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Road related data and how to use them

CALL FOR PROPOSALS

Deadline for submission of proposals: January 24, 2020

1 PURPOSE AND STRATEGIC SIGNIFICANCE

1.1 Introduction

The World Road Association (PIARC) has established a Special Projects mechanism to enable it to respond outside the usual four years Technical Committee cycle to emerging issues and priorities identified by its members. This paper is a Call for Proposals to conduct the "Road related data and how to use it (RRD)" Special Project.

1.2 Preliminary definition of Data in the context of this project

Since Big Data, Smart Data and Smart Road have an important meaning in this study, a common understanding of the terms must be ensured. The following definitions are proposed and can be modified in consultation with the POT.

Big Data: Big Data refers to data volumes that are too large, too complex, too fast moving or too weakly structured, for example, to be evaluated using manual and conventional data processing methods. Big Data is usually coming from different sources in different formats. Big Data is often used as a collective term for digital technologies, which are held responsible in technical terms for a new era of digital communication and processing and in social terms for a social upheaval. Big Data also describes the complex of technologies that are used to collect and evaluate these amounts of data, including Artificial Intelligence and Internet of Things. For this project Big Data also includes Social Network Data.

Smart Data: The term "Smart Data" refers to useful, high-quality and secure data stocks which are often generated from Big Data by means of algorithms taking into account data security and protection as well as data quality, utility and semantic aspects. Smart Data can be used both to gain knowledge from raw data and to generate new models for data analysis.

Smart Road: A Smart Road can monitor, measure, analyze, communicate and act, based on information captured from road sensors and external ones to achieve an improved performance with regards to safety, efficiency, comfort and environmental impact.

1.3 Purpose of the project

In the course of the rapidly advancing digital transformation, the collection and fusion of data forms a central building block for future real-time applications for the operation of road infrastructure as well as for data-driven predictive and/or cognitive approaches for the management of road infrastructure. It can be assumed that, in addition to the data already available and maintained by the owners and operators of road infrastructure, data from other sources are beneficially.

On the other hand, road owners and operators have a wide range of data which are of interest to road users and for the development of services for road users, either directly by road operators (e.g. Variable Message Signs, Real Time Traffic Information services) or by private companies.

The topic of data usage has already been dealt with in several research projects and scientific publications. A first overview with possibly relevant literature was prepared by BASt and enhanced by the POT members. The literature review is included in the appendix of this call for proposals and can provide a first impression of what literature may be of interest to the study. Individual aspects have also been addressed within PIARC. However, an overview and compilation of the state of the art, including the identification and analysis of the state of the art, is still lacking and shall be developed within the RRD project.

The focus of this Special Project should not be solely on the technical aspects but should rather enable PIARC members to consider possible cooperation with private data providers and to develop appropriate approaches and strategies both for road infrastructure management and for providing services to road users.

1.4 Out of the scope

The project should not focus in data that most of the road administrations and operators have been using for decades for road operations and maintenance (e.g. bridge inventory, bridge inspection, road/pavement condition data, traffic data from conventional sources....). However an executive list of this conventional data should be included in the report as a starting point for road administrations. PIARC POT will link some of the items in this executive list to PIARC existing reports.

The project should not focus on comparing in too great technical detail the pros and cons of data collection methods. For example, comparing in great detail the accuracy of various methods for measuring road/pavement condition is out of the scope of this work. However, identifying various data sources, identifying existing quality comparisons, and identifying how such data can be sourced and under what conditions is in the scope.

2 METHODOLOGY AND APPROACH

2.1 Overview and compilation of the state of the art, including the identification and analysis of case studies, implemented projects and scientific approaches including possible business models

1. First, the study should provide a short general overview of what data is already being used by infrastructure owners and operators as well as road users or is being made available, for example, for road user services. This is to serve an introduction and to clarify the significance of road infrastructure and traffic related (big and smart) data. A definition of big and smart data should also be addressed, as it will be relevant for further discussion in this study. The definitions listed above are proposed and can be modified in consultation with the POT.

2. Overview and compilation of the state of the art, including the identification and analysis of case studies, implemented projects and scientific publications dealing with:

    - Data sources, which could be of interest in addition to data already used by the owners and operators of road infrastructure

    - Approaches to use data of road owners and operators in other contexts as well, such as services for road users.

    - Smartphone applications or online webpages as a new communication tool between road owners and road users (new service) and as a new vector to create data. Including social networks applications or specific road applications.

The following data sources can be mentioned here as examples:

- Extraction and generation of data and information for and from Big Data and social networks; i.e. real time data about accidents and disasters

- Traffic and traffic related information from various sources (infrastructure monitoring, transport fleets, smart phones, taxis, individual drivers etc),

- Data and information regarding condition analysis and maintenance management (measurement campaigns, monitoring data, smart phones, 3D data),

- Data from connected and automated vehicles for road condition analyses and maintenance management.

The compilation shall address, for example, the source and collection of the data as well as their use in the field of road infrastructure, traffic and road users. The state of the art should be sorted and structured accordingly.

3. Potentials and challenges that can be derived from the state of the art with regard to added value compared to conventional practice, availability of data, applicability, regulatory framework (data protection and security), technical requirements, costs, etc. should be described.

4. The different data sources and their use in the field of road infrastructure, road user communication and traffic are developing in different parts of the world and are fostered by different players. The task is to describe players around the world with regard to their involvement, incentives and their ambition in road infrastructure and traffic related data and its use.

5. Possible business models can be derived from the state of the art and the challenges and risks discussed. The task is to describe the different scenarios and business models that are under discussions among the actors and in the case studies.

6. Data disclosure and Open Data to promote the use of Big Data for business.

   It is essential that the study focuses on the needs of PIARC members both in High Income Countries (HIC) and Low Middle Income Countries (LMIC) as it should enable them to identify the potential of the use and deployment of data and to identify ways to exploit this potential.

2.2 Business model from Road Administration perspective

The report should enable to identify the potential of the use and deployment of data and to identify ways to exploit this potential.

The report should identify best practice and make recommendations that would help road operators and road authorities tap this data potential in its many dimensions.

The report should present the conditions that are necessary, such as skill development, organizational change, etc. from a road administration perspective.

2.3 Approach

Proposals in response to this Call should use the template "Answer to the Call for Proposals for the Road related data and how to use them PIARC Special Project". The answer should include a description of the approach to be taken to collect and compile the information being requested. The proposal should answer the following questions about the tenderer's approach:

1. How will the study collect international information regarding road related data and their current use?
2. How will the study collect world-wide state-of-the-art sources, applications and business cases that deal with road infrastructure and traffic related data and how to use them?
3. How will the study identify data sources which are of interest and which criteria are used for this?
4. How will the study be structured in order to ensure a clear presentation and to show the potential of the use and deployment of data?
5. How will players around the world regarding the topic be identified?
6. How the study will analyze a business model from Road Administration perspective?
7. How the study will take into account LMIC reality to provide specific recommendations to them regarding road related data?
8. What will be the study milestones in terms of deliverables? What will be the approach for monitoring the progress and to include the inputs from the Project Oversight Team (POT)? It is recommended to organize monthly videoconference, and to share with the POT regularly intermediate deliverables asking for feedback.
9. How the management of the project will be organized including quality assurance and quality control without taking significant resources from the project.

2.4 Options

The proposal can be structured as a core proposal plus additional options. The bid would then include a core proposal within the proposed budget, and then some options which would be described in detail as well as priced.

If the bid is selected, PIARC would place the order for the core proposal and maybe as well for some of the options. This would be done at PIARC's discretion.

In any case, the core proposal has to answer all the expectations which are presented in this call for proposals document.

2.5 Key areas

Please describe the key areas for consideration in the framework:

1. What will be the study's means of collecting information from different areas of road administration, academia and relevant industry (i.e. planning, financing, asset management, design, construction, operations, and maintenance) from international road sector including successful and unsuccessful case studies?
2. LMIC represent an important share of PIARC membership and it is crucial that their needs,

opportunities and challenges are addressed within PIARC activities. How will case studies from LMIC be gathered and how their needs will be taken into account? How some of the findings of the project will be identified as particularly suitable for LMIC?

3 FINAL DELIVERABLES

The final deliverables will comprise:

1. A **report** presenting the state of the art regarding the use and deployment of road infrastructure and traffic related data, including possible business models.

   The general structure of the report should be as follows (adjustments with the agreement of the POT are acceptable):

   Executive Summary
   1. Introduction: project background, objectives and scope.
   2. Methodology and approach.
   3. Description of various data sources and their use with regard to road infrastructure and traffic
   4. Overview of the state of the art regarding the use and deployment of road infrastructure and traffic related data
   5. Description of potentials and challenges in this field
   6. Business models for road administrations.
   7. Conclusions of the study.
   8. Recommendations, for road administrations, LMIC and PIARC.
   9. References
   10. Appendices

   - Taking into consideration the LMIC in the study: each chapter of the report should make reference to LMIC when relevant. A chapter inside the report's conclusions with possible **specific recommendations for LMIC** should also be considered.

   - The specific recommendations for road administrations and road operators are a key element of the report. They should be relevant for high decision makers and operators.

   - The specific recommendations for PIARC could include recommendations to liaise with specific industries, take part in existing conferences and/or create a new technical committee / task force on the subject.

2. Presentation material to present the results of the Special Project at PIARC Council meeting on 20th, 21st or 22nd October 2020 in Dakar, Senegal (final date will be defined first semester 2020). Selected tenderer will also be invited to join the meeting physically or via videoconference. The retained option should be specified in the proposal.

3. Voluntary contribution to the Session on the Special Projects inside the World Road Congress in Prague October 2 – 6 October 2023. Retained consultant will be invited to join the Session (participation is optional) and to provide inputs to the Session program. This contribution will be requested after finalizing the project and out of the project budget. So, this point is provided as information.

The final products will be submitted in electronic form in English. The report will be owned by PIARC and it will acknowledge the contribution of the external consultant. The report will use the Word template provided by PIARC. The World Road Association will ensure translation into French and Spanish. In addition, they will make it available free of charge in the World Road Association's Virtual Library to ensure a large world outreach for the report.

4 KEY DATES

The proposal should also include a proposed draft of a work schedule. The schedule should identify dates or timeframes for accomplishing major milestones in the project. The work schedule will include monthly videoconference meetings and dates or timeframe for an interim product or products that allows adequate time for review and feedback prior to the final deliverable. The schedule must be completed, and final report should be delivered by September 16th, 2020, so PIARC can proceed to translation and dissemination of document in advance to participants to PIARC Council meeting and the World Road Congress.

These are some of the milestone to be included in the offer:

1st half of February: Kick-off videoconference meeting.

Intermediate milestones to be proposed by the tenderer.

16thof September 2020: Finalization of the report in English.

1st of October 2020: Finalization of Council presentation.

16th of October 2020, Presentation at PIARC Council meeting.

2-6th of October 2023, Voluntary presentation at the World Road Congress.

5 PROPOSED BUDGET

Please provide a general budget for the project. The funding requested from PIARC should not exceed 40.500 Euros all taxes included. The budget should include a general itemization of the costs of the major work elements of the project and provisional schedule of invoicing.

Invoices will be processed only for completed and approved items, with 10% of each invoice payment to be held back until final deliverables have been accepted by the Project Oversight Team and approved by PIARC.

Since a timing delivery of the outputs is at the essence of the Special Projects mechanism, late penalties could be applied if the external consultant fails to deliver the outputs in the proposed milestones. The framework to apply these penalties will be agreed with the tenderer before signing the purchase order based on the milestones scheduled included in the tenderer's proposal.

6 PROPOSED EXPERTS AND INTERNATIONAL NETWORK

The proposal should also include a description of the relevant expertise that qualifies the contractor to undertake the project. Specifically:

1. Please describe any past or current work projects that relate to the subject of this proposal.

2. Please also identify the person or persons who will be working on this project, describing their roles and estimated contribution to the project, and providing information on their backgrounds, experience and expertise.

3. Please provide information about any other international network, other than the World Road Association, from which tenderer could receive inputs.

7 PROJECT OVERSIGHT AND PROPOSALS EVALUATION

The project will be overseen by a project evaluation and steering committee called "Project Oversight Team" (POT) to select the preferred tenderer and assist in the development of the project. These experts will be drawn from PIARC membership and will include representatives from Technical Committees TC 1.1 Performance of Transport Administrations, TC 1.5 Disaster management, TC 2.4 Road Network Operations/ITS, TC 3.2 Winter Service, TF B.2 Automated Vehicles, D1 Asset Management and the PIARC Strategic Planning Commission and some member countries.

The POT will assess proposals and select the preferred tenderer on the basis of its assessment of:

a) Technical approach and methodology (up to 35 points): how well tenderer address the project objectives and deliverables and how effective and resilient is the proposed approach and methodology including collecting case studies internationally and addressing the needs of different PIARC member countries, such as LMIC;
b) Proposed work plan including intermediate milestones (up to 15 points).
c) Value for money offered by the tenderer (up to 20 points): including additional contributions leveraged by the proposal; and the time offered by different contributors of the tenderer's team.
d) Experience of the proposed team on the holistic vision of the road sector (up to 10 points)
e) Experience of the proposed team on the RRD sector (up to 10 points)
f) International experience and network of the proposed team (up to 10 points)

The POT will oversee progress of the Project, including participating in periodic calls, reviewing interim and final products. The POT will also provide any relevant information from the PIARC work to the selected tenderer (e.g., information obtained from surveys) for use in the project. In addition to review and oversight by the POT, input may also be sought from the other members of Technical Committees and the PIARC Executive Committee and Strategic Planning Commission.

8 PROPOSAL SUBMISSION

Proposals should include the elements identified in this Call for Proposals.

Answers should use the Word template "Answer to the Call for Proposals for the Road Related Data and how to use it PIARC Special Project".

Proposals should be submitted electronically in English to the World Road Association General Secretariat at:

info@piarc.org

no later than:

January 24 , 2020

For any questions, please send E-mail to info@piarc.org

Appendix to the Call for proposals
PIARC Special Project
Road related data and how to use it

Preliminary literature review conducted by BASt

Data generation for and from social media	
Literature	Abstract
Biswas, S., Mukherjee, A., Chan, M.C., Chakraborty, S., Kumar, A., Mandyam, G., Shorey, R, Ed., *TRAFAN: Road traffic analysis using social media web pages*. Piscataway, NJ: IEEE, 2018.	TRAFAN, a system to analyze traffic activities of various cities in India. Traffic information is publicly available on various social networking sites. We aim to analyze the transportation data moving through the most popular social networking site Facebook. Our system can assist the government organizations to know the most chaotic traffic issue in a city. Organizations can retrieve all the problems in a city related to a traffic issue. The system also allows to compare the severity of an issue across the cities.
D. M. Hang, *Detection of Traffic Events from Finnish Social Media Data.* [Online] Available: https://trepo.tuni.fi/bitstream/handle/10024/100334/GRADU-1481816716.pdf?sequence=1&isAllowed=y.	The purpose of this study is to develop a Finnish traffic information system that relies on social media data. The potential of using social network streams in traffic information extraction has been demonstrated in several big cities, but no study has so far investigated the possible use in smaller communities such as towns in Finland. The implemented traffic event detection system is able to detect and classify incidents from the public Twitter stream. Although certain limitations and possible improvements should be considered in the future, the ready traffic information system has already demonstrated satisfactory performance and lay the foundation for further studies and research.
Q. Nie, P. Sheinidashtegol, A. Musaev, and A. J. Graettinger, *A Social Media - Machine Learning Approach to Detect Public Perception of Transportation Systems.* [Online] Available: http://amonline.trb.org/68387-trb-1.4353651/t0005-1.4505752/1322-1.4506161/19-05908-1.4495755/19-05908-1.4506162. Accessed on: Oct. 29 2019.	Research has utilized Twitter to: –Detect traffic accidents –Detect real-time tweets for incident management (e.g., hazardous material spill or leak) –Detect transportation related incident information (e.g., potholes, broken traffic lights) Project Goal and Objectives •Propose a novel approach to monitor and detect real-time incidents (e.g., potholes, crashes or

	road closures) using information from social media users (Twitter)
Z. Zhang, *Fusing Social Media and Traditional Traffic Data for Advanced Traveler Information and Travel Behavior Analysis.* [Online] Available: https://pdfs.semanticscholar.org/a32b/9c9f0b5ed248abf64c79de9a94f0770e07fd.pdf.	Analyzing travel behavior using high-resolution Twitter data Extracting the human mobility patterns from social media and decoding the travel motivations behind the long-distance tweet displacements. Combining loop-detector data and the social media data to detect on-site traffic accidents. Combining the traffic data and social media data to study the social events and their impacts on traffic operations

Traffic and traffic related information from various sources	
Literature	Abstract
S. Dabiri and K. Heaslip, "Transport-domain applications of widely used data sources in the smart transportation: A survey," Mar. 2018. [Online] Available: http://arxiv.org/pdf/1803.10902v3.	Smart transportation is a framework that leverages the power of Information and Communication Technology for acquisition, management, and mining of traffic-related data sources, which, in this study, are categorized into: 1) traffic flow sensors, 2) video image processors, 3) probe people and vehicles based on Global Positioning Systems (GPS), mobile phone cellular networks, and Bluetooth, 4) location-based social networks, 5) transit data with the focus on smart cards, and 6) environmental data. Review of the transport-domain applications of each data source that have been conducted by the previous studies and classfication Moreover, in order to alleviate the shortcomings pertaining to each single data source and acquire a better understanding of mobility behavior in transportation systems, the data fusion architectures are introduced to fuse the knowledge learned from a set of heterogeneous but complementary data sources.
N. Howard, Ed., *Big data processing framework of learning weather information and road traffic collision using distributed CEP from CCTV video: Cognitive image processing*, 2017.	The road occupancy, vehicle speed, accident detection, traffic collision and weather information are calculated in CCTV. These are big data comes from varying sources, such as, social sites or mobile phone GPS signals and so on. In this paper, we propose a new architecture for distributed processing that enables big data processing on the road traffic data with specially weather information and its related information analysis. The framework is tested in Korea.
J. Joshi, Ed., *A real-time autonomous highway accident detection model based on big data processing and computational intelligence*, 2016.	In this study, we propose a preliminary real-time autonomous accident-detection system based on computational intelligence techniques. Istanbul City traffic-flow data for the year 2015 from various sensor locations are populated using big data processing methodologies. The extracted features are then fed into a nearest neighbor model, a regression tree, and a feed-forward neural network model. For the output, the possibility of an occurrence of an accident is predicted. The results indicate that even though the number of false alarms dominates the real accident cases, the system can still provide useful information that can be used for status verification and early reaction to possible accidents.
Li-Minn Ang and Kah Phooi Seng, "Big Sensor Data Applications in Urban Environments," *Big Data Research*, vol. 4, pp. 1–12,	The emergence of new technologies such as Internet/Web/Network-of-Things and large scale wireless sensor systems enables the collection of data from an increasing volume and variety of

http://www.sciencedirect.com/science/article/pii/S2214579615300241, 2016.	networked sensors for analysis. In this review article, we summarize the latest developments of big sensor data systems (a term to conceptualize the application of the big data model towards networked sensor systems) in various representative studies for urban environments, including for air pollution monitoring, assistive living, disaster management systems, and intelligent transportation. An important focus is the inclusion of how value is extracted from the big data system. We also discuss some recent techniques for big data acquisition, cleaning, aggregation, modeling, and interpretation in large scale sensor-based systems. We conclude the paper with a discussion on future perspectives and challenges of sensor-based data systems in the big data era.
N.B. Hounsell, B.P. Shrestha, and A. Wong, "Data management and applications in a world-leading bus fleet," *Transportation Research Part C: Emerging Technologies*, vol. 22, pp. 76–87, http://www.sciencedirect.com/science/article/pii/S0968090X11001707, 2012.	Automatic Vehicle Location (AVL) Systems are being introduced increasingly in many major cities around the world to improve the efficiency of our road-based passenger transport systems. Satellite-based location and communication systems, particularly the Global Positioning System (GPS) have been the platform for AVL systems which are now supporting real-time passenger information (RTPI), fleet management and operations (FMOs) and public transport priorities (PTPs), to name three key applications. The process of real-time on-board bus location can result in a substantial database where the progress of the bus is stored typically on a second-by-second basis. This is necessary for the primary real-time applications such as those listed above (e.g. RTPI, FMO and PTP). In addition, it is clear that such data could have an array of 'secondary' purposes, including use off-line for improving scheduling efficiency and for automatic performance monitoring, thus reducing or removing the need for manual on-street surveys. This paper looks at these and other innovative uses of AVL data for public transport, taking the recent iBus system in London as a current example of a modern AVL/GPS application in a capital city. It describes the data architecture and management in iBus and then illustrates two further examples of secondary data use – dwell time estimation and bus performance analysis. The paper concludes with a discussion of some key data management issues, including data quantity and quality, before drawing conclusions.
Big data analytics in smart mobility: Modeling and analysis of the Aarhus smart city dataset. Piscataway, NJ: IEEE, 2018.	How can big data technologies in the context of smart cities be used to implement a framework to analyze road traffic and pollution data to make a step towards smart mobility. The main objective: calculation and visualization of the least polluted route from a chosen start to an end point.
L. Bacon, J. Ma, and L. M. MacKinnon, Eds., *Analysis of road traffic fatal accidents using data mining techniques*. Piscataway, NJ: IEEE, 2017.	Roadway traffic safety is a major concern for transportation governing agencies as well as ordinary citizens. In order to give safe driving suggestions, careful analysis of roadway traffic data is critical to find out variables that are closely related to fatal accidents. In this paper we apply statistics analysis and data mining algorithms on the FARS Fatal Accident dataset as an attempt to address this problem. The relationship between fatal rate and other attributes including collision manner,

	weather, surface condition, light condition, and drunk driver were investigated. Association rules were discovered by Apriori algorithm, classification model was built by Naive Bayes classifier, and clusters were formed by simple K-means clustering algorithm.
C. H. Chapman, O. B. Downs, A. Barker, Burns, Mitchel A., Jr., and S. R. Love, "FILTERING ROAD TRAFFIC CONDITION DATA OBTANED FROM MOBILE DATA SOURCES," US9449508B2, United States.	Techniques are described for assessing road traffic conditions in various ways based on obtained traffic-related data, such as data samples from vehicles and other mobile data sources traveling on the roads, as well as in some situations data from one or more other sources (such as physical sensors near to or embedded in the roads). The assessment of road traffic conditions based on obtained data samples may include various filtering and/or conditioning of the data samples, and various inferences and probabilistic determinations of traffic-related characteristics from the data samples. In some situations, the filtering of the data samples includes identifying data samples that are inaccurate or otherwise unrepresentative of actual traffic condition characteristics, such as data samples that are not of interest based at least in part on roads with which the data samples are associated and/or that otherwise reflect vehicle locations or activities that are not of interest.
A. Mohammadi, M. Ahmadi, and A. Gharagozlu, "Developing a Minimum Data Set for an Information Management System to Study Traffic Accidents in Iran," (eng), *Iranian Red Crescent medical journal*, vol. 18, no. 3, e23677, 2016.	BACKGROUND Each year, around 1.2 million people die in the road traffic incidents. Reducing traffic accidents requires an exact understanding of the risk factors associated with traffic patterns and behaviors. Properly analyzing these factors calls for a comprehensive system for collecting and processing accident data. OBJECTIVES The aim of this study was to develop a minimum data set (MDS) for an information management system to study traffic accidents in Iran. MATERIALS AND METHODS This descriptive, cross-sectional study was performed in 2014. Data were collected from the traffic police, trauma centers, medical emergency centers, and via the internet. The investigated resources for this study were forms, databases, and documents retrieved from the internet. Forms and databases were identical, and one sample of each was evaluated. The related internet-sourced data were evaluated in their entirety. Data were collected using three checklists. In order to arrive at a consensus about the data elements, the decision Delphi technique was applied using questionnaires. The content validity and reliability of the questionnaires were assessed by experts' opinions and the test-retest method, respectively.

	RESULTS An (MDS) of a traffic accident information management system was assigned to three sections: a minimum data set for traffic police with six classes, including 118 data elements; a trauma center with five data classes, including 57 data elements; and a medical emergency center, with 11 classes, including 64 data elements. CONCLUSIONS Planning for the prevention of traffic accidents requires standardized data. As the foundation for crash prevention efforts, existing standard data infrastructures present policymakers and government officials with a great opportunity to strengthen and integrate existing accident information systems to better track road traffic injuries and fatalities.

Data and information regarding condition analysis and maintenance management	
Literature	Abstract
S. S. C. Congress and A. J. Puppala, "Evaluation of UAV–CRP Data for Monitoring Transportation Infrastructure Constructed over Expansive Soils," *Indian Geotech J*, vol. 37, p. 367, 2019.	Application of unmanned aerial vehicles (UAVs) for civil infrastructure monitoring has gained impetus owing to the advancement of aerial platforms paralleled with the development of sophisticated sensors. Photogrammetry is the science of measuring distances from two or more images, and close-range photogrammetry (CRP) is a part of photogrammetry that involves calculating measurements of an object within a maximum distance of 305 m away from the inspecting sensors. Geotechnical problems including differential heaving and related cracking of expansive soils cause extensive damage to pavement infrastructure. Feasibility of using UAV–CRP technology in health monitoring of pavement infrastructure constructed over problematic soils has been comprehensively studied, and this paper presents an overview of these results. Pavement performance data including longitudinal and transverse slopes, as well as distress conditions such as pavement surface cracking, pothole formation, and rutting or excessive deformation, are monitored via UAV–CRP technology, and these data sets are comprehensively analysed. UAV–CRP-interpreted performance indicators showed a very good agreement with those obtained from traditional methods surveys and profiler studies. With the further research, the UAV–CRP technology will play an important engineering role in safe, inexpensive and comprehensive health monitoring of infrastructure built over problematic soil conditions.
V. Douangphachanh and H. Oneyama, *A Study on the Use of Smartphones for Road Roughness Condition Estimation*. [Online] Available: https://www.jstage.jst.go.jp/article/easts/10/0/10_1551/_pdf/-char/en.	Using smartphone to collect data is a promising alternative because of its low cost and easy to use features in addition to its potentially wide population coverage as probe devices. This paper explores features and relationship of acceleration vibration that may be useful to express or estimate road roughness condition, which is the main focusing road surface condition for this paper. Results from our experiment and analysis show that acceleration data collected by smartphone sensors at different driving speeds has different significant linear relationships with road roughness condition.
Finnish Transport Infrastructure Agency (Liikennevirasto), *Digitalization program 2016-2018*. [Online] Available: https://vayla.fi/documents/21386/115391/Digital+program+2016-2018_presentation_pdf/dc98d8cb-6323-474a-8957-dde84f7e226c.	Different finnsih projects related to infrastructure data (railway network capacity management, traffic and mobility data, proactive maintenance management, proactive railway maintenance management and asset management systems, smart marine fairways, digitalization of customer interactivity)
L. Forslöf and H. Jones, "Roadroid: Continuous Road Condition	By using the built-in vibration sensor in smart phones, it is possible to collect road

Monitoring with Smart Phones," *JCEA*, vol. 9, no. 4, pp. 485–496, 2015.	roughness data which can be an indicator of road condition up to a level of Class 2 or 3 in a simple and cost efficient way. The continuous data collection can also give early warnings of changes and damage, enable new ways to work in the operational road maintenance management, and can serve as a guide for more accurate surveys for strategic asset management and pavement planning.
A. Ghose *et al.*, *Road condition monitoring and alert application: Using in-vehicle Smartphone as Internet-connected sensor.* [Online] Available: https://ieeexplore.ieee.org/abstract/document/6197543/authors#authors. Accessed on: Oct. 29 2019.	The proposal describes a road condition monitoring and alert application using the in-vehicle Smartphone as connected sensors, which are connected to an Internet-of-Things platform over the Internet. In addition to providing a generic Internet-of-Things based platform, the proposed solution brings in novel energy-efficient phone-orientation-agnostic accelerometer analytics in phone, reduces the data volume that needs be communicated between phone and the back-end over Internet, brings in multi-user fusion concepts to create authentic road condition maps and addresses privacy concerns for the phone user for sharing the required data.
B. Lau *et al.*, "A survey of data fusion in smart city applications," *Information Fusion*, no. 52, pp. 357–374, https://doi.org/10.1016/j.inffus.2019.05.004, 2019.	The common technique for handling multiple data sources is data fusion, where it improves data output quality or extracts knowledge from the raw data. In order to cater evergrowing highly complicated applications, studies in smart city have to utilize data from various sources and evaluate their performance based on multiple aspects. To this end, we introduce a multi-perspectives classification of the data fusion to evaluate the smart city applications. Moreover, we applied the proposed multi-perspectives classification to evaluate selected applications in each domain of the smart city. We conclude the paper by discussing potential future direction and challenges of data fusion integration.
R. Rossetti, Ed., *Supporting road maintenance with in-vehicle data: Results from a field trial on road surface condition monitoring*. Piscataway, NJ: IEEE, 2016.	In this paper we present a prototypical implementation of a road surface condition monitoring system which analyses the vertical acceleration signal from vehicle-mounted accelerometer sensors (physical jerks). The work proposes a linearly referenced road surface condition index (RSCI), being derived from position and accelerometer measurements and being capable of describing vehicle-sensed road surface quality. A road operator supported field trial - using a prototypical system for raw data collection, analysis and integration of the derived road surface condition information into the road operator's legacy systems - was conducted to collect sample data as well as field experiences and to learn about the benefits of such an approach from the perspective of road operators. Results clearly demonstrate that the derived road surface condition information (RSCI, heavy jerks) is able to supplement existing maintenance information and provides a

	valuable additional data source for road operators by helping to focus monitoring and maintenance tasks.
Stefania C. Radopoulou and Ioannis Brilakis, "Improving Road Asset Condition Monitoring," *Transportation Research Procedia*, vol. 14, pp. 3004–3012, http://www.sciencedirect.com/science/article/pii/S2352146516304434, 2016.	Road networks often carry more than 80% of a country's total passenger-km and over 50% of its freight ton-km according to the World Bank. Efficient maintenance of road networks is highly important. Road asset management, which is essential for maintenance programs, consist of monitoring, assessing and decision making necessary for maintenance, repair and/or replacement. This process is highly dependent on adequate and timely pavement condition data. Current practice for collecting and analysing such data is 99% manual. To optimize this process, research has been performed towards automation. Several methods to automatically detect road assets and pavement conditions are proposed. In this paper, we present an analysis of the current state of practice of road asset monitoring, a discussion of the limitations, and a qualitative evaluation of the proposed automation methods found in the literature. The objective of this paper is to understand the issues associated with current processes, and assess the available tools to address these problems. The current state of practice is categorized into: 1) type of data collected; 2) type of asset covered and 3) amount of information provided. The categories are evaluated in terms of a) accuracy; b) applicability (efficiency); c) cost; and d) overall improvement to current practice. Despite the methods available, the outcome of the study indicates that current condition monitoring lacks efficiency, and none provide a holistic solution to the problem of road asset condition monitoring.
T. Usman, L. Fu, and L. F. Miranda-Moreno, "Quantifying safety benefit of winter road maintenance: Accident frequency modeling," *Accident Analysis & Prevention*, vol. 42, no. 6, pp. 1878–1887, http://www.sciencedirect.com/science/article/pii/S0001457510001442, 2010.	This research presents a modeling approach to investigate the association of the accident frequency during a snow storm event with road surface conditions, visibility and other influencing factors controlling for traffic exposure. The results have the premise to be applied for evaluating different maintenance strategies using safety as a performance measure. As part of this approach, this research introduces a road surface condition index as a surrogate measure of the commonly used friction measure to capture different road surface conditions. Data from various data sources, such as weather, road condition observations, traffic counts and accidents, are integrated and used to test three event-based models. This research is the first showing the empirical relationship between safety and road surface conditions at a disaggregate level (event-based), making it feasible to quantify the safety benefits of alternative maintenance goals and methods.

Data from connected and automated vehicles for road condition analysis and maintenance management	
Literature	Abstract
C. Chen, T. H. Luan, X. Guan, N. Lu, and Y. Liu, "Connected Vehicular Transportation: Data Analytics and Traffic-Dependent Networking," *IEEE Veh. Technol. Mag.*, vol. 12, no. 3, pp. 42–54, 2017.	With onboard operating systems becoming increasingly common in vehicles, the real-time broadband infotainmentand Intelligent Transportation System (ITS) service applications in fast-motion vehicles become ever demanding, whichare highly expected to significantly improve the efficiency and safety of our daily on-road lives. The emerging ITS andvehicular applications, e.g., trip planning, however, require substantial efforts on the real-time pervasive informationcollection and big data processing so as to provide quick decision making and feedbacks to the fast moving vehicles,which thus impose the significant challenges on the development of an efficient vehicular communication platform. In this article, we present TrasoNET, an integrated network framework to provide realtime intelligent transportationservices to connected vehicles by exploring the data analytics and networking techniques. TrasoNET is built upon two key components. The first one guides vehicles to the appropriate access networks by exploring the information of realtime traffic status, specific user preferences, service applications and network conditions. The second component mainly involves a distributed automatic access engine, which enables individual vehicles to make distributed access decisions based on access recommender, local observation and historic information. We showcase the application ofTrasoNET in a case study on real-time traffic sensing based on real traces of taxis.
J. J. Castillo Aguilar, J. A. Cabrera Carrillo, A. J. Guerra Fernández, and E. Carabias Acosta, "Robust Road Condition Detection System Using In-Vehicle Standard Sensors," (eng), *Sensors (Basel, Switzerland)*, vol. 15, no. 12, pp. 32056–32078, 2015.	In this work, we try to detect the road condition the vehicle is being driven on, using the standard sensors installed in commercial vehicles. Vehicle models were programmed in on-board systems to perform real-time estimations of the forces of contact between the wheel and road and the speed of the vehicle. Subsequently, a fuzzy logic block is used to obtain an index representing the road condition. Finally, an artificial neural network was used to provide the optimal slip for each surface. Simulations and experiments verified the proposed method.
A. M. Hainen, S. M. Remias, T. M. Brennan, C. M. Day, and D. M. Bullock, *Probe vehicle data for characterizing road conditions associated with inclement weather to improve road maintenance decisions*.	Connected vehicle concepts can provide an enormously rich new data source that can be used for a variety of safety and performance measure applications. However, to date there are very limited connected vehicle deployments or applications other than graphical color coded maps provided by private sector companies. This paper takes an approach of introducing the concept of tabulating statistical distributions of highway segment space-mean speed to characterize roadway conditions associated with inclement weather. These statistics are computed for segments that correspond to a particular winter weather highway maintenance route. Several examples are

	presented that illustrates how these statistics can be used to identify the onset of hazardous winter weather and provide outcome oriented performance measure for the roadway condition. During one of the winter storms analyzed, the space mean speed decreased approximately 20mph during a storm and the interquartile range, increased from about 8mph to about 12mph. The paper concludes with a table that summarizes the number of hours, by day, that each snow and ice maintenance route had space mean speeds below 45mph. Using such statistics, geographic influences and alternative strategies for winter operations can be quantitatively assessed to determine the best practices for maintaining high travel time reliability during inclement weather conditions.
M. Kamrani, B. Wali, and A. J. Khattak, "Can Data Generated by Connected Vehicles Enhance Safety?: Proactive Approach to Intersection Safety Management," *Transportation Research Record*, vol. 2659, no. 1, pp. 80–90, 2017.	Traditionally, evaluation of intersection safety has been largely reactive and based on historical crash frequency data. However, the emerging data from connected and autonomous vehicles can complement historical data and help in proactively identifying intersections with high levels of variability in instantaneous driving behaviors before the occurrence of crashes. On the basis of data from the Safety Pilot Model Deployment in Ann Arbor, Michigan, this study developed a unique database that integrated intersection crash and inventory data with more than 65 million real-world basic safety messages logged by 3,000 connected vehicles;
R. Omer and L. Fu, "An automatic image recognition system for winter road surface condition classification," 2010.	This paper investigates the feasibility of classifying winter road surface conditions using images from low cost cameras mounted on regular vehicles. RGB features along with gradients have been used as feature vectors. A Support Vector Machine (SVM) is trained using the extracted features and then used to classify the images into their respective categories. Different training schemes and their effect on the classification rate are also discussed along with the possibility of developing an automated winter road surface classification system in future.

Literature that provides an overview	
Literature	Abstract
I. T.F. OECD, *Big Data and Transport: Understanding and assessing options.* [Online] Available: https://www.itf-oecd.org/big-data-and-transport.	This report examines issues relating to the arrival of massive, often real-time, data sets whose exploitation and amalgamation can lead to new policy-relevant insights and operational improvements for transport services and activity. It is comprised of three parts. The first section gives an overview of the issues examined. The second broadly characterises Big Data, and describes its production, sourcing and key elements in Big Data analysis. The third section describes regulatory frameworks that govern data collection and use, and focuses on issues related to data privacy for location data. The work for this report was carried out in the context of a project initiated and funded by the International Transport Forum's Corporate Partnership Board (CPB). CPB projects are designed to enrich policy discussion with a business perspective. Led by the ITF, work is carried out in a collaborative fashion in working groups consisting of CPB member companies, external experts and ITF researchers.
M. L. Pack, *Transportation Data Today: What's new and what's coming…*	
M. Ben Ahmed and A. A. Boudhir, Eds., *Toward an Intelligent Traffic Management Based on Big Data for Smart City*. Cham: Springer International Publishing, 2018.	The focus is on the use of non-traditional data generated by smart city initiatives and emerging mobile applications, including data from social media, smart phones and more generally all connected objects. Research on this subject allows us to have a global view on the studies carried out in this field not on the infrastructure side but control and management of road traffic, based on the main objectives according to the users of the road. These objectives are the elaboration of a shortest path between a source and a destination, as well as the time required to traverse this path.