https://doi.org/10.3311/PPtr.14892

Periodica Polytechnica Transportation Engineering, 49(1), pp. 42–59, 2021

Analysis of In-Vehicle Warning System for Rail-Road Level Crossings: Case Study in the City of Thessaloniki, Greece

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Received: 26 August 2019, Accepted: 19 November 2019, Published online: 30 March 2020

Abstract

The present research has investigated the impact of a Cooperative – Intelligent Transport Systems service for increasing Rail – Road Level Crossing safety, in terms of driving dynamic of the taxi drivers who used the service at the city of Thessaloniki, Greece. The Cooperative – Intelligent Transport Systems service informed drivers when approaching a Rail – Road Level Crossing, through 6 different paths, at the western area of the city of Thessaloniki. The results were yielded after comparing two datasets concerning the use of the Cooperative – Intelligent Transport Systems service by 168 taxi drivers for 28 days and without the use of the Cooperative – Intelligent Transport Systems service by 15 taxi drivers for 25 days. Even if conclusions are contrasting for the different types of the Rail – Road Level Crossing transits, the findings highlight a relation between speed reduction with types of transits whose first road segment is rectilinear, during Cooperative – Intelligent Transport Systems service use, while minor differentiations are noticed for Rail – Road Level Crossing transits with sharp turns and stop signs.

Keywords

Cooperative Intelligent Transport Systems, in-vehicle warning systems, Rail-Road Level Crossings, taxi drivers

1 Introduction

Transport is considered as one of the most significant sectors worldwide. In the European Union (EU), around 13 million people are employed on the transport industry as well as transport constitutes about 6.3 % of the Union's Gross Domestic Product (GDP) (Horizon 2020, 2017). Transport safety is an issue of major concern. Towards this issue, EU invests on Intelligent Transport Systems (ITS) and Cooperative Intelligent Transport Systems (C-ITS) for increasing safety.

C-ITS aim at the improvement of safety, comfort and capacity of the network as well as at enabling road users and traffic managers to share useful information. Furthermore, the improvement of the safety of Rail-Road Level Crossings (RRLCs) is of great importance as the majority of each country' sectors are involved. However, few research has been conducted for the assessment of C-ITS services whose objective is the improvement of RRLC safety. Indeed, it is a fact that level crossings are a very important element in transport sector because they represent the unique case in which two separate transport systems (road and rail) are intersected. This complex interaction between the two systems is often unpredictable due to the behavior of road users. Despite the increasing number of technological systems that aim to increase safety at RRLCs, such as in – vehicle warning systems, Variable Message Signs (VMS), Closed-Circuit Television (CCTV) systems, obstacle tracking systems, corns and intelligent RRLCs, the occurrence of accidents is consistent and their consequences are classified as the most serious in relation to those of the other road accidents (Davey et al., 2005).

Around 2000 serious accidents occur at European Unions' (EU's) rail infrastructure every year. More specifically, RRLC accidents, which are one of the most significant accident categories, constitute the 26 % of all serious accidents in EU during 2012-2014 (ERA, 2017) and the 25 % during 2011-2015, excluding suicide events which also take place in railway premises (ERA, 2019). However, during 2010 – 2016 there is a gradual decrease of RRLC

Cite this article as: Skoufas, A., Basbas, S., Salanova Grau, J. M., Aifadopoulou, G. (2021) "Analysis of In-Vehicle Warning System for Rail-Road Level Crossings: Case Study in the City of Thessaloniki, Greece", Periodica Polytechnica Transportation Engineering, 49(1), pp. 42–59. https://doi.org/10.3311/PPtr.14892

accidents in the EU, with exception the year 2012 (Report on Railway Safety and Interoperability in the EU, 2018). Moreover, according to a survey, a person is killed or seriously injured in European RRLCs every day on average (ERA, 2017). The external cost of the accidents in the EU countries seems to be particularly high. More specifically, in 2014 the cost of the accidents at EU countries was about 1.4 billion euros of which the 103 million concern material damage, the 71 million concern the external cost of the delays due to the accidents and 71 million the cost of the environmental damage (ERA, 2017). Greece is ranked among the last EU countries as far as the economic impact of the serious accidents is concerned, during 2014-2016 (ERA, 2017; ERA, 2019; Report on Railway Safety and Interoperability in the EU, 2018).

C-ITS services and especially in-vehicle warning systems are becoming one of the most common. Although these emerging technologies allow the communication between the driver with either other drivers or the infrastructure these warnings (especially the visual ones) can lead to drivers' distraction. The time required for the message to be comprehended as well as the time for the processing of the message by the driver should be taken into consideration (Brookhuis and de Waard, 1999). Furthermore, as the implementation of such services is becoming even more popular attention should be paid for the design of the user interface as well as for the presentation of the alert information (auditory, visual or audiovisual).

The purpose of this paper is to provide an enlightening view on the effect of the C-ITS service, whose goal is the increase of RRLC safety, on professional drivers in terms of speed, acceleration and the rate of change of acceleration (jerk). The examined C-ITS service was developed by the Hellenic Institute of Transport of the Centre for Research and Technology Hellas (HIT/CERTH) as part of the European research project "SAFER-LC".

2 Literature review – Impacts of C-ITS in road safety

The section of literature review will highlight the different initiatives that have been taken for the deployment of in-vehicle warning systems. Furthermore, the main C-ITS impact assessment methods will be referred as well as the main impact categories. Last, this section will report the main behavioral characteristics of taxi drivers.

2.1 In-vehicle warning systems

It is significant to point out that the gradual implementation of new technologies for increasing RRLC safety should not be considered as a substitute of the traditional approaches. These new technologies are part of the active RRLC protection as drivers are notified about the presence of RRLCs or about the presence of an approaching train. These notifications can be visual, auditory or a combination of the aforementioned (i.e. audiovisual).

More specifically, these warning technologies concern either direct communication between the car and the train or communication between the cars with the infrastructure. In general, there are two approaches for the communication between vehicles. The first one deals with the direct communication between the train and the car (Vehicle to Vehicle – V2V) while the second one concerns that the communication is accomplished with transceivers (Roadside Unit – RSU) located at RRLCs. It is obvious that cars should be equipped properly to receive the warning messages. These messages could be transmitted by a system consists of a variety of technological equipment such as antennas, transmitters and receivers, radar, microwave technology, Global Navigation Satellite Systems (GNSS), short-range communication devices and Closed-Circuit Television (CCTV) (Towards zero: A strategy for improved level crossing safety in Victoria, 2009).

In-vehicle warning systems are one of the most popular C-ITS approaches for increasing RRLC safety. According to an Australian survey, it has been proved that the in-vehicle warning systems were the most promising in relation to other proposed interventions for increasing safety at RRLCs (Larue et al., 2010). Furthermore, Washington and Oh (2006) have confirmed the suitability of the in-vehicle alert systems as the in-vehicle warning system is among the three best measures for managing RRLC accidents, including obstacle detection and constant warning time.

The prerequisite of the alert systems' functionality is the simultaneous movement of both a train and a car to the RRLC in overlapping time, using RSUs. In-vehicle warning systems can also be adjusted to inform the drivers for RRLC presence even if there is no train approaching the RRLC in overlapping time. This type of alert can contribute to an easier RRLC detection by the driver, the promotion of such a driver behavior for a safer pass-through the RRLC as to the minimization of the drivers' complacency when the alert system is turned off.

On the contrary, at RRLCs with low traffic volumes the alert systems' reliability can be reduced because of the drivers' lower awareness for an approaching train. As a result, drivers would pay less attention to the alerts intentionally. Therefore, it is recommended to distinguish the informative alerts for approaching a RRLC and the alerts that warn drivers for trains' presence at the RRLC (Larue et al., 2010).

A number of tests and pilot projects for in-vehicle warning systems have been carried out in global scale (Larue et al., 2010). The in-vehicle alert system "EV – Alert" has been implemented at Queensland, Australia. The alert system has been used from the industry for the warning of truck drivers, car drivers and tractor drivers about train presence at RRLCs (Tey, 2008). Furthermore, in Australia, a pilot test of an in-vehicle alert system has been taken place relying on cooperative technology (C-ITS). This cooperative service has been deployed as far as the project "ITS to improve safety at Level Crossings" is concerned with 82 % of the drivers reporting that alerts occurred in the right time (Singh et al., 2012).

On that note, GNSS technology is one of the most applicable and has heavily affected the implementation of in-vehicle warning systems. Moreover, the installation of GNSS devices in trains allows the real-time monitoring of trains; If GNSS devices were up to date with the accurate RRLCs locations of an area and if trains were properly equipped, then the car drivers could be reliably warned of the train' position for the approaching RRLC (Odgen, 2007). One of the main advantages of the alert system is that such a system makes an inexpensive alternative for increasing RRLC safety without making interventions at the existing infrastructure. Surveys have revealed that the alert system is theoretically feasible while its reliability (minimization of false positive alerts) and its user (driver) friendly interface design are critical issues (Carroll et al., 2001).

According to Carroll et al. (2001) an evaluation procedure has been carried out for three systems in the United States (US) for the determination of their feasibility in emergency vehicles as well as in heavy vehicles. The two systems which used transmitters and receivers were proven technologically feasible, while the third system which used "an acoustic-detection system that selectively responds to the audio frequency spectrum of locomotive horns" was proven unreliable (Carroll et al., 2001:pp.3-5). The perceived effectiveness of an in-vehicle system implemented at Illinois, US, in a sample of 300 drivers, was described as "high" or "very high" by 43 % of the drivers when 25 % of the drivers characterized its effectiveness as "low" or "very low" (Benekohal and Aycin, 2004; Benekohal and Rawls, 2004; Medina and Benekohal, 2006).

Respectively, in a pilot project for in-vehicle alert (visual, auditory alert) that has taken place in Minnesota, US for 6 months, 30 school buses have taken part and 5 RRLCs. 80 % of drivers described alerts as valuable; however, only 15 % of drivers stated that the alerts affected their driving behavior (RRLC approaching speed, RRLC visual scan when pass through). Additionally, the audiovisual alert system was proven more effective than the audible one according to 55 % of the drivers. Last, only 15 % of the drivers stated distraction during system operation (Carroll and Oxley, 1999; United States Department of Transportation, 2001).

In Canada, a pilot project for an intelligent transit control system (Intelligent Crossing Controller - IXC) has been applied in several heavy vehicles for a large number of RRLCs. The system has been described as feasible but not as viable due to the large number of the vehicles and of the RRLCs (Tadif, 2004).

As far as in-vehicle warning system tests and pilot projects in Europe are concerned, the Technical Research Centre of Finland – VTT, in the context of the project "Junavaro" elaborated an in-vehicle warning system for railway level crossings at the railway section between Hanko and Karjaa, Finland. In total, 63 successful alerts were provided, and 166 trains were detected. The system was characterized by 56.1 % of reliability and by 82.9 % of precision. Warnings were provided to professional drivers and neighbors in RRLCs and data were collected through RRLCs video recording (Öörni, 2014). Furthermore, in Finland, the project "LeCross" allowed the railway operators to provide timely and reliable information, regarding train approach at RRLC, to road network users (Havârneanu et al., 2018).

In France, a first attempt for the deployment of an in-vehicle warning system was made. However, its implementation was not progressed as research and funding resources have been allocated to other programs to improve RRLC safety (Peck and Bousquet, 2012).

2.2 C-ITS impact assessment methods and main impact categories

Transport sector as well as the C-ITS have impacts regarding the social, the economic and the environmental aspects of life. C-ITS services for improving safety require a framework for the assessment of their effects towards the driver, the vehicle and the traffic environment (Giannopoulos et al., 2012).

There are several impact assessment categories concerning the answering of different issues such as the technical assessment of the system performance, the impact assessment, the user acceptance assessment, the economic/financial evaluation, the social evaluation and the market assessment (Salanova Grau et al., 2016). Additionally, there are different evaluation strategies about "how" an evaluation process should be conducted (Mitsakis et al., 2016).

The core categories of the impacts are: scientific, technological, economic, social, political, environmental, health and cultural. The impacts presented afterwards are categorized in an integrated way with focus given in social-health and environmental impacts. Social-health impacts concern the reduction of accidents/injuries, congestion, efficiency and comfort while the environmental impacts concern the protection of the environment (reduction of pollutants) (Chalkiadakis et al., 2019).

The right method chosen for the evaluation of a C-ITS service is of major concern. Factors such as the desirable complexity of the evaluation as the complexity of the method itself have to be taken into account. The chosen method should maintain a balance between the complexity and the cost of the impact assessment procedure. The first step in any impact assessment procedure is the selection of the appropriate evaluation approach (Chalkiadakis et al., 2019).

A first main approach is the goal-oriented approach (GOA). In the context of GOA, the goals are predefined. The predefined objectives concern better safety, better operational efficiency and capacity, enhanced productivity, enhanced personal mobility, convenience and comfort as well as the reduction of energy consumption. This method is mainly used for understanding the impacts, quantifying benefits, help making future investment decisions as well as for the optimization of existing systems design and operation. In GOA there are two types of measures which are critical for the impact assessment process: output and outcome evaluation measures and "few good measures". Output measures concern aggregated facility statistics and therefore they cannot reveal details for the individual's behavior (e.g. travel volumes, vehicle delays). Then, outcome measures concern individual level and thus are easier to be measured (e.g. travel time, travel cost per trip). "Few good measures" provide coherence between evaluations as well as yearly progress of ITS and C-ITS initiatives. However, they demand large amount of data which may increase the total budget of the assessment. Some examples are crashes, fatalities, travel time and cost (Chalkiadakis et al., 2019).

The second main approach is the economic analysis approach (EAA) which focuses on short term and long term economic impacts of ITS and C-ITS perspectives on the: economy, users, private sector, community and environment. This approach enables the quantification of the monetary value of ITS and C-ITS impacts. Hence, it reduces every impact to a single cost-benefit ratio (Chalkiadakis et al., 2019).

2.3 Taxi drivers' driving behavioral characteristics

Taxis are not significantly different from private cars in terms of size and mechanical properties. However, the behavioral characteristics of taxi drivers are relatively different from those of private car drivers. Taxi drivers, as being professional drivers, have better driving skills since they are more familiar with the road environment due to their continuous exposure to different traffic conditions (Stewart et al., 2005).

Nevertheless, taxi drivers' driving experience and their constant exposure to traffic may lead to less careful driving, as far as traffic related risks are concerned (Öz et al., 2010). On the other hand, taxi drivers' income is strongly affected by the number of their customers. As a result, taxi drivers often drive under the pressure of attracting and transferring a customer to his/her destination. Professional drivers, including taxi drivers, are exposed daily to stressful factors such as the driving behavior of other drivers, traffic congestion, noise and the prevailing climatic conditions (Evans et al., 1999). In general, according to Mayhew (2000), Schaufeli and Taris (2014) the profession of taxi driver is considered to be one of the most dangerous and stressful given the frequent emotional load during their working hours but also because of their increased workload (Chin and Huang, 2009).

The behavioral characteristics of taxi drivers make taxis a unique means of transport which may has different functional and safety performance with private cars. According to a survey of Rosenbloom and Shahar (2007), who studied the driving behavior differences between taxi and private car drivers, it has been noticed that taxi drivers take into account, to a lesser extent, the highway code in relation to private car drivers. This suggests that taxi drivers are more susceptible to offenses than car drivers. According to Burns and Wilde (1995), taxi drivers' behavior involves high risk level (speed limit exceedance, reckless traffic lane change, non-observance of safe distance from a vehicle in front) in relation to that of private car drivers. The reckless taxi drivers' behavior does not endanger only drivers themselves but also their customers as well as the other road users (Cheng et al., 2016).

In general, it is concluded that professional drivers are more likely to adopt dangerous driving behavior compared to drivers belong to the general population (Nævestad et al., 2015; Shi et al., 2014; Tseng, 2013). According to surveys, there are some specific personal characteristics related to the frequency of dangerous driving behavior such as sex, age, work experience, educational level and driving experience (Tseng, 2013; Chung and Chang, 2015; Tay and Choi, 2016). Newnam et al. (2014) research which has been conducted between 216 professional drivers, including taxi drivers, has proved that the driving behavior of the older and educated drivers is more dangerous compared with the driving behavior of the eldest and less educated drivers which proved to be contrary to the original assumptions of the research. One additional characteristic of taxi drivers' behavior is their increasing irritation in relation to non – professional drivers' as well as its' close relationship with fatigue according to survey carried out on sample of 70 taxi drivers (Öz et al., 2010).

It is worth mentioning the discontent of taxi drivers to drive within the speed limit in city (Öz et al., 2010). Taxi drivers' irritation can lead to distraction and increasing possibilities for collision (Sullman et al., 2013). According to a survey carried out on sample of 1021 Chinese taxi drivers, the two main reasons for the aggressive behavior of taxi drivers are their increasing fatigue levels as well as their working conditions (Yonggang et al., 2018). More specifically, as far as the male taxi drivers are concerned, it has been proved that they show more frequent unconventional driving behavior (unsafe transit, red light violation, speed limit exceedance, non-observance of safe distance from a vehicle in front, reckless traffic lane change) as well as they are more frequent engaged in collisions (Wang et al., 2014).

In conclusion, it is obvious that taxi drivers are prone to risky driving behavior. Peltzer and Renner (2003) questionnaire survey on a sample of 130 taxi drivers revealed that 40% of the drivers admitted that agreed or strongly agreed with risk taking driving behavior. Last, as far as the taxi drivers' opinion for their driving skills is concerned, Dalziel and Soames Job (1997) survey on sample of 42 taxi drivers revealed the overestimation of taxi drivers' driving skills in relation to the average driver as well as drivers' "certainty" about driving under fatigue conditions.

3 The case study in the city of Thessaloniki, Greece

Thessaloniki is the second largest city in Greece where approximately one million inhabitants are residing in its greater area. The city is located in the northern Greece and because of its geographical position Thessaloniki plays an important financial and commercial role both in Balkan and national region. Furthermore, Thessaloniki was the living lab for ITS and C-ITS services testing for many research projects (COMPASS4D, COGISTICS, C-MOBILE). Additionally, Thessaloniki is one of the most significant railway hubs in national level (Mitsakis et al., 2013).

3.1 The C-ITS service

The implementation of the C-ITS service is one of the first tests of such cooperative service in European level. The main elements of the warning system for RRLC presence are the following:

- Location tracking devices and monitoring systems
- Detection system
- Alert system / Human – Machine Interface (HMI)

The detection system is based on a map for crosscheck taxis' location in real time. The RRLC is traced out by two pre-defined polygons of the road and rail network. A polygon area around every RRLC was defined manually in a case by case approach, due to the different nature and topology of each LC and nearby road network. All polygons are designed considering two general principles, according to which:

- They should include all road sections heading to the RRLC within a 80-meter radius from the rail, to ensure that alerts will be generated for all test vehicles heading to RRLC well before they reach the dangerous area.
- They should exclude all nearby road sections not heading to RRLC, to avoid false positives (irrelevant alerts for vehicles not heading to the level crossing).

Rail polygon includes the railway tracks for a length of approximately 1 kilometer from the RRLC in both directions. Therefore, trains can be monitored sufficiently before reaching the RRLC.

If one taxi enters the polygon or a train and a taxi are in the same polygon group, an audio-visual alert will be generated. This alert informs the taxi driver about the RRLC's presence (static message) when the driver enters in the polygon or informs him/her about the approaching train and the estimated time of arrival (ETA) when a train enters the polygon simultaneously (dynamic message) (Salanova Grau, 2019). ETA is calculated using train' position and speed (Boufidis et al., 2019a). The ETA predictions are made using machine learning algorithms (Boufidis et al., 2019b). The alert system relies on mobile communication and the alert is provided through a pop-up window appearing on the navigation devices of the taxis (SAFER Level Crossing by integrating and optimizing road-rail infrastructure management and design. Implementation guidelines, 2018).

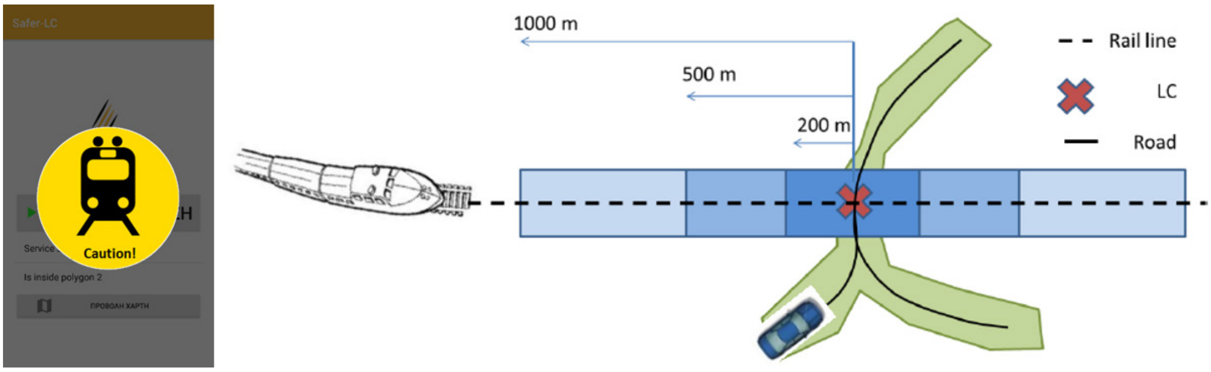


Fig. 1 Warning (static) message when approaching the RRLC (left) and theoretical representation of rail and road polygons for the alert system in Thessaloniki, Greece (right)

Fig. 1 represents the static message (alert) which informs drivers for the RRLC presence as well as the theoretical representation of the road and rail polygons for the alert system.

3.2 Site profile

The RRLC at the 3+400 kilometer mark of the railway line Thessaloniki – Athens (Polygon 17) was chosen as the site of research because of its high traffic volumes. The RRLC – site of the present study is an active RRLC with automatic user side protection and warning and rail side protection. Although the RRLC is protected, there are a lot of cases during which the protection system is out of order when a train is approaching the RRLC. At the specific RRLC a local road with 2 traffic lanes and the triple track railway line are intersected as well as RRLC' length is 11 m. The speed limit of all local roads is defined to 50 km/h according to the Greek highway code. Furthermore, the 2 railway tracks southern of the RRLC are not used either from passenger or freight trains.

Fig. 2 illustrates the RRLC polygon of the road network as well as the elements of the vertical signing that already exist (OpenStreetMap).

Figs. 3 and 4 presents the southern and the northern view of the RRLC respectively.

As a next step, all possible types of transit had to be defined. In total, there are six (6) RRLC transit types which have been occurred from the estimation of all possible entrance points of the RRLC polygon (origin points). In Fig. 5 the two (2) types of transit with their origin point northern of the RRLC are described.

Table 1 describes the types of transit whose origin point is northern of the RRLC as well as their vertical signing elements (Flaticon Support).

Fig. 6 are described the four (4) transit types with their origin point southern of the RRLC.

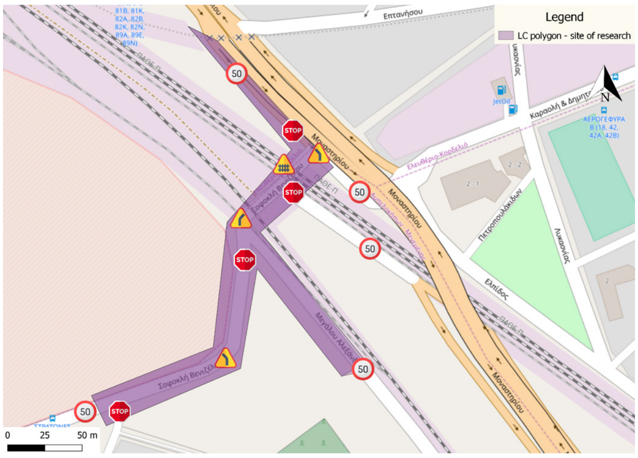


Fig. 2 The RRLC - site of research, the pre-defined polygon and the vertical signing elements of the road network

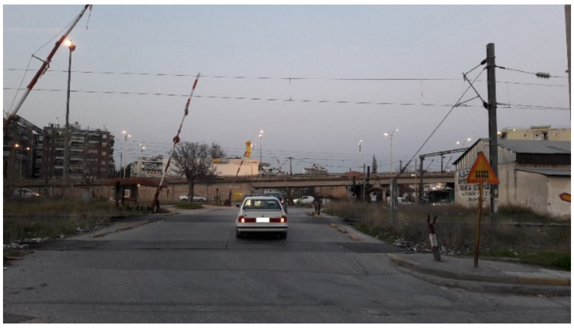


Fig. 3 South view of the RRLC

Fig. 4 North view of the RRLC

Table 1 Transit types with origin point northern of the RRLC

Transit type	Map color	Vertical signing elements
1	Red	Polygon entrance → STOP → ⚠ → RRLC
2	Green	Polygon entrance → ⚠ → ⚠ → RRLC

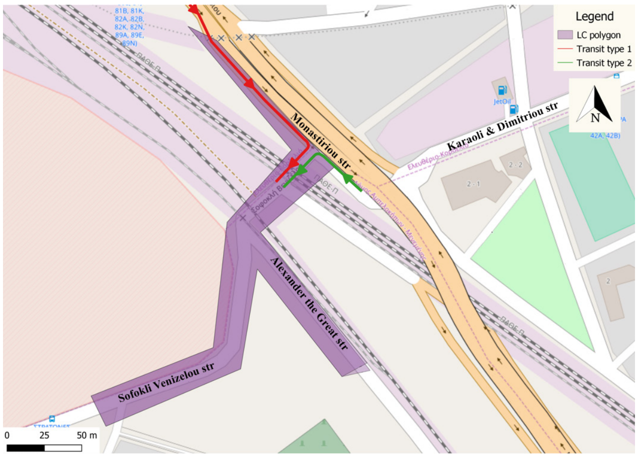


Fig. 5 Transit types with origin point northern of the RRLC

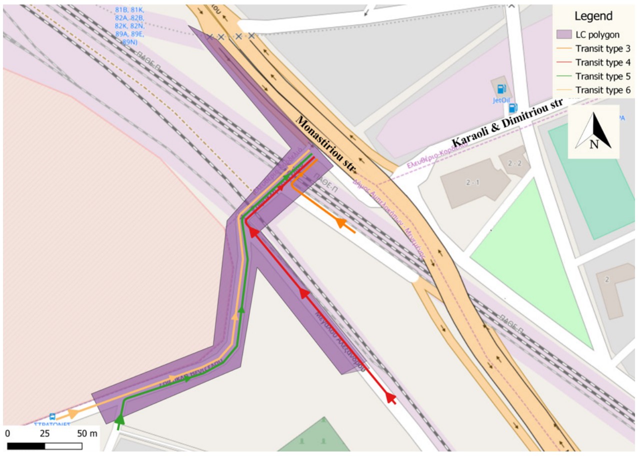


Fig. 6 Transit types with origin point southern of the RRLC

Table 2 Transit types with origin point southern of the RRLC

Transit type	Map color	Vertical signing elements
3	Orange	Polygon entrance → STOP → ⚠ → RRLC
4	Red	Polygon entrance → ⚠ → ⚠ → RRLC
5	Green	Polygon entrance → STOP → ⚠ → STOP → ⚠ → ⚠ → RRLC
6	Salmon	Polygon entrance → ⚠ → STOP → ⚠ → ⚠ → RRLC

Table 2 describes the types of transit whose origin point is southern of the RRLC as well as their vertical signing elements.

3.3 C-ITS service test

At first, data collection was conducted without the activation of the C-ITS service. Hence, data accuracy was examined. Data were gathered with successively transits through 3 different RRLCs at the western area of Thessaloniki (including the one which is the site of the research). Transits were taken place in different times in the same day with different approaching speeds and breakings. Then, the first data were analyzed and visualized for the purpose of testing. The specific RRLCs belong to the railway line Athens – Thessaloniki which is the most important line in the Greek area from passenger view. According to the European Railway Safety Directive 2016/798 the specific RRLCs are classified as active with automatic user side protection and warning and rail side protection (SAFER Level Crossing by integrating and optimizing road-rail infrastructure management and design. Implementation guidelines, 2018).

Fig. 7 illustrates the three (3) RRLCs as well as the polygons of the road network where the C-ITS service was tested before the deployment by the taxi drivers.

3.4 Data and descriptive analytics

In general, datasets generated by taxi fleets fall into two main categories. The first one concerns trajectory related data (GPS coordinates, status, orientation, speed) while the second one taxi trip related data (origin, destination, submission time, departure time, duration, distance and cost) (Salanova Grau et al., 2017)

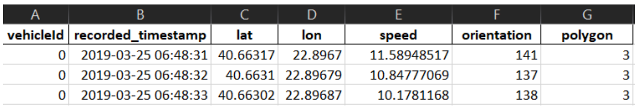
Fig. 7 The location of the RRLCs where the C-ITS service tested

The data analyzed for the purpose of the specific research fall into the category of Floating Car Data (FCD) which were collected by HIT/CERTH during "SAFER-LC" pilot test and part of them were conceded for the elaboration of the present research. FCD consist of vehicle id, timestamp, latitude, longitude, speed (m/s), orientation and polygon id. FCD inside the polygon were recorded every one second (1s). Fig. 8 presents an overview of the FCD.

This high density of taxis' GPS data inside the predefined polygon enables the estimation of the cars' emissions to the environment (Salanova Grau et al., 2019).

Fig. 9 summarizes the number of the recorded transits for all types of transit for the two periods.

Last, Table 3 presents the number of FCD records for every type of transit for the two recording periods as well as the number of drivers (of the total drivers' sample) that recorded for every type of transit.



A	B	C	D	E	F	G
vehicleId	recorded_timestamp	lat	lon	speed	orientation	polygon
0	2019-03-25 06:48:31	40.66317	22.8967	11.58948517	141	3
0	2019-03-25 06:48:32	40.6631	22.89679	10.84777069	137	3
0	2019-03-25 06:48:33	40.66302	22.89687	10.1781168	138	3

Fig. 8 Overview of the FCD

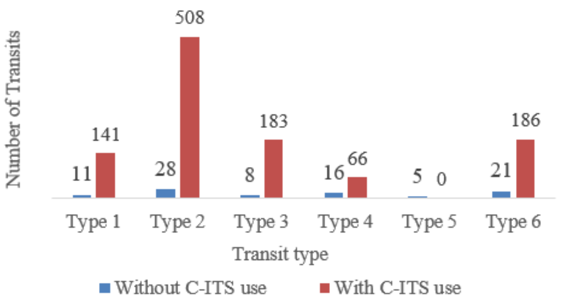


Fig. 9 Number of transits recorded without the use of the C-ITS service and with the use of the C-ITS service

Table 3 Number of FCD records and drivers that recorded during baseline and application scenarios

Transit Type	Baseline scenario		Application scenario	
	Number of FCD records	Number of drivers recorded	Number of FCD records	Number of drivers recorded
1	368	5	6567	58
2	713	11	17118	133
3	121	3	4979	90
4	491	7	2855	38
5	284	3	-	-
6	1061	9	9668	85

3.5 Methodological framework for the assessment of the C-ITS service

Initially, first data that were obtained for 25 days concern no use of the C-ITS service by the taxi drivers (baseline scenario). Then, taxi drivers were recorded for a period of 28 days using the C-ITS service (application scenario). Moreover, the driver' dynamic indicators (speed, acceleration, jerk) were chosen for the implementation of the service' assessment. For both datasets, data filtering was preceded in the data analysis procession. FCD that do not concern RRLC transits were cleaned (i.e. trajectories with both origin and destination point northern or southern of the RRLC). Furthermore, possible false positives were cleaned too.

From the initial data analysis, the general profiles of speed, acceleration and jerk versus the distance from the RRLC start were estimated using the Local Estimated Scatterplot Smoothing (LOESS) method and the formula for less than 1000 observations of the relative dataset. Generalized Additive Model (GAM) and formula was used for greater than 1000 observations of the relative dataset. For the estimation of the profiles, data concerning up to drivers' exit from the RRLC were used as well as data with drivers' speed over 5 km/h. This last "convention" was considered important because almost zero speeds could designate a potential consignment of the road segment where the drivers drove or a driver' stop when approaching the RRLC. Confidence level of the profiles was set to 0.95.

Table 4 summarizes methods and formulas used for the different types of transits.

For transit type 5 there were no record during the application scenario.

For the GAM formula:

s: Function used in definition of smooth terms within GAM model formula.

bs = "cs": These have a cubic spline basis defined by a modest sized set of knots spread evenly through the covariate values. They are penalized by the conventional integrated square second derivative cubic spline penalty (Stat.ethz.ch, 2019).

The comparative analysis between the two datasets was made in terms of speed, acceleration and jerk for every type of transit separately. For every type of transit, there is a comparative plot of speed vs. RRLC distance, acceleration vs. RRLC distance and jerk vs. RRLC distance. Furthermore, for a better understanding of the spatial visualization of the 3 variables (speed, acceleration, jerk), data are depicted on map concerning the use and without of the

Table 4 Methods and formulas used for the general profiles of speed, acceleration and jerk for the different types of transit

Transit type	Baseline scenario	
	Method	Formula
1	LOESS	$y \sim x$
2	LOESS	$y \sim x$
3	LOESS	$y \sim x$
4	LOESS	$y \sim x$
5	LOESS	$y \sim x$
6	GAM	$y \sim s(x, bs = \text{"cs"})$
Transit type	Application scenario	
	Method	Formula
1	GAM	$y \sim s(x, bs = \text{"cs"})$
2	GAM	$y \sim s(x, bs = \text{"cs"})$
3	GAM	$y \sim s(x, bs = \text{"cs"})$
Transit Type	Application scenario	
	Method	Formula
4	GAM	$y \sim s(x, bs = \text{"cs"})$
5	-	-
6	GAM	$y \sim s(x, bs = \text{"cs"})$

C-ITS service use. It is worth mentioning that during the application scenario there was no record of transit type 5. As a result, no comparison was made for the specific type of transit. Last, for the spatial visualization of speed, acceleration and jerk every type of transit was binned into 10m segments, beginning from polygon' entrance point and ending at the ending point of the RRLC.

4 Results

In the section of results the comparative analysis in terms of speed, acceleration and jerk will be presented for all types of transit (except transit type 5). Alongside, the spatial profiles of speed, acceleration and jerk will be presented.

4.1 Transit type 1 – comparative results

During baseline period 11 transits by 5 drivers were recorded (12 % of transits sample) while during the period with the C-ITS service use 141 transits by 58 drivers were recorded (13 % of transits sample). Table 5 summarizes the main statistics of the two datasets which were analyzed.

C-ITS service use affected drivers' behavior in terms of speed, acceleration and jerk. More specifically, the use of the service reduced drivers' mean approaching speed by 12.1 % as well as led to a rise of the mean approaching acceleration and jerk by 10.4 % and by 25 % respectively.

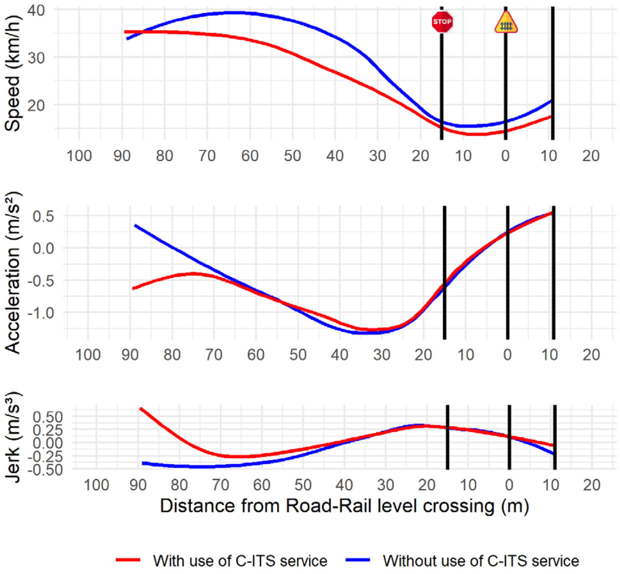


Fig. 10 General profiles of speed, acceleration and jerk during baseline and application period for transit type 1

Table 5 Main comparative statistics for transit type 1

Main statistics	Baseline scenario		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	6.12	−4.50	−2.70
Median	20.59	−0.40	0.00
Mean	23.31	−0.48	0.08
Maximum	52.99	1.70	5.00
Main statistics	Application scenario		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	5.04	−10.10	−9.70
Median	17.17	−0.30	0.00
Mean	20.49	−0.43	0.10
Maximum	62.14	3.30	17.00

Fig. 10, including the elements of vertical signing as well as the end of the RRLC of the transit type 1, compares the general profile of speed, acceleration and jerk between baseline and application scenario for transit type 1.

According to Fig. 10, during application scenario, drivers drive with lower speed throughout the transit in comparison with their speeds during baseline scenario. More specifically, mean approaching speed is reduced by 13.1 % in the road segment between polygon' start point and the stop sign as well as by 11.8 % in the road segment between the stop sign and RRLC end. As far as acceleration and jerk profile are concerned, little differentiation is observed especially for the first 50 m from entering the polygon.

Figs. 11, 12 and 13 visualize the spatial general profiles of speed, acceleration and jerk during baseline and application scenario respectively (OpenStreetMap).

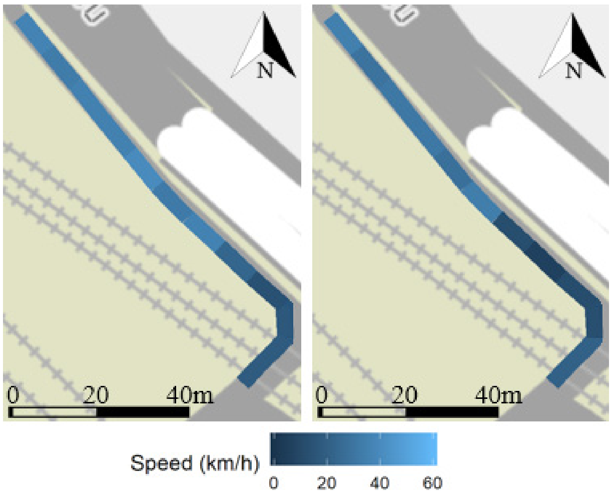


Fig. 11 Spatial general profile of speed during baseline period (left) and application period (right) for transit type 1

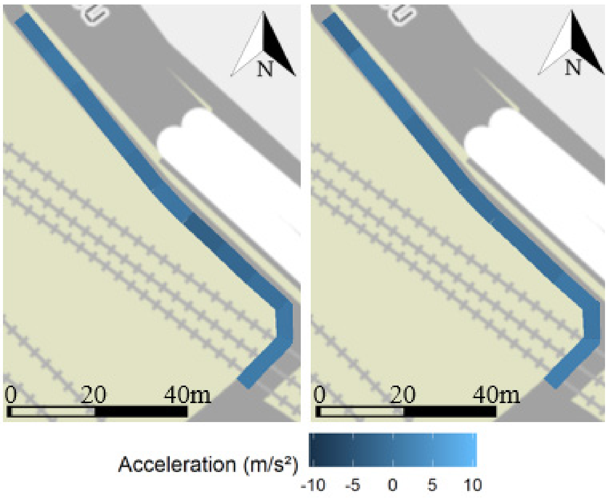


Fig. 12 Spatial general profile of acceleration during baseline period (left) and application period (right) for transit type 1

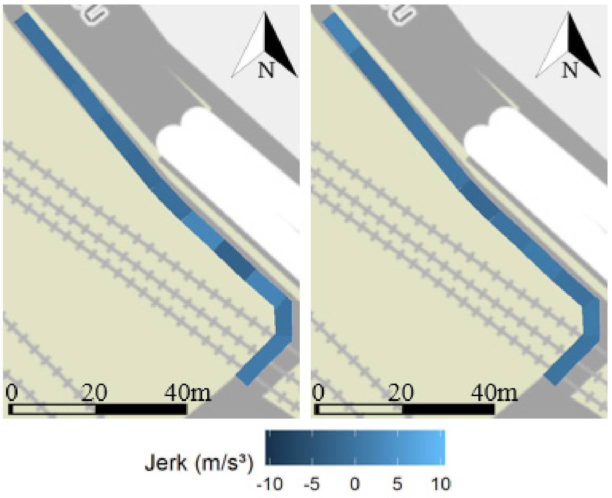


Fig. 13 Spatial general profile of jerk during baseline period (left) and application period (right) for transit type 1

4.2 Transit type 2 – comparative results

Transit type 2 is the most beaten transit type since 28 transits by 11 drivers (31 % of transits' sample) were recorded during baseline scenario and 508 transits by 133 drivers (47 % of transits' sample) were recorded during application scenario. Table 6 summarizes the main statistics of the two datasets which were analyzed.

According to Table 6, C-ITS service use led to an increase of the mean approaching speed by 1.7 % as well as a reduction of the mean approaching acceleration by 152.4 % and to an increase of the mean approaching jerk by 133.3 %.

Fig. 14, including the elements of vertical signing as well as the end of the RRLC of the transit type 2, are compared the general profiles of speed, acceleration and jerk between baseline and application period for transit type 2.

Table 6 Main comparative statistics for transit type 2

Main statistics	Baseline scenario		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	6.05	−1.30	−1.90
Median	14.11	0.20	0.10
Mean	13.87	0.21	0.06
Maximum	24.55	1.60	1.80
Main statistics	**Application scenario**		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	5.04	−8.70	−13.00
Median	14.08	−0.10	0.10
Mean	14.11	−0.11	0.14
Maximum	64.01	4.30	15.50

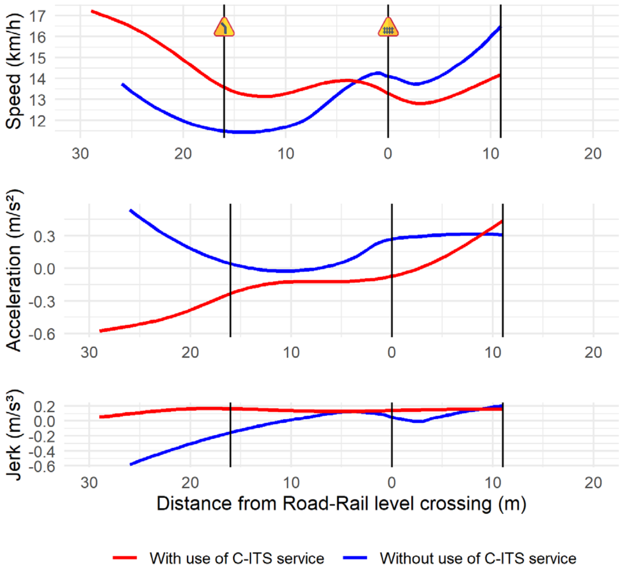


Fig. 14 General profiles of speed, acceleration and jerk during baseline and application period for transit type 2

According to Fig. 14, at the road segment between 3 m before RRLC start and RRLC end, the mean approaching speed with use of the C-ITS service is reduced by 7.7 %. Furthermore, the use of the C-ITS service led drivers to approach the RRLC decelerating. On the contrary, drivers during baseline period approach the RRLC accelerating. Last, the mean approaching jerk during the baseline period is greater because of the greater changes in acceleration.

Figs. 15, 16 and 17 illustrate the spatial general profiles of speed, acceleration and jerk during baseline and application scenario respectively.

4.3 Transit type 3 – comparative results

During baseline period 8 transits by 3 drivers (9 % of transits' sample) were recorded and 183 transits by 90 drivers (17 % of transits' sample) were recorded during application period. Table 7 summarizes the main statistics of the two datasets which were analyzed.

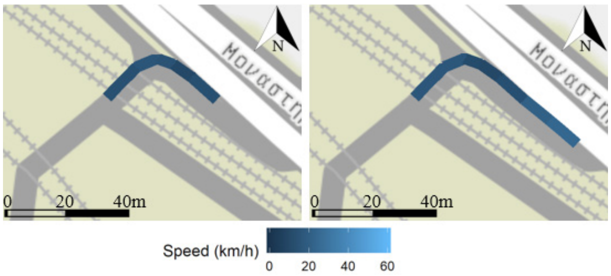


Fig. 15 Spatial general profile of speed during baseline period (left) and application period (right) for transit type 2

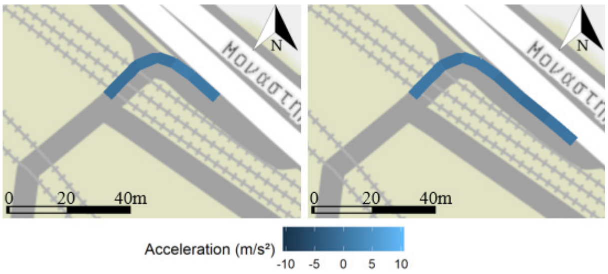


Fig. 16 Spatial general profile of acceleration during baseline period (left) and application period (right) for transit type 2

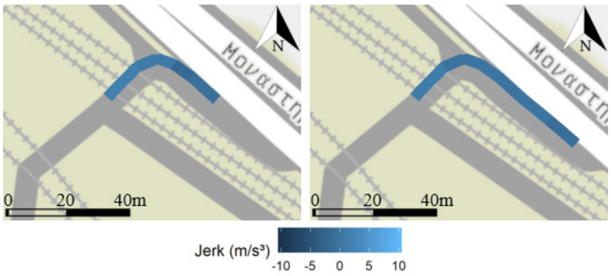


Fig. 17 Spatial general profile of jerk during baseline period (left) and application period (right) for transit type 2

Table 7 Main comparative statistics for transit type 3

Main statistics	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
	Baseline scenario		
Minimum	5.83	−4.00	−2.00
Median	10.85	0.00	0.10
Mean	10.50	0.02	0.28
Maximum	15.70	1.40	7.90
	Application scenario		
Main statistics	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	5.04	−5.20	−5.20
Median	11.23	0.00	0.10
Mean	11.64	−0.05	0.14
Maximum	37.66	3.00	8.40

During the period with the C-ITS service use the mean approaching speed was increased by 10.9 %. The mean approaching acceleration and the mean approaching jerk were both reduced by 350 % and 50 % respectively. Additionally, during application period, drivers approach the RRLC decelerating while during baseline period approach the RRLC slightly accelerating.

Fig. 18, including the elements of vertical signing as well as the end of the RRLC, are compared the general profiles of speed, acceleration and jerk between baseline and application period for transit type 3.

Figs. 19, 20 and 21 visualize the spatial general profiles of speed, acceleration and jerk during baseline and application period for transit type 3 respectively.

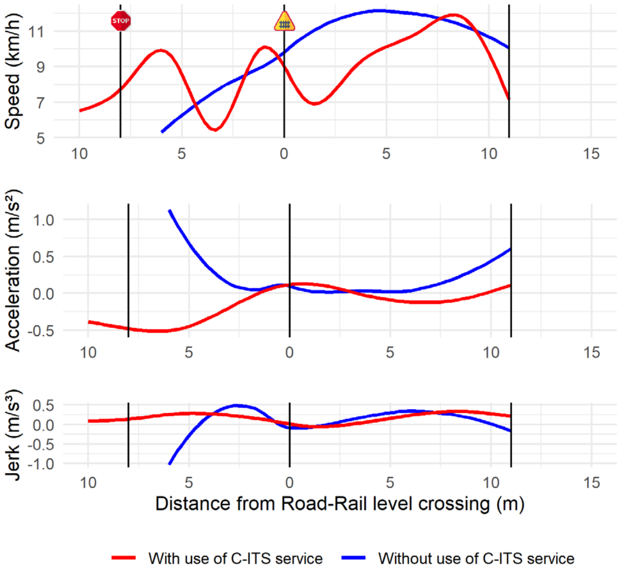


Fig. 18 General profiles of speed, acceleration and jerk during baseline and application period for transit type 3

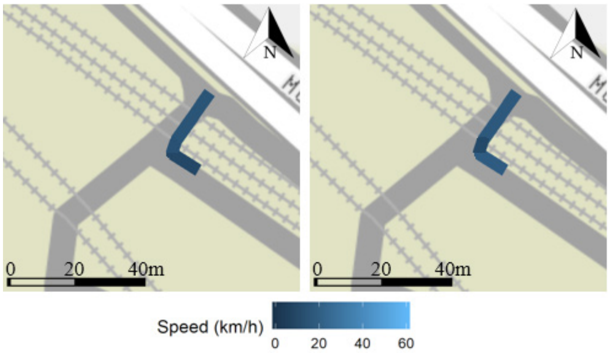


Fig. 19 Spatial general profile of speed during baseline period (left) and application period (right) for transit type 3

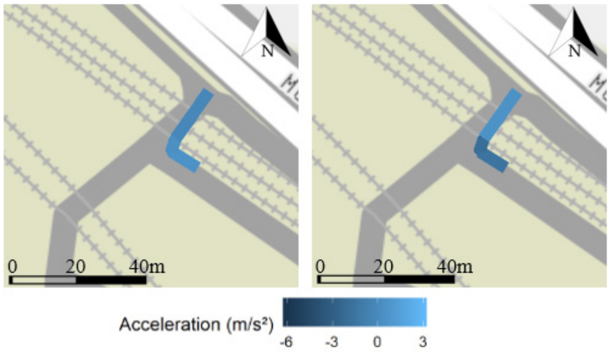


Fig. 20 Spatial general profile of acceleration during baseline period (left) and application period (right) for transit type 3

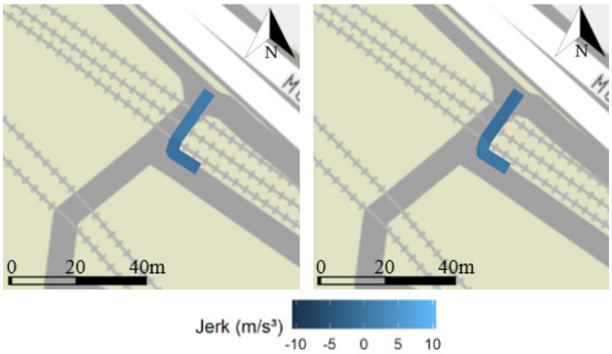


Fig. 21 Spatial general profile of jerk during baseline period (left) and application period (right) for transit type 3

4.4 Transit type 4 – comparative results

During baseline period 16 transits by 7 drivers (18 % of transits' sample) were recorded and 66 transits by 38 drivers (6 % of transits' sample) were recorded during application scenario. Table 8 summarizes the main statistics of the two datasets which were analyzed.

The use of the C-ITS service result in an increase of the mean approaching speed by 4.2 %, a reduction of the mean approaching acceleration by 27 % and an increase of the mean approaching jerk by 1000 %.

Table 8 Main comparative statistics for transit type 4

Main statistics	Baseline scenario		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	5.15	−12.70	−12.10
Median	15.84	−0.25	0.00
Mean	20.06	−0.37	0.02
Maximum	58.07	1.40	13.40
Main statistics	**Application scenario**		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	5.04	−18.10	−10.20
Median	16.78	−0.30	0.00
Mean	20.90	−0.47	0.22
Maximum	65.20	3.50	34.00

Fig. 22 including the elements of vertical signing as well as the end of the RRLC, are compared the general profiles of speed, acceleration and jerk between baseline and application period for transit type 4.

According to Fig. 22, the main differences in speed, acceleration and jerk profiles are observed during the first 40m from entering the polygon as drivers (during the application scenario) entering the polygon with mean speed, acceleration and jerk 26.81 km/h, −1.73 m/s^2 and 0.43 m/s^3 respectively. During baseline scenario drivers entering the polygon with mean speed, acceleration and jerk 44.12 km/h, −0.32 m/s2 and 0.31 m/s^3 respectively.

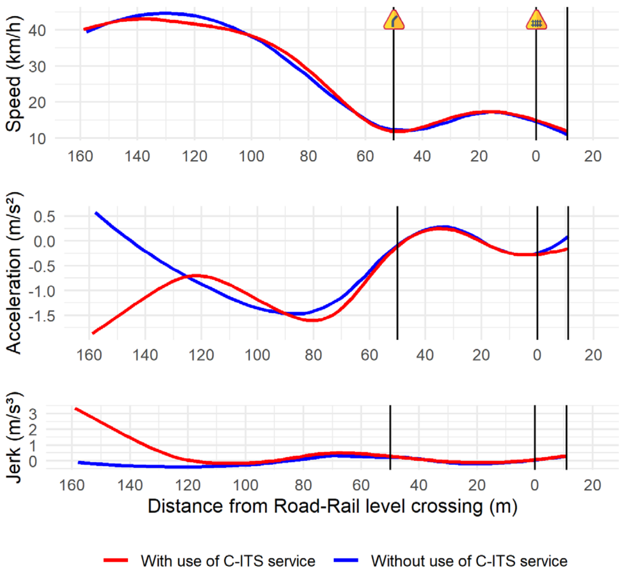


Fig. 22 General profiles of speed, acceleration and jerk during baseline and application period for transit type 4

Figs. 23, 24 and 25 visualize the spatial general profiles of speed, acceleration and jerk during baseline and application period respectively.

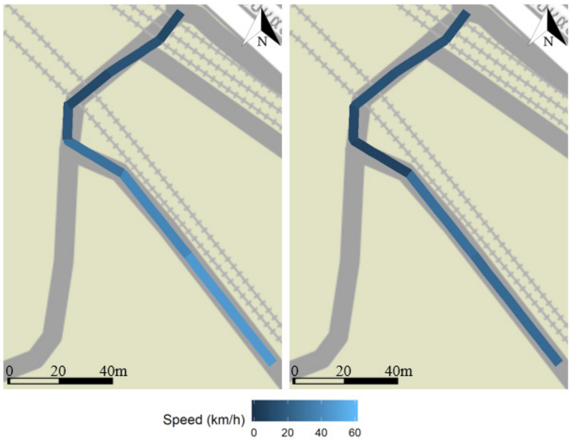


Fig. 23 Spatial general profile of speed during baseline period (left) and application period (right) for transit type 4

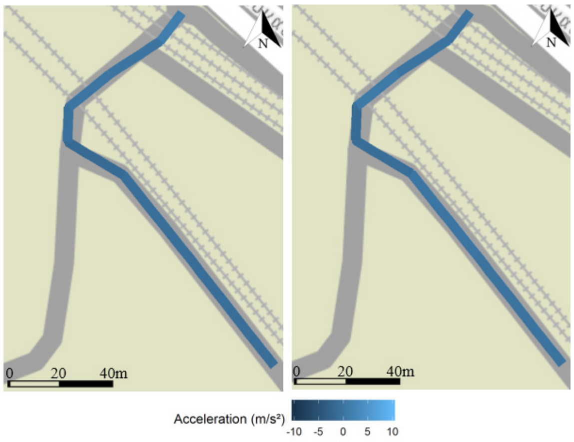


Fig. 24 Spatial general profile of acceleration during baseline period (left) and application period (right) for transit type 4

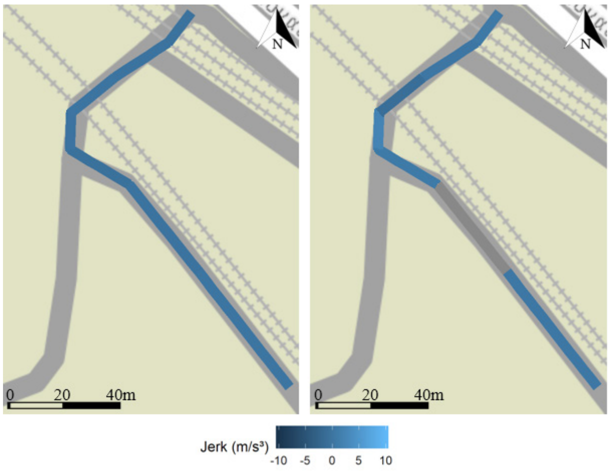


Fig. 25 Spatial general profile of jerk during baseline period (left) and application period (right) for transit type 4

4.5 Transit type 5 – comparative results

During baseline period 5 transits by 3 drivers (6 % of transits' sample) were recorded. However, during the period with use of the C-ITS service there was no a record of such a transit. As a result, a comparison between the two datasets could not be realized.

4.6 Transit type 6 – comparative results

In baseline period 21 transits by 9 drivers (24 % of transits' sample) were recorded and 186 transits by 85 drivers (17 % of transits' sample) were recorded during application period. Table 9 summarizes the main statistics of the two datasets which were analyzed.

During the period with use of the C-ITS service, drivers' mean approaching speed decreased by 2.9 % as well as the mean approaching jerk increased by 400 %. As far as the mean approaching acceleration is concerned, there is no differentiation with the C-ITS service use.

Fig. 26 including the elements of vertical signing as well as the end of the RRLC, are compared the general profiles of speed, acceleration and jerk between baseline and application period for transit type 6.

According to Fig. 26, the main difference in speed profile is in the road segment between polygon start and 120m before the RRLC (180 – 120m before the RRLC). For this specific segment, the mean speed is decreased by 6.8 % during the application scenario. Furthermore, the general profiles of acceleration and jerk during the application period are sharpener due to the greater differences of speed.

Figs. 27, 28 and 29 visualize the spatial general profiles of speed, acceleration and jerk during baseline and application period respectively.

Table 9 Main comparative statistics for transit type 6

Main statistics	Baseline scenario		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	5.04	−4.60	−4.20
Median	17.24	−0.20	0.00
Mean	19.17	−0.22	0.01
Maximum	51.01	1.70	7.70
Main statistics	Application scenario		
	Speed (km/h)	Acceleration (m^2/s)	Jerk (m^3/s)
Minimum	5.04	−12.10	−12.80
Median	16.63	−0.20	0.00
Mean	18.61	−0.22	0.05
Maximum	45.72	3.60	19.70

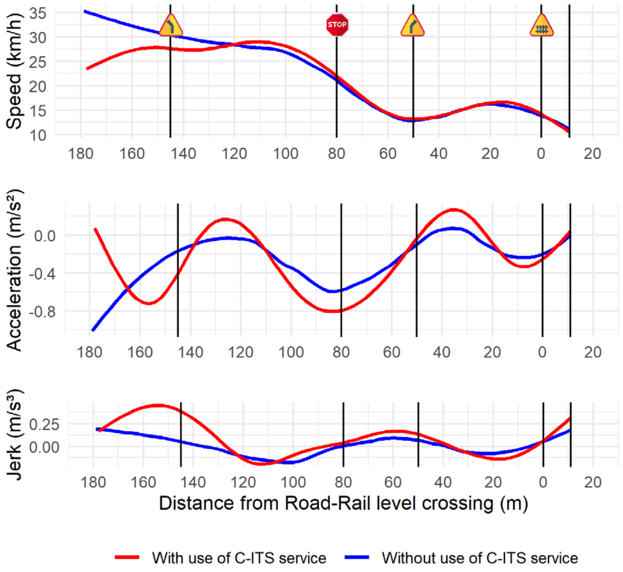


Fig. 26 General profiles of speed, acceleration and jerk during baseline and application period for transit type 6

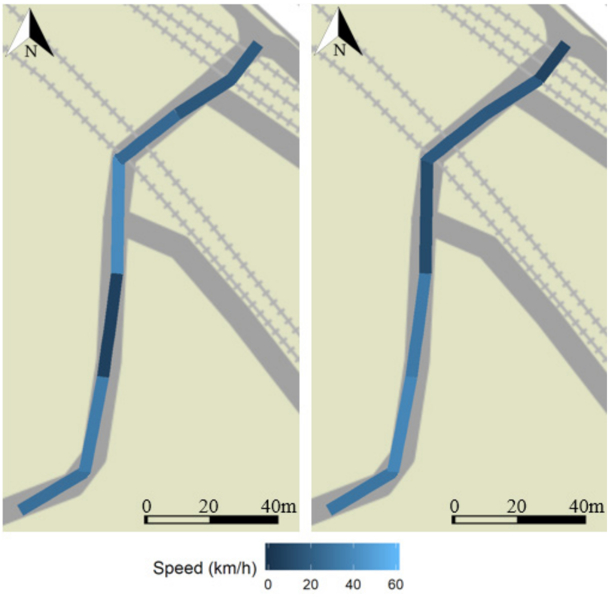


Fig. 27 Spatial general profile of speed during baseline period (left) and application period (right) for transit type 6

According to the analysis, one can notice that during application period the total number of transits is noticeably bigger. Namely, 1084 transits were recorded during application period in contrast with the 89 transits during baseline scenario. Fig. 30 summarizes the speed percentage difference with the C-ITS service use in comparison with the baseline period.

Last, Table 10 summarizes the speed, acceleration and jerk percentage difference with the C-ITS service use.

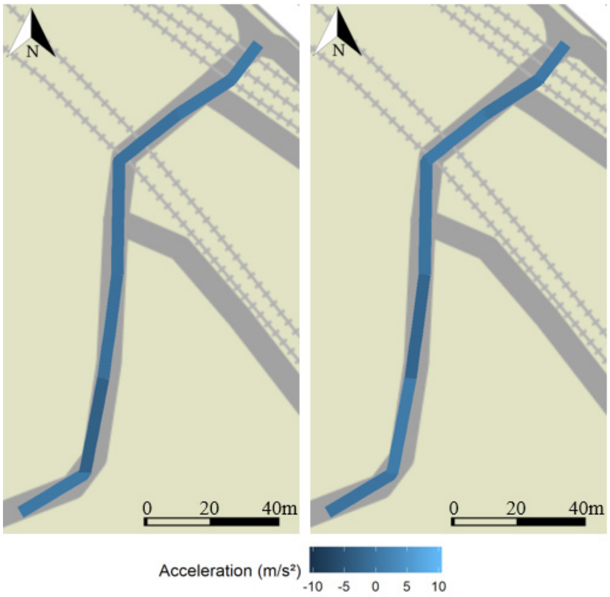


Fig. 28 Spatial general profile of acceleration during baseline period (left) and application period (right) for transit type 6

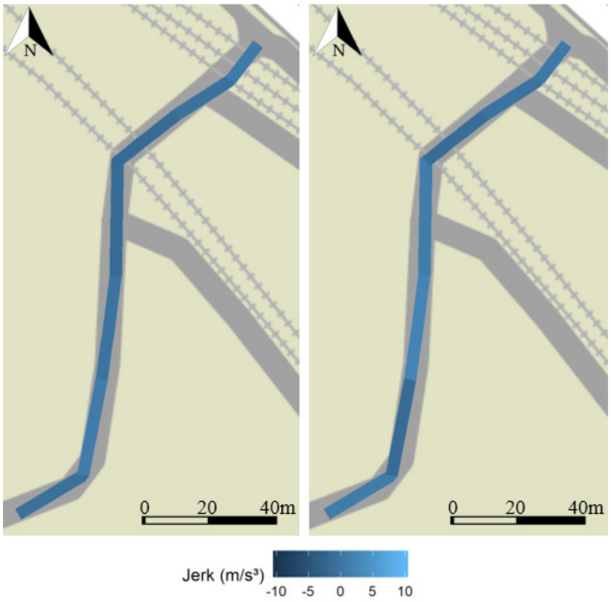


Fig. 29 Spatial general profile of jerk during baseline period (left) and application period (right) for transit type 6

Table 10 Summary of the speed, acceleration and jerk mean percentage difference for all transit types

Transit Type	Speed difference	Acceleration difference	Jerk difference
1	−12.1 %	+10.4 %	+25 %
2	+1.7 %	−152.4 %	+133.3 %
3	+10.9 %	−350.0 %	−50.0 %
4	+4.2 %	−27.0 %	+1000.0 %
5	No recording during the period of the C-ITS service use		
6	-2.9 %	0.0 %	+400.0 %

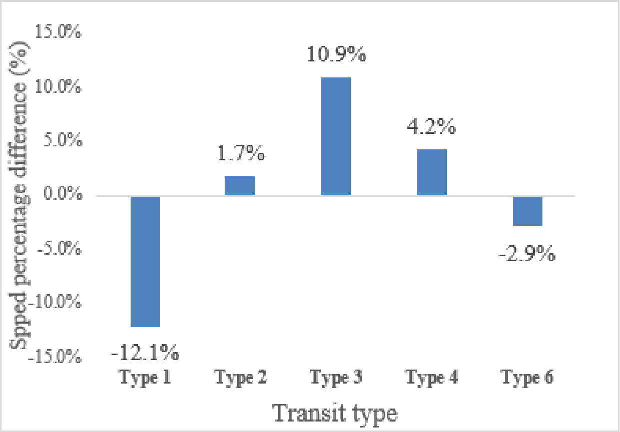


Fig. 30 Speed percentage difference with the C-ITS service use for all types of transit

5 Discussion and future directions

Several factors should be taken into consideration when one interprets the results of the present research. To begin with, the data samples were selected with the criterion of sample' duration for one month approximately. Therefore, these samples cannot be considered as representative samples of taxi drivers who used and who did not use the C-ITS service. Moreover, the present research does not attempt to provide empirical generalizations about taxi drivers who used the service. The results concern only the specific drivers who used the service for the specific period. Despite these limitations, taxi drivers provided an enlightening insight on how new technologies affect the behavior of professional drivers in terms of speed, acceleration and jerk. Furthermore, the assessment of the C-ITS service could be also realized with ordinary drivers as participants. It should be taken into consideration that taxi drivers, as being professional drivers, are more familiar with the road environment in general and with the RRLC presence specifically. As a result, a percentage of the latter might be alerted for an already known situation. It would be more informative to study drivers' behavior when they were warned about the train' ETA. As a result, a relation between ETA and the variables of speed, acceleration and jerk could occur. In the present research, this relation could not be realized since there were only two scenarios during which taxi drivers were informed about the ETA. Hence, it is no possible for clear conclusions to arise.

If ordinary drivers were used as participants, the results may differ for the different types of transit. For further research purposes, revealed preference questionnaires should be conducted so the taxi drivers can have the opportunity to assess the C-ITS service by their side. Additionally, this survey could reveal their relation with new technologies, taking into account socio-demographic attributes (age, sex, income, educational level etc.).

However, few research has been conducted for the assessment of C-ITS services whose goal is the improvement of RRLC safety or the management of risky situations around the RRLC environment. The present research presents the first results of the assessment of a C-ITS service regarding RRLC safety using FCD. FCD analysis can point out behavioral characteristics of the taxi drivers under different traffic (congestion or not), RRLC (approaching train or not) and weather conditions. Furthermore, FCD can contribute to the identification of traffic congestion as well as to the calculation of accurate travel times. In that case, both railway and taxi operators can coordinate their actions such as optimizing their schedule (real-time rescheduling, information for taxi ranks) and providing reliable information to their passengers (such as the arrival time in real-time traffic conditions). Of course, in the context of the present research FCD originate only from taxi drivers and trains only so there are limitations of achieving broader targets.

Transportation data are one of the most significant for the smart city concept. In a smart city data (or Big Data) and Information and Communication Technologies (ICT) are used for many purposes such as optimization of network, increasing safety and performance by using new technologies and services, reducing fuel consumption or establishing electronic payment systems. As a result, it is obvious that C-ITS systems are the basic pillar of smart cities as far as transport sector is concerned. Hence, the realization and testing of C-ITS services are strong initiatives which lead to the transformation of cities to smart cities with significant economic, social and environmental benefits for all citizens.

Last, the use of transportation data by transport operators may raise questions concerning privacy and morality. For example, real-time data can reveal whether a driver violates the highway code (e.g. speed limit exceedance). At this point, the dilemma of informing the competent authorities (e.g. traffic police) emerges. If one takes into consideration that connected mobility is the previous step before automated mobility, then a lot of questions regarding privacy, liability, interoperability and cybersecurity are emerged. As a result, the testing of connected services requires sufficient policy elaboration for handling the key issues.

6 Conclusions

RRLC safety is a critical issue that concerns all the involving sectors worldwide. Even if a lot of technological solutions were implemented for the improvement of RRLC safety, few research has been conducted about C-ITS services whose goal is the improvement of RRLC safety. The current study was designed to assess one of the first C-ITS services in Europe in terms of speed, acceleration and jerk with professional drivers as participants. Therefore, the present results contribute to the literature review as far as how professional drivers adapt their behavior (in terms of speed, acceleration and jerk) using a C-ITS service.

According to the present research, taxi drivers seem to be conformed to the local speed limit in general. Furthermore, during the application scenario, drivers' approaching speed is reduced for the transit types whose first segment is rectilinear. For the types of transit whose horizontal alignment includes sharp turns or stop signs are existing, drivers' mean approaching speed is marginally increased. Despite this slightly increase in speed, taxi drivers are decelerating in a more intense way during the application scenario. As far as approaching jerk is considered, the present research highlights an increase in its mean approaching value for all types of transit except transit type 3. It should be taken into consideration that either sharp turns or stop signs can affect drivers' behavior in terms of speed in advance. Moreover, each driver is responsible for the acceleration and jerk levels that occur during the route since the driver can freely select the level of the moving speed, according to the prevailing traffic conditions.

Similar research should be carried out worldwide so more general conclusions could be arisen regarding this issue. In the present research, for the different transit types an association with the characteristics of the horizontal alignment as well as the elements of the vertical signing of the different types of transit has emerged. The findings of the present study may pave the way towards further research in this specific scientific field.

Acknowledgement

The data of the present research have been conceded in the framework of "SAFER-LC" project by HIT/CERTH. The project has received funding from the EU's Horizon 2020 research and innovation programme under grant agreement No 723205.

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