NOVEL SYSTEM FOR COMPLIANCE MONITORING OF SOUTH AFRICAN CROSS-BORDER TRANSPORT

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ABSTRACT

Cross-border road transport corridors form a vital element of regional economies. To remain globally competitive, compliance enforcement must be reconciled with streamlined trade flows. This requires the use of IoT (Internet-of-things) technology to collect data in real time from ongoing operations, and AI (artificial intelligence) applied to complex data sets to implement intelligent Green Lane systems. These techniques must be applied to vehicle, route, overload control, customs, and transport operator management system data to non-intrusively verify compliance in each functional area. Data from different sources must be combined using matching identifiers and interpreted against the background of trade and transport regulations. Statistical techniques are utilised to identify non-compliant behaviour, ensuring that only compliant operators can apply for cross-border permits, and enabling preferential treatment based on compliance scores. Compliance outcomes are accessible through a cloud-based web dashboard, allowing both commercial operators and cross-border authorities to observe compliance behaviour and take corrective action in real time. The system provides decision support by explaining the reasons for allocated compliance scores and by comparing the compliance ratings of different vehicles and operators. The incentives provided to operators will enable the simultaneous improvement of trade efficiencies and trade compliance, resulting in improved economic performance of the region.

1. INTRODUCTION

The cross-border road freight industry forms the backbone of the sub-Sahara African economy (Hoffman, 2010). Due to the deteriorating rail infrastructure road transport is responsible for at least 76% of cargo movement in Southern Africa (Havenga, 2013). The resulting increase in road freight transport causes accelerated deterioration of road infrastructure and road safety, with trucks being involved in most fatal road accidents (South Africa's Freight News, 2021). In addition, to protect legal traders from unfair competition secure customs procedures must verify the legal status of cross-border trade flows (Hoffman, Grater, Venter, Maree, & Liebenberg, 2018, 2019). Due to the above factors, the Cross-Border Road Transport Agency (C-BRTA) of South Africa is implementing the Operator Compliance Accreditation System (OCAS) for all cross-border road transport operators (OCAS Implementation Manual, 2019). OCAS applies evidence-based compliance management to heavy truck transport operations (Mooren, 2016). OCAS is the first cross-border compliance measurement and enforcement system in a developing country to apply quality regulation to safety outcomes and risk exposure factors of fleet operations.

1.1 Aim of Paper

1.1.1 Problem Statement

The main contribution of this paper is the definition of a concept that promotes cross-border road transport compliance through a combination of incentives and penalties that streamline rather than disrupt normal traffic flows. To achieve its objectives OCAS requires data from both enforcement agencies and commercial transport operators (Hoffman, 2022). Due to isolated systems that contain subsets of the data required for a comprehensive compliance overview but that do not share this data with a common platform, most non-compliant behaviour is currently not detected. Efforts towards intrusive compliance enforcement cause disruptions to all cross-border traffic, as existing systems cannot differentiate between compliant and non-compliant operators (Hoffman, 2017). Previous research provides evidence that value can be added when data silos are broken down and combined to provide a holistic view across the complete value chain (Barreto, Amaral, & Pereira, 2017). This paper explores implementation of the approach as described above.

1.1.2 Scope of Paper

This paper provides a description of the compliance measures that were defined, the data that was collected, and the way in which the data was processed to extract compliance measures in a manner that does not disrupt traffic flows. Some of the results that were obtained are displayed. The paper is organized as follows: Section 2 provides a literature overview of cross-border road transport compliance enforcement. Section 3 describes the methodology used for OCAS. Section 4 summarizes the data that is collected for OCAS. Section 5 describes how compliance scores and ratings are calculated. Section 6 describes the OCAS system design and section 7 discusses the results based on collected data. Section 8 and 9 discusses conclusions and recommendations for future work.

2. LITERATURE STUDY

The OCAS concept is a combination of road transport operator safety compliance, cross-border customs compliance, and operator management system compliance (OCAS implementation manual, 2019). While different elements of compliance are separately addressed by literature, no references could be found of compliance systems that simultaneously address all the combined facets of cross-border road transport. Within the South African context, it may be viewed as an extension of the RTMS (Road Transport Management System), which is a system for voluntary self-regulation of truck fleet operators (Nordengen, 2008). Compliance measurement studies applied to land-based transport mostly focused on public transport operators (Wu, Yang, Jiang & Zhang, 2012). To improve monitoring of the compliance of road transport using existing rules, the European Union introduced the European Registers of Road Transport Undertakings (ERRU), a system that allows exchange of information between Member States (Rychter & Rychter, 2016).

Studies applied to commercial fleet operators primarily focused on safety management aspects (Mooren, 2016) and overload control, which has been one of the primary causes of serious road accidents (Batool, Hussain, Kanwal & Abid, 2018) (Dolcemascolo, Hornych, Jacob & Schmidt, 2015) (Nordengen, De Saxe & Kienhöfer, 2016). The importance of truck safety has been widely reported and studied (Zhang, Yau & Zhang, 2014; Douglas, 2009; Kemp, Kopp & Kemp, 2013). A recent South African study performed by the RTMC showed that a total of 4,001 trucks and buses were involved in fatal crashes between 1 January 2018 and 31 December 2022. A total of 2,560 fatal crashes were recorded, with 3,413 fatalities and a combined crash severity of 1.33 (average fatalities per crash) (BusinessTech, 2023). In 1997, 98 percent of fatalities from crashes between a truck and a passenger vehicle were occupants of the passenger vehicle (TRUCK SAFETY: Motor Carriers Office Hampered by Limited Information on Causes of Crashes and Other Data Problems, 1999). According to Chen, Sieber and Lincoln (2015), commercial trucks were involved in 3,464 fatal, 73,000 injury-causing and 241,000 property-damaging crashes in 2012 in the US alone. It was found that it would be beneficial to road safety if high-risk carriers could receive reviews of their compliance with safety regulations. An IoT solution for enhancing road safety based on drivers' risk assessment and detecting extreme road user behaviour was proposed by Jabbar, Shinoy & Kharbech (2019). Miller (2017) studied the performance of carriers under the IDP (Information Disclosure Program) and found that metering leads to improved performance. IT-enabled monitoring of truck drivers to enforce compliance with work hour rules resulted in increased unsafe driving practices due to speeding (Scott, Balthrop & Miller, 2020). This resulted in increased crashes across all size cohorts once strict enforcement of the electronic logging device mandate started. The use of weigh-in-motion (WIM) technology was proposed by Jacob & Feypell-de La Beaumelle (2010) to allow trucks to be weighed in traffic flow, without any disruptions to operations, thus contributing to both safer and more efficient operations. Such systems profile fleet operators who frequently infringe the law and have been shown to increase efficiency by a factor of 3 (Dolcemascolo, Hornych, Jacob & Schmidt, 2015).

Much research has been published about AEO (authorized economic operator) programs to promote the global standardization of customs compliance (Jiang, 2016; Kafeero, 2017; Torres, 2020). AEO is a concept created by the WCO (World Customs Organization) to promote voluntary compliance with international customs standards. A recent study measured compliance and non-compliance of firms in New Zealand to understand the underlying patterns with specific best practices (Torres, 2020). Kafeero (2017) examined the dynamics of global value chains (GVCs) and concluded that AEO programs are beneficial to GVCs. The Revised Kyoto Convention, The SAFE Framework of Standards and the Trade Facilitation Agreement were identified as the basic international legal framework that guides AEO programs.

None of the above references however addressed the problem statement of this paper: a compliance-based accreditation system for cross-border transport operators, covering all stated areas of compliance. To the best of our knowledge this is the first paper that combines data available from law enforcement agencies and from commercial transport operators to assess non-compliance based on behaviour measured in real time, enabling effective action against offenders without negative implications for non-offenders.

3. METHODOLOGY

This research firstly uses an inductive approach: empirical observations were made regarding the behaviour of road transport operators, which revealed patterns of non-compliant behaviour within defined behavioural areas from a significant fraction of operators. The OCAS system combines data from a variety of sources to extract compliance measures and calculates a compliance rating for each operator in each area. We hypothesize that the measurement of compliance, with incentives for compliant operators and penalties for non-compliant ones, will result in a higher level of voluntary compliance. This second deductive element will be tested through future research once the OCAS system has been in operation for a sufficient period of time.

Based on historical experience and discussions with various shareholders (roads agency, customs authority, transport operators, cargo owners, etc), a list of compliance areas was defined to characterize non-compliant cross-border road transport operator behaviour. A list of data fields required to identify incidents of non-compliance was defined and the appropriate data sources were identified. To limit the deployment cost of OCAS, incidents were limited to those that could be detected based on existing data from stakeholder IT systems. A cloud-based system was created to collect data from stakeholder IT systems, using various identifiers to associate data from different sources with the same incidents. Interfaces were created to these systems to allow the collection of the required data, including IoT data from GPS tracking systems and weighbridges, transactional data from transport and customs authorities, and data supplied by transport operators from within their systems. Information was extracted from these raw data sets to allow the calculation of compliance scores for each behavioural area. Thresholds were applied to compliance ratings to determine an accreditation level of each operator. Data mining is used to measure long term compliance behaviour and to allocate a compliance rating to operators. The database and processing software are securely hosted in the cloud and KPIs (key performance indicators) are displayed on dashboards that are embedded into the C-BRTA IT systems. Operators that do not achieve the minimum required level cannot apply for or renew cross-border permits. Operators with basic accreditation are allowed to apply for permits. Operators with higher levels of accreditation qualify for additional transport corridor benefits, such as fewer inspections. This is regarded as a significant benefit, as any delays have a big impact on the profitability of cross-border transport operators (Hoffman, 2017).

4. DATA COLLECTED

Table 1 provides an overview of the compliance areas and data sources used by OCAS.

Table 1: Compliance Areas and Data Sources

Nr	Compliance Area	Data Source
1	Company Registration	CIPC (Companies and Intellectual Property Commission)
2	Vehicle licensing and roadworthiness	eNatis (National Traffic Information System)
3	Driver licensing	eNatis
4	Overload control	SANRAL (South African National Roads Agency) weighbridges
5	Route	Permits, Consignment Notes and GPS tracking systems
6	Customs	SARS (South African Revenue Services)
7	Management system	Operator MIS systems

All operators must submit the following information:

- Permit applications must indicate the nature of cargo, origin, destination, border posts and vehicles to be used.
- Monthly information uploads must confirm trips that were completed, cargo and passenger volumes, vehicles used, and border posts crossed.

Operators who wish to obtain higher accreditation ratings may provide the following voluntary information:

- Monthly verification of 10 management functions, including safety checks, maintenance activities, load control, driver authorization and monitoring and speed and fatigue management.
- GPS tracking information for cross-border vehicles to enable verification of route, speed, and fatigue compliance.

5. COMPLIANCE SCORES AND RATINGS

Collected data is used to calculate various compliance ratings, as explained in the subsections below. The compliance ratings are combined into an overall compliance rating and used to determine the accreditation level of operators.

Company registration information provided by operators is compared to the CIPC database. The operator is non-compliant if the company is not found, not in business or not registered in South Africa. Operator vehicle information is compared to the eNatis system. Vehicles are non-compliant if not properly licensed, if not considered roadworthy, or if the operator is not the current legal owner of the vehicle. Operator driver information is compared with the eNatis system. Drivers are considered non-compliant if their driver's license or PDP (professional driver permit) has expired.

Cross-border permits are linked to specific border posts (Regulations in terms of the Cross-border Road Transport Act 4 of 1998 of South Africa, 2011). Route compliance is verified by ensuring that trips are completed using the correct vehicles and by crossing the correct border posts. Data from border post ANPR cameras and operator GPS tracking systems are used for additional verification when made available by operators.

Customs declarations are electronically declared to SARS before vehicles may proceed to border posts. The outcome of the electronic customs process is used to determine compliance. In the case of cargo rejections, non-compliances are registered in OCAS (Hoffman, Grater, Venter, Maree & Liebenberg, 2019).

Legislation requires drivers of commercial vehicles to comply with prescribed rest periods, depending on the duration of their journeys. Vehicle GPS tracking data is analyzed to ensure that drivers remain compliant while completing their journeys.

Different vehicle types must adhere to different speed limits on freeways and within urban areas. Vehicle GPS tracking data is analyzed to determine if vehicles are compliant. If the vehicle exceeded the speed limit for its type and for the location, a speed non-compliance is recorded. The speed compliance rating is calculated as the fraction of trips for which no speed non-compliance was observed.

Cross-border routes are equipped with ANPR enabled static weighbridges and weigh-in-motion (WIM) scales used for overload law enforcement. Overload regulations require trucks to drive in the WIM lane to allow the system to determine if a truck should be guided to the static scale. GPS tracking data is combined with WIM scale data to determine if the vehicle used the WIM lane, if it properly crossed the WIM scale with all tyres, and if it visited the static scale in case of exceeding the WIM scale threshold. At the static scale it is determined if the vehicle exceeded the legal limit. The algorithms developed for this purpose are described in more detail in (Hoffman, Schutte & Rabe, 2022).

While the compliance measurements extracted from transactional and telemetry data is valuable to identify specific non-compliant incidents, it may not cover all aspects of cross-border operations. For this reason, it is also required of operators to implement internal management systems that apply quality control to all operations that may result in non-compliances. Information is extracted from the operator's MIS to obtain evidence of quality control for each vehicle and each trip.

6. SYSTEM DESIGN

The system consists of building blocks as schematically depicted in Figure 1 and described below. Data is collected from various data provider systems. WIM and static scale data is provided through a private event stream hosted on the Telegram platform. When a vehicle on a pre-determined list is spotted by ANPR cameras at a weighbridge facility, an event with vehicle information is published onto the event stream. The event stream is constantly monitored and events are captured in storage. GPS data is queried at 5-minute intervals from a SOAP API for each client providing data. GPS and vehicle data is combined and captured in storage. eNatis data is fetched through a REST API. A list of vehicles from the C-BRTA system is looped through every few weeks to verify that the local copy of each vehicle's information is identical to data available from eNatis. CIPC, Home Affairs and Customs data is received as static database files provided monthly and are ingested into a database with SSIS packages. In future these processes will transition to using APIs once available. Transport operator data is received in different formats depending on the capabilities of their management systems. For larger operators, API integrations are used to collect information automatically. For smaller operators without sophisticated software solutions, data is collected through standardized online submissions. The C-BRTA database used for daily OLTP (online transaction processing) activities has a read replica available within the OCAS system. This allows data generated from daily operations to be combined with the various datasets collected from industry without affecting the performance of daily operations. Table 2 describes the amount of data the system currently contains for each of the various sources. As more stakeholders participate in the project, the volume of data will continue to grow rapidly.

Table 2: Number of data entries provided by each provider

Data Source	Data Entry Estimate
WIM & Static Scale	400 000 vehicle measurements
Vehicle GPS	26 million GPS data entries
SARS Customs	4 million customs transactions
eNatis Vehicle	230 000 vehicle status entries
CIPC Company	5 million company status entries
Home Affairs	100 000 personnel status entries

Since this system is built on top of already existing infrastructure, we incorporated the existing Microsoft SQL Server database used for daily OLTP activities. Each data provider is assigned a dedicated data storage solution.

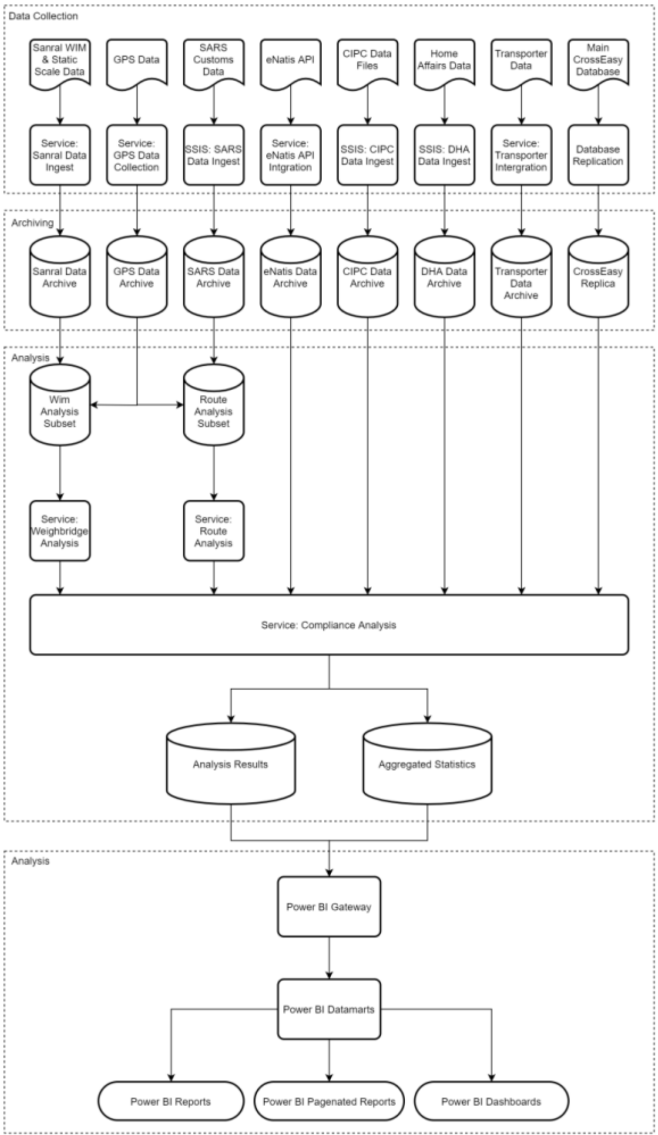

Figure 1: Schematic description of the system architecture

Each of the different datasets within the database can be classified as one of the following types:

- Archival: 1:1 representations of the data received from data providers. These archives serve as the single source of truth for all data. All other datasets extract or derive their results from these datasets.
- Analysis: These datasets are extracted from the archival data and only contain what is needed to perform specific data analysis tasks.
- Results: Result datasets contain the outputs of data analysis tasks such as historical statistics or compliance scores and serve as a caching solution for Power BI. Results can be retrieved repeatedly without repeating costly analysis tasks.

A key consideration of the database is scalability to accommodate more and bigger data providers. As shown in the table above most of the data used for analysis is time-series data, describing events with timestamps combined with relevant data field values. Efficiently managing time-series data is pivotal to scalability. As an example, all GPS data recorded at a single location can be combined into a single event. These aggregations reduce the number of stored events but sacrifices detail in the process. Knowing exactly which of these aggregations to perform significantly speeds up downstream processing.

After the various analysis operations have produced results, Power BI uses the results to present Key Performance Indicators (KPIs) and compliance reports to users of the system. Figure 2 illustrates a summary of the location all the border posts where permits are verified.

Figure 2: Location of South African border posts

Figure 3 shows an example of a statistic for the different types of permits that have been issued. For a specific system user, the types of permits issued might be valuable information, but that same information might not be of any use to other users. Interpreting results from the perspective of different stakeholders and presenting each with unique KPI's that they consider valuable is thus a key goal of the system.

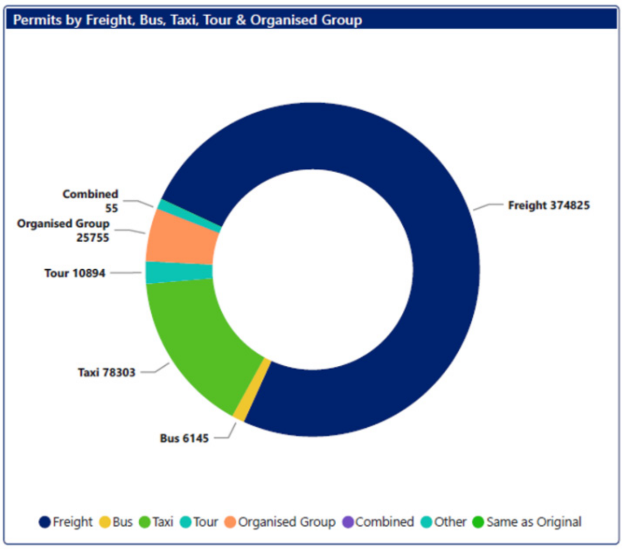

Figure 3: Breakdown of permits issued per vehicle type

7. RESULTS

The current C-BRTA system collects data for 668 cross-border road transport operators. The list of compliance areas for which results are generated was described in Table 1. Due to lack of space, we can only display results for a representative subset of results generated for these compliance areas.

We extracted vehicle data from the eNatis system reflecting the licensing and roadworthiness status of all vehicles declared by operators when registering on the

C-BRTA system. Figure 4 displays the number of vehicles for a subset of operators, as well as the number of unlicensed and unroadworthy vehicles for the same operators. The system allows this data to be sorted based on any criteria to highlight problematic aspects; in this case the number of unlicensed vehicles was used as sorting criteria.

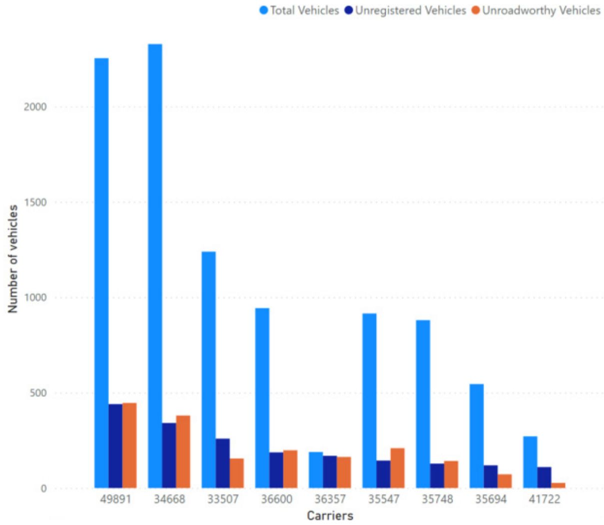

Figure 4: Vehicle compliance status

For route compliance we compared trip declarations against the conditions linked to the permits referenced by the trip declarations, to identify vehicle and border post non-compliances. Table 3 displays information about operators, the number of trips declared, the number of detected offenses and the resulting average route non-compliance per operator type. Freight operators were clearly the biggest route offenders. To provide additional decision support information, we sorted the operators based on number of offenses from high to low and calculated the fraction of operators as well as the fraction of offenses represented by these operators. Figure 5 shows that 90% of offenses can be eliminated by acting against less than 10% of operators, all with known identities.

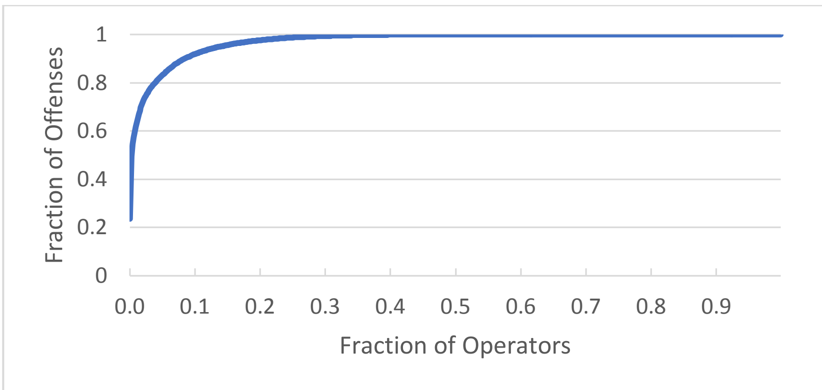

Figure 5: Accumulative fraction of offenses for accumulative fraction of drivers

Table 3: Route Compliance per Operator Type

Operator Type	Number of Operators	Number of Trips	Number of Route Offenses	Average Route Non-Compliance
Bus	32	2,942	228	7.7%
Freight	275	80,478	17,717	22.0%
Other	24	1,026	72	7.0%
Taxi	337	13,508	636	4.7%

The fraction of trips containing speed offenses as extracted from GPS tracking data is used to calculate a speeding rating for each operator. Figure 6 displays an example of such compliance data, measured daily to indicate if significant changes are detected as function of time; similar results can be displayed on monthly or annual basis. The speeding rating varied between 0.5% and 7%.

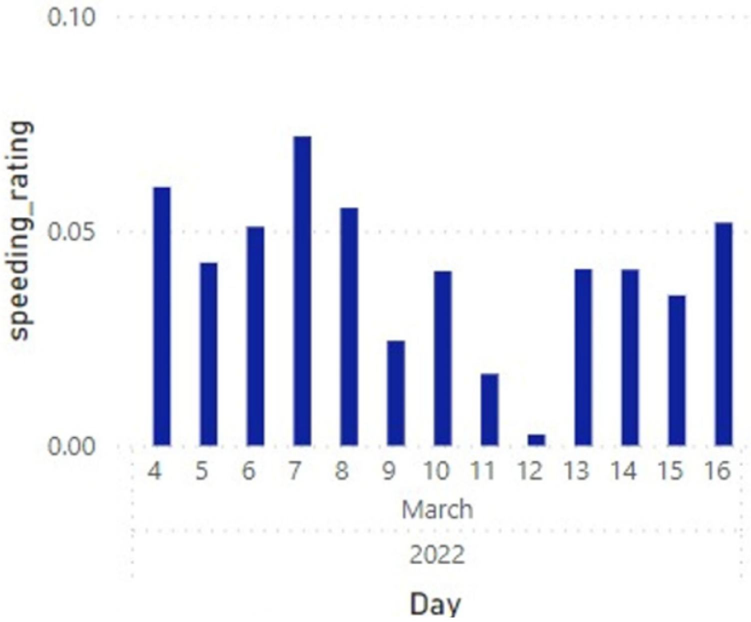

Figure 6: Speeding rating per day for two operators

Overload offenses are extracted from WIM and static scale data. Figure 7 displays the different types of WIM scale offenses collected for individual vehicles over a period of about 2 years; the different offense types are identified in terms of codes from 0 to 5. Figure 8 displays the fraction of offenses represented by different offense types calculated over all vehicles; this indicates how serious each offense type is for the entire industry.

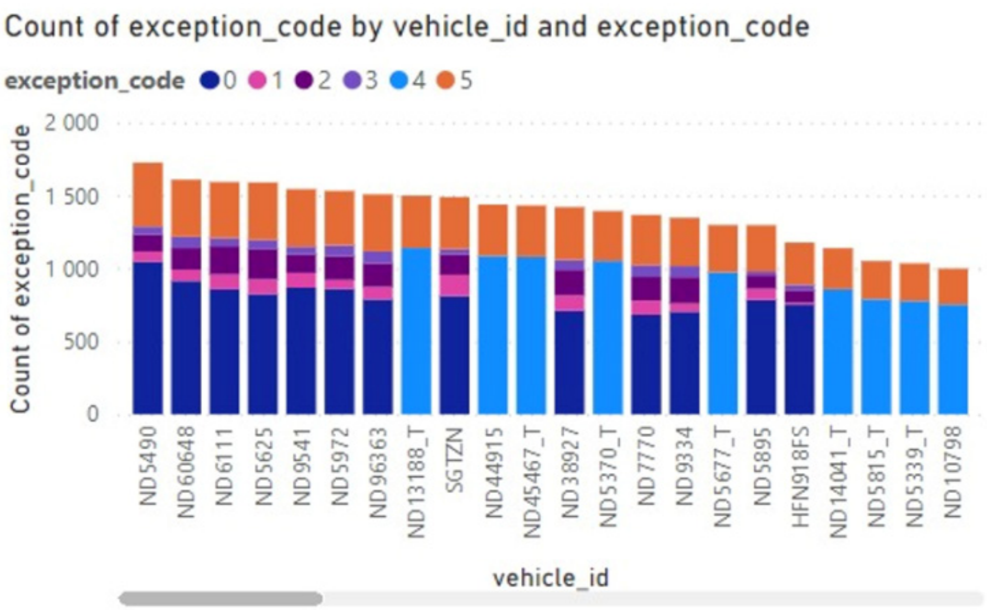

Figure 7: Overload offenses per vehicle

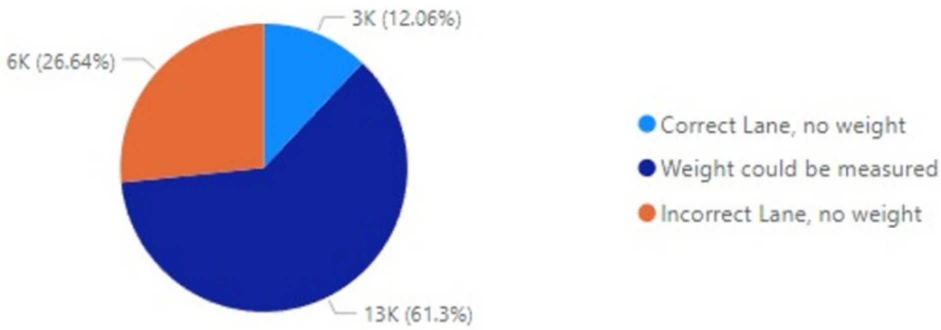

Figure 8: WIM scale offense statistics averaged over all vehicles

Table 4 displays statistics of safety and security incidents that were recorded for vehicles participating in the pilot implementation. We also applied ANOVA analysis to determine the statistical level of significance of the relationship between vehicle IDs and incident outcomes. The results displayed in Table 5 below confirms that vehicle ID is a significant indicator of incident prevalence, given that both F-statistics are much larger than 1 and that both p-values are very small (Hoffman, Schutte & Rabe, 2022).

Table 4: Statistics on incidents recorded

Statistic	Safety Incidents	Security Incidents
Total number of observations	10,718	1,680
Average observations per vehicle	282	44.2
Total number of incidents	1,552	75
Average incidents per vehicle	40.8	1.97
Incidents as percentage of observation	14.5%	4.5%

Table 5: ANOVA results assessing relationship between vehicle ID and incident rate

Incident Type	F-statistic	p-value
Security	7.81	5.7E-37
Safety	8.13	2.99E-54

8. CONCLUSIONS

The results presented in this paper demonstrate that Industry 4.0 principles can be applied to implement a cross-border road transport compliance accreditation system by using existing data from a variety of sources. By linking data from different stakeholders, the defined compliance measures can offer additional insights into operator compliance behaviour. A relevant example is route compliance, that can only be reliably determined if data is available from the C-BRTA (permit conditions and trip declarations), operators (GPS tracking data) and Customs (ANPR camera and cargo manifest data). The same is true for overload compliance that relies on eNatis data (vehicle ownership) roads authority data (static, WIM scale and ANPR camera data) and GPS tracking data from operators. The OCAS system thus demonstrates that it is possible to extract incidents representing non-compliant behaviour in real-time, and to translate such data into long term behavioral characteristics on which operators' rights and benefits can be based. As all compliance data is collected in an unobtrusive manner, it is possible to implement a compliance enforcement system that will act against offenders without causing any disruptions to compliant operators. Enforcement is applied through the simple mechanism of withdrawal of cross-border permits. The incentive for operators to participate and share data on a voluntary basis is the benefit of Green Lanes treatment at border posts, weighbridges, and other processing points, resulting in faster vehicle turnaround and thus higher profitability levels. The successful application of the OCAS concept however relies on cooperation between different data custodians, as no single agency has access to sufficient data to extract all the required compliance measures. Future work will focus on the analysis of relationships between compliance behaviour and offense levels, the integration of OCAS into AEO programs as well as the impact of OCAS on compliance levels and corridor performance.

9. ACKNOWLEDGEMENTS

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