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USE OF EVENT DATA RECORDER SYSTEMS AS A BASIS FOR THE DEVELOPMENT AND APPLICATION OF TRAINING PROCEDURES FOCUSING ON SAFETY, OPERATIONAL AND ECONOMICAL ASPECTS FOR ROAD FREIGHT TRANSPORTATION: AN APPLICATION AND ANALYSIS APPROACH.

Luid Pereira de Oliveira

Tese de doutorado apresentada ao Programa de Pós-graduação em Engenharia de Transportes, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Engenharia de Transportes.

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Felipe Jiménez Alonso

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DEDICATORY

I dedicate the conclusion of this whole investigative process to God, my parents, siblings, family and friends.

And I thank especially my beloved wife and partner Aline and also my children Ana Luisa and André Luis for always being by my side, I love you.

> "Unshakable faith is only that which can face reason in all human epochs."
>
> Allan Kardec.

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USE OF EVENT DATA RECORDER SYSTEMS AS A BASIS FOR THE DEVELOPMENT AND APPLICATION OF TRAINING PROCEDURES FOCUSING ON SAFETY, OPERATIONAL AND ECONOMICAL ASPECTS FOR ROAD FREIGHT TRANSPORTATION: AN APPLICATION AND ANALYSIS APPROACH.

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Na maioria dos países, o Transporte Rodoviário é o principal meio de deslocamento de cargas e passageiros, no entanto, há uma série de fatores que atuam de forma isolada ou associada na amplificação da ineficiência e instabilidade do setor. Dentre os principais fatores, é possível destacar: elevado número de acidentes, precariedade estrutural, baixa qualificação da mão de obra e ausência de ferramentas de controle e gestão baseadas em tecnologia. Além da ineficiência e instabilidade, o caso específico do Brasil merece destaque uma vez que o país convive diariamente com um dos trânsitos mais violentos do mundo onde, os custos dos acidentes ao país são da ordem de U$ 5,45 bilhões anuais. Diante deste cenário, a pesquisa tem como motivação compreender como a aplicação de um procedimento de capacitação profissional e emissão de *feedback* embasados em dados extraídos de sistemas de *Event Data Recorder* (EDR) impactam no comportamento e no padrão de condução de motoristas profissionais em função de critérios de: segurança, operação e economia. Para se alcançar este objetivo, o processo de investigação foi estruturado e aplicado por meio de etapas específicas que contaram com a participação e apoio de cinco empresas de transporte rodoviário de cargas brasileiras. Foram implementadas fases de monitoramento do processo de condução e operação dos veículos associadas a intervenções direcionadas a qualificar e quantificar o impacto da inserção do procedimento de capacitação e do uso da tecnologia,

com fito de avaliar os padrões de eficiência dos pares veículo/condutores, considerando como objetivo a maximização dos níveis de segurança e operação sem incorrer em piora de indicadores econômicos. Os estudos de caso propostos, permitiram demonstrar que a adoção da tecnologia EDR apresenta resultados superiores à sua não utilização, contudo, também foi evidenciado que estes resultados são potencializados a partir da integração entre um procedimento de capacitação, emissão de *feedback* baseado em dados extraídos do sistemas EDR. Entre as contribuições do trabalho pode se destacar o desenvolvimento de um estudo inovador capaz de atuar em uma lacuna do conhecimento científico, a partir do uso de dados coletados por sistemas EDR como base de avaliação de padrões de condução em função de critérios específicos ligados a segurança, operação e economia, indicando desta forma, a aplicabilidade da tecnologia para o aumento da eficiência no segmento rodoviário de cargas no Brasil. No entanto, a contribuição principal está relacionada à comprovação da efetividade do procedimento de capacitação desenvolvido pela pesquisa, como ferramenta de aumento da eficiência da frota e melhoria no comportamento dos condutores ao permitir que dados de operação sejam convertidos em conhecimento aplicado.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

USE OF EVENT DATA RECORDER SYSTEMS AS A BASIS FOR THE DEVELOPMENT AND APPLICATION OF TRAINING PROCEDURES FOCUSING ON SAFETY, OPERATIONAL AND ECONOMICAL ASPECTS FOR ROAD FREIGHT TRANSPORTATION: AN APPLICATION AND ANALYSIS APPROACH.

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For most countries, road transport is the main means of moving cargo and passengers. However, there are a number of factors that act in isolation or association to amplify the inefficiency and instability of the sector. Among the main factors are the high number of accidents, structural precariousness, low qualification of the workforce, and the absence of control and management tools based on technology. Besides inefficiency and instability, the specific case of Brazil deserves to be highlighted, since the country lives daily with one of the most violent traffic systems in the world, where the cost of accidents to the country is around US$ 5.45 billion a year. Given this scenario, this study aims to understand how the application of a professional training and feedback procedure based on data extracted from event data recorder (EDR) systems impacts the behavior and driving patterns of professional drivers according to safety, operational and economic criteria. To achieve this goal, the research process was structured and applied through specific stages with the participation and support of five Brazilian road transportation companies. First, the monitoring phases of the driving and vehicle operation process were implemented, associated with interventions aimed at qualifying and quantifying the impact of inserting of the training procedure and the use of technology, with the purpose of evaluating the efficiency standards of the vehicle/driver pairs, with the objective of maximizing the safety and operation levels without worsening the economic indicators. The case studies conducted demonstrated that the adoption of EDR technology had positive results, and that these results were enhanced by the integration of a training procedure and feedback based on data extracted from EDR systems. Among the contributions is the development of an innovative method using data collected by EDR systems as a basis to evaluate driving patterns according to specific criteria related to safety, operation and economy, indicating the applicability of the technology to increase efficiency in the road cargo segment in Brazil. However, the main contribution is demonstration of the effectiveness of the training procedure developed as a tool to increase fleet efficiency and improve driver habits by allowing operation data to be converted into applied knowledge.

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ACRONYMS LIST

ANTT	Agência Nacional de Tranporte Terrestre
BAT	Boletim de Acidente de Trânsito
BCC	Banker, Charnes e Cooper
BCR	Benefit Cost Ratio
CAM	Certificado de Aptidão para Motorista
CAP	Certificado de aptidão Profissional
CCR	Charnes, Cooper e Rhodes
CONTRAN	Conselho Nacional de Trânsito
CRS	Constant Returns to Scale
CSEAA	Certificación de Seguridad de Empresas de Autobuses y Autocares
CTB	Código de Trânsito Brasileiro
DMU	Decision-Making Unit
DENATRAN	Departamento Nacional de Trânsito
DGT	Direção Geral de Trânsito
ECU	Electronic Control Unit
EDR	*Event Data Recorder*
EF	Frequencia de Eventos
GDP	Gross Domestic Product
GPRS	General Packet Radio Services
GPS	Global Positioning System
IPEA	Instituto de Pesquisa Econômica Aplicada
ISO	International Organization for Standardization
ITS	Intelligent Transport System
JDR	Journey Data Recorders
KPI	Key Performance Indicator
NHTSA	National Highway Traffic Safety Administration
OBU	On Board Unit
SIA	Sistema de Informações Ambulatoriais
SIM	Sistema de Informações de Mortalidade
TRC	Transporte Rodoviário de Cargas
VRS	Variable Returns to Scale

1. INTRODUCTION

1.1 Initial considerations

Traffic accidents on the world's highways are a problem of great concern to authorities of developed and developing countries, and according to the World Health Organization (WHO), should be considered a global public health problem. It is estimated that such occurrences are responsible for 50 million serious injuries and 1.25 million deaths annually. The annual global financial loss of these events is approximately US$ 518 billion, representing between 1% and 3% of the each country’s GDP (Oliveira 2016; Waiselfisz 2013; WHO 2017).

Brazil is among the countries with the highest rates of fatal traffic accidents, placing the country in an unenviable position on the world stage. This reality is even alarming when a direct comparison is made between Brazilian traffic fatality rates and those in developed countries.

According to Volvo (2019), 69,229 accidents involving 161,288 people were registered in Brazil in 2018, which caused 5,271 deaths and 17,650 serious injuries; in the same period, according to DGT (2018), 102,299 accidents involving 100,620 victims, 1,697 deaths and 8,935 hospital admissions were registered in Spain, i.e., despite Spain’s higher number of accidents, the total numbers of people involved and deaths are substantially lower, indicating a higher morbimortality and aggressiveness of Brazilian traffic.

Sivak and Schoettle (2014) presented a study comparing traffic fatalities in 193 countries from all continents, where the global average was 18 deaths/100,000 inhabitants. According to the authors, Brazil was ranked 148th, with 22 deaths/100,000, while Spain, our object of comparison, had 7 deaths/100,000 people, occupying 35th place. The report also stated that the Brazilian mortality rate was 22.2% higher than the world rate, 57% higher than the North American rate, and approximately four times higher than the rate found in European Union countries.

Such findings related to the violence in Brazilian traffic conflict directly with the proposal of the World Health Organization (WHO), which in 2010 established the "Decade of Action for Road Safety" (2011-2020), with the general goal of reducing the global trend of growth in the number of traffic fatalities by 50% in the period, equivalent to a reduction of 5 million deaths worldwide (Toroyan 2009; WHO 2011a).

In contrast to the Brazilian case, in 2015 the Spanish government presented significant results during the 2nd Global Ministerial Conference on Road Safety, such as an 82% reduction in traffic fatalities (1989-2015), placing the country among the 10 with the lowest death rates in the world, thanks to the application of public policies involving effective controls, improvement of the quality of road infrastructure, educational campaigns based on prevention, and mainly implementation of technology-based tools that facilitate the enforcement process, as presented by the head of the General Directorate of Traffic (DGT) during his presentation (DGT 2015; Exame 2015).

In addition to the great loss of lives, there is a high cost related to traffic accidents in Brazil, equivalent to approximately US$ 5.45 billion, 62% of which refers to costs associated with accident victims (injuries, loss of productivity, health care, death).

Even an accident without victims costs the country an approximate average of US$ 63,5161; however, if there are fatal victims, this cost rises to US$ 161,364. In this context, considering that road freight transportation (RFT) accounts for 44% of the total costs of accidents on federal highways, it is estimated that its impact is equivalent to US$ 1.37 billion a year (IPEA 2006, 2015b).

Unlike countries of the same size, the main means of moving cargo and people in Brazil is over roads and highways. Currently, 61% of cargo and 95% of passengers depend on the road mode for their circulation CNT (2017). These data characterize the country's dependence on one of the most polluting and least efficient modes of long-distance transport.

Besides the impacts caused by the high number of accidents, Brazilian carriers are forced to live with a series of obstacles, such as insufficient road capillarity (low density), poor infrastructure (poor road conservation), lack of public policies aimed at increasing competitiveness, reduced corporate actions aimed at the adoption and implementation of training and professional qualification procedures, and absence of control and management tools, based on the use of technologies and embedded intelligence (CNT 2017; EPL 2017; VOLVO 2020; Wanke 2010).

To understand and summarize the main causes of this inefficiency, I analyzed articles, reports, regulations and studies developed by various agencies, bodies, entities and researchers, among them De Andrade et al. (2008), Bacchieri and Barros (2011), Balbinot et al. (2011), Bartholomeu and Filho (2008), CNT (2019), Colavite and Konishi (2015), EPL

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1 To convert the values into dollars, the base year of publication of the study (2015) and the exchange rate between the Brazilian real and the dollar in February 2020 (R$ 4.35/US$) were considered, respecting the source of the information.

(2017), Hoffmann (2005), IEA (2007), IPEA (2015b), Lima et al. (2008), Stillwater and Kurani (2013)

From these studies, it was possible to draw an Ishikawa diagram, also known as a cause-and-effect diagram, presented in Chapter 4, which illustrates the complexity of causal relationships in the transport sector, taking as a basis the interdependence between the main categories that exert some kind of influence on the definition of efficiency in RFT. In the diagram, inefficiency was considered as a problem (effect) and the main causes in the categories economic, environmental, safety, vehicle, human factor and infrastructure are highlighted.

According to the WHO (2011b), there are several ways to mitigate the risk of accidents and increase the efficiency of road transport, with emphasis on effective interventions for speed management, restructuring the design of highways, increasing safety mechanisms in vehicles and improving infrastructure.

The global competitiveness ranking of 2019 WEF (2019) evaluated 141 global economies according to 12 pillars based on 114 indicators related to productivity and long-term prosperity. The study highlighted the low capacity of Brazil in relation to the pillar called "adoption of innovation", due to the low performance of key indicators such as innovation capacity, quality of scientific research institutions and collaboration between business and academia for R&D.

Regarding innovation, the use of onboard intelligence systems and event data recorder (EDR) tools is commonplace in road transport in countries in Europe and North America, focusing mainly on increasing road safety.

However, several authors and governmental bodies have been studying functionalities of these systems in relation to consumption reduction, behavioral analysis and professional training Wu, Chen, and Yeh (2014), NHTSA (2013a), Schimidt-Cotta (2009a), ETSC (2009), DGTren (2007a), Kusano, Gabler, and Kusano (2011), Jiménez et al. (2013), Hynd and McCarthy (2014), Torrao et al. (2016).

Corroborating the analysis prepared by WEF (2019), regarding the adoption of innovation processes in Brazil, the systematic and bibliographic review used as a basis for the preparation of this study identified there is still a gap in scientific development related to the application of embedded intelligence systems for road transport, especially when it comes to the use of EDR systems integrated with professional training procedures aimed at reducing costs, raising safety levels, and increasing operational efficiency.

The structural precariousness, relative lack of training of the workforce, absence of onboard intelligence systems and lack of regulations that encourage users and companies to adopt procedures and tools for monitoring and controlling the operation of vehicles all create barriers that limit the increase of competitiveness and the reduction of accidents in Brazil (FICVI 2015).

The scenario presented indicates the importance of identifying and developing mechanisms, tools and procedures to improve RFT management in the country. The approach proposed here is based on the structuring and systematized application of a professional training model integrated with the use of data collected by EDR systems, prioritizing the improvement of the standard of driving from increased levels of safety and efficiency without negatively impacting operating costs.

1.2 Problem and motivation

The research involved the development, application and validation of a specific procedure for training and feedback supported by data collected via EDR systems, where this validation is configured from the reduction of risk indicators and severity of claims, besides the enhancement of economic and operational efficiency applied to trucking companies.

In view of the above, the investigation was based on the following question:

Does the application of a training procedure and feedback from data extracted from EDR systems improve driving patterns based on safety, operational and economic criteria?

The findings contribute to the understanding of how training tools and technology can help the road transport sector in Brazil to be safer and more competitive.

1.3 Hypothesis

The central hypothesis is that the data collected by EDR systems associated with propositions contained in international standards (among them ISO 10015:2019, ISO 39001:2015, CSEAA and EC Directive 59/2003 and EU 2018/645) can serve as a basis for the development, proposal and application of a driver training procedure adapted to Brazilian reality that aims to reduce unsafe acts in driving and raise operational efficiency of road freight transport vehicles.

The second hypothesis assumes that the use of EDR systems offers better results than not using them as a tool to improve driver behavior; based on safety, economic and operational criteria.

However, I also assumed that the results obtained with the use of technology can be enhanced through the application of a specific professional training procedure based on data analysis and feedback to drivers and managers.

1.4 Objectives, general and specific.

The general objective of this work is to propose a method to analyze the application of a specific professional training procedure associated with the use of EDR systems, aiming to increase operational efficiency (cost and productivity) besides reducing unsafe behaviors and acts related to the occurrence of accidents.

The specific objectives are:

- To identify in the literature the positive and negative impacts of using EDR systems and driver training procedures that focus on mitigating the factors contributing to accidents and improving key efficiency-related performance indicators (KPI);
- To evaluate gains related to lower accident risk and higher efficiency linked to behavioral factors, through comparison between the isolated use of technology and its integrated use with training procedures and management follow-up; and
- To evaluate the impact of technology on driver behavior in order to reduce the importance of the human factor as the main cause of road accidents.

The results of this study have the potential to offer to trade associations, companies and governmental bodies scientific support to justify investment in the development and systematization of a training model based on data from onboard intelligence systems that work as tools to promote safe, efficient and humanized traffic behavior.

In a complementary way, the academic relevance of this study for the transportation area is based on its integrated evaluation of operational safety and economic criteria, as well as the proposal to implement a training mechanism based on technology, which places the theme in a scientific gap.

1.5 Justification

In Brazil, road transport accounts for 61% of cargo transport, which causes an imbalance in the transport matrix due to the excessive reliance on this modality. This favors unfair competition with other modes, limiting the emergence of a scale that justifies investments in segments where the fixed cost is high (Wanke 2010).

According to Fleury, P. F. Figueiredo, K. F. Wanke (2003) and Rocha, Ronchi, and Moura (2011), this situation favors the emergence of a vicious circle, where the prices paid by shippers do not sufficiently compensate the carrier's costs, causing a financial deficit that contributes to lower maintenance and less fleet renewal.

Added to this, data from the National Registry of Road Transportation of Cargo (RNRFT) and the National Land Transportation Agency (ANTT) for 2017 showed that 85.6% of trucks had age greater than 13.5 years, which shows the advanced stage of obsolescence of the national fleet, (ANTT 2017; DENATRAN 2020; SINDIPEÇAS 2016).

The combination of these factors with the precarious maintenance of part of the circulating fleet and the excessive workload imposed on drivers translates into increased risk of accidents and reduced energy efficiency, i.e., increased cost and consequently lower productivity Borken et al. (2007), IPEA (2015a), Newnam and Goode (2015), Radović and Stević (2018) Zhang et al. (2016).

However, despite the dependence on road transport, the road/highway network has structural capillarity (density) far short of standards that could avoid negative impacts on efficiency and productivity. According to CNT (2019), the country has 24.8 km of paved roads/1000 km^2 while the USA, which prioritizes rail transport, has 438 km/1000 km^2 of roads.

As if the low road density were not enough, 59% of the country's paved highways have some type of deficiency in the pavement, signaling, or geometry, being classified as regular, bad, or terrible CNT (2019),. This structural panorama explains the high number of accidents related to the road-environmental factor.

However, the main cause of accidents is related to the human factor, which is present in approximately 90% of the registered accidents. The main causal factors are negligence, imprudence and carelessness, which when associated with the lack of a training and qualification procedure for professional drivers, cause learning to occur in practice, thus reducing the degree of safety (Borsos, Birth, and Vollpracht 2016; ETSC 2009; Ferreira, De

Almeida, and Da Silva 2015; Inaba 2013; Paleti, Eluru, and Bhat 2010; Simmons, Hicks, and Caird 2016; Waiselfisz 2012).

In this respect, event data recorder (EDR) systems have good potential to act as tools to control the driving process, since they allow driver behaviors to be monitored in real time, thus favoring the correction of undesirable behaviors related to the occurrence of accidents and energy waste (Comeau, German, and Schramm 2017; Silva 2008; Tang et al. 2017; Vagg et al. 2013; Wouters and Bos 2000a).

Based on the factors presented regarding the unfavorable characteristics of road transport in the country, this study's relevance is the proposal of a procedure for training drivers and thus improving safety and operational efficiency.

Moreover, the association and adaptability of the training cycle to the information extracted from the EDR systems ensures that behaviors outside the desired standard can be: tracked, interpreted and addressed promptly in the training procedure.

Therefore, the choice of the line of investigation in this thesis is justified by the existing scientific gap regarding the deployment of embedded intelligence in RFT vehicles in Brazil.

However, the main observation arising from the results obtained here indicates that the adoption of systematized training metrics has a strong influence on improving the behavior of professional drivers, with considerable impact on fleet efficiency, so as to increase operational safety without causing increases in the costs of trucking companies in Brazil.

1.6 Research delimitation

The work described here is part of an exploratory study involving multidimensional analysis of a training procedure associated with the use of EDR systems. For this, EDR devices were implemented in 11 companies operating in various segments of RFT.

The implementation allowed us to understand the impact of the association of the procedure with the technology on aspects related to safety improvement, operational cost reduction and better qualification of professional drivers.

Data regarding safety, operation and consumption were collected and transformed into indicators, allowing the evaluation of the performance obtained as a function of the isolated use of EDR technology and its use associated with a specific training procedure, created based on scientific criteria, along with the emission of feedback throughout the monitoring phases.

I sought to understand how the data collected could be used in the proposal and development of a medium- and long-term training procedure, with the objective of standardizing the level of skills required according to safety and operational criteria.

The entire development of the training procedure was based on the rules contained in the Brazilian Traffic Code (CTB), regulations adopted by European Union countries, such as the Certificación de Seguridad de Empresas de Autobuses y Autocares (CSEAA) and the EU Directives 2018/645 and CE 59/2003, which involve road safety, emphasizing the importance of training and qualification processes for professional drivers.

However, the structural framework of the training procedure applied is strongly based on the determinations of the international certifications ISO 10015:2019, which discusses the establishment of guidelines for the management of competencies and personnel development, and ISO 39001:2015, which defines the requirements and guidelines for road safety management systems.

The proposal of this thesis is to evaluate a training procedure based on RFT vehicle operation data extracted by EDR systems.

With the purpose of delimiting the scope of this study, overall analysis (involving the entire fleet of vehicles) and individual analysis (driver/vehicle) were structured. However, sensitivity analyses based on ideal speed according to route sections, and determination of ideal driving patterns based on segregated indicators are not included in the scope here.

Regarding the proposed training procedure, the current stage of development guarantees robustness of the proposition, due to the traceability of the criteria emphasized in the training cycles and the measurement of the evolution of the results of the trained drivers, as determined by international standards.

154 drivers from 11 participating transport companies underwent the training procedure. However, in the construction of the thesis, the case studies analyzed the behavior of a sample of 42 vehicles, which momentarily limits extrapolation to the segment as a whole.

In this way, the process of construction and development of the research considered as a fundamental point the adoption of an EDR system that allowed the monitoring of a significant number of variables, capable of representing the integration of the criteria studied (economy, safety and operation). And, in a synergistic way, it considered that the chosen system should demonstrate the capacity to base the formatting of the drivers' evaluation process, guiding the construction and establishment of a robust training procedure. In this sense, the development and improvement of the investigative process described in the thesis allowed us to establish a correlation between the use of monitoring systems and the application of training procedures based on specific data and indicators.

1.7 Thesis structure

Chapter 1 describes the investigation, the research problem, motivation, hypotheses, objectives, justification, and topic delimitation.

Chapter 2 describes the bibliometric review process and the systematic review based on the application of the Proknow-C method associated with the Vosviewer® software, which allowed the elaboration of the scientific mapping of the established research axes, according to the analysis of the distribution of publications, bibliographic coupling and co-occurrence among keywords of the articles included in the bibliographic portfolio. The association of these tools made it possible to validate the quality and the alignment of the proposal in relation to the theme, highlighting the relevance of the works published, arranged in chapters 3, 4, and 5.

Chapter 3 describes the analysis performed on data from 12 vehicles from three road transport companies as a result of the implementation of the EDR system and the collection of variables such as distance travels, number of excess speed episodes in dray and rainy conditions, traffic fines for speeding, and number of idling, and sudden braking and acceleration events. The participating drivers underwent initial training related to awareness of the use of the technology, in addition to an economical driving course provided by a major heavy vehicle manufacturer. The results were verified by comparing variables according to the monitoring stages. The chapter takes into consideration the economic results as a function of the reduction in fuel consumption, operational results determined by reducing the engine RPM rate and increasing safety from the reduction of speeding events on dry and rainy roads, as well as variations in the number of sudden braking and acceleration events.

Chapter 4 presents the analysis of 33 drivers of a trucking company according to the variation of 9 indicators related to the criteria safety, operation, and economy. The analyses took place during three monitoring phases, in which the drivers were followed for a period of seven months and were subjected to a specific training procedure structured specifically for the investigation, receiving feedback at the end of each trip cycle. The training procedure used the data collected during the hidden monitoring phase, taken as the basis for establishing which technical concepts should be reinforced within the training cycles. Two analyses were prepared considering the indicators, the first one referring to the overall analysis of the fleet, and the other is related to the individual analysis considering the driver/vehicle pair. The chapter also describes the comparative analyses carried out based on the results of the monitoring phases in order to check if there was improvement from the isolated use of technology versus the integrated use of technology, training and feedback.

Chapter 5 mainly focuses on evaluation of the implementation of the training procedure compared to the isolated use of technology. For this purpose, the clustering of the fleet, the creation of four analysis scenarios involving the studied criteria, and the inclusion of a third monitoring phase called conscious monitoring 3 (C3) were proposed. The indicators were analyzed using the DEA method, thus allowing the calculation of the efficiency of the DMUs (driver/vehicle), which reinforced the previously observed trend that the implementation of long-term training procedures based on data collected by the EDR system enhances the results.

Chapter 6 presents a structured synthesis, involving the approaches and observations contained in chapters 2, 3, 4 and 5, highlighting the contributions obtained from the case studies comprising the thesis, focusing on analysis of the influence of the application of the training procedure and the feedback associated with the information extracted from the EDR systems.

Chapter 7 deals with the considerations and conclusions of the research, also presenting the developments from continuation of the investigations, the challenges identified, the agreements signed between companies and drivers, as well as proposals for future work.

Finally, the bibliographical references and appendices are presented.

2. BIBLIOMETRIC REVIEW

Based on the factors presented concerning the unfavorable characteristics of road transportation in Brazil, the initial aim was to demonstrate its relevance of aspects related to a procedure for training for professional drivers based on the analysis of data collected by EDR systems, in order to convert the procedure into an instrument to increase safety and operational efficiency.

In addition, the association and adaptability of the training cycle to the information extracted from the EDR systems is intended to ensure that behaviors outside the desired standard can be: traced, interpreted and addressed in the training procedure.

However, the association needs to be supported by a validated and objectively measurable scientific framework, achieved through the bibliometric review and analysis.

According to Cobo et al. (2011), bibliometric analysis involves a set of methods used to study or evaluate document portfolios and scientific information, with the aim of understanding the impact generated by authors, publications and research topics, intended for two main uses: performance analysis and scientific mapping.

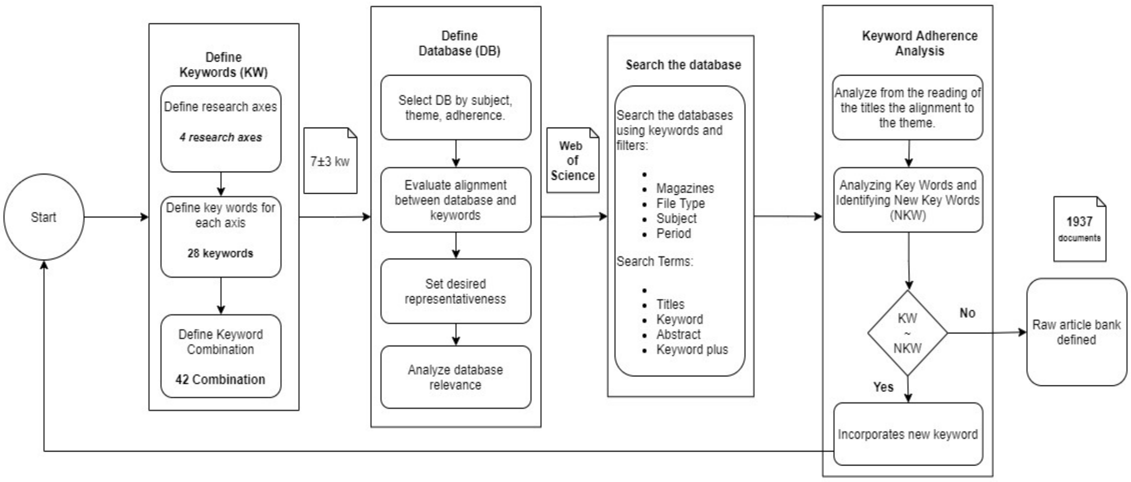
Regarding the performance analysis process, the ProKnow-C (Knowledge Development Process-Constructivist) method proposed by Ensslin and Ensslin (2007) was adopted.

This method allows an objective evaluation of the publication portfolio of one or more scientific databases considering authors, integration, knowledge area, approach, area of interest, delimitations and intrinsic restrictions; fundamentally focusing on the scientific recognition of the documents incorporated to the research portfolio (Lacerda, Ensslin, and Ensslin 2012)..

The ProKnow-C method determines a cycle composed of structured steps, beginning with the definition of the keywords and search strings, search for the articles in the databases, analysis of the alignment of the documents to the research topic, analysis of relevance, and systemic analysis of the selected portfolio (Lizot et al. 2016).

Figure 1 presents the initial step, involving definition of the keywords, search strings, database to be searched, adherence testing and structuring of the raw article bank.

Figure 1: Flow of article selection for the formation of the raw article bank.



Source: Adapted from Lacerda et al. (2012)

The flowchart describes the structural sequence of the ProKnow-C method, starting from the establishment of the research axes. In this case; the research focus was divided into four main axes around the theme of road freight transport (RFT), as described in Table 1.

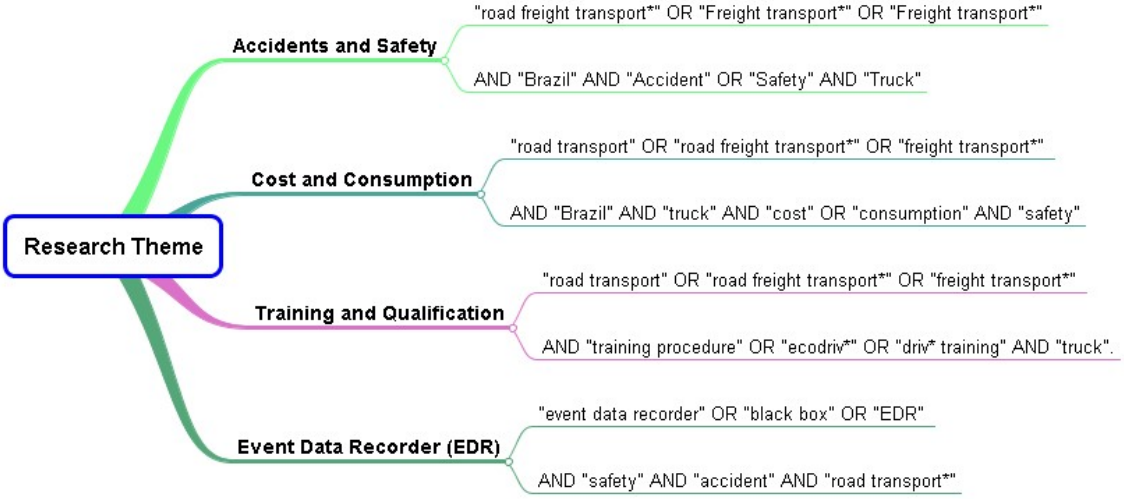
Table: 1: Purpose of the literature search according to the research axis.

Research Axis	Purpose of the bibliographic research
Cost and Consumption	Characterize the state of the art regarding the main fuel consumption items as well as RFT operational cost items in order to evaluate the procedures and methods employed to minimize both.
Accidents and Safety	Understand the main factors contributing to the occurrence of traffic accidents, focusing on safety measures and mechanisms with the potential to mitigate the number and severity of accidents in RFT.
Training and Qualification	Evaluate the training procedures proposed and applied by authors of the portfolio, focusing on the evolution of driving behavior and reduction of undesirable acts causing increased productivity and operational safety in RFT.
Event Data Recorder (EDR).	Describe the mechanism of use, characteristics, and application areas of EDR systems, as well as evaluate the use of this technology integrated with professional driver training and other intelligent transportation systems for RFT.

Source: Author

Next, the keywords and their combinations were defined in order to characterize the search strings. For the case at hand, 42 combinations were tested until establishing the search strings most adherent to the theme, as described in Figure 2.

Figure: 2: Theme, areas and search strings by research axis.



Source: Author

Parallel to the definitions of theme, keywords and strings, the method highlights the importance of defining the database(s) that will serve to define the bibliographic portfolio.

I chose to use works indexed in the Web Of Science (WoS) database, for the quality of its portfolio, for being among the most relevant and comprehensive in the areas of exact and human sciences, for having greater representativeness and consistency within the research topic, and for being the most widely used database for bibliometric studies in the areas of management and organization (Zupic and Čater 2015).

As part of the search process, I decided to include a co-occurrence analysis among the keywords as a criterion for qualifying the resulting documents, using for this the network maps generated by the Vosviewer® software, which will be presented later.

From the analysis of these maps, the strings that presented the greatest synergy in describing the research theme were selected. Thus, following the ProKnow-C, two articles from each of the axes were randomly selected and read in their entirety in order to verify the adherence of the documents found with the scope related to the keywords, thus defining the need for inclusion or exclusion of keywords.

The searches originated four banks of raw articles linked to the research axes, containing 1,937 documents, distributed as described in Table 2.

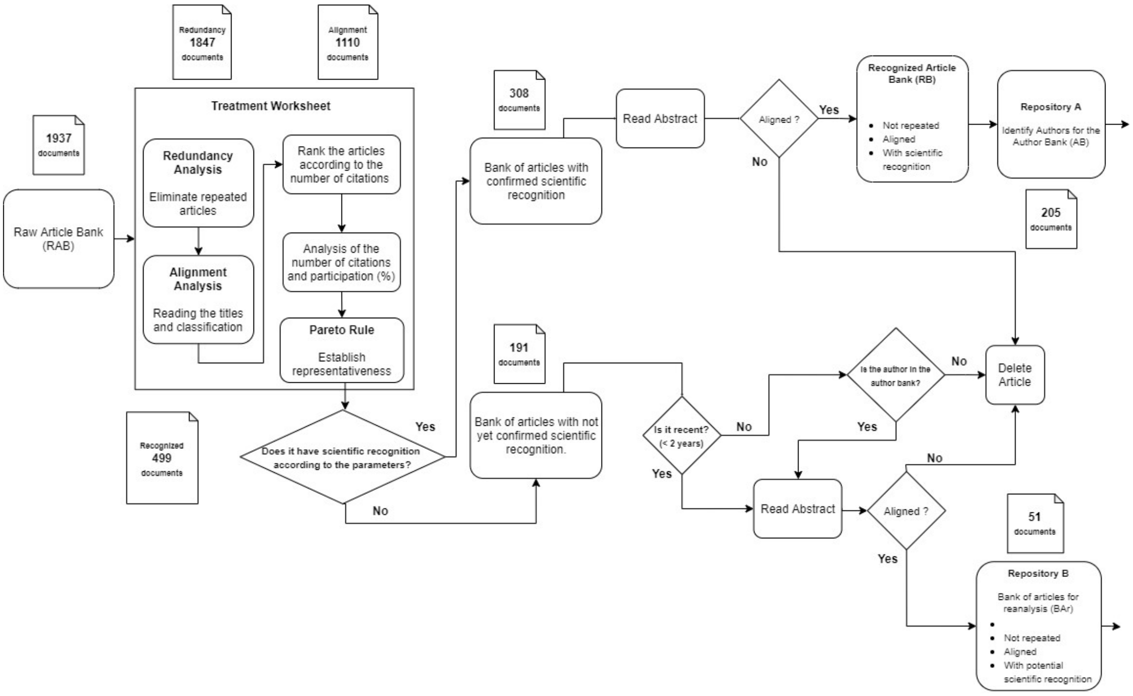
Table: 2: Number of keywords and documents per raw article bank.

Axes	Keywords	Raw article bank
Accidents and Safety	7	631
Cost and Consumption	8	546
Training and Qualification	7	612
Event Data Recorder (EDR)	6	148
Totals	**28**	**1937**

Source: Author

In possession of the raw article banks, the second step of the ProKnow-C method is the analysis of the alignment and classification of the documents, aiming at the creation of two repositories, as shown in Figure 3.

Figure: 3: Flowchart of the filtering and alignment process of the article bank.



Source: Adapted from Lacerda et al. (2012)

The four raw article databases generated by the searches were placed in an Excel spreadsheet to begin the evaluation of alignment and classification. First, redundancy analysis was performed to eliminate repeated papers. Then, the alignment of the selected articles to the research theme was checked by reading the titles of the papers contained in the raw article bank.

The articles resulting from the application of these filters were then sorted taking into account the number of citations, ranked in descending order. The importance of the number of citations was highlighted by Üsdiken and Pasadeos (1995), who stated that the number of citations can be used as a measure of influence of a work and/or the author within the research area.

From this ordering, the process of citation analysis was started to define the articles that should be considered as scientifically recognized and included in the portfolio.

To this end, the percentage relevance of the number of citations of each article was calculated in relation to the total number of citations of the article bank, establishing as a cutoff point the definition contained in the Pareto principle, where articles with proven scientific recognition are classified as those included in the 80% most cited (Maia and Marchiori 2016).

Next, the method determines that the abstracts of the selected articles be read, after which those that are in fact aligned with the research topic are included in the bank of articles, called "with scientific recognition”. This portfolio is called "Repository A" and comprises 205 non-repeated articles, aligned with the research theme in terms of title and abstract, and with scientific recognition in terms of citations. From this database of articles, the author database is extracted, an indispensable step for the reclassification of articles with potential scientific recognition.

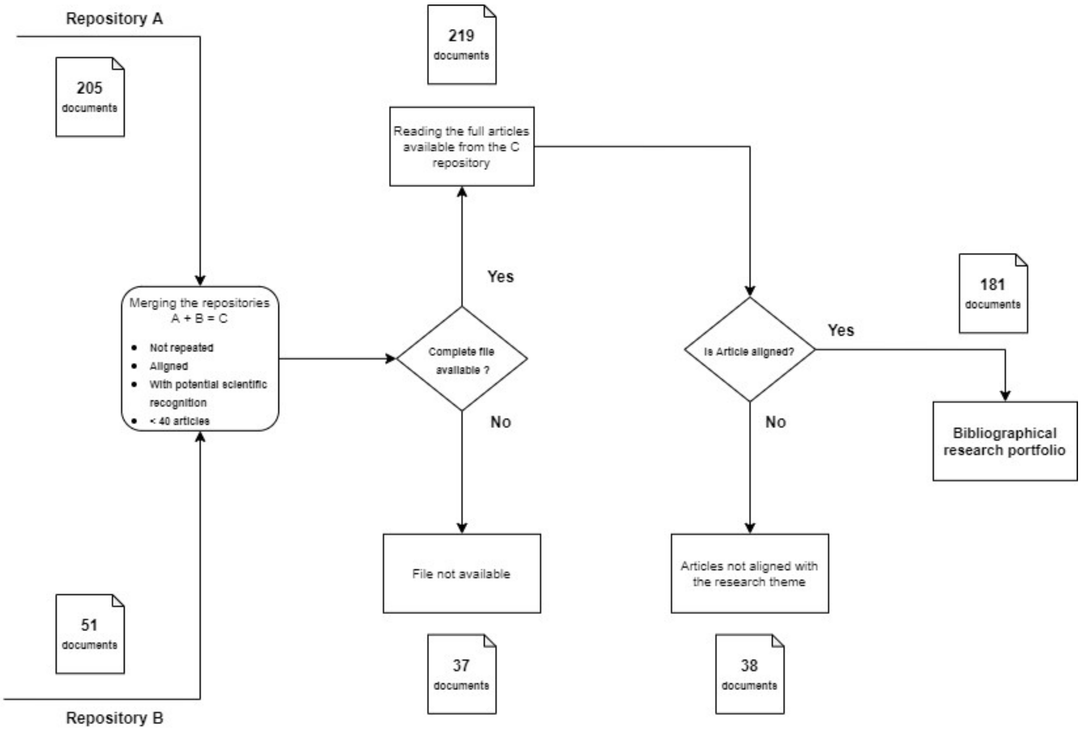
As for this reclassification, the method defines that articles that have not had their scientific recognition confirmed are re-evaluated, first regarding the timeliness of the publication, where articles published less than two years ago have their abstracts read, and those that are aligned with the research theme become part of "Repository B".

However, the articles discarded for having been published more than two years ago still undergo a complementary evaluation, in which documents from authors who integrate the bank of authors, defined by "Repository A", must have their papers’ abstracts read and those that are aligned with the researched theme are also incorporated in "Repository B", which in this case, comprised 51 non-repeated articles, aligned as to title and abstract and with potential scientific recognition.

The implementation of the third and last step of the filtering process determines the merging of repositories A and B, giving rise to "Repository C", which is first subjected to a check of the availability of documents in their entirety, discarding those that do not meet this requirement.

Next, the method determines the complete reading of the articles in the bank, and upon alignment of each article's content with the theme, the document is included in the bibliographic research portfolio, as described by the flowchart presented in Figure 4.

Figure: 4: Final selection phase of the bibliographic portfolio.



Source: Adapted Lacerda et al. (2012)

The number of documents obtained in each step of the method is described in each of the steps of the flowchart of the Proknow-C method, Figures 2, 3 and 4. The unfolding of the search results can be seen in Table 3, which describes the number of articles per research axis at the end of each stage of the filtering process determined by the Proknow-C method.

Table: 3: Number of articles per research axis and per filtering process step.

	Filtering process			
Research Axes	Redundancy	Title alignment	Scientific recognition	Bibliographic Portfolio
Accidents and Safety	523	295	170	24
Cost and Consumption	593	378	139	47
Training and Qualification	597	319	104	56
EDR	134	118	86	54
Totals	**1847**	**1110**	**499**	**181**

Source: Author

2.1 Comparative analysis between the bank of articles with scientific recognition and the bibliographic portfolio.

Following the proposition of Lacerda et al. (2012), I carried out an analysis considering the theoretical perspectives, with the purpose of delimiting and guiding the investigation so that the practical application of the contributions proposed could be objectively verified and supported by the bibliographic portfolio.

To this end, the review process was based on the analysis of elements contained in the citation reports, generated by the Web of Science database, considering the set of publications with scientific recognition and the bibliographic portfolio of each research axis according to three aspects:

- Total number of publications,
- Total number of citations.
- H-index.

The analysis of this dataset also allowed the structuring of the scientific mapping of the theme, which according to Cobo et al. (2011) aims to demonstrate structural and dynamic aspects of publications, in which the scientific mapping has the role of describing the cognitive structure of the researched field by determining the conceptual subdomains (general and/or particular thematic areas).

To this end, analysis lenses were applied with the help of the VosViewer® software, which allowed the visualization of the relationship networks of the documents with scientific recognition and of the bibliographic portfolio, generated from the application of the ProKnow-C method.

The analyses offered by the system took into account criteria of co-authorship, co-occurrence, citation, co-citation and bibliographic coupling considering keyword content, keyword plus, organizations, countries of origin, publication interval and authors.

I decided to evaluate the behavior of the article banks according to the number of citations because they are considered one of the main measures of a publication's impact, since they help in the evaluation of the influence of a certain work or author (Moed 2005).

However, I considered as basic analyses the co-occurrence analysis of keywords, which allows establishing by statistical means the strength of association among terms, allowing the creation of maps that represent the state of a field of knowledge at a given moment (Robredo and Cunha 1998).

I then applied the bibliographic coupling analysis proposed by (Kessler (1963), which measures the strength of the link between articles, taking as a basis the references contained in the list of articles analyzed, in order to highlight the theoretical prox22imity and consequently the similarity of the theoretical environment of the works, where the greater the number of common references, the stronger the between them (Araújo et al. 2019; Grácio 2016).

2.1.1 Analysis of the RFT accident and safety axis

The search for documents related to the axis accident and safety in RFT was represented by the search string ("road freight transport*" OR "Freight transport*" OR “freight transport*” AND "Brazil" AND "Accident" OR "Safety" AND "Truck"), which returned 631 articles. After applying the Proknow-C method, 170 articles with scientific recognition were found, with an h-index equal to 50 and an average citation per document of 49.21.

The bibliographic portfolio related to the axis, on the other hand, was composed of 24 articles with an h-index equal to 21 and an average of 74.79 citations per article, as shown in Table 4.

Table: 4: Comparative analysis between the recognized article bank and the bibliographic portfolio of the accident and safety axis.

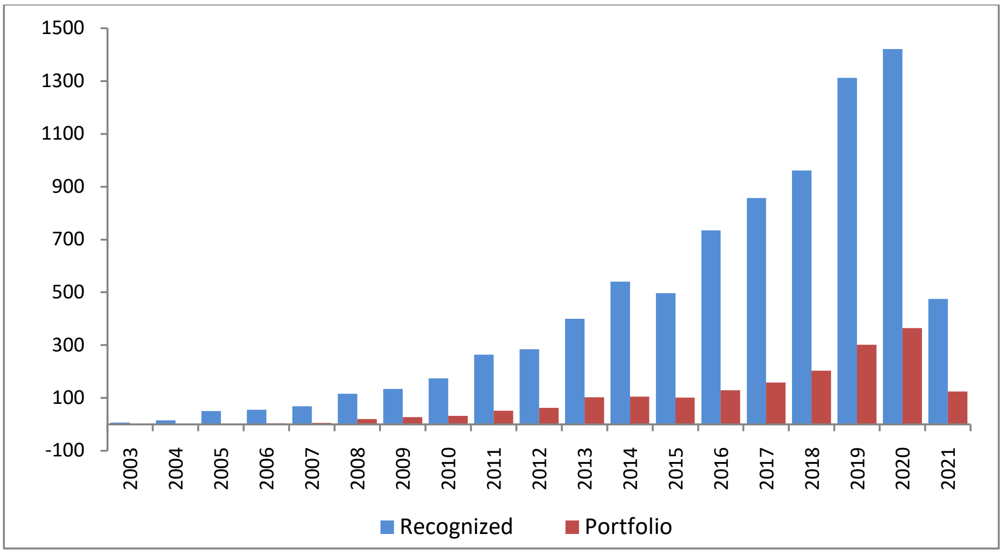
	Recognized	Portfolio
Documents found	170	24
Total citations	8373	1796
Average citation per document	49,21	74,79
H-index	50	21

Source: Adapted from Web of Science

In other words, although the portfolio files had a lower h-index than the bank of articles with scientific recognition, the average citation of the portfolio articles was 51.9% higher than the results from the bank of files with recognition, indicating a greater influence of the research portfolio within the axis.

The comparison of citations from the recognized article bank and the portfolio of the accident and safety axis can be seen in Graph 1.

Graphic: 1: Annual distribution of citations from the scientifically recognized article bank and the bibliographic portfolio of the accident and safety axis.

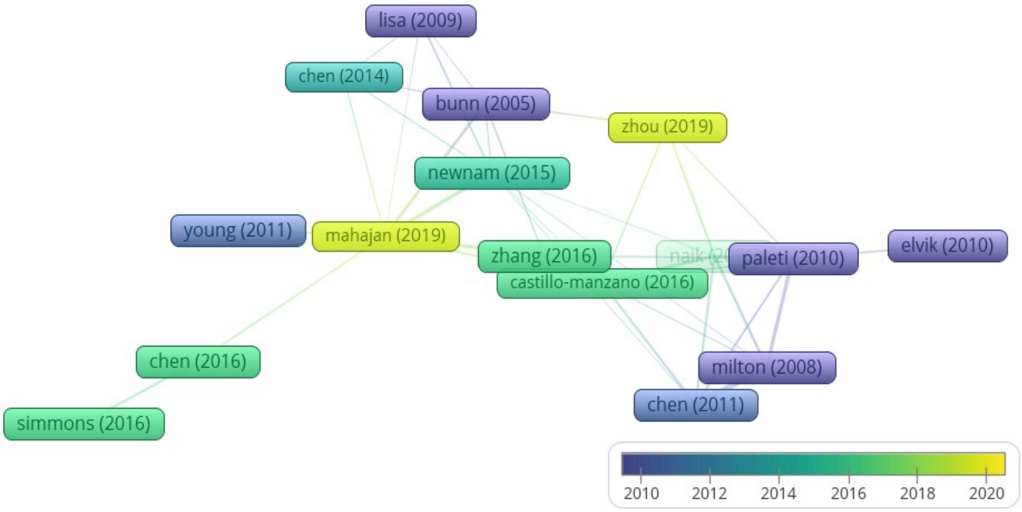


Source: Adapted from Web of Science

Another evaluation proposed came from the bibliographic coupling analysis, which measures the similarity between documents by comparing the number of references shared by them, i.e., the greater the overlap of the bibliographies used, the stronger the connection between the articles (Zupic and Čater 2015).

In this sense, the bibliographic coupling analysis of the accident and safety portfolio, considering documents with two or more citations, relied on the normalization analysis by the strength association method Codato, Lorenceti, and Bittencourt (2019). Therefore, the software allocated the documents in the portfolio in five clusters according to the convergence and synergy of themes, methods, and subjects addressed by them. From the bibliographic coupling analysis, it was possible to structure the network map of the publications containing the 16 documents with 37 links between them and a total link strength of 66, as shown in Figure 5.

Figure: 5: Bibliographic coupling of the RFT accident and safety portfolio.



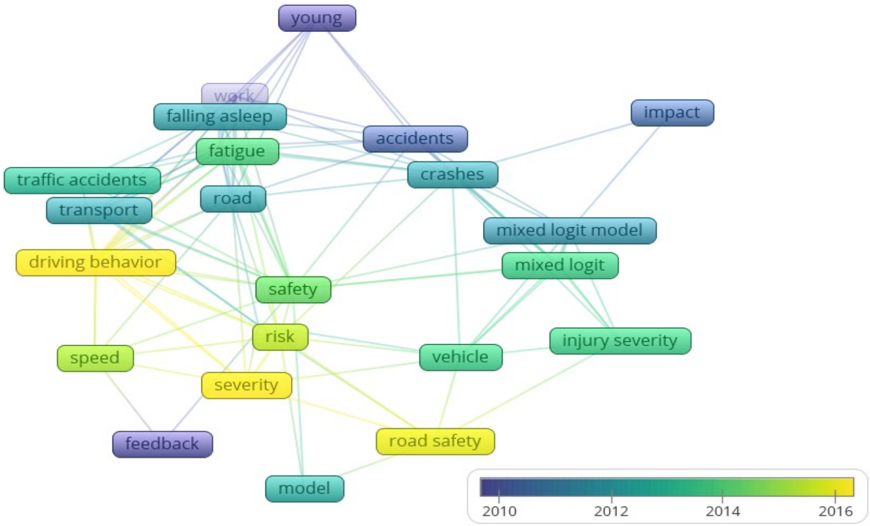
Source: VosViewer®

In complementation, I chose to perform co-occurrence analysis, which according to Hu et al. (2013) is a technique used to map the strength of association between keywords in textual data in order to identify relationships and interactions between researched topics and the trends of emerging research lines, where a higher frequency of co-occurrence means a stronger correlation between pairs of words, suggesting their relationship to a specific topic.

The co-occurrence analysis found 194 keywords in the portfolio, but a cutoff point of the occurrence of at least two citations was applied for document inclusion. Thus, the resulting total of keywords was reduced to 27, which were allocated to four clusters, related to accidents and fatigue; vehicles and severity; driver behavior; speed and feedback; and risk and road safety.

Figure 6 shows the relationship network of the keywords together with the year of publication.

Figure: 6: Co-occurrence network between keywords - RFT (accident and safety).



Source: VosViewer®

2.1.2 Axis Analysis - RFT cost and consumption

The search related to the axis cost and consumption in RFT used the search string ("road transport" OR "road freight transport*" OR "freight transport*" AND "Brazil" AND "truck" AND "cost" OR "consumption" AND "safety"), returning 546 documents, which after the filtering process originated a bank of scientifically recognized articles containing 139 documents with an h-index of 25, where each document had an average of 13.94 citations.

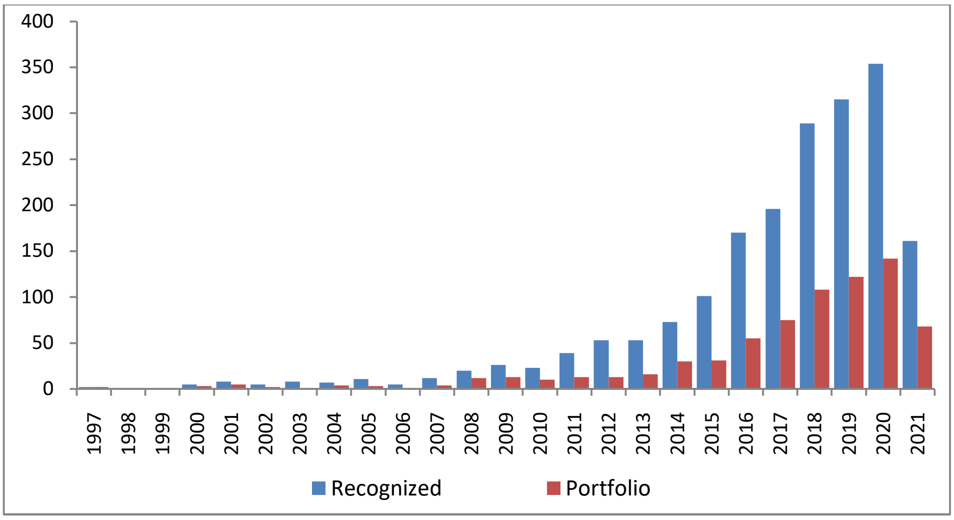
On the other hand, the bibliographic portfolio of the cost and consumption axis was composed of 47 indexed articles with an h-index of 16 and an average of 15.62 citations per document, as shown in Table 5.

Table: 5: Comparative analysis between the bank of recognized articles and the bibliographic portfolio of the cost and consumption axis.

	Recognized	Portfolio
Documents found	139	47
Total citations	1938	734
Average citation per document	13,94	15,62
H-index	25	16

Source: Adapted from Web of Science

Graphic: 2: Annual distribution of citations from the bank of scientifically recognized articles and the bibliographic portfolio of the cost and consumption axis.

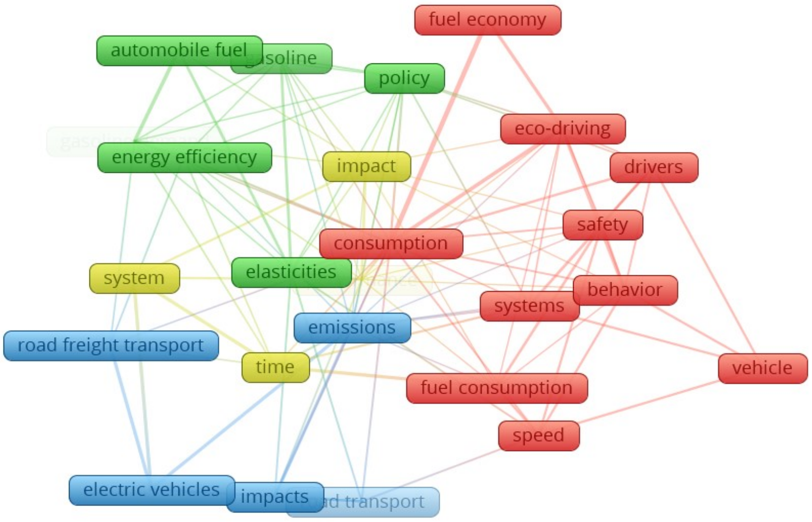


Source: Adapted from Web of Science

The co-occurrence map was structured considering as inclusion criterion only keywords with more than two citations. This reduced the keywords from 294 to 25, which were distributed in four clusters with 105 links between them.

The clusters are related to the following aspects: impacts and performance; road transport and emissions; driver behavior and speed; and ecodriving and fuel economy, as shown in Figure 7.

Figure: 7: Co-occurrence network between keywords - RFT (consumption and cost).

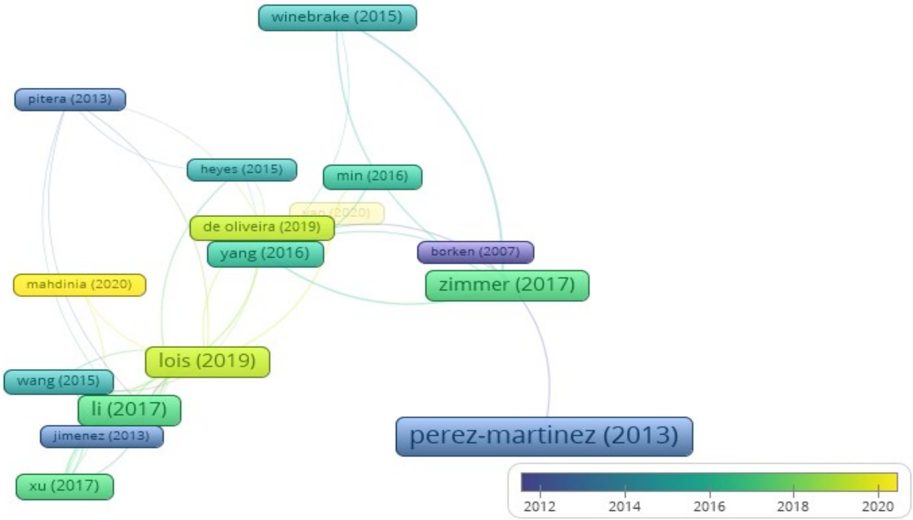


Source: VosViewer®

Regarding the bibliographic coupling analysis, all documents with a number of citations greater than two were considered, using the normalization analysis by the strength association method, which returned 39 articles distributed in seven clusters with 50 links between them and a total link strength of 95.5.

Figure 8 details the bibliographic coupling of the main works of the cost and consumption axis. It is worth noting that the published document (Chapter 4) is one of the articles that make up cluster 1, registering a total of four links and total link strength to the portfolio of 3, placing it in position 18 within the 39 documents that make up the portfolio in relation to the total link strength among them.

Figure 8: Bibliographic linkage of the RFT axis cost and consumption.



Source: VosViewer®

2.1.3 Analysis of the Axis - RFT training and qualification

The representation of the state of the art related to papers focusing on training and qualification building procedures for RFT, returned 612 documents considering the search string ("road transport" OR "road freight transport*" OR "freight transport*" AND "training procedure" OR "ecodriv*" OR "driv* training" AND "truck").

After the filtering process, 104 documents were included in the bank of scientifically recognized articles, which had an h-index of 30 and an average of 25.37 citations per document, while the bibliographic portfolio of the axis was structured from 56 articles with an h-index of 25 and an average of 29 citations per document.

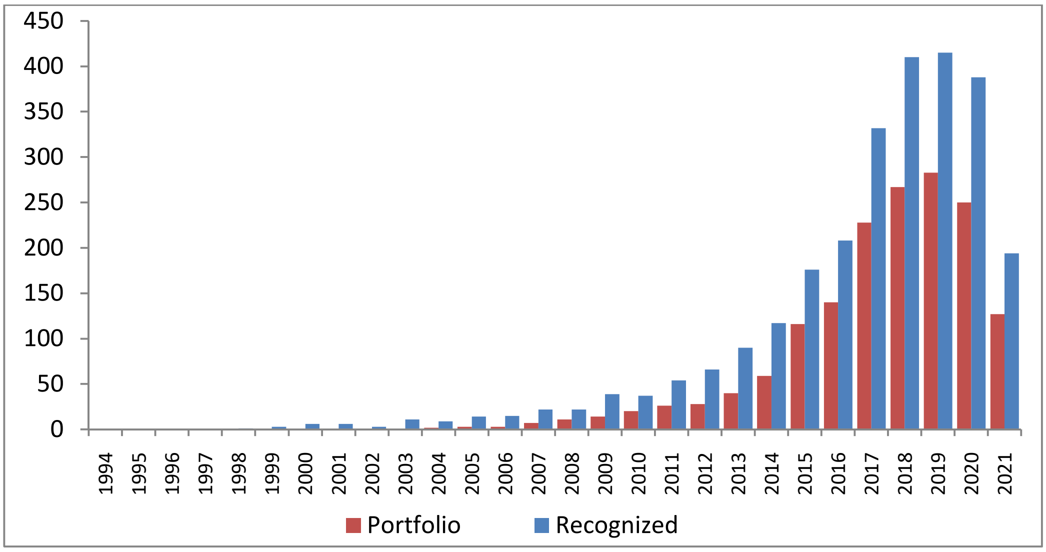
The comparative analysis between the recognized bank and the portfolio is presented by Table 6.

Table 6: Comparative analysis between the bank of recognized articles and the bibliographic portfolio of the training axis.

	Recognized	Portfolio
Documents found	104	56
Total citations	2638	1624
Average citation per document	25,37	29
H-index	30	25

Source: Adapted from Web of Science

Graphic 3: Distribution of citations from the recognition database and bibliographic portfolio of the training and capacity building axis.

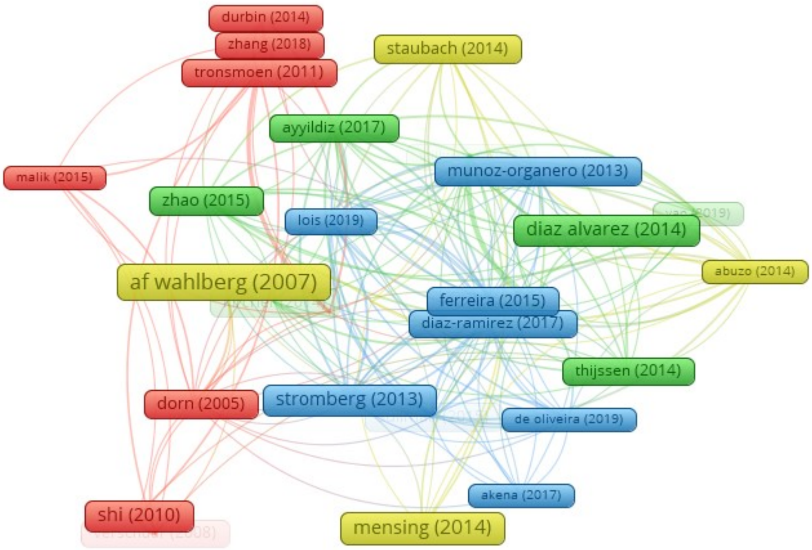


Source: Adapted from Web of Science

To structure the bibliographic linkage analysis of the portfolio, the inclusion criteria considered articles with two or more citations and with greater total link strength between documents.

The process returned 30 articles distributed in four clusters, with 180 links and total link strength of 322. The map of document linkage can be seen in Figure 9. Due to its total link strength, one of the documents published (Chapter 4) was allocated by the software to cluster 3, with 14 links and a total link strength equal to 20, figuring in position 13 among the 30 documents with the highest total link strength in the bibliographic portfolio of training and qualification.

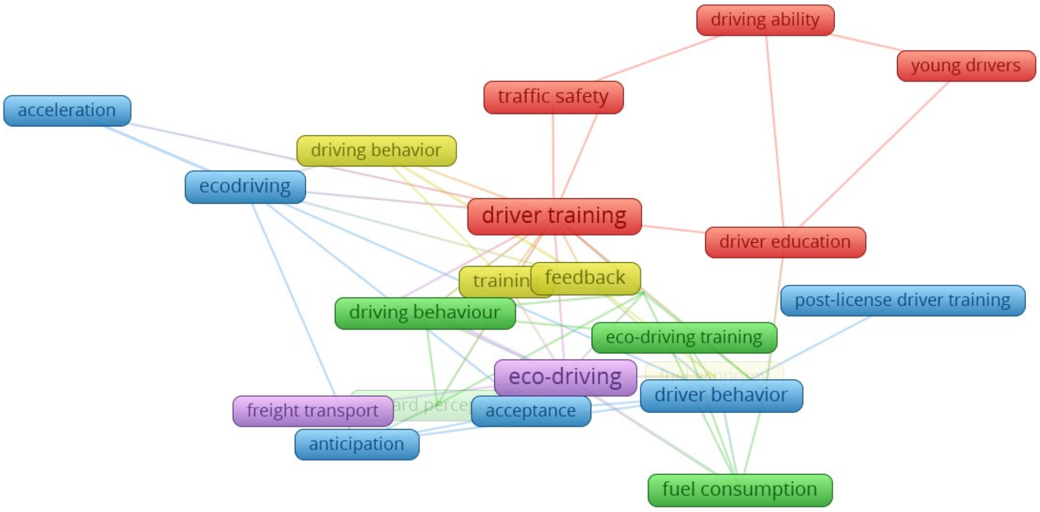
Figure 9: Bibliographic clustering of the RFT training and qualification axis.



Source: VosViewer®

When performing the co-occurrence analysis of the keywords defined by the authors, I found that the portfolio was composed of 194 words. However, when considering only those with at least two citations, the configuration of the training axis was represented by 25 keywords, distributed in five clusters related to behavior and feedback: behavioral assessment and fuel consumption; ecodriving; anticipation and acceleration; cargo transport; ecodriving. and driver training and accidents, as presented in Figure 10.

Figure: 10: Co-occurrence network between keywords - RFT - training and qualification.



Source: VosViewer®

2.1.4 Axis Analysis - Event Data Recorder

The last research axis, defined by the literature review, was analysis of event data recorder (EDR) systems. In this sense it is necessary to highlight that the number of publications analyzing the deployment, use and functionalities of embedded intelligence systems is considerably more restricted, especially regarding research applied to Brazilian reality.

This scientific gap was shown to be more forceful when processing searches related to the use of EDR technology as a function of the integration of safety, economic and operational criteria.

The number of publications involving the search string ("event data recorder" OR "black box" OR "EDR" AND "safety" AND "accident" AND "road transport*"), returned only 148 documents for the composition of the raw database, of which 86 were classified as scientifically recognized and 54 became part of the bibliographic portfolio related to the research axis.

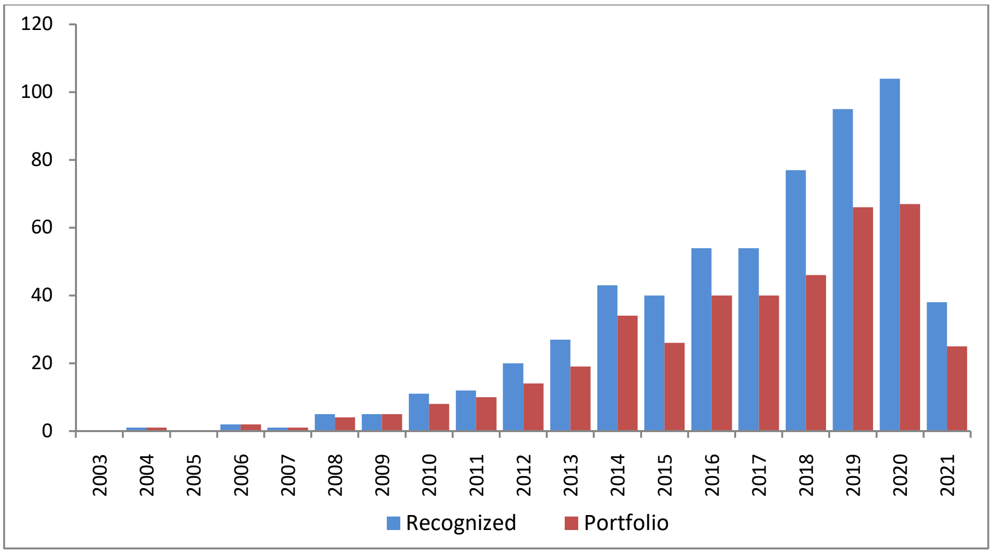
In the comparative analysis between the bank of scientifically acknowledged articles and the bibliographic portfolio, the average number of citations per document, the h-index value and the total number of times the documents were cited in relation to the RDE axis were all considerably lower than for the other research axes, corroborating the perception of the scientific gap related to the theme, as well as the limited degree of influence of the publications due to the reduced average number of citations per element. Table 7 and Graph 4 present the comparative data between the recognized article databases and the portfolio for the axis.

Table 7: Comparative analysis between the bank of recognized articles and bibliographic portfolio for the EDR axis.

	Recognized	Portfolio
Documents found	86	54
Total citations	589	408
Average citation per document	6,85	7,56
H-index	10	8

Source: Adapted from Web of Science

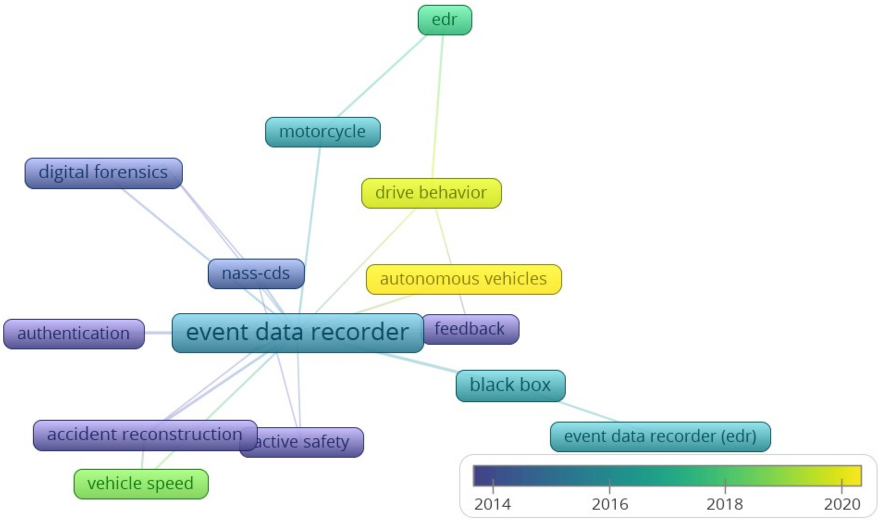
Graphic 4: Distribution of the publications in the EDR axis recognition bank and bibliographic portfolio.



Source: Adapted from Web of Science

The co-occurrence analysis of the keywords defined by the authors showed that the research portfolio was composed of 194 words. However, when considering only the keywords with at least two citations, the list was reduced to 18 words, distributed among six clusters with 23 links related to the topics: event data recorder and authentication; black box and EDR; active safety and accident reconstruction; driver behavior and feedback; driver and speed recording; and autonomous vehicles.

Figure 11: Keyword co-occurrence - EDR.

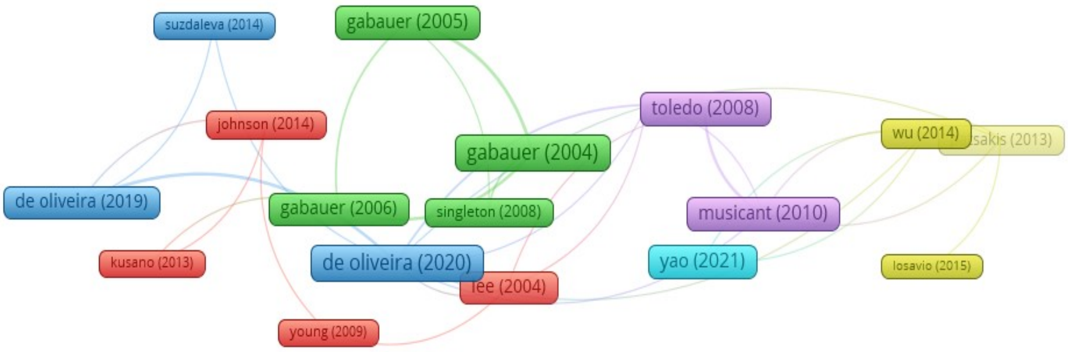


Source: VosViewer®

The bibliographic coupling analysis considered the total count of the documents in the portfolio, taking as inclusion criterion the articles with more than two citations assuming the normalization analysis by the strength association method. Therefore, of the 54 documents in the portfolio, only 31 satisfied the criteria, and were distributed in six clusters with a total of 32 links to each other and total link strength of 56, considerably lower than the other research axes.

Figure 12 presents the bibliographic coupling map with all links in the bibliographic portfolio. It is possible to see that the two publications arising from the research (chapters 4 and 5 of the thesis) figured among the main documents involving the EDR axis portfolio when considering parameters of the total link strength as weights where De Oliveira et al. (2019) appears in position 9 of the 31 articles in the portfolio, with three links and total link strength of 6, while De Oliveira et al. (2020) is in the first position among the documents of the research axis, with a total of eight links and total link strength of 12.

Figure 12: Bibliographic coupling of the RFT - EDR axis.



Source: VosViewer®

2.2 Considerations about the bibliometric review.

The main observation arising from the application of the bibliographic and bibliometric review using the ProKnow-C method in the performance evaluation and the VosViewer® software in the structuring of the scientific mapping of the article banks was timely and consistent, since it allowed the structuring of a robust bibliographic portfolio, aligned with and recognized by peers.

The specificity of the research theme proved to be a limiting factor, which could be circumvented by breaking down the research theme into four axes. The bibliographic portfolio of each axis allowed the investigation and proposals developed to be scientifically grounded during the entire research process.

Of particular note is the fact that the articles published, based on the research (chapters 4 and 5 of the thesis), appear in three of the four bibliographic portfolio axes, considering two types of ranking. The first is related to the number of citations obtained by each article. In this sense, the publications did not present an evident highlight due to their recent publication. The second ranking mechanism is related to the concept of total link strength, which indicates the total number of links that the article presents in function of the documents that make up the portfolio, that is, it represents the frequency with which two or more publications appear simultaneously in a paper. The higher this indicator is, the more centrality the document will have in the network, due to its importance in the organization of this theoretical field (Araújo et al. 2019; Grácio 2016).

Table 8 reports the total number of articles that make up the bibliographic portfolio of each axis and the classification of publications according to the number of citations and in relation to the total link strength of the articles.

Table 8: Classification of the research publications according to the number of citations and total link strength of the articles.

			Classificação	
Research Axes	Publication of the research	Total of articles in portfolio	Citation	Total link strength
Cost and Consumption	(De Oliveira et al. 2019)	47	39º	18º
Training and Qualification	(De Oliveira et al. 2019)	56	30º	13º
EDR	(De Oliveira et al. 2019)	54	23º	10º
	(De Oliveira et al. 2020)	54	26º	1º

Source: Author

Regarding the classification based on citations, it is important to observe that because these are recently published articles, still having a low number of citations, the classification within the bibliographic portfolio is impaired.

However, when considering as a classification mechanism the total strength of connection between the documents, the research publications had a higher position, especially in relation to the research axis linked to event data recorder, demonstrating adherence and synergy between the portfolios found, articles published, and the research proposal.

2.3 Consolidation and systematic review of the integrated portfolio

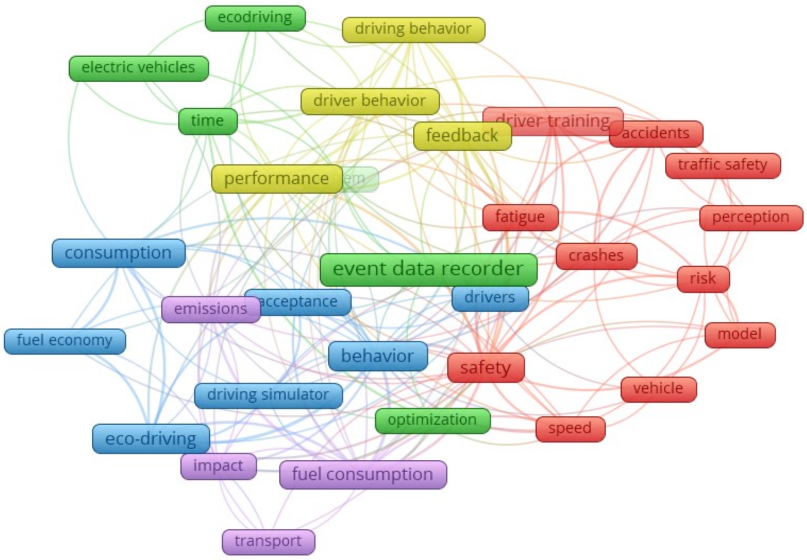
2.3.1 Consolidation of the integrated portfolio

The adherence of the scientific base used, within the proposed research topic, was validated from the process of merging the four resulting portfolios into the integrated research portfolio, composed of the 181 documents.

The co-occurrence analysis of the resulting portfolio presented a total of 812 keywords described by the authors, which were reduced to 33 when the minimum number of five occurrences within the portfolio was conditioned as an inclusion criterion. Therefore, the keyword network map, described in Figure 13, showed 180 links to each other with total link strength of 253, distributed in five clusters, related to the following subjects:

- Accidents, fatigue, speed, traffic safety, driver training;
- Event data recorder, ecodriving, road freight transportation;
- Fuel economy, consumption, drivers;
- Driver behavior, feedback, performance;
- Emissions, fuel consumption, impact.

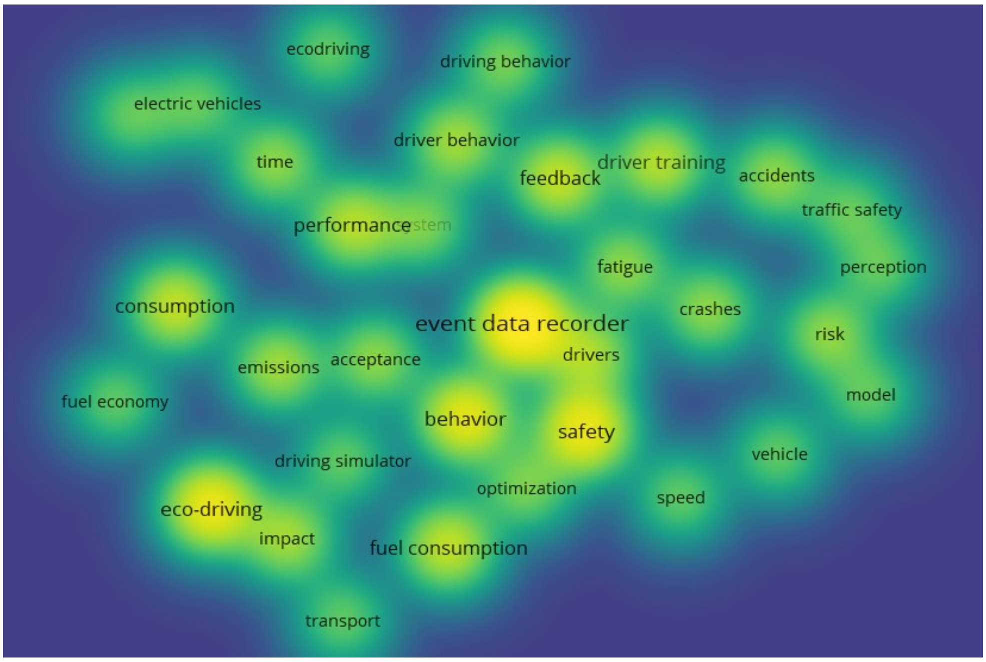
Figure: 13: Keywords co-occurrence - Integrated research portfolio.



Source: VosViewer®

Figure 14 presents the density map of the integrated portfolio, where it is possible to identify that the most numerous keywords listed by the authors were: event data recorder, safety, risk, accidents, ecodriving, feedback, behavior, driver behavior, driver training, and fuel consumption.

Figure 14: Density visualization map of the integrated research portfolio.



Source: VosViewer®

It is also possible to identify that the term event data recorder has a central position, since it is the keyword with the highest number of occurrences within the portfolio, with a total of 19 occurrences. However, when taking the total link strength of the set of keywords as a basis, the main terms are safety, behavior, fuel consumption, ecodriving, driver training, and feedback.

This highlights the importance and robustness of the documents that make up the integrated portfolio in order to characterize the researched theme, since the current state of the art has not yet developed in the direction proposed by the thesis.

The results obtained from the application of the bibliographic review procedure based on the Proknow-C method associated with the use of the Vosviewer® software proved to be appropriate and precise regarding the proposal.

The bibliometric review of the documents forming the integrated portfolio acted as an inductive process, guiding the research construction process, since it allowed the delimitation of the research theme, being capable of scientifically supporting the thesis' propositions in the sense that the adoption of systematized training procedures, based on data collection and analysis, has the potential to positively influence professional driver's behavior, with measurable impact on the efficiency of heavy vehicle fleets, so as to increase operational safety without increasing the costs of trucking companies.

However, one of the biggest obstacles found is related to the scarcity of studies that allow evaluation and comparison of the impact of the EDR technology in an integrated manner with mechanisms and training procedures aimed at increasing safety, improving operational efficiency and reducing costs, a gap on this thesis intends to fill.

It is also necessary to consider that in order to strengthen the scientific support obtained from the literature review process, aiming to ensure that the entire procedure is adapted to the reality of RFT in Brazil, besides the documents selected by the bibliometric review process, research portfolio included numerous reports, studies, standards, laws, regulations and research documents issued/produced by government agencies and research entities, both in Brazil (Institute for Economic and Applied Research, National Transport Confederation, Ministry of Transport, National Traffic Department, National Land Transport Agency) and internationally (World Health Organization, Central Intelligence Agency, World Road Association, Directorate-General for Mobility and Transport), among others.

2.3.2 Systematic review of the integrated portfolio.

As part of the systematic review, the detailed analysis of the documents in the integrated portfolio made it possible to establish a delimitation regarding the thesis topic in the aspects proposed by the research axes, which are summarized in this item and detailed in chapters 3, 4 and 5, with the objective of representing the current stage of development and looking ahead.

The characterization of the scenario related to the road freight transport (RFT) in Brazil focused on aspects related to infrastructure, accidents, accident costs, driver training and technologies used. In this sense, the delimitation of the structural scenario was based mainly on the provisions of the CNT highway survey CNT (2019), which assesses the quality of the country's road network in relation to geometry, signaling and sidewalks, highlighting mainly the low road density and the precariousness of the existing network as factors that contribute directly or indirectly in the poor performance and safety of the national road system.

The CNT research reports for the 2003-2019 period indicated that an average of 92,213 km of paved roads were evaluated annually, of which 64.79% were classified as deficient, bad or terrible, i.e., they presented problems compromising the safety, drivability and/or efficiency of roadways.

The scenario becomes more complex when data from the National Highway System DNIT (2018) are associated, which shows that 87.6% of the total number of paved roads corresponds to road with one lane in each direction, considerably increasing travel time due to the difficulty in overtaking, and significantly increasing the risk of fatal accidents due to head-on collisions.

In addition to these characteristics, the systematic review also showed that RFT operators in Brazil face financial difficulties, described by the report "Cargo transport in Brazil - Threats and opportunities for the development of the country (diagnosis and action plans)" CEL (2002). In this sense, here I updated and extended the analysis, using data provided by the transportation cost simulator EPL (2019) and the freight price table ANTT (2020). According to these data, the financial deficit of the carriers went from US$ 6.08 / 1000 km in 2002 to US$ 35.29 / 1000 km in 2019.

All these factors, in addition to several others that make up the systematized review (highlighted in chapters 3, 4 and 5), contribute to the increase in the level of accidents registered on the country's highways, as described by the global status report on road safety (WHO 2018).

Additionally, it should be noted that the country does not have an established standard for the collection and processing of accident data. According to IRTAD (2016), the absence of structured and reliable information has a negative impact on the quality of statistics related to accidents, hindering comprehensive evaluation of the accident scenario, as well as its consequences.

This is a present reality in Brazil, since the main sources of data and official statistics comes from traffic accident reports. However, according to information presented by IPEA (2006), the these reports are not standardized, a fact recognized by researchers, authorities and inspection agencies (Chagas, Nodari, and Lindau 2011; de Sena, da Silva, and Finelli 2016).

Another point necessary to characterize the scenario is related to understanding the financial impact of accidents. In this regard, the research was supported by studies and reports from several government institutions, among which the following stand out: “Traffic accident costs on federal highways” (DNIT 2004), “Social and economic impacts of traffic accidents on Brazilian highways” (IPEA 2006) “Traffic accidents on Brazilian federal highways -

characterization, trends, and costs to society” (IPEA 2015a), “Estimation of the costs of traffic accidents in Brazil based on the simplified update” (IPEA 2015b), and “National plan for the reduction of deaths and injuries in traffic 2018” (CONTRAN 2019), which are reliable sources and are among the most complete and referenced diagnoses of Brazilian reality.

The analysis performed from this material, allowed me to determine that the annual cost of accidents on federal highways was around R$ 9.1 billion in 2007, R$ 13 billion in 2010 and R$ 12.3 billion in 2014, that is, a growth of 35% in the period, corresponding to impacts of 0.33%, 0.35% and 0.21% in relation to the GDP in the respective years. This way, following the cost updating method proposed by OKA (2011) and (IPEA 2015a), the updated cost of traffic accidents on federal highways was R$ 16.6 billion in 2020, which is equivalent to a growth of 82.4% in the costs of accidents in the previous 13 years.

In addition, the estimated cost of accidents on state and municipal highways (IPEA 2015a) ranged between R$ 24.8 and R$ 30.5 billion for 2014, hence the overall annual cost of accidents on highways (federal, state, and municipal) in 2014 was between R$ 37.1 and R$ 42.8 billion. Updating the data to 2019, the total value, considering all the highways and roads in the country, would be between R$ 45.8 and R$ 53.5 billion, or 0.72% of GDP in 2019.

These findings are reinforced from the cross-reference with data made available by (DPVAT (2019), DENATRAN (2020), IHME (2019), Actualitix (2016) e OICA (2016) in relation to two coefficients linked to accidents. The first is called traffic risk, which in Brazil is equivalent to 39.1 deaths / 100,000 vehicles, while in the United States, Canada and Spain the respective figures are 15, 11 and 8 deaths/100,000 vehicles. The second comparison is related to the mortality coefficient, which in Brazil corresponds to 24.02 deaths by traffic accidents/100,000 inhabitants, while the United States, Canada and Spain registered 11.3, 5.2 and 3.6 deaths/100,000 people, respectively.

From these analyses it was possible to delimit the delineate accident cost rates and the current structure of road transport of cargo in Brazil. However, the delimitation of the theme also requires analysis of the axes training and EDR.

In relation to the training aspect, the systematic review indicated the positive impact of adopting metrics and applying training processes in relation to the reduction of fuel consumption, undesirable driving behavior and greenhouse gas emissions, in order to increase safety, economy and productivity levels.

Xu et al. (2017) found driver training to be an effective strategy for saving fuel and reducing emissions, based on the use of an ecodriving algorithm that acts to limit the specific power while maintaining the average speed and total distance traveled reaching a 5% NOx reduction associated with a 7% savings in fuel consumption for long distance vehicles.

According to Lois et al. (2019), the variation in fuel consumption is mainly associated with driving patterns adopted by drivers (speed profile) as well as by road conditions, in which, external factors such as congestion and sections with steep grades, exert negative influences on energy efficiency. The study evaluated free-flow conditions relating speed and consumption, while also analyzing inefficient driving behavior as internal variables. The training profile described by the authors followed the same parameter adopted here, as described in chapter 3, sub-item 3.2.3.

From a different approach, Ferreira et al. (2015) found driver performance evaluation to be a key determinant of the level of driving efficiency. To this end, the authors emphasized the importance of training to promote good driving styles based on a multidimensional analysis involving drivers, routes, consumption, traffic information, and weather conditions, through evaluation of 44 internal parameters and 21 external parameters. Of the ten impact factors highlighted by that article as having the greatest influence on average fuel consumption, seven were considered here to be variables or figure in the composition of the indicators as highlighted by sub-items 3.2.1; 3.2.2; 4.4.2; 5.4.1 and 5.4.4.

The contribution of Nævestad, Elvebakk, and Phillips (2018) was extremely timely regarding the proposition of an organizational safety management (OSM) strategy for transportation companies, based on the concept of a safety ladder that stipulates four evolutionary steps. The first step addresses the commitment of those involved with the safety process (drivers, managers and directors); the second refers to monitoring speed, driving style, and seat belt use; the third is related to controlling the influencing factors on safety such as fatigue, stress and time pressure; and the last step refers to the implementation of a safety management system (SMS), such as the ISO 39001 standard (ABNT 2015).

It is relevant to highlight the adherence of the concept proposed here to the structure applied in the research due to the steps of profile analysis, implementation of RDE systems, monitoring phases, and training and evaluation of results, as described in chapters 4 and 5 in the flowcharts of the experiment (Figures 17 and 21). The training procedure developed here adopts not only concepts proposed from ISO 39001 (ABNT 2015), but also is based on the propositions contained in ISO 10015, (BSI 2019), which defines the guidelines for training.

The systematized review involving the event data recorder has a central role, since the technology allows real-time monitoring of the entire operation of the vehicles, besides providing the basis for the adequacy of the training process applied.

The bibliometric review in the EDR axis, showed that a significant number of researchers have considered technology primarily to be a robust tool, capable of allowing accident reconstruction, from the analysis of speed, video images and accelerometer data, in order to indicate the causal factors of accidents, as well as estimate their severity assign responsibilities (Aldimirov and Arnaudov 2018; Eriksson and Bjørnskau 2012; Inhwan 2019; Johnson and Gabler 2014; Qiu et al. 2020)

EDR technology was also considered by Aliane et al. (2014) as the key part of a traffic violation management system applied to drivers, which associated with a computer vision subsystem for traffic sign detection, has the ability to provide early warnings about speed limits and signaling features, with the aim of preventing accidents, while also offering feedback on their driving habits.

In turn, Naude et al. (2019) identified a relationship between driving incidents and traffic accidents using the statistical model proposed by Heinrich called the risk pyramid, which states that the incidents are at the bottom of the pyramid since they are more frequent and offer less potential to cause accidents. In this sense, the authors used EDR systems as a tool to provide access to all relevant vehicle parameters, allowing detection of anomalous driving situations as well as undesirable habits. The authors also pointed out that EDR systems are important both in the registration of low-severity events and in genuine incident events in which the vehicle is subject to dynamic demands.

Still in relation to driver behavior analysis, Wu et al. (2014) reported the development of EDR technology for the recognition of seven types of behavior related to safety: normal driving, acceleration, deceleration, lane change (left, right), zigzag driving and maintenance of safe distance. The work developed by the authors allowed inferring, through fuzzy logic, the level of risk posed by each of these behaviors, so that managers could evaluate the performance of drivers individually. In this sense, the proposed method was able to detect 95% of the behaviors, besides identifying level of danger inferred by fuzzy rules.

From the systematic review in relation to this axis, it was possible to understand that EDR systems have been successfully applied to increase safety as well as an indispensable tool for accident reconstruction.

However, the development of studies involving the use of technology for these purposes is still limited, which makes it difficult to establish comparisons between investigations. Hence, there is an opportunity for new contributions to the state of the art. A broader review focusing on different uses of the technology is described in chapters 4 and 5, in sub-items 4.2.1; 4.2.3; 4.3.2; 5.1 and 5.4.1.

In short, the literature review process adopted here was structured from the integration of bibliometric review techniques and systematic review in order to define and delimit the research theme.

The bibliometric analysis made it possible to identify the relationship networks between authors and keywords along with bibliographic coupling in function of each research axis, so that the main articles, contributions and leading authors could be selected to compose the integrated research portfolio.

In complementation, the systematic analysis of the content, methods and propositions contained in the works of the integrated portfolio allowed visualization of the critical success factors involved, the standouts in Brazil being the lack of a reliable data source of accidents, low level of driver training, delay in the adoption of technologies, and scarcity of works focused on the use of EDR system for purposes other than safety.

3. EDR SYSTEMS AND TECHNICAL TRAINING INTEGRATION TOWARDS COST AND ACCIDENT REDUCTION ON ROAD FREIGHT TRANSPORTATION IN BRAZIL

Abstract

In Brazil, approximately 61% of all production is transported by road, and despite its importance, this method of transportation does not receive, on the part of business and government, the same attention given to other types of transportation in terms of accident reduction and professional preparation. In 2012, the Cargo Road Transport (TRC), accounted for 62,851 to 131,269 accidents, including approximately 3,682 deaths and 24,500 injured; these events generate a social expense of about $ 4 billion annually to the country. These scenarios enhances the damage caused by the low productivity of road transport, generating a direct impact on rising prices of Brazilian products, while significantly reducing the competitiveness of Brazilian companies in the international arena. In this article we present the initial results of a training procedure for professional drivers, based on aspects of the Directive 2003/59 EC of the European Union and PROFDRV project data, addressing aspects of awareness to the use of technology, Eco driving, defensive driving, traffic instruction, health and ergonomics, environment, where all efforts are aimed towards the professional drivers in Brazil. This, experimental procedure aims to adapt and integrate such data analysis along with training techniques generated during the driving process. All information and processes are collect by an Event Data Reorder system (EDR), the main technological tool used in this research. This article is an initial document since this research is a still work in process and is being developed along with the participating businesses.

Keywords*: Event Data Recorder, driver, safety, cost, training system*

3.1 Introduction

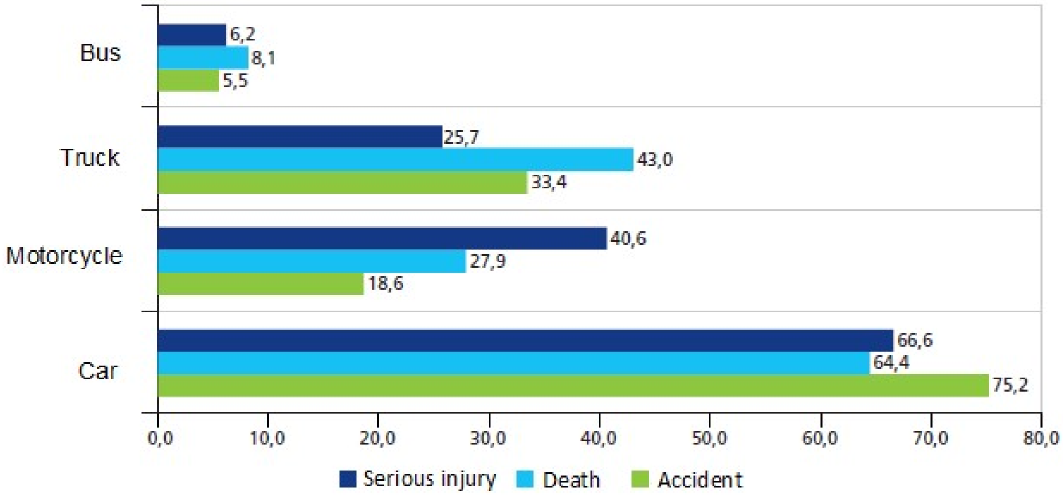
In Brazil, over-reliance on Cargo Road Transport (TRC) has a huge weight on the country due to the elevated number of accidents and operational inefficiency, causing prices of goods and services to drastically increase, reducing the international competitiveness of the country.

A key element which confirms this negative result is related to the low professional qualification of professional drivers. The effects of this reality have as a major liability in the loss of human lives on road accidents in 2012 were recorded 54,767 deaths and 444,000 cases of permanent disability in the country.

According to data from VOLVO (2013) in 2012, the cargo vehicles accounted 62,851 accidents with 3,682 deaths, corresponding to approximately 40% of the total number of deaths on federal highways, compared to 2008 this number grew 19.54% thus, in the overall statistics of accidents. The road freight transportation is responsible for 59 deaths / 1,000 accidents and the main causes are reckless driving, ingestion of drugs and alcohol, fatigue and speeding; on which are all directly related to the unpreparedness of the human factor.

Graphic 5, developed by the (IPEA 2015b), presents data on the involvement of various types of road vehicles on accidents when there are victims with serious injuries and deaths. With this, we can observe that whenever there are accidents involving heavy vehicles, the death rate is higher than the percentage of those accidents involving lighter vehicles.

Graphic 5: Degree of involvement of the accidents.



Source: IPEA (2015)

Due to the fact that national statistics classify as "fatal victims" only deaths occurring at the crash site, one must consider that the number of deaths are understated, which further increases the social impact of accident occurrences.

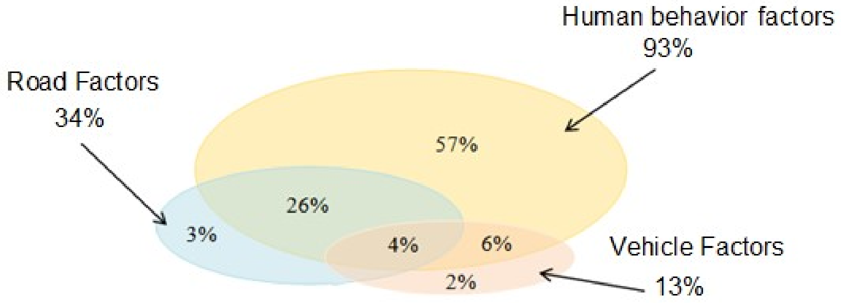
According to this study, the cost of accidents involving fatalities reached U$ 157,000 and the annual cost of accidents on the highway network reaches $ 10 billion. This figure is higher than what the government's annual budget to improve national infrastructure and actions aimed at the development of industry professionals.

According to PAMCARY (2007) diagnosis, the human factors is responsible for approximately 93% of accidents, while the failure of drivers to perform is present in 66% of them, and of these 43% are related to recklessness, 13% to excessive speed, 10 % to fatigue. Peden et al. (2004) claims that traffic accidents in the world are overlooked and have become a public health problem, it also states that the road transportation is the most complex and dangerous of all the existing methods, to (PIARC 2007), the worldwide death toll caused on roads is at 1.2 million individuals.

> “Drivers and other road users basically determine their movements on the road due to a sense of obligation to adapt their behaviour to existing traffic regulations and rules, to road surfaces, to traffic and weather conditions in accordance with their driving skills and health status. Furthermore, human behaviour itself is influenced by a myriad of elements related to the individual and their ability, skill and experience, current physical and psychical state, and perception of the actual traffic and road conditions.”

The study affirms that accidents produce costly consequences, especially in under developed and developing countries. Figure 15 shows, clearly, that human factor is the most important contributing factor for accidents and points out that this must be the area on which planned actions but take into action in order to reduce the number of occurrences.

Figure 15: Contributing factors on accidents



Source: (PIARC 2007)

Based on these assumptions, we can conclude that investing on the qualification of professional drivers has the ability to generate positive multiple positive effects, mainly focusing on the reduction of traffic accidents and safety of the population. However there is not regulation in Brazil that states which are the basic competences that a professional driver should have during their training process to ensure a safer and more efficient way to carry on with their daily routines.

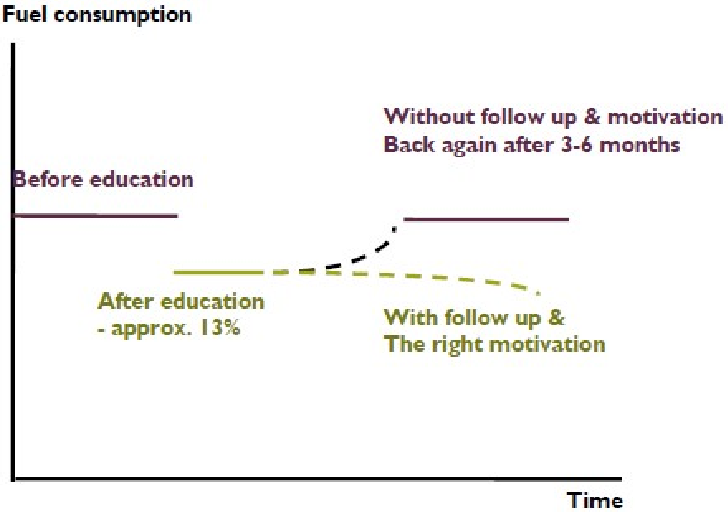
Aware of the importance of trained drivers in relation to road safety, the European Union members and the DG Energy and Transport committee introduced in 2003, the 2003/59 EC directive that regulates common basic mechanisms and periodic training for professional drivers. This directive aims to ensure that professional drivers qualification are up to date and that they are constantly getting trained to maintain their expertise and reliability according to the document in its paragraph:

> "The development of defensive driving - anticipating danger, driving awareness of other road users - along with the resulting rationalization of fuel consumption, will have a positive impact both on society and on the road transport sector itself."

The most important factor highlighted by the 2003/59 EC directive deals with the need for a process of continuous training so that the learned concepts are strengthened and maintained, thus avoiding errors or setbacks over time. Supporting this view, the Clean Truck program conducted by the city of Stockholm, Sweden, turns its attention to the improvement of energy efficient trucks with the primary goal of reducing dependence on fossil fuels.

According Skogens (2013), the major challenge is to change the default behavior of professional drivers, adopting efficient driving programs based on four pillars: leadership, constant feedback and interaction, communication and motivation. According to the author, the process needs to be applied on a continuous and flawless manner to prevent the return of bad habits as well as human error, as shown by Graphic 6.

Graphic 6: Fuel consumption behavior compared to recycling programs.



Source: (Skogens 2013)

With the appearance of new technologies, many opportunities are being created to increase the level of road safety and increased energy efficiency, mainly due to the use of embedded and intelligent vehicle systems. According to DGTren (2007a), there are several actions that can be taken to effectively improve road safety, among which are highlighted:

- To improve the implementation of the existing laws and rules;
- To improve infrastructure available;
- To introduce safety features in vehicles;
- To improve and educate driver's behavior.

Among these actions, the latter two can be achieved through the use of Event Data Recorder Systems (EDR), which are installed to the vehicle, having the function of capturing all the electronic signals and electrical pulses generated by the various modules of the vehicle, transforming these data into information from its own platform (software).

Under these possibilities, research has developed an evaluation of 21 solutions for road safety, which allowed the formatting of a list of valuable data, defining which technologies offer the best value Benefit Cost Ratio (BCR) to reduce the number of accidents. Based on these premises, this article analyzed the basic aspects of training set by the European directive, adapting them to the Brazilian reality and introducing the EDR systems as a monitoring and behavioral analysis tool that qualifies drivers during the process.

The purpose of this article is to understand how technology, along with training mechanisms and monitoring results impact on improving road safety and reducing fuel consumption.

Moreover, this article is part of a project that is being developed in partnership with national companies, technology manufacturers, Federal Universities and research centers in Brazil and Spain. It also involves the study of aspects related to environmental impacts, evaluation of operating times and improved logistics efficiency.

3.2 Measurement techniques

To develop this paper we used data from three companies operating in Brazil, which adopted the implementation of EDR systems across its fleet totaling 90 vehicles and 100 drivers, however the training process only started in November 2015, not being disseminated in full with the whole picture of drivers in this article were evaluated 12 vehicles and their drivers have received training focused on understanding technology and economical driving.

The EDR systems were deployed in March 2015 in all fleets, and have gone through a process of validation efficiency. The behavioral monitoring process based on the technology was being divided into three phases:

- Hidden Monitoring: Alerts and feedbacks issued by EDR systems were deactivated and the drivers are not informed about the deployment of the technology. The objective of this phase is to define usual standards adopted by the drivers without technology interference in order to create an individual history background.
- Conscious Monitoring : at this stage, alerts and feedback have been activated, and the system starts to interact in real time with drivers, in addition, the functions and data monitored by EDR`s systems are reported. The objective of this phase is to analyze the impact of technology on driving pattern in relation to unsafe behaviors, actions and fuel consumption.
- Capacitated Monitoring: from the beginning of this stage, drivers are subjected to an intensive training process and begin to receive guidance on the points that

need be improved. The feedback and warnings issued by the system are maintained as described in the previous phase.

3.2.1 Hidden and Conscious Monitoring

The first two stages are carried out over a period of about ninety days, whereas the comparison parameter takes into consideration the distance traveled between the phases. af Wåhlberg (2007), discusses the effects of long-term training of reduced fuel consumption while improving safety increase based on the analysis of vehicle acceleration, safety awareness and fuel consumption with a similar procedure to that described in the article, including the use of EDR system's feedback as a data source.

Since Strömberg and Karlsson (2013a), similar procedures were adopted to use feedback systems called "eco-driving support system". For this work we have decided to expand the number of variables including: continuous speed control on dry and wet pavements, reckless braking, hard acceleration, engine RPM, RPM patterns and driving in neutral gear, as described in Tables 9 to 14 show that the number of events (errors) occurred every 100 km traveled during the first two stages of hidden and conscious monitoring.

Table 9: Company 1 – Hidden monitoring

License plate	Distance (km)	Speed excess	Speed in rain	RPM	Braked sharply	Aceleration	Neutral gear
OPB-6143	4739.5	23.61	2.85	0.00	2.83	2.36	0.08
HOH-8528	4519.9	18.14	2.65	1.33	1.59	0.80	0.11
KNY-9304	6375.4	11.94	1.13	3.22	0.60	0.11	0.08
GXA-0910	5389.9	41.08	1.50	0.00	0.37	0.11	0.06
OXH-5153	2348.5	26.95	0.17	0.00	0.81	0.00	0.00
OPD-4329	4922.6	13.69	5.16	0.18	1.36	0.10	0.02

Table: 10: Company 1 – Conscious monitoring

License plate	Distance (km)	Speed excess	Speed in rain	RPM	Braked sharply	Aceleration	Neutral gear
OPB-6143	4742.6	0.70	0.34	0.00	1.48	0.72	0.00
HOH-8528	4512.2	3.94	0.75	0.02	0.75	0.47	0.07
KNY-9304	6406.4	0.11	0.00	3.75	0.56	0.12	0.03
GXA-0910	5423.7	2.99	0.13	0.00	0.09	0.07	0.04
OXH-5153	2351.6	0.43	0.17	0.00	0.38	0.04	0.00
OPD-4329	4921.1	0.41	0.26	0.04	0.98	0.06	0.02

Table 11: Company 2 – Hidden monitoring

License plate	Distance (km)	Speed excess	Speed in rain	RPM	Braked sharply	Aceleration	Neutral gear
GYS-6039	5596.5	11.33	0.23	0.21	2.84	0.59	0.00
OLO-5095	5071.2	6.35	3.33	0.00	0.34	0.04	0.02
OLO-5282	7080	0.00	0.68	0.00	0.25	0.21	0.06

Table 12: Company 2 – Conscious monitoring

License plate	Distance (km)	Speed excess	Speed in rain	RPM	Braked sharply	Aceleration	Neutral gear
GYS-6039	5598.7	4.82	0.52	0.05	2.93	0.50	0.00
OLO-5095	5149.6	10.45	0.10	0.00	0.31	0.04	0.00
OLO-5282	7203.4	0.00	0.28	0.00	0.06	0.04	0.04

Table 13: Company 3 – Hidden monitoring

License plate	Distance (km)	Speed excess	Speed in rain	RPM	Braked sharply	Aceleration	Neutral gear
GSW-0611	4191.3	15.27	1.02	0.72	0.000	0.00	0.05
GSW-0380	5746.8	10.09	2.59	5.53	1.24	0.19	0.02
HDG-6547	6046.8	4.82	0.82	0.00	0.46	0.26	9.64

Table 14: Company 3 – Conscious monitoring

License plate	Distance (km)	Speed excess	Speed in rain	RPM	Braked sharply	Aceleration	Neutral gear
GSW-0611	4260.3	1.41	0.00	1.41	4.48	4.58	0.05
GSW-0380	5872	8.06	0.66	0.85	1.40	0.07	0.00
HDG-6547	6110	0.49	0.03	0.00	0.29	0.36	0.03

3.2.2 Fuel consumption – energy efficient

In regards to fuel consumption, af Wåhlberg (2007), Villeta et al. (2012) e Strömberg and Karlsson (2013a), Jiang (2015) the use of instant feedback equipment can generate a saving in fuel consumption of between 3% and 7%. In vehicles analyzed, were collected every supply data during the first two stages of monitoring so that the efficiency was measured in kilometers per liter, could be measured and compared as shown in Table 15.

Table 15: Data reduction of fuel consumption

	Hidden monitoring			Conscious monitoring			
License plate	Distance (km)	Consumption (liters)	Efficiency (km/l)	Distance (km)	Consumption (liters)	Efficiency (km/l)	Evolution (%)
OPB-6143	4739.5	1196.8	3.96	4742.6	1129.2	4.20	6.06
HOH-8528	4519.9	1403.7	3.22	4512.2	1334.9	3.38	4.97
KNY-9304	6375.4	1886.2	3.38	6406.4	1799.6	3.56	5.32
GXA-0910	5389.9	1298.8	4.15	5423.7	1235.5	4.39	5.78
OXH-5153	2348.5	665.3	3.53	2351.6	632.8	3.77	6.79
OPD-4329	4922.6	1435.2	3.43	4921.1	1359.4	3.62	5.53
GYS-6039	5596.5	1593.8	3.51	5598.7	1580.5	3.54	0.8
OLO-5095	5071.2	1157.8	4.38	5149.6	1115.6	4.62	5.48
OLO-5282	7080	1592.8	4.44	7203.4	1527.5	4.72	6.30
GSW-0611	4191.3	1960.8	2.14	4260.3	1854.7	2.30	7.47
GSW-0380	5746.8	1798	3.20	5872	1750.6	3.35	4.68
HDG-6547	6046.8	1655.9	3.65	6110	1596.5	3.83	4.93

Source: Authors

3.2.3 Training process and Capacitated Monitoring

According to Bonilha (2013), a research on the Brazilian national freight transportation, with 1120 respondents and 120 opinion leaders as companies, entrepreneurs and entities linked to the sector, the main obstacle to the development of the sector is linked to infrastructure and drivers issues such as: low-skilled, overwork, wage gap.

Regarding the general perception, 39% of respondents have a negative opinion about the Brazilian national freight transportation, mainly due to factors related to insecurity, lack of structural investment and low level of preparation of drivers, which is enhanced due to the low educational level of Brazilian professional drivers. According to data Cassane (2014) 35%, of the 66,37 drivers, completed high school levels, 25.6% completed primary school and 14.5% only had basic education which becomes a factor that hinders the absorption of new knowledge especially because cultural resistance.

This view is shared by Fleury and Oliveira Jr. (2001) by highlighting that learning can be understood through a process of change, which starts in the individual, caused by stimuli, and that such consequences generate change in behavior and one should also consider the emotion intelligence in this process.

As described by Burchert and Petermann (2011), it was decided to develop and implement an introductory training of eight hours, called awareness of the use of technology, which aims to clarify the technology in various aspects, in order to prepare drivers to the process of interaction with the EDR system and the monitoring of results, geared to the improvement process of:

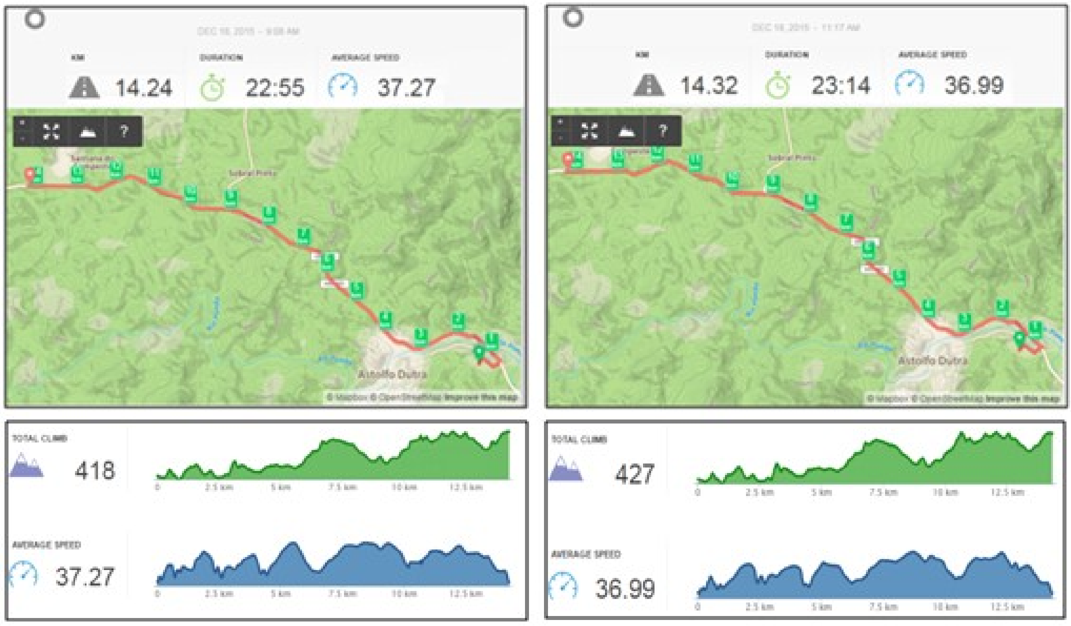
- Safety;
- Economy;
- Sustainability;
- Professional skills.

From this training, professionals were submitted to economical driving training, based on the methodology developed by a major manufacturer of heavy vehicles, being implemented in partnership with one of its dealers through one of his instructors. thus, each driver drove a vehicle Mercedes Benz Atego 2425 Model loaded with 14.15 ton. in two steps, that were named:

- Usual driving pattern - the driver drives the vehicle based on their knowledge and the instructor just observes the standards, collecting the number of occurrences and examining how to interact with the vehicle. At this stage there is no interference from the instructor.
- Power driving pattern - During the second round the same course, the instructor guides in advance, the driver on aspects of: use of brakes, inertia, engine brake use, gear distribution and anticipation.

The course set for the analysis of economic driving training was the same at all stages and comprises a stretch of 14.3 km. Thus, during the training, every driver drove 28.6 km and were analyzed through specific guidelines, data on the altitude, average speed, time of onset, duration and distance, as shown in figure 16.

Figure 16: Training route altimetry


Before training

After training

Source: Author

During the training phases, they analyzed the number of gear shifting, clutch use, brake pedal patterns, use of engine brake and conjugate, total mileage, total fuel consumption and the overall kilometers per liter use, being performed a direct comparison of evolution data as can be seen below in Table 16.

Table 16: Comparative before and after training

	Before training	After training	Evolution (%)
Gear shifting	578	242	-58.13
Clutch use	579	236	-59.24
Brakes use	314	135	-57.01
Engine brake use (conjugate)	15	41	273.33
Engine brake use (activated)	16	60	375.00
Distance (km)	171.6	171.7	-
Fuel consumption (l)	71.2	68.1	-4.35
Yield (km/l)	2.41	2.52	4.56

Source: Author

3.3 Discussion and Conclusions

The process of integration of the EDR systems with training techniques based on the 2003/59 EU directive EC, is particularly promising in countries like Brazil, where the actions to improve operational driving efficiency and security awareness are not part of everyday practices from governments and national companies.

Even though the integration proposition presented in this article is still in its early stage, we realized that the main critical success factors for adoption of the training process and implementation of the EDR systems, are prove to employers that such procedures generate competitive ad financial advantages in the medium and long term periods.

Meanwhile, the background continues to work on scientific analysis, so that it can present to the Brazilian government a proposal able to be cost effective and to reduce the annual expenditure of public budget for consequences of road accidents.

With regard to system efficiency in the reduction of operating costs, the average reduction in fuel consumption was quite significant where the comparison between the first two phases of monitoring, reached 5.34% improvement in vehicle efficiency, representing a saving of 728.3 liters of fuel through the 62,500 km monitored.

Considering the average monthly mileage of vehicles, 5,000 km, the projection of these results for the three participating companies can generate a monthly savings of approximately 6,069 liters. Another fact that validates this improvement is the decline in the average speed of the engines as the EDR systems enabled a reduction was achieved in the medium RPM 7.3%, this means that in the long run the engines will have your life extended in a less aggressive regime which impacts directly on reducing consumption.

As for safety, comparing the evolution of data during the hidden and aware monitoring and presented in tables 1-6, there was a considerable reduction in all unsafe acts related to negligence and recklessness practiced by drivers.

The number of excessive speed in the dry event was reduced in 8,688 to 1,782 events which represents a reduction of 79.5% in respect of speeding in the wet, the reduction achieved was 1137 events for the occurrences to 169 representing a fall of 85% and as observed in other studies conducted in the research, there was also a significant reduction in the number of hard braking, which fell from 643 incidents to 356 events representing a decrease of 45%.

These data are important because they are directly related to the main types of accidents that generate death caused in Brazilian highways, according VOLVO (2013), by improper overtaking and inconsistent speed.

As we begin the implementation of the training process, we realized that drivers showed great resistance to the use of technology creating situations to test the hardware security premises; therefore, the sensitivity training to the use of technology has proved a powerful tool as it aims to level the knowledge of all participants on the real purpose of the system.

The aim of this training is to present the benefits of technology for drivers, advising on the adoption of a procedure that allows educate and not punish. This premise is fundamental part throughout the training process, since all the data collected serve as guiding the actions to be taken by managers to understand what behaviors need to be acquired and worked for each of its drivers.

In addition, this stage of the training served as a valuable source in the assessment of opportunities for improvement of technology integration procedure with the training process. We observe that the drivers themselves made suggestions which, when adopted, optimized the process of analysis and formatting of the economical driving training Heyes et al. (2015).

In relation to this stage of the training process, they were trained 51 drivers of the three companies and from the analysis of the questionnaires: General and professional data of the participants, profile analysis and team building stage and Driver Behavior Questionnaire (DBQ) assessing related to the occurrence of errors, violations and lapses, we found that participants drivers fall within the profile described by Shi et al. (2010), Cassane (2014), with low education and difficulty to absorb new knowledge. DBQ questionnaire analysis determined that 80% of participants are likely to make mistakes with relative frequency and 73% said that they commit violations ranging from running a red light to speeding above the permitted limits or parking in prohibited places.

From the profile analysis team found that groups of drivers of the three companies are in the stage called "training" where according Rinke (1999), members of the staff bother to test the limits of appropriate behavior. The author states that it is necessary to train all staff in order to improve the maturity as a group.

These findings reinforce the proposal of the relevance of a multifocal analysis involving social, behavioral and psychological drivers in order to raise the level of success of the training process.

The second step of the training procedure involved the economic driving techniques where the instructor responsible for training evaluated in an objective way, the drivers before and after training as well as aspects relating to: acceptance to training, interest in learning, driving in skills, knowledge and use of vehicle technology, anticipatory driving and use of inertia, defensive driving, use of the RPM screen and brakes and clutch and for using both Likert scale.

The goal was to measure the attitudes and the degree of compliance of those involved and it was found that there was a 20% improvement in the observed aspects, especially the anticipatory driving questions, use of inertia and knowledge of the vehicle and its technologies.

By analyzing the data of table 8, we see that the economic driving training allowed the drivers reduce, significantly, the use of gears, clutch and brakes. The maintenance of this behavior has the ability to act directly on the professional quality of life since, during pattern of usual driving step called, drivers used an average of 3.37 gear changes and clutch use for each driven kilometer, while during the assisted driving pattern, this rate was reduced to 1.41 shifts and use of clutch per kilometer.

When we consider that on average each participant drives 5,000 kilometers per month, we will have a reduction of 16,850 gear changes for 7,050 exchanges which translates into greater comfort and less wear for the professional, besides representing an increase of the useful life of vehicle components. Also in the sense of economy, it is seen that a reduction in the consumption of fuel 4.35%, which represents a monthly saving 90.57 liters per vehicle associated with the reduction obtained during step consciously monitoring, reaches approximately 9 %.

It is necessary to reaffirm that the proposed procedure presents many opportunities for improvement, however, there is in Brazil studies and applied research, as found in European Union countries, which limits further comparative initial analysis.

It should be emphasized that investments by government and business are practically nonexistent so in Brazil, work in developing this type of study is time consuming so much because of the low level of resources devoted to research in road transport. Still, it is imperative that companies, universities and research centers maintain focus on such developments, since the annual cost of waste and accidents creates an extremely promising market for use of technology and training procedures in the country.

We believe that the scientific evidence of such proposals is a matter of time and that the capacity of this project is able to save lives, in it justifies greater attention from the scientific community, businesses and governments as to other in developed countries.

4. ANALYSIS OF THE EVENT DATA RECORDER SYSTEM REGARDING CRITERIA OF SAFETY, OPERATION AND CONSUMPTION IN A BRAZILIAN TRUCKING COMPANY

Abstract

Raising the safety and efficiency of trucking in Brazil has been a considerable challenge to industry managers and public officials in Brazil. The high number of injuries and deaths, low qualification of drivers and dependence on this type of transport have combined to create a vicious circle of inefficiency and risk. This article evaluates nine indicators related to criteria of safety, operational efficiency and consumption of inputs, based on analysis of a truck fleet in Brazil, using data collected by an event data recorder (EDR) system. The objective of this analysis is to understand whether EDR systems allow better efficiency of truck fleets with respect to the proposed criteria, and whether the driver training process influences the results. For this purpose, we developed an experimental procedure composed of three monitoring phases – Hidden (H), Conscious 1 (C1) and Conscious 2 (C2) – to allow evaluation of the fleet performance and behavior of each driver according to the proposed criteria. The results indicate that EDR systems can be applied to trucking in Brazil to reduce risks and costs and improve transport operation. Besides this, the process of training and feedback enhanced the results obtained in relation to use of the technology alone.

Keywords: *EDR, trucking, safety, consumption, training, drive behavior.*

4.1 Introduction

Traffic accidents on highways pose a global problem, causing concern among trucking company representatives and governmental authorities in both developed and developing countries. According to the World Health Organization (WHO), traffic accidents in general should be considered a global health problem. It is estimated that about 1.2 million people die annually from traffic accidents, and another 50 million suffer serious injuries or permanent aftereffects, causing economic losses of approximately US$ 518 billion (WHO 2011c).

According to official statistics, in 2014 there were 56,408 accidents on federal highways in Brazil involving at least one truck, corresponding to 33.4% of the total number of accidents recorded. These occurrences caused 3,537 deaths and 28,263 injuries, accounting for 43% and 28% of the number of deaths and injuries, respectively. Accidents on federal highways increased by 50.3% between 2004 and 2015 and the number of deaths grew by 34.5% in the same period (IPEA 2015a).

Sivak and Schoettle (2014), in a study of traffic fatalities in 193 countries, found that Brazil occupies 42nd place, with 22 deaths/100,000 inhabitants, only being ranked better than some African and Middle Eastern countries. Further according to the authors, Brazil's mortality rate is 22.2% higher than the global rate, 57% higher than that in the United States, and nearly four times higher than the rate in Sweden. Those findings for traffic violence in Brazil are in stark contrast to the WHO's proposal in 2010 for a "Decade of Action for Road Safety"(2011-2020), which has the general objective of reducing the increasing global trend in road traffic fatalities by 50%, meaning 5 million lives saved during the period (WHO 2011a).

In Brazil, the cost of accidents is calculated by the sum of each cost component associated with the control variables of an additive model, subdivided into costs related to persons, vehicles and property damage (IPEA 2006). In 2014, the costs of accidents on federal highways, not considering state highways and urban road systems, reached approximately US$ 3.41 billion, of which 64.7% refers to the component associated with persons. Each accident generates an average loss to society of US$ 20,000. However, considering accidents with fatalities, the cost rises to US$ 178,330. In this context, considering that trucks account for 44% of the total costs of accidents on federal highways, their impact is about US$ 1.5 billion a year.

Besides the aspects related to loss of life and financial impact, other consequences impair the efficiency of highway freight transport, such as inefficiency and precarious condition of highways (CNT 2015), lack of public policies and business actions to promote training of drivers Wanke (2010), and absence of control and management tools based on onboard technology and intelligence. The overall impacts of these problems on the economy are aggravated by the country's heavy dependence on highway freight transport. In this respect, between 2005 and 2015 the Brazilian truck fleet grew by 65% (DENATRAN 2016).

The substandard training of drivers, relative shortage of onboard intelligence systems and lack of regulations requiring truckers and logistics companies to use monitoring and control systems are barriers to the reduction of accidents. It is therefore important to search for mechanisms and tools that can improve the management of truck fleets regarding accidents, as well as reduce operating costs and raise efficiency of trucking in Brazil.

The use of EDR systems is widespread in the context of trucking in countries in

Europe and North America. In these countries, the main focus is to improve highway safety. But academics and public policymakers have also been studying the functionalities of EDR systems in relation to consumption, and driver behavior and qualification ETSC (2009), DGTren (2007b), Kusano and Gabler (2013). In Brazil, however, there is a gap in the scientific knowledge with respect to all these aspects associated with the use of this technology, in trucking as well as other roadway transport segments.

Therefore, the research problem studied here is the applicability of EDR systems in the Brazilian trucking company. The specific hypotheses considered are: (1) EDR systems allow computing better indicators of input consumption, operational efficiency and safety; (2) the association of EDR systems with driver training and feedback improves the results achieved from isolated use of such systems; and (3) there is a relationship between the safety and consumption indicators. In this respect, this article evaluates the performance of nine indicators related to the criteria of input consumption, operational efficiency and road safety, using EDR tools during distinct monitoring phases.

The article is organized into five sections including this introduction. Section 4.2 contains a literature review, briefly presenting the results of related research and examining the main variables considered by other researchers, to support our choice of indicators. Section 4.3 describes the procedures and methods used to develop the study and gather the data, covering the entire monitoring process used. Section 4.4 presents the analysis of the results based on the criteria for safety, operation and consumption, with focus on overall fleet analysis, followed by individualized analysis of the vehicles and behavior of the drivers. Finally, Section 4.5 contains our concluding remarks and some suggestions for future research.

4.2 Literature review

4.2.1 EDR systems

As part of the project called “Vehicle Event Recording based On Intelligent Crash Assessment”, or “VERONICA” , developed by the Directorate-General for Transport and Energy of the European Commission (DG TREN), Schimidt-Cotta (2009a). A technical, administrative and legal evaluation was conducted of road safety, looking toward implementation of control and data management systems. As part of this effort, it was defined that the expression event data recorder (EDR) should be used for any type of onboard vehicle intelligence technology, such as sensing and diagnostic modules (SDM), accident data recorders (ADR), incident data recorders (IDR) or journey data recorders (JDR).

According to the report called “Best Practices in Road Safety: Handbook for measures at the country level” DGTren (2007b), the use of EDR systems is among the best practices in existence. These systems monitor a range of variables, among them speed, acceleration, deceleration, use of lights, gear shifting and use of safety belts. Among the existing models are recorders of collision data, generally used to reconstruct the events leading to an accident, and trip data recorders, generally used to provide feedback to drivers on their habits from the standpoint of the environment (e.g., fuel efficiency) and/or safety.

The system analyzed in this study is composed of a central onboard electronic device connected to sensors that capture pulses generated by the vehicle when moving. These pulses are transformed into data, which are stored in the device’s internal memory and sent via a general packet radio service (GPRS) to a central server, where they are processed and then made available on a web platform. This platform allows extracting reports on the driving habits of each driver, according to various aspects, such as geographic position, time intervals, speed, acceleration/deceleration, engine rotation ranges, temperature, distance traveled and driver identity, among others.

We stress that since studies of this type of technology in Brazil are virtually nonexistent, we relied on the premises assumed by European researchers and organizations, as well as the WHO, as parameters to define the concepts and criteria involving the EDR technology.

4.2.2 Ecodriving techniques

The concept of ecodriving involves the use of more efficient driving styles, aimed mainly at reducing the fuel consumption and the associated carbon dioxide emissions. The reduction in fuel consumption can vary from 5% to 20% (Stillwater and Kurani 2013).

Mensing et al. (2014) discussed the ecodriving concept from the standpoints of fuel consumption and emission of pollutant gases. For this purpose, they compared two different situations, called economic and ecologic driving styles. They developed an algorithm to find an optimal velocity for each distance/route traveled. They concluded that using the tools and method described led to a reduction of 27.8% in fuel consumption, and thus in CO_2 emissions.

The Austrian Energy Agency (AEA 2012) defines the concept of efficient driving as the act of driving so as to save fuel, by taking advantage of the benefits of the technologies incorporated in vehicles, while at the same time improving road safety.

In our experiment, we traced out the individual profile of each driver, and based on the ecodriving concept we applied some short-term training techniques with all those involved. In this training process, we addressed fuel saving aspects such as keeping speed as constant as possible, with low engine rotation (by staying within the economy range indicated on the tachometer), as well as defensive driving techniques such as anticipating traffic flow and maintaining a safe following distance. There were two training sessions, with total duration of six hours.

4.2.3 Association between EDR and ecodriving techniques

To support the variables and indicators used in this article, we carried out a literature review of sources that have discussed the use of EDR systems and ecodriving techniques. The authors of the works consulted indicate 10 main variables, which we allocated in function of the criteria of safety, operation and consumption, as shown in Table 17.

Table 17: List of variables by authors.

	SAFETY			OPERATION			CONSUMPTION			
	Speed	Breaking	Acceleration	Engine Speed (RPM)	Travel time	Gear Changing	CO2 Emission	Average Speed	Fuel Consumption	Distance
Álvarez et al. (2014)	x		x							
Beusen et al. (2009)				x						
Beusen et al. (2009)				x					x	x
Caufield et al. (2014)							x		x	x
DG Tren (2007)	x		x	x						x
Duarte et al. (2013)		x		x						
Elvik (2010)	x									
Elvik (2015)	x									x
ETSC (2009)	x									
Kircher et al. (2014)	x	x	x						x	
Kusano et. al. (2013)										
Mensing et al. (2014)	x		x	x		x	x		x	x
Montiel et al. (2012)					x	x			x	x
Musicant et al. (2010)		x			x					x
Rutty et al. (2013)							x		x	x
Staubach et al. (2014)		x			x	x			x	
Stillwater & Kurani (2014)			x				x		x	
Stromberg&Karlsson (2013)		x						x		x
SUPREME (2007)	x							x		x
Suzdaleva & Nagy (2014)	x			x					x	x
Thijssen et al. (2013)		x	x	x					x	x
VERONICA (2006)	x	x	x							x
Villeta et al. (2012)	x		x	x					x	
Wahlberg (2007)	x	x	x						x	
Wahlberg et al. (2002)								x	x	
Young et al. (2010)	x	x					x		x	
Number of citations	**13**	**9**	**9**	**8**	**3**	**3**	**5**	**3**	**14**	**13**

Source: Authors

The studies examined investigated the use of EDR systems associated with ecodriving techniques to reduce fuel consumption and greenhouse gas (GHG) emissions and to improve road safety.

In relation to roadway transportation in general (trucks, buses and passenger cars), in developed countries of Europe and North America the use of EDR systems is mainly aimed at increasing traffic safety, due to the complexity of the transport modality and the associated accident rates Schimidt-Cotta (2009b), ETSC (2009), DGTren (2007b), Kusano and Gabler (2013), Alises, Vassallo, and Guzmán (2014). However, the functionalities of EDR systems allow the development of studies in areas important to enhance the efficiency of trucking, such as analysis of driver behavior, training programs to improve driving habits, better management methods and reduction of operational costs. These research areas can be pursued individually or in varied combinations.

Strömberg and Karlsson (2013a) used EDR systems as a tool to evaluate the impact of ecodriving, applying a method similar that described here to collect data, and stressed the relevance of ongoing training.

af Wahlberg (2002) also discussed the use of the tool to assess the effect of ecodriving on fuel consumption, analyzing aspects such as acceleration, driving time and instantaneous consumption. The author also proposed general principles for fuel saving, such as uniform acceleration to reach the desired velocity, using engine braking and defensive driving practices (anticipating traffic flow).

Musicant, Bar-Gera, and Schechtman (2010) conducted a study applying the concept of events frequency (EF) to analyze undesirable events, with focus on the importance of human behavior on the occurrence of traffic accidents. The EF is calculated from the number of events in relation to the driving time.

Caulfield et al. (2014) reported that the respect for speed limits is a potential indicator of drivers' willingness to follow safe driving practices. He also concluded that after examining the general trend, the provision of training to drivers can contribute to diminish the fuel consumption and emissions, as well as raise safety. In turn, Duarte, Gonçalves, and Farias (2013) reported that the variables vehicle speed, engine speed, excessive speed, excessive time with gearbox in neutral, excessive RPM in movement, excessive RPM in neutral gear and brusque braking are factors related to strategies to change driving styles among bus drivers.

Elvik (2010) described the five main problems related to traffic accidents, with highlight on excessive speed. He stressed that this aspect is one of the most relevant and that drivers are reluctant to change, stating that elimination of speeding would reduce the number of deaths and injuries on highways. Alvarez, Garcia, and Naranjo (2014) and Montiel et al. (2012) analyzed the effectiveness of ecodriving techniques over various routes, adopting different average speeds associated with travel times. They found fuel savings of 27.6%, 10.8% and 10.9% by increasing driving time by 7.8%, 6.25% and 7.5%, respectively.

Kircher, Fors, and Ahlstrom (2014) evaluated the impact of installing information devices in vehicles on ecodriving in real time, in continuous and intermittent formats. The system analyzed provided drivers with information such as average fuel consumption, speed, acceleration and deceleration. Although the aim of the study was to determine whether the adoption of this technology can increase risks due to driver distraction, the authors stressed that the observance of ecodriving principles regarding maintenance of moderate speeds and avoidance of abrupt braking reduced fuel consumption.

Likewise, the results presented by Kircher et al. (2014) and Suzdaleva and Nagy (2014) support the idea that ecodriving techniques can help reduce fuel consumption and CO_2 emissions, which are concerns of drivers and the automotive industry. Therefore, the authors proposed the implementation of programs to orient drivers on the best timing of gear changes and the ideal acceleration to achieve maximum reduction of fuel consumption. Another conclusion obtained from these studies is that ecodriving can reduce occurrences of excess speed as well as save fuel.

Thijssen, Hofman, and Ham (2014) analyzed the willingness of truck drivers to adopt anticipation behavior, which corresponds to judging when to release the accelerator pedal according to the stopping distance to an obstacle. According to the results, the adoption of this behavior has the potential to reduce fuel consumption by up to 9.5%, and can be instilled through training and onboard driving support systems. Rutty et al. (2013) highlighted ecodriving as a practice to increase efficiency associated with reduction of greenhouse gases.

Besides this, the authors indicated excessive time spent stopped with the engine running (gearbox in neutral) as one of the factors causing inefficiency, since it unnecessarily increases fuel consumption. Montiel et al. (2012), Caulfield et al. (2014), Rutty et al. (2013), Alvarez et al. (2014), Staubach et al. (2014), Duarte et al. (2013), Strömberg and Karlsson (2013b), Young, Birrell, and Stanton (2011), af Wåhlberg (2007), Pérez-Martinez (2012), Rutty et al. (2013) and Villeta et al. (2012) all converge in stating that standardized driving practices, driver training and implementation of onboard data systems are factors that can reduce the risk of accidents and improve fuel consumption.

These findings corroborate the hypothesis that ongoing training and monitoring can have a positive influence on drivers' behavior.

4.3 Procedures and methods

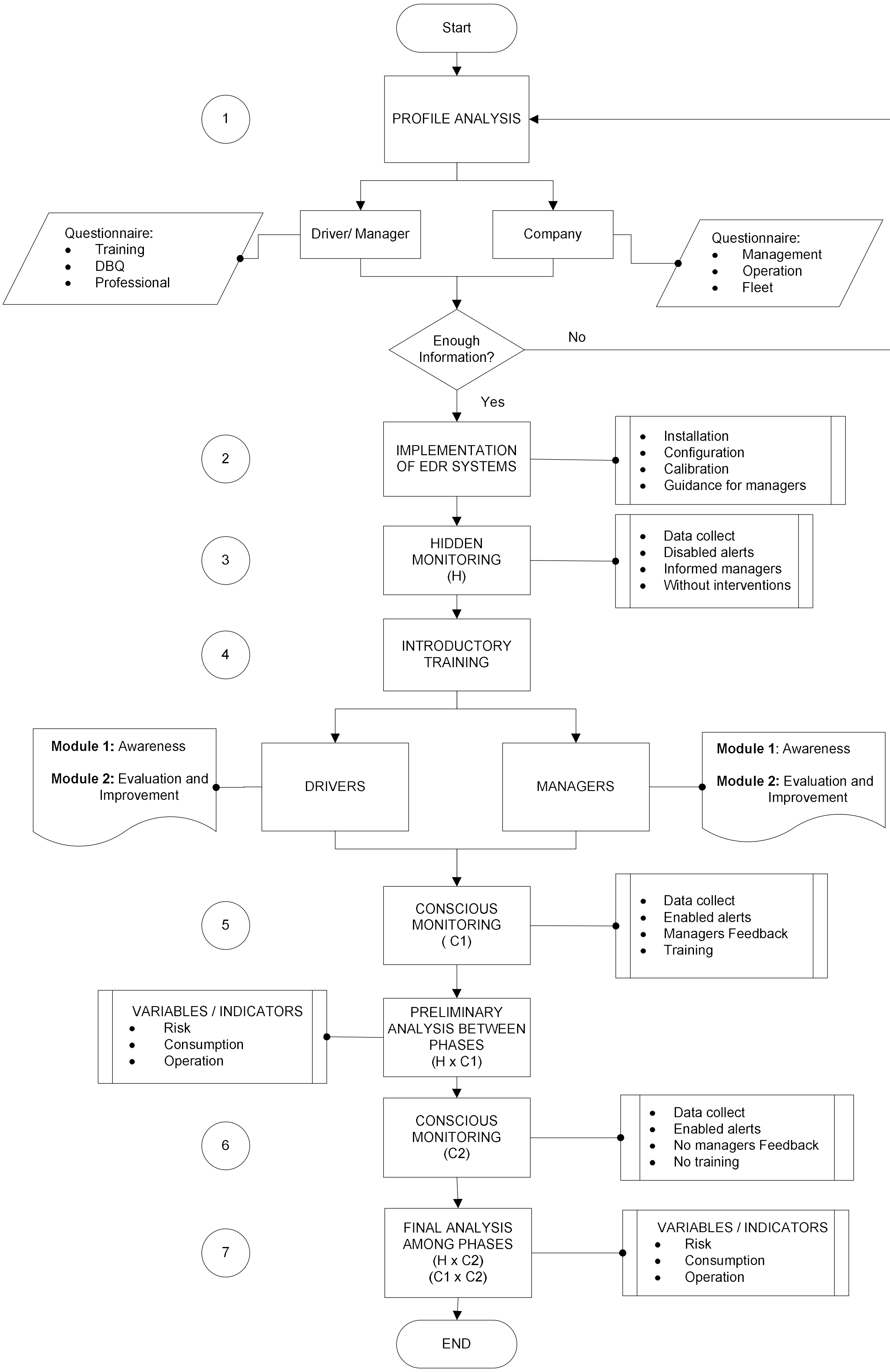
4.3.1 Description of the experiment

The data analyzed in this article were obtained from evaluation of 33 trucks (Mercedes Benz and Volvo), all equipped with EDR systems. These vehicles are used to haul juices and other beverages and they travel over routes determined for each round trip in light of the demand of customers, spread in ten Brazilian states (no fixed routes).

The transport occurs under a dedicated regime, where all the trucks leave the factory loaded and normally return empty. The company has a rigorous control and record-keeping system regarding fuel consumption, distance covered, weight carried, truck maintenance and working hours of drivers. There are no changes of drivers during each delivery circuit and the price of diesel is US$ 0.84 per liter.

The experimental procedure was divided into seven steps, as depicted in Figure 17. The first two steps are related to the preliminary analyses and implementation of the EDR system; steps 3 to 6 refer to the monitoring and training phases; and the seventh step involves comparative analysis of the indicators obtained during the monitoring phases.

Figure 17: : Flowchart of the experiment.



Source: Authors

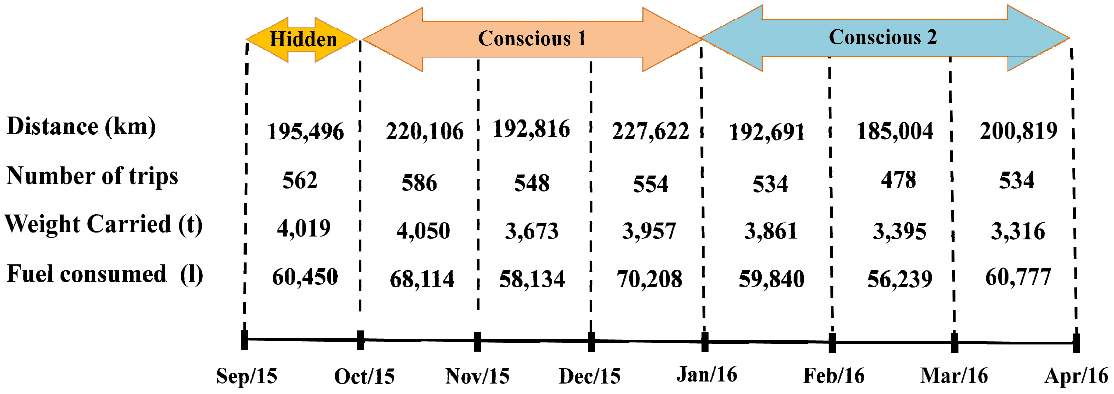
4.3.2 Monitoring phases

To carry out the comparative analysis of the driving pattern and profile of evolution of the data, each vehicle was monitored individually. The aim was to ascertain the driving pattern of all the vehicles without interruption. It was divided into three monitoring phases: the first to define the baseline driving style of each driver; the second to allow evaluation of the effect of training regarding technology associated with ecodriving techniques in the short term, with feedback to the drivers from managers; and the third to detect whether the drivers' behavior tended to return to the initial patterns after the end of the training and feedback procedures. We call these monitoring phases Hidden (H), Conscious 1 (C1) and Conscious 2 (C2), respectively.

The EDR system used to collect the data was customized according to the parameters established by the company's managers, as follows: maximum permitted speed of 80 km/h, with tolerance of 3 seconds for recording; maximum speed in the rain of 60 km/h, with tolerance of 20 seconds for recording; and abrupt braking and acceleration as of 11 km/h. The engine rotation (RPM) parameters followed the recommendations of the makers of each model composing the fleet, as indicated by the tachometer of each vehicle.

Figure 18 presents the data on distance traveled, number of trips made, weight carried and fuel consumed by the fleet in each of the monitoring phases. Data were also collected on time of engine running, rotation (RPM), excessive speed events, idling, available productive time, and brusque braking and acceleration.

Figure 18: Data on distance traveled, number of trips, weight carried and fuel consumed during the three monitoring phases.



Distance (km)	195,496	220,106	192,816	227,622	192,691	185,004	200,819
Number of trips	562	586	548	554	534	478	534
Weight Carried (t)	4,019	4,050	3,673	3,957	3,861	3,395	3,316
Fuel consumed (l)	60,450	68,114	58,134	70,208	59,840	56,239	60,777

Source: Author

4.3.2.1 Hidden monitoring – (H)

The drivers did not participate during the implementation of the EDR system by the company and they did not receive any information regarding the functionalities of the system. In this phase, all the alert sounds and lights were disabled, so there was no interaction of the drivers with the system aboard each truck.

This enabled tracing out a baseline driving style for each driver and a fleet-wide average, without any external influence. The operating times and data referring to the driving pattern were collected and processed by the EDR system. The objective of this step was to create an individual and overall reference of driving history, similar to the method described by (Strömberg and Karlsson 2013a).

4.3.2.2 Conscious monitoring 1 – (C1)

In this phase, the EDR devices onboard each truck continued to monitor the same data on driving behavior and vehicle performance, but now with the alert sounds and lights enabled. Also, the drivers received six hours of training, for the purpose of explaining the use of the technology and inform them of the expectations regarding safety, operational efficiency and fuel saving.

In this phase, the managers analyzed the data on each driver and provided feedback about their behavior. The objective of this phase was to assess the short-term impact on the variation of the data after enablement of the alerts emitted by the EDR device, associated with intervention of the managers through feedback and the two training sessions (Af Wåhlberg 2006).

4.3.2.3 Conscious monitoring 2 – (C2)

In this phase, the same data continued to be collected and the alerts emitted by the EDR devices were maintained active. However, there was no intervention through training and feedback. The objective of this phase was to ascertain whether the aspects related to safety, operation and fuel saving continued the trend observed in C1, or if the drivers tended to revert to the same patterns observed during the first phase (H).

4.4 Analyses and results

4.4.1 Treatment of the data

Based on the literature review presented in Section 2, we formulated nine indicators for the three criteria (safety, operation and consumption), for the purpose of assessing the performance of the fleet and drivers. The indicators were: distance traveled, times spent (gearbox in neutral, normal movement and excessive speed) and number of occurrences, called "events" (excessive speed on dry roads, excessive engine rotation (RPM), abrupt acceleration and abrupt braking), all extracted from the EDR system. Besides these data, the company provided data on fuel consumption, weight carried and number of trips for each vehicle.

We analyzed the data in two aspects. The first involved the overall behavior of the fleet, where the data on all the trucks were analyzed in consolidated form. The second entailed analysis of the individual behavior of each driver/truck, since the assignment of drivers to trucks did not vary.

4.4.2 Overall analysis

Here we analyze the consolidated data on the entire fleet to assess its performance during the experiment. As mentioned, the distribution of cargoes and establishment of routes were determined according to customer demand, thus avoiding bias in the analyses.

As said previously, the assignment of drivers to vehicles did not change, allowing analysis of the variation of their behavior in function of the proposed criteria. Table 18 presents the data obtained during the three monitoring phases.

Table 18: Data from monitoring phases.

Criteria	Data collected	Hidden	Conscious 1	Conscious 2
	Monitoring period	Sept. 2015	Oct.-Dec. 2015	Jan.-March 2016
Safety	Distance traveled (km)	195,496	640,544	578,514
	No. of excessive speed events	19,808	20,608	19,995
	Time with excessive speed	104:00:00	39:25:00	116:14:00
	No. of abrupt braking events	839	8,386	9,991
	No. of abrupt acceleration events	626	1,820	1,304
Operation	Total idling gear	575:05:37	1594:09:58	1554:34:04
	Time in movement	2745:13:29	9182:10:26	7827:12:21
	Time available	17424:00:00	52272:00:00	52272:00:00
	Productive time available	5808:00:00	17424:00:00	17424:00:00
	No. of over-revving events (RPM)	146	152	251
	Total weight carried (t)	4,019	11,681	10,571
	Number of trips	562	1,688	1,546
Consumption	Fuel consumption (l)	60,103	196,456	176,857

Source: Authors

With respect to the safety criterion, we evaluated one of the main acts related to the occurrence and severity of accidents, excessive speed (WHO 2008). That evaluation allowed calculating two indicators, the first referring to the number of events recorded in function of the distance traveled and the second, called risk exposure, measuring the time spent traveling faster than the established speed limit in function of total time in movement. Besides these two, we also calculated the number of abrupt braking events in function of distance traveled.

With respect to the operational efficiency criterion, we analyzed the fleet productivity, obtained from the ratio between the time in movement and the available productive time, according to the definitions contained in Law 13,103/2015, which among other matters, defines the daily working period of professional drivers in Brazil (BRASIL 2015). The second indicator of this criterion is represented by the number of engine over-revving events in function of distance traveled. Besides these, we also calculated an indicator of the duration with the gearbox in neutral for each kilometer traveled.

Finally, the three indicators for the consumption criterion are: (1) time with gearbox in neutral in function of time in movement, which allows calculating the percentage of time when the engine is running and consuming fuel with the vehicle stopped; (2) fuel consumption in function of weight hauled and kilometers traveled; and (3) cost of fuel per kilometer traveled.

The results obtained in the monitoring phases and the formulas to calculate the proposed indicators are presented in Table 19.

Table 19: Indicators in different monitoring phases

Criteria	Indicators	Hidden	Conscious 1	Conscious 2
Safety	Nº. of excessive speed events/1000 km traveled	101	32	35
	Nº. of abrupt braking events/1000 km traveled	4	13	17
	Time of excessive speed / time of total movement (%)	3.79	0.43	1.48
Operation	Time of movement/available productive time (%)	47.3	52.6	44.9
	Nº. of over-revving events/1000 km traveled	0.747	0.237	0.434
	Idling / km (s)	00:00:11	00:00:09	00:00:10
Consumption	Idling / time with engine running (%)	17.32	14.79	16.57
	Consumption (l) / t.km	0.6103	0.0596	0.0609
	Fuel cost / km traveled (U$)	0.258	0.256	0.254

Source: Authors

For the safety criterion, in the (H x C1) comparison, there was a reduction of 68.3% in the number of speeding events per kilometer. This, associated with the reduction of risk exposure time to 0.49% of the time in movement, represents an important increase in fleet safety in one of the main aspects related to accidents.

The (H x C2) comparison also indicated reduction of the two indicators, but in the (C1 x C2) comparison, there was an increase of 10.82% in the number of speeding events and a three-fold increase in the indicator related to risk exposure.

The brusque braking event per kilometer indicator had peculiar rising incidence during the last two phases. This can be explained by the intervention of the system, which emits a spoken alert “reduce speed” any time the established limit is exceeded for more than three uninterrupted seconds, usually prompting the driver to step on the brake pedal rather than reduce pressure on the accelerator to allow the vehicle to slow down gradually.

In the operation criterion, there was an increase of 11.27% in fleet productivity, a reduction of time spent with gearbox in neutral of 2 seconds/km and a 68.27% drop in the number of over-revving events in the (H x C1) comparison. These indicators show that the fleet’s operational efficiency increased during the (C1) period. Besides the fall of 5.01% in productivity in the (H x C2) comparison, the other indicators improved. However, in the (C1 x C2) analysis, all the indicators got worse. Therefore, the best operational efficiency was achieved during (C1).

With respect to the consumption criterion, the (H x C1) comparison revealed a reduction of 14.6% in the time spent in neutral. This is equivalent to a reduction of 43.5 hours/month in the idling gear. Besides this, the fuel cost per kilometer declined by US$ 0.002, representing fleet-wide saving of US$ 1,281.00 during (C1). From (C1) to (C2), all the indicators increased, again showing that consumption was lower and hence efficiency was higher in (C1) than in (C2).

In this respect, the overall analysis allows inferring that all three criteria improved in (C1) and (C2) in relation to (H). This supports the hypothesis that EDR systems have a beneficial influence on these aspects. Moreover, the indicators got worse from (C1) to (C2), further supporting the hypothesis that the process of training and providing feedback to the drivers enhances the improvement of the indicators. However, assessing the impact of the individual behavior of each driver/truck pair requires more detailed analysis.

4.4.3 Individual analysis of the driver/truck pairs

For individual analysis of the vehicles and drivers, we used the quartile concept, to enable the individual driving behavior to be evaluated and compared. The procedure utilized was applied to the data collected in the first phase (H) and the intervals found for each indicator, based on this distribution, were adopted as parameters to assess the movement of vehicles in the other monitoring phases.

We performed the comparative analysis of the indicators based on the same parameters used in the overall analysis: (H x C1), (H x C2) and (C1 x C2).

The evaluations of the indicators reported in this section reveal the evolution of these indicators in each of the 33 trucks composing the fleet. The objective is to understand where the most serious problems are and the changes in the indicators during the monitoring phases, to enable maximizing the result of the training and feedback process in the future.

Table 4 presents the movement of the vehicles by quartile in the monitoring phases (C1) and (C2), based on the results obtained in phase (H). The data in the table show the tendencies for improvement or reversion of parameters of each vehicle in individual form. To be able to consider that evolution occurred, we took as a parameter the growth of quartiles Q1 and Q2 in comparison with the basic initial distribution in (H). The increase in the number of vehicles in Q3 and Q4 shows a tendency for the indicator to get worse.

However, to compose this analysis, we prepared Tables 20 and 21 from the individual data on each vehicle in each of the criteria, where we present the mean, standard deviation and coefficient of variation of the nine indicators of the vehicles that compose each quartile during the monitoring phases. The joint analysis of the data in all the tables indicates the tendency for improvement or worsening of each indicator during the monitoring phases.

Table 20: Distribution of vehicles by quartile during the monitoring phases.

CRITERIA SAFETY

		Nº. of excessive speed events / 1000 km traveled								Nº. of abrupt braking events / 1000 km traveled								Time of excessive speed / time of total movement							
		Conscious 1 (C1)				Conscious 2 (C2)				Conscious 1 (C1)				Conscious 2 (C2)				Conscious 1 (C1)				Conscious 2 (C2)			
	Quartile	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Hidden (H)	Q1	5	4			3	5	1		2	2	1	4	1		2	6	5	3	1		2	7		
	Q2	3	5			1	5	1	1			2	6				8	5	1	1	1	3	5		
	Q3	1	7				7	1				1	7				8	5	1		2	3	4	1	
	Q4		6	2			6	1	1				8				8	2	1	1	4	1	3	2	2
	Grand total	9	22	2		4	23	4	2	2	2	4	25	1		2	30	17	6	3	7	9	19	3	2

CRITERIA OPERATION

		Time of movement / available productive time								Nº. of RPM /1000 km traveled								Idling / km							
		Conscious 1 (C1)				Conscious e 2 (C2)				Conscious 1 (C1)				Conscious 2 (C2)				Conscious 1 (C1)				Conscious 2 (C2)			
	Quartile	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Hidden (H)	Q1		5		4	2	3	2	2	3		6		6	3			8	1			8		1	
	Q2		2	5	1	1	5	2			6	2			5	1	2	3	5			6	1		1
	Q3		1	2	5		7	1				3	5		2	4	2	4	4			4	1	3	
	Q4	1	5	2		3	4	1		1		5	2		1	4	3	1	2	1	4		3		5
	Grand total	1	13	9	10	6	19	6	2	4	6	16	7	6	11	9	7	16	12	1	4	18	5	4	6

CRITERIA CONSUMPTION

		Idling / time with engine running								Consumption (l) / t.km								Fuel cost / km traveled (US$/ km)							
		Conscious 1 (C1)				Conscious 2 (C2)				Conscious 1 (C1)				Conscious 2 (C2)				Conscious 1 (C1)				Conscious 2 (C2)			
	Quartile	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Hidden (H)	Q1	8	1			5	2		2	8	1			7			2	9				9			
	Q2	5	3			5	2		1	2	3	2	1	2	2	1	3	6		2		3	3	2	
	Q3	3	2	2	1		2	5	1			5	3			4	4			8				8	
	Q4		2	1	5		1	2	5				8				8				8				8
	Grand total	16	8	3	6	10	7	7	9	10	4	7	12	9	2	5	17	15		10	8	12	3	10	8

Source: Authors

Table 21: Analysis of the mean, standard deviation and coefficient variation of the indicators, in function of the safety, operation and consumption criteria.

CRITERIA SAFETY																											
	Nº. of excessive speed events / 1000 km traveled									Nº. of abrupt braking events / 1000 km traveled									Time of excessive speed / time of total movement								
	Mean			Standard Deviation			Coefficient of Variation			Mean			Standard Deviation			Coefficient of Variation			Mean			Standard Deviation			Coefficient of Variation		
	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2
Q1	0.003	0.003	0.004	0.002	0.002	0.002	0.782	0.655	0.581	0.000	0.000	0.000	0.000	0.000	0.000	1.515	1.000	0.000	0.001	0.001	0.001	1.207	1.103	0.814	0.001	0.001	0.001
Q2	0.074	0.037	0.061	0.035	0.030	0.037	0.472	0.804	0.605	0.001	0.002	0.000	0.001	0.000	0.000	0.611	0.246	0.000	0.010	0.000	0.006	0.453	0.150	0.586	0.023	0.003	0.010
Q3	0.151	0.145	0.156	0.018	0.000	0.016	0.120	0.002	0.100	0.004	0.004	0.003	0.001	0.001	0.000	0.186	0.185	0.023	0.006	0.000	0.008	0.124	0.056	0.166	0.047	0.005	0.046
Q4	0.234	0.000	0.202	0.043	0.000	0.003	0.185	0.000	0.013	0.012	0.013	0.022	0.005	0.009	0.023	0.417	0.691	1.025	0.035	0.013	0.006	0.379	0.637	0.072	0.092	0.021	0.090
CRITERIA OPERATION																											
	Time of movement / available productive time (%)									Nº. of over-revving events /1000 km traveled									Idling / km (s)								
	Mean			Standard Deviation			Coefficient of Variation			Mean			Standard Deviation			Coefficient of Variation			Mean			Standard Deviation			Coefficient of Variation		
	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2
Q1	0.277	0.435	0.239	0.035	0.000	0.028	0.126	0.000	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	00:00:04	00:00:06	0.001	00:00:03	00:00:02	00:00:02	0.624	0.448	0.384
Q2	0.485	0.563	0.454	0.030	0.059	0.057	0.062	0.105	0.126	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.716	00:00:10	00:00:10	0.006	00:00:01	00:00:01	00:00:01	0.089	0.076	0.101
Q3	0.559	0.563	0.571	0.024	0.007	0.016	0.042	0.013	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.283	0.388	0.168	00:00:12	00:00:12	0.008	00:00:01	00:00:00	00:00:00	0.061	0.000	0.018
Q4	0.650	0.623	0.665	0.035	0.015	0.036	0.054	0.024	0.055	0.003	0.001	0.002	0.003	0.001	0.002	0.911	0.967	0.991	00:00:29	00:00:19	0.006	00:00:19	00:00:03	00:00:04	0.676	0.136	0.195
CRITERIA CONSUMPTION																											
	Idling / time with engine running (%)									Consumption (l) / t.km									Fuel cost / km traveled								
	Mean			Standard Deviation			Coefficient of Variation			Mean			Standard Deviation			Coefficient of Variation			Mean			Standard Deviation			Coefficient of Variation		
	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2	H	C1	C2
Q1	0.125	0.117	0.124	0.010	0.010	0.009	0.077	0.083	0.073	0.021	0.021	0.024	0.010	0.010	0.006	0.469	0.447	0.268	0.200	0.203	0.203	0.092	0.098	0.100	0.133	0.140	0.143
Q2	0.144	0.144	0.142	0.006	0.007	0.004	0.042	0.047	0.026	0.036	0.035	0.034	0.002	0.001	0.000	0.048	0.030	0.006	0.226	0.218	0.226	0.005	0.018	0.003	0.007	0.024	0.004
Q3	0.170	0.164	0.167	0.006	0.000	0.007	0.035	0.001	0.043	0.045	0.044	0.043	0.001	0.001	0.001	0.023	0.028	0.032	0.248	0.245	0.247	0.030	0.032	0.030	0.035	0.038	0.035
Q4	0.277	0.233	0.246	0.108	0.039	0.044	0.392	0.167	0.180	0.146	0.104	0.089	0.108	0.080	0.072	0.741	0.769	0.815	0.200	0.203	0.203	0.207	0.167	0.176	0.164	0.134	0.139

Source: Authors

4.4.3.1 Analysis of the safety criterion

The indicator of excessive speed events per kilometer traveled in Table 4 shows in increase of 82.3% in the number of vehicles in quartiles Q1 and Q2 in the (H x C1) comparison, with a counterpart reduction of the vehicles in Q3 and Q4, demonstrating a consistent reduction in the number of excessive speed events.

Besides this, analysis of Table 5 reveals that the average number of speeding events per kilometer traveled in Q2 fell from 0.074 to 0.037, which represents improvement of the corresponding drivers in behavior related to risk. However, of the 22 vehicles composing Q2 during (C1), 14 had migrated from Q3 and Q4, which configures an even greater improvement, considering that the averages of the events in these quartiles were 0.151 and 0.234 excessive speed events/km, respectively, during (H).

The data for (C2) also show growth in the number of vehicles in Q1 and Q2 of 58.8% compared to (H). However, the number of vehicles in Q3 and Q4 increased and the average number of errors rose, almost reaching the levels observed during (H). The (C1 x C2) comparison shows that all the average values got worse. In other words, the results in (C1) and (C2) were better than in (H), more so in (C1), after which they tended to reverse. This corroborates the hypothesis that the training and feedback process enhances the positive results.

Regarding the indicator of the number of abrupt braking events per kilometer traveled, Table 4 reveals migration of 17 vehicles from Q1, Q2 and Q3 to Q4, a substantial deterioration of this indicator because of the increase of abrupt braking events. Analysis of Q4, due to the high concentration of vehicles during (C1) and (C2), reveals an increase in the coefficient of variation, demonstrating heterogeneity of the data during (H).

The vehicles of Q4 presented variation from 5.5 to 20.4 abrupt braking events/1000 km traveled, while in (C1) this value ranged from 5.2 to 43.1 abrupt braking events/1000 km traveled and in (C2) from 5.6 to 125.3 abrupt braking events/1000 km traveled. This behavior can be attributed to the interaction of the system with the driver, since when an excessive speed event occurs, the onboard system emits a sound alert that generally prompts the driver to step on the brake pedal to slow the vehicle as quickly as possible, to reduce the total time of excessive velocity.

The indicator of time spent traveling at excessive speed was obtained by the ratio between the total time each vehicle was traveling faster than the speed limit and the total time the vehicle was in movement, i.e., not counting time spent with the gearbox in neutral. In the (H x C1) comparison, the number of vehicles in Q1 and Q2 grew by 35% regarding this indicator. While in (H), the vehicles of Q3 and Q4 traveled faster than the permitted speed 6.95% of the total time, in (C1) this percentage fell to 1.6%, the lowest risk exposure level. In the (H x C2) comparison, there was an increase of 64.7% in the number of vehicles in Q1 and Q2, representing an improvement in the indicator, but once again in the (C1 x C2) comparison, there was greater heterogeneity of the data in (C2), where the vehicles of Q1 and Q2 spent 0.73% of the time in movement traveling above the maximum speed limit while in (C1) this percentage was 0.11%.

Evaluation of the three indicators related to safety reveals a smaller number of excessive speed events along with a reduction of the time spent speeding from the Hidden monitoring phase to the two Conscious phases. This indicates improvement of safety behavior, since the drivers spent more time traveling under the speed limit. With respect to abrupt braking events, as mentioned, the increase in the number of occurrences can be attributed to drivers' responses to the sound alerts of excessive speed.

4.4.3.2 Analysis of the operation criterion

The indicator of time in movement in relation to available productive time was obtained by the ratio between the time each vehicle was in movement (not counting idling) and the available productive time. To define this latter parameter, we considered a standard month of 24 business days multiplied by the maximum daily working hours of professional drivers as specified in Federal Law 13,103/2015. Unlike the case of the other indicators, the objective here is to increase the percentage of time in movement in relation to the available productive time. Therefore, the increase in the number of vehicles in in Q3 and Q4 indicates improvement.

In the (H x C1) comparison, the productivity of the vehicles of Q1 and Q2 in (H) represented 37.4% of the available time, while in (C1) this figure rose to 43.4%. There was an increase of 11.7% in the number of vehicles in Q3 and Q4, but there was no meaningful increase in the productivity index in these quartiles. In the (H x C2) comparison, there was a 50% reduction in the number of vehicles in (C2) in relation to (H), again with no significant change in productivity. Finally, in the (C1 x C2) comparison, the number of vehicles in Q3 and Q4 was 58% lower in (C2), but the productivity was practically the same. The general productivity in (H) was 48.6% of the available time, while in (C1) it was 52.7%, followed by 44.9% in (C2).

The indicator of excessive engine rotation (RPM) per distance traveled was established as the ratio between the number of each vehicle's over-revving events and the distance traveled, revealing the behavior pattern of the corresponding driver. The (H x C1) comparison revealed that the drivers of vehicles in Q1 and Q2 did not commit any over-revving events. Despite the reduction in the number of vehicles in these quartiles in (C1), the average number of errors in Q3 and Q4 was 0.3 excesses of RPM/1000 km traveled, versus 1.6 excesses of RPM/1000 km traveled during (H), demonstrating improvement of this indicator. In the (H x C2) comparison, the number of vehicles in Q1 and Q2 taken together was the same, but the number of vehicles in Q1 was lower in (C2). Despite this, the number of over-revving events per 1000 km traveled was 0.8 in (C2) while it was 1.6 in (H).

The idling per kilometer traveled indicator is obtained by dividing the total time with the engine running with the gearbox in neutral by the distance traveled by the vehicle. More time spent in neutral raises fuel consumption without contributing to productivity. In the (H x C1) comparison, the number of vehicles in Q1 and Q2 increased by 64.7% in (C1), although the average time spent with the gearbox in neutral was the same, 7 seconds. This migration caused a decline in the number of vehicles in Q3 and Q4, where the duration of the indicator was 2.7 times greater than that observed in Q1 and Q2. In the (H x C2) comparison, the number of vehicles was 35% higher and the idling was 15.8% lower in (C2). Finally, in the (C1 x C2) comparison, the vehicles performed better in (C1), further supporting the hypothesis that the training and feedback process improves the results related to operational efficiency.

The indicators related to operation allowed noting a rise in productivity and a reduction of time spent with the gearbox in neutral and the number or speeding events during the Conscious 1 monitoring compared with the Hidden monitoring phase. In turn, in the Conscious 2 phase, the productivity declined, attributed to the 9.2% reduction in the average number of monthly trips and the higher percentage of idling. Nevertheless, the training and feedback process had a positive influence on the results: the indicators improved in the Conscious 1 period, but when this process was interrupted, the drivers had a natural tendency to return to their original driving patterns as measured during the Hidden monitoring.

4.4.3.3 Analysis of the consumption criterion

The indicator of the time with the gearbox in neutral in relation to the time with the engine running represents the percentage of productive time of each vehicle. The higher this percentage is, the greater the fuel consumption will be for each kilometer traveled, *ceteris paribus*. In the (H x C1) comparison, there was a 41% increase in the number of vehicles in Q1 and Q2 during (C1). Besides this, the percentage of engine running time with the gearbox in neutral declined from 13.3% in (H) to 12.6% in (C1). In turn, in the (H x C2) comparison, the number of vehicles in Q1 and Q2 remained unchanged regarding the neutral gear metric. Finally, in the (C1 x C2) comparison, the performance in (C1) was better than in (C2), and it can be seen in Table 5 that the data of this indictor can be considered homogeneous in (C1) and (C2).

The indicator of liters of fuel burned per ton-kilometer was obtained by the ratio between the total number of liters of diesel consumed by each truck and the total weight hauled divided by the total distance traveled by each vehicle. This is an indicator of the productivity of the vehicle in terms of load carried. For this indicator, in the (H x C1) comparison there was (for the first time) a reduction of 18% in the number of vehicles in Q1 and Q2 in (C1), but these vehicles presented average consumption 11% lower than in (H). Besides this, in Q3 and Q4 the average consumption was 0.0957 l/t.km in (H) while in (C1) it was 0.0818 l/t.km. In the (H x C2) comparison, this consumption was practically the same in Q1 and Q2 during (C2), and better in the vehicles of Q3 and Q4, which presented average consumption of 0.0783 l/t.km. In the direct (C1 x C2) comparison, the result was better in (C1), since the average consumption was 0.0578 l/t.km in (C1) against 0.0608 l/t.km in (C2). Also, the heterogeneity of the vehicles in Q3 and Q4 increased during the monitoring phases starting with (H).

The fuel cost per kilometer indicator is widely used by fleet managers, since together with other parameters (e.g., lubricating oil consumption, tire usage and maintenance costs), it allows measuring productivity and efficiency. We decided to use it alone rather than combined with other parameters since fuel is among the largest operating costs of trucking companies (indeed, often the largest). In the (H x C1) comparison, there was no significant movement when analyzing the vehicles in Q1 and Q2 regarding average fuel cost. In (C1) this was US$ 0.203/km while in (H) it was US$ 0.212/km. The same applies to the vehicles of Q3 and Q4, which presented costs of US$ 0.307/km and US$ 0,296/km in (H) and (C1), respectively. In the (H x C2) comparison, the only quartile that showed substantial movement was Q2, with migrations to Q1 and Q3, but there was a reduction of the average cost in (C2) in all the quartiles, where in Q1 and Q2 it was US$ 0.299/km versus US$ 0.206/km in Q3 and Q4. Once again in the (C1 x C2) comparison, the results in (C1) were better than those in (C2), indicating backsliding by the drivers regarding road habits.

The consumption criterion has the largest impact on the analysis of fleet operators regarding the efficiency and effectiveness of actions to adopt new technology and training programs, since its results regarding reducing costs and thus increasing profit margins can be measured immediately. With respect to this criterion, all the indicators declined during the Conscious 1 monitoring phase. This represented a saving of US$ 1,281.00 and a lower rate of engines running with the gearbox in neutral and a reduction in the cost per kilogram of cargo hauled. In turn, in the Conscious 2 monitoring period, despite the improvement in relation to the Hidden phase, the indicators analyzed were worse than in the previous phase, supporting the positive influence of training and feedback associated with the use of the EDR technology.

4.5 Discussion and Conclusions

Based on the analyses carried out, it is possible to conclude that EDR systems can be effectively applied by Brazilian trucking companies, due to the positive impact on the safety, consumption and operation criteria, answering the proposed research question. Besides this, the results show that this technology can generate a considerable improvement in the indicators investigated and adds support to the hypothesis that the use of technology alone shows limitations regarding efficacy.

As observed, there was a decided tendency for the drivers to revert to their original habits without ongoing training and feedback, even with interaction with the onboard devices. In other words, the results of installing an EDR system are enhanced when associated with training programs and feedback mechanisms. With respect to this last hypothesis, there are indications of the existence of a relation between the safety and consumption criteria. Nevertheless, in this study it was not possible to clearly define which safety aspects were directly responsible for the variation of the consumption aspects.

Both in the overall analysis and the individual analysis of the vehicles, the results showed improvement in the indicators during (C1), when the training and feedback process occurred, and tendency for backsliding in (C2) when these practices were discontinued. It is important to note that the results in (C2) still were better than those in (H), but the use of EDR technology alone did not lead to sustained improvement of the proposed criteria, particularly the safety criterion. This strengthens the hypothesis that training and monitoring of drivers are fundamental factors to improve the indicators related to operation, safety and consumption.

This conclusion corroborates the results of studies by Montiel et al. (2012), Mensing et al. (2014), Alvarez et al. (2014), Staubach et al. (2014), Duarte et al. (2013), Strömberg and Karlsson (2013a), Rutty et al. (2013) and Villeta et al. (2012), all of whom argue that driver behavior is a determining factor to reduce risk of accidents, increase productive vehicle operating times, and mainly to decrease fuel consumption and hence CO_2 emissions.

Despite the large volume of data collected and the broad scope of the criteria analyzed regarding the Brazilian trucking company, this study has some limitations related to the sample size, preventing making wider inferences from the results obtained regarding roadway transportation in general.

Therefore, in future studies we intend to apply other statistical techniques to analyze the data, expand the sample and the monitoring process, as well as propose the development and application of a cycle of training and feedback for drivers, adapted to Brazilian reality, based on Directive EC 59/2003 from the European Parliament and Council of the European Union, on the initial qualification and periodic training of professional drivers.

Another aspect for future study is whether a relationship exists between fuel consumption and the safety indicators, including analysis of the time of operating vehicles in various engine rotation ranges.

5. ANALYSIS OF THE INFLUENCE OF TRAINING AND FEEDBACK BASED ON EVENT DATA RECORDER INFORMATION TO IMPROVE SAFETY, OPERATIONAL AND ECONOMIC PERFORMANCE OF ROAD FREIGHT TRANSPORT IN BRAZIL

Abstract:

Road transport is the principal means of transporting freight and passengers in most developing countries, but several factors, both alone and in conjunction, contribute to increased inefficiency, risk and instability in the sector. The main factors are related to the high number of accidents, structural precariousness, fleet obsolescence, low-skilled drivers and high rates of greenhouse gas emissions. This paper evaluates the influence of implementing a training and feedback procedure associated with event data recorder (EDR) systems for the promotion of better behavior among professional drivers based on safety, operation and economy criteria. The analyses are based on interventions that were carried out during four monitoring phases using data generated by vehicles collected over 13 months of research. The data were converted into indicators and evaluated individually against the criteria and through data envelopment analysis (DEA). The analyses led to the conclusions that the use of EDR systems had positive impacts on all three of the criteria under analysis, and that safety levels can be increased without having to reduce productivity or increase fuel consumption. However, the safety criterion was more sensitive to the association between the technology and training process applied, leading to significant reductions in the indicators analyzed. The study contributes to the association between the methods of analysis and the adoption of specific indicators derived from time variables, leading to the conclusion that the use of EDR systems associated with management training and monitoring procedures can improve economic and operational results in road freight transport (RFT). Furthermore, using the trip data as a structural basis for the training and feedback proved to be very promising for the reduction of unsafe behavior to avoid road accidents.

Keywords: *road safety; event data recorder; drive behavior; training procedure; feedback; consumption reduction; operation behavior; data envelopment analysis*

5.1 Introduction

In Brazil, road transport represents 61% of transport volume. This creates an imbalance due to the excess supply of road transport, which favors unfair competition with other modes of transport and limits the emergence of a scale that would justify investments in transport segments with higher fixed costs Wanke (2010). According to Fleury, P. F. Figueiredo, K. F. Wanke (2003), this fact generates a vicious circle in which the prices paid by shippers barely remunerate the costs of carriers, causing narrow profit margins that contribute to lower maintenance rates and slower fleet renewals (Rocha et al. 2011).

Data from the National Registry of Road Transport of Goods (RNTRC) and (ANTT 2017) show that in the current road transport of cargo, 85.6% of vehicles have an average age of 13.5 years, meaning there is a high rate of obsolescence (DENATRAN 2016), (ANTT 2017). The association of this factor with the precariousness of preventive and corrective maintenance means that there is a higher risk of accidents and a lower energy efficiency in road transport, which can lead to reduced productivity.

Additionally, road freight transport (RFT) operates with precarious infrastructure, considering that only 13.6% of the 1,563,447 km of roads in the country are paved (CNT 2016a). This increases greenhouse gas (GHG) emissions (MMA 2013) and reduces energy efficiency Dernir, Bektaş, and Laporte (2014). The most serious problem is related to accidents on Brazilian roads. According to data from the Seguradora Líder statistical bulletin, 37,492 deaths, 263,923 cases of permanent disability and 53,823 cases of reimbursement of medical expenses Líder (2016) were recorded as a result of traffic accidents between January and November 2017.

Data published in Oka (2011) indicate that the total cost of traffic accidents on Brazilian roads has been about USD 7.89 billion, which adjusted by the Hamonised Index of Consumer Price (HICP) to values of December 2017 reaches USD 12.69 billion. This amount corresponds to 0.63% of Brazilian GDP in 2017, and was higher than the government investment in road infrastructure and measures to mitigate factors generating accidents.

The problems identified above, combined with the importance of RFT for the economic development of the country, gives rise to discussions on how to increase the level of safety, reduce the cost of transport and improve the functioning of the trucking industry. Based on a study published in De Oliveira et al. (2019) that compared the influence of event data recorder (EDR) systems on driving patterns after the introduction of two short-term training sessions, it was perceived that the training process enhanced the results obtained.

Thus, this paper evaluates the results of applying a specific training procedure, developed by us, based on the data collected by the EDR systems, and evaluates the efficiency indices calculated from those data through data envelopment analysis (DEA) with respect to safety, operational and economic criteria during different monitoring phases.

In this context, we respond to the following questions: (1) Can the data collected by EDR systems be used as a basis for structuring training and feedback procedures aimed at reducing undesirable behavior? (2) Do driver training procedures and feedback from managers influence results? (3) On the basis of the variables collected, can indicators be defined that characterize the various criteria? (4) Which of the criteria evaluated are most sensitive to the training and feedback procedures?

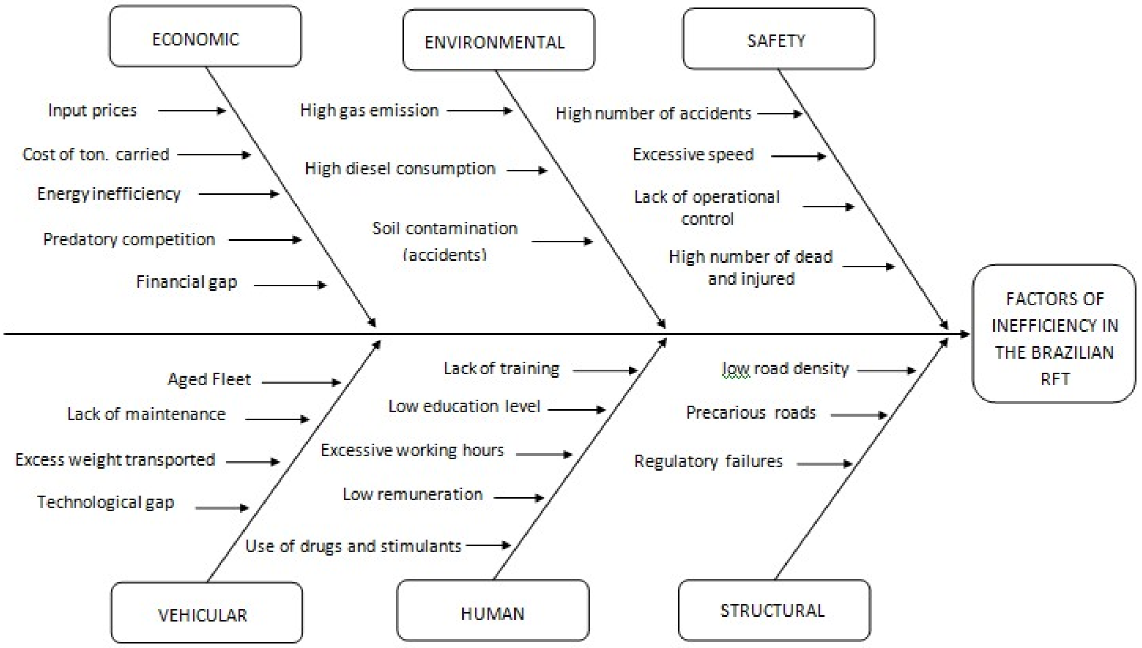
Thus, the objective of this phase of development is to analyze the evolution of driving behavior through efficiency indices calculated using DEA, incorporating criteria for the economy, operation and safety in road freight transport fleets and taking into account the applications of specific training and feedback procedures elaborated from the data obtained by the EDR systems in different monitoring phases.

5.2 Background

The economies of most developing countries are strongly dependent on the road transport of goods and passengers. Despite this dependence, RFT has many factors that increase inefficiency. To understand the causes of this inefficiency in Brazil, data presented by several authors were analyzed, including (Choi et al. 2020).

Based on these sources, it was possible to prepare an Ishikawa diagram (a cause and effect diagram) in which the problem (effect) was inefficiency in the Brazilian RFT, and the causes were the following factors: vehicular, human, economic, environmental, safety and infrastructure (Figure 19).

Figure 19: Diagram of factors related to road freight transport (RFT) inefficiency in Brazil.



Source: Authors

Among these factors, the most serious consequences are related to safety. According to ETSC (2009),Peden et al. (2004), the human factor is the main reason for the occurrence of accidents, and is present in 93% of cases. A previous study Knauth, D. R. (2012), Williamson et al. (2011), Botessini, G., Noradi (2008) found that a lack of training processes, drug use and a low remuneration of drivers contributed to the adoption of unsafe actions that consequently reduced safety levels. Furthermore, PIARC (2013) found relationships among vehicular, human and structural factors in the occurrence of accidents.

The safety level and economic factors are also affected by the infrastructure factor. In Brazil, according to the (CNT 2016b), 58.2% of the 211,468 km of paved roads are considered regular, bad or very bad, depending on their paving, signaling and/or geometry.

According to Bartholomeu, D. B. Caixeta (2008), operating on roads with better paving conditions allows a reduction of up to 7.8% in fuel consumption and 2.8% in travel time. Also in relation to roads, in the world competitiveness ranking, comprehensive and efficient infrastructure ensure the proper functioning of a country’s economy WEF (2017). One of the main aspects cited by the study was quality of roads, and in this sense, Brazil was ranked 111th out of the 138 countries evaluated.

Regarding energy efficiency, the main problems arise as a result of the use of obsolete vehicles, with the average age of the fleet being 13.6 years (DENATRAN 2016). These vehicles operate with less efficiency and more pollution being emitted from their engines. In this respect, the Brazilian fleet on average operates with engines at stage P2 of the Program to Control Air Pollution by Automotive Vehicles (Proconve), which is equivalent to Euro 0, while current engines in Europe operate at P7 (Euro 5) or higher. This an 87% increase in CO_2 emissions, an 81% increase in HC emissions and an 86% increase in NO_x emissions (CNT 2012).

In relation to risk reduction, some actions and tools such as safety devices and integrated technologies have a good capacity to mitigate both the probability and severity of accidents in vehicles. The study in WHO (2011a) identifies five pillars that can increase safety, with the third being the need to promote the development of safe vehicles through the implementation of technologies that are active, passive or that combine the two. In this context, passive technologies aim to reduce the severity of injuries (e.g., airbags, seat belts, bumpers), while active technologies have the function of preventing accidents (e.g., EDR, electronic stability control, intelligent speed adapters) (Morris et al. 2008).

The relationship between reducing the number of accidents and increasing the number of safety systems, combined with associated and integrated technologies, is described in Jiménez, Naranjo and Gómez (2015). It is highlighted in Chen and Chen (2011), (Emami, Dhillon, and Jenab (2012), that human errors are the main cause of road accidents, and that advanced driver assistance systems (ADAS) can reduce exposure to risk, since their main function is to support drivers through alerts, and in some cases take control in situations of eminent accident.

A large number of integrated technologies that have enabled the collection of relevant data on both safety and driving behavior are discussed in Roetting (2003), NHTSA (2013b). Four active safety technologies (forward collision warning, lane departure warning, side view assist and adaptive headlights) are evaluated in Jermakian (2011), which states that the combined use of these technologies could prevent or mitigate 1,866,000 collisions per year, including 149,000 serious and moderate accidents and 10,238 deaths on US roads. Twenty-one safety technologies applied to road vehicles were assessed for their cost–benefit ratio (CBR) (COWI 2006).

The report analyzed the impact of these technologies on reducing the number of occurrences and the degree of severity of accidents, and event data recorder (EDR) systems were ranked as the most promising technology by which to mitigate and minimize the factors associated with primary accident risks, justifying the investment required for their implementation.

EDR systems normally comprise an electronic control unit (ECU) that incorporates an Electrically-Erasable Programmable Read-Only Memory (EEPROM) , with the objective of continuously recording parameters measured and recorded by the sensors and systems of the vehicle (Rosenbluth 2013). These technologies are commonly known as “black boxes”, whose function is to capture all the electronic signals and electrical impulses generated by the various modules of the system, transforming these data into statistics via a proprietary platform Schimidt-Cotta (2009b),Gabler et al. (2004).

According to Wouters and Bos (2000b), EDR has a preventive character, with the capacity to reduce accidents by 20%, deaths by 5.5% and serious injuries by 3.5%. On the other hand, ETSC (2009) describes several functionalities of these systems that can be exploited in the driver training process to promote safety awareness and reduce accident rates with significant benefits to companies, drivers and society. In addition to the safety aspects, these systems can allow companies to improve their efficiency and reduce fuel consumption.

The importance of EDR systems in reducing travel time and fuel consumption and improving environmental quality is also highlighted in (Nowacki, G. Niedzicka, A. Krysiuk 2014). Feedback systems based on the Ecodriving concept, which evaluates variations in consumption and emissions that are generated during idling, is discussed in Caulfield et al. (2014), Yang and Rakha (2017), Lois et al. (2019).

The benefits of EDR systems in three areas (accident research, driver performance and vehicle maintenance) are evaluated in Westbrook, R. Sapper, D. Cusack, H. Staes (2009), which posits that fuel consumption profiles are clearly related to the driving profiles, and that technology allows correcting errors and undesirable behavior in order to reduce consumption.

Concerning vehicle maintenance, that study corroborated the capacity of these systems to provide continuous control and consequently identify defects and faults in fleets, generating relevant data for maintenance personnel that allow preventive interventions instead of corrective maintenance that could be more costly. The study also found that monitoring these variables over time has the potential to provide fleet performance indicators that can reduce costs, mitigate problems, prevent accidents and promote the improvement of environmental aspects.

According to De Oliveira et al. (2019), the introduction of a standardized training that combines existing common and standardized training methods (based, for example, on the concepts of efficient driving, vehicle maintenance and transport planning, among others described in EC59/2003 and EU 645/2018 (Parlamento Europeu 2003), (Parlamento Europeu 2018), can have a positive effect on safety, economic and operational criteria.

However, it is necessary to analyze the degree of efficiency of these criteria when analyzing drivers' behavioral patterns when involved in specific training processes where procedures and courses are structured based on individual characteristics. For this reason, we developed a procedure based on the individual data of drivers, allowing training procedures to be tailored to each driver's unique driving profile.

The final aim of the study is to check whether there is a positive change in driving behavior when using this procedure than when using a normal training program, and to check whether or not the isolated use of this system guarantees that behavioral changes are maintained over time.

5.3 Data Envelopment Analysis (DEA)

Data envelopment analysis (DEA) is a nonparametric method that was originally developed in Charnes, Cooper, and Rhodes (1978) to compare the performances of homogeneous production units (HPUs) using multiple inputs in the production of one or more outputs Charnes et al. (1985),Zhu (2009).

A decision-making unit (DMU) can represent any type of productive unit that has autonomy in a decision-making process, including schools, industries, banks, private companies, military bases and governments, among others Charnes et al. (1978), (Gökşen, Doğan, and Özkarabacak (2015).

The results presented by the DEA model permit the formation of a standard efficiency frontier that is based on standard efficiency indices considering the optimal ratios of outputs to inputs. One of the advantages of the DEA method is the possibility of using several inputs and outputs whose units may differ from one another without the results being modified Bastos et al. (2015). Another advantage is the possibility of considering outliers as a reference (benchmark) to be studied according to the other DMUs Cooper, Seiford, and Zhu (2011). It is mentioned in Acosta (2008) that one of the greatest advantages of the DEA method is the flexibility of using weighting parameters, since this allows the identification of inefficient DMUs.

Among the disadvantages of DEA are the sensitivity of the results to the inclusion or exclusion of certain variables (inputs and/or outputs), as well as the inability to consider the differences between the external environments of the DMUs, which can result in a false result affecting the management capacity of the decision-makers (Cooper et al. 2011).

To evaluate the performances of DMUs, the DEA method utilizes two types of models: classic and advanced. The classic model is composed of a constant return to scale (CRS) model and a variable return to scale (VRS) model (Cooper, Seiford, and Tone 2007).

The Charnes, Cooper and Rhodes (CCR) model, based on the CRS model type, considers that the amount of resources (inputs) used is proportional to the amount of outputs produced (Charnes et al. 1978). Graphically presented, the area of this model includes the values of the DMU variables that present the optimal relationships between outputs and inputs, as shown by Equations (1–4) (Cooper, Seiford, and Joe 2010).

$$\max z = \sum_{k=1}^{m} u_k y_{kj}$$

Subject to

$$\sum_{k=1}^{m} u_k y_{kj} - \sum_{k=1}^{m} v_k x_{kj} \leq 0$$

$$\sum_{k=1}^{m} v_k x_{ko} = 1$$

$$u_k, v_k > 0$$

$$k = 1, \dots, m$$

where x_{kj} and y_{kj} represent input and output data, respectively, for DMU_k; and u_k and v_k represent the weights associated with the inputs and outputs, respectively.

The Banker, Charnes and Cooper (BCC) model, based on the VRS model type, was developed from the CCR model, in which the axiom of proportionality is replaced by the axiom of convexity (u_*), as shown in Equations (5 – 8) (primal) and Equations (9 **Erro! Fonte de referência não encontrada.**– 12) (dual) (Banker, Charnes, and Cooper 1984),(Mello et al. 2005).

$$\min h_o$$

Subject to

$$h_o x_{io} \sum_{k=1}^{m} x_{ik} \lambda_k \geq 0, \forall i$$

$$-y_{jo} + \sum_{k=1}^{m} y_{jk}\lambda_k \geq 0, \forall j$$

$$\sum_{k=1}^{m} \lambda_k = 1$$

$$\lambda_k \geq 0, \forall k$$

$$\min Eff_o = \sum_{j=1}^{s} u_j y_{jo} + u_*$$

Subject to

$$\sum_{i=1}^{r} v_i\, x_{io} = 0$$

$$-\sum_{i=1}^{r} v_i x_{ik} + \sum_{j=1}^{s} u_j y_{jk} + u_* \leq 0, \forall k$$

$$v_i, u_j \geq 0, u_* \in \Re$$

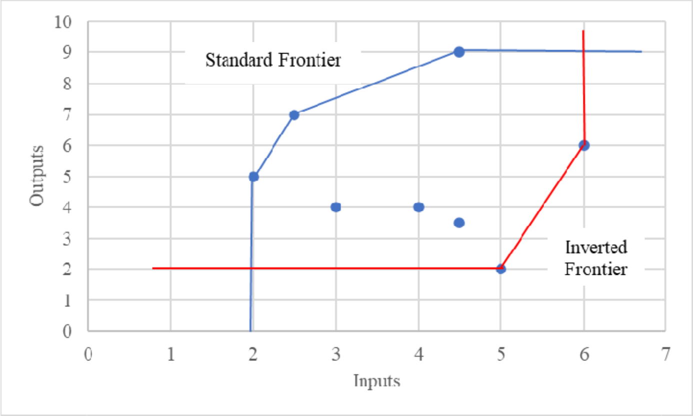
Both models (CCR and BCC) have envelope and multiplier versions. The results presented by the multipliers are the weights assigned by the DEA model and the efficiency indices, which allow the formation of the efficiency frontier in the graph. The envelope determines the objectives, gaps and benchmarks of the inefficient management mechanisms, which determine to what extent the inefficient management mechanisms should increase (if they are production-oriented) or decrease (if the orientation is an input) the values of the problem's variables (Banker et al. 1984).

Classical DEA models can be input- or output-oriented. Output orientation occurs when the maximum number of outputs is desired without changing the amount of inputs used. The objective of this orientation is to identify the production potential of the DMUs. On the other hand, input orientation occurs when resources (inputs) need to be minimized without changing the outputs. In this orientation, the DEA model allows the free capacity of the DMUs to be identified (Cooper et al. 2011).

The DEA method is benevolent in its evaluation of the DMUs, considering the variables that most favor the calculation of efficiency and assigning greater weights to these variables and lower ones to unfavorable variables (Sexton, Silkman, and Hogan 1986).

As a result of this benevolence, it is possible for a high number of DMUs to be considered efficient, which can affect the analysis. To overcome this drawback, the evaluation of the inverted frontier allows increased discrimination of efficient DMUs, since they should be in the standard efficiency frontier, which is located as far as possible from the inverted border. DMUs that integrate the two frontiers (standard and inverted) are falsely efficient, as they are just as efficient as they are inefficient. Figure 20 shows the standard and inverted limits of the BCC in the DEA model.

Figure 20: Standard and inverted frontiers of the data envelopment analysis (DEA) BCC model.



Source: (Garcia et al. 2019)

The composite efficiency index ($E_k^{Composite}$) used to increase the discrimination of efficient DMUs is calculated using Equation (13) (Entani, Maeda, and Tanaka 2002; Garcia et al. 2019; Melo et al. 2018).

$$E_k^{Composite} = \frac{E_k^{Standard} + (1 - E_k^{Inverted})}{2}$$

where $E_k^{Standard}$ is the standard efficiency of the kth DMU and $E_k^{Inverted}$ is the inverted efficiency of the kth DMU.

The $E_k^{Composite}$ results range from 0 to 1. The normalized composite efficiency index ($E_k^{Composite*}$) is a way of prioritizing $E_k^{Composite}$, the ratio of each $E_k^{Composite}$ value to the highest $E_k^{Composite}$ of all DMUs (Max [$E_k^{Composite}$]), as shown in Equation (14) (Entani et al. 2002).

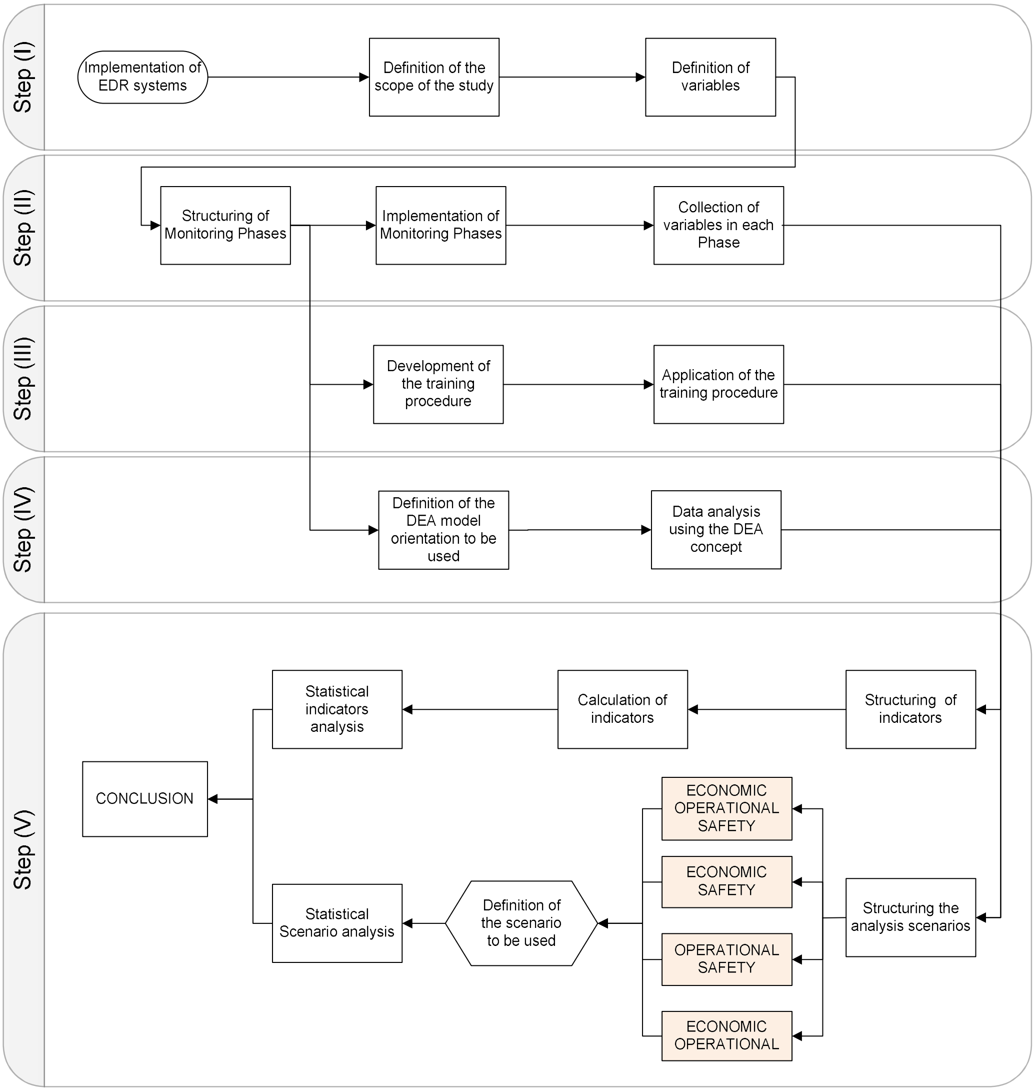
$$E_k^{Composite*} = \frac{E_k^{Composite}}{\text{Max }[E_k^{Composite}]}$$

5.4 Materials and Methods

The procedure presented used a sample of 22 heavy trucks from a transport company. The trucks were monitored using EDR systems over a period of 13 months, with each driver permanently assigned to a truck, so that the observations regarding the behavior of vehicles pertained to the respective drivers.

The system used was equipped with the following modules: a global positioning system (GPS), a driver identification card, a general packet radio service (GPRS) and a telemetry system. These modules allowed a set of variables linked to the driving habits of the drivers to be obtained, which were then converted into indicators based on economic, operational and safety criteria and submitted to DEA in four different scenarios, as shown in Figure 21.

Figure 21: Flowchart of the experiment.



Source: Author

5.4.1 Step I—Implementation of the event data recording (EDR) system

This step corresponded to the preparation and implementation of the EDR systems, including the definition of the study objective and the variables used as parameters for the analysis (Table 22).

Table 22: Variables collected by the event data recorder (EDR) system.

Variables	**Description**
Number of speeding periods	Number of times the vehicle exceeds the speed limit
Number of severe decelerations	Number of times deceleration of more than 11 km/h per second occurs
Number of periods of excess engine revolutions per minute (RPM)	Number of times the engine is revved above the set limit
Initial odometer reading	Initial mileage of each trip
Final odometer reading	Final mileage of each trip
Excessive speed on dry road	Maximum speed reached except in rainy conditions
Excessive speed on wet road	Maximum speed reached in rainy conditions.
Idle time	Total idling time (engine on at a speed of zero)
Time in movement	Total time operated at a speed other than zero
Time speeding	Total time of vehicle exceeding the speed limit
(%) of driving in the engine economy range	Percentage of driving time in the economy range (optimal consumption)

Source: Author

5.4.2 Step II—Definition of the monitoring and data collection stages

For the development of this stage, the structuring and implementation of monitoring phases was proposed based on the model applied in Strömberg and Karlsson (2013a), following parameters to allow the evaluation of natural driving habits and their evolution based on the variables collected and in accordance with the interventions proposed in the monitoring phases.

Hidden Monitoring (Hidden)—The objective of this phase was to evaluate the driving pattern of each driver without any type of intervention by researchers, managers or technology (e.g., over-revving alert). Thus, drivers did not accompany the process of installing the systems, and all sound signals and alerts were muted so that the system did not interact with them.

Conscious Monitoring 1 (C1)—In this phase, the EDR systems continued to monitor the driving pattern of the vehicles. However, all signals and alerts provided by the system were enabled and the technology began to interact with the drivers. In addition, drivers received specific training developed for this study related to knowledge of the use of the technology, safety aspects, operating efficiency and fuel savings that were based on the aspects contained in ISO 39001 and CSEAA (Sánchez-Toledo Ledesma and Baraza Sánchez 2015), (UPM 2010).

In this specific phase, the managers began to analyze the data and disseminate regular information to drivers on their behavior. The objective of this phase was mainly to evaluate the impact on the variation of the data after enabling the alerts emitted by the EDR, and evaluate the results of the training procedure carried out by the managers (Af Wåhlberg 2006).

Conscious Monitoring 2 (C2)—In this phase, the data collection continued and the alerts were kept active, but there was no training or feedback offered by the managers. The objective of this step was to evaluate if the criteria related to economy, safety and operation would maintain the trend observed in C1, or if they would return to the levels observed in the Hidden Monitoring phase. During this phase, the intent was to evaluate the impacts related to the isolated use of the technology and compare them with the applications with associated training and feedback.

Conscious Monitoring 3 (C3)—Based on the analysis of the data obtained in the previous phases, the alerts issued by the system were maintained and the procedure involving continuous training and periodic feedback was incorporated into the fleet management process as a way of maintaining the improvement process.

5.4.3 Step III—Development and implementation of the training procedure

For this stage, a training procedure for drivers and managers was developed and applied that was aimed at improving skills and attitudes in relation to economic, safety and operational criteria, based on the studies of (Crackel and Small 2010; Huang and Ford 2012; Johansson 2012; Murphy and Leach 2013; Sullman, Dorn, and Niemi 2015; Topolšek, Babić, and Fiolić 2019) Thus, the training procedure focused on aspects related to four areas:

operational safety, knowledge of the use of technologies, practical application of skills and perception of aspects of fatigue and stress.

All the drivers went through all the 30-h training sessions. Associated with the training procedure during C1 and C3, the drivers began to receive feedback from the fleet managers at the end of each trip with the aim of increasing operational efficiency, mainly in relation to economy and safety Toledo, Musicant, and Lotan (2008),Gonder, Earleywine, and Sparks (2012).

According to Almqvist (2013), investment in systematic developments for road safety such as training and control can improve profitability. Thus, the basis for the training process was structured in accordance with the requirements established by ISO 39001 Sánchez-Toledo Ledesma and Baraza Sánchez (2015), Johansson (2012) and CSEAA (UPM 2010), oriented mainly towards the evaluation of aspects related to safety.

5.4.4 Step IV—Application of data envelopment analysis (DEA)

For the analysis of data using the DEA method, we chose to use the BCC model because it considers the production scales in the efficiency calculation, which allows the technical efficiency of the vehicles (DMUs) to be identified. This is important, since the objective is to analyze the driving habits in consideration of the interventions made in the monitoring phases. In this way, the orientation to results became more adequate, since the objective was to maximize the results obtained based on the indicators related to safety and operational criteria (outputs).

The behavior of the DMUs was analyzed based on standard, inverted, composite and standardized composite efficiency indices in order to increase the discrimination of the DMUs located in the efficiency frontier. However, the results presented here are based on the composite values, since their calculation considers the standard and inverted efficiencies. The graphical analysis of Composite allowed us to observe the behavior of the average efficiency rates of the best and worst management practices (standard and inverted efficiency) of each vehicle.

5.4.5 Step V—Development of scenarios, analysis and results

To assess the effect of the interventions, the analysis focused on statistical variations in driving behavior based on the indicators described in Table 23.

Table 23: Distribution of indicators according to criteria.

Criteria	Indicators	Relevance
Safety	Number of speeding events/1000 km	Evaluates the number of times the speed limit was exceeded Analyzes risk acceptance
	(%) of speeding time	Evaluates the percentage of time above the speed limit as a function of total driving time and analyzes the exposure to risk
Economy	Consumption (l) /km	Assesses consumption according to the distance traveled
	Idling / time with engine running (%)	Total idling time (engine on at a speed of zero) as a function of time with engine running.
Operation	(%) of operation in the economy range (Eco Zone)	Evaluates performance according to the optimal use of the truck within the best performance zone

Source: Author

For the safety criterion, the indicators considered were the number of speeding events and the percentage of speeding time. The first of these was the number of times the maximum speed set was exceeded for more than 3 s. This indicator shows the driver's acceptance of the speed limits imposed by legislation and/or by the company.

The second indicator referred to the percentage of driving time above the speed limit, and was represented by the total driving time above the speed limits divided by the time the vehicle was moving. This indicator represents the exposure to the risk of driving too fast.

For the evaluation of the economic criterion, an analysis of the variation of fuel consumption as a function of distance traveled and the percentage of idle time as a function of engine running time was considered with the maintenance of weight, route, and driver characteristics.

For the operational criterion, the indicator of percentage time in the economy range was considered in relation to the total time that the engine remained in operation. The economy range is determined by the manufacturer and aims to inform the driver about the most efficient mode of operation. Operation in this zone allows power and torque optimization, and hence fuel consumption optimization.

A second analysis was also proposed based on the results obtained from the data processing through the DEA method and the scenarios involving these criteria. The analysis was subdivided into individualized analyses, which included the behavior of each vehicle and a global analysis, which included the response of the fleet according to the criteria of safety, operation and economy. From the analysis of the indicators, it was possible to understand their influence, as well as to define their relevance when performing an analysis that integrated all the criteria.

The analysis focused on the structuring of four scenarios based on the composite values calculated with the DEA tool. The comparative scenarios included all the criteria under investigation (economic, operational and safety), as presented in Table 24.

Table 24: Scenarios considered.

Scenario	Orientation	Variables	Criteria
1	Input	Fuel consumption (l)	Economic
		(%) Idling / time with engine running	
	Output	(%) of operation in the economy range (Eco Zone)	Operational
		(%) of speeding time Number of speeding events	Safety
2	Input	Fuel consumption (l)	Economic
		(%) Idling / time with engine running	
	Output	(%) of speeding time Number of speeding events	Safety
3	Input	Unitary	Unitary
	Output	(%) of operation in the economy range (Eco Zone)	Operational
		(%) of speeding time Number of speeding events	Safety
4	Input	Fuel consumption (l)	Economic
		(%) Idling / time with engine running	
	Output	(%) of operation in the economy range (Eco Zone)	Operational

Author: Source

The development and analysis of the four scenarios made it possible to verify the variations in the relative efficiency indices of the DMUs based on a global analysis of the criteria (Scenario 1) and a paired analysis (Scenarios 2–4). Based on the analyses of all scenarios, we decided to use Scenario 1, since it covered all three criteria, making it possible to establish an overall view of the indicators and their correlation.

5.5 Results

The analyses proposed in this paper focus on verifying the variations in behavior of the indicators according to the interventions applied throughout the monitoring phases. It is important to note that the hidden monitoring phase was determined as a comparative reference, since there was no external intervention in this phase, allowing us to infer that the data collected by the EDR system represented the natural driving behavior.

At the end of this monitoring period, three conscious monitoring phases (C1–3) were initiated in which all audio and visual signals emitted by the system were enabled. In C1 and C3, all drivers underwent the training procedure, and began receiving feedback from managers at the end of each trip based on an analysis of data collected by the system. These actions ensured that all participants were aligned with the objectives of the training procedure and the implementation of the technology.

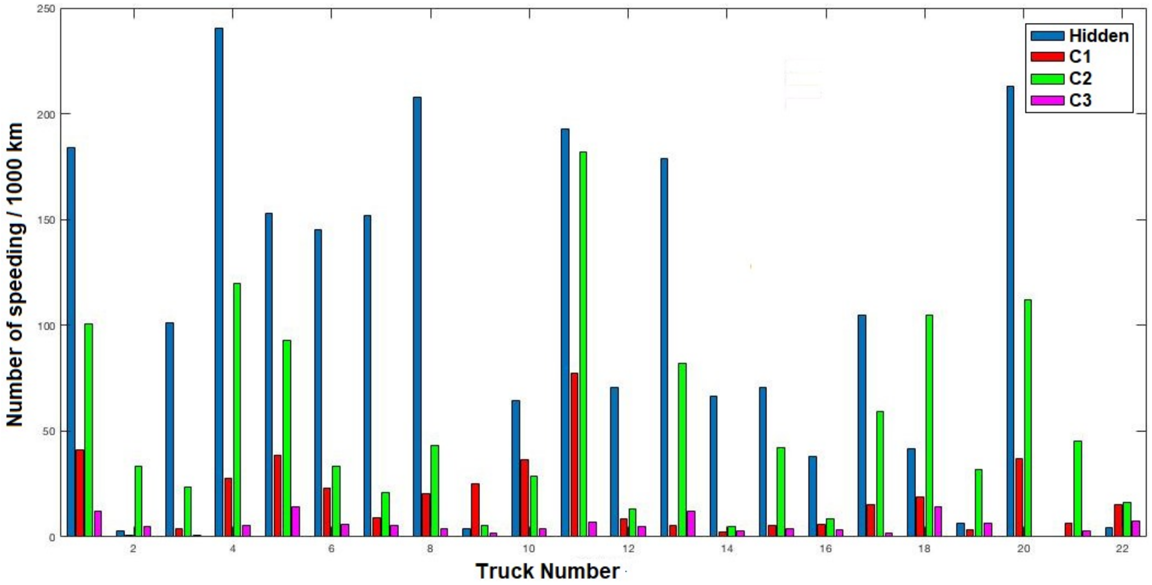
The only difference in the phases of conscious monitoring was that in C2 there was an interruption in the training procedure to assess whether there was any variation in behavior due to the isolated use of the technology. This revealed whether the training procedure and feedback had improved the results.

5.5.1. Analysis of Indicators Based on Individual and Aggregated Driving Behavior Patterns

The analysis of the indicators made it possible to evaluate the behavior of the drivers according to the criteria of safety, operation and economy throughout the monitoring phases. However, it was also possible to make a general analysis of the fleet.

Regarding the safety criterion, Figure 22 shows the variation in the behavior of the vehicles in relation to the monitoring phases. It can be seen that only three vehicles performed worse than during the hidden monitoring; that is, 86.4% of the vehicles observed showed improvement in this indicator. In particular, the number of speeding events in the fleet went from 2243 events per 1000 km traveled during the hidden monitoring to 126 events per 1000 km traveled during C3, which is a significant reduction in the level of risk acceptance. Figure 23 presents the global percentage variation of this indicator in the conscious monitoring phases in relation to the hidden monitoring phase.

Figure 22: Number of speeding events per 1000 km traveled. C1–3: conscious monitoring phases 1–3.

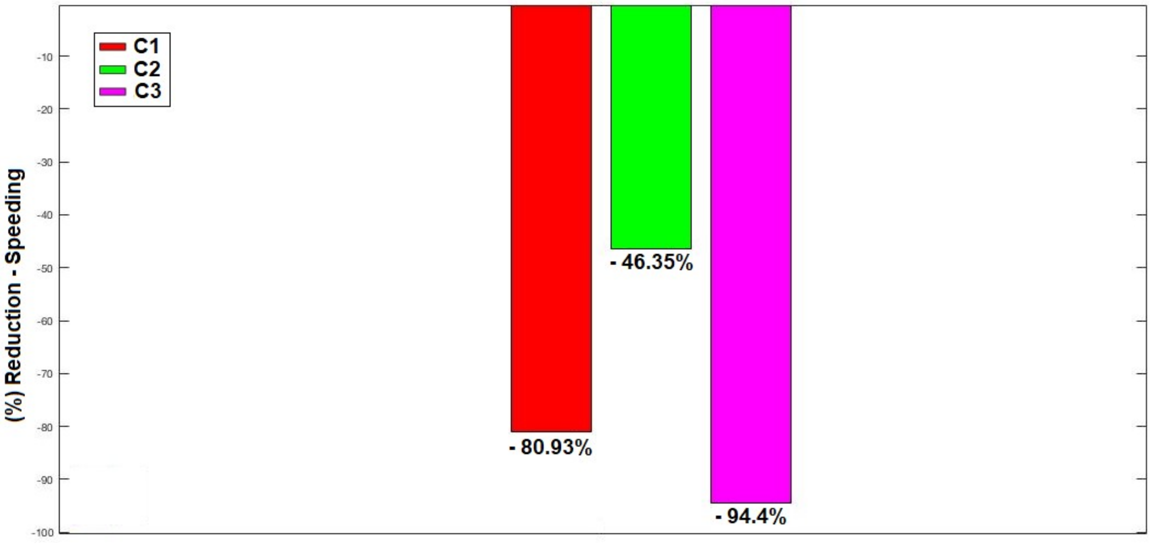


Source: Author

Another important conclusion about this indicator concerns the comparison between the conscious monitoring phases, where 95.5% of the vehicles performed worse during C2 than during C1 or C3. This supports the hypothesis that this training procedure and feedback on driver behavior are effective.

Furthermore, in relation to the safety criterion, the indicator concerning the percentage of speeding time as a function of total driving time was analyzed.

Figure 23: Reduction (%) of speeding. Base: hidden monitoring.

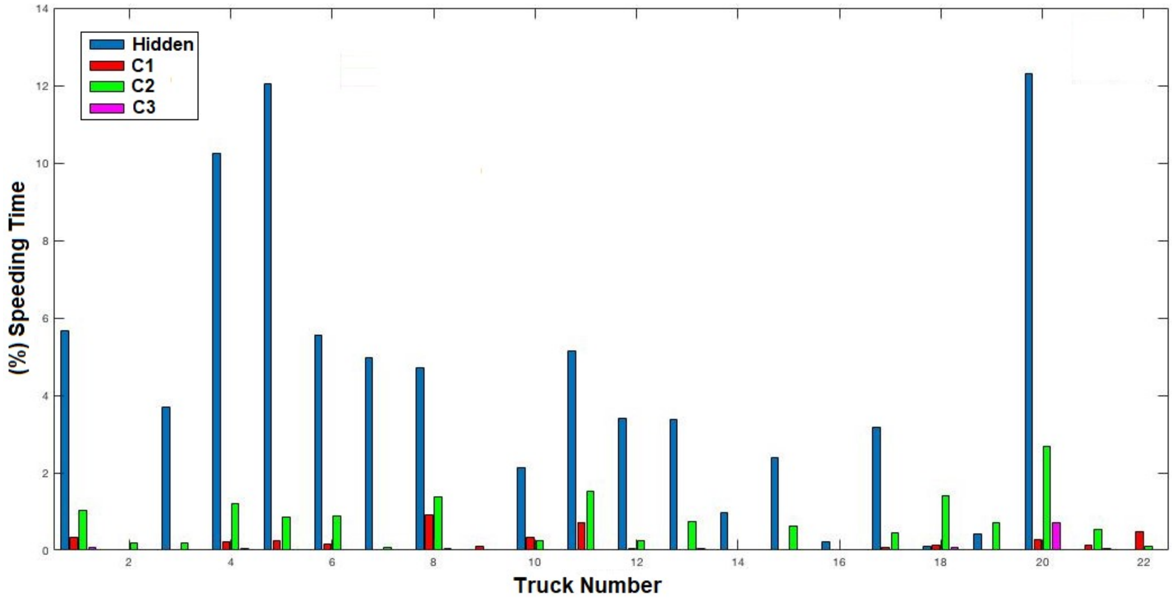


Source: Author

Figure 24 shows the individual behaviors of the vehicles, and it is possible to perceive a reduction in risk exposure by reducing the driving time above the speed limit during the monitoring phases, representing an increase in safety and a significant reduction in the risk of accidents. During the hidden monitoring, the vehicles remained above the speed limit on average 3.6% of the total driving time.

Based on the average speed and distance traveled, this means vehicles traveled above the speed limit for 5838 seconds on average per month. The interventions applied reduced the speeding time to 0.05% of the total driving time, which is equivalent to driving above the limit for 83 seconds on average per month.

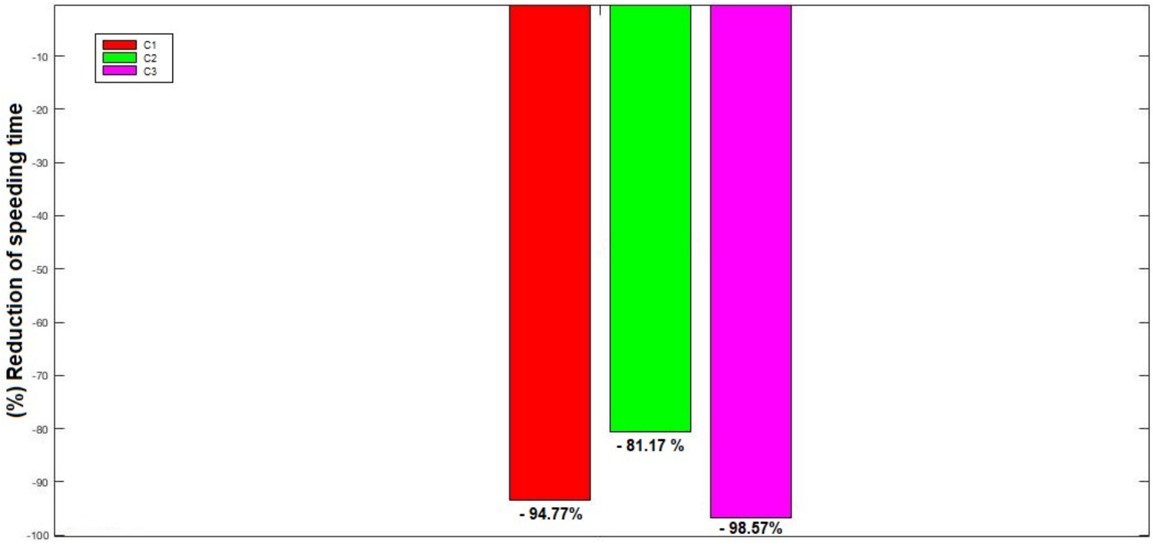
Figure **24**: Speeding time (%) as a function of total driving time.



Source: Author

Figure 25 shows a comparison of the reduction percentages obtained during the conscious monitoring phases in relation to the data obtained in the hidden monitoring phase.

Figure: 25 Reduction (%) of speeding time. Base: hidden monitoring.



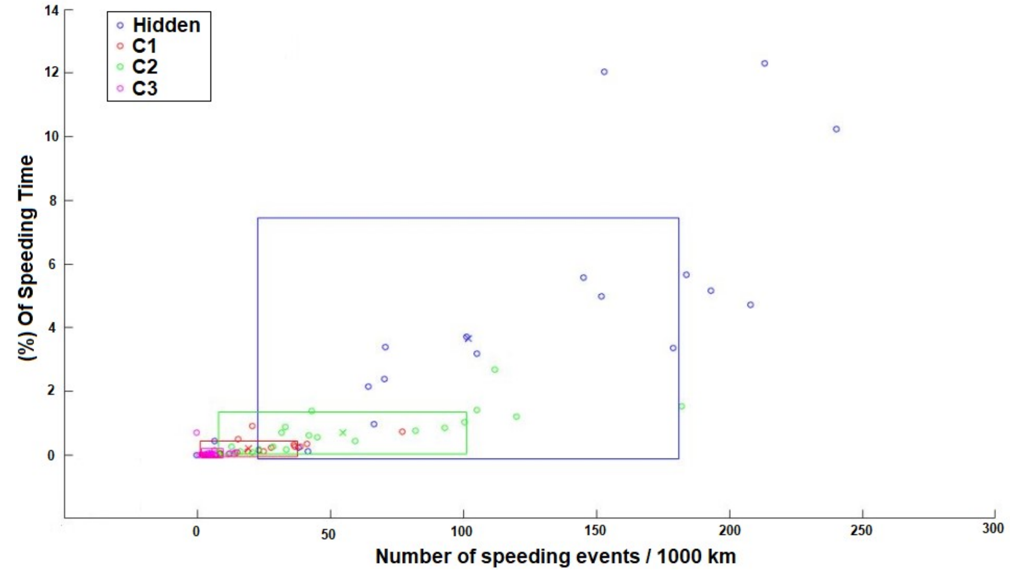
Source: Author

Through more extensive analysis of the criterion, we sought to relate driving behavior based on the dispersion of the points obtained in the two indicators, and it was possible to evaluate the evolution of driver behavior in relation to safety, as shown in Figures 26 and 27.

These figures ratify the trend of a reduction of the indicators and consequent standardization of behavior as a function of the monitoring phases based on the reduction of variance, dispersion and averages. These figures show that driving behavior was safer in the conscious monitoring phases than in the hidden monitoring phase, since both speed-related indicators declined.

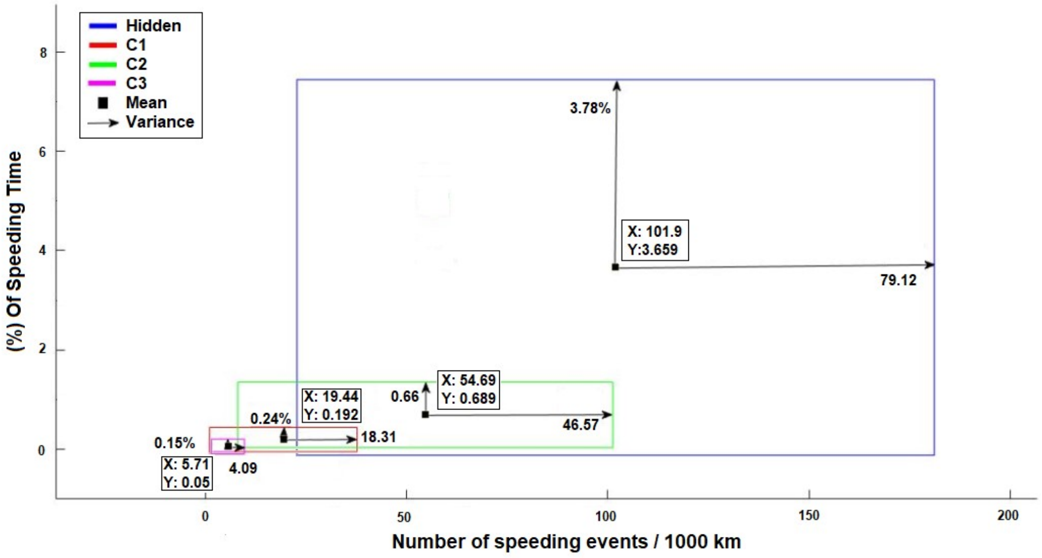
The best performance occurred during C1 and C3, where the training and feedback procedure was applied, and this reinforces the hypothesis that associated training, feedback and technologies produces better results than the isolated use of EDR systems.

Figure 26: Dispersion of vehicles according to safety indicators.



Source: Author

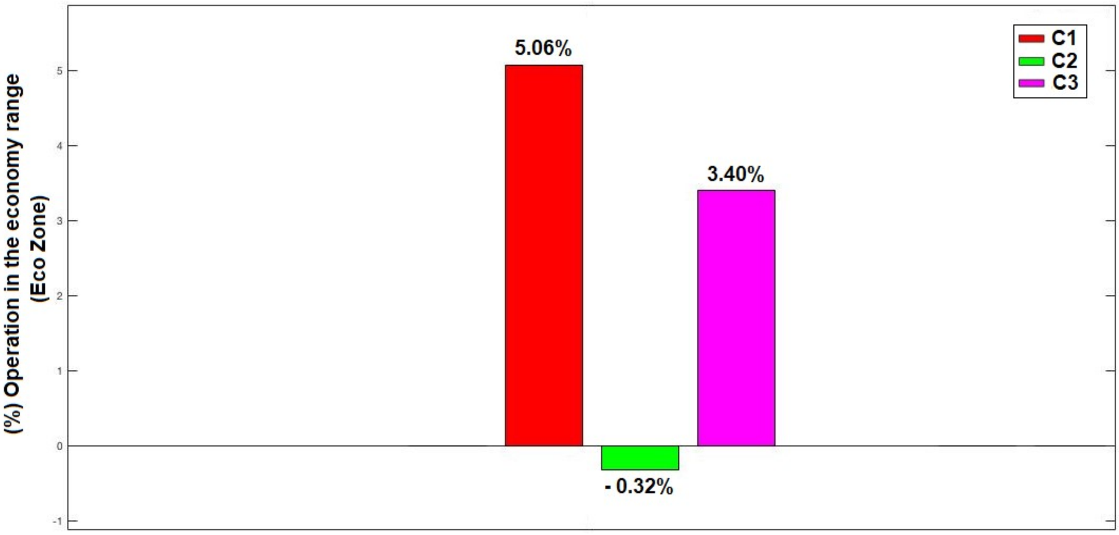
Figure 27: Behavior of variance and average as a function of safety indicators.



Source: Author

In relation to the operation criterion, the indicator of percentage of time in the economy zone was used, assuming that the higher the percentage of driving in this zone, the better the operational performance of the vehicle will be. Figure 28 presents the behavior of the vehicles throughout the monitoring phases, showing that this indicator was more sensitive to the monitoring phases in which there were complementary training and monitoring actions. Ten vehicles showed better performances, six remained the same and six showed worse results than those observed during the hidden monitoring.

Figure 28: Operational behavior in the economy zone. Base: hidden monitoring.



Source: Author

These results indicate improvements of 5.06% and 3.4% in the driving patterns of the vehicles in C1 and C3, respectively, compared to the hidden monitoring. Furthermore, during C2, there was a 0.32% worse result compared to the hidden monitoring, which can be explained by the absence of the training procedure and the provision of feedback, since the EDR system did not perform any real-time interaction with the driver such as audio warnings or visual alerts.

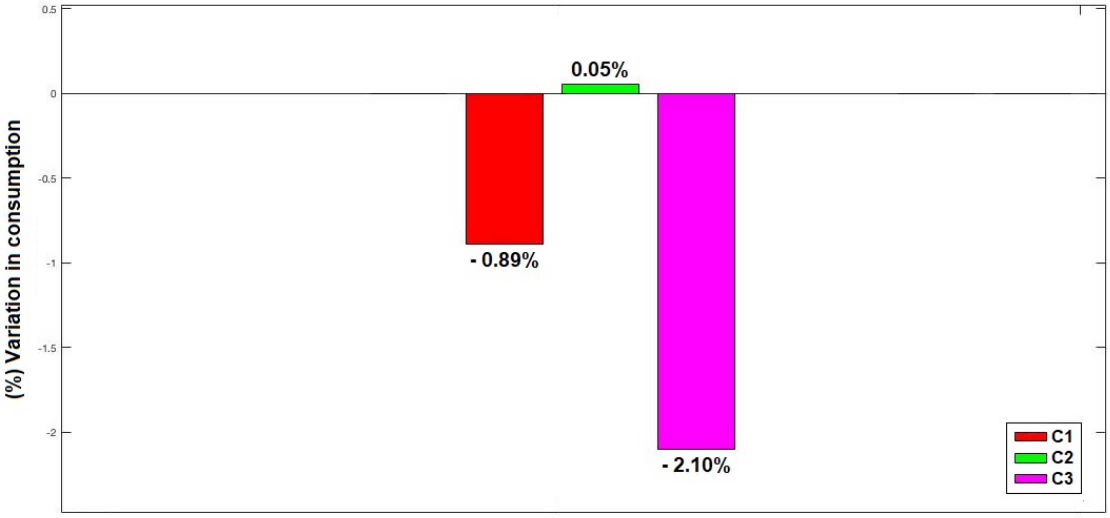
It is important to highlight the relevance of the analysis of this indicator, since during C1 and C3, the vehicles were driven for 61.06% and 60.09% of the total moving time, respectively, in the most efficient engine operating zone. This means that in addition to a reduction in fuel consumption, a decrease in greenhouse gas emissions was also achieved, along with an increase in the maintenance of moving parts (e.g., the engine, transmission and tires).

With regard to the economic criterion, only the fuel consumption indicator was analyzed, since variables such as weight carried, route and driver, among others, remained unchanged throughout the interventions, reducing the level of external factors linked to the variability of this indicator.

Regarding consumption behavior, throughout the monitoring phases, 59.1% of the vehicles showed a positive evolution and 22.7% remained practically stable, while 18.2% showed worse results. However, these latter vehicles were among those that presented higher consumption during the hidden monitoring.

Regarding an overall analysis of fuel consumption (Figure 29), behavior was similar to that observed for the indicator of percentage of time spent driving in the economy zone. Furthermore, although the reduction percentage seems small, when converted into cost and consumption based on the results of the hidden monitoring, a monthly reduction of 345 L of fuel among the fleet (or 15.7 l per vehicle) was achieved for C1, while 811 liters was saved among the fleet (or 36.9 l per vehicle) in the case of C3. The payback calculation reveals that the savings achieved during C3 could lead to an amortization of the investment in technology within approximately 36 months.

Figure 29: Overall fuel consumption behavior. Base: hidden monitoring.



Source: Author

5.5.2. Data Envelopment Analysis (DEA) Applied to Safety, Operational and Economic Criteria

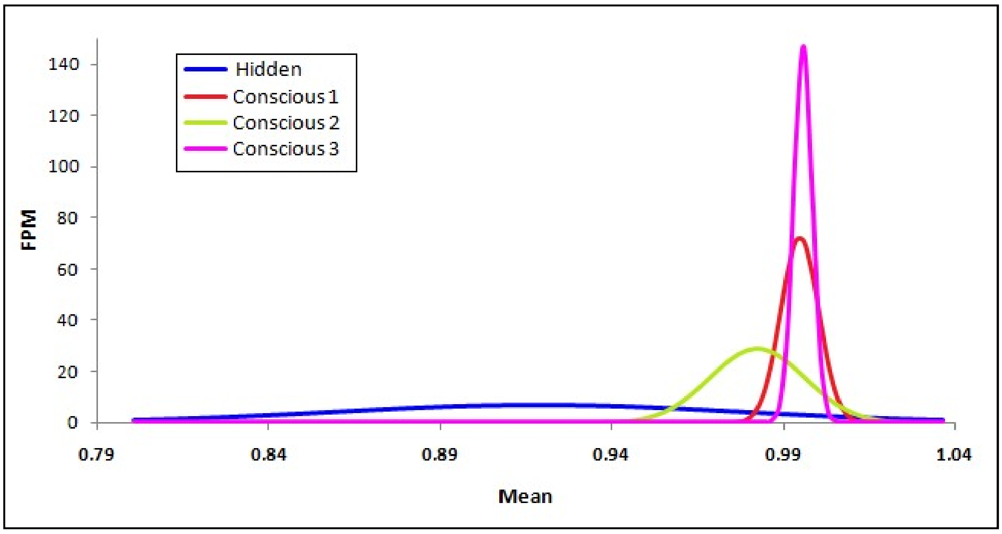
After analyzing the indicators, we performed a more in-depth analysis with the help of data envelopment analysis (DEA) tools, based on the variations of the indicators. It was possible to calculate the $E_k^{Composite*}$ for each vehicle in each monitoring phase, and thus possible to calculate the probability function, considering its distribution curves with a confidence interval of two standard deviations.

To verify the effectiveness of the interventions carried out in each of the monitoring phases, we assumed the null hypothesis (H_0) that all the means were the same and that there would be no difference in the observed means. We also assumed as an alternative hypothesis

(H_1) that there was a difference between the means and that these differences would be greater during the phases in which the interventions related to training and feedback occurred.

The distribution of the data in Figure 30 shows that a change in driving behavior occurred in relation to the hidden monitoring phase, with a reduction in the dispersion and increase of the mean and frequency. Based on the statistical analyses, Table 25 shows a statistical summary in relation to the monitoring phases, and Table 26 shows the analysis of variance, in which it can be seen that the *p*-value was less than 0.05, indicating the existence of a statistically significant difference between the average values in the monitoring phases.

Figure 30: Distribution of composite normalized according to the criteria of economy, safety and operation.



Source: Author

Table 25: Statistical summary of data from all monitoring phases.

Monitoring Phases	**Mean**	**Standard Deviation**	**Coefficient of Variation**	**Minimum**	**Maximum**	**Range**
Hidden	0.917836	0.060258	6.565%	0.7859	1.0	0.2141
C1	0.994414	0.005603	0.563%	0.9819	1.0	0.0181
C2	0.982509	0.014139	1.439%	0.9491	1.0	0.0509
C3	0.995541	0.002748	0.276%	0.9869	1.0	0.0131
Total	0.972575	0.044393	4.565%	0.7859	1.0	0.2141

Source: Author

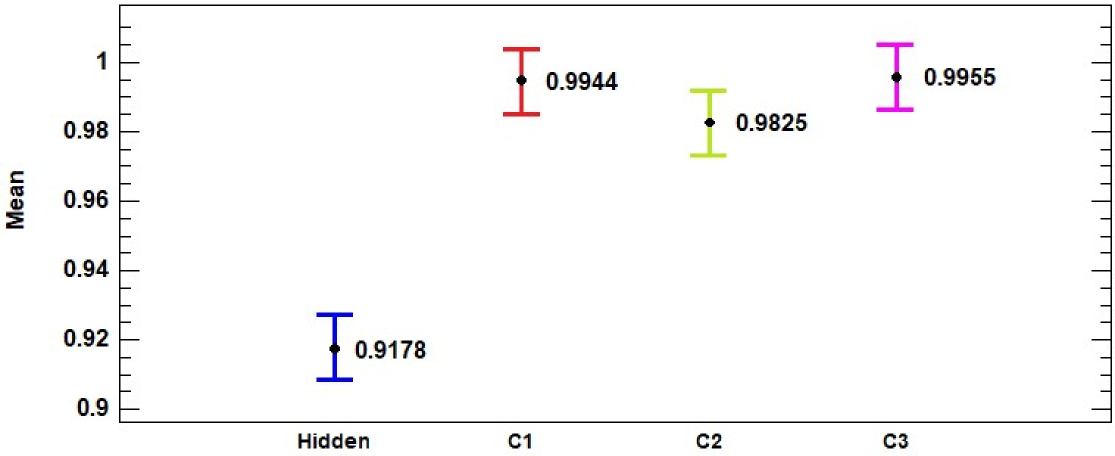
Table 26: Analysis of variance.

Source	Sum of Squares	Df	Squared Average	F-Ratio	p-Value
Between groups	0.090186	3	0.030062	31.07	0.0000
Within groups	0.081268	84	0.000967		
Total (Corr)	0.171454	87			

Source: Author

Figure 31 presents the results of a Fisher's statistical significance test, showing that the average of the data obtained in the hidden monitoring was different from the others monitoring phases, since there is no overlap between the two.

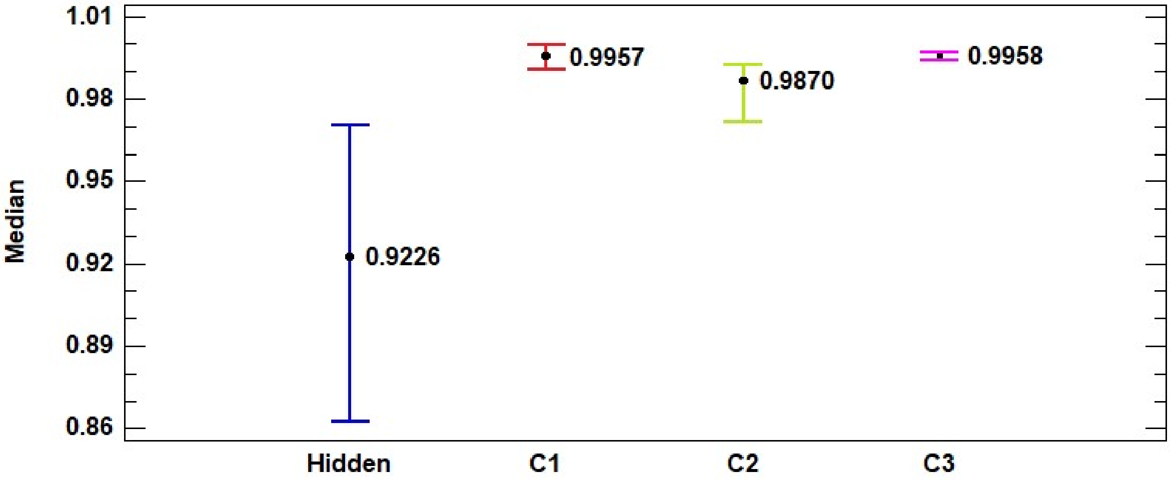
Figure 31: Mean 95% Fisher's least significant difference (LSD).



Source: Author

These observations are reinforced by the analysis in Figure 32, which shows the behavior of the medians associated with a Mood's statistical test, with a *p*-value of 7.40725 e^{-10} found for a chi-square test of 45.4545. Thus, we can affirm that the medians presented pairwise statistical differences.

Figure: 32: Median with 95% confidence.



Source: Author

The statistical tests applied to composite normalized data obtained by the DEA indicate a change in driver behavior from the moment the technology was enabled and the training and feedback procedure applied. In other words, there was a positive evolution in the criteria resulting from the application of conscious monitoring.

Based on this result, it is important to verify whether the initial hypothesis that the association of technology with the training and feedback procedures would produce better results in relation to the isolated use of EDR systems is valid.

To this end, we performed an analysis using only data from the conscious monitoring phases. It can be seen in Tables 27 and 28 that the *p*-value was lower than 0.05, indicating a statistically significant difference between the average values in the conscious monitoring phases.

Table 27: Statistical summary of data from conscious monitoring phases.

Monitoring Phases	Mean	Standard Deviation	Coefficient of Variation	Minimum	Maximum	Range
C1	0.99441	0.00560	0.5634%	0.9819	1.0	0.0181
C2	0.98251	0.01414	1.4390%	0.9491	1.0	0.0509
C3	0.99554	0.00275	0.2761%	0.9869	1.0	0.0131
Total	0.99082	0.01060	1.0703%	0.9491	1.0	0.0509

Source: Author

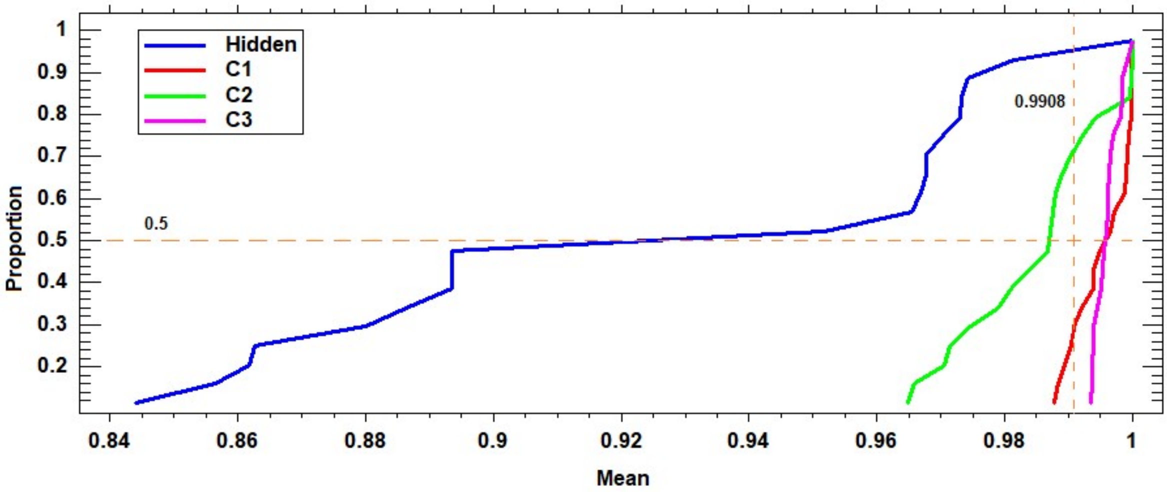
Table 28: Analysis of variance of conscious monitoring phases.

Source	Sum of Squares	Df	Squared Average	F-Ratio	p-Value
Between groups	0.00230	2	0.00115	14.41	0.0000
Within groups	0.00502	63	0.00008		
Total (Corr)	0.00731	65			

Source: Author

Analyzing the behavior of the data distribution in relation to proportionality, as presented in Figure 33, similarity can be observed in the behavior of the data referring to C1 and C3, where more than 80% of the vehicles obtained results above the population average. In relation to conscious monitoring, only 26% of the vehicles remained above this level, which shows that there was standardization of behavior with a tendency toward better results and an improvement of the observed criteria.

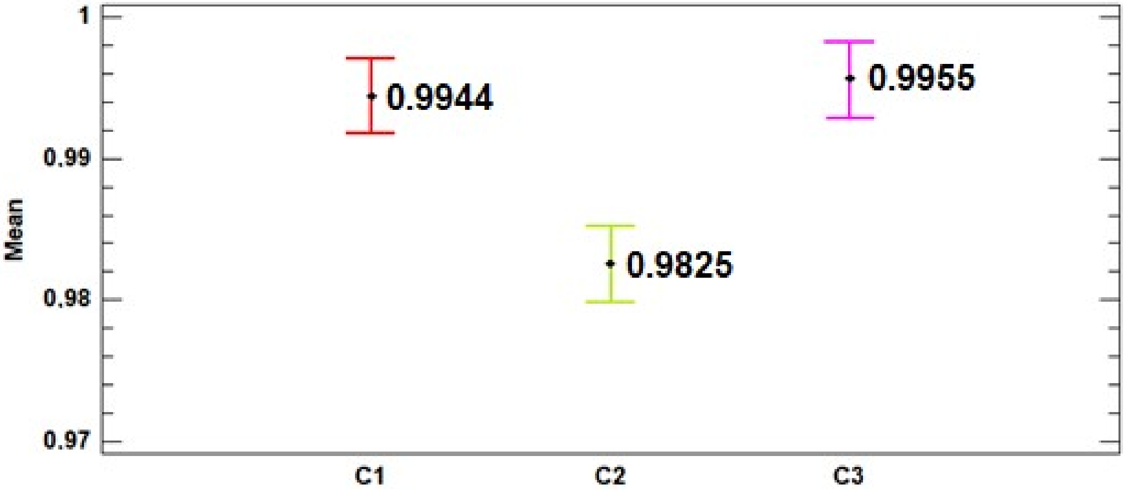
Figure 33: Proportional distribution of data according to monitoring phases.



Source: Author

However, to define whether there was a statistically significant difference between the means, we applied a Fisher’s test again, which determined that only C1 and C3 were part of homogeneous groups, as can be seen in Figure 34, where there is no overlap between the results of C2 and the others.

Figure 34: Mean 95% Fisher's least significant difference (LSD) conscious monitoring phases.



Source: Author

5.6 Discussion and Conclusions

The analyses allowed an integrated assessment of the effects of introducing EDR systems into the behavior of truck drivers based on objective criteria related to the improvement of safety levels and operational standards and associated with a reduction of fuel consumption. Based on the results, it is possible to conclude that the use of EDR systems enables an improvement of safety levels without affecting operational efficiency or the cost of road transport.

The results show that the application of the technology had the capacity to improve indicators. The experiment also demonstrated that associating the use of the technology with the application of a structured training procedure based on continuous feedback substantially improved the results. The data also show that after restarting the training and feedback procedure (C3), the results were even higher than those obtained during C1, suggesting that the establishment of a training process and long-term monitoring can improve the safety and efficiency of trucking operations.

The EDR technology is a tool that can actively improve both the safety and efficiency of road transport. Furthermore, associating technology with training procedures and the provision of feedback can enhance the positive results of the isolated technology (C2). In this study, the most immediate and significant impact occurred to safety-related behavior, since the number of speeding events observed throughout the phases of conscious monitoring was reduced by more than 46.35% (Figure 23), and the time spent driving time above the speed limit was reduced by 81.17% (Figure 25).

In addition, Figures 26 and 27 show that standardization of safety-related behavior led to a significant reduction in unwanted behaviors, and comparison of this criterion with the other criteria revealed more significant short-term reductions. Another issue raised by the study is the potential relationship between the monitored variables and the proposed indicators when characterizing the investigated criteria. To this end, we gathered 21 variables and converted them into four indicators; however, some EDR systems allow the collection of up to 400 variables regarding the performance of a vehicle and its driver.

Therefore, while the variables used in this paper characterized the current criteria, it is necessary to expand the collection of information regarding different variables so that researchers can better explain the individual behaviors of drivers. These results allow transport companies to create a mechanism to evaluate the behaviors of their drivers and to promote specific actions aimed at reducing unsafe acts related to the occurrence of accidents, leading to increased operational quality.

A proposal for future research is to broaden the scope by including a sensitivity analysis focused on individual DMU behaviors. Furthermore, it would be good to expand the sample size to diversify the segmentation related to the type of transport. Finally, it would be edifying to investigate the effect of structuring the entire training and feedback procedure as described by standards such as ISO 39001, CSEAA and Directives EC 59/2003 and EU 2018/645.

6. SYNTHESIS

This section describes and presents an overview of the different case studies described in Chapters 3, 4 and 5, taking into account their confluence during the maturation process of the research.

The chapters in question describe the development, construction and communication of the research process throughout the doctorate program, in which, among all the works published by me during the period of the course, I decided to include those with greater scientific recognition due to the medium in which they were published.

However, it is also necessary to summarize the contributions arising from the integration strategy between the ProKnowC method and the VosViewer® software, which allowed me to characterize the research theme, covering simultaneously the four complementary axes that focus on road freight transport.

6.1 Integration of the bibliometric review tools

One of the biggest challenges encountered during the construction of the research proposal was choosing the mechanism to characterize the research theme, which should simultaneously involve the axes EDR systems, safety, economic and operational, in addition to information related to the professional training process.

Therefore, the proposal of segmenting the central theme into research axes allowed the investigation to build a vision of each axis, having as a convergence point road freight transportation (RFT). Such proposition demonstrated its viability, assertiveness and robustness by allowing the characterization of the axes as a function of the bibliographic portfolios generated.

The generation of these portfolios, obtained by applying the Proknow-C method associated with analysis using the VosViewer® software, allowed for investigations related to the impact of each portfolio within the state of the art when considering as criteria, consecrated analytical metrics, such as evaluation according to the h-index, counting the total and average number of citations, both in documents with bibliographical recognition and in the list of articles that make up the bibliographical portfolio of each axis.

The complementation of the bibliometric analysis was achieved from the insertion of these portfolios in the VosViewer® software, which made it possible to map, from the bibliographic coupling analysis, the theoretical and thematic affinity between the documents, taking into account the total strength of their links. Another analysis that allowed the evaluation of the relevance and adherence of the portfolio to the research objectives was co-occurrence of keywords, through which it was possible to measure the recurrence of central issues and/or concepts that represent and delimit the investigated area of the portfolio. Table 29 summarizes all the bibliometric indicators of the research portfolios.

Table: 29: Bibliometric indicators of the research axes and of the integrated portfolio.

	Accidents and Safety	Cost and Consumption	Training and Qualification	EDR	Integrated Portfolio
Documents found	24	47	56	54	174
Total citations	1796	734	1624	408	4545
Average citation	74,79	15,62	29	7,56	26,12
H-index	21	16	25	8	37
Clusters	5	7	4	6	12
Links	37	50	180	32	544
Total link strength	66	95,5	322	56	984

Source: Adapted Web of science and VosViewer

In relation to the comparative analysis considering the research axes, all the indicators referring to the EDR axis presented the worst results, evidencing the still limited impact of the scientific production linked to the proposed research theme. The average of citations of the EDR axis was 48.4% of the average of citations of the axis with the second worst mark.

The portfolio related to the Accident and Safety axis presented similar behavior to the EDR axis in some aspects, but its composition counted on a reduced number of publications that registered a high total number of citations and consequently a high average value of citations per document, demonstrating the relevance and influence of such documents within the thematic area.

Another highlight in relation to the research axes referred to the Training and Capacity building axis, in which the results pointed to the occurrence of a reduced number of clusters, demonstrating a convergence of the research lines within the axis, linked to the largest number of connections, as well as total strength of connection among the researched axes. Such attributes evidenced cohesion in relation to bibliographic coupling.

Finally, the Cost and Consumption axis demonstrated behavior linked to the dispersion of themes of interest within the axis, due to the high number of clusters in which the articles were distributed. However, the axis presented the second highest total strength of connection among the documents, demonstrating cohesion within the clusters.

The use of portfolios by axis only makes sense for the characterization of the theme if when integrated they maintain or improve their characteristics, managing to transform the themes EDR, safety, training and consumption into points of evidence.

In this direction, the density map, presented in Figure 14, shows the fulfillment of this objective, since the integrated portfolio gives centrality to the EDR axis, which appears as the focal point in relation to the other keywords that make up the integrated portfolio.

Complementarily, the analysis of the bibliometric indicators also points to some gains in relation to the integration, such as the substantial increase in the total link strength, the increase in the total number of links, and finally the growth in the h-index of the integrated portfolio.

Thus, the strategy employed to determine the composition of the bibliographical portfolio of the research proved to be capable of scientifically supporting the propositions contained in the thesis, providing robustness in the proposed analyses, guidance regarding the methods and models available, in addition to guaranteeing the reliability of the developments.

6.2 Synthesis and integration

Chapters 3, 4 and 5 act as time frames in relation to the research construction process and describe stages of structuring, development and application of the research steps.

6.2.1 Preparatory Stages

The case studies developed and described in Chapters 2, 3 and 4 were preceded by preparatory steps involving several aspects, among which were obtaining EDR systems from manufacturing companies; technical implementation of this equipment in the participating companies; structuring of training and qualification mechanisms; definition of statistical tools and analysis mechanisms; and the checking and feedback process.

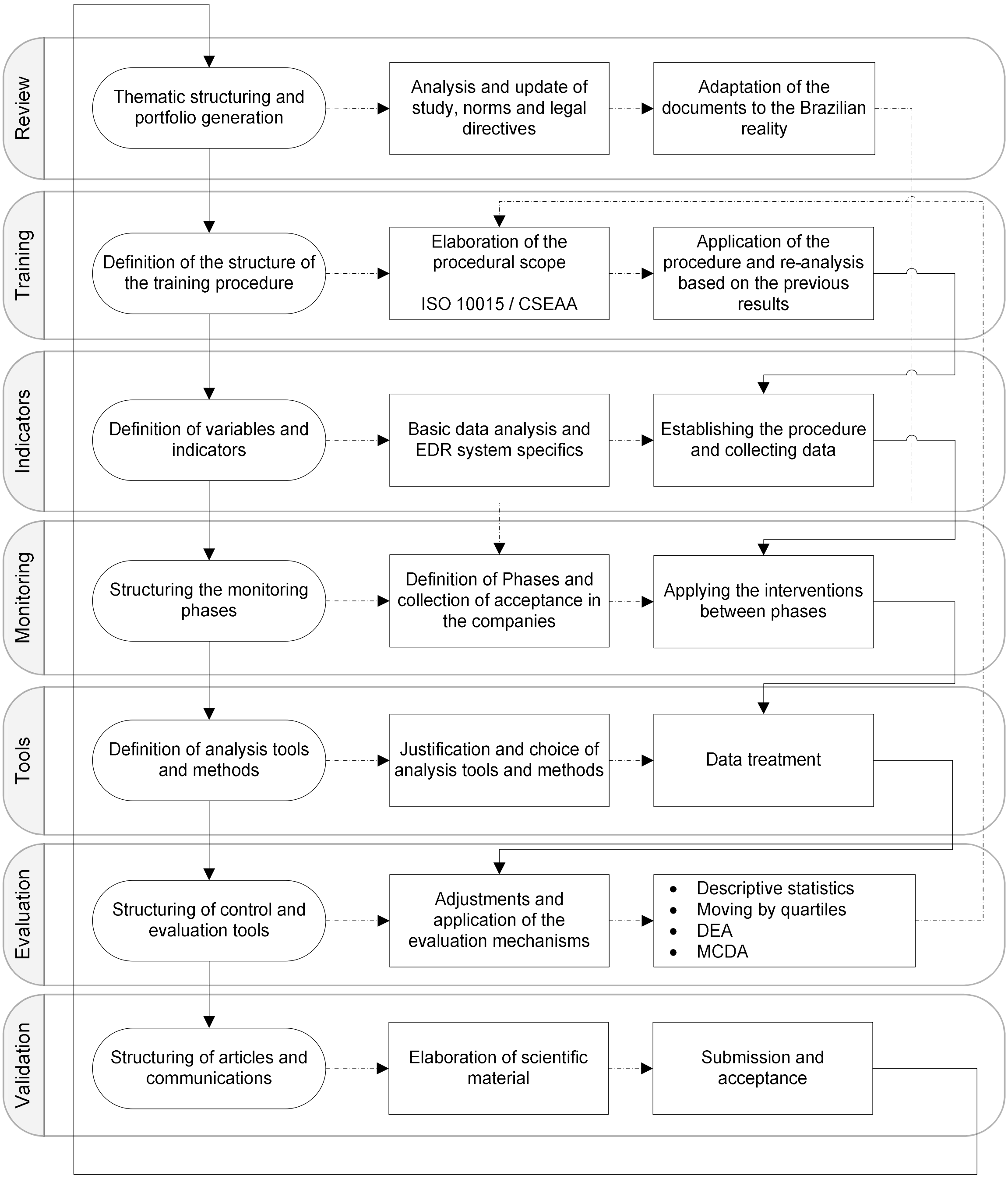
These preparatory steps were developed based on the concept proposed by the PDCA cycle (Plan-Do-Check-Act), since it provides from continuous improvement mechanisms the improvement and standardization of processes, where the goal is to promote increased efficiency and assertiveness (Ramírez et al. 2018).

In the three studies, the implementation of such steps demonstrated their relevance, mainly as a way to act on the main critical success factors for the research:

- loss of data caused by the withdrawal of participating companies, due to failure to understand the scope of the research and the commitment required during the investigative process;
- impossibility of implementing the stages of the monitoring process;
- adequacy of the data collection process and feeding of the analysis tools; and
- mechanism of validation, communication of results, and feedback of the research procedure.

The summarization of the preparatory steps adopted in the development of the case studies is depicted in Figure 36.

Figure: 35: Planning scope of the preparatory steps.



Source: Author

6.2.2 Structural basis and application of the training procedure

The research proposal assumed as one of its hypotheses that the data collected by EDR systems have the ability to support the proposition of a training procedure based on national and international standards and legislation.

In this sense, it was initially up to the investigation to verify the existence or not of professional driver training mechanisms, legally established by the regulatory agencies responsible for traffic in Brazil, as well as in European countries.

In Brazil, there is no type of regulatory content determined by a traffic agency that establishes a minimum training procedure for the qualification of professional drivers, much less that deals with the need for periodic refresher training of these drivers.

In contrast, the European Parliament established, through Directives EC 59/2003 and EU 2018/645, the regulation of the process of initial qualification and continued training aimed at drivers of heavy passenger and goods vehicles, where the training is subject to a broad set of requirements, knowledge and skills needed to obtain and subsequently maintain the driver's certificate of aptitude (CAM).

In order to provide the research contribution, it was necessary to establish a training procedure solidly based on existing standards, which was adaptable to Brazilian reality and could be replicated regardless of the road segment.

Regarding the structuring and application of the procedure, the contents presented in Chapters 3, 4 and 5 allow punctuating the results observed, marking the research advances over time. However, there was no deepening in relation to the theoretical basis, training content and other aspects, making it necessary to explain them.

In this sense, the training procedure developed focused on aspects related to planning, data analysis, behavioral analysis and feedback, awareness of the use of technology, driving technique, defensive driving, economical driving, and the action of forces.

The proposed areas consider aspects contained in the standards ISO 10015:2019, ISO 39001:2015 and devices of international standards such as CSEAA (Certificación de Seguridad de Empresas de Autobuses y Autocares, or “Safety Certification of Bus and Van Companies”), directive EC 59/2003 and EU 645/2018 adapted to the reality of RFT in Brazil, focusing on the criteria of safety, economic and operational.

As for the safety criterion, the parameters contained in ISO 39001:2015 (ABNT 2015) were used as a basis, with respect to road safety performance factors, support, resources, awareness, and operation.

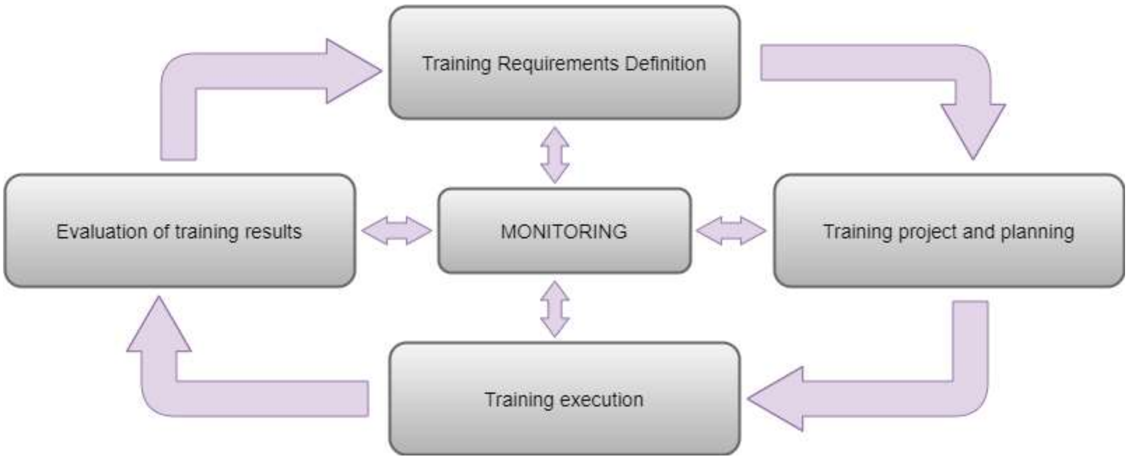
Several aspects were also considered from the CSEAA standard (INSIA 2016), developed by Instituto Universitario de Investigación del Automóvil of Universidad Politécnica de Madrid (UPM), which certifies the safety level of passenger transportation companies in relation to the analysis of five factors (driver, vehicle, operations, operating environment, and safety management) and 11 sub-factors covering 39 specific indicators.

Regarding the operational and economic criteria, the methods developed by Mercedes Benz professional training programs, called Master Driver, and contents of the manual of driving technique of diesel motor vehicles Morales and Guzmán (2012), were used as a basis.

Both documents provided support for improvement of the training procedure, aiming at increasing economy and productivity through application of practical rules of economic driving based on the evaluation and correction of undesirable habits such as excessive use of the clutch, use of brakes and retarders, excessive gear changes and underuse of the inertia of the vehicle, engine use, speed diagrams and fuel consumption.

To establish the structural design of the training, the determinations contained in ISO 10015:2019 (BSI 2019) were adopted in relation to the stages of application of that standard, as presented in Figure 37, since the mechanism allows for feedback through the process of evaluating the results of the training.

Figure: 36: Stages of application of the ISO 10015 Standard



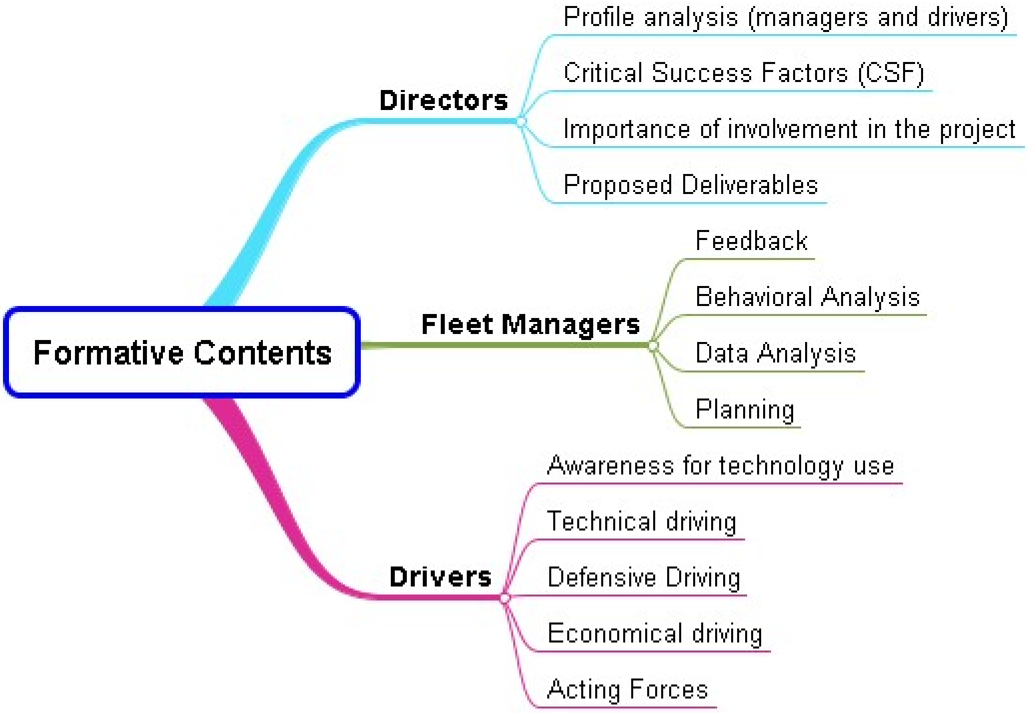
Source: adapted from BSI (2019)

The execution process put into practice all the previous developments and analyses. It was chosen to structure a training cycle involving the three hierarchical levels of the organizations in order to ensure the commitment of the organization as a whole. The structural scope is described in Appendix II, indicating the participants, objectives, expected duration, procedures, documents produced and critical success factors.

The company's executives, instead of a training process, participated in a cycle of alignment meetings where they were oriented as to the degree of importance of their commitment so that success could be obtained in the execution of the project.

The training content developed and applied according to the hierarchical levels is shown in Figure 38

Figure 37: Training content according to the hierarchical level



Source: Author

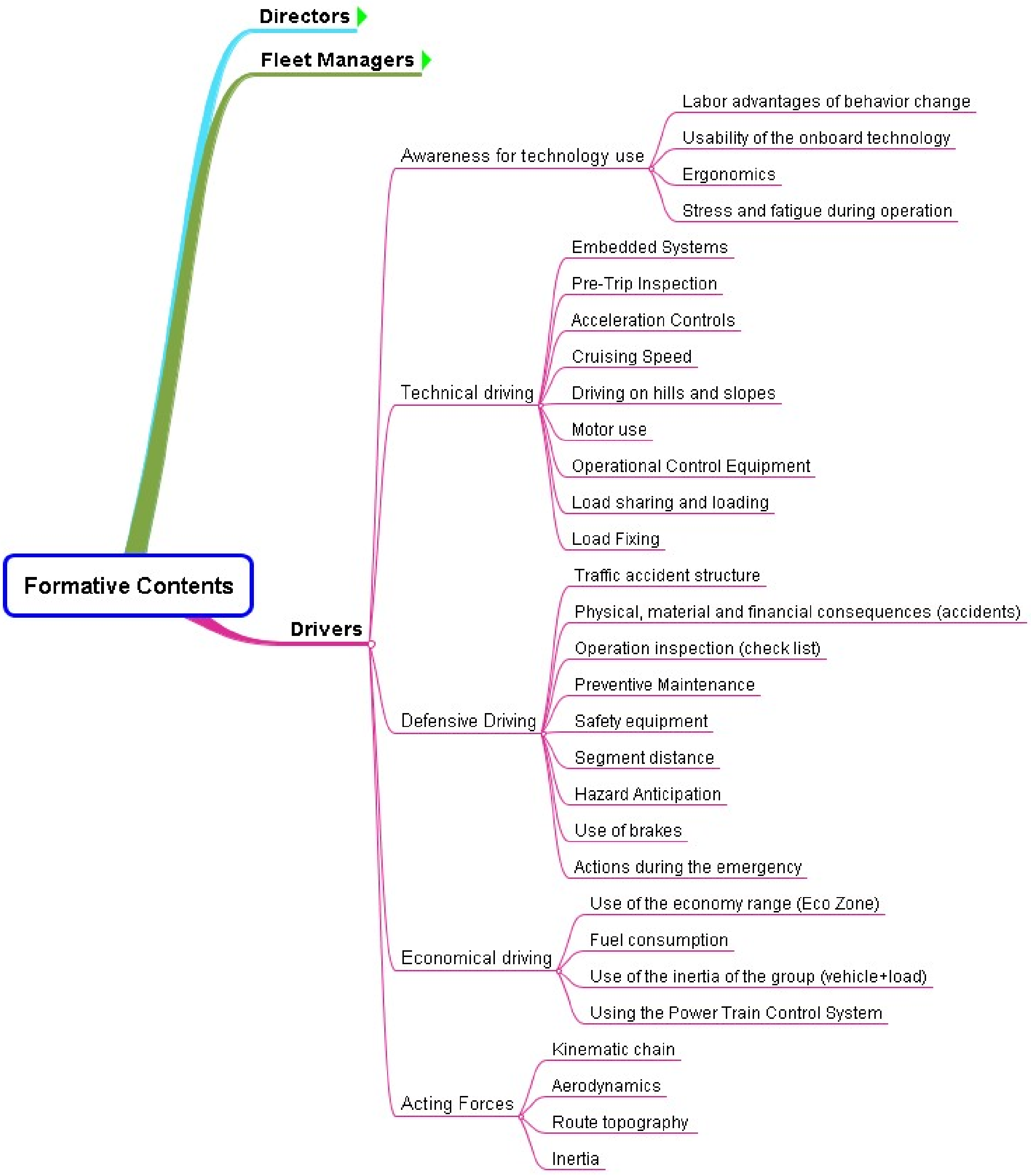
The application of the procedure with the drivers proved to be the most challenging and sensitive to occasional errors. It was challenging due to several factors, particularly the drivers' work routine, which made it impossible to execute the training steps with the whole team simultaneously due to travel schedules.

In addition, it was important to consider the functional influence of adopting training techniques based on the positive psychological effect described by Schulz, Luthans, and Messersmith (2014), since a certain degree of resistance and doubt naturally occurred as soon as drivers become aware that their actions on the road would be monitored.

However, this possible obstacle had already been detected during the planning stage, in which mitigation mechanisms were developed based on the concept of Positive Organizational Behavior (POB), in which the only latent factor is the so-called PsyCap.

In this sense, the training procedure kept its focus on the individual and collective importance of the drivers, focusing on the gains in relation to the reduction of fatigue, stress and risk as well as the increased productivity, which would eventually be converted into an increase in variable remuneration. Figure 39 shows all the content covered during the driver training procedure.

Figure 38: Training content – Drivers



Source: Author

6.2.3 Association of the EDR system and the training procedure

A complementary aspect important to answer the research problem is the ability to assess drivers' behavioral evolution using data extracted by the EDR system in order to support a training procedure.

In this sense, the investigative process was refined throughout its development as a function of the learning from each of the case studies.

Chapter 3 describes the initial phase of using the monitoring, data collection, and capacity building processes. In this development stage, the monitoring phases were aimed at discerning the usual pattern of conduct through hidden monitoring, then evaluating the impact of the isolated use of technology from conscious monitoring, and finally measuring the impacts from the association of the use of technology and the training process.

In relation to training concepts, the instruction process, which involves the use of introductory mechanisms to the training process from the documentation and communication of procedures and rules, as proposed by (Giovelli, Calvetti, and Bevilacqua (2012), was adapted and applied in the participating companies, Annexes 1 and 2 describe the construction of the research's documental base.

The variables extracted from the EDR system were considered as evaluation and training support metrics as well as evaluation items of the economic driving training, as set out in Table 30.

Table 30: Variables of evaluation and support for the training

Criteria	**Variable**
Safety	Speed Excess Speed in rain Braked Sharply Engine Brake Use
Operations	RPM Neutral Gear Clutch use Gear Shifting
Economy	Aceleration Efficiency (km/L)

Source: Author

The results obtained, showed that the use of EDR systems was able to promote consistent improvements by the evolution of variables in the comparison between the stages hidden, conscious and trained monitoring.

In relation to savings, an increase in energy efficiency of 5.34% was registered, equivalent to 11.7 liters of diesel for every 1000 km traveled, which when projected for the entire fleet of the participating companies, resulted in monthly savings of U$ 3,903. Only one vehicle showed savings below those proposed by Strömberg and Karlsson (2013b). The other variable related to the economic criterion, on the other hand, showed a worsening trend, since the number of sudden accelerations increased from 477 to 707, specifically due to the behavior of three drivers, while the others obtained positive results.

As for the operational criterion, the variable number of RPM excesses declined by about 45.3%, which meant a drop from 1119 to 612 events during the monitoring stages. The same was observed in relation to driving in neutral, where a 97.2% drop in events was registered, and likewise, the use of the clutch fell by 59.24% and the number of gear changes decreased by 58.13%. Only two drivers showed worsening in one of the variables making up the criterion, showing a change in the observed behavior.

However, the main impact of this first stage of the study was observed in relation to the safety criterion, which showed a consistent reduction in the number of events related to the variables speeding on dry roads, a drop of 81.6%, and speeding in the rain, a drop of 85.4%. Moreover, another aspect that corroborates directly the establishment of a higher level of safety was the activation of the engine brake, whose function is to ensure greater drivability and control of the vehicle in relation to the use of brakes: the observed growth was more than 3 times after the training.

In this way, the case study, described in Chapter 3, involved the initial phase of application of the research proposals, confirming the hypotheses that the use of EDR systems offers positive results. The initial results also corroborated the hypothesis that it is possible to use the data collected by these systems as support for driver evaluation and training.

However, several questions and needs for improvement of the research process were identified during this stage, in particular a more robust structural theoretical foundation, grounded in precepts related to the standardization of training procedures based on international standards such as ISO, CSEAA, EC 59/2003 and EU 645/2018.

In this direction, Chapter 4 describes the improvement of the research in various aspects, including expanding the bibliography, analyzing the profiles, and implementing the system. However, the initial proposition was focused on discovering whether there would be impacts from the implementation of the training procedure associated with the provision of feedback, and then to evaluate if there is a change in the drivers' behavior when the training and feedback sessions were interrupted.

The mechanism proposed for such evaluation is represented in Figure 17, in which from stage 3 on, the hidden monitoring began, following the same patterns described in Chapter 3, including the training process for managers in relation to the provision of feedback to drivers, thus configuring the stage of conscious monitoring 1.

The introductory training comprised the application of modules 1 and 2, related to the structural procedure of the training cycle, described in Appendix II. Thirty-three drivers received training for a total of 6 hours, spread over 3 sessions. The managers received another 6 hours of specific training, focusing on the use of the technology, mitigation of resistance and presentation of results, focusing not only on communication of management, but mainly of the drivers.

Unlike what was described in Chapter 2, the training sessions of the conscious monitoring 1, were adapted in function of 9 indicators representing the criteria safety, operation and economy. The data extracted from the EDR system proved to be crucial for the construction of the indicators that allowed characterizing the criteria and evaluating the impact of the interventions on the drivers' behavior.

The feedback process also proved to be a powerful tool for the correction of undesirable behavior, since at the end of each trip cycle, during the debriefing, the manager started to provide guidance to drivers about their weak points and the progress achieved.

At the end of conscious monitoring 1, conscious monitoring 2 began, where the sound signals and voice alerts issued by the EDR system were kept active. However, the application of the training and feedback procedure was interrupted. The purpose of this monitoring step was, to check for changes in the indicators that would demonstrate changes in driving habits.

The three monitoring phases occurred in a 7-month interval, following the 33 drivers over a distance of 1,414,554 km, considering 3,796 travel cycles that totaled 19,754 hours of vehicle movement, extensively monitored. The large volume of basic data and the capacity of EDR systems to collect more than 40 different variables explain the complexity of monitoring and managing with the aim of measuring the influence of technology and the training procedure on driver behavior.

Thus, the decision to use a restricted number of indicators provided greater assertiveness, traceability and efficiency in the follow-up process. In this sense, of the 9 indicators used, 5 had innovative characteristics by adding time control variables related to idling, engine running and vehicle movement, among others.

In a complementary way, besides the overall analysis, which characterized the each fleet's behavior, Chapter 4 contains an individual analysis of the driver/vehicle pairs, focusing on their movement from the establishment of quartiles, parameterized and established according to the results obtained during the hidden monitoring.

In the analysis related to the safety criterion, the indicator number of speeding events per 1000 km registered the migration of the worst performing vehicles to the quartiles composed of the best performance during the conscious monitoring 1, but when the training and feedback procedure was removed (in conscious monitoring 2), it was possible to observe a tendency of less presence in quartiles with the best results. The reduction in the number of speeding events was 68.3% in C1 and 65.3% during C2.

Similar behavior was identified in the analysis of the indicator speeding time per time on the road, which evaluates the degree of acceptance of risk due to the time spent driving above the maximum speed. For this indicator, the growth in the number of vehicles in the quartiles containing best performers was noticeable due to the migration of vehicles toward Q1 during conscious monitoring 1, as well as the migration of vehicles from Q3 and Q4 toward Q2 during conscious monitoring 2.

This is one of the indicators that showed significant positive results, since the total driving time above the established maximum speed was reduced from 104 hours during covert monitoring to 20 hours in C1 and 21 hours during conscious monitoring 2.

However, the behavior of the indicator number of sudden stops per 1000 km, registered a negative result, namely growth in the number of drivers migrating to the quartiles linked to the worst results, both in C1 and C2. However, from the process of collecting impressions and orientations, included in modules 1 and 2 of the training procedure, a natural reaction was noted, linked to actuation of the brake pedal to avoid speeding, whenever the system issued voice alerts determining that the speed should be reduced.

The analysis of the operational criterion considered the inclusion of an indicator to evaluate the percentage of time in motion as a function of the productive time available, allowing analysis of the productivity of the vehicles. The intention of this indicator is for drivers to migrate to the Q3 and Q4 quartiles, indicating an increase in vehicle use time.

There was migration from Q1 to Q2 during both stages of conscious monitoring, demonstrating an evolution trend below the expected level. However, based on the hidden monitoring, it was possible to observe that productivity registered an increase of 5.3% during

C1 followed by a decrease of 2.4% in C2. In the direct comparison of C1 and C2, the worsening caused by the removal of the training and feedback procedure reached 7.7%.

The indicator number of RPM excesses per 1000 km traveled showed different behavior, due to the concentration of vehicles in Q3, indicating a worsening of the migration flow during conscious monitoring 1, followed by a slight improvement during conscious monitoring 2.

However, the reduced number of over-revving events made the evolution of the results less evident, since during the hidden monitoring, 0.746 excess RPM events occurred for every 1000 km traveled, while in C1, a drop to 0.237 over-revving event per 1000 km traveled was recorded followed by an increase in C2 to 0.434 excess RPM events per 1000 km traveled.

The third indicator that represents the operational criterion also offers an innovative feature by associating the analysis of idling time as a function of the distance traveled. This indicator allows the manager to evaluate the profile of idling as a function of the route profiles. Additionally, the variable idling time also has a direct impact on fuel consumption, since the engine keeps running without offering production.

The result indicated a large migration of drivers to the most efficient quartiles both in C1 and C2, corresponding to an increase of vehicles in these quartiles of 64.7% and 35.3%, respectively. The results obtained pointed to a reduction of 290 idling hours during C1 and 147 idling hours during C2, In other words, besides a reduction in idle time, the procedure also provided an opportunity to reduce fuel consumption.

To represent the economic criterion, the idle time as a function of the time in motion was used, which determines the percentage impact of the idle cost during operation. Again there was migration to the quartiles Q1 and Q2 during the conscious monitoring stages 1 and 2, consequently representing a reduction in the time that the vehicles were operated in the idling regime.

With this, the impact of the idling time in relation to the total time the vehicle remained in motion was reduced from 20.95% during the hidden monitoring, to 17.36% in C1 and 19.9% in C2.

The indicator consumption per ton-kilometer showed atypical behavior regarding the migration of vehicles between the quartiles, starting with change from Q2 and Q3 to the extremes, Q1 and Q4, in both stages of conscious monitoring. The overall behavior of the fleet in relation to the indicator showed a reduction of 2.29% in the comparison between the hidden monitoring and C1, and a reduction of 0.26% in the comparison between the hidden monitoring and C2.

The last indicator used represents the cost of fuel as a function of distance traveled. This is a widely used indicator in the road transport sector. Its analysis pointed to a 75% migration of vehicles from Q2 to Q1 during conscious monitoring 1, followed by a similar behavior in which 37% of the vehicles from Q2 migrated to Q1 during conscious monitoring 2.

However, regarding the financial impact, measured by the cost per kilometer, obtained during the hidden monitoring, the monthly savings obtained was U$ 1,281.09 during conscious monitoring 1 and U$ 2,314.06 during conscious monitoring 2. This was the only indicator where the results of C2 exceeded the results obtained during C1, a phase characterized by the provision of training and feedback.

The results obtained from this case study converged in the same direction presented in Chapter 3, in the sense that the adoption of EDR systems was capable of generating positive impacts on driver behavior, and that its association with the training process was able to enhance such impacts.

There also was a tendency for the behaviors not yet assimilated to revert to the previous patterns after the withdrawal of the training and feedback procedures, thus corroborating the propositions of Skogens (2013).

The use of indicators, structured from variables collected by the EDR system, afforded greater reliability, assertiveness, robustness, and representativeness to the analyses. In this sense, the adoption of indicators based on time control, besides being innovative, was important for understanding the willingness of drivers to accept the definitions proposed by the training procedure, due mainly to the reduction of intercurrences and undesirable behaviors.

However, the central point of the case study was based on the application of the training procedure from the introduction of training modules and feedback mechanisms throughout the conscious monitoring 1.

This procedure allowed the training sessions to be supported by results verified during the hidden monitoring, and also allowed adjustments to be made based on data collected during conscious monitoring 1, thus demonstrating that it is feasible to adopt evaluation mechanisms for training procedures associated with RDE systems.

The third case study, described in Chapter 5, complements the research by consolidating the analysis of the influence of the training procedure on the positive evolution of the indicators. This analysis occurred by the inclusion of a third monitoring stage, called conscious 3 (C3), where the training and feedback supporting the application of modules 2 and 3 (Annex II) were reintroduced in part of the fleet participating in case study 2.

The purpose of this inclusion was to discover whether the behavioral involution, observed during conscious monitoring 2 (C2) could be reversed by applying the training and feedback procedure; in addition to checking which of the criteria would more sensitive to training.

The conscious monitoring stage 3 was executed over 6 months, in which it was decided to cluster the vehicles composing the fleet of the company, considering as inclusion criteria the mechanical similarity of the vehicles and the segmentation by type of operation. The objective of this proposal was to minimize the effect of external variables such as route, distribution profile and vehicles' mechanical specifications, among others.

In this sense, 22 Mercedes Benz Atego 2425 vehicles, responsible for medium and long distance trips, met the restrictions. These vehicles were monitored during 848,846 km, which represented 2,079 trip cycles, equivalent to 10 trips per vehicle per month.

In order to substantiate the observations obtained, it was necessary to submit the data collected to a more robust analysis method that would allow further characterizing the influence of the use of technology and the provision of professional training on improving the results in terms of efficiency.

To this end, data envelopment analysis (DEA) was applied, considering each pair (driver/vehicle) as a decision making unit (DMU).

Five indicators linked to the proposed criteria were evaluated, as shown in Table 23. The analysis focused on improving the indicators linked to the safety and operation criteria, defined as outputs. Since the problem established variable returns to scale, the model that met the conditions presented was the output-oriented BCC model.

In order to complement these analyses, four distinct scenarios were created: an overall global scenario, which includes all criteria (safety, economic and operational); and three scenarios involving pairwise analyses of these criteria. With the results of each scenario, the overall analysis was chosen since it allows the behavior variation to be visualized considering all the indicators together.

The data collected during the monitoring steps were processed by the SIADv3 software, which helped determine the efficient frontier, made up by the best performing DMUs, being considered the productive efficiency analysis, since it refers to the DMUs' capacity to increase results (maximize outputs) without the necessary reduction of resources.

The evaluations considered the normalized composite efficiency analysis as a parameter, which allows the establishment of a hierarchy of results and consequently favors better discrimination of DMUs.

In this sense, the observed advances were summarized through the global analysis of the indicators considering the analyzed criteria and the results of the DEA method.

The integrated analysis of the indicators that represent the safety criterion, Figures 26 and 27, allowed the explicit visualization of the positive impact promoted by application of the training and feedback procedure in the conscious monitoring steps 1 and 3. Through them, it was possible to notice a substantial reduction in the fleet dispersion throughout all the conscious monitoring stages. However, the standardization of safety behavior occurred systematically during C1 and C3, as reinforced by the behavior of the variances of the safety indicators at each monitoring stage (Table 31).

Table 31: Variance of the safety indicators in the monitoring steps

	Number of speeding events / 1000 km	(%) Speeding Time
Hidden	79,12	3,78
C1	18,31	0,24
C2	46,57	0,66
C3	4,09	0,15

Source: Author

The behavior of the indicators revealed a tendency to amplify the impact during C3, indicating that the continued training and feedback process were mechanisms to ensure the introjection of the desired behaviors.

To configure the operational criterion, indicator of the percentage of vehicle operating in the economic zone was chosen, which represents the optimal operating range for each vehicle, allowing the analysis of the driving pattern adopted in each trip cycle. The relevance of this indicator is justified by aspects related to the analysis of driving according to engine speed range associated with operating speed and control of peak times and interruptions.

Again, the results obtained highlighted the monitoring stages C1 and C3, since the drivers increased the percentage of operation in the economic zone, from 58.11% in the hidden monitoring, to 61.06% during C1, followed by a reduction to 58.09% during conscious monitoring 2. When reinserting the provision of training and feedback in the conscious monitoring 3, the result rose again, reaching 60.09%.

The behavioral analysis involving this indicator is very important, because it brings together aspects linked to skills, concepts and habits often ingrained over several years of driving. The positive evolution of indicators of this caliber act as critical success factors since they indicate the transformation of knowledge obtained into daily habits.

To represent the economic criterion, the indicators fuel consumption as a function of distance traveled and idling percentage were used. Both indicators followed the trend pointed out by the others, converging in the sense that the results obtained in the phases where the integration of the use of technology and the training and feedback occurred presented better results than those registered from the isolated use of the EDR system or its non-use.

The only exception was in the analysis of the idling percentage during monitoring in C2 and C3, which exceeded the results observed in the hidden monitoring by 0.48% and 0.26% respectively.

The reduction in fuel consumption per kilometer, taking the hidden monitoring as a basis, was 0.89% in C1, reaching 2.1% during C3, which represented, for this part of the fleet, a monthly savings of 811 liters and 345 liters of diesel, respectively. In C2, the result was a small increase of 0.05%, which represented an increase in consumption of 19.38 liters, which can be considered insignificant.

The percentage of idling, on the other hand, dropped from 15.47% during the hidden monitoring, to 14.2% in conscious monitoring 1, followed by an increase to 15.95% in conscious monitoring 2, closing the monitoring cycle with a drop to 15.73% in C3.

In the same direction, the analysis developed from the data of the normalized composite efficiency, calculated by the DEA method, allowed evaluation of the fleet's behavior and that of each driver/vehicle pair, determining a positive effect and statistically significant effect of the proposed interventions during the monitoring phases.

For this purpose, the probability mass function was calculated, allowing plotting the graph with the distribution curves, Figure 30 shows the data convergence during phases C1, C2 and C3 due to the low dispersion of the samples and the elevation of the average values of the normalized composite efficiency. Again, the results highlighted the stages of conscious monitoring, with emphasis on stages C1 and C3, where the training process occurred.

The same behavior can be observed from the analysis of the quantile plot, Figure 33, which illustrates the proportion of data from each sample that is below or above the population mean. In this sense, during stages C1 and C3 more than 80% of the drivers obtained results above the sample average considering the steps of conscious monitoring, while in C2 only 60% of the drivers exceeded the determined level, indicating that improvements occurred in the enhanced conscious monitoring that in C1 and C3.

Two other analyses were also performed: Fisher's statistical significance test and Mood's median test, which objectively determined that, statistically speaking, there were differences between the hidden monitoring stage and the other monitoring stages, considering a 95% confidence interval.

The first analysis encompassed all monitoring steps, with the objective of assessing whether there were significant differences between the monitoring steps. Table 32 contains the estimated differences for each analyzed pair as well as the significance limits. The results indicated that the behaviors of the hidden monitoring step were significantly different from the habits recorded in the conscious monitoring steps.

Table 32: Multiple range test - least significant difference (LSD) - all monitoring steps

	Significant difference	Difference Value	+/- Limits
Hidden x C1	*	-0,07657	0,01865
Hidden x C2	*	-0,06467	
Hidden x C3	*	-0,07770	
C1 x C2		0,01190	
C1 x C3		-0,00112	
C2 x C3		-0,01303	

Source: Author

However, to verify whether the application of the training/feedback procedure had a positive influence on the increase of fleet efficiency, it was necessary to isolate the steps of conscious monitoring and verify whether they presented significant pairwise differences.

Again, Fischer's test was used, considering the values presented in Table 33, indicating that, with 95% confidence, the comparisons (C1 x C2) and (C2 x C3) presented statistically significant differences, while (C1 x C3) did not.

Table: 33: Multiple range test - least significant difference (LSD)

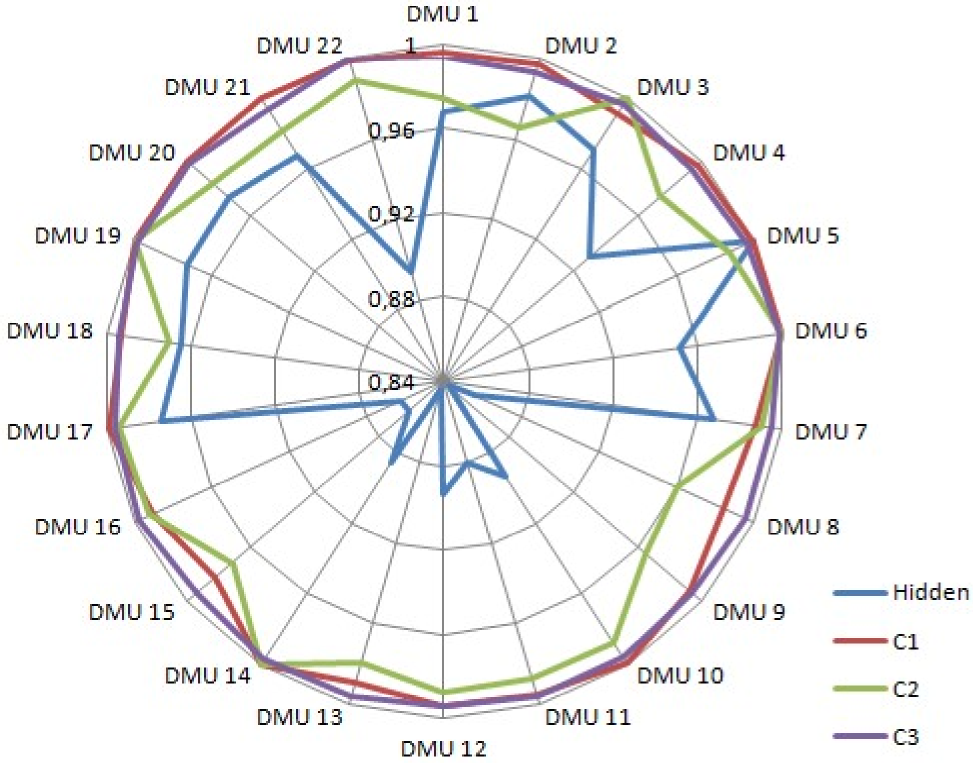
	Significant difference	Difference Value	+/- Limits
C1 x C2	*	0,0119	0,00538
C1 x C3		-0,0011	
C2 x C3	*	-0,0130	

Source: Author

On the other hand, the data obtained from the analysis by the DEA method corroborated conclusions of the individual analysis of the evolution of the drivers' efficiency during the monitoring stages.

Figure 40 presents the behavior of the normalized composite efficiency values for each of the driver/vehicle (DMU), reflecting the evolution of their behavior along each monitoring phase.

Figure 39: Evolution of normalized composite efficiency values in each monitoring phase



Source: Author

Figure 40 shows that the data referring to the hidden monitoring were almost completely displaced from the efficient frontier, considering the value 1 as the optimal efficiency. Only DMU 2 and 5 presented efficiency values, in the hidden monitoring, higher than at least one result obtained during at least one of the conscious monitoring steps.

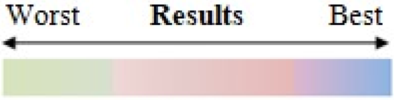
Furthermore, the five worst efficiencies observed during all the monitoring steps occurred during the hidden monitoring, with an average result of 0.854. The five worst results of C2, a stage where there was no training and feedback, averaged 0.967, which represents improvement in the behavior of the worst drivers of 13.23% in the direct comparison between these monitoring steps.

Still in this sense, these DMUs, which presented the worst results during the hidden monitoring, presented improvements ranging from 15.29% to 18.05% at the end of the training and feedback procedure, in the direct comparison with the results obtained in conscious monitoring 3, as shown in Table 34.

Table 34: Evolution of the efficiency indexes of the worst drivers (DMU)

	Hidden	C1	C2	C3	Evolution (Hidden x C3)
DMU 09	0,8431	0,9921	0,9648	0,9934	17,83%
DMU 13	0,8438	0,9894	0,9789	0,9961	18,05%
DMU 08	0,8565	0,9838	0,9600	0,9960	16,29%
DMU 15	0,8618	0,9819	0,9715	0,9936	15,29%
DMU 16	0,8627	0,9909	0,9922	0,9982	15,71%
Mean	0,85358	0,98762	0,97348	0,99546	16,63%

Subtitle:



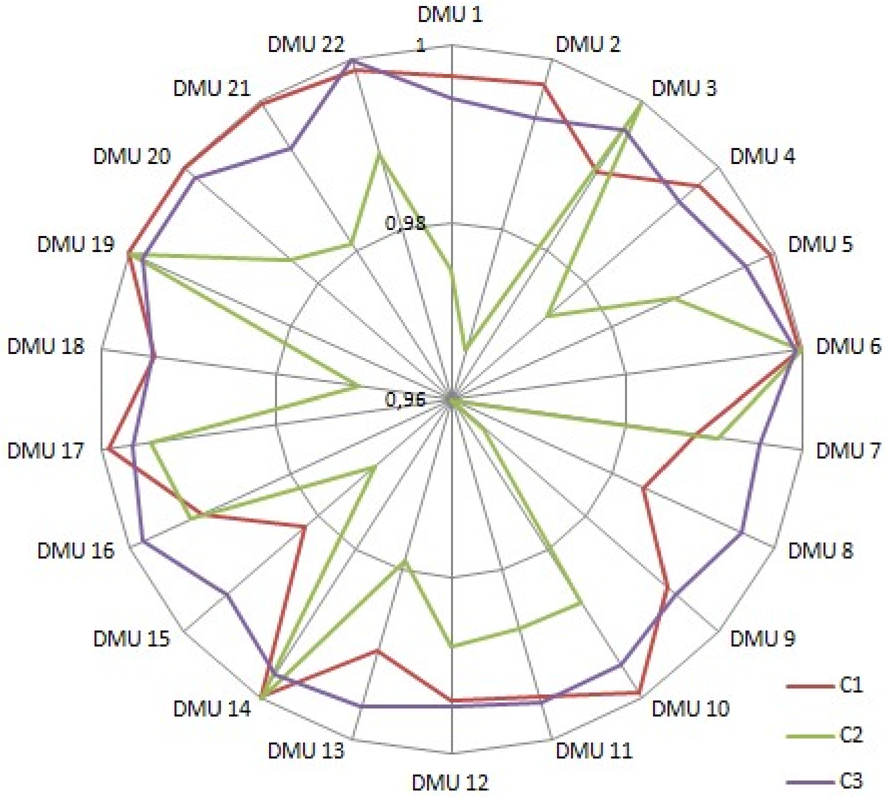
Source: Author

With this, it was possible to identify that 91% of the driver/vehicle pairs showed an increase in the values of the normalized composite efficiency in all phases of conscious monitoring, corroborating the hypothesis that the interventions would be able to improve the indicators.

However, this hypothesis states there would be a difference between the results of monitoring 2, which considers the use of technology alone, with the results obtained from monitoring 1 and 3, stages if integrated use of technology and training.

In this way, the analysis focusing only on the conscious monitoring steps allowed evaluating the results of each of the phases where the interventions of technology combined with training and follow-up were applied. Figure 41 presents the values of the normalized composite efficiency for each DMU during the conscious monitoring phases.

Figure 40: Evolution of normalized composite efficiency values in each phase of conscious monitoring



Source: Author

The comparison of the data from the conscious monitoring stages indicates that only 6 DMUs during conscious monitoring 2 presented better results than recorded during C1 or C3.

The analysis of the 5 DMUs with the best results in each monitoring stage, Table 35, also points to positive evolution, but in a smaller growth percentage than that observed in the case of the worst DMUs. The only atypical behavior corresponds to DMU 5, which logically represents the most efficient DMU of the monitoring stage in question.

Table 35: Evolution of the efficiency indexes of the best drivers (DMU)

	Hidden	C1	C2	C3	Evolution (Hidden x C3)
DMU 05	1	0,9994	0,9876	0,9965	-0,35%
DMU 02	0,9814	0,9972	0,9658	0,9933	1,21%
DMU 17	0,9743	0,9991	0,9943	0,9964	2,27%
DMU 20	0,9732	0,9999	0,9841	0,9984	2,59%
DMU 19	0,9730	1,0000	0,9998	0,9983	2,60%
Mean	0,98038	0,99912	0,98632	0,99658	1,66%

Worst **Results** Best

Subtitle:

Source: Author

It should be noted that even among the best driver/vehicle pairs, it was possible to identify a positive impact due to the interventions and research procedures performed, with average improvement of 1.66%.

The comparison between the best and worst drivers indicated that the main impact of the association between technology, training and monitoring was verified among drivers with higher incidences of undesired behavior during the hidden monitoring stage. However, the proposed procedure demonstrated the ability to influence all drivers involved.

With this, it is possible to state that the results reported in the studies of Chapters 3, 4 and 5 indicate that the interventions carried out exerted a significant influence on the improvement of the drivers' behavior. They also demonstrated that the implementation of training procedures needs to be based on reliable data, preferably available in real time, so that not only the organization benefits, but the entire chain including stakeholders: customers, office staff, drivers, and society as a whole.

7. FINAL CONSIDERATIONS

7.1. Conclusions

The development and application of the training procedure proposed in this thesis demonstrated its relevance as a tool to promote the improvement of driving habits of professional drivers, generating an increase in operational efficiency and safety and reduction of economic indicators.

In this sense, the literature review process adopted was crucial to delineate the research theme, allowing the identification of a gap in scientific knowledge to be explored. For this purpose, the division of the central theme into research axes and the structuring of independent bibliographic portfolios, connected by the topic of road freight transportation, provided the necessary scientific support for the characterization of the safety, economic and operational criteria according to the research propositions.

Complementarily, the co-occurrence analysis and bibliographic coupling allowed consolidation of the choice of variables, and consequently the definition of which indicators should be monitored as a priority to represent the criteria studied.

Furthermore, the integration of the Proknow-C method with the VosViewer® software allowed generation of network maps that revealed improvements related to the research axes. With this, it was possible to validate the relevance and contribution of the works published by related to the research project (Chapters 4 and 5) involving the proposed theme, by virtue of their high total connection strength to the publications that characterize the theme.

The proposed research problem was based on the possibility of structuring and applying a training and feedback procedure, based on data and standards, that was able to measure through specific criteria the improvement of driver conduct.

In this respect, the research hypotheses were confirmed, since as foundation for the development and application of the training procedure, the association of data collected by EDR systems and the main precepts of international standards were considered, among them ISO 39001, ISO 10015, CSEAA, EC 59/2003 and EU 645/2018, making the structural framework adequate to Brazilian reality.

The second hypothesis was also confirmed, in the sense that the use of the EDR systems provided positive short-term changes in the drivers' behavior, thus indicating that the use of EDR systems is more advantageous than not using them. However, it was also possible to determine that the isolated use of the EDR system does not guarantee long-term operational improvement, since ingrained behaviors tended to outweigh short-term changes.

Thus, of the hypotheses was ratified, but it is necessary to emphasize the importance of the feedback process to perpetuate the guidance received at the end of each trip cycle.

Throughout the entire investigation 6,435 trip cycles were monitored, of which in 3,767 cycles the drivers received feedback from the fleet managers.

The proposal to integrate the fleet manager in the training process proved to be decisive to ensure the long-run establishment of the results generated by the feedback process, since this mechanism worked as a filter to more persuasively eliminate unwanted behaviors.

In this sense, the research process demonstrated high complexity of execution due to several factors, internal and external. One of the greatest findings related to the success or failure of the proposal was identified during the execution of case study 1, which counted on the participation of three trucking companies.

During this stage, it was possible to identify as a critical success factor the commitment of the managerial and executive levels for the implementation of the training procedure and long-term monitoring, since the increase in safety, operational and economic standards in the fleet is directly linked to the elimination of unwanted driving habits as well as the adoption of habits linked to efficiency, which are mainly based on medium and long-term actions.

Thus, the use of the EDR system proved to be a powerful tool not only in the process of data collection but also for its ability to interact in real time with the drivers to prevent unwanted behaviors, from the alerts and voice commands issued by the system, besides generating a database allowing comparison of individual evolution between groups and within groups.

In addition, the technology proved to be capable of expanding its scope of action with the collection of new variables, the ability to integrate with other peripheral systems and communicate between various technologies, opening an even wider field of research.

The proposed use of EDR systems allowed evaluating not only the impact of the technology in reducing the factors that contribute to the occurrence of traffic accidents, but also its capacity to promote and monitor reductions linked to fuel consumption and idling, all linked to the economic criterion. In a correlated way, the technology also helped to improve indicators associated with the operational criterion, by considering the driving profiles within the economic zone and the movement percentage in relation to the available production time.

Although the indicators of the safety criterion showed greater sensitivity to the application of technology, the other criteria were also positively affected, thus allowing broadening the discussions about the capacity of the EDR system to act as an integrating agent of information capable of favoring the establishment of a more efficient, safe and measurable transportation.

The mechanisms of statistical analysis and mathematical tools used in the case studies were important because they acted as a guiding axis for the research to reach such a stage where data envelopment analysis (DEA) method could be performed.

The use of the method proved to be fully adherent to the purposes of the analysis, also demonstrating the existence of additional tools that can be incorporated to allow new analyses, considering various inputs and outputs.

The DEA enabled the driver/vehicle pairs to be ranked according to their efficiency, providing considerable support for the decision-making process regarding the need for changes in the training cycles based on individualized data.

However, the point of convergence of all the actions was consolidated in the training procedure developed. The theoretical basis on which the procedure was structured was able to ensure its replicability, evaluation, and adaptation, since it met the validation mechanisms internationally disseminated and accepted by the scientific community.

A second innovative aspect, related to the training procedure, is related to the use of driving data as a source for driver assessment, allowing modulating the emphasis of specific contents of the training cycle, identifying the most appropriate areas to be addressed among different groups of drivers or even different company profiles according to the transportation segment in which they operate.

Therefore, the proposal achieved its goal by presenting an innovative training procedure based on fundamental precepts of international standards, taking as sources of the generation, collection and evaluation information monitored by EDR systems, considering the evolution of safety, economic and operational criteria for making decisions.

7.2 Future developments and work

The investigation reported here sought to validate the possibility of using EDR systems structured by world-class heavy vehicle manufacturers to improve driver habits. Thus, in late 2019 the research proposal was presented to the technology and operations directorate of a major European truck producer.

After approval of the proposal and the paperwork inherent to the process of data access and confidentiality, I was granted access to the manufacturer's system. Initially, access was restricted to the company's dedicated fleet data. Then, due to the initial results presented, access to customer data was approved, becoming part of the project's scope.

The objective of this new phase was to evaluate the entire list of variables collected by the EDR system developed by the manufacturer in order to define which variables can be converted into performance indicators and which other criteria should be included with the aim of increasing users' productive efficiency and safety.

Another consideration arising from this development was the need to expand the sample studied. In this respect, the manufacturer's collaborative participation was able to obtain adhesion of trucking companies and consequent expansion of the number of vehicles and drivers.

With this, the propositions for future developments are directed to the analysis of profiles and driving patterns adopted according to the characteristics of routes, types of loads, mechanical characteristics, weather conditions and periods of the day, in order to establish specific evaluation and classification parameters involving driving patterns. For this purpose artificial intelligence and machine learning techniques can be applied to create ranking metrics based on telematics that act in a collaborative, predictive and standardized manner, whether by route, vehicle and/or driver.

In relation to the training procedure, the proposal enables improving the training results, including all the metrics determined by international standards, so that the procedure can be integrated into a certification system, capable of promoting improvements in road safety associated with the increase in operational efficiency from the standardization of the behavior of drivers in road freight transport in Brazil.

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APPENDICES

Appendix I– Driver identification questionnaire

PARTICIPANT IDENTIFICATION QUESTIONNAIRE

Name:____

Profession: ____

Age: ____________ Gender: _______ Education: _________________

Marital Status: _________________ Birthplace: ____________________

Driving licence time:	______________
Professional qualification time:	______________
How many years have you been driving?	______________
Category?	______________
How many kilometres you drive each month?	______________
Have you ever used illicit substances?	______________
How many accidents have you been involved in?	______________
Are you sleeping well?	______________
Do you have stomach problems?	______________
Do you feel nervous or irritable?	______________
Do you eat correctly, at the right times?	______________
Do you use a mobile phone while driving?	______________
Do you have a desire to change profession?	______________
Do you always wear your seat belt?	______________

Appendix II – STRUCTURAL METRICS OF THE TRAINING CYCLES

MODULE 1: AWARENESS RAISING

Participants: Drivers and Managers

Objectives:

Drivers:

- Present the technology and propose a usage model;
- Define undesirable behaviours (risk, operation and consumption);
- Present individual and group goals and objectives.

Managers

- Define the standard of feedback to be directed to drivers.
- Present analysis model.
- Follow up with drivers at the end of each trip cycle

Duration of the stage: minimum 60 days

Process:

03 Training - 9 hours (awareness for using the technology)

03 Meetings with managers - 6 hours (Planning, feedback process)

04 Driver feedback meetings - 4 hours

Documents:

- - Company profile questionnaire
- - Informed consent form
- - Team assessment questionnaire
- - Identification questionnaire
- - DBQ questionnaire

Critical success factors

- - Commitment from top management
- - Monitoring of the system by the managers
- - Quality and reliability of the data collected in the company system
- - Team commitment (drivers and managers

MODULE 2: EVALUATION AND IMPROVEMENT

Participants: Drivers and Managers

Objectives:

Drivers:

- To build capacity in relation to technical aspects linked to the investigated criteria.
- Present the comparative evolution of data and indicators.
- Propose targets according to behaviour (safety, operation and economy)
- Implement the management action plan on sight
- Gathering impressions on the system (strengths and weaknesses)

Managers

- Evaluate feedback pattern to drivers.
- Implementation of the spot management chart
- Improve communication process (Implement suggestions program)

Duration of the stage: minimum 90 days

Process:

04 Training sessions - 12 hours (Technical driving, defensive driving, Master Drive, economic driving)

06 Meetings with managers - 12 hours

05 Drivers' feedback and orientation - 10 hours

Documents:

- Spot management board data
- Johari window (communication)
- CSF form
- Organizational climate self-analysis questionnaire
- PDCA

Critical success factors

- Commitment of managers;
- Systematic monitoring of individual and overall results.
- Analysis of the trips made at the end of each cycle
- Feeding of spreadsheets and procedure documents

MODULE 3: FOLLOW-UP

Objectives:

Drivers

- Promote continuous and systematic recycling (mitigate the effect of the forgetting curve)
- To expose and apply the planning of goals and objectives

Managers

- Feedback on the planning of goals and objectives
- Structure an incentive programme proposal
- Structure payback analysis according to the results
- Improve the use of the cash management tool

Duration of the stage: constant cycle

Process:

08 Training sessions - 18 hours/year (Defensive, technical and economic driving; posture, health, quality, legislation, results)

Meetings with managers - 36 hours/year

Orientation meetings with drivers - 54 hours/year

Documents:

- View management tool data analysis
- Johari's window (communication)
- PDCA
- DBQ Questionnaire
- BCR analysis (Benefit Cost Ratio)
- Staff evaluation questionnaire
- Payback analysis

Critical success factors

- Present a positive BCR;
- Maintain the commitment of all parties (Direction, Managers and Drivers)
- Improve the analysis in the definition of optimal behaviours that should be replicated
- Structure segmented analysis of behaviours according to the routes