the ability of the model to reproduce travel times observed on site is one of the aspects to be refined during calibration, as well as the volumes of modelled trips compared to counting done on site.

In general, professionals acting on transportation are constantly looking for various sources of data to characterize traffic on the road network. This characterization is used to understand better the mobility and to propose the most appropriate improvement measures. The data can also be used to evaluate the effectiveness of measures that are already in place.

Bluetooth (BT) data can be used to characterize traffic by measuring the time it takes to travel an itinerary between two capture sensors of BT signal. The ability to collect and save a large group of "real, unprocessed" raw observations at low cost is among the advantages of this data. However, the processing of BT data presents a challenge to extract travel times in a simple manner appropriate to the study context. Before the appearance of this technology, the traditional method was to circulate "floating cars" on the network to calculate travel times at different times of the day on defined roads. However, this method was laborious and required much more time and preparation than installing Bluetooth sensors.

In 2018, professionals from the Ministry of Transportation (MTQ) working on the Highway 30 (A30) optimization project between the Highway 20 and Matte Boulevard on the south shore of Montreal were looking to measure travel times (or speed) during different hours of the day to characterize the axis and calibrate the microscopic model that was developed for the project. The use of Bluetooth sensors has proven to be the simplest and least expensive method to measure the variation of travel times in the axis. Thus, five Bluetooth sensors were installed at various locations along Highway 30 (A30) to collect data during the month of October 2018.

MTQ's Transportation Systems Modeling Department (TSMB) developed a three-step approach of processing the BT data using SQL programming. The first step analyzes the data at each BT sensor to identify the representative time of passage using a density-based data partitioning method ("clustering"). The second step calculates the "Raw Travel Times" (GRT) between sensors. The last step analyzes the RTTs to eliminate outliers and to calculate the "Net Average Travel Time" (NATT) between each pair of sensors.

The data processing allowed the creation of a speed profile in each section of the studied A30 Highway. The analysis of the results shows that the estimated NATT reflects the traffic fluidity during different hours of the day. The NATTs calculated in 15-minute intervals (NMPT15) over several days were then compared with average times from other data providers. The comparison shows the similarity of the general tendency of BT average travel times to the other data sources during the hours of the days studied.

In conclusion, the proposed approach is developed with intuitive parameters and transparent hypothesis that facilitate the interpretation of results and the identification of methodological limitations. This approach can be generalized and applied easily to other cases by using the same source code (SQL) to estimate travel time on the road network. In addition, the study identified best practices to be used on the selection of the installation sites of the BT sensors and on the characteristics of the sensors used.

3.15.2. Objectives

- The main objective of this case study is to valorize the Bluetooth data collected by the
- MTQ by developing a simple and transparent processing approach to measure travel times
- on highway sections which will be used in the modelling and planning process.
- Develop a simple, quick and transparent processing approach to measure Bluetooth travel times on highway sections.
- Develop an average speed profile for the A30 to better understand the traffic dynamics of the road and use this profile in the development of the project's microscopic model.
- Compare and analyze Bluetooth travel times with those from Google and HERE.
- Identify the benefits and limitations of using Bluetooth data to estimate travel times on the highway network (especially in the lack of other data sources).

3.15.3. Technical challenges

The challenges are at several levels:

- Technological: choosing the right sensor characteristics (collection radius and direction, range, power supply, device power, etc.).
- Installation: choosing a safe site that suits the collection objectives (ease of installation, suitable coverage, etc.).
- Processing: select an appropriate processing method. This method may be influenced by several factors such as target modes (car, bicycle, etc.), route lengths or desired results (instantaneous or average travel time), etc.

The characteristics of the sensors should allow to cover, as possible, only the desired zone; a sensor with wide coverage area will detect more undesired devices and may have a greater number of noisy data. In addition, greater the distance between the sensors, the less the impact of the margin of error on the estimation of the passage time at each sensor.

3.15.4. Non-technical challenges

User behavior influences the quality and interpretation of the results (number of devices per car, active device, type, etc.)

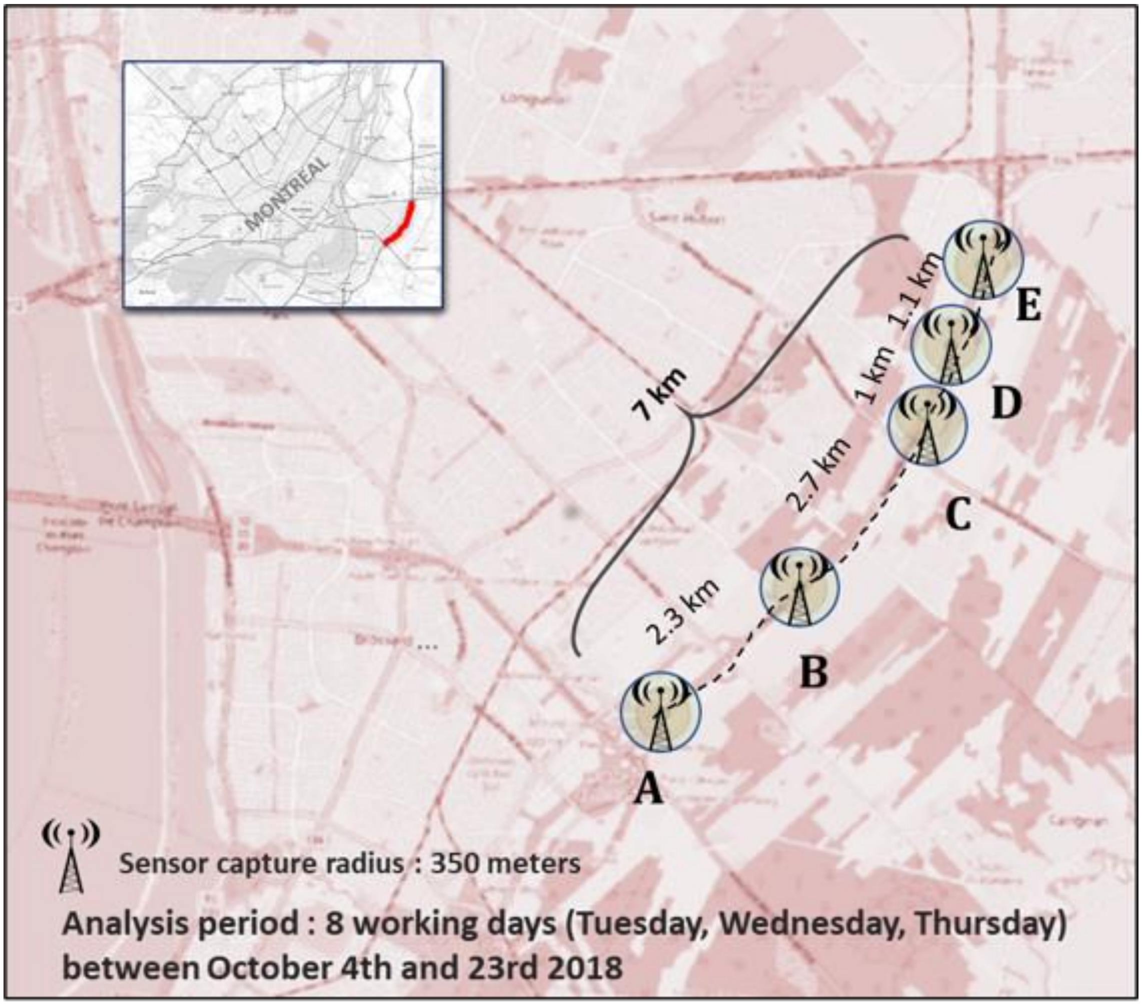
Privacy protection conducts users and device producers to block device detection.

Difficulty in validating results and understanding variances between different data sources in the lack of descriptive data explaining events and conditions in the field (obstacles, weather, accidents, etc.).

3.15.5. Evaluation

Five sensors were installed by MTQ in October 2018 along the A30 corridor and collection was conducted between October 4 and 23, 2018. The five sensors were assembled and installed in collaboration with two MTQ departments: the “Supervision and the Expertise in Exploitation department” and the “Circulation Department in Montreal Metropolitan Area”.

The average speed profiles of the ten routes for the eight working days in the study period were established (in 15-minute intervals), the



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illustrates the location of the five sensors and Table 1 gives the basic information about each route.

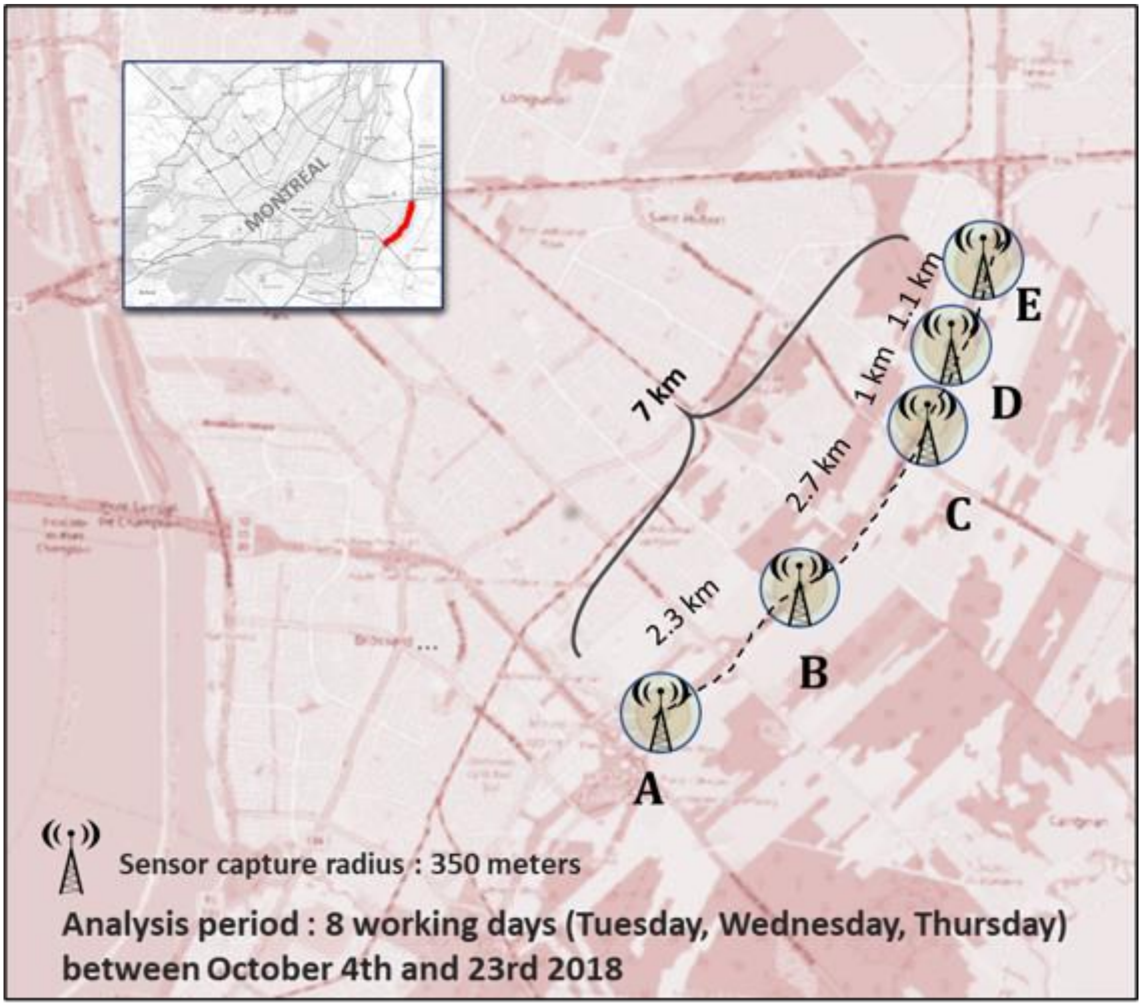

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Figure 18 – The case study zone

Table 1 : basic information about the studied routes.

route	1 east	1 west	2 east	2 west	3 east	3 west	4 east	4 west	5 east	5 west
Between sensors	A-B	B-A	B-C	C-B	C-D	D-C	D-E	E-D	A-E	E-A
Length (m)	2 329	2 329	2 709	2 709	938	938	1 086	1 086	7 062	7 062

The three-step approach used to process the BT data to obtain the travel time and speed is explained in detail in the annex and the following hypothesis are used in this study:

- Each BT device represents one vehicle.
- Each route has only one possible itinerary between two sensors, so the Bluetooth time between the sensors represents the time on the studied route.
- Each sensor has a radius of detection of 350 meters, and it covers 360°.
- No activity is possible on the path between two sensors (no voluntary stop).

Observations with extreme values are eliminated (< 10 km/h and > 1.2 * indicated speed). These values can be limiting to detect congestion if the speed drops below 10 km/h.

In our case, the distances between the sensors are not too long and the detection radius is relatively long, so a filter is applied to ensure the use of data with the less margin of error. To insure so, signals that are not in continual communication with a sensor while the detection are filtered out and removed. Specifically, signals detected at a sensor from one vehicle with a frequency of detection of more than 5 seconds between two consecutive detections are removed. This value was chosen after testing several values and it may be adjusted in other studies.

The annex presents more details about each step in the three-step approach.

Types of results obtained:

- The Figure 16 illustrates the variation of the average speed per 15 minutes for four routes.

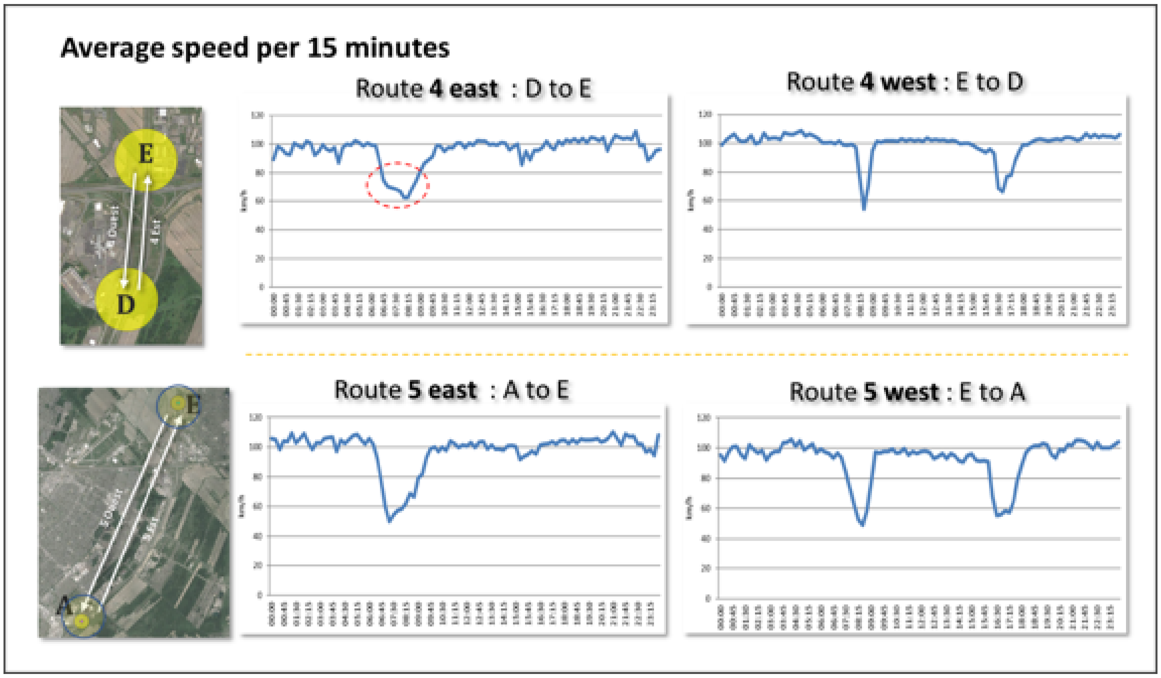


Figure 16 : The variation of the the average speed on four routes.

Comparison between different data sources:

For comparison purposes, an extraction of travel time/speed data was made from the two complementary data sources (HERE and Google Distance Matrix). The comparison between Google, HERE and BT speeds is done only for the same hours and days. The Figure 17 illustrate the variation of the average speeds from BT, HERE, and google data.

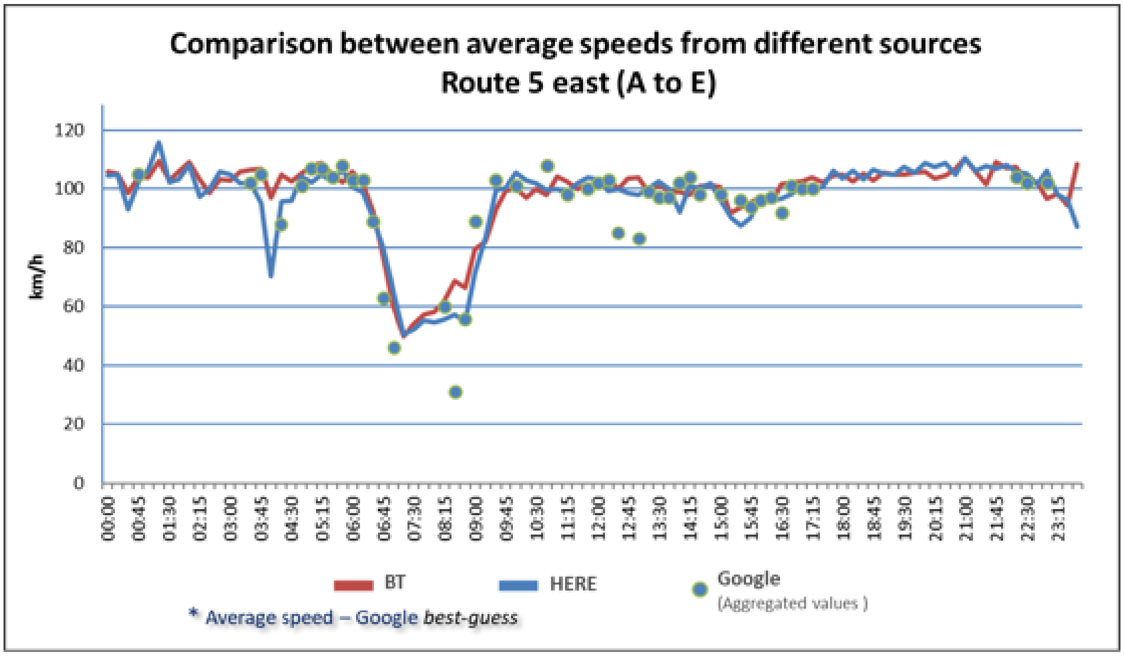


Figure 17 : comparison between the average speeds from BT, HERE, and Google data.

In general, the BT average speed curve and those of Google and HERE follow the same trend during the same period.

3.15.6. Future

The approach and the SQL code developed by DMST are valid for other studies that would use BT sensors.

The location of the BT sensors in our future studies will consider the fact that greater the distance between BT sensors, the less the impact of the margin of error on the estimation of the average speed. In addition, the selection of sensors characteristics will be made in connection with the study area and its environment.

In future studies, DMST would like to use floating cars to validate the results of its analyses and understand some of the changes in speed captured by BT sensors.

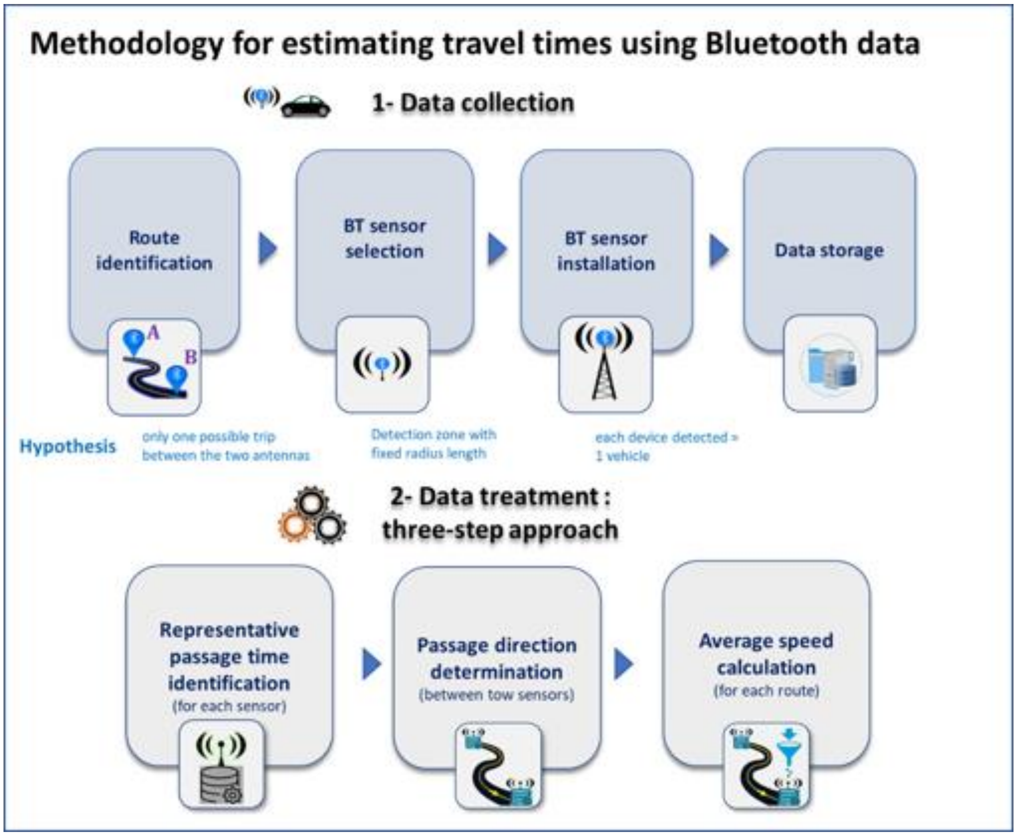
Further information

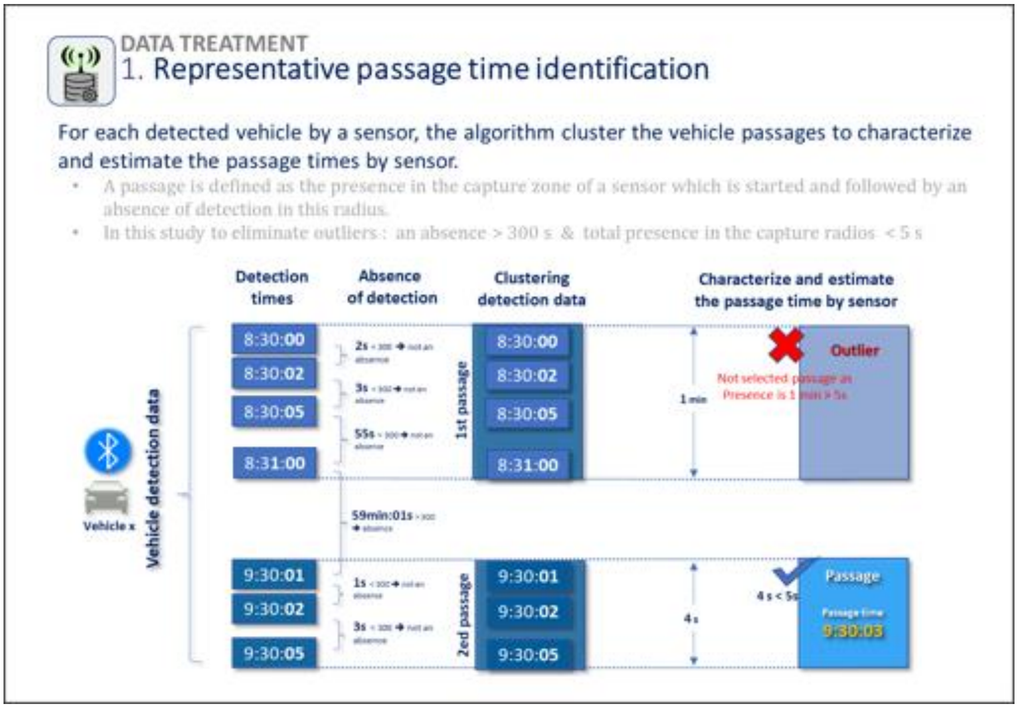
Cojoc I. and Bahbouh K., Methodology for processing Bluetooth data to estimate travel times, 2020 TAC Conference & Exhibition, https://events.decorporate.ca/TAC2020/abstract/event-schedule.php.

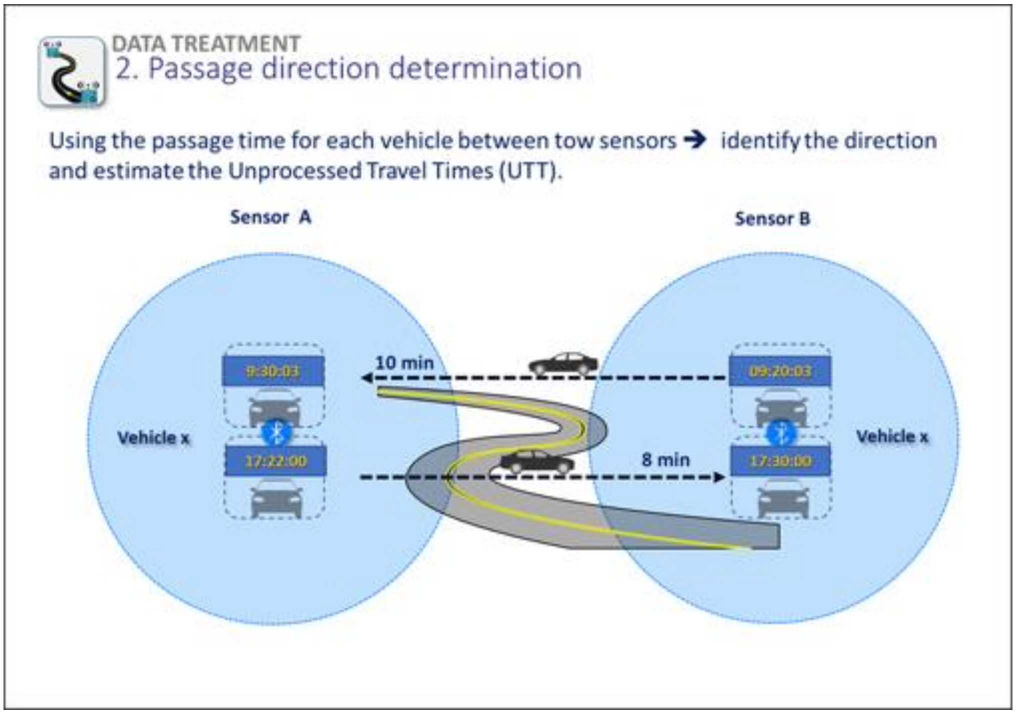
Ion Cojoc, Direction de la modélisation des systèmes de transport, Ministère des Transports du Québec, Ion.Cojoc@transports.gouv.qc.ca

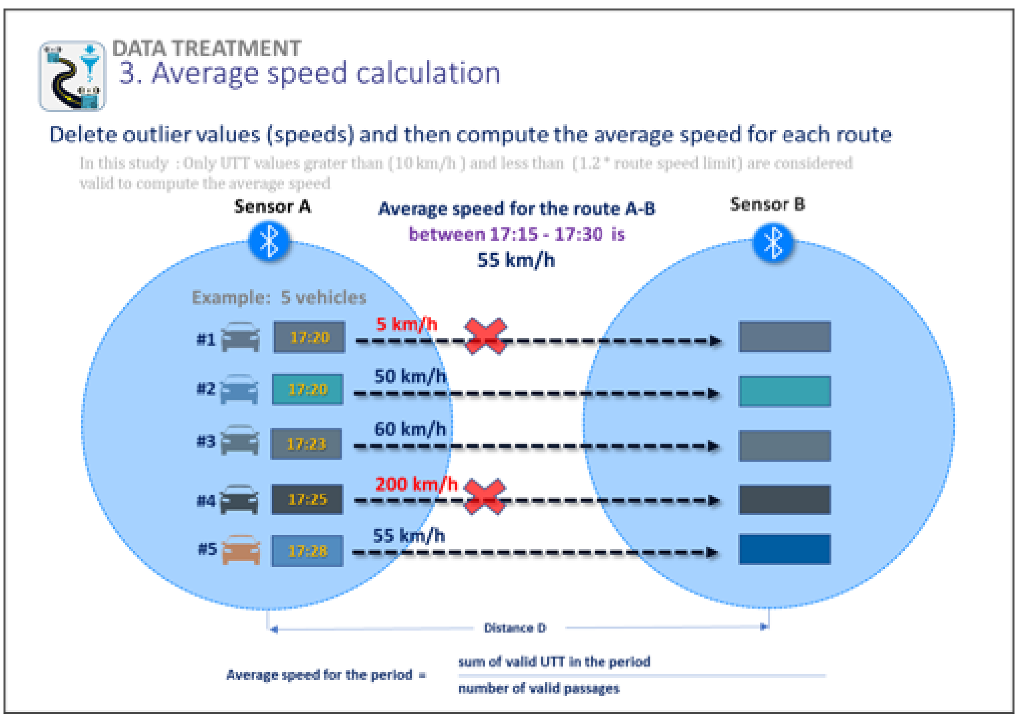
Kinan Bahbouh, Direction de la modélisation des systèmes de transport, Ministère des Transports du Québec, kinan.bahbouh@transports.gouv.qc.ca

Annex


Methodology for estimating travel times using Bluetooth data
1- Data collection
Route identification
BT sensor selection
BT sensor installation
Data storage
A
B
Hypothesis
only one possible trip between the two antennas
Detection zone with fixed radius length
each device detected = 1 vehicle
2- Data treatment : three-step approach
Representative passage time identification
(for each sensor)
Passage direction determination
(between tow sensors)
Average speed calculation
(for each route)


DATA TREATMENT
1. Representative passage time identification
For each detected vehicle by a sensor, the algorithm cluster the vehicle passages to characterize and estimate the passage times by sensor.
• A passage is defined as the presence in the capture zone of a sensor which is started and followed by an absence of detection in this radius.
• In this study to eliminate outliers : an absence > 300 s & total presence in the capture radios < 5 s
Detection times
Absence of detection
Clustering detection data
Characterize and estimate the passage time by sensor
Vehicle x
Vehicle detection data
8:30:00
8:30:02
8:30:05
8:31:00
2s
3s
55s
59min:01s
1st passage
1 min
Outlier
9:30:01
9:30:02
9:30:05
1s
3s
2ed passage
4 s
4 s < 5s
Passage


DATA TREATMENT
2. Passage direction determination
Using the passage time for each vehicle between tow sensors → identify the direction and estimate the Unprocessed Travel Times (UTT).
Sensor A
Sensor B
9:30:03
10 min
09:20:03
Vehicle x
17:22:00
8 min
17:30:00
Vehicle x


DATA TREATMENT
3. Average speed calculation
Delete outlier values (speeds) and then compute the average speed for each route
In this study : Only UTT values grater than (10 km/h) and less than (1.2 * route speed limit) are considered valid to compute the average speed
Sensor A
Average speed for the route A-B
between 17:15 - 17:30 is
55 km/h
Sensor B
Example: 5 vehicles
#1
17:20
5 km/h
#2
17:20
50 km/h
#3
17:23
60 km/h
#4
17:25
200 km/h
#5
17:28
55 km/h
Distance D
Average speed for the period =
sum of valid UTT in the period
number of valid passages

3.16. CASE STUDY 16 – REAL-TIME NETWORK SITUATIONAL AWARENESS PLATFORM (AUSTRALIA)

3.16.1 Description

"Situational Awareness" is delivered as one of the pillars of the "Smarter Roads" program. This program provides a package of investments aimed at uplifting the ability of the Victoria Department of Transport to manage the road network and deliver an improved experience for users of the network. This experience may ultimately be expressed as providing improved and more responsive network operations through changes to traffic signal operations and associated ITS systems and providing consumers with more accurately and timely information to allow them to make more informed choices to complete their journeys. Several packages of investments within the "Smarter Roads" program provide additional devices (cameras, sensors, messaging systems) installed in designated places across the road network.

The "Situational Awareness" application built on the "Optimal Reality" platform (developed by Deloitte Australia) is a system enabler for proactive management of the transport network, by creating a technical solution that enables implementation of new capabilities, incorporating more enriched datasets whilst leveraging and augmenting the systems/data that are currently used.

The solution provides real-time awareness of traffic conditions allowing Traffic Operation Centre (TOC) and complementary traffic management functions to apply appropriate and timely treatment(s) to:

- Maximise efficient traffic flow;
- Maximise the utilisation of road spaces; and
- Provides road users with most up-to-date information to help them make informed journey choices.

Vision

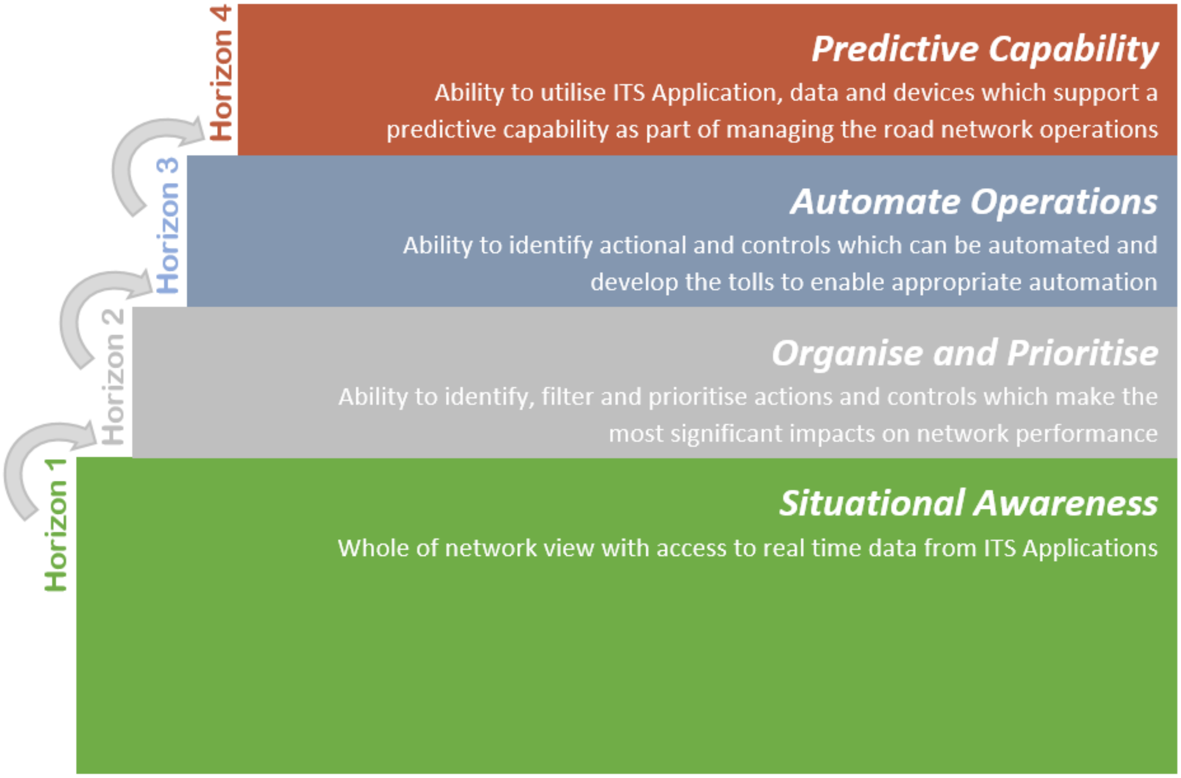
The ability to achieve an integrated transport network view comprises of visualisation and embedded traffic metrics of the entire traffic network's current performance (Common Operating Picture). The network view needs to include multiple modes of transport, incidents, events and congestion, with the ability to drill down to lane-level information. This aims to provide a clear understanding of the priority actions required to proactively manage the traffic network and communicate with users across transport modes and in real time.

Of note to this vision is the fact that any view of the current traffic network performance very much depends on the particular system user and their available control and intervention tools. It is about supporting many different perspectives on the different aspects of network performance being monitored.

The Department's outlook is that the Situational Awareness solution will have four levels of maturity as follows:

- Situational Awareness – whole of network view with access to real-time data from all ITS Applications;

- Organise and Prioritise – ability to identify, filter and prioritise actions and controls which make the most significant impacts on network performance;
- Automate Operations – ability to identify actions and controls which can be automated and develop the tools to enable appropriate automation (this requires control integration through a defined System to System Integration protocol); and
- Predictive Capability – ability to utilise ITS Applications, data and devices which support a predictive capability as part of managing the road network operations to enable options and network performance consequences to be presented in real time to enable effect decision making that benefits the road users.



3.16.2 Objectives

The objectives for this project at this phase are to provide a solution that will:

- Deliver a real-time Situational Awareness Solution providing a single “whole of network” view of the Victorian road network and its current condition.
- Extend to support multiple modes of transport to maximise traffic and passenger flows
- Present the situational awareness to users across all roles involved in managing the road-based transport network (Common Operating Picture).
- Enable proactive transport network management.
- Optimise performance of the road network
- Provides road users with most up-to-date information to help them make informed journey choices.

At this phase of the project, the solution is also expected to identify, organise and prioritise the locations where treatments/actions are needed for those most impacted road section(s) in order to minimise risks of unwanted disruptions and achieve maximum network performance outcomes.

Horizon 1 and 2 will be the initial delivery focus for this phase with Horizons 3 and 4 being considered for future development.

These objectives are to be met through:

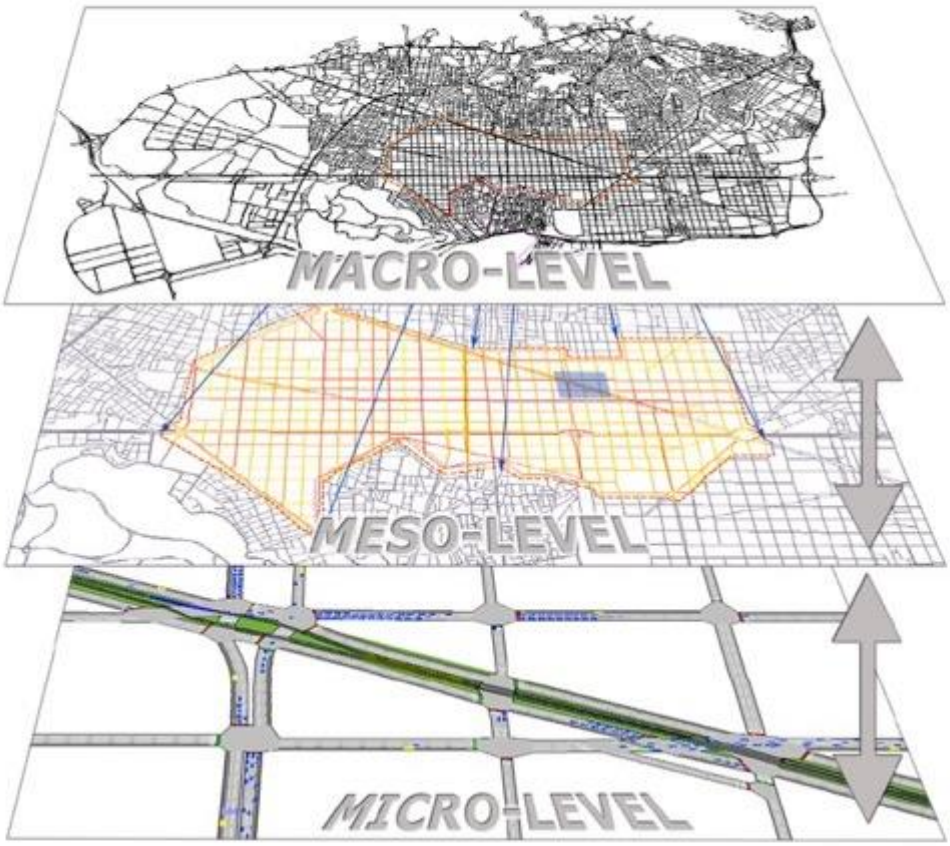
- Accessing ingested data including DoT's internal source systems (such as STREAMS – Motorway Management System, SCATS – Dynamic Adaptive Traffic Signal Control System, AddInsight -Bluetooth/WiFi detection technology, etc.) and external data sources (such as 3rd party traffic data, weather, social media, public transport and real-time traffic and road information, etc).
- Comprehending data and information from different sources and detecting relationships across current readings and events to present meaningful situational information to the operators and assisting them to make prompt and appropriate decisions/actions.
- Presenting the current state of the road network in a way that provides whole of network situational awareness in real time and that is accurate and relevant to each end user role.
- Enabling real-time assessment of the risks of undesired events.
- Providing end user functionality required to target situational awareness (e.g. zoom, search, filter) in order to determine appropriate actions.
- Providing visibility of the various road management actions carried out by all roles within DoT utilising the Situational Awareness Solution in managing the traffic network.

The table below outlines many of the source systems and services and data types to be ingested.

Source Systems / Services	Broad Data Types
STREAMS – (Motorway Traffic Management System) Travel time, tow allocation, active incident and roadworks on motorway, and device alarms SCATS – (Traffic Signal Control System) Vehicle detection, unusual congestion and device alarms AddInsight – Bluetooth Travel time and device alarms Security Center – CCTV live video streaming and device alarms External source/s for weather conditions and radar (Bureau of Meteorology) External source/s for a travel time (TomTom, HERE etc.) RWE – Traffic events and planned roadworks RAI – ITS asset management, ITS maintenance management, incident management and task management ETS – Enquiry tracking system for public queries SITREP – Situational Reporting database to identify currently active events Eyefi – Incident Response Vehicle GPS tracking and in-board video IRS - An electronic log of Incident Response Service incidents vMap – DoT mapping system which can provide layers of data mapped and geo-located to a standardized mapping system. PTV – Public Transport Victoria applications External source/s for Social media feed	Traffic data (real time and historic) including speed, volume, occupancy, travel time, classification etc. Control System operating information (real-time traffic signal and motorway control operating states and metadata) ITS asset locations (and other asset metadata) ITS asset operational and device states (including displayed information and device health) ESLS zone (arterial road electronic speed limit sign) display and device status Public transport timetables (current and planned) Public transport vehicle locations (real time) and variance from timetable Planned and unplanned disruption events Emergency events VicRoads incident response vehicle locations (real time) Emergency vehicle locations (real time) Designated Routes (for over dimensional vehicles, public transport services etc.) Clearway zones (no parking / kerbside stopping) Weather (current and forecast)

The ability to view the transport network from different perspectives is important for different users to access the information they need to take necessary actions, from operators through to organisational leaders. The application will enable the network to viewable from three different perspectives, as well as the ability to zoom into corridor segments or individual sites to access additional detail. The three principal views are like those adopted for transport modelling approaches, being macro, meso and micro views:

- Macro View - the highest-level view of the road network providing an overall strategic view of the entire road network with highly summarised information being presented.
- Meso View - a mid-level view of the road network providing a strategic view over a particular segment of the overall network and presenting summarised information about the current situation within this segment.
- Micro View - a detailed view of a portion of the road network, focusing on a particular section of road or a particular area. Highly detailed information is presented about the current situation and network performance.



(Source: Transport Simulation Systems)

To enable effective response to events occurring on the transport network, the application will enable an operator to identify, classify and pin events of interest to an active workspace. Operators will be able to associate various on-road devices, control system responses and network metrics with an active event to enable the evolving situation to be monitored and the performance tracked as response actions are applied. Operators will also be able to playback the network situation to determine event initiation and review the changing network performance and control system conditions leading up to the current network state.

3.16.3 Technical Challenges

The solution is ingesting data from more than 20 system sources (for the initial phase and more have been identified for subsequent phases) from both internal Department and external 3rd party data sources in real-time. Each data source has its own schema, characteristics, granularity, frequencies, quality and latency. Pulling all this data together and transforming them in real-time to be presentable on a common underlying network model is a challenge especially as each of the data source uses different underlying geospatial models.

The project has many technical integration points with existing Department systems and infrastructure which is serviced by multiple external Service Providers. This requires significant collaboration between the Department project team and Contractors to orchestrate every dependent change activity. Due to the very tight delivery time frame, many careful pre-planning activities are required which leaves little room for any major slippage or error from all Service Providers and Contractors.

Security compliance with the Department security policies/standards assurance is required and ensuring relevant ISM (Information Security Manual) controls based on the IVA (Information Value Assessment) Level are implemented according to the detailed design of the solution. This is followed by validation of the build against the design eventually leading to attaining IRAP (Infosec Registered Assessors Program) certification (as mandatory requirements) within the delivery timeline which poses many challenges.

Calibration of the application is also expected to take a while following initial implementation. In order to have metrics for comparison over time, the system will need to form a baseline over an initial period and settle. Various performance metrics need to be normalised from the fused or ingested data sources such as speed, travel time, congestion, density or occupancy, productivity, reliability and queue length values for every road segment and the entire network. This is required to ensure that any traffic event alerts, especially for those unplanned events, are presented to the operators accurately and appropriately (not too many that it overwhelms operators and not too little where it misses opportunity for any early intervention for network optimisation) as defined by the business rules.

3.16.4 Non-Technical Challenges

The application is a system enabler to transform the Department of Transport's Operations from a reactive to a proactive Transport network manager, and so deploying the application alongside the current response technologies and processes is only the beginning of further transformation. The Department of Transport's Operation Centre is undergoing a review of their "as-is" operational processes and incorporating the implementation of the application to determine the "to-be" process covering any planned and unplanned incidents, events, congestion, disruptions (across all modes) and emergency management. This poses a major change management challenge.

In addition, during the critical delivery stage of the application, the Department was undergoing a major restructure which added another layer of complexity to this change process.

The development and delivery of the application also occurred during significant COVID-19 pandemic restrictions and extended lockdown conditions also posed many collaboration challenges between the

Department Project team, Subject Matter Experts (SMEs), and the Contractor in delivering the solution. At the time of providing this case study report, all design, requirements gathering, and discussion occurred online with multiple teams and individuals all working remotely to deliver the solution.

Privacy impacts are an important aspect that the project team is very cautious about where the solution needs to ensure that it will not breach any of the privacy requirements. Some data by itself does not pose any concerns, however, when fusing with multiple data sources there is the potential for a breach of privacy requirements. Hence, an extensive privacy impact assessment (PIA) was conducted.

Some of the future operational challenges when implementing automation in Horizon 3 are:

- Standardising and agreed on a standing operating procedure for respond and controls between Transport Operation Centre and various transport operators across modes; and
- Timeliness of any event response with dissemination of information needed to travellers across different modes to pre-plan their transport choices and for those impacted by an event providing information that can help minimise the impact to their remaining journey.

Due to the budgetary and program timeline constraints, the Department has 12 months to deliver well over 200+ functional requirements and another 100+ non-functional requirements leading to thousands of test cases for acceptance and so testing poses a huge challenge.

3.16.5 Evaluation

With the application currently in the delivery phase of the project (at the time of authoring this case study), the main tools, operational application and system assessment are yet to occur and so an evaluation of the first two initial phases of the production system is not available at this stage.

3.16.6 Future

The current implementation of the application only provides the real-time situational awareness common operating picture and some degree of organise and prioritisation (Horizon 1 and part of Horizon 2).

The aim of the subsequent phase(s) is to provide:

- More in-depth micro view of the road network down to lane level with various approaches at traffic intersections;
- Enhance the multi-model integration of various modes of transport;
- Extend the automatic incident detection capability (through AI video analytics) with technology able to detect potential traffic incidents on all approaches of traffic intersection;
- Integrate with the Department’s existing traffic control systems to allow control of traffic devices such as traffic signals and electronic signs through a single unified user interface; and
- Allow the data associated with any traffic event (within the previous 12 months) to be played back – current delivery only allow for one peak traffic cycle.

Future functionality is also planned to enable predictive and future network state capabilities (Horizon 4) to allow the Department Transport Operations Centre to understand the potential impact to network performance that traffic controls or road closure implemented can cause. It also aims to be able to predict in advance what the traffic condition going to be like based on all data, baseline and simulation, such that advance notice could be provided to road travellers to allow them to make informed decision to avoid congested areas leading to a smoother travel experience.

Further information

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3.17. Case Study 17 – Automatic Classification of Road Visibility Conditions by AI (Canada-Quebec)

3.17.1. Description

To ensure the safety of road user and to prevent accidents caused by poor visibility (often caused by driving too fast while the driver can not see far enough ahead), it is necessary to monitor the visibility distance on roads in storms or fog, for example. To do so, employees of the Ministère des Transports du Québec (MTQ) periodically evaluate visibility conditions using existing traffic cameras and can raise alarms when the visibility distance reaches an unsafe level. This study aims to demonstrate the possibility of automating this evaluation using an artificial intelligence (AI) approach applied to traffic camera images. This automation would allow for continuous sight distance assessment across many cameras without increasing employee workload.

Most of the traffic cameras are located at high elevation and are oriented towards a road section. To limit the type of images on which the automatic evaluation must operate, only images from traffic cameras were used in this study. The evaluation would not be reliable for other types of images, such as those produced by dashcams or images taken at ground level. The manually assessed sight distance levels were separated into three categories: "Good" for visibility greater than 500 m, "Reduced" for visibility between 250 m and 500 m, and "Null" for visibility less than 250 m. These thresholds are summarized in Table 1. The automatic categorization takes these three visibility levels and introduces the new category "Invalid", which is assigned to images that do not allow visibility to be determined. Images that are corrupted, have a bad viewpoint, or too dark in night conditions were classified as "Invalid".

The approach chosen to automatically detect the visibility category is to use a supervised deep learning classification network. Images from 225 traffic camera viewpoints and 40 weather station camera viewpoints were harvested. A total of 26,540 images were harvested during the winter 2020-2021 period. Of these images, 8,460 were annotated for supervised learning of the neural network. In order to quickly verify the possibility of AI detection of sight distance, the GoogLeNet classification network, pretrained on the Places365 dataset, was selected to apply transfer learning with our annotated image bank. Among the annotated images, 80% were used for supervised training and 20% were kept for validation.

At the end of the training process, the validation performance was 90%, i.e., the automatic detection estimated the correct visibility category for 90% of the images selected for validation purpose. By applying category balancing, a performance of 80% was achieved. The 10% drop was due to the increased amount of "borderline cases", as the proportion of images in the "Good" visibility category was much higher than the other categories. Often, a borderline case is an image whose visibility is near the boundary between two categories. The network was also tested with a post processing of images from weather stations equipped with a visibility sensor. The resulting visibility category of the network was compared to the visibility distance measured by the sensor. Most of the poor visibility cases are well detected. It should be noted, however, that the sensor viewpoint can affect the detected category for the same location at the same time.

In conclusion, visibility detection by AI on images seems to be possible. A dataset has been built and a neural network trained on this data gives good results. In the future, this type of approach could be used on many cameras in real time as a "decision aid" and an alert could be raised when visibility conditions deteriorate in an area.

3.17.2. Objectives

The objective of this project is to develop a decision support tool to assist operators monitoring traffic. Indeed, different messages could be displayed on variable message sign and operators can modify messages according to the tool. This tool will automatically detect the visibility category in an objective way using robust AI techniques. More precisely:

- Collect an images dataset of various winter weather conditions recorded by MTQ cameras.
- Annotate the dataset according to the visibility categories used at MTQ.
- Develop an AI-based visibility category detection method with supervised training on the dataset.
- Allow a mass evaluation of visibility conditions on the cameras owned by MTQ.

3.17.3. Technical Challenges

- The MTQ uses Genetec's software to monitor the traffic cameras. This software only allows export of videos instead of image capture. In order to obtain images for the dataset, five second videos were extracted from all cameras at various times during the winter. A software utility was then created to extract an image for each video file.
- The quality of images recorded at night in some unlit areas are not good enough to determine the visibility category. These images have been classified as "Invalid". In order to be able to detect these cases, another type of detection, with lighted bollards, could be used.
- Since our dataset does not have as many images as the Places365 dataset, some measures must be taken to avoid overtraining. Thus, the training of the network is stopped when the validation performance deviates too much from the training performance.
- Since no classification network is perfect, the detection of the visibility category may be erroneous. A moving average could be applied to the detection over time to limit false alarms.

3.17.4. Non-Technical Challenges

- During the collection of the images dataset, it was noticed that cases of poor visibility were infrequent, especially cases of "Null" visibility. The reliability of the automatic detection of these cases would be reduced if the actual visibility category was used. In order to obtain more cases in the poor visibility categories, the category threshold was raised. The dataset is therefore more "severe" on the visibility categories.
- Since the main objective of the study was to explore the possibility of AI visibility classification from images, a relatively simple network was used in this study. The GoogLeNet network was selected since it is a good starting point as a relatively small

network. The variant pretrained on the Places365 dataset was selected, as the content of the camera images is more scene-like than object-like.

3.17.5. Evaluation

- The validation performance on the dataset is 90%. Figure 1 shows examples of cases where the network estimated the correct category. Figure 2 shows cases where the network did not estimate the correct category. Some cases of poor detection are due to borderline cases and could have ended up in another category when annotating the images. Ideally, weather experts should review the image annotation.
- The confusion matrix shown in Figure 3 shows the number of predictions for each type of visibility. It is found that detection errors occur more frequently on categories close to each other.
- The detection category is shown at a weather station site with a visibility sensor in Figures 4 and 6. The black line represents the visibility sensor result while the background color represents the category detected by AI. The maximum value of the visibility sensor is constrained to 3 km. The colors represent the following categories:
  - Gray: Invalid image
  - Green: Good visibility
  - Yellow: Reduced visibility
  - Red: Null visibility
  - Dark gray: Station failure (no data).

An example image of these viewpoints where the detection category diverges is shown in Figures 5 and 7. The "Invalid Image" category periods in Figure 6 correspond to nighttime periods, as this viewpoint contains no light sources.

On a computer equipped with an Nvidia Quadro RTX 5000 graphics card, the speed of network prediction on a series of images is 150 frames per second.

3.17.6. Future

- Test the AI approach on different neural networks in order to increase detection performance.
- Harvest more images of poor visibility to prevent neural networks from being overtrained.
- Implement real-time detection to raise alerts in poor visibility conditions.
- Have weather experts review the image annotation.

Further information:

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Visual Content

Table 1 - Visibility Categories

Category	**Threshold**
Good visibility	Visibility > 500 m
Reduced visibility	250 m < Visibility < 500 m
No visibility	Visibility < 250 m

Figure 1 - Examples of good detection

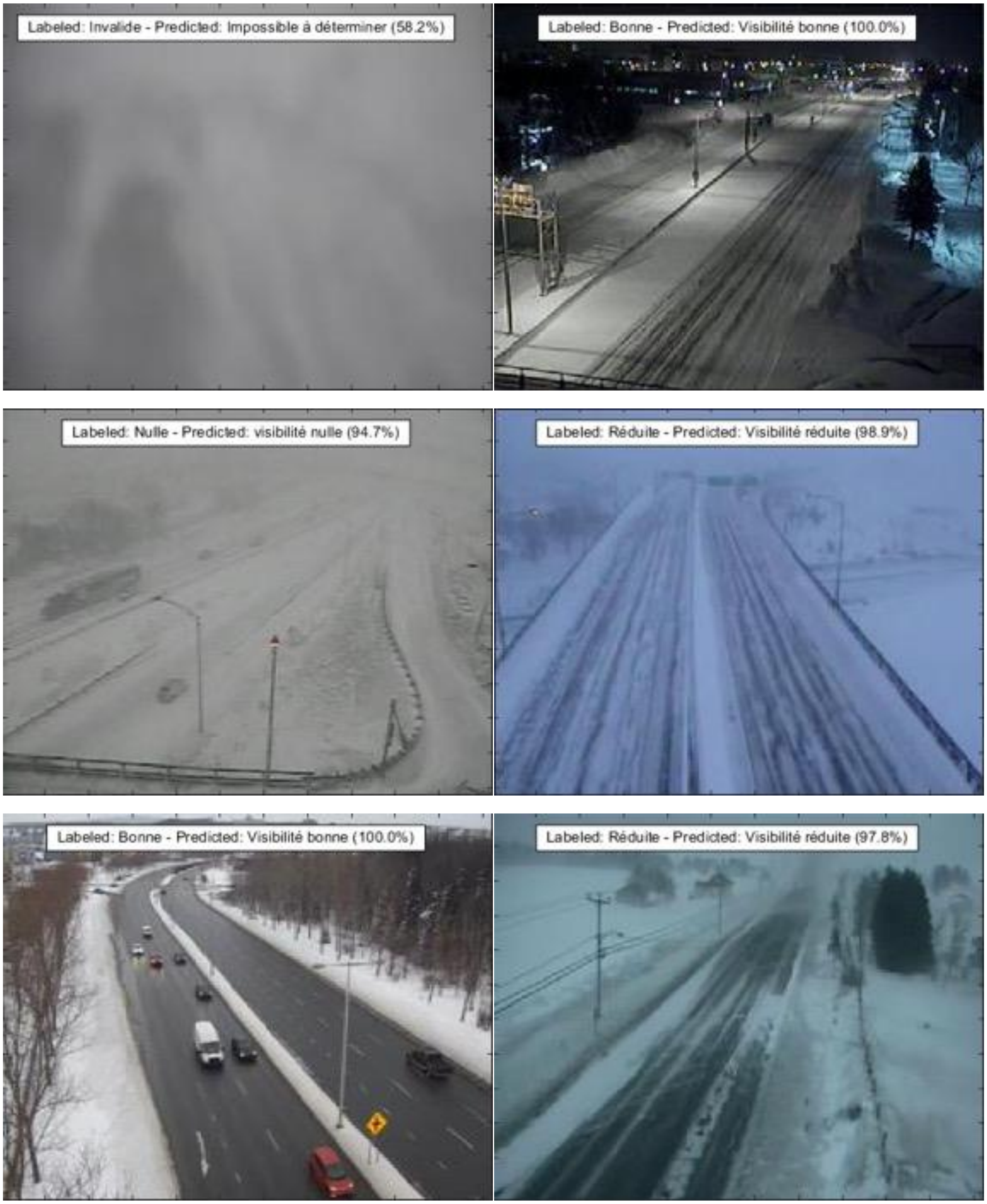
Labeled: Invalide - Predicted: Impossible à déterminer (58.2%)
Labeled: Bonne - Predicted: Visibilité bonne (100.0%)
Labeled: Nulle - Predicted: visibilité nulle (94.7%)
Labeled: Réduite - Predicted: Visibilité réduite (98.9%)
Labeled: Bonne - Predicted: Visibilité bonne (100.0%)
Labeled: Réduite - Predicted: Visibilité réduite (97.8%)

Figure 2 - Examples of poor detection

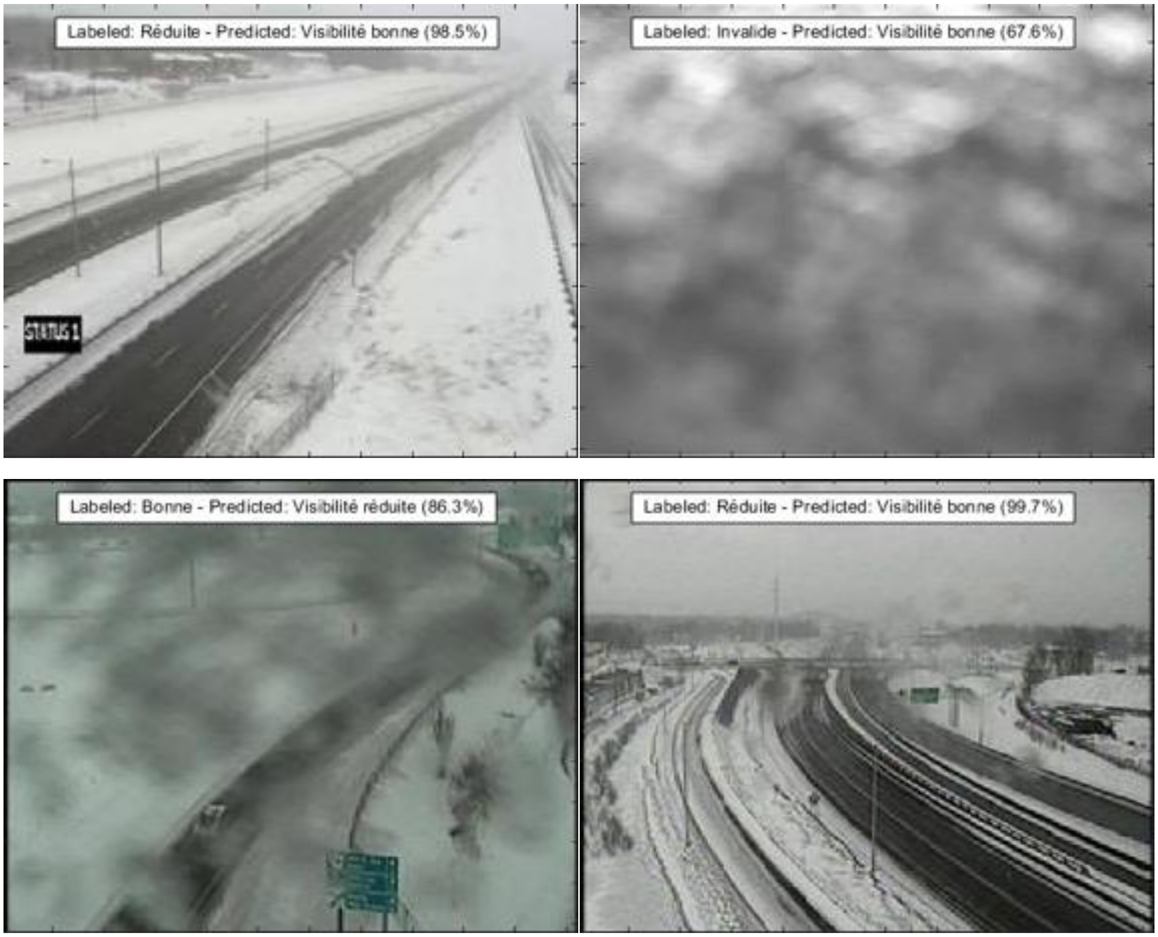

Figure 3 - Confusion Matrix

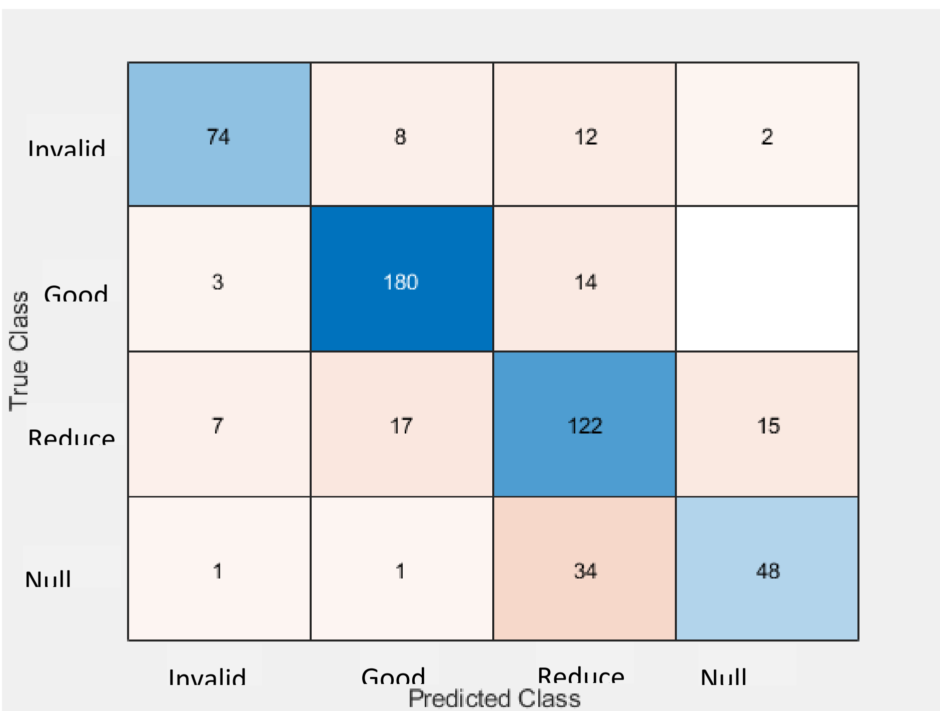

Figure 4 - Comparison with a visibility sensor, view 1 (Gray: Invalid image, Green: Good visibility, Yellow: Reduced visibility, Red: Null visibility, Dark gray: Station failure (no data)).

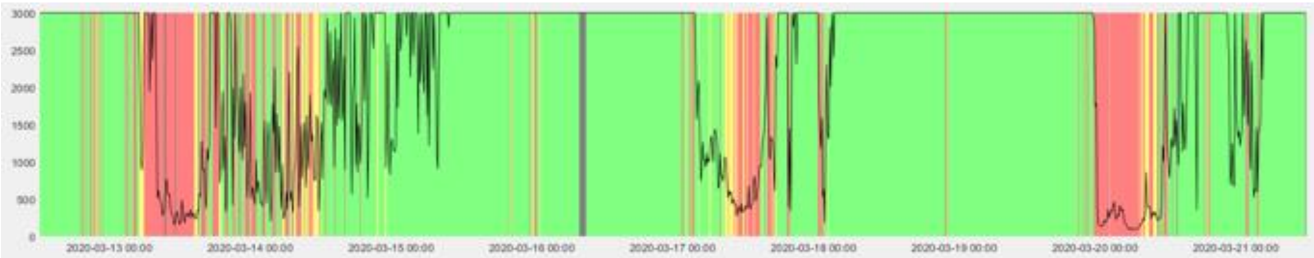

Figure 5 - Image synchronized with the visibility sensor, view 1

Figure 6 - Comparison with a visibility sensor, view 2 (Gray: Invalid image, Green: Good visibility, Yellow: Reduced visibility, Red: Null visibility, Dark gray: Station failure (no data)).

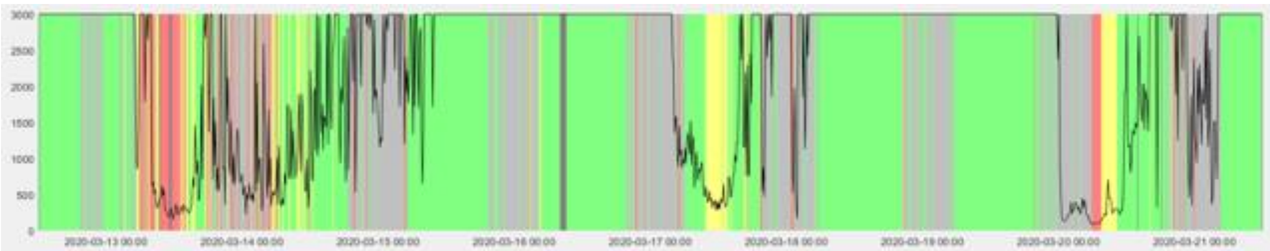

Figure 7 - Image synchronized with the visibility sensor, view 2

3.18. Case Study 18 – System that uses Big Data to Identify Passable Roads After Disasters (Japan)

3.18.1 Description

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) developed and deployed the Traffic Record Display System that collects and visualizes traffic records using vehicle's probe data. This system allows users to display traffic records on a map using ETC2.0 probe data. ETC 2.0 probe data is collected by using road-to-vehicle communications via the network of about 3,000 roadside units installed across Japan. The probe data displayed on the map is updated every 15 minutes. By displaying the probe data on the map, users can determine the accessibility of all the sections of roads travelled by vehicles equipped with ETC2.0 on-board units. This enables them to identify passable roads in areas impacted by a major disaster. In addition, this information can be used in rescue operations and transport of goods. The system is available within the MLIT network and is being used by Regional Development Bureaus to respond to disasters. Furthermore, MLIT is using the system in combination with field surveys to create "Passable Maps." The maps are published on MLIT's website and contain information on passable and non-passable roads during times of disaster.

How this system has been used is illustrated by an example from a real disaster response.

In 2020 heavy rains struck a wide area of Japan, mainly in the southern part of Kumamoto prefecture. This led the Japan Meteorological Agency to issue an emergency heavy rain warning for the prefectures of Kumamoto and Kagoshima on July 4 at 4:50 a.m. The disaster caused enormous damages across a wide area, including 86 dead or missing persons, 77 injuries, 6,129 fully or partially destroyed houses, and 6,825 inundated houses. It also caused road closures on many routes for reasons such as bridge runoff, sediment runoff, slope collapse, and road collapse.

On July 5, the Prime Minister temporarily established an Emergency Response Headquarters in the Cabinet Office to address disaster response.

MLIT set up Emergency Response Headquarters at the ministry itself and at regional development bureaus, and gathered and published information on emergency road closures. In Kyusyu Regional Development Bureau, was put on red alert on July 4 at 3:50 a.m., and created the map (Figure 1, Passable map) summarizing the road status in the area based on the traffic record from ETC2.0 probe data. They published it on the Internet on July 4 at 5:00p.m. After that, they gathered information through field surveys, and if there was a change in the passable roads, they updated the maps from the previous version and re-published.

Fig. 1: The publicly available Passable Map (first version)

Source: Kyushu Regional Development Bureau

(http://www.qsr.mlit.go.jp/site_files/file/bousai_joho/bousai200704_1700map.pdf)

3.18.2 Objectives

In the event of a disaster, it is necessary to provide drivers with road closure information as quickly as possible. In the past, field surveys were necessary to determine the locations of road closures, but Japan has more than 1.2 million km of roads over about 380,000 km2 of land. It has been very difficult for road administrators to study all roads by themselves. The field survey process involved first gathering information and identifying disaster sites, and then conducting field studies and providing information on road closures. However, the issue with this process was lack of immediacy due to the time it took to collect the initial information. As a result, there has been demand for a system that provides road administrators with real-time information on non-passable roads and traffic restrictions.

3.18.3 Technical Challenges

The Traffic Record Display System can display the following types of information overlaid on a map: traffic records derived from vehicle probe data, including private-sector probe data provided by ITS Japan and ETC 2.0 probe data from the approximately 3,000 ETC 2.0 roadside units installed across Japan, which is collected by MLIT using vehicle to roadside communication, as well as road regulation information from VICS (Vehicle Information and Communication System). This system has made it possible to visually grasp the traffic status of all roads in Japan, and it is useful after large-scale disasters to identify passable routes that can access disaster areas.

Since MLIT built the Traffic Record Display System in 2013, we have been using it in road administration, for example, to grasp whether a road is passable after damages due to a large-scale disaster. In 2018, MLIT upgraded the system to respond to current needs. The following aspects of the system were improved: (1) display of number of passing vehicles, (2) segmented display by road type, (3) immediacy of data, and (4) displayable time frame.

(1) Display of number of passing vehicles

The Traffic Record Display System displays the sections of vehicle travel for vehicles with ETC 2.0 on-board units as lines on the map.

Before the upgrade, the system would display the movement of one or more vehicles as traffic records on the map. In practical use, however, urban areas and mountainous areas use different standards to determine the road is passable, and what users want to confirm in terms of the number of passing vehicles may vary depending on the circumstances. For that reason, users need to be able to adjust the settings freely to fit the local traffic situation.

Given this, the system was improved to display the number of passing vehicles classified by category. Specifically users can adjust the settings for (1) number of categories displayed, (2) classification by number of passing vehicles (threshold for maximum and minimum values for number of passing vehicles), (3) display for each road type (color and width of displayed lines), and (4) whether to show/hide the lines

(2) Segmented display by road type

Before the upgrade, the system would display traffic records on the map by road type in two categories: expressways and general roads. On general roads, the individual regional development bureaus of MLIT serve as the road administrators for directly managed national roads, while local government bodies serve as the road administrators for other general roads. Therefore, when considering rescue operations or detours, it cannot be determined from the map which road administrator is in charge. This led to the issue of delayed disaster response, so the system was improved to allow for segmented display by road type.

Specifically, users can adjust the settings for whether to display or hide (1) expressways (expressways/urban expressways), (2) directly-controlled national highways, and (3) other roads (subsidized national highways/principal local-roads/ prefectural roads/ordinance-designated city roads).

(3) Immediacy of data

Before the upgrade, the system would aggregate the number of passing vehicles in one-hour intervals. However, if a disaster occurred immediately after aggregation began, it could take nearly two hours at maximum to output the number of vehicles that passed the road after the disaster occurred. This was an obstacle to prompt response, so data aggregated in 15-minute intervals was added, enabling earlier output of the number of passing vehicles post-disaster.

If a disaster occurred at 12:10, it would previously have taken until 14:00 to output the number of passing vehicles, but now it only takes until 12:30, potentially shortening the maximum output time by 1.5 hours.

Also, the one-hour interval of aggregation for the number of passing vehicles is still available after the upgrade.

(4) Displayable time frame

Before the upgrade, the system would allow users to display the eight most recent days of data in one-hour intervals in comparison to the same day of the previous week. It would also display the traffic records superimposed in one-hour units, but it could not display continuous periods of traffic records. For that reason, there was a short displayable time frame to confirm the transitions of traffic records from past disasters, which posed a problem in terms of user-friendliness.

In order to resolve the issues above, the system was improved to increase the displayable time frame to the past year and also made it possible to re-aggregate and display traffic records for a maximum of 48 continuous hours. These improvements have made it easier to use the system to investigate traffic records from past disasters.

3.18.4 Non-Technical Challenges

The current penetration rate of vehicles equipped with an ETC2.0 unit is approximately six percent. As the number of ETC2.0 compatible car navigation systems increases in the future, it will be possible to provide even denser and more accurate information on traffic conditions by increasing the amount of actual traffic data during disaster. If there is not enough ETC2.0 probe data, it is not possible to determine whether a section with a small sample size is impassable or not. In order to overcome these problems, it is necessary to promote the ETC2.0 compatible car navigation systems and to examine the possibility of adopting more probe data held by private companies.

The system determines a road section is passable when “the number of ETC2.0 probe data observed at the section” is over “the threshold set by a road administrator in the region.” Therefore, the section on which no vehicle (or vehicles fewer than the threshold) were driving due to low traffic demand is not regarded as “passable section.” Although this is the limitation of the system, providing the information on passable sections can help road users make decisions which routes to take.

3.18.5 Evaluation

The Traffic Record Display System has aggregated and visualized traffic records so that road administrators can promptly grasp which road section is passable. This has made it possible to promptly provide road users with information on road closures after a disaster occurs.

3.18.6 Future

In the future, it is important for the Traffic Record Display System to be used effectively and as a planning tool for road administration. To achieve this, it is intended to evaluate the system by gaining an understanding of the needs and opinions of regular users, and to implement function improvements accordingly.

Further information

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3.19. Case Study 19 – Automated Diversion System for Wind and Fog (Spain)

3.19.1 Description

The dual carriageway Cantabrian Motorway or A-8 extends along the coast of the Cantabrian Sea, linking the Basque Country, Cantabria, Asturias and Galicia. The A-8, with a length of 486 km, begins in Bilbao at the junction of the AP-8 with the AP-68 and ends in Baamonde (Province of Lugo) where it joins the A-6.

In February 2014 the sections Mondoñedo-Lindín and Lindín-Careira were opened, passing through the municipalities of Lourenzá, Mondoñedo, Abadín and Pastoriza. These sections comprise 15.9 km of dual carriageway that runs southeast of the old N-634. The infrastructure consists of 2 carriageways, each with 2 lanes of 3.5 m, outer verges of 2.5 m and inner verges of 1.0 m, separated by a median between 2.0 and 6.0 m wide depending on the section.

These sections of dual carriageway have required important and complex engineering work as they run through very rugged and geotechnical complicated terrain. For this reason, important cuttings, superficial and deep drainage works, supporting walls in the mid-slope sections and many structures of different types have been constructed. Among them, the Fiouco viaduct stands out.

The implementation section of the study on the section of the A-8 corresponding to the Alto del Fiouco, which lies between Kilometer Posts (KP) 545+500 and 549+500, runs at 700 m above sea level and presents two main problems: high winds and lack of visibility due to fog.

Since it opened in February 2014, there have been numerous episodes of intense fog that have caused multiple major collisions. On 26 July 2014, the most serious multiple collision took place, involving a total of 39 cars and trucks and resulting in 1 person killed and more than 40 injured to varying degrees. From that moment on, specific measures were implemented to mitigate the effects of fog on this section of the A-8.

3.19.2 Objectives

The objectives of the initiative are listed below:

- Provide a coordinated framework for action in the event of a traffic situation conditioned by weather conditions.
- To inform road users about the weather conditions on the road and the necessary adjustment of speed or diversion.
- Contribute to road safety in adverse weather situations associated with fog and intense winds.
- Contribute to optimal traffic management: information on adverse weather episodes on the roads enables Traffic Management Centers to make decisions quickly and efficiently.

3.19.3 Technical Challenges

Based on the meteorological records of the visibility distance in the presence of fog and the intensity and direction of the wind in the area, an action protocol was defined for this section of the highway to adapt the speed limit for vehicles according to the meteorological conditions at the time, also taking into account what is indicated in the Spanish national Instruction 3.1-IC («BOE» of February 2nd, 2000) in relation to visibility and stopping distance.

In the case of wind speed, the protocol establishes three levels similarly to the traffic light color code: a first level (green level) of recommendation of moderation of traffic speed when the wind speed exceeds 30km/h and two levels of restriction of traffic speed limit to 80km/h (yellow level) if the wind speed exceeds 50km/h, and speed limited to 60km/h (red level) if the wind speed exceeds 80km/h.

In the case of fog and reduced visibility, four levels are established: one level of recommendation and three levels of restriction. In the first level (green), when the visibility distance is between 120 and 250 meters, moderation of traffic speed is recommended. In the second level (yellow), with visibility between 60 and 120 meters, the speed limit is restricted to 80 km/h. In the third level (red), with visibility between 40 and 65 meters, speed is limited to 60 km/h and finally, when visibility is less than 40 meters (black), the highway is closed and the diversion is activated.

Figure 1- Protocol for action in the presence of fog and/or wind

Automated diversion and action protocol in the presence of fog and wind

The main objective of automated diversion is to optimize the time necessary to implement the diversion or opening of the road until it becomes effective, ensuring the safety of users and improving the management of the operation of the road.

The aim is to facilitate the diversion methodology, reducing the number of agents involved and therefore reducing the time required for coordination between them.

The current diversion methodology proposes application of new technologies to send/receive information on road conditions and monitoring of offending vehicles and alternative routes in real time. For this reason, various ITS equipment such as Variable Message Panels, Beacons, CCTV and Traffic Light Signaling are installed in the area.

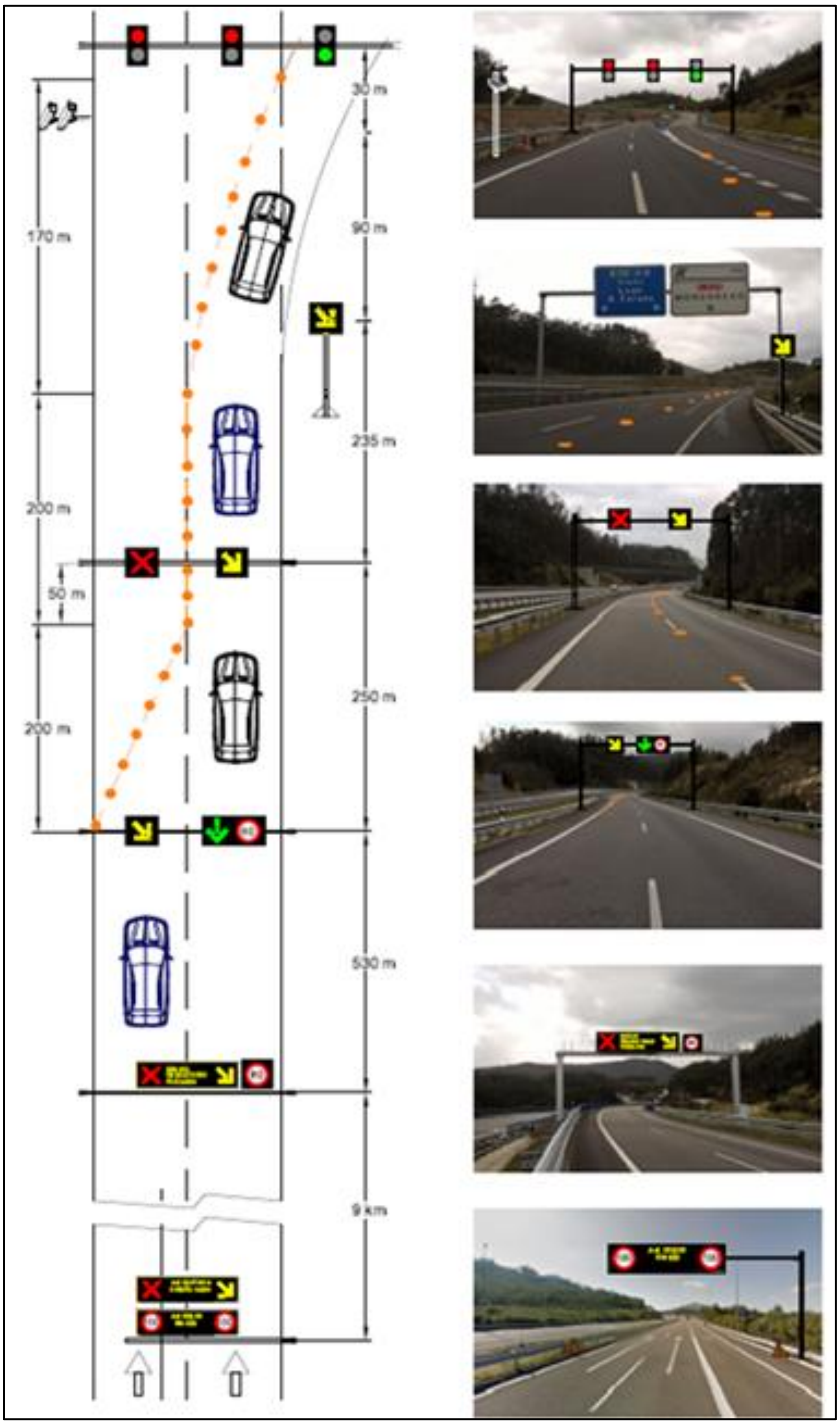
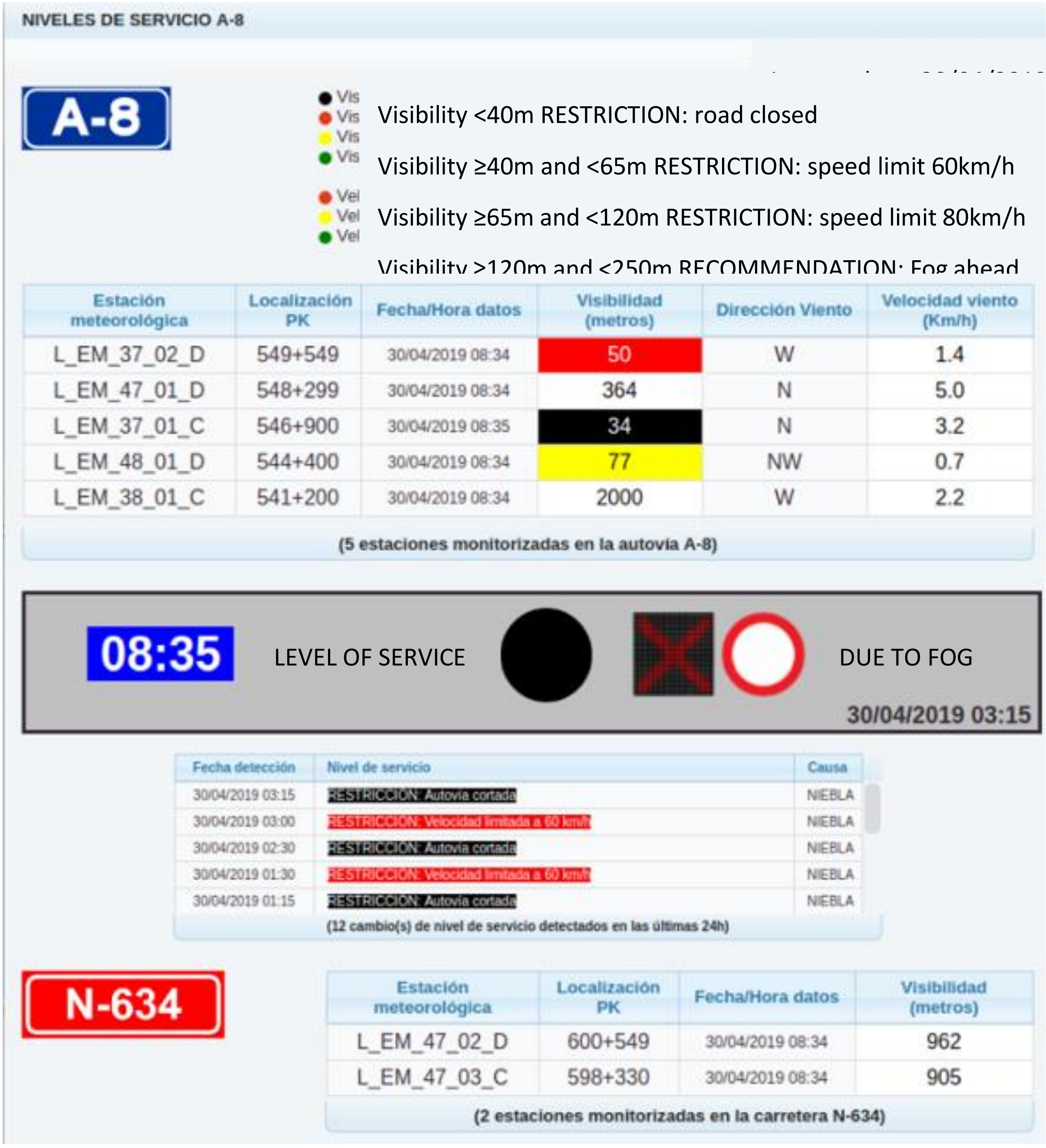


Figure 2– Detail of the automated detour scheme. Motorway A-8. Alto del Fiouco (Lugo). Spain

In this new methodology, the diversion is automatically established from the Northwest Traffic Management Center and the steps to follow are summarized below:

- <u>Detection:</u> by means of the devices installed in the road (weather stations and CCTV) the level of visibility in the Northwest Traffic Management Center is evaluated and detected when the visibility in the section was less than 40 meters.



Estación meteorológica	Localización PK	Fecha/Hora datos	Visibilidad (metros)	Dirección Viento	Velocidad viento (Km/h)
L_EM_37_02_D	549+549	30/04/2019 08:34	50	W	1.4
L_EM_47_01_D	548+299	30/04/2019 08:34	364	N	5.0
L_EM_37_01_C	546+900	30/04/2019 08:35	34	N	3.2
L_EM_48_01_D	544+400	30/04/2019 08:34	77	NW	0.7
L_EM_38_01_C	541+200	30/04/2019 08:34	2000	W	2.2

(5 estaciones monitorizadas en la autovía A-8)

Fecha detección	Nivel de servicio	Causa
30/04/2019 03:15	RESTRICCIÓN: Autovía cortada	NIEBLA
30/04/2019 03:00	RESTRICCIÓN: Velocidad limitada a 60 km/h	NIEBLA
30/04/2019 02:30	RESTRICCIÓN: Autovía cortada	NIEBLA
30/04/2019 01:30	RESTRICCIÓN: Velocidad limitada a 60 km/h	NIEBLA
30/04/2019 01:15	RESTRICCIÓN: Autovía cortada	NIEBLA

(12 cambio(s) de nivel de servicio detectados en las últimas 24h)

Estación meteorológica	Localización PK	Fecha/Hora datos	Visibilidad (metros)
L_EM_47_02_D	600+549	30/04/2019 08:34	962
L_EM_47_03_C	598+330	30/04/2019 08:34	905

(2 estaciones monitorizadas en la carretera N-634)

Figure 3 – Atmospheric variable monitoring system. Northwest Traffic Management Center. General Directorate of Traffic, Ministry of the Interior, Spain

- <u>Panel Signaling:</u> Once detected, deficiencies in visibility are communicated from the Northwest Traffic Management Center incorporating speed limitations and / or closure of the road and diversion to the N-634. Signage will be displayed on the Variable Messaging Panels (VMS) installed at the beginning and end of the section. In addition, illuminated pavement markers will be lit to direct vehicles as shown in the figures below.

Figure 4 – Variable Message Signs and pavement beacons. A-8 Motorway. Alto del Fiouco (Lugo). Spain

- <u>Tracking control:</u> To check that vehicles comply with speed restrictions, two radars have been installed. In addition, red light photo systems have been installed at the diversion points of the motorway.

Figure 5 – Variable Message Signs and traffic lights. A-8 Motorway. Alto del Fiouco (Lugo). Spain

Project for the installation of beacons to complement the automated detour

As a complementary method to the automated diversion, a system of vehicle detection and warning beacons in low visibility conditions was implemented on a pilot basis. Like the segmentation of railway track sections, the beacons are installed on both sides of the road, 50 meters apart, and their function is to warn drivers of the presence of other road users in low visibility conditions, so that they can adapt their speed and keep their distance from other vehicles.

The system of beacons for vehicle detection in low visibility conditions has already been put into operation in a 500-meter stretch in the O Fiouco area. The following images show how it operates. In the presence of dense fog, with distance to be determined, the lower amber lights of all the beacons installed on the stretch are activated to alert vehicles of the situation. Then, as soon as a vehicle enters this zone, the upper red light of the beacons closest to the vehicle on both sides is turned on to warn the following vehicle that there is another vehicle driving on that stretch, and so on, the following beacons are turned on as the vehicle moves along the stretch, so that the following vehicles know that in the next 50 meters there is another vehicle driving ahead and that they must adapt their speed and keep their distance.

Figure 6– Project of beacons in low visibility conditions. A-8 Motorway. Alto del Fiouco (Lugo). Spain

Figure 7– Beacons in low visibility conditions. A-8 motorway. Alto del Fiouco (Lugo). Spain

To inform drivers about the meaning of these beacons, in order to proceed with caution rather than stop at a red signal, explanatory static signs have been installed at the beginning of the section. As can be seen in the image, it is also indicated that this is an experimental section.

Figure 8– Vertical sign at the beginning of the section. Alto del Fiouco (Lugo). Spain

3.19.4 Non-Technical Challenges

One of the main obstacles or barriers in this case was the precise definition of an action protocol in the face of a novel situation for which there were no precedents at the national level.

It is noted that another main barrier to overcome was the change in driver behaviour while traveling through this area. Although the number of offenders who skip the detour is very low, there is a unique situation regarding fog and wind in this section and not all drivers are used to driving in fog conditions. This unique situation refers to the fact that the fog completely covers this stretch in less than a minute, so drivers need to respond immediately.

3.19.5 Evaluation

The type of fog that occurs in this environment is characterized by the fact that it reduces the visibility distance very quickly, covering the entire highway section in less than a minute, which complicated the decision to close the highway. This closure was carried out manually by traditional signaling and beaconing elements, so that the hours during which the highway remained closed exceeded by a high percentage the hours of visibility recorded below 40 meters, generating a low efficiency in the use of the road, around 40%.

Since the implementation of the automated detour in December 2016 until December 31th, 2020, a total of 1,974 hours with visibility of less than 40 meters have been recorded on that section. This would have meant 4,524 hours of highway closure with the manual detour methodology, while with the automated detour this figure is reduced to 2,934 hours of effective detour, which means a total of 1,590 hours of "savings" (equivalent to 66 days) in which the highway has been able to be open to traffic.

From the point of view of the operation and effectiveness of the detour, from December 15th, 2016 to December 31th, 2020, 0.8% of the total number of vehicles circulating on the stretch have been detected to continue on the highway despite the closure, which means 99.20% compliance with the indications.

In view of these results, the new detour methodology has had a significant effect in improving the efficiency of traffic operation and in increasing the number of operating hours of the highway. With the new detector beacons, it will be possible in the future to reduce the value of the visibility limit from which the detour is made.

In this regard, based on the data recorded from the weather stations, the number of hours with visibility below 40, 35, 30 and 25 meters has been monitored from September 1st, 2014 to December 31th, 2020. The results indicate that if it is decided to lower the limit and activate the detour when visibility is less than 35 meters, the number of hours with low visibility would go from 2,941.25 hours to 1,943.67 hours, i.e. the highway could be opened 34% longer, and if the limit of 30 meters of visibility were lowered, we would be increasing availability by 77%.

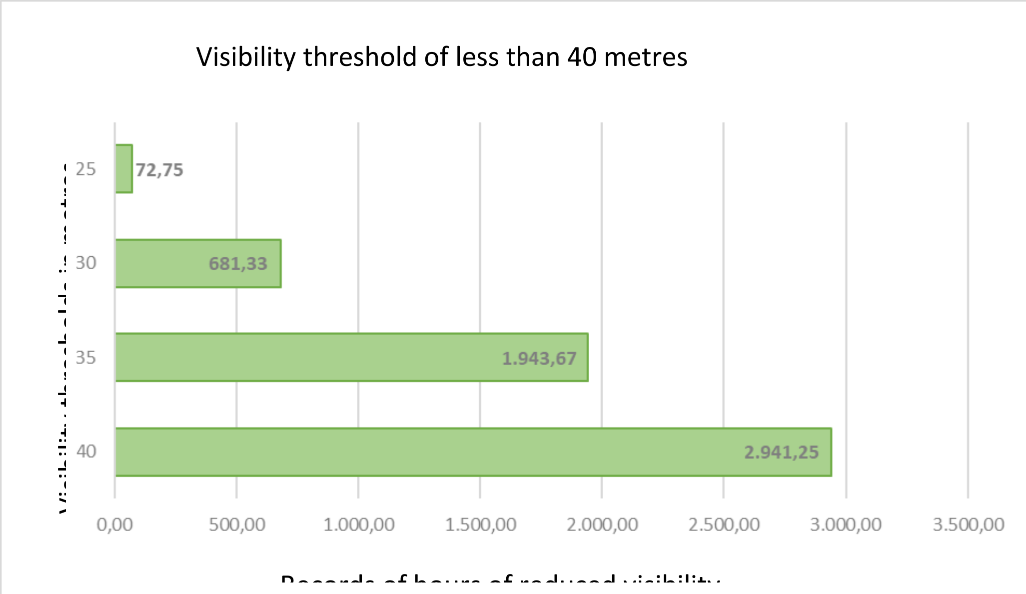


Figure 9– No. of hours of low visibility at 40, 35, 30 and 25 meter limits

From the point of view of road safety, the automated detour has avoided the physical presence of personnel on the highway for the manual installation and removal of the barriers every time it was necessary to close the highway, so this is a risk that has been eliminated. It should also be noted that since the implementation of the system in December 2016 to date, a total of two rear-end accidents with minor injuries have been recorded in the critical area, both in conditions of good visibility without the presence of fog, and no accident with fatalities or serious casualties.

Lessons Learned

The main lesson learned from the case study was about the vital importance of effective detection and communication. Initially, communication was not direct with road users and the process of closing the road was manual, which meant more time, cost and risk on the road. However, with the installation of the appropriate equipment, it has been seen that the problem is reduced in a faster and better way.

In this sense, it is important to highlight the importance of having real-time information that allows the right decisions to be made at the right time. In addition, it should be noted that sometimes the combination of several strategies or solutions that already exist in the market may be required to achieve the right solution.

Costs

The cost of installing the automated diversion elements was part of the ITS equipment improvements in the area. The cost of the installation of the detector beacons in the experimental section was one of the improvements of the maintenance of the zone, being the cost of the new beacons to be installed in the section from PK 545+400 to PK 549+680 of 873,100€ in total.

3.19.6 Future

Due to the good results being obtained, the idea of further optimising the operation of the A-8 in the future is being considered.

The number of drivers who skip the diversion and continue on the A-8 is 0.8% in both directions, which is considered minimal.

The medium-term approach will be to activate the diversion when visibility is less than 35 metres, thus increasing by 34% the number of hours the A-8 can remain open (compared with using a visibility trigger of 40m).

Further information

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3.20. Case Study 20 – Connected Vehicle Data Ecosystem for Roadway Safety (United States of America)

3.20.1 Description

The Utah Department of Transportation (UDOT) has deployed V2X equipment along several roadways in the area surrounding Salt Lake City (see map below) and in a number of fleet vehicles. The resulting connected vehicle ecosystem collects Basic Safety Message (BSM) data from these vehicles, per the SAE J2735 standard, combines this data with information from Road Weather Information Stations (RWIS), and generates warning messages which are broadcast back into the equipped vehicles. V2X operations occur within the 5.9GHz spectrum allocated in the U.S.A by the U.S. Federal Communications Commission (FCC). Current use cases include:

- Detection of likely crash events or other roadway disruptions
- Spot Weather Impact Warning (SWIW) – warning the driver of likely adverse road weather conditions, including slippery roads and strong winds.
- Curve Speed Warning (CSW) – warning the driver as the vehicle approaches a sharp curve when the vehicle is exceeding the posted curve speed.
- Conditional Transit Signal Priority (TSP) – providing extra green time at signalized intersections to buses that are behind schedule
- Active Snowplow Pre-emption (SPE) – providing green lights to snowplows at signalized intersections when they are actively plowing snow.

UDOT's first deployments included 24 signalized intersections along an urban corridor (Redwood Road in Salt Lake County) to provide conditional TSP, in partnership with the Utah Transit Authority (UTA). V2X devices were Dedicated Short Range Communication (DSRC) roadside and on-board radios. This system became operational in 2017 and was subsequently expanded to several additional corridors. Intersections equipped with DSRC radios are shown as blue dots on the map below and all are still operational. A web-based tool was also created which allowed traffic operators to observe the movement of the equipped buses and monitor the priority requests issued by the buses, and logged data from the system. In addition to the BSM, this application made use of SAE J2735 Signal Phase and Timing (SPaT), digital intersection mapping (MAP) and Signal Status (SSM) messages broadcast by the intersection, and the Signal Request Message (SRM) broadcast by the vehicle.

Capability for snowplow pre-emption was added to the system in 2019, including the installation of V2X roadside units along several additional corridors. By the end of 2019, there were 131 roadside units installed at intersections and 87 equipped vehicles. These vehicles included 52 UDOT snowplows and 35 UTA buses.

In 2019 UDOT began a new phase of connected vehicle deployments and entered a partnership with Panasonic of North America to expand efforts. Based on projected changes to FCC regulations, UDOT began to deploy Cellular V2X (C-V2X) roadside and on-board units in new deployments to verify the functionality of this newer platform. Over the next year, 69 roadside units were installed, including 15 at signalized intersections and 54 at locations along freeways and local roads. The roadside units are dual-mode, capable of broadcasting using both the DSRC and the C-V2X protocols. The locations of these roadside units are shown as orange dots on the map below. The non-signalized road locations were mostly rural and were selected specifically because they were in areas prone to adverse winter weather or had curves with high crash rates. Thirty-five UDOT fleet vehicles which frequent the deployed roadways were equipped with on-board units. About half of these on-board units were DSRC and half were C-V2X. In contrast to the earlier vehicle deployments, these installations tapped the on-board diagnostics (OBD-II) port in the vehicles to provide the full suite of data defined for the BSM. Further, all the wireless messages broadcast in these new deployments are secured with a Security Credential Management System (SCMS).

In conjunction with these new deployments, a cloud-based data analytics system, known as Cirrus by Panasonic, was developed. This platform collects, aggregates, stores, and actualizes the V2X data. Visualization of the data shared by the vehicles, in real time or historically, is possible with this system. The system also includes hardware management tools, easing the installation, validation, and on-going maintenance of the V2X field hardware.

The primary applications developed during this phase of the project were the CSW and SWIW messages, using the J2735 Traveller Information Message (TIM), and insights into road weather conditions, potential crashes, and other roadway disruptions based on the data found in the BSM.

Beginning in late 2021, additional V2X installations have begun. UDOT has partnered with the City of Orem, a vibrant and growing city of about 100,000 people in northern Utah, to create a dense network of V2X roadside deployments. Nearly every signalized intersection in Orem will be equipped with a roadside unit – about 53 locations. In addition, approximately 100 Orem and UDOT fleet vehicles will be equipped with on-board units. The vehicles which have emergency functions, like fire engines and ambulances, will have the ability to request signal pre-emption when they are in response mode. Other vehicles will simply share BSM information. UDOT and Orem will explore potential use cases enabled through the collection of BSM data in a compact, urban setting. In addition, 75 signalized intersections along four major state-owned corridors in the vicinity of Orem will be equipped with roadside units to facilitate transit signal priority and snowplow pre-emption. Thirty UTA buses and 17 UDOT snowplows will be equipped with on-board V2X units. These new capabilities will be in place by late summer 2022. The locations of new V2X roadside units are shown as green dots on the map below.

Work is also underway to test intersection broadcasts (SPaT and MAP) to certify compliance with new guidance and meet the expectation of the automakers. It is essential that data broadcast from signalized intersections be correct (match the actions of the physical signal displays) and consistent so that automakers can trust the data and make beneficial use of it in their vehicle systems. Using V2X equipment installed at intersections along State Road 224 near Park City, Utah, the UDOT team is working with a group of automakers working under the auspices of the Crash Avoidance Metrics Partnership (CAMP) to verify that broadcasts meet the criteria established in the USDOT-sponsored Institute of Transportation Engineers (ITE) Connected Intersections Implementation Guide. [Connected Transportation Interoperability (CTI) Standard CTI 4501 v01.00, Sept 2021: https://www.ite.org/pub/?id=76270782%2DB7E4%2D7F75%2DBC72%2DD5E318B14C9A

3.20.2 Objectives

The long-term objective for the UDOT Connected Vehicle Data Ecosystem Project is to reduce roadway crashes, injuries, and deaths by creating a data-sharing synergy between vehicles and our roadway that benefit both the drivers and the road agency. The full realization of this goal will require automakers to equip their vehicles with V2X hardware and software to both send and receive messages. As such, a related goal for the Utah project is to equip many roadside locations with equipment that is fully compatible with the automaker's systems. In addition, UDOT intends to use the connected vehicle system to improve mobility and traffic operations. Supporting, shorter term goals include the following:

- Deploy roadside V2X equipment in areas where specific applications can yield measurable results (such as TSP and SPE)
- Install V2X equipment in fleet vehicles to make use of developed applications, generate data, demonstrate system capabilities, and assess alternatives.
- Develop a cloud-based data storage, analysis and processing system.
- Design, develop and deploy software applications to beneficially use the real-time BSM data and create warning messages which can be delivered to the vehicle.
- Ingest and incorporate data from traditional intelligent transportation systems, such as RWIS, into the system to augment connected vehicle data.

3.20.3 Technical Challenges

Over several years of development and deployment, many technical challenges were encountered. Some of the primary issues have included:

- Incompatibility of hardware platforms, specifically between hardware manufactured by different vendors. Even though V2X hardware has generally met published standards, variations in implementation of these standards have often resulted in communication failures between them.
- Immaturity of hardware. As hardware design and construction has evolved, RSU and OBU hardware usually performs basic functions, like sending and receiving BSM and SPaT messages, but often does not support other activities, such as sending and receiving SSM and SRM messages, making use of GPS correction messages, being equipped for SCMS system operations, and signing certain messages with security certificates.
- Inconsistent vendor support. Because the V2X industry is relatively new and small, many vendors have limited field experience with their equipment and offer inconsistent or inadequate customer support. Since hardware platforms have often been incompatible and immature, support from the vendor has been necessary.
- Lack of software applications. Since most V2X deployments are small and many are test beds, there has been limited availability of software applications. It has been necessary to create those applications.

3.20.4 Non-Technical Challenges

The primary non-technical challenge faced in the Connected Vehicle Data Ecosystem Project has been the uncertainty caused by the FCC in their evolving spectrum regulations. Although the 5.9GHz wireless spectrum needed for these systems, a 75 MHz band, was allocated in 1999, and DSRC technology was developed to use that spectrum beneficially, the past decade has presented significant uncertainty. A proposed National Highway Traffic Safety Administration (NHTSA) rule to make DSRC equipment mandatory in light-duty vehicles in the U.S. did not come to fruition. The FCC proposed that the spectrum should be shared with unlicensed Wi-Fi, supported testing of that proposal, and then acted in early 2021 to reduce the spectrum to 30MHz and sunset DSRC before the testing was complete. The FCC simultaneously decided that C-V2X systems, a technology that many agencies had no experience with, would be the preferred technology in the spectrum. Limits on potentially dangerous out-of-band emissions adjacent to the remaining spectrum are still being debated and licensing and operating rules for C-V2X are not complete. Deployers of CV technology, like UDOT, have had to navigate these challenges and unknowns.

Another non-technical challenge, as a government agency, is the difficulty associated with specifying and procuring new and evolving technologies, like V2X systems. Government agencies have rigid requirements for procurement, often based on lowest cost. In an environment where hardware is immature, software development is difficult to define, and vendor offerings are inconsistent it is challenging to create procurement documents that meet usual requirements.

3.20.5 Evaluation

Range of Receipt Testing: As part of the deployment of dual-mode RSUs, a set of field tests were conducted to evaluate the maximum distance from which an RSU can receive a BSM message from a moving vehicle. Tests were performed in an urban setting, using RSUs installed at signalized intersections, and along a mountainous freeway corridor. Tests were performed in three scenarios: The RSU operating in DSRC mode receiving BSMs from a DSRC OBU; 2) the RSU operating in C-V2X mode receiving BSMs from a C-V2X OBU; and 3) the RSU operating in dual-active mode, both DSRC and C-V2X, receiving BSMs from both a DSRC OBU and a C-V2X OBU, in two adjacent vehicles, simultaneously broadcasting. Results indicated that in over 99% of C-V2X test and 97% of DSRC tests the range of reception exceeded the nominally expected range of 300 meters. The C-V2X range of reception was, on average, 25% greater than the DSRC range of reception across all RSUs in all tests. In addition, operating DSRC and C-V2X in dual-active mode resulted in no significant decrease in range of reception when compared to single mode operations.

This study, "Field Tests on DSRC and C-V2X Range of Reception" can be found here: https://transportationtechnology.utah.gov/what-were-learning/

Transit Schedule Benefits Studies: Two studies have been performed to assess various aspects of the UDOT / UTA conditional transit signal priority effort. The first attempted to evaluate the impact on the transit schedule by providing signal priority to late buses. Data from several sources, including the V2X messages, facilitated an analysis of priority requests made, requests served, and bus on-time performance. By comparing actual schedules of four equipped buses over a four-month period with buses which do not have the ability to request signal priority, it was determined that the equipped buses met their published schedule 2-6% more frequently, depending on the direction and time of day, with the most significant improvement of 6% in the southbound afternoon peak.

The second study evaluated the impact of altering the requesting threshold on bus performance. The UDOT conditional TSP system allows buses to request priority at the intersection when more than five minutes behind their published schedule. This study evaluated the impact of reducing that threshold value to 3, 2, or 0 minutes. A combination of observational and statistical analyses concluded with convincing evidence that on-time performance, schedule deviation, and travel time improved with decreasing threshold values. When the values were changed from 3 minutes to 2 minutes, and from 2 minutes to 0 minutes, the on-time performance increased 2.0 percent and 2.5 percent, respectively, mean schedule deviation improved 15.9 and 20.9 seconds, respectively, and travel time decreased at 72 percent of the time points along the route. Negative impacts to other traffic, measured by an increase of split failures on cross-streets, was inconsequential.

The “Demonstrating Transit Schedule Benefits with a DSRC-Based Connected Vehicle System” study can be found here: https://transportationtechnology.utah.gov/what-were-learning/

The “Impacts of Changing the Transit Signal Priority Requesting Threshold” study can be found here: https://rosap.ntl.bts.gov/view/dot/54889

Effectiveness of Signal Pre-emption on Snowplow Operations: A recent study has evaluated the benefits of providing signal pre-emption to snowplows on their schedule and operation by comparing routes equipped with V2X technology against routes which are not equipped. The study concluded that equipped corridors had more consistent percentile speeds (speed as a percentage of speed limit) and improved travel safety when compared to un-equipped corridors. Plow drivers also found their operations to be more efficient. This study has not yet been published.

3.20.6 Future

Based on the FCC regulations currently being formalized, UDOT plans to replace existing DSRC hardware with C-V2X hardware beginning in summer 2022. This process will take two years, based on funding availability.

Funding is in place for additional V2X deployments throughout Utah and the development of additional use cases. In 2023 and 2024, 105 roadside units will be installed along freeways, rural roads and at signalized intersections in various parts of the state, and nearly 300 vehicles will be equipped. These deployments will extend the geographic reach of the applications previously deployed and will support use cases for:

- rural road safety (such as road departure crashes),
- safety of vulnerable road users at intersections, and
- weather-responsive variable speed limits.

Further information:

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Further information can be found at: https://transportationtechnology.utah.gov/

3.21. Case Study 21 – Washington State DOT Truck Parking Information Management System (United States of America)

3.21.1 Description

In 2016, a truck parking study was completed by Washington State Department of Transportation (WSDOT) – Rail, Freight and Ports Division. A survey of commercial vehicle operators and stakeholders in Washington State performed as part of the study identified dissemination of current truck parking information as a need for improvement. In 2019, WSDOT – Transportation Operations began working with University of Washington (UW) Smart Transportation Applications and Research (STAR) Lab on a pilot project to develop a truck parking information management system (TPIMS) that would use sensors to detect parking space availability, predict future availability using artificial intelligence (AI), and disseminate this information to the public. Through this pilot project, Transportation Operations has installed in-pavement occupancy sensors at 2 parking facilities on I-5. UW has developed an algorithm that can project space availability 4 hours ahead with approximately a 12% error and has been working on the development of the application/website to disseminate this information. A schematic of the TPIMS developed through the pilot can be seen in Figure 1.

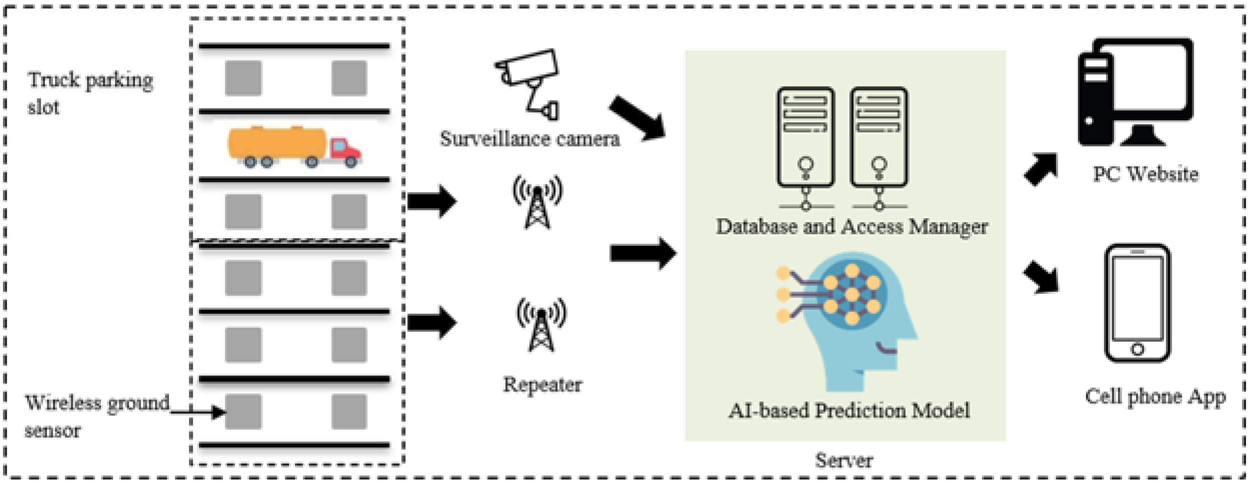

Figure 18- TPIMS System Schematic

3.21.2 Objectives

The objectives for this project include development of a Truck Parking Information Management System (TPIMS) that would perform the following:

- Collect real-time information about truck parking space occupancy.
- Develop an algorithm using artificial intelligence to perform data analytics and project future parking space availability.
- Disseminate this truck parking space availability information to the public through a website/application.

3.21.3 Technical Challenges

Most truck parking prediction neural networks are based on a temporal learning architecture, which is mainly designed to capture patterns in historical input sequences of parking behaviour. However, to infer the future truck parking occupancy, the historical sequential learning approach needs to be further improved by integrating other useful information sources, which are always in various data formats. These attributes, including time of day, environmental conditions and traffic behaviour, need to be fully involved in the prediction scheme. The pilot project integrated data from nearby weather stations to determine impacts of weather on parking behaviour. WSDOT aims to explore additional data sources in addition to techniques in Artificial Intelligence, representation learning and other data management solutions to address this concern.

3.21.4 Non-Technical Challenges

The detection system selected for this pilot project was considered a gold standard. As WSDOT expands the deployment of detection systems to parking facilities state-wide, considerations for life cycle planning costs (installation, maintenance, etc.) will be factored into the selection of the appropriate system at each truck parking facility.

3.21.5 Evaluation

So far, the truck parking pilot project has acted as a proof-of-concept and has shown the ability of the algorithm, developed by UW, to predict parking availability up to 4 hours ahead with approximately 12% error.

3.21.6 Future

WSDOT Transportation Operations recently received a grant from the Federal Motor Carrier Safety Administration (FMCSA) that will deploy occupancy detection technology to additional weigh stations and rest areas along Interstate-5 (I-5) and Interstate-90 (I-90). This funding will expand truck parking monitoring to an additional 470 stalls at 28 locations. In addition to evaluating the inclusion of various detection systems (including video, above ground radar, magnetometers, etc.) for deployment, this phase of the project will look at developing an application programming interface (API) that will allow third-party information providers to disseminate parking availability information through their system/application.

This grant funding will also be an opportunity to continue discussions with public and private partners to develop a more robust TPIMS that crosses state lines. The states along the I-5 corridor have expressed interest in addressing truck parking issues in their states. North/West Passage (a consortium of states on I-90 and I-94 between Washington and Minnesota) has identified Truck Parking as an area of interest with more detailed work to review regional concerns anticipated to begin in January 2022. Transportation Operations also hopes to engage the private sector in exploring opportunities to disseminate truck parking availability information through various applications that are currently in the market.

Further information:

For more information on truck parking in Washington State, contact Karthik Murthy at Washington State Department of Transportation. Karthik.Murthy@wsdot.wa.gov

4. CONCLUSIONS AND NEXT STEPS

This collection of case studies illustrates the growth in use of new technologies and data to support road network operations. This report summarizes work across 21 different projects in 10 countries to utilize new data sources and new data analysis techniques to advance capabilities to monitor and manage the operation of the road network. The case studies illustrate the growing availability and utilization of data for both monitoring of road network performance as well as implementing real-time applications for road network operations. The early stage of several of the projects described in case studies illustrates the nascent status of big data applications for road network operations. But even in this early stage, it seems clear that these data technologies will continue to transform road network operations over the coming years.

Several case studies highlight the very important role that data and data analysis played in monitoring and managing the response to the Covid 19 public health crises. This global public health event showcased the ability for these emerging big data transportation data sets to be utilized in this novel application for measuring the impact of and compliance with public policy directives.

These case studies clearly demonstrate that new technologies and improvements in the quantity and quality of data are driving innovation in road network operations. The Road Network Operations and ITS Technical Committee is continuing to explore this topic by reviewing current literature on the subject, completing additional research, and developing a technical report to be published later in this PIARC work cycle. As illustrated in this case study report, applications of data to road network operations are growing rapidly, and these applications appear to be rapidly transforming road network operations. It is a topic that warrants further monitoring as projects such as the ones highlighted in this report are implemented and present opportunities to share lessons learned and best practices.

5. GLOSSARY

Term	Definition
AI	Artificial Intelligence
Big Data	A term referring to very large data sets or data streams that may be analyzed to reveal trends, patterns, and associations.
Bluetooth	A standard for wirelessly pairing and transmitting data between electronic devices over a short distances. It includes a unique device identification called the Media Access Control (MAC) address.
Data Lake	A large repository of data stored in its native or raw format.
Data Warehouse	A type of data management system involving the aggregation of structured data sets for the purpose of reporting and data analysis.
DOT	Department of Transport or Department of Transportation
ETC	Electronic Toll Collection
ITS	Intelligent Transportation Systems
LIDAR	Light detection and ranging. A technology that utilizes a pulsed laser to locate objects position in three dimensional space and/or measure distances to objects.
Probe Data	Typically anonymized data gathered from users of the transportation system typically derived from global positioning system or cellular telephone network triangulation.
RNO	Road Network Operations
Spatial Data	Data with a location component
Temporal Data	Data with a time or date component
Visualization	Presentation of data analysis in a visual form.

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