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Scientific Review

The possibility of traffic accident reconstruction using event data recorders – a review

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Abstract: *Event Data Recorders (EDRs) have been used for the purpose of investigating traffic accidents for more than 20 years. Some countries have regulated their application by law, and they are a valid evidence during investigations and reconstructions. However, recording devices are used as a source of information, not as a database from which it is possible to reconstruct the event. Investigations using only recording devices are still not possible due to thesome phenomena that exist, and due to the constructional features of the devices. Scientists from Japan and Poland tested the accuracy of the data from the devices and performed reconstructions of accidents. Both teams have established that it is possible to perform reconstruction only in simple situations, such as a straight-line crash of one vehicle into another. When there are several participants in a crash, or a crash was preceded by a maneuver, it is not possible to determine what really happened. Further development of data*

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recording devices is necessary, in order to increase their efficiency during the reconstruction of traffic accidents.

***Keywords**: Event Data Reorder, Crash test, Crash simulation, Reconstruction.*

Mogućnost rekonstrukcije saobraćajnih nesreća pomoću uređaja za beleženje podataka – pregledni rad

***Apstrakt**: Uređaji za beleženje podataka koriste se u svrhu istraga saobraćajnih nesreća više od 20 godina. Neke zemlje su zakonski regulisale njihovu primenu i validan su dokaz u istragama i rekonstrukcijama. Međutim, uređaji za beleženje se koriste kao izvor informacija, a ne kao baza podataka na osnovu kojih je moguće rekonstruisati događaj. Istraživanja samo pomoću uređaja za beleženje još uvek nisu moguća zbog određenih pojava, kao i zbog konstruktivnih karakteristika uređaja. Naučnici iz Japana i Poljske testirali su tačnost podataka iz uređaja i na osnovu njih izvršili rekonstrukcije udesa. Oba tima su utvrdila da je rekonstrukciju moguće izvesti samo u jednostavnim situacijama, poput pravolinijskog udara jednog vozila u drugo. Kada je u udaru više učesnika, ili je udaru prethodio neki manevar, nije moguće utvrditi šta se zaista dogodilo. Neophodan je dalji razvoj ovih uređaja, kako bi se povećala njihova efikasnost prilikom rekonstrukcije saobraćajnih nezgoda.*

***Ključne reči**: Uređaj za beleženje podataka, Kreš test, Simulacija sudara, Rekonstrukcija.*

1. Introduction

The introduction of airbags in vehicles has contributed to a significant increase in passive passenger safety, but also to great importance in the development of other systems (Trivedi, Gandhi & McCall, 2007). Event Data Recorders were created thanks to the computer unit of the airbag system, and thanks to the data processed by this unit (Trooper, 2006). The first mass use of these devices took place in the United States, in the mid-1990's, when these devices began to be installed by Ford and General Motors in their vehicles, although this was not mandatory at the time (Nat'l Highway Traffic Safety Admin., 2006).

A major obstacle to a better understanding of driver behavior is the availability of accident data.

Research conducted in the United States in the late 1990's showed that the installation of data recording devices affects driver consciousness, and it lead to a 15 – 30% reduction in crashes in the fleets that owned these devices, and a significant reduction in costs.

Experts from the Department of Industrial Engineering and Management at Ben-Gurion University in the Negev (Israel) have developed data recording device (IVDR) to analyze the behavior of drivers in different situations. The system they developed records vehicle movement and uses that data to identify and classify various maneuvers. These maneuvers are used to calculate different driving risk index. Risk indexes can be used as an rate indicator of driver involvement in traffic accidents (Toledo, Musicant & Lotan, 2008).

A study on the number of crashes in the period before and after the installation of the device, where drivers had feedback from the device, statistically showed significant reductions in the rate of traffic accidents (Nowacki, Niedzicka &Krysiuk, 2014). Even without the feedback, the impact on the driver's consciousness lasted for several months. Also, other studies have shown that this impact decreases over time. Therefore, further research and development of long-term impact is needed, and development of feedback management principles, because of the driver's interest in feedback.

Such devices can be used for objective measurements and assessments of driver behavior while driving. They can also be used to influence driver behavior by monitoring and providing feedback. Continuous vehicle tracking throughout all journeys creates a large database that is valuable to subjects interested in tracking drivers, identifying and correcting driver behavior, such as speeding, vehicle abuse and aggressive driving, or the behavior of novice drivers in traffic.

Vehicle data can be important for insurance companies, for determining liability and compensation, and for the competent road safety services, in order to determine potential safety problems through analyzes of locations and types of maneuvers at those locations, based on data from a number of vehicles (Toledo, Musicant & Lotan, 2008).

The standards of the countries that regulated the use of EDRs (China, Japan) were adopted on the model of the standards applied in the United States (Gabler, Hampton & Hinch, 2004).

2. Experimental determination of data accuracy

2.1. Testing procedure and differences in measured values

Mandatory data recorded by devices are defined by the laws of the countries where these devices are used. EDR data may differ from some vehicle (device) manufacturers, without departing from the law. Given the technological development and growth in the number of devices implemented in vehicles, there is a possibility of expanding the list of data to be recorded (United Nations, 2019).

In this paper, the results of two conducted tests will be used to determine the efficiency of the data and data recording devices.

The first method of testing:

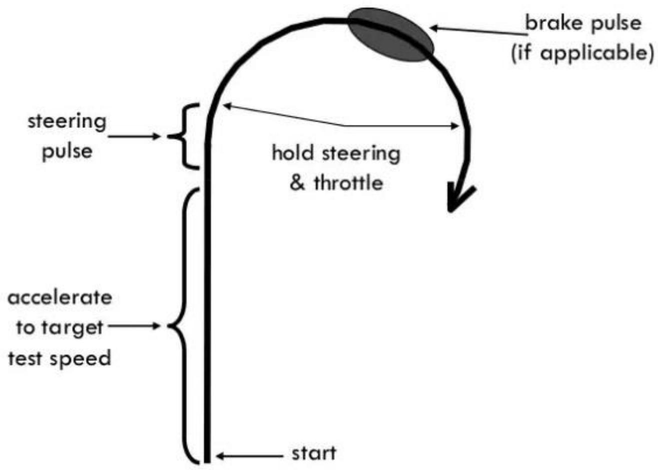
The first method of testing – comparing the trajectory of the center of gravity of the vehicle obtained by simulation, with the trajectory defined on the basis of data obtained from data recording devices, was conducted by scientists from the University of Warsaw. Based on the final position of the vehicle, when the event ended, and the parameters recorded by the device during the maneuver simulation, the reciprocal procedure determines the vehicle trajectory, starting position, and vehicle speed before the maneuver.

In order to conduct initial testing for the purpose of detecting individual errors of data recording devices, easily varying certain parameters, and gaining basic knowledge on the issue of data recording errors. For that purpose, models of behavior of vehicles of category M1 up to a maximum permissible mass of 1550 kg, and vehicles of category N2 up to a maximum permissible mass of 11500 kg were used.

During this testing, realistic maneuvers that drivers most often undertake when avoiding various traffic hazards were selected. The following maneuvers were simulated:

- Maneuver 1: Braking without changing direction (a few dozen cycles);
- Maneuver 2: Change of traffic lane;
- Maneuver 3: Turn the vehicle by an angle of 180° (J turn).

Figure 1. J turn



The simulation used an algorithm based on real data recording devices, with the assumption of ideally accurate sensors. Then, the parameters of vehicle movement were taken from the previously mentioned maneuvers, and the values of acceleration/deceleration from the positions where the sensors should be on the real vehicle. Finally, with such data, a reciprocal process of determining the vehicle trajectory was performed on the basis of the data obtained from the sensors. The difference between the paths and speeds obtained represents the total error of the data recording device (Guzek & Lozia, 2002).

In the first method of testing, during the first maneuver (after the reconstruction of the event) the following diferences were noticed:

- The calculated value of the initial speed V_0 by the reconstruction procedure obtained the value of 95,1 km/h (the set speed of the vehicle is 90 km/h), i.e. the error is 5,7%;
- The calculated value of the braking distance by the reconstruction procedure was 68 m (the exact value is 64,2 m), i.e. the error is 5,9%.

The total errors for this maneuver are 5-8%, depending on the speed of the vehicle (for the actual speed of 50 km/h, V_0 differs by 3 km/h and the braking distance by 1,5-2 m; for the actual speed of 90 km/h V_0 differs by about 6 km/h, and braking distance by 5-6 m).

During the test with the second maneuver, the following differences were noticed (maneuvers were performed by varying the speed for the passenger vehicle, and the speed and load for the truck; the distance from the middle of one to the middle of the other lane is 3,5 m):

- The difference between the real trajectory and calculated in the lateral direction, for a passenger vehicle is -0,86 m at a speed of 50 km/h, and -0,8 m at a speed of 90 km/h in the unladen state. In the laden state, for the same values of the speed, the errors are -0,93 m and -0,88 m.
- Differences in the assessment of the trajectory in the longitudinal direction (length of the travelled distance during the maneuver) are from -0,08 m for an unlodaed vehicle at a speed of 50 km/h, to 1,69 m for an laden vehicle in the longitudinal direction, at a speed of 90 km/h. The length of the road with two traffic lanes for maneuver is 120 m.
- In percent, the largest errors are 26,57% for the deviation from the actual trajectory in the lateral direction (in the laden state, at a speed of 50 km/h), and 1,4% for the deviation in the longitudinal direction (in the laden state, at a speed of 90 km/h).
- The deviation between the real trajectory and calculated in the lateral direction, for a truck, is -0,08 m at a speed of 50 km/h, and -0,14 m at a speed of 70 km/h in the unladen state. In the laden state, for the same values of the speed of movement, the errors are 0,19 m and -3,16 m.
- Deviations in the assessment of the trajectory in the longitudinal direction (length of the travelled distance during the maneuver) are from 1,25 m for an unladen vehicle at a speed of 50 km/h, to 0,36 m for a laden vehicle at a speed of 70 km/h. The length of the road with two traffic lanes for which the deviation was calculated is 100 m.
- In percent, the largest errors are 90,28% for the deviation from the actual trajectory in the lateral direction (in the laden state, at a speed of 70 km/h), and 1,2% for the deviation in the longitudinal direction (in the laden state, at a speed of 5 km/h).
- The largest deviation occur when estimating the initial position of the vehicle's center of gravity (at the beginning of the maneuver).

In the third maneuver, the following deviations were noticed (vehicle speed and vehicle loads were varied; the width of the polygon is 7 m, i.e. two traffic lanes):

- As in the previous maneuver, the biggest deviation occur during estimation of the initial position of the vehicle's center of gravity. This data is the most disputable, because large errors that occur can lead to a completely different conclusion, e.g. that the vehicle is moving in the wrong lane.

- The difference between the actual trajectory and calculated in the lateral direction, for a passenger vehicle, is initially 2,46 m at a speed 50 km/h, and 2,45 m at a speed of 90 km/h in the unladen state. In the laden state, the error values for the same values are 2,84 m and 2,79 m.
- Differences in the estimation of the trajectory in the longitudinal direction (length of the travelled distance during the maneuver) are from -1,17 m for an unladen vehicle at a speed of 50 km/h, to -0,86 m for a laden vehicle at a speed of 90 km/h. The length of the road with two lanes for which the deviation was calculated is 60 m.

In percent, the largest errors are 40,57% for the deviation in the lateral direction (in the laden state, at a speed of 50 km/h), and 1,95% for the deviation in the longitudinal direction (in the unladen state, at a speed of 50 km/h) (Guzek & Lozia, 2002).

The second method of testing:

The second method of testing – vehicle impact testing, i.e. comparing the values from the Event Data Recorders and the values from extern optical sensor on the test site. This research was conducted by scientists from the National Institute of Police Sciences, Department of Traffic Sciences in Kishiwa (Japan).

The aim of the test was to determine the performance of data recording device in real conditions, for the relevance of use in the reconstruction of traffic accidents.

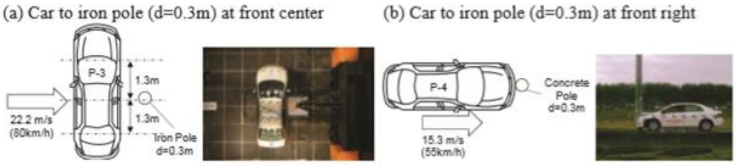
In order to determine the exact change of speed ΔV, 4 acceleration sensors were installed on the vehicle. The vehicle speed was measured using an optical speedometer placed in front of the barrier, and the whole event was recorded by a high-speed camera (Takubo, Oga, Kato, Hagita, Hiromitsu, Ishikawa & Kihira, 2010).

All tests are shown in Figures 2, 3, and 4.

Figure 2. Car to pole crash test

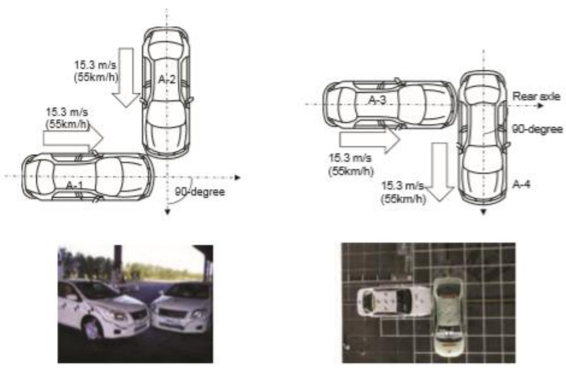
(a) Car to barrier, 40% offset (b) Car to concrete block, full-lap

(a) Car to iron pole (d=0.3m) at front center (b) Car to iron pole (d=0.3m) at front right



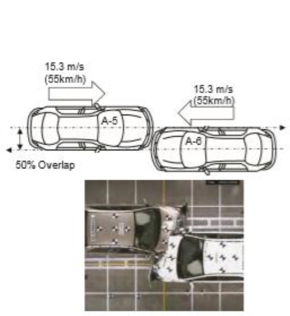
(c) Car to iron pole (d=0.3m) at side right (d) Car to concrete pole (d=0.3m) at front center

Figure 3. Car to car crash test

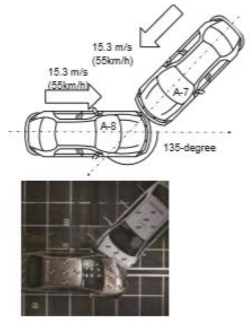


(a) 90-degree side impact, front-left and front-right (b) 90-degree side impact, front and side-right

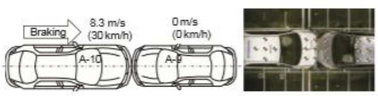
Figure 4. Car to car crash test



(c) 50% offset (right) frontal impact,

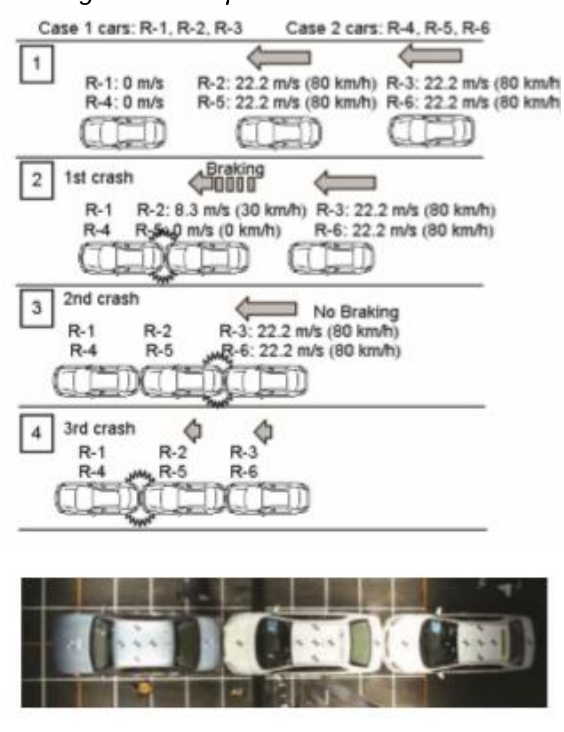


(d) 135-degree impact, front-center and front-left



(e) full-lap frontal impact

Figure 5. Multiple rear-end crash tests



The second method of testing was performed to assess the performance and accuracy of the device for recording data in real conditions. For this purpose, 13 impact tests were conducted, 6 vehicle crash tests in some type of obstacle (rigid barrier, concrete block, concrete pillar and iron pillar), 5 crash tests of two vehicles (frontal and side crash), and two multiple crashes from rear side. All 21 test vehicles were equipped with a data recording device, and 25 events were recorded by their recording devices.

This differences between the recorded and reference values observed during the test are given in Tables 1 and 2:

Table1. Comparison of impact velocity pre-collision results in crash reconstruction tests

Test Type	No.	Model	Impact-direction	Brake	V_{OP}	V_{EDR}	Difference	
					m/s	m/s	m/s	%
Frontal	1	O-1 (offset rigid barrier)	front-right	off	17.9	17.8	-0.1	-0.6
	2	F-1 (concrete block)	front	off	8.9	8.9 *1	0	0.2
Pole	1	P-1 (iron, d=0.3m)	front-center	off	22.4	22.8	0.4	1.8
	2	P-2 (iron d=0.3m)	front-right	off	22.2	22.2	0	0
	3	P-3 (iron d=0.3m)	side-right	off	22.3	*2	*2	*2
	4	P-4 (iron d=0.3m)	front-center	off	15.3	15.6	0.3	1.6
Car to car Impact	1	A-1	front-left	off	15.4	15.6	0.2	1.3
		A-2	front-right	off	15.4	15.6	0.2	1.3
	2	A-3	front	off	15.4	*3	*3	*3
		A-4	side-right	off	15.4	15.6	0.2	1.3
	3	A-5	front-right	off	15.3	15.6	0.3	1.4
		A-6	front-right	off	15.3	15.6	0.3	1.4
	4	A-7	front-center	off	15.3	15.6	0.3	1.6
		A-8	front-left	off	7.6	7.8	0.2	2.2
	5	A-9	front	off	0	0	*4	*4
		A-10	front	on	10	12.2	2.2	22.4
Multiple rear-end	1	R-1	rear	on	0	0	*4	*4
		R-1	rear	on	0	0	*4	*4
		R-2	rear	on	8.5	11.1	2.6	30.6
		R-2	rear	on	0.6	1.7	1.1	*5
		R-3	front	off	21.5	21.7	0.2	0.9
	2	R-4	rear	on	0	0	*4	*4
		R-4	rear	on	0	0	*4	*4
		R-5	front	on	4.1	4.4	0.3	7.3
		R-5	rear	on	0	0	*4	*4
		R-6	front	off	22	22.2	0.2	0.9
Average					-	-	0.5	4.2
Number of analyzed data					-	-	18	19
Root mean square					-	-	0.8	9.2

*1 – Data from video image analysis
*2 – No speed data because of side slip condition in pre-crash period
*3 – Vehicle without EDR
*4 – Excluded data because of stop condition in pre-crash period
*5 – Excluded data because of too small pre-crash impact velocity
V_{EDR} –EDR impact velocities
V_{OP} – Velocities from the optical speed sensors

Source: (Takubo, Oga, Kato, Hagita, Hiromitsu, Ishikawa & Kihira, 2010)

Table 2. Comparison of post-crash maximum delta-V results of accident reconstruction tests

Test Type	No.	Model	Impact-direction	Max $\Delta V_{A\text{-}EDR}$	Max ΔV_{EDR}	Difference	
				m/s	m/s	m/s	%
Frontal	1	O-1 (offset rigid barrier)	front-right	17.4	20.2	2.8	16.1
	2	F-1 (concrete block)	front	7.3	7	-0.3	-4.1
Pole	1	P-1 (iron, d=0.3m)	front-center	25 *[1]	17.5	-7.5	-30
	2	P-2 (iron, d=0.3m)	front-right	22.5	20.9	-1.6	-7.1
	3	P-3 (iron, d=0.3m)	side-right	8	7.9	-0.1	-1.3
	4	P-4 (concrete, d=0.3m)	front-center	12.6	11.7	-0.9	-7.1
Car to car impact	1	A-1	front-left	8.3	8	-0.3	-3.6
		A-2	front-right	8.8	7.9	-0.9	-10.2
	2	A-3	front	4.5	*[2]	*[2]	*[2]
		A-4	side-right	3.8	3.5	-0.3	-7.9
	3	A-5	front-right	16.2	15.9	-0.3	-1.9
		A-6	front-right	15.9	15.6	-0.3	-1.9
	4	A-7	front-center	12.4	11	-1.4	-11.3
		A-8	front-left	9.7	8.8	-0.9	-9.3
	5	A-9	front	5.7	5.3	-0.4	-7
		A-10	front	5	5.3	0.3	6
Multiple rear-end	1	R-1	rear	3.8	4.2	0.4	10.5
		R-1	rear	6.6	6.9	0.3	4.5
		R-2	front	5.7	6.1	0.4	7
		R-2	rear	7.5	6.9	-0.6	-8
		R-3	front	17.7	16.8	-0.9	-5.1
	2	R-4	rear	1.9	1.9	0	0
		R-4	rear	6.3	6.7	0.4	6.3
		R-5	front	4.2	3.2	-1	-23.8
		R-5	rear	8.3	9.1	0.8	9.6
		R-6	front	16.8	16	-0.8	-4.8
Average				-	-	-0.5	-3.4
Number of analyzed data				-	-	25	25
Root mean square				-	-	1.7	10.5
*[1] – Data from $\Delta V_{A\text{-}C}$ (central accelerometar)							
*[2] – Vehicle without EDR							
Max $\Delta V_{A\text{-}EDR}$ –Maximum reference delta-V - longitudinal							
Max ΔV_{EDR} – EDR maximum delta-V - longitudinal							

Source: (Takubo, Oga, Kato, Hagita, Hiromitsu, Ishikawa & Kihira, 2010)

For vehicle speed before crash, the most important factor is pre-crash braking (as shown in Table 1). The distinction between the data from recording device and the reference data were over 20% in the two cases with pre-crash braking. The first data of the R-5 crash in the case of 2 multiple crash had fewer errors even though the vehicle was braking before the crash. Therefore, it is very difficult, from these data, to identify the extent of the impact of pre-crash braking on the accuracy of the data from the recording device (Takubo, Oga, Kato, Hagita, Hiromitsu, Ishikawa & Kihira, 2010).

3. Causes of deviations of measured data

The accuracy of event reconstruction using data from the recording device is significantly affected by the type of maneuver to be reconstructed (rectilinear/curvilinear movement), level of acceleration/deceleration, duration of maneuver, etc… Experimental studies have also shown that vehicle properties can affect accuracy of reconstruction (Han, 2018), but also from the data frequency (defined number of samples, according to the recorded data (e.g. delta-V up to 100 times per second; activation of the service brake 2 times per second...)) (Nat'l Highway Traffic Safety Admin., 2011).

At the beginning, EDR (Event Data Recorder) technology used devices that measured longitudinal and lateral acceleration, and the angle of rotation of the vehicle around the vertical axis, i.e. acceleration in two directions, and one angle of rotation (Brol & Mamala, 2006) (the first type of testing in this paper).

Today, most commonly used sensors are accelerometer that measure acceleration in all three directions (vertical, longitudinal and lateral), and all three angles of rotation of the vehicle (pitch, yaw and roll angle). Experiments have shown that it is possible to efficiently determine the behavior of drivers with a certainty of 94,7%, with using 3-axes sensors (Cao, Lin, Zhang, Dong, Huang & Zhang, 2017).

The errors that occur due to the sensors which record only transverse and longitudinal acceleration, and angle of rotation around the vertical axis, are significantly expressed in the first type of testing, in maneuvers 2 and 3. Namely, the large deviations that occurred are a direct consequence of the characteristics of the sensors, actually impossibility to register the roll angle. Due to the height of the center of gravity of the truck, the rolling is more intense in the curves, so the errors in estimating the position of the vehicle in the simulation were greater for the truck than for the passenger vehicle.

Since the process of path reconstruction during the maneuver (in the first type of test) is a reciprocal process, the biggest differences appeared at the start of the maneuver, gradually increasing the deviation by reconstructing the event from its end to its start (errors are added). As a result, the wrong vehicle position were obtained at the start of the maneuver.

Deviation that cannot be eliminated come from the design characteristics of the sensors (they have certain imperfections that affect the accuracy of the measurement). With the technological progress that has led to the improvement of measuring equipment, the errors of this type have been reduced, but they still exist. We call these errors internal system errors.

The second type of data inaccuracy is obtained due to the location of the sensor for measuring acceleration in all directions. Ideally, this encoder should be in the center of gravity of the vehicle at all times, but since it is impossible to place it there (usually the center of gravity is in the volume of passenger space and its position changes depending on the vehicle load), the sensor is placed in a convenient place as close as possible to the center of mass. Due to that, certain torques occur, (according to the center of gravity in all directions), which give a certain measurement error. This type of error is called fixed error.

Also, one of the present errors, which is reduced by the development of electronics, depends on the speed of data sampling during the event which directly depends on the characteristics of the sensor and the capabilities of the computer unit that performs data processing.

Different oscillations of the measured acceleration/deceleration can also occur from the components of the gravity force, depending on the motor vehicle. Such errors are visible in the first simulation test, where the length of the braking distance is a consequence of rising the vehicle's center of gravity due to sudden braking, i.e. rotation of the vehicle around the transverse axis, with the front side towards the ground (Guzek & Lozia, 2002).

The deceleration values of the vehicle, which are recorded by the sensor of airbag activation system, depends of the position of the deceleration sensor, and place of impact with the vehicle. This means that if an obstacle hits the accelerometer directly, it will record high deceleration values, and the start of event will be recorded in a timely manner. If the impact occurs in one of the corners of the vehicle, with significant deformations (elastic parts, deformation zones, etc...), it takes time for the elastic zones to deform (compress), in order to achieve a significant increase in deceleration. In some cases, the deceleration does not reach the peak values for airbag activation. This phenomenon can be avoided by installing a separate accelerometer that records vehicle deceleration/acceleration only for data recorder.

Differences in measured speed values are also significantly affected by tire slip during sudden braking immediately before a crash (Takubo, Oga, Kato, Hagita, Hiromitsu, Ishikawa& Kihira, 2010).

4. Conclusion

In this paper, several researches and conclusions were considered, which were provided by the studies of several teams of scientists.

Based on obtained results and their processing, it is possible to draw several conclusions:

- Deviations of recorded data are still significant, and it is caused by various factors. Testing in real conditions and in a virtual environment with real parameters showed the impossibility of using data exclusively from data recording devices during event reconstrustions (in complex cases it is not possible to determine what exactly happened, and it is possible to report completely wrong conclusions).
- Devices used for the accident analysis in the last 20 years, and their continuous development has not yet provided a completely reliable source of data in all domains of investigations, i.e. there are data that can be used certanly, and there are those which have some deviations (as tests have shown).
- Investigations that use data from recording devices are still used as an aid in conducting investigations with traditional methods of event reconstruction, due to the shortcomings that are included in this paper.
- These devices have made a great contribution in the analysis of the behavior of traffic participants, which can be further used in various trainings in the prevention, and proper response in dangerous situations.
- With greater use of data recording devices, e.g. if all participants in the event have devices, by comparative interpretation of the data, it is possible to perform the necessary analysis with greater certainty, i.e. to reduce some system errors.

Mass application of data recording devices can be provided by insurance companies with benefits to owners during vehicle registration. In addition to the interests of the investigation companies that deal with traffic accidents, and the study of driver behavior, insurance companies have a great interest in establishing criminal and material responsibility when compensating for damages caused in traffic accidents (Pereira de Oliveira, Jiménez Alonso Vieira da Silva, Tostes de Gomes Garcia & Messias Lopes, 2020).

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