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# Collaborative Management of Traffic Accidents Data for Social Impact Analytics

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**Abstract.** Traffic accidents have a devastating effect on society, and despite the measures taken by transport authorities, numbers still are of concern. As such, various studies emphasize the need for investments in the road infrastructure, vehicle safety, and enforcement measures. However, traffic and accident data are scattered among several stakeholders. Police authorities, emergency agencies, hospitals, road concessions, and the national road safety authorities all hold partial data about accidents and their consequences related to human lives. If such data could become widely available on production time, e.g., when an emergency doctor reports injuries or deaths, a police officer registers the scenario, etc., intelligent analytics could be used on such data towards helpful decision support. To cope with the wide diversity of data sources and ownership, more than data integration, this requires an approach for collaborative data management. Based on previous work on strategies to structure computing and communication artifacts and data science management, we present and discuss a collaborative traffic data management strategy considering the data producers as part of an intelligent traffic collaborative network. The challenge is thus to rethink traffic and accident data collection and management under the responsibility of diverse organizations, keeping their processes and technology culture, but promoting sharing and collaboration. Therefore, the proposed approach considers data analysis performed through business processes executed in the context of virtual organizations.

**Keywords:** Collaborative Networks, Data Science and Analytics, Distributed Systems Integration, System of Systems Integration, Virtual Organizations.

## 1 Introduction

Traffic accidents' consequences on human lives are a long-standing problem, which can be derived from the vehicle's construction, drivers' behavior, and quality of road infrastructures. While recent debates discuss the role of autonomous vehicles and their contribution to safety [17], traffic data collection remains an essential source for research about road safety. Investments in road infrastructure quality have proven to be a valuable decision to reduce accidents [6], "... *spending on road maintenance ...*

*contributes to reducing road deaths ...*". Speed enforcement is another typical measure to prevent accidents. For instance, a study from 2005 [11] identifies that the enforcement led to a "... *safety effect ... a reduction of 21% in both the number of injury accidents and the number of serious casualties ...*". In another study in Lithuania, a couple of years later [10], mentions that "... *vehicles exceeding the speed limit up to 20 km/h decreased from 20.84% to 9.91%, i.e., by 10.93% ...*", which led to a substantial reduction of accidents with a positive impact on the reduction of traffic casualties. However, one main problem in these and other research works is the lack of more comprehensive data sets.

Moreover, increasing the data quality for traffic safety management is a concern discussed in [21]. This study considers that "... *Ex-ante research only delivers good quality results if good quality road safety data are available ...*", suggesting the use of safety performance indicators (SPIs) as a step to qualify road safety effects. Nevertheless, the reality is that traffic and accident-related data are scattered among several stakeholders. Road concessions and local and national road safety authorities collect traffic data; police authorities and emergency agencies gather accident data, and hospitals record injured people data. In this manner, each stakeholder has a partial view of the global scenario. Given the difficulties and concerns regarding data sharing, the used decision models, based on partial information, are certainly limited in scope.

Ideally, models for decision support should be trained to identify and understand the causes from and for the globality of collected data. Authorities need to access global injury data to measure the socio-economic impact of traffic accidents. Furthermore, hospitals should assess accident characteristics to determine injury severity, and then being able to predict it. However, data access is often limited due to either the collection process (in many cases, manual or without proper digital tools and data modeling standards) or the lack of sharing mechanisms. An example is the data collected by a fire department or ambulance service where "... *sheets archived within departmental structures and rarely shared ...*" [4], which could be essential sources for global accident data sets.

In this paper, we argue that reliable and up-to-date traffic accident data hold value for analytics if made available and managed in the context of a collaborative data collection network. Due to data privacy concerns in the different contexts, sharing requires extreme safety measures. On the other hand, some behaviors associated to the power of data ownership need to evolve to a culture of collaboration and recognition of the benefits of sharing and reciprocity. **Fig. 1** illustrates the diversity of potentially interested stakeholders for both roads and urban contexts in the Portuguese case. According to our approach, it is important that they join efforts and make their Information Technology (IT) infrastructures prepared to federate traffic accident data that can then be managed by collaborative analytics business processes.

As such, the main guiding research question is: *In which way can we re-organize distributed traffic accidents data collection and management in order to facilitate better decision-making?*

As a research hypothesis, our approach assumes that a collaborative network among all relevant stakeholders can establish win-win management of distributed accident-related data, supporting a collaborative data analytics system with more value than the sum of its parts. In this way, all stakeholders can get richer insights for improving their efficiency and offer better decision support.

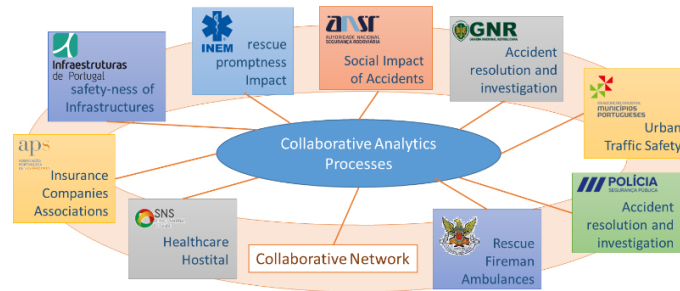


Fig. 1 Example of a potential collaborative network of traffic safety related stakeholders

This assumption is based on and supported by previous work on strategies to structure multi-stakeholder computing and communication artifacts. The approach considers each data source stakeholder as a potential member of an intelligent traffic collaborative network. As such, the challenge is to rethink traffic and accident data collection and management methods, which are performed under the responsibility of diverse organizations, while keeping their own processes and technology culture, but inducing a collaborative spirit. Thus, a collaborative network strategy is suggested to “join” valuable data sources from diverse traffic safety-related stakeholders to create federated data sets with up-to-date data to feed analytic applications. For this purpose, we propose to structure the required technology to be framed as an *Informatics System of Systems* (ISoS) infrastructure [16], where each informatics system (ISystem) is a composition of one or more Cooperation Enabled Services (CES) abstractions composed of one or more *Services*.

The remaining of this paper is structured as follows: Section 2 briefly summarizes and discusses related work; Section 3 presents and discusses the adoption of the ISoS framework for collaborative data collection and management. Section 4 discusses data management and analytics under the proposed framework, and finally Section 5 presents the conclusions and further research prospects.

## 2 Traffic and Accidents Data Analytics and Collaboration

An increased interest in exploring artificial intelligence (AI) technologies is reflected in the growth of the range of their applications. For instance, *urban analytics* is one of the fields that has gained track to enhance the understanding of reality in our cities. As an expression of collective behaviors, road traffic is one of the relevant targets in urban analytics. We may identify problematic patterns, find new solutions, and detect alarm situations through such analytics. However, proper data sets for valuable decision support are challenging to collect.

Traditional traffic security analysis used to be developed by specialized studies based on manual forms to collect data from accidents for obtaining statistics like the Abbreviated Injury Scale score (AIS) or the Injury Severity Score (ISS) [9]. The

Association for the Advancement of Automotive Medicine (AAAM) maintains the two classification systems. Since in fact many stakeholders are involved in traffic safety, e.g., road authorities, police authorities, emergency rescue service providers, road infrastructure operators, healthcare authorities, and the automotive industry, data collection is challenging and requires an effort to harmonize data collection, from their types to their semantics. The automotive industry, which is also an important stakeholder, has been involved in a related ISO 12353-1:2020 standard (Road vehicles –Traffic accident analysis), addressing the vehicle side. More recently, research on autonomous vehicles also brought in new elements for the discussion. For instance, the report [13] from an OECD workshop points for “... *a proactive safety framework where vehicles are embedded in a communicative network ...*”. Indeed, new data sources can be foreseen with autonomous vehicles, as suggested by the study of intelligent accident investigation strategies under driver, car, and infrastructure viewpoints [23].

Considering such multi-stakeholder / multiple data sources contexts, various research works have identified the need and importance of collaboration. For instance, [19] presents a collaborative strategy for data collection, stating that “... *a collaborative environment is necessary, and a web-based solution is ideal for permitting multi-user access and data insertion ...*”, and proposing a centralized coordination and management for obtaining data. But many related contributions can be found in the developments from the area of Collaborative Networks in the last decades. For instance, the roots for data federation in collaborative networks can be found in works such as [1], [2], [18].

Collaboration between two or more partners is the strategy for reducing the number of casualties [3]. Therefore, the research challenge is how to develop a technology strategy and architecture through which a group of stakeholders join efforts to reach a comprehensive traffic accidents analytic (T2A) system. This involves a complex socio-technical system where the parts are diverse organizations with their own processes and technology culture, i.e., each component is itself a complex socio-technical system made of persons, organizational models, governance, and technology systems.

To address this challenge, we propose to structure the technology as an Informatics System of Systems [16] (ISoS) infrastructure [16], establishing what we name the ISoS informatics (or information) technology (IT) landscape. Under this view, an informatics system (*ISystem*) is a composition of one or more Cooperation Enabled Services (CES) abstractions composed of one or more *Services* [16].

### 3 The ISoS Architecture for Collaborative Data Collection

In order to exemplify the proposed approach, let us consider the case of the Portuguese vehicle speed enforcement network (SINCRO), which is part of the National Road Safety Authority (ANSR) IT infrastructure. An existing informatics system (SIGET), responsible for obtaining and validating enforcement events, is planned to evolve to adopt the ISoS framework [16]. To simplify the illustration, we assume that also the remaining stakeholders adopt the ISoS framework. The adoption involves structuring operating computational entities as service abstractions and these as abstractions of informatics systems (*ISystem*).

Furthermore, all stakeholders participating in some collaborative network [7] are assumed to implement the  $ISystem_0$  meta-informatics system responsible for maintaining metadata about the remaining informatics systems, i.e., adopting an ISoS IT landscape.

Another condition in this validation scenario is the adoption of the Enterprise Collaborative Network (ECoNet) framework operationalized by the Enterprise Collaboration Manager (ECoM) informatics system [15]. Nevertheless, adopting the ECoNet CN infrastructure is not mandatory since any  $ISystem/CES/Service$  of a stakeholder's ISoS can be discovered through the respective  $ISystem_0$ , i.e., by default accessing *isos.<stakeholder's public domain server>:2058* endpoint with the proper authentication credentials. A drawback of not using ECoNet is that interactions between service elements are point to point, meaning acquaintances need to understand underlying communication protocols. While adopting ECoNet, acquaintance operating services can use the ECoM's collaboration context (CC) to mediate data and coordination exchanges without being concerned with the underlying communication protocols, including security issues. Furthermore, The Virtual Collaboration Context (VCC) of ECoNet makes it possible to establish multitenant groups where the creator partner can invite other ECoNet nodes to join.

The VCC is based on the Virtual Private Network (VPN) or the more recent concept of Virtual Private Cloud (VPC), wherein we can assume the offer of Virtual Private Cloud services to securely manage resource pools [22]. The ECoM's VCC makes transparent for service elements of an ISoS landscape the exchange or the sharing of application data without any concern with the underlying communication protocols or security mechanisms and policies.

**Fig. 2** depicts the Traffic Analytics Virtual Organization created for the case of ANSR, presenting an example of a collaborative process – the “*Severity of accidents for the driver, passengers, and pedestrian*” process. The process is enacted by a data analysis informatics system, where process instances handle the data collection and processing towards process objectives. The informatics system that implements the process definition, e.g., embedding an enactment service to execute the *Road Accidents Severity (RAS)* process, is modeled in Business Process Model and Notation (BPMN) using the MagicDraw modeling driven systems engineering tool [12], [5].

The RAS process model has an initial activity to establish a VCC to be created by the ECoM. The process, which is not detailed here, includes the invitation to the National Institute of Medical Emergency (INEM), National Health Service (SNS), and firefighters' federation to join the Traffic Analytics VO sharing all the same CC. A collaboration context makes available domain services specialized in realizing the mission of hiding middleware or infrastructure level mechanisms, e.g., sharing files of any size, authentication, and security. The ECoNet concept is expected to evolve as an adaptive and intelligent layer hiding or making transparent complex distributed systems issues. One foreseen example is to make failures transparent to some extent by introducing fault tolerance strategies.

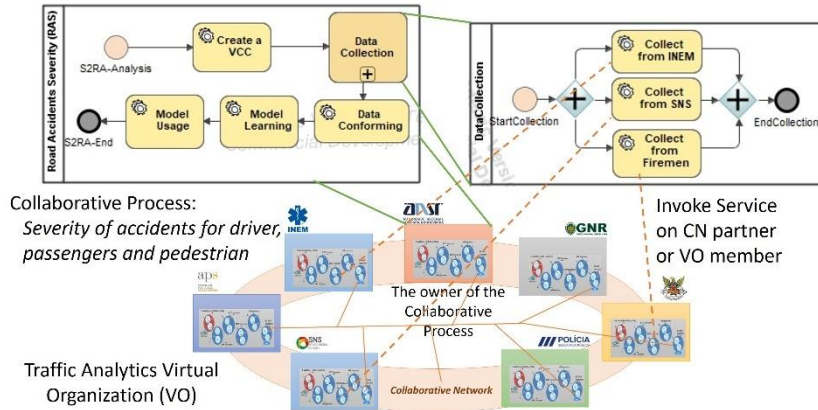


Fig. 2 The Traffic Analytics Virtual Organization

Therefore, the proposed system collects the relevant data to feed a traffic analysis system (modeled as a process). Such a system, being a massive data-driven one, shall comprise both descriptive and predictive models, for diagnosis and forecasting purposes, respectively. Moreover, it must be centered on a data management system, able to grant access, protect privacy, and even report unauthorized access attempts.

#### 4 Data Analytics in an ISoS IT Landscape

According to the ISoS architecture, any integrated system becomes interoperable, cooperating with other systems following the same architecture. Although data can be viewed as the oil fueling the systems, data are often centrally managed by some data management system, either a specific database management system from some specific vendor or, more usually, a data management server created to operationally support the rest of the cooperative systems. Note that even distributed or federated databases can be abstracted to this metaphor.

Actually, in a data-driven system, the ISoS architecture may incorporate such a data management ISystem, storing and providing the required data to any other ISystem in the informatics landscape of the collaborative network. We may consider a generic data science system as an ISoS system dedicated to performing all data processing, including data collection, storage, distribution, aggregation, modeling, analysis, and usage. Fig. 3 depicts the example of seriously injured victims per road type for 2019, based on data obtained by ANSR [20] from participating collaborative stakeholders.



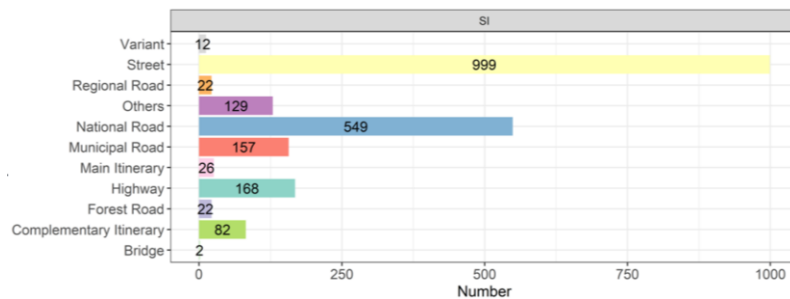


Fig. 3 Number of seriously injured victims per road type, from [20]

Our aim is then to design the systems needed to support the analysis and management of traffic and road accidents (DS-TRAM), but also for feeding other systems, in a collaborative network, such as the systems from police authorities and civil protection departments (materializing a perspective of win-win to multiple stakeholders).

Following the ISOs architecture, adding new functionalities through ISystems to DS-TRAM is trivial and can be accomplished at any time. But in the end, the system shall have at least four core systems, besides the ISystem<sub>0</sub> and the ECoM ISystem, as shown in - the data management (DMg), the business intelligence (BI), the diagnosis (Diag), and the forecasting (Frctst) ISystem, as illustrated in Fig. 4.

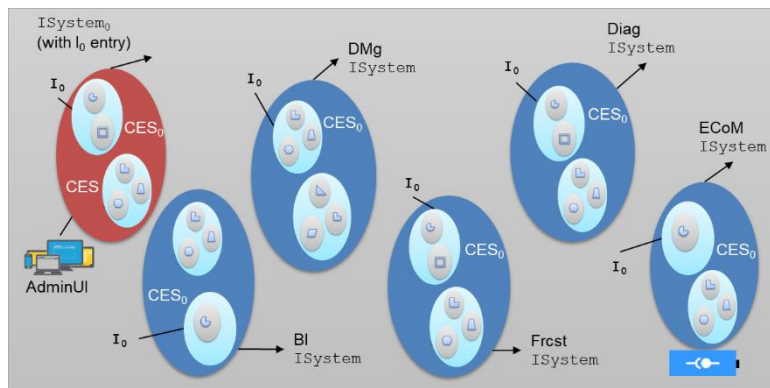


Fig. 4 Organization’s ISOs landscape for supporting DS-TRAM

Next, we detail the main functionalities provided by each of the ISystems.

#### 4.1 Data Management ISystem

As a truly ISOs, the internal architecture of the Data Management (DMg) ISystem is not relevant, only its functionalities matter. Indeed, traditionally this would be implemented through a data warehouse and management system. However, it could

also be implemented in a distributed way, either in the cloud or any distributed or federated environment. Definitely, in the context of the ISoS architecture, the technology behind the data and its associated models are irrelevant. The key idea is that all services that need to deal directly with the data are contained inside a DBMS service, and all the other services or systems ask it for the required data. The DMg ISystem will support the “Data Collection” and “Data Conforming” elements of the RAS process presented in **Fig. 2**.

The primary CES in the DMg ISystem is responsible for *retrieving* data from the available data sources. Note that data collection may be distributed under diverse CES, but in order to make it available for the rest of the services and systems, the data shall be managed, but not necessarily stored, centrally. It can more likely follow a federation approach. This service is then responsible for *cataloging* the stored data, and *providing* it whenever required, either for internal or external services in the network.

To accomplish those tasks, the ISystem has another CES to *control access rights*, warranting that only authorized client services receive the data. Of particular importance is the guarantee of data conformance with the privacy policy regulations in force, such as the GDPR in Europe [8]. For example, no prohibited data is processed, and anonymization services are required to feed internal and external data requests.

Being this service accountable for all the data management, machine learning feature engineering tasks shall be under the DMg ISystem. Any feature extracted or generated shall be communicated to the cataloging CES. Indeed, those tasks might be agglomerated under a *feature engineering* CES, that besides feature extraction, generation, and selection, shall be accountable for all data preparation tasks. The DMg ISystem will also function as a feature store [14]. Examples of such tasks are cleaning the data, conforming it to the data structures/models that best suit the analysis tasks (through discretization, dummification, scaling, etc.), and extraction techniques such as principal component analysis (PCA) and discrete Fourier transform (DFT) or aggregation ones.

The last service to consider is a *data profiling* one that shall be kept up to date, supplying a detailed description of the available data, its distribution, granularity, sparsity, and dimensionality. Along with the catalog, they will be used as a showcase for analytic services to consult.

## 4.2 Business Intelligence ISystem

The Business Intelligence (BI) ISystem has two main responsibilities: i) To give an instant picture of the current scenario; ii) To report summary data of interest for analysis.

Each operational unit (traffic agencies, police units, civil protection, or hospitals) shall have a CES able to display the number and type of occurrences in real-time. This kind of display is known as a *situation dashboard*, and usually, it does not contain any private-sensitive data. A noteworthy ability of such dashboards is showing the data at diverse granularity levels, allowing for navigating through the different levels of detail. Of particular importance is accessing any occurrence in its most atomic detail.

In this context, another CES to consider is the one accountable for *reporting*. Reports reveal analysis and decision support data, giving a clear and effective summary of key

performance indicators (KPIs), per time unit, like days, weeks, or months, and any other dimension of interest. Examples of such KPIs are the ones reported in [20].

### 4.3 Diagnosis ISystem

The third ISystem to consider comprises the different diagnosis (Diag) services running to support the “Model Learning” element of the *Road Accidents Severity* RAS process presented in Fig. 2. These services may be of two main kinds: i) Services to automatically classify or predict situations; ii) Services based on pattern mining and clustering methodologies.

The first kind of service follows a pre-trained model. Examples of such services are the ones for recognizing regular and anomalous situations. Independently of the task at hand, these services involve the existence of a classification or predictive model, pre-learned through some machine learning algorithm and validated against past data. After approved, the model can be put to work, classifying or predicting current situations. However, those models may have different lifespans, from being *timeless* (like disease diagnosis) that needs to be learned once or *ephemeral* (like behavior modeling) that changes over time. Furthermore, the incoming data flow for each one may also be different. Such services must be prepared to evaluate their quality performance and refresh the models whenever they are not accurate enough.

The second kind of service can identify and characterize the set of frequent occurrences and identify cause-effect dependencies.

Nevertheless, with those two kinds of services, the diagnosis ISystem shall comprise as many CES as different diagnosis services running. Indeed, each one shall run, be refreshed, and monitored at its own speed.

### 4.4 Forecasting ISystem

At last, the fourth considered ISystem comprises the different forecasting (Frst) services. These services differentiate from the diagnosis ones by their nature. Instead of classifying or describing a given situation, they look at the past data to predict future occurrences. In a manner, they are intrinsically temporal. Despite their differences, they are constructed following similar strategies, and the Forecasting ISystem shall follow an identical structure. This ISystem is responsible for supporting the “Model Usage” element of the RAS process.

## 5 Discussion

The impact of traffic accidents on society has been recognized to be wide and spreading from personal, both physical and emotional, to social, with evidence on economics in particular [21]. Nevertheless, the quantification of this impact, and subsequent support for decision-making over public road safety policies, depends on the existence of accurate and comprehensive data, in the first place.

As discussed, current technical solutions, lead to data scattered across the diverse stakeholders, who following the rules in place (the GDPR [22], for example) are not allowed to process more than what is strictly required for their operation. Now, the data collected by each partner in the collaborative network respect to the same events – the traffic accidents, viewed from diverse perspectives which make them to be complementary.

Following our proposal thus, several issues are addressed. First, each partner keeps their own data confined to their servers, using their preferred technology. In this manner, nothing changes on their internal activity. Second, each partner controls external access to their data, both by authorizing the access to recognized partners and by negotiating which data to share, in accordance with partners needs and rights (following the regulations in place). Third, and most importantly, each partner accesses more rich data, allowing for a wider view of the situation, and consequently better data to train the analytic models.

From a public point of view, there are also gains, since the data around traffic accidents will be up-to-date and accessible through a single channel. In this manner, studies like the ones mentioned before can be performed more regularly, avoiding the difficulties inherent to the collection of data scattered across different sources.

## 6 Conclusions

Collecting and managing traffic accident data is an example of challenging application domain which involves a large diversity of stakeholders, each one being responsible for partial subsets of data. In order to be able to make proper decisions, it is important to find ways to collaboratively federate those subsets of data. For this purpose, this paper proposes an approach to establish a network of relevant stakeholders, supporting collaborative analytics business processes.

The work is part of an ongoing initiative that started with a project for the Portuguese national road safety authority and is now being expanded to include other stakeholders in traffic management. Once the aimed collaborative network is established and properly supported by the conceived IT infrastructure, it will be possible to implement sound federated learning mechanisms in support of multiple analytics services according to the interests of the various stakeholders.

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