Big Data and Emerging Transportation Challenges: Findings from the NOESIS project

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***Abstract*— In the last years many Big Data technologies have been applied to the transportation sector all over the world. Despite existing and future promising applications, critical factors which lead to a successful application and value generation from Big Data technologies in transport are largely unknown. The European Union (EU) Horizon 2020 (H2020) NOESIS project aims at identifying critical features leading to the successful implementation of Big Data technologies and services in the field of transport. In order to accomplish that aim, key challenges of Big Data utilization in the transport domain, need to be initially identified. The scope of this paper is to present the research findings on the major Big Data in Transportation challenges. The NOESIS challenges describe the major transportation areas and sub-problems that could benefit by Big Data. Firstly, a literature review was conducted in order to obtain the main areas (challenges) within the transportation domain which have the potential of greater exploitation through Big Data methods. 10 initial focus areas were identified from reviewing the state-of-the-art in Big Data and transportation research. Secondly, findings from the literature review were discussed and validated during a workshop with experts on Big Data in Transportation, increasing those challenges to 13. For each of the focus areas, corresponding sub-problems have been also identified. The findings of this paper contribute to the exploitation of Big Data within transportation in two ways: i) it provides the necessary literature review and experts' discussion for identifying the transport domain areas in which big data technologies could be successfully applied and ii) it identifies sub-problems linked to each of the challenges that big data could help to improve transportation. As a result, it is believed that this work initiates a first step towards enhancing the socioeconomic impact of transportation investments using Big Data.**

Keywords—Big Data, Transportation, Challenges

I. INTRODUCTION

The NOESIS project aims at identifying the critical factors or features which could lead to the successful implementation of Big Data (BD) technologies and services in the field of transport and logistics with significant value generation from a socioeconomic viewpoint. To fulfil this aim, areas and contexts throughout Europe, in which information and communication technologies investments and exploitation of data should be implemented, are to be examined and assessed. The impact of BD will be evaluated in a series of transportation use cases, i.e. the Big Data in Transport Library (BDTL) by developing and applying a "Learning framework' and a "Value Capture" mechanism which will estimate the expected benefits and costs. More specifically, the NOESIS BDTL is a collection of use cases of BD applications in transport which will be used to extract the most relevant and crucial features for generating socioeconomic value. Based on the BDTL, the "Learning framework" will define value ranges for the identified features and will apply appropriate BD techniques for classifying use cases and recognizing the underlying patterns. Finally, the "Value Capture" mechanism will define a set of evaluation criteria for BD use cases, assess the socioeconomic impacts and translate the benefits of this impact assessment into viable business models.

The scope of this paper is to describe the research findings on emerging BD challenges in Transportation which formed the basis for constructing the BDTL. Particularly, this paper mainly elaborates on the identification of the NOESIS challenges, which as mentioned before, describe the major transportation areas and sub-problems that are affected by BD. Initially, the following subsection will provide useful concepts and definitions used in BD Research for transportation applications. This is followed by the methodology to extract the NOESIS challenges, the review of literature and the validation of the challenges. Finally, the last part of the paper summarizes the outcomes and provides insights on how results can be used for further research.

II. CONCEPTS AND DEFINITIONS FOR BD RESEARCH IN TRANSPORT

This section describes the development of the NOESIS Lexicon, a vocabulary containing terms that are going to be used throughout the project and correlate the use of BD with transportation applications.

In order to promote research and accomplish the key objectives of the project, the main conceptual terms commonly used to enable the project's methods as well as in the literature within the field of BD and transportation need to be defined.

The term 'Big Data' refers to the techniques of advanced analytics (e.g. machine learning, pattern recognition) or a collection of structured and unstructured, large-volume, highly complex, growing data that may be analysed to reveal underlying patterns, understand complex phenomena, trends, and associations within the data. The main concept underpinning the NOESIS project is the "Big Data for Big Data" (BiD4BiD). It is based on the idea that useful conclusions can be drawn in respect to the potential value generated from BD investments and applications in transport, by applying BD techniques on the characteristics and information of such investments and applications relating to the wider transportation and implementation context.

A BD application is a specific Information and Communication (ICT) technology making use of BD which is implemented or utilized to provide an enhanced service. On the other hand, a BD investment corresponds to the resources and the associated cost that have to be allocated and used in order to implement a BD application in practice.

A BD product is a combination of BD technologies and applications which could be implemented in a specific transportation context. Such a product can be comprised of different technologies and ICT applications. BD products are characterized by the infrastructure/equipment needed, the data, the analytics methods to be used and the applications which are in place.

The broad areas/challenges of interest, in the field of transport and logistics (i.e. planning, operations, management and maintenance) which could be potentially benefited from BD applications and related ICT technologies are termed as BD themes or challenges.

BD use cases are examples of implementing a BD solution or service for a specific transportation problem. Each use case is characterised by several features including the transport sector (e.g. passenger of freight), transport mode (e.g. air, rail, road or ship), the application area (e.g. urban, regional, national or international), cost-benefit details etc.

To assess the impact of BD on transportation, a Data Benefit Analysis should take place. Such an analysis aims at evaluating and quantifying the magnitude of the impacts of a BD application for a given transport use case, by identifying a set of evaluation criteria. For the same purpose, a set of Key Performance Indicators (KPIs) used to assess the benefits or costs inflicted from a BD implementation on a particular transport use case needs to be identified. These KPI scores of BD use cases can then be translated to a generalised well-defined socio-economic value by extending the Cost-Benefit Analysis framework. The aforementioned procedure is usually termed as an Impact Assessment Methodology.

Finally, the impact of a specific BD use case in terms of value for public, user benefits, life-cycle investment and efficiency is generally termed as value generation. It is evaluated through the aforementioned evaluation criteria (i.e. KPIs)

III. METHODOLOGY

As mentioned, challenges are broad areas of interest, in the field of transport and which could prosper from BD methods and techniques. This section describes the necessary methodological and research steps followed in order to review the literature and obtain specific challenges or focus areas in the transportation domain.

The plan for deriving the challenges within the NOESIS project, was to initially conduct a literature review in order to determine the initial areas of focus. This was followed by the validation of the initial ten challenges through project meetings and external experts so as to finalize the focus areas.

At first, reviewing the NOESIS proposal, it was observed that in the corresponding section describing the challenges, transportation planning, freight transport operations and transportation infrastructure are considered as the main axes/challenges.

The next step involved reviewing EU research databases in order to understand the state-of-the-art in BD transportation research. A systematic search took place in the Transport Research and Innovation Monitoring and Information System (TRIMIS) [1] as well as the COmmunity Research and Development Information Service (CORDIS). The purpose of these initial searches was to identify the aim of current BD research in transportation and the focus areas.

Lastly, a short search was performed on the Transportation Research Board (TRB) database TRID [2], as well as Scopus [3] to get a hold of worldwide research databases on BD for transportation purposes.

After the initial derivation of 10 challenges along with the corresponding sub-problems within each challenge, from the state-of-the-art in the literature, the project partners were to provide feedback and validate those challenges during the NOESIS 2nd project meeting. Subsequently, an updated version was prepared, which contained 13 challenges, and was finally validated after coordination with the project partners and external experts on BD and transportation during a one-day workshop which took place in Munich, on the 15th of June 2018.

The members of the NOESIS consortium that reviewed and validated the challenges were: Stratos Arampatzis, Ilias Trochidis (ORTELIO), Christos Katrakazas, Constantinos Antoniou (TUM), Jose Manuel Vassallo, Natalia, Sobrino (Technical University of Madrid), Soizic Linford, Kuo-Ming Chao (Coventry University), Gyözö Gidofalvi, Robin Palmberg (KTH Royal Institute of Technology), Corné Versteegt (MACOMI), Mirjana Bugarinovic, Slađana Janković, Vladislav Maraš (University of Belgrade), Megi Sharikadze and Roland Pichler (Leibniz Supercomputing Centre; LRZ). The invited external experts on BD and Transportation were: Bahar Namaki Araghi (DTU; Technical University of Denmark), Tom Voege (International Transport Forum), Balasz Hajos (SIEMENS), Haris Koutsopoulos (Northeastern University), Anestis Papanikolaou (Jacobs), Panayotis Christidis (EU Joint Research Centre), Johannes Albert-von der Gönna and Hai Nhuyen (LRZ).

IV. EMERGING TRANSPORTATION CHALLENGES IN THE ERA OF BIG DATA

A. Initial results from literature review

The following section describes the literature review which took place in order to obtain the main challenges which will be mostly benefited by the use of BD as well as corresponding sub-problems. Through the systematic literature review, ten challenges were identified with sufficient evidence: Environment, Connected and Autonomous Vehicles (CAVs), Road Safety, Traffic Management, Transport planning, Freight and Logistics, Aviation, Railways, Cost-Effectiveness and Data-related issues. The review for each of these challenges is described in the next sub-sections.

1) *Environment*

The EC has mandated a low-emission mobility strategy until 2050 [4]. According to this strategy, the energy efficiency of the transport system should be increased by making use of digital technologies, smart pricing, the shift to alternative fuel sources (e.g. biofuels, hydrogen, renewable synthetic fuels) or electric vehicles, as well as the movement towards low- and zero-emission vehicles. Examples of European projects on the environmental impact and BD are JAM [5] and COLOMBO [6] which aim at improving vehicle performance with regards to emissions and environmental policies compliance and reduction of emissions through optimized traffic surveillance and operations respectively. Recent research papers which correlate BD and their applications for counteracting on environmental transport-related issues [7]-[10], indicate that areas of interest which can be benefited by BD investments are: (i) the potential of electric vehicles in replacing conventional fuel vehicles and the related modal shift, (ii) the energy demand modelling coming from electric vehicles, (iii) a smart design of the recharge infrastructure and Vehicle-to- Grid, and (iv) real-world driving and evaporative emissions assessment and mapping.

2) *Connected and Autonomous Vehicles (CAVs)*

CAVs are considered a very popular and emerging research topic during the past years [11], [12]. The EU has identified that handling and the potential use of BD generated by CAVs is a major issue [13]. The most relevant European project on CAVS with regards to BD, is 'SCOUT' [14] which concerned with the multiple socio-economic benefits of CAVs by capturing expectations and quantifying the advantages in terms of safety, business models and policies. Moreover, literature indicates that in order to ensure a safe navigation, CAVs are going to utilize a large number of sensor data [11], and as their driving skills are enhanced through learning, a vast amount of data is needed in order for them to be accepted as a reliable transport mode from the public [15]. Other identified problems in the literature include the handling of mixed traffic scenarios [16]–[19], the development of resilient (multi-)sensor systems for navigation and localisation, the use of a mix of communications (i.e. Wi-Fi, 5G, V2X, I2X communications) and cooperativeness levels in ITS technologies[20], [21], the deployment of connected and multimodal transport solutions for people and goods[16], [22]–[24] and the development of a framework for human-machine interactions, human- like driving/navigation behaviour and human acceptance levels (in terms of safety, comfort, etc.) for automated transport[25]–[27].

3) *Road Safety*

Road safety is a major societal issue for the EU [28]. As ITS have rapidly become popular in the past decades, the number of available data used for road safety applications has also rapidly increased (e.g. floating car data [29], loop detectors [30], automated vehicle identification [31], microwave vehicle detection systems [32], cameras [33] and drones). Regarding safety, BD were found worth of exploitation in proactive real-time collision prediction including Vulnerable Road Users (VRUs) [34], driver behaviour modelling [20], naturalistic driving data mining [35], [36], the integration and exploitation of safety databases [37], as well as driver monitoring through in-vehicle sensors [38], [39].

4) *Traffic Management*

As mentioned previously, the popularization of ITS has brought about massive available data sets and the EC is looking to utilize such data in order to shift from reactive to proactive traffic management in order to increase road efficiency [40]. The main areas within traffic management that BD applications could offer new insights are: real-time applications of: personalised travel information systems [41], congestion prevention and route planning [20], [41], [42], parking demand modelling [7], [43], short-time forecasting [44], [45] and fleet management [46]. These problems have been identified in the aforementioned literature but to date a limited number of projects or research has been carried out to overcome them.

5) *Transport Planning*

According to the view of the EU for transport in the year 2050 [40] the main challenges associated with planning are: (i) multimodal traffic operations, (ii) real-time spatiotemporal planning for road, rail, freight and air transportation, (iii) ticketing, (iv) infrastructure changes to accommodate CAVs, and (v) mobility on demand or Mobility as a Service (MaaS). Examples of European projects which have attempted to overcome such challenges are 'LeMO' [47] which overviews the implications of BD in terms of economic sustainability and competitiveness, 'PROXITRAK' [48] which focuses on the exploitation of real-time BD analytics for supply chains, 'AutoMat' [49] which aims at analysing cross-sectional, vehicular BD for reducing the cost of providing transport services and 'SETA' [50] that is concerned with the use of BD in future sustainable mobility applications. Recent literature also demonstrates that social media and BD applications provide new awareness challenges for transportation planning and traffic forecasting [51], [52]. Moreover, challenges arise on the impacts that BD have on real transport systems through private and commercial information, the impact on travel patterns and behaviour, as well as on the reconsideration of data analytics and predictive models for planning, formulating policies and making decisions so as to optimize understanding and exploitation of information [53]

6) *Freight and Logistics*

According to a recent review paper from Zaman et al. [54] challenges for BD in freight transport and logistics are connected to remote real-time sensing, route planning, freight traffic management, proactive operational prediction and forecasting (mode detection, condition monitoring, maintenance), vessel safety and security as well as performance monitoring and optimization. In more detail, the review by Tiwari et al.[55], focused on the value creation from BD in supply chains and more specifically on the development of responsive and agile chains with regards to marked trends and customers through real-time monitoring, the application of Internet of Things (IoT) to supply chain activities using real-time telemetry and GPS data, the impact on emissions, costs and fuel consumption from the exploitation of BD and the globalization of supply chain to perform act proactively in scenarios of natural hazards or disruptions). Some of the above mentioned challenges are also depicted in the 'Transforming Transport' project [56], where it is mentioned that using BD, ports can act as intelligent logistics hubs by improving on issues like operational efficiency, energy consumption, supply chains and port congestion. On the same principle, the 'PROXITRAK' project [48] is associated with real-time monitoring and sensing for logistics applications.

7) Railways

In the latest EC TRIMIS digest [57] the main challenges which BD and the IoT can overcome for railways were summarized in five areas:

- Information Management (e.g. Passenger Information, Ticketing, Operation Management and Tracking)
- Train control (Balise data, Communication systems, Automation, Localisation)
- Energy (Smart metering and Intelligent power supply)
- Infrastructure (monitoring, surveillance analytics, track condition, signalling systems, emergency communications)
- Predictive maintenance (real-time re-scheduling, rail decision support systems, safety)

These challenges are also reflected in recent literature on railways [58] – [63]. The focal point of these researches are operations [59], [61], signalling [63], asset management [58], while recent reviews on BD and railway systems [57], [62] demonstrate that BD analytics are to be mostly exploited in operations, safety and maintenance. Safety and signalling have also been on the focus of European projects [64]– [66] which indicate that there is still space for further research in those domains.

8) Aviation

According to the EC initiative 'Flightpath 2050' [67] challenges in the aviation sector, can be categorized into three sub-categories:

- Operations and Air Transport Management (ATM) (mitigation of delays, weather resistance, optimization of flight plans)
- Security and Safety (e.g. on-board monitoring, all-weather same airspace operations, privacy, resilience against cyber-attacks)
- Integration of new technologies (e.g. drones in air logistics)

European examples of using BD in aviation applications mostly focus on passenger- centric ATM [68], aviation security [69]and aircraft trajectory prediction [70]. These problematic areas and especially security and ATM are further validated in international literature [71] – [76] where it is demonstrated that BD could provide solutions in optimizing air traffic scheduling and routing [73], [76], aviation asset management [75] as well as providing efficient passenger-oriented security solutions[71].

9) Cost-Effectivess

The challenge of cost-effectiveness is not associated to a unique transportation problem or transportation mode. It describes the problem of developing cost-effective transportation solutions or BD processing architectures for transportation problems. The problem of planning cost-effective solutions is mentioned in the EC vision for transportation in 2050 [40] and also highlighted in commercial reports on BD and transportation [77], [78]. The challenge can be divided into two sub-challenges which are:

(i) The development of cost-effective BD architectures for transportation problems [79], [80] and

(ii) The use of BD to increase the benefit to cost ratio of transportation application [81] – [83].

Cost-effectiveness was also within the scope of the EU project 'Learn Big Data' [84], while the use of BD to increase the benefits of a specific transportation development was highlighted in the 'STADIUM' [85] project.

10) Data-Related issues

Data-related issues encompass the challenges related to BD handling, such as security, privacy, ownership and fusion. Similar to the Cost-Effectiveness challenge it is not contained on a specific transportation problem or sector. Such problems have been reported commercially [77], [78], and in research papers regarding BD [54]. According to these sources, problems that may occur in the use of BD for transportation purposes, can be mainly categorized as:

- Data transferability
- Data Security and content protection
- Data quality
- Data ownership
- Data fusion and integration

From the above mentioned problems, mostly security has been researched within Europe by projects such as 'Privacy Flag' [86], 'EVITA' [87] and 'QUATRA' [88]. Moreover, two significant open topics are: i) how data related to transport systems is likely to change compared to traditional 'small data' sources and ii) how tackling limitations with regards to the information that emerging data sources can provide, can help in avoiding loss of useful detail while maximising benefits from new features [62].

B. Validation of the NOESIS Challenges

The initial results from the literature review, were distributed to the NOESIS partners for review. It was indicated that the list of challenges could be initiated from more general challenges that are applicable to every mode (reliability, cost-efficiency, environment, comfort, reliability, financing, funding, MaaS, Transport integration) and are more related to the user experience. Furthermore, it was decided that the challenges should be as broad and self-contained as possible.

With regards to each partner's expertise, suggestions were made so as to expand the list of main challenges to 13 to incorporate a broader spectrum of transportation applications and services that could be affected by BD. The updated list of challenges along with sub-problems for each challenge identified by the project's consortium can be observed in Table I.

The final list of challenges was the main objective of The 'Knowledge Elicitation Workshop" as it was termed within the NOESIS project. The workshop aimed to compare, contrast and evaluate the results to date against the knowledge and opinion of the aforementioned invited experts on the field of BD and transportation. The workshop served also as an idea generation ground in order to take into account the views and feedback from the invited experts, so as to proceed according to the timeframe of the project.

In general, the experts were affirmative that the identified challenges, resemble the main transportation domains, which are to be benefited by the use of BD or will demand methodological or analytical breakthroughs regarding the use of BD technologies. Minor comments regarding the challenges included the addition of specific sub-problems to some of the challenges and more specifically:

- Implementation or testing protocols within the challenge of 'Automation"
- Signal states phasing, inclusion of sensor, weather and crowd sourcing data within the 'Transportation management and operations" challenge
- Taking into account that impact assessment could be long, short or mid-term within the 'Transport policy and planning" challenge
- Inclusion of harmonized fare payment and demand-supply prediction with regards to the 'Integration" challenge
- Social/Psychological challenge should make a mention of social inclusion. Note that the equation is centered using a center tab stop.

V. CONCLUSIONS

The current paper summarized the initial results of the NOESIS EU H2020 project with regards to challenges in Big Data (BD) applications for transportation problems. More specifically, useful BD terminology, and the list of NOESIS challenges which is a list of transportation areas which are more keen on benefiting from the use of BD were presented. The methodology on how literature was reviewed, as well as the results of this review, were presented. Initially, 10 initial focus areas were identified through literature and this number was later extended to 13 NOESIS challenges, after two project meetings and a workshop with the help of experts on BD in Transportation.

The results presented in this paper are of significant importance for the project. They allow the identification of useful terminology by different partners and the public (i.e. with the dictionary) while positioning the project within the state-of-the-art in BD and transportation with the NOESIS challenges. The validation of the challenges from experts in BD and transportation was a significant milestone for the project. It confirmed that the identified challenges sufficiently capture the obstacles in today's transportation spectrum which can be overcome from the use of BD.

Finally, the challenges and the corresponding sub-problems play a significant role both within the project as well as in terms of BD research in transportation generally. Within the NOESIS project, the results presented in this work, form the basis for the use cases collection template which will be used in order to build the BDTL. In order to reach the expected number of collected BD use cases, the developed template includes all the necessary questions and features in order to capture the characteristics and limitations associated with each challenge and its sub-problems. Simultaneously, the terminology and the literature review with regards to the challenges provides a broad overview of areas and focal points which can become the starting point for young researchers in the field of big data for transportation applications.

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TABLE I. THE NOESIS CHALLENGES

NOESIS Challenges (Validated)

Challenge	(sub)Problems
Environment and Health	Decarbonisation
	Pollution reductionn (air, water, soil)
	Transport electrification (e.g. electric vehicles)
	Noise and vibrations reduction
	Environmental effects of the built transport environment
	Resource consumption
	Environmental monitoring
Automation	Induced demand
	User acceptance
	Liability allocation (e.g. in cases of accidents)
	Employment (job shift)
	Infrastructure adoption and alterations
	Systems interoperability
	Connectivity
	Cyber security
	Transition period and incorporation of AVs into the traffic environment
	Legal and regulatory framework
Safety and security	Human events management
	Human factors and human behaviour modelling
	Safe mobility of challenged passengers
	Transportation of illicit goods
	Enforcement and protection against theft or other crimes
	Tort liability
	Surveillance
	Vehicle safety design
	Contingency/Recovery planning
Transport management and operation	Traveller Information Systems
	Resources optimization and cost management
	Demand and delays management
	Parking demand management and modelling
	Traffic management in emergency or extreme events
	Management of traffic environment changes (e.g. MaaS, Automation)
	Slot allocation
	Congestion pricing
	Short-time Forecasting

Challenge	(sub)Problems
Freight and logistics	Supply chain management
	Vehicle capacity optimization
	Transparency and Traceability of goods
	Intermodality / Synchro-modality
	Blockchain
	Fuel efficiency
	Driver shortage and retention
	Increased demand for goods requiring
	fast delivery times (e.g. fresh foods and goods)
	Cooperative business models,
	networked markets and IT systems integration
	Route programming
	Customization of logistics (e.g. smaller volumes,
	end-customer transport)
	Proactive operational prediction
	Fragmentation of freight industry goods data
Integration (MaaS)	Integration of transport fares, ticketing and pricing
	Infrastructure and services integration
	Transport policies integration and coordination
	with other sectors (e.g. healthcare, environment)
	IT systems integration
	Description, usefulness and differentiations
	of APIs between different systems
	Shared mobility
	Harmonization of scheduling and connections between modes
	Cooperative business and economic models
Funding, Financing, Cost efficiency	Pricing
	Funding and revenues across modes
	Financial and business models
	Optimization of the regulation/privatization levels
	Modal competition
	Procurement and contracting
	Economic regulations, fairness of fares and taxation
	Mobilisation of private funds, implementation and anti-corruption measures

NOESIS Challenges (Validated)			
Challenge	**(sub)Problems**	**Challenge**	**(sub)Problems**
Transport policy and planning	Optimization of the regulation/privatization levels	*Social / Psychological aspects*	Employment
			Social justice
	Transport sustainability		Affordability
	Governance and subsidiarity		Accessibility (elderly, disabled etc.)
	Social justice including intergenerational equity		User rights
	Impact assessment and ex-post evaluation of measures/treatments		Acceptability / User acceptance
	Integration of land use planning and environmental concerns		Adoption process
	Identification of the maturity levels of new technologies		Gender issues
Data related	Redundancy		Well being
	Data ownership		Mobility culture / lifestyle
	Data privacy		Sustainable community
	Data value	*Quality of service*	Information
	Quality		Reliability
	Cyber security		Comfort
	Data collection		Accessibility (elderly, disabled etc.)
	Interoperability and regulation of data (e.g. standardisation)		Convenience
	Data Accessibility		Connectivity/ IT systems integration / Data openness
	Business models for efficient data exploitation		Staff and passenger satisfaction
			Quality control and monitoring
Maintenance	Fault or error prediction and prevention		Waiting/Service time
	Ageing infrastructure	*Resilience*	Natural phenomena (adaptation)
	Mapping databases of roadway assets for asset management		Events (human based)
	Obsolete systems or parts		Contingency planning
	Development of advanced maintenance concept vehicles		Risk assessment
	Life-cycle optimization		Interdependencies
	Integration of new infrastructures hosting new technologies (e.g. autonomous vehicles)		Infrastructure adoption and adaptation
	Real-time monitoring and inventory		Emergency integration (communication)
	Incorporation of new technologies (e.g. robotics, 3D printing) for maintenance tasks		

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