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AN OVERVIEW OF THE FEATURES AND ACTIVITIES OF INDEPENDENT CAR WORKSHOPS IN THE REPUBLIC OF SERBIA

*Dragan Ružić[1]**

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PROFESSIONAL ARTICLE

ABSTRACT: The paper deals with an overview and analysis of the main features and activities of independent passenger car workshops in the Republic of Serbia. A field survey was conducted during the year 2021 and 2022 among randomly chosen 27 independent car workshops. The number of employees, the number of workplaces, the scope of activities and other relevant information are data that have been collected. Results of the survey showed that there is a problem with lack of professional workers and apprentices. Regarding the scope of repair activities, engine overhauling became too complex and cost ineffective for many workshops. Problems are often associated with repair costs of old and high mileage vehicle which can be very high compared to the value of the vehicle. The workshops from the sample are equipped with different kinds of diagnostic tools and certain percentage of technician in the sample attended on one or more aftermarket trainings or seminars.

KEY WORDS: *car workshop, maintenance, diagnostics, training*

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PREGLED OSOBINA I AKTIVNOSTI NEZAVISNIH AUTOSERVISA U REPUBLICI SRBIJI

REZIME: Rad prikazuje pregled i analizu osnovnih osobina i aktivnosti nezavisnih autoservisa u Republici Srbiji. Tokom 2021. i 2022. godine obavljeno je terensko istraživanje među nasumično odabranih 27 autoservisa. Sakupljeni su podaci o broju zaposlenih, broju radnih mesta, obimu aktivnosti i druge relevantne informacije. Rezultati su pokazali da postoji problem u vidu nedostatka profesionalaca i početnika. U vezi obima aktivnosti, obimnije popravke motora postale su previše složene i neisplative za mnoge servise. Dodatni problemi se javaljaju zbog radova na starijim vozilima velike kilometraže gde troškovi popravke mogu biti veoma visoki u poređenju sa cenom samog vozila. Servisi iz uzorka su opremljeni dijagnostičkim uređajima, a određeni broj mehaničara je pohađao jednom ili više puta seminare i obuke.

KLJUČNE REČI: *autoservis, održavanje, dijagnostika, obuka*

AN OVERVIEW OF THE FEATURES AND ACTIVITIES OF INDEPENDENT CAR WORKSHOPS IN THE REPUBLIC OF SERBIA

Dragan Ružić

INTRODUCTION

Quality and quantity of road vehicle maintenance and repair has significant influence on regional economy, energy consumption, pollution and traffic safety. Ever increasing complexity of vehicles that are to be serviced, emerging new technologies for driver assistance and emission control, wide range of vehicle types and wide range of part manufacturers (and product quality too), permanent increase of total costs of vehicle ownership and customers as well as workshop time constrain put a lot of stress and demands to nowadays automotive workshops. Complexity of automotive service activities as well as trends that are emerging in the automotive aftermarket (AM) segments are presented in the paper of Velimirović et al. [1].

Statistical data indicate that 2831 registered enterprises for wholesale and retail trade and repair of motor vehicles and motorcycles in year 2020 contributed to the total turnover with 2.5% in the Republic of Serbia [2]. The most of them (89%) are micro enterprises (0-9 employees) and small enterprises (10-49 employees) with 9% of share [2]. However, number of wholesalers and retailers is not separated from workshops in the data. It is assumed that there are significantly more workshops than wholesalers and retailers. The situation is supposed to be similar in the other countries of Western Balkans (Montenegro, Bosnia and Herzegovina).

A review of state of technicians' education in field of modern emission control of internal combustion engine (ICE) technologies and components that are used in today's mobile mechanisation in the Republic of Serbia is given in the work of Ružić et al. [3]. The results showed that theoretical and practical trainings exist, but mostly carried out by authorised vehicle workshops or of a part manufacturer brand. It could be taken that the similar situation is in the field of passenger vehicle maintenance as well. However, the number of training centres and educational centres is still low in the region [3]. The OE (original equipment) and premium brand part manufacturers constantly publish technical information in form of (digital or hardcopy) bulletins, flyers or videos in order to reduce claims on their products and further vehicle damages caused by improper diagnostics and installation errors. This material is usually available online, but mostly in English or German languages. Despite of the availability, searching of right information during the vehicle repair could be time demanding.

Direct contact and surveys are effective, though time-consuming, methods for gathering specific information from practice. An example is paper [4], where the attitude of agricultural mechanization users in region of AP Vojvodina towards waste materials generated by the mechanization maintenance was investigated. The survey had a good response and pointed to aspects of the lack of subsequent training in certain segments of the field of machinery maintenance. The observed problems and the applied method were the motivation for the research in this paper. In order to make closer insight in car workshop activities, their size and structure, equipment as well as demands regarding a technical support, data from field survey performed among randomly chosen independent car workshops in the Republic of Serbia are used in this study. The paper includes some basic statistical data about passenger car fleet in the Republic of Serbia, description of the method used in the research and presentation, analysis and discussion of the results.

1. FEATURES OF PASSENGER CAR FLEET IN THE REGION

According to the official sources, there are more than 2.1 million of registered passenger cars in operation in the republic of Serbia in year 2021 [2], [5]. In the same year, there were around 22,000 new passenger cars registered for the first time, which make around 1% of total number of cars [2]. The similar trend was present in the previous three years, taking this period as a typical warranty period for passenger cars. It is estimated that more than 160,000 cars are older than 20 years (data for year 2020) [6]. In total, an average age of passenger cars in the Republic of Serbia is between 13 and 20 years, depending on the region [7]. The data does not make a difference between the commercial vehicles (trucks) and light commercial vehicles (vans). Vans usually have the same chassis and powertrain technologies like passenger cars, demanding the same maintenance and repair technologies and facilities. Precise data about brand and age of current vehicles in operation were not available at the moment of this research. A rough approximation is that 97% of the cars in operation could be maintained in independent car services, although some of out-of-warranty cars are still maintained in the authorised services.

A number of registered new cars in one year could be taken as a rough indicator of vehicle brand distribution in the Republic of Serbia for vehicles in operation. The distribution is shown in Figure 1. Cars with up to 2 litre engines and with diesel engines make up a majority of cars in the region [8]. However, data on up to two years old passenger cars registered for the first time indicate an increasing number of cars with petrol engines [8]. This would result in a decrease of diesel cars share in operation in the following years.

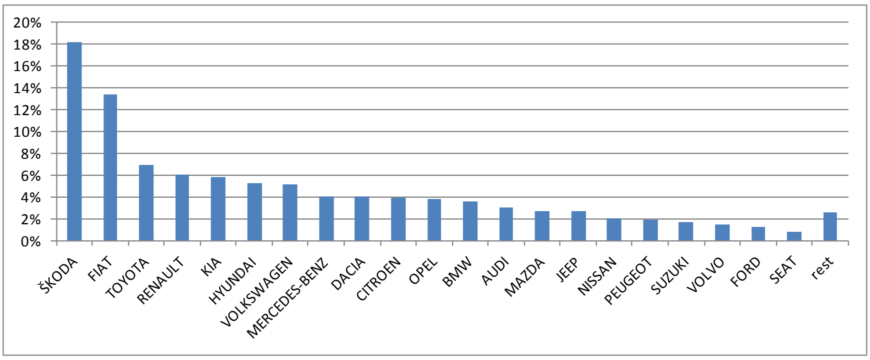

Figure 1. Distribution of brands of new cars sold in the Republic of Serbia in the year 2021[6]

2. METHOD

The field survey was performed by personal meetings with owners and/or managers of 27 independent car workshops. The survey was conducted during the year 2021 and 2022. Workshops specialized in a vehicle subsystem servicing only or specialized in specific repair operations (diesel system service, part machining shop, air-conditioning service, tyre shop, body shop, automatic transmission service etc.) have not been included in the study. The names and locations of the workshops, vehicle and equipment brands are not revealed in this paper.

The data about number of employees (mechanics and technicians), number of workplaces, car brands and types that are serviced, scope of activities, previous trainings, plans and needs for further education and equipment of the workshop have been collected. Additional information such are typical technical and organisational problems were also recorded.

The difference was made between specialists for cars of certain manufacturer and those that work on several vehicle brands. One manufacturer can include multiple vehicle brands. The examples are VAG group (Volkswagen, Audi, Seat, Škoda), PSA group (Citroen and Peugeot), or Fiat group (Fiat, Alfa Romeo, Lancia) etc.

The main questions about workshop activities and other features were:

- does the workshop perform engine overhaul (cylinder block, cylinder head and/or crank drive reconditioning),
- does the workshop perform diagnosis and/or repair electronic units and components, using an oscilloscope or other advanced equipment,
- does the workshop perform diagnosis and replacement of mechatronic components, using an diagnostic tools (scanners),
- are there additional aftermarket activities (part shop, tyre shop, car wash, rent-a-car etc.),
- how many diagnostic tools the workshop use, how many of them are OE,
- do employee attended seminars or trainings.

3. RESULTS AND DISCUSSION

The data collected and sorted in the survey of 27 car workshops are presented in Table 1, Table 2 and Table 3.

Workplace counted in the Table 1 presents a car lift or service pit in a workshop. Typical workshop has also an indoor or outdoor free surface suitable for work, but they are not counted as a workplace in this study.

Eleven workshops out of the sample (41%) are workshops specialized for a specific vehicle manufacturer or brand. Although they still have a vehicle brand in their workshop name, they very often accept vehicles of other brands too. The reasons are similarity of components and subsystems that are independent of a vehicle brand (electronics and mechatronics, engine and entire chassis platform sharing between brands, to mention a few), wide versatility of universal diagnostic tools and mostly unrestricted availability of parts for independent workshops.

An average number of technicians per workplace are 1.3, which classifies the workshops as micro-enterprises. Histogram of technicians and workplaces in the sample of workshops is shown in Figure 2. It can be noted that there are three workshops with only one employee (11% of the sample). General complaint by the most workshop owners/managers was that a problem with lack of professional workers and apprentices is noticeable in the region.

Table 1. Car workshops size and structure

	Employees (service technicians)	Workplaces
total	91	70
min	1	1
max	10	4
average	3.37	2.59
median	3	3

Figure 2. Histogram of technicians and workplaces in the sample of workshops

Table 2. Scope of workshop activities

	Engine overhauling/ reconditioning	Mechatronics	Electronics	Additional AM activities	Attended trainings/ seminars
total	16	26	2	6	11
relative	59%	96%	7%	22%	41%

Almost half of the services in the sample no longer do major engine repairs (cylinder head and/or crank drive reconditioning), but optionally replace the engine with a used one. They mostly work on engine periphery repair (mechatronics, belt drive, timing...) and vehicle maintenance as well as on brake, transmission and suspension systems repairs etc. According to their statements they used to work on engines before, but engine overhauling and reconditioning became too complex and cost ineffective in comparison to other maintenance and repair works. It could be expected that in the future, the number of car workshops that overhaul engines will further decrease. The availability of used or reconditioned engines in good condition on the market is also a factor that determines the need for their repair. The repair could be carried out by engine specialists in the region whose number is still relatively low.

Current technologies include high number of mechatronic components in cars. For that reason almost all workshops perform diagnostics and replacement of faulty sensors and actuators and the workshops are equipped with different kinds of diagnostic tools (96%).

However, only two workshops in this sample (7%) are familiar with a use of an oscilloscope and carry out diagnostics and repairs on electronic units and components.

They recognize importance and necessity of constant education and being up-to-date with modern technologies and there is relatively high percentage of workshops in the sample (41%) whose employees attended on one or more aftermarket trainings or seminars. Seminars were organized by regional automotive part wholesalers. The role of trainer or presenter is usually taken by a person from the technical support of a particular spare parts manufacturer. In the period from 2020 to 2022, due to the COVID-19 pandemic, no live seminars were organized in the region. It is expected that seminars and training will be organized again in the following period. The technicians are in general interested in specialized education in field of modern vehicle technologies.

Table 3. Number and sort of diagnostic tools

	Diagnostic tools	OE diagnostic tools
total	37	9 (33% of the sample)
min	0	1
max	10	2
average	1.37	-
median	2	-

The number of OE diagnostic tools (scanners) indicates that not every specialist in the sample has OE scanner. Costs of OE scanner purchase and update are usually higher than the price of universal scanner. The choice of type of scanner is trade off between the price, diagnostic capability and range of vehicles covered by the scanner. Only one workshop of the sample still has no diagnostic tool. To perform proper diagnosis and other service actions which require use of scanner, the service of another workshop must be engaged. In addition to equipment and software costs, proper application of diagnostic tools depends on the technician's skill and knowledge of diagnostic procedures [9]. Although many types of scanners are available on the market, only a few manufacturers of diagnostic equipment offer training and support. Despite this, almost 60% of the workshops in the sample use the same brand of universal diagnostic tool without official support.

Additional remarks that are recorded during the research are more-less similar for most of the workshops in the sample. Problems are often associated with old and high-mileage vehicle repair costs which can be very high compared to the value of the vehicle. Emission control system, automatic transmission, comfort systems, etc. are complex and expensive systems that have a certain lifespan. The average age of vehicles in operation and the fact that only about 10% of new vehicles are registered annually out of the total number of cars registered for the first time, as well as the fact that the import of used vehicles with emission level EURO 3 is still allowed, indicates the state of the vehicle fleet and the need for more extensive (and relatively expensive) maintenance and repair works.

4. CONCLUSIONS

A survey of the randomly chosen 27 independent passenger car workshops in the Republic of Serbia is presented in this paper. The size of the sample presents less than 2% of total number of passenger car workshops in the Republic of Serbia but gives valuable data about workshop size and personal structure, equipment, the scope of activities as well as about potentials and needs for additional training and education in the field of modern vehicle technologies.

The main conclusions can be summarized as follows:

- There is noticeable problem with lack of professional workers and apprentices in the region.
- There are a lot of old vehicles with high mileage on the market whose repair costs could be very high compared to the value of the vehicle.
- Engine reconditioning is done in less extent than before, mostly due to increasing complexity and high costs. Working on mechatronic components requires constant improvement of knowledge and updating of equipment.
- Technicians are willing to attend seminars and training as an effective way to become more familiar with current automotive technologies.

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UTILISATION OF ALTERNATE FUELS IN DIESEL AND CRDI ENGINE FOR ELIMINATING VEHICULAR EMISSIONS

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RESEARCH ARTICLE

ABSTRACT: Nitrogen oxides and smoke are the substantial emissions for the diesel engines. The objective of this research is to assess the potential of bio-fuels by comparing it with diesel. Initially, the biofuel and diesel were taken in separate containers, then it was measured for the different proportions by volume basis and were mixed together. After 24 hours, it was used as a fuel. Experiments have been conducted with net biofuel (B100), diesel and (B80-D20 and B60-D40) type blends. Fuel undergoes good combustion and hence there is a significant improvement in performance and reduction in emissions. Similarly, I have conducted my own research work and found out results by using an CRDi engine with Jatropha oil-diesel blend. I could attain a decrease in emission levels of Smoke opacity by 20% for JD10 than diesel at IP of 400 bar. NOx emission for JD10 at 400bar has been found to be 20 ppm less than that of diesel. Better atomization of fuel is found at 600 bar IP. The usage of alternate fuels like Jatropha, Ethanol can help us move towards a greener society, help us to live emission free by inhaling pure oxygen content and can reduce the dependence on conventional fuels.

KEY WORDS: *Alternate fuel, Biofuel, CRDi engine, Diesel engine, Emission, Injection pressure*

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UPOTREBA ALTERNATIVNIH GORIVA U SAMNJENJU EMISIJE VOZILA KOD DIZEL I CRDI MOTORA ZA ELIMINISANJE EMISIJA VOZILA

Oksidi azota i dim su značajni zagađivači iz emisije dizel motora. Cilj ovog istraživanja je da se proceni potencijal bio-goriva u poređenju sa dizel gorivom. U početku su biogorivo i dizel su uzimani u odvojenim kontejnerima, zatim su izmerene različite zapreminske proporcije i pomešani zajedno. Posle 24 sata mešavina je korišćena kao gorivo. Eksperimenti su sprovedeni sa neto biogorivom (B100), dizelom i mešavinama tipa (B80-D20 i B60-D40). Gorivo je dobro sagorevalo i stoga dolazi do značajnog poboljšanja performansi i smanjenja emisija. Slično, su realizovana samostalna istraživanja i dobijena saznanja korišćenjem mešavine dizela i ulja barbadoskog oraha kod CRDi motora. Bilo je moguće smanjenjiti nivoa emisija neprozirnosti dima za 20% za JD10 u odnosu na dizel gorivo pri IP od 400 bara. Utvrđeno je da je emisija NOx za JD10 na 400 bara za 20 ppm manja nego kod dizela. Bolja atomizacija goriva je dobijena pri IP od 600 bara. Upotreba alternativnih goriva kao što su ulje barbadoskog oraha, ethanola može pomoći: da se krene ka zelenijem društvu, da živimo bez emisija zagađivača, da udišemo čist kiseonik i da se smanji zavisnost od konvencionalnih goriva.

KLJUČNE REČI: *Alternativno gorivo, Biogorivo, CRDi motor, Dizel motor, Emisija, Pritisak ubrizgavanja*

UTILISATION OF ALTERNATE FUELS IN DIESEL AND CRDI ENGINE FOR ELIMINATING VEHICULAR EMISSIONS

R Shenir, G. Balaji

INTRODUCTION

The demand for renewable energy sources can be satisfied by alternative fuels that have minimal negative environmental effects, including biodiesel and ethanol. Ethanol is being used as a full or partial gasoline substitute in several countries. The uses of ethanol as a fuel are discussed below.

The effects of the use of ethanol being added to diesel oil- soybean biodiesel blends on fuel consumption have been investigated. The authors discovered that adding more ethanol to the fuel blend resulted in a longer cold start time, while adding more biodiesel to the fuel blend or using 2% ethanol as an addition had no effect on the amount of a particular fuel that was consumed. However, the B20 blend's increased specific fuel consumption was caused by the usage of 5% ethanol content [13].

Another research focused on lowering the brake specific fuel consumption (BSFC) of diesel engines by incorporating ethanol or dimethyl ether (DME) into the air intake while also supplying the diesel engine with emulsified fuel [17]. With all the benefits of renewable ethanol in terms of the environment and energy security, higher fuel conversion efficiency had been noticed for a dual fuel ethanol-diesel than the diesel solely throughout the whole range of speeds and loads [3].

Previous research study has examined the emission characteristics of a four-stroke motorbike engine using a fuel mix that contained 10% ethanol and 90% gasoline (E10) [8]. They discovered that using E10 fuel reduces the amount of CO and HC emissions in the exhaust compared to using unleaded petrol. According to He et al research, blending ethanol with diesel fuel can lower particulate matter (PM) emissions while also improving the flexibility of NOx emissions management under a range of engine operating situations. This research also denotes that the increased fuel consumption and poor ignition quality are the main barriers to ethanol use in diesel engines [7].

In a two-stroke diesel engine with exhaust gas recirculation, ethanol fuel benefits from a low cetane number. This study also demonstrated that ethanol increases thermal efficiency by 2% to 3% while also produces less soot and NOx [9].

The performance and emissions of a four-cylinder turbocharged indirect injection diesel engine running at various fuel injection pressures (150, 200, and 250 bar) at full load were examined in the presence of 10% and 15% by volume of ethanol. The addition of ethanol reduces CO, soot, and SO2 emissions but increases NOx emissions and causes power reductions of between 12.5 and 20 % [4].

The usage of biofuels as a diesel engine fuel replacement has increased recently [2]. Biofuels are manufactured from biomass and come from either biological waste or agricultural practises (such as producing maize for ethanol) (i.e waste products from animals). Any diesel engine may consume biofuels, typically without any modifications. In comparison to diesel fuel, it promises a decrease in hazardous emissions (excluding NOx emissions) [6].

Large volumes of garbage are generated by the industries as a result of both industrialisation and a rise in world population. These trash streams and piles are currently disposed as landfill or left to fester. During the decomposition process, CO2 contained in trash is released into the atmosphere [5]. The solution to these issues is to turn these wastes into energy. The term "Waste to Energy" (WTE) refers to a broad range of technologies, and the best way to handle wastes is using a heat-based process like direct combustion (incineration), pyrolysis, or gas cleaning [10].

Pramanik used diesel and Jatropha oil blends to investigate the performance of a single-cylinder Compression Ignition (CI) engine. Compared to utilising only vegetable oil, engine performance was markedly enhanced. The reduced viscosity of the vegetable oil led to a drop in the amount of fuel used and the temperature of the exhaust gases. It was possible to get a satisfactory level of thermal efficiency for the engine with blends including up to 50% volume of jatropha oil. Based on the characteristics and the outcomes of engine tests, it has been found that 40 to 50 % of diesel can be replaced with Jatropha oil without altering the engine [12].

Forson used a single-cylinder direct-injection engine to research various diesel and Jatropha oil mixtures. 97.4%/2.6%, 80 %/20%, and 50 %/50 % by volume were the mixes' tested concentrations. They found that although all fuels had equivalent carbon dioxide emissions, the 97.4% diesel/2.60% Jatropha fuel blend had the lowest net contribution to the atmospheric level. The 97.4% diesel/2.6% Jatropha fuel blend produced the highest values of brake power and brake thermal efficiency as well as the lowest values of specific fuel consumption, which is the study's most significant discovery. The test results for Jatropha oil and its blends with diesel generally demonstrated improvements in brake thermal efficiency, brake power, and reduced specific fuel consumption. Jatropha oil was also recommended as a diesel fuel additive for use as an ignition-accelerator [1].

1. JATROPHA OIL

For Compression Ignition (CI) engines, vegetable oils are produced as fuels. Due to their higher cetane number, vegetable oils can be used in diesel engines. When compared to traditional fuels like diesel and gasoline, vegetable oils including Jatropha oil are viscous. To fix this, the injection system's injection pressures can be raised, which will atomize the fuel mixture. The thermal efficiency of this Jatropha oil is inversely correlated with the length of its fatty acids. Due to its increased density, Jatropha oil has a similar heat content to diesel oil [11]. With a rise in saturation, the heating value decreases. The location of the double bonds on this particular glycerol backbone determines how the heat content and cetane number differ. Vegetable oil including Jatropha oil is environmentally user friendly. The engine is preheated before using any vegetable or green oil due to its higher viscosity.

Fig 1 - Jatropha Seed and Oil

2. METHODOLOGY

DIESEL ENGINE

For this experiment, a single cylinder, four-stroke, air cooled, DI, constant speed diesel engine producing 4.5 kW of power was used. Table 1 lists the specifications for test engines. An eddy current dynamometer, which transfers the mechanical energy produced by the engine power directly to the network, was attached to the engine and mounted on a permanent table. To handle the control and acquisition of measured signals, two systems were deployed. The first system manages the engine dynamometer as well as the collection of low-frequency measurements (torque, engine speed, pressure and temperature in the collectors). The second system measures high-frequency signals that mostly relate to the cylinder pressure, fuel injection pressure, as well as the crankshaft's angular position [14].

The intake air flow was measured using an LPX 5481 type differential pressure transducer. The test engine was equipped with a number of thermocouples of type K to measure temperature. The ambient temperature was determined using an active transmitter of type HD 2012 TC/150 for sensing temperature and humidity. The fuel flow was gauged by a Coriolis mass flow meter. A chemiluminescence nitrogen oxide analyzer, model number TOPAZE 32 M, was used to quantify emissions of nitric oxide (NO) and nitrogen oxide (NOx). Using a heated hydrocarbon analyzer, FID flame ionisation was used to detect hydrocarbon emissions (HC) (model GRAPHITE 52 M). The emissions of carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) were measured using a 2 M MIR analyzer.

Table 1 - Specifications of test engine (diesel)

Parameters	**Specifications**
Cylinder Number	One
Type of cooling	Air cooled
Bore * stroke	95.5 * 88.94 mm
Length of Connecting rod	165.3 mm
Displacement	630 cm^3
Injection timing of fuel	20˚bTDC
Injection pressure of fuel	250 bar
Compression ratio	18:1
Rated power	4.5 kW @ 1500 rpm

CRDi ENGINE

Similarly, I have conducted a comparative study in a CRDi (Common Rail Direct Injection) engine by using alternate fuel blend of Jatropha oil and diesel blends. Various specifications of the CRDi engine are given in Table 2. This was carried out using a Kirloskar 5.2 kW power, 1500 rpm, single-cylinder, water-cooled diesel engine that is coupled to an eddy current dynamometer. We investigated the effect of FIP and SOI time on the motor copying characteristics using the uni-chamber model of the CRDi Engine. The exploratory investigation was expressed using four various FIPs (300, 500, 750, and 1000), four distinct SOI timings, and 4 distinct fuel intake measures at a constant motor speed of 1500 rpm.

Tests of the motor's consumption characteristics were conducted using information from the in-chamber pressure level. The roundabout infusion CI DICI motor, fuel vaporisation, and heat energy movement are combined by the timing of the FIP and SOI [15]. The injection boundary unit plays a key role in controlling the heat discharge rate (HRR) and charge per unit of weight rise (ROPR), which also has an impact on the motor's output power. Limiting the fuel inflow parametric quantity is essential for creating a CI diesel motor that burns efficiently and without pollution.

CRDi ENGINE SPECIFICATIONS

This study used a single-cylinder, water-cooled Kirloskar diesel engine with 5.2 kW of power that runs at 1500 rpm and is coupled to an eddy current dynamometer. To measure the quantity of exhaust gases and smoke, the AVL gas and smoke analysers were placed in the exhaust tail pipe. This kind of smoke metre can be used to determine the amount of smoke at 1% opacity. The engine's altered fuel ignition and timing are 200 bar and 20 deg, respectively, and this instrument's uncertainty percentage is 1.4. The production of power and efficiency were assessed by varying the load to 0%, 25%, 50%, 75%, and 100%. Prior to the load being applied for each test fuel, the engine is permitted to run for 10 minutes after starting with each test gasoline. Using the manual valve the engine produces, the EGR valve opens [16].

We have used a fuel blend with diesel (90%) and Jatropha oil (10%). The reason for choosing this blend is because Jatropha has a higher flash point and fire point. Jatropha also has a higher kinematic viscosity. It results in consumption of lower oil. Diesel on the other hand has lower viscosity than Jatropha oil. JD10 blend gives better fire and flash point while optimizing the kinematic viscosity of Jatropha oil along with diesel.

Table 2 - Specifications of CRDi engine

Specifications	**Parameters**
Make	Kirloskar TV1
Cylinder number	1
Stroke number	4
Fuel	Diesel
Rated power (kw)	3.5 kW@1500rpm
Type of dynamometer	Eddy current dynamometer
Bore of cylinder (mm)	87.5
Length of stroke (mm)	110
Swept volume(cc)	661.45
Compression ratio	18

Diameter of Orifice (mm)	20
Length of Connecting rod (mm)	234
Injection point variation of fuel	0 to 25˚ bTDC

Table 3 and 4 depicts the various fuel properties for Jatropha, biofuel and diesel oil.

Table 3 – Fuel Properties of Jatropha & diesel

S.NO	**Characteristics**	**Diesel**	**Jatropha**	**JD(10) blend**
1.	Kinematic viscosity @ 40°C in CST	2.3	37	5.14
2.	Flash point (°C)	45	75	48
3.	Fire point (°C)	53	83	56
4.	Gross calorific Value (kJ/kg)	42497.21	37555.5	41753
5.	Density in kg/m^3	830	918	846

Table 4 – Fuel Properties of biofuel and diesel

Properties	**Unit**	**Biofuel**	**Diesel fuel**
Flash point	˚C	57	56
Dynamic viscosity at 20˚C	Ns/m^2	2.32	2.52
Density at 20˚C	kg/m^3	825	830
Kinematic viscosity at 20˚C	mm^2/s	1.7	2
Auto ignition temperature	˚C	230	220
Cetane number	---	57	52

AVL GAS ANALYZER

An AVL DiGas 444 gas analyzer was used to examine the exhaust gases. It calculates NO, HC, CO, and CO_2. The Model 114 smoke metre, which operates in accordance with British Standard Institution testing standards BS AU 141:1967, was utilised to measure the smoke intensity. Its piston displacement for the suction pump is 330 cc. It has a 5 m long plunger hose. The plunger travels its distance in 30 seconds. The ammeter range of the evaluating unit is 0 to 10.

Fig 2 – AVL Gas Analyzer

SMOKEMETER

Prior to and after the start of serial production, emission monitoring and combustion optimization on prototype engines are the main applications for smoke metres. Additionally, the instrument can measure the bulk content of soot or black carbon in raw exhaust gas in compliance with ISO 8178-3 criteria (for example, upstream of a DPF). The AVL Smoke Meter's easy integration into an automation system and potential for remote maintenance save operational costs, service times, and training needs.

Fig 3 – Smoke meter

3. RESULTS AND DISCUSSION

The advantage of using biofuel in current diesel engines without modification is that it may be freely combined with diesel. The biofuel and diesel were first measured for the various ratios on a volume basis while still in separate containers. The prescribed quantity of biofuel and diesel were blended in a container. Each fuel is blended separately for 15 minutes, which causes the fuel (blend) to be stirred. The mixture was used as a diesel engine fuel while it was being monitored 24 hours for phase separation. In the studies, several blends of biofuel and diesel as well as pure biofuel (B100) were employed (B80D20 and B60D40).

Similarly, I have done a research work by using Diesel-Jatropha oil blend in the ratio (90:10) in a CRDi engine. In order to attain the best efficiency of engine and for minimising the various emissions emitted from a vehicle, fuel injection pressure was varied in the pressure range of 400, 500, 600 bar. The various results obtained in terms of performance and emission characteristics are given below.

4. PERFORMANCE CHARACTERISTICS

EFFECT OF BRAKE THERMAL EFFICIENCY BY USING BIOFUEL

For biofuel, diesel, and diesel addition with biofuel, the variation of brake thermal efficiency with braking power is analysed. The greatest brake thermal efficiency for neat biofuel (B100) is 32.4%, whereas the maximum brake thermal efficiency for neat diesel is 29.98% at 80% load. Due to the biofuel's high cetane number and high oxygen concentration, it has the highest possible brake thermal efficiency. At full load, the thermal efficiency of the brakes is slightly reduced for all fuels. Although the ignition delay is less than the quantity of gasoline injected at maximum load, the fuel amount prepared during the delay period is much less than the total amount of fuel supplied. Therefore, more gasoline is burnt following premixed combustion, reducing the thermal efficiency of the brakes at full load. Premixed combustion often directly reflects the thermal efficiency of the brakes in CI engines.

EFFECT OF BRAKE THERMAL EFFICIENCY BY USING JATROPHA

Similarly, the performance stats for Jatropha-diesel blend are given below.

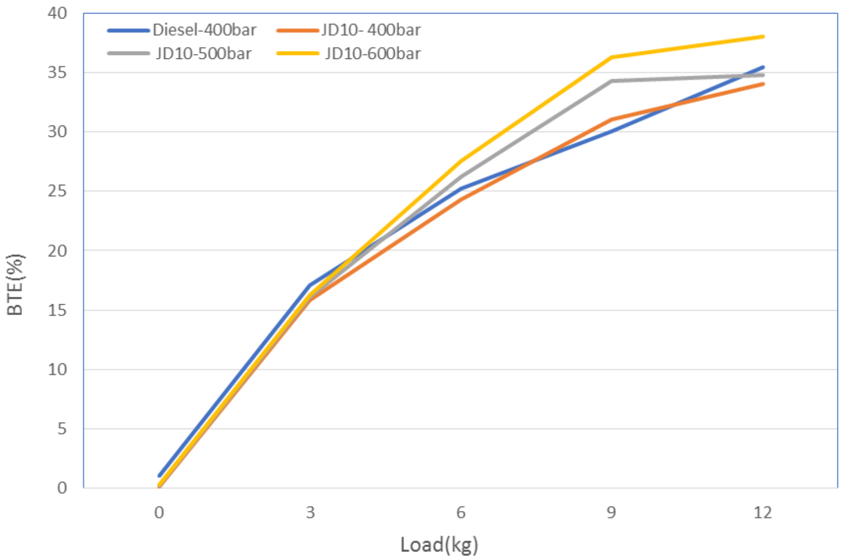

Fig 4 - Variation of BTE (%)

This graph displays the BTE for a Jatropha mix that was obtained at a constant speed of 1500 rpm. Due to an increase in power and a decrease in heat loss, BTE for JD10 mix is shown to rise for higher loads. Similar to stated thermal efficiency, brake thermal efficiency grows with increasing compression ratio at full load, but at a decreasing rate. The maximum BTE, which is 5.26% higher than that of diesel at 400 bar, was found at 600 bar injection pressure when employing a 9:1 fuel mix of Jatropha oil blend and diesel under full load conditions.

EMISSION CHARACTERESTICS

CO EMISSION USING BIOFUEL

Analysis has been done on the variance in CO emission with brake power for various test fuels. Comparing the neat biofuel to diesel and other blends, it emits a little less CO. This could be as a result of increased oxygen concentration and combustion temperatures, which promote the transition of CO to CO_2. Comparing blended biofuel to neat biofuel, CO emission rises. It is well known that biofuels with high oxygen content contribute to combustion much better than other fuels. At full load, the CO emission rates for neat biofuel, neat diesel, B80D20, and B60D40 are, respectively, 0.39%, 0.59%, 0.42%, and 0.45%.

CO EMISSION USING JATROPHA

When comparing the fuels at an IP of 400 bar, gasoline has a CO emission value of 0.38, whereas diesel has a value of about 0.23. Nearly similar to diesel value at 400 bar is JD10 mix at IP 600 bar. This might be because diesel and JD10 blend have different Cetane numbers. This might possibly be brought on by JD10's improved brake thermal efficiency at 600 bar.

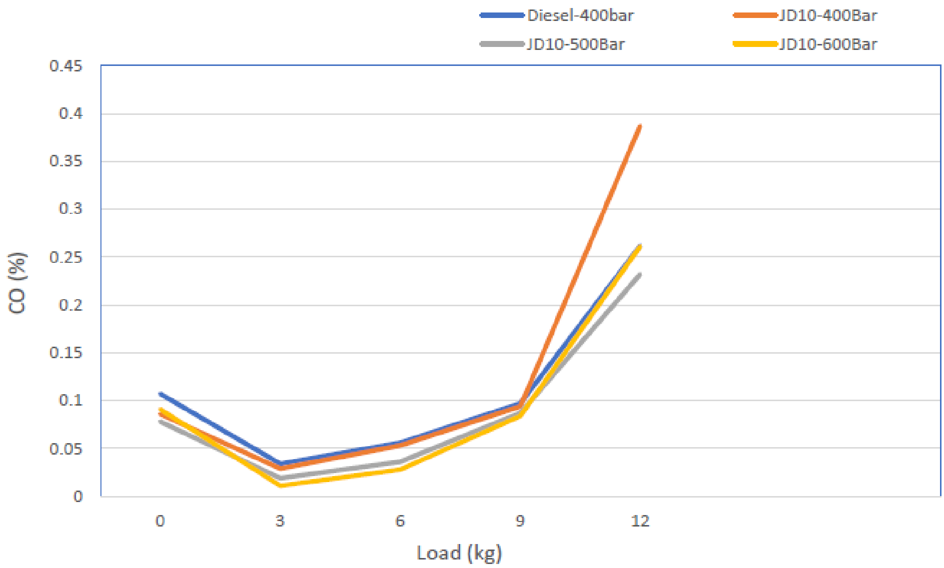

Fig 5 - Variation of CO emission

HC EMISSION USING JATROPHA

At 600 bar, we find that JD10 blend has a 20% lower HC emission than diesel. This is mostly because diesel has a higher viscosity and a larger atomization of the Jatropha blend at 600 bar compared to 400 bar. By raising the fuel injection pressure, HC were enhanced.

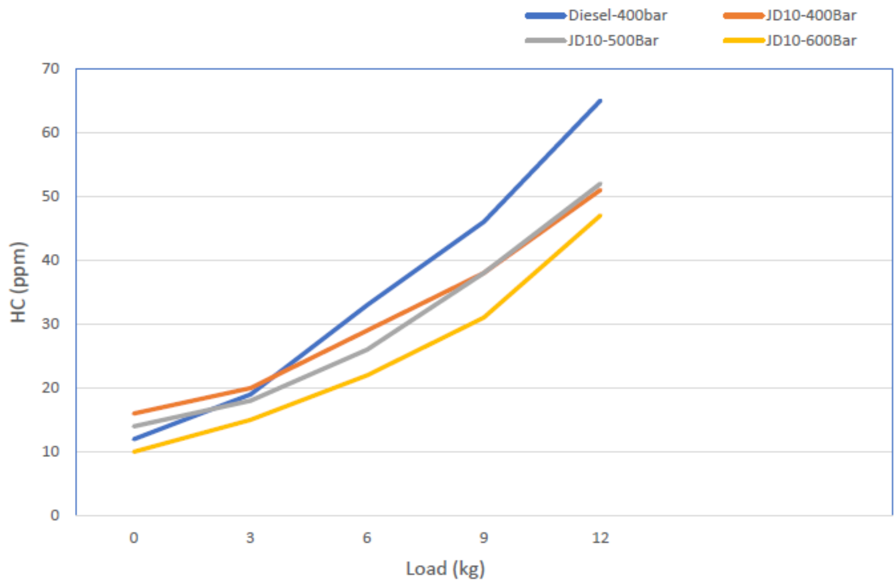

Fig 6 - Variation of HC emission

NO_x EMISSION USING BIOFUEL

From 20% load to 80% load, NO_x emissions rise, and at full load for all fuels, they fall. In comparison to other test fuels, NO_x emissions for the neat biofuel operation are maximal at 857 ppm at full load. Premixed combustion increased intensity, which occurs with neat biofuel operation, is what causes the increase in NO_x. The higher cetane number of the biofuel, which starts the combustion early, is what causes the higher premixed combustion. The gasoline burns quickly thanks to its higher oxygen content as well. As the percentage of diesel in the blend increases, NOx emissions fall down. At full load, B80D20 blend NOx emissions are 841 ppm and B60D40 blend NOx emissions are 826 ppm. The reduction in NOx is the result of inadequate fuel and air mixing, which also causes a reduction in premixed combustion.

NO_x EMISSION USING JATROPHA

The graph shows that NOx emissions rise with increasing load, which is caused by higher combustion temperatures. When operating at maximum load, NOx emissions at injection pressure of 600 bar are observed to be 4.6% higher than those at 400 bar (JD10 BLEND). When compared to regular diesel, JD10 at 600 bar varies by 6.7%.

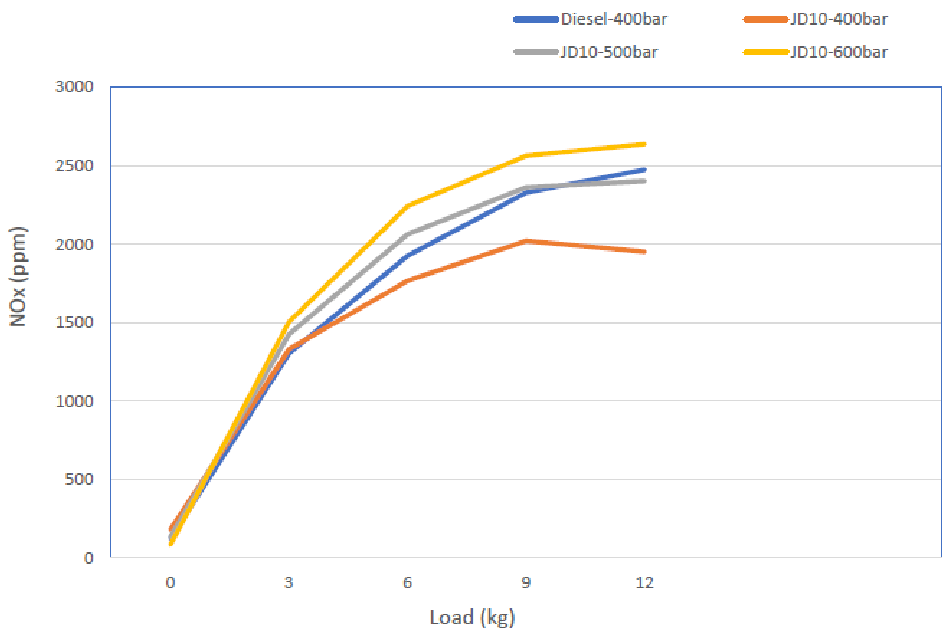

Fig 7 - Variation of NO_x emission

CO_2 EMISSION USING BIOFUEL

The primary cause of ozone layer loss and global warming is CO_2 gas. It is an understanding that biofuels with a high oxygen content aid burning significantly more effectively than other fuels. When using neat biofuel, the CO_2 emission is 9.74% at full load, which is extremely high when compared to other fuels. This is because the biofuel's oxygen-bound oxygen helps to greater fuel oxidation, which results in more CO being transformed to CO_2. With the addition of biofuel-based diesel, the CO_2 is decreased. Diesel has a 9.5% value, B80D20 a 9.42% value and B60D40 a 9.15% value.

CO_2 EMISSION USING JATROPHA

The CO_2 emission values for diesel and JD10 mixes are not significantly different. When using both fuels at increasing loads, the emission value falls between 7.7 and 7.7%. For both fuels, the fuel inside the piston gradually degrades. By raising the fuel injection pressure, CO_2 emissions increased. This is due to the fact that the fuel is more effectively atomized and the fuel drops get smaller as the injection pressure increases.

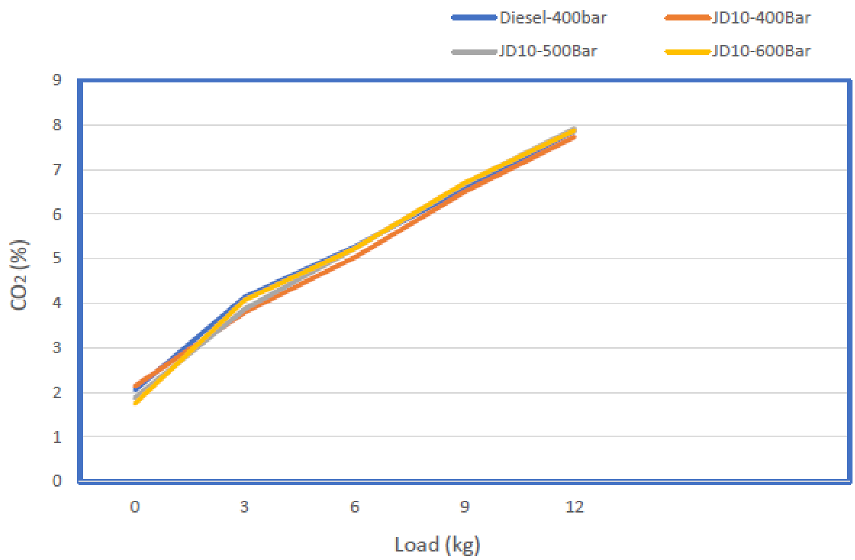

Fig 8 - Variation of CO_2 emission

OPACITY USING JATROPHA

We have lower values of opacity at higher FIP because JD10 blend has higher air fuel mix optimization. In contrast, diesel has a higher opacity because of the increased density of the smoke particles, which is brought on by light scattering. Diesel has very high opacity ratings because of its poor atomization, whereas blends have correct atomization and produce less smoke. Diesel produces a lot of smoke, which is bad for the environment. When compared to diesel, the smoke for JD10 at 600 bar is 37% more clear. This suggests that better atomization results in less smoke.

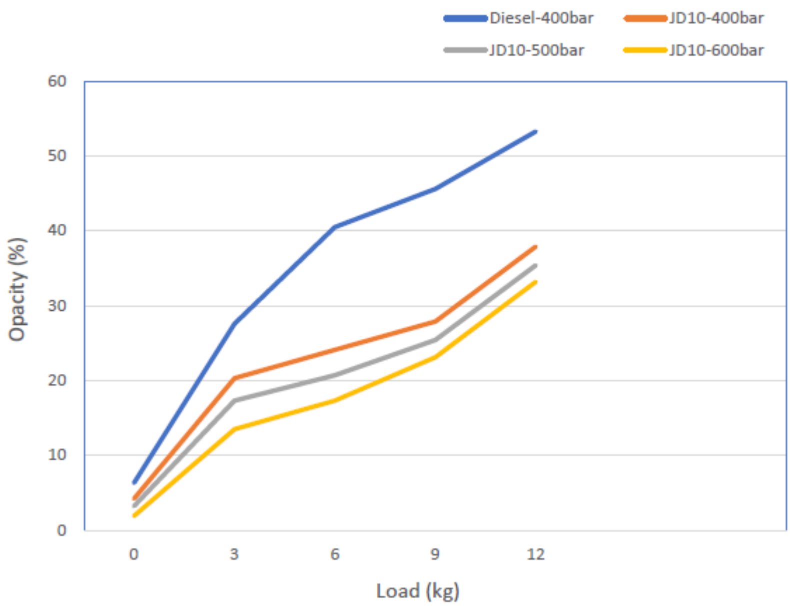

Fig 9 - Variation of Opacity

5. CONCLUSION

In the case of neat biofuel and its blend with diesel, the following are the main observations.

- The brake thermal efficiency is high with pure biofuel and it slightly reduces upon the addition of diesel. With the ideal B80D20 mix at 80% load, it falls from 32.4% to 31.8%.
- Due to early burning, clean biofuel has lower exhaust gas temperatures than diesel with an increase in the amount of diesel in the biofuel-diesel blend, the exhaust temperature rises.
- Because of the increased premixed combustion of neat biofuel compared to diesel, NOx emissions are particularly significant. When diesel and biofuel mixes, NOx emissions are only slightly reduced.
- Pure biofuel has been discovered to have very low UHC and CO emissions. Mixing of diesel and biofuel lead to a rise in UHC and CO emissions.

Jatropha oil can be directly utilised in a CRDi engine without making any changes to engine. It is very much better than conventional diesel fuel. The major points that are obtained by using this kind of alternate fuel blend are:

- By varying the injection pressures we could observe increase in the volumetric efficiency with better fuel consumption.
- There is a 33% decrease in frictional loss for JD10 blend at 600 bar when compared to diesel.
- BTE increases for JD10 blend at 600bar compared to other fuels at their respective injection pressures. BTE is increasing by a range of 3% for diesel (400bar) and 5% for JD10 (400bar).
- Opacity value for JD10 blend at 600 bar is 20% less than for diesel at 400 bar.
- Better atomization is found at 600 bar throughout the experiment.

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APPLICATION OF MULTI-PARAMETER FREQUENCY ANALYSIS IN EXPERIMENTAL IDENTIFICATION OF VIBRATION PARAMETERS IN MOTOR VEHICLES

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RESEARCH ARTICLE

ABSTRACT: During exploitation, motor vehicles are exposed to vibrational loads that cause fatigue for users and material fatigue of their components. Therefore, vibrations must be studied at the earliest stage of design, using mathematical models, experiments, or a combination of both. Generally, there are idealizations during theoretical analysis, particularly concerning operating conditions and the interrelationships of motor vehicle components. This paper attempts to develop a method for identifying actual loads in continuous vehicle systems in exploitation conditions, based on recorded spatial vibrations. Multi-parameter frequency analysis was used for 2D, 3D, and 4D Fourier transformations. An illustration of the application of these procedures was carried out on idealized continuous vehicle elements such as bars, membranes, and parallelepipeds.

KEY WORDS: *Vehicle, continuous systems, vibrations, multi-parameter frequency analysis*

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PRIMENA VIŠEPARAMETARSKE FREKVENTNE ANALIZE PRI EKSPERIMENTALNOJ IDENTIFIKACIJI PARAMETARA VIBRACIJA MOTORNIH VOZILA

REZIME: Motorna vozila su, tokom eksploatacije, izložena vibracijskim opterećenjima koja dovode do zamora korisnika i materijala njihovih agregata. Zbog toga se vibracije moraju izučavati još u najranijoj fazi projektovanja, uz korišćenje matematičkih modela, eksperimenata, ili njihovih kombinacija. U teorijskim razmatranjima se, obično, čine idealizacije, naročito u pogledu eksploatacionih uslova i međusobnih veza agregata motornih vozila. U ovom radu je učinjen pokušaj razvoja metode za identifikaciju stvarnih opterećenja kontinualnih sistema vozila u eksploatacionim uslovima, na osnovu registrovanih prostornih vibracija. Naime, za višeparametarsku frekventnu analizu korišćene su 2D, 3D i 4D Furijeove transformacije. Ilustracija mogućnosti primene tih postupaka je izvršena na idealizovanim kontinualnim elementima vozila (štapovi, membrane i paralelopipedi.

KLJUČNE REČI: *Vozilo, kontinualni sistemi, vibracije , višeparametarska frekventna analiza*

APPLICATION OF MULTI-PARAMETER FREQUENCY ANALYSIS IN EXPERIMENTAL IDENTIFICATION OF VIBRATION PARAMETERS IN MOTOR VEHICLES

Miroslav Demić

INTRODUCTION

During exploitation, motor vehicles are exposed to vibrational loads that cause fatigue for users and material fatigue of their components. Therefore, vehicle vibrations must be studied at the earliest stage of their design using mathematical models, experiments, or a combination of both. Theoretical considerations usually focus on the vibration of concentrated masses, but with the development of numerical methods, especially finite element methods [1-3], attention has also been paid to the vibration of continuous vehicle systems.

Generally, there are idealizations, particularly concerning operating conditions [1-6] and the interrelationships of motor vehicle components. Then, usualy, idealizations are made, especially in terms of exploitation conditions and interconnection of motor vehicle aggregates [1]. The specific nature of motor vehicle exploitation conditions is their random nature, making theoretical considerations challenging to deal with using models, making experiments practically irreplaceable. Despite significant progress in the development of software for the automatic design and calculation of motor vehicles [7], their final characteristics are determined based on experimental studies.

Experimental methods are still relevant, particularly when considering continuous vehicle systems that are subject to vibration, such as different shafts, plates, support systems, chassis, and others. In this regard, methods for identifying their vibration parameters have been developed, such as modal analysis [8,9]. These methods, practically carried out in laboratory conditions, determine the vibration modes.

However, a problem arises when actual operating conditions are necessary for generating loads on shakers in the laboratory since modal analysis does not provide opportunities for generating these signals. Therefore, it is essential to develop a procedure for identifying vibration parameters that will enable their generation in laboratory conditions.

One possibility is frequency analysis using the Fourier transformation, which allows the determination of the frequency content of a signal by calculating magnitude and phase spectra. The data on magnitude spectra and phase angles [10], along with the inverse Fourier transformation, enables the generation of the original time-variant signal, which is routinely performed when the signal depends only on time.

However, the vibration of continuous systems depends on several parameters, such as size and time. Therefore, multi-parameter Fourier transformation must be used (2D, 3D, 4D...)[1-15] depending on the degree of simplification (idealization) of the problem. For the analysis of bar vibration, 2D transformation can be used, while for flat plates, 3D, and for spatial continuous bodies, 4D Fourier transformation can be used.

This paper analyses the possibilities of applying multi-parameter Fourier transformations to create the conditions for investigating the vibration of continuous vehicle systems in laboratory conditions.

$$F(\xi_1,\xi_2....\xi_n)=\int_{R^n} e-2\pi i(x_1\zeta_1+x_2\zeta_2+...+x_n\zeta_n)* \\ f(x_1,x_2....x_n)dx_1dx_2****dx_n \tag{1}$$

where:

- function of n variables,
- variables,
- circular frequency, and
- multiple integral (for 2D-double, 3D-triple, etc.).

1. METHOD

As previously mentioned, this paper aims to explore the possibility of applying multi-parameter frequency analysis (Fourier transformation: 2D, 3D, 4D) in the identification of vibration parameters of motor vehicles. Considering that the continuous elements and aggregates of motor vehicles can be simplified by modelling them as continuous bars (shafts, etc.), membranes (body parts...), and spatial bodies (engine, transmission, wheels...), it is deemed appropriate to explain the procedure on elementary elastic elements: bars, membranes, and parallelepipeds, using the multi-parameter Fourier transformation.

In the absence of experimental data on registered vibrations of mentioned continuous bodies (bar, membrane, parallelepiped), the method is illustrated with data obtained from mathematical models. As it is known, vibrations of continuous elements are described by partial differential equations [17]. Since performing partial differential equations that describe vibrations of observed continuous bodies are described in detail in [11,17], this will not be done here, but their final form will be given. For further consideration, images 1 to 3 will be observed.

Forced longitudinal vibrations of the bar

Forced longitudinal vibrations of the bar [11,17] are described by the differential equation:

$$\frac{\partial^2 u}{\partial t^2}=c^2\frac{\partial^2 u}{\partial x^2}+f(x,t) \tag{2}$$

where:

- u(x,t) - longitudinal vibrations of the bar,
- x - coordinate along the length of the bar,
- $f(x,t)$ - the force,
- t - time, and

$$c^2=\frac{E}{\rho}$$

where:

- E – Young’s modulus , and

- ρ – Membrane material density.

Forced transverse vibrations of the membrane

The differential equation that describes forced transverse vibrations of a rectangular membrane is of the form [11,17]:

$$\frac{\partial^2 u}{\partial t^2} = s^2 \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + f(x, y, t), \qquad (3)$$

where:

- u(x, y, t) - transverse vibrations of the membrane,
- x - coordinate along the membrane length,
- y - coordinate across the membrane width,
- f(x, y, t) - force,
- t - time, and

$$s^2 = \frac{\sigma}{\rho}$$

where:

- σ-axial stress, and
- ρ – membrane material density.

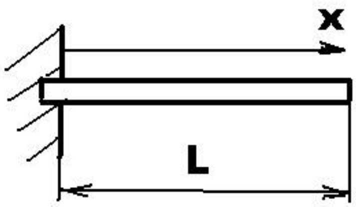

Figure 1. The continuous bar

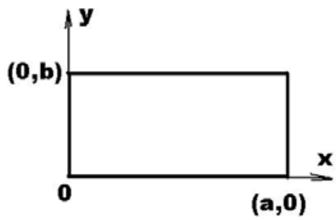

Figure 2. Rectangular continuous membrane

1.1 Forced spatial vibrations of continious parallelopipe

There are several forms of partial differential equations in the references that describe forced vibrations of a continuous parallelepiped, but it is considered useful to adopt the form [11,17] for further analysis:

$$\frac{\partial^2 u}{\partial t^2} = s^2 \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + f(x, y, z, t), \qquad (4)$$

where:

- u(x, y, z, t) - spatial vibrations of the Parallelepiped,
- x - coordinate along the length of the Parallelepiped,
- y - coordinate across the width of the parallelepiped,
- z - coordinate along the height of the Parallelepiped,
- f(x, y, z, t) - force,
- t - time, and
- $s^2 = \frac{\sigma}{\rho}$
- σ-axial stress, and
- ρ - mass density of the Parallelepiped.

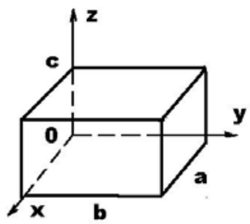

Figure 3: The continuous parallelepiped

As it is known [11,12,17,18], to find the general integral of partial differential equations (2-4), boundary and initial conditions must be known, as well as forces, which are shown in Table 1 in this specific case.

Table 1. The Boundary, initial conditions, and forced force

Bar	Membrane	Parallelepiped
$u(0,t)=0$ $\frac{\partial u(L,t)}{\partial x}=0$ $u(x,0)=0$ $\frac{\partial u(x,0)}{\partial t}=0$ $f(x,t)=a_m*\sin(4\pi t)$ $a_m=1, mm$	$u(0,y,t)=0$ $u(a,y,t)=0$ $u(x,0,t)=0$ $u(x,b,t)=0$ $u(x,y,0)=0$ $\frac{\partial u(x,y,0)}{\partial t}=0$ $f(x,y,t)=a_m*(random-0.5)$ $a_m=1, mm$	$u(0,y,t)=0$ $u(a,y,t)=0$ $u(x,0,z,t)=0$ $u(x,b,z,t)=0$ $u(x,y,0,t)=0$ $u(x,y,c,t)=0$ $u(x,y,z,0)=0$ $\frac{\partial u(x,y,z,0)}{\partial t}=0$ $f(x,y,z,t)=a_m*(random-0.5)$ $a_m=1, mm$

To verify the accuracy of the integration method for the bar, a harmonic force was used, while for the membrane and parallelepiped, very rigorous excitation forces with "white" noise were used.

The partial differential equations (2-4) are only possible to be solved in the case of the bar due to the harmonic force, while for the membrane and parallelepiped, it was not possible due to the random nature of the force. Therefore, an attempt was made to solve the partial differential equations using the program Wolfram Mathematica 13.2 [16]. However, difficulties arose in listing numerical data, particularly for the membrane and parallelepiped.

As a result, the problem was solved numerically [19] using the finite difference method with software developed in Pascal for the case of 2D, 3D, and 4D Fourier transform. Using the developed softwares, vibration values were calculated in all three cases with data (bar: l=256mm, h_x=1mm, ht=0.01s; membrane: a=b=128mm, h_x= h_y= 8mm, h_t=0.1s; parallelepiped: a=b=c=128mm, h_x=h_y=h_z=16mm, h_t=0.2s).

It is noted that in the case of analyzing the vibration of the bar, the solution depends on two parameters (which requires the use of 3D graphics) and in the case of the membrane and parallelepiped, it is necessary to use 4D or 5D graphics (which commercially does not exist). To use existing commercial 3D graphics, only the results for the center of gravity axes are shown for the membrane and parallelepiped. For illustration, the results of the numerical integration of the partial differential equation (2) are shown in Figures 4-6.

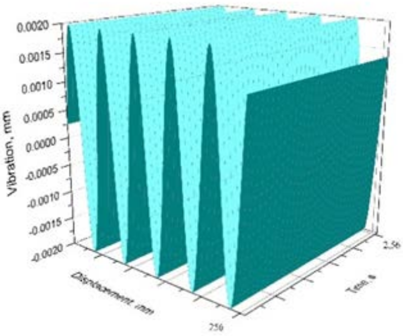

Figure 4. The longitudinal vibrations of the bar

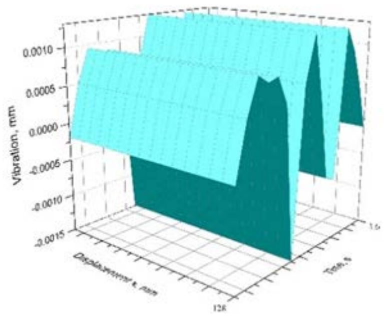

Figure 5. The longitudinal vibrations of the membrane in the "x" direction of the center of gravity axe

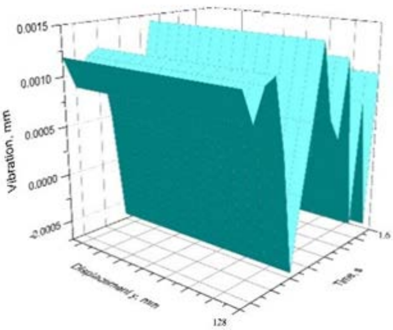

Figure 6. The longitudinal vibrations of the membrane in the "y" direction of the center of gravity axe

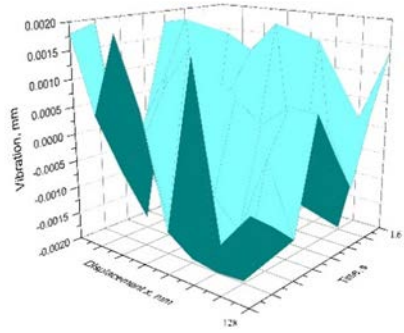

Figure 7. The vibrations of a parallelepiped in the" x "direction of the center of gravity axe

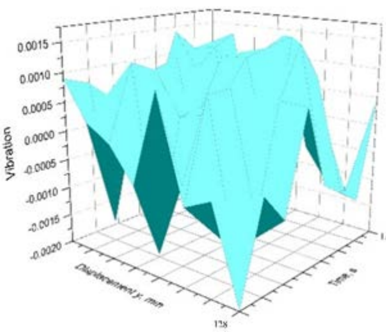

Figure 8. The vibrations of a parallelopiped in the "y" direction of the center of gravity axe

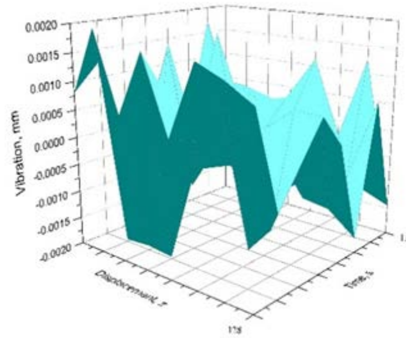

Figure 9. The vibrations of the parallelopiped in the "z" direction of the center of gravity axe

Analysis of Figure 4 shows the harmonic character of the vibrations that move along the length of the bar in the form of waves because it is a test with harmonic excitation, which is similar with theoretical solutions from [11, 17]. Longitudinal vibrations of the bar depending on the displacement of "*x*" and time "*t*". Therefore, the 2D Fourier transform must be applied, and for illustration, graphs of the spectrum magnitude and phase angle of vibrations are shown in Figures 10 and 11.

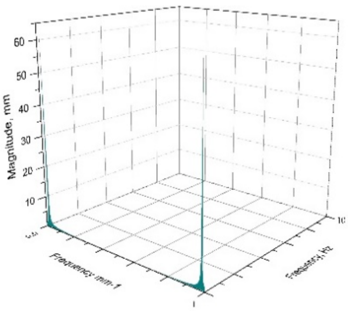

Figure 10. Spectrum magnitude of the longitudinal vibration of the bar

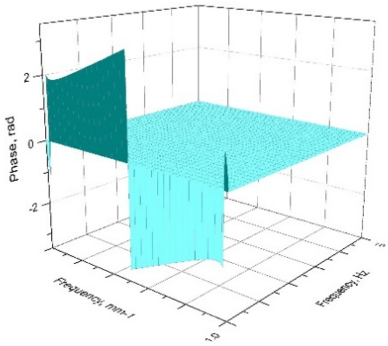

Figure 11. Phase angle of longitudinal vibrations of the bar

Transverse vibrations of the membrane spread wave-like over its surface and depend on three parameters: displacement along the “x” and “y” axes and time “t”. In this case, it is necessary to apply the 3D Fourier transform, for which graphic display requires 4D graphics. To solve the problem, only data of vibrations along the center of gravity axes are shown in Figures 12-15.

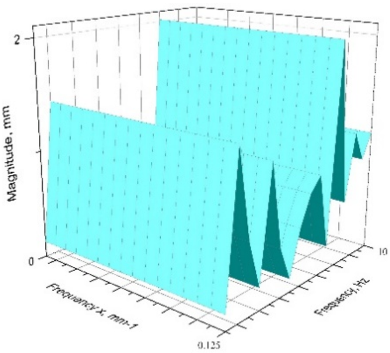

Figure 12. The spectrum magnitude of transverse vibrations of the membrane for the “ x” center of gravity axe

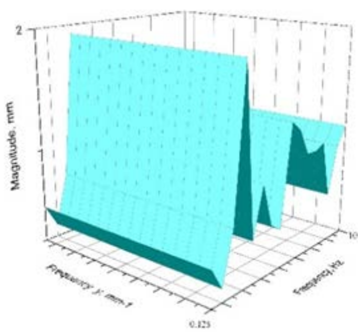

Figure 13. The spectrum magnitude of transverse vibrations of the membrane for the” y”center of gravity axe

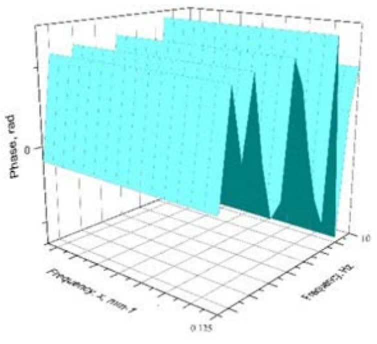

Figure 14. The phase angle of the spectrum of transverse vibrations of the membrane for the "x" center of gravity axe

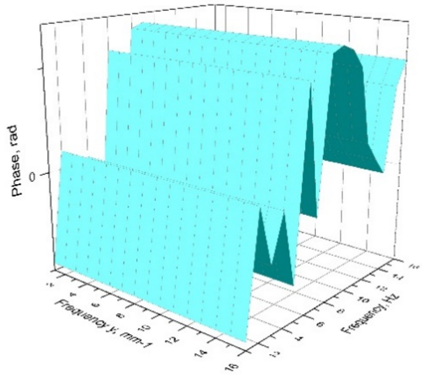

Figure 15. The phase angle of the spectrum of transverse vibrations of the membrane for the "y" center of gravity axe

Vibrations of parallelepiped spread throughout its volume and depend on 4 parameters: displacement in the "x", "y", and "z" directions and time" t". Frequency analysis requires the use of 4D Fourier transform and graphic display of 5D graphics. Therefore, it has been deemed appropriate to show only the results along the center of gravity axes, as shown in Figures 16-21.

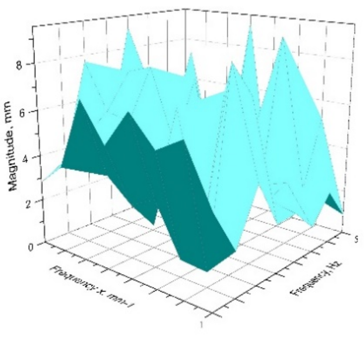

Figure 16. The spectrum magnitude of spatial vibrations of parallelepiped for the "x" center of gravity axe

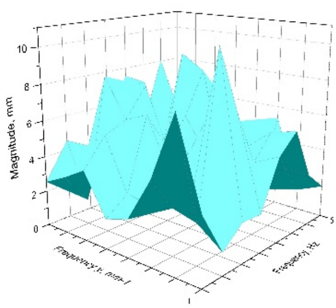

Figure 17. The spectrum magnitude of spatial vibrations of parallelepiped for the "y" center of gravity axe

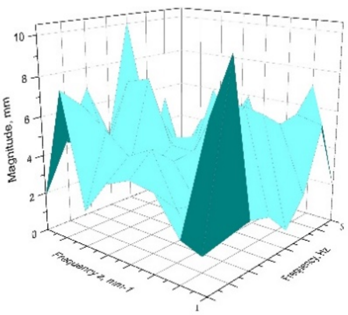

Figure 18. The spectrum magnitude of spatial vibrations of parallelepiped for the" z "center of gravity axe

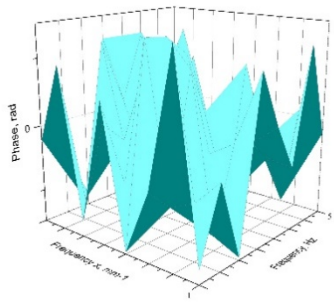

Figure 19. The phase angle of the spectrum of vibrations of parallelepiped for the "x" center of gravity axe

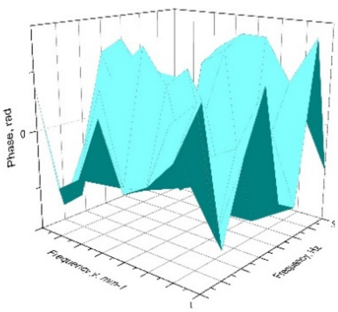

Figure 20. The phase angle of the spectrum of vibrations of parallelepiped for the "y" center of gravity axe

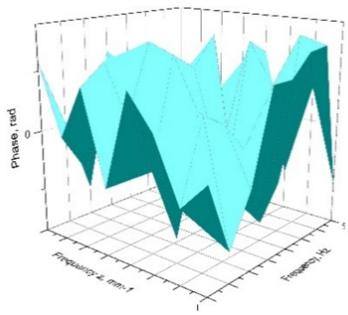

Figure 21. The phase angle of the spectrum of vibrations of parallelepiped for the "z" center of gravity ax

2. DATA ANALYSIS

By analysing the partially displayed data in Figures 10-21, it can be concluded that the spectrum magnitudes and phase angles describe the shape of vibrations in observed continuous bodies.

In the case of the bar, considering the harmonic nature of the excitation, the harmonics along its length (figures 9-11) are more noticeable, which is also theoretically confirmed in [11,17].

Data on transverse vibrations of the membrane, partially displayed in figures 12-15, show that harmonics occur across the surface of the membrane, regardless of whether the excitation was random, which agreed with theoretical interpretations related to transverse vibrations of the membrane [11,17].

By analysing all calculated data on spatial vibrations, partially shown in figures 16-21, extremes can be observed that indicate the character of wave movement through the volume of the parallelepiped, which agreed with theoretical conclusions [11,17].

Based on the previous analysis, it can be claimed that multi-parameter Fourier transform reliably enable data analysis of vibrations, which can have a practical applications in examining vibrations in motor vehicles, because the complex data on registered vibrations on any of the motor vehicle systems can be subjected to multi-parameter frequency analysis.

Calculated spectrum magnitude and phase angles, using multi-parameter inverse Fourier transform, enable the generation of identical vibrations both in the laboratory and under operating conditions [20].

It should be noted that in Fourier transform, there are no explicit procedures for calculating errors in spectrum calculation for multiple variables, as in the case of 1D Fourier transformation [10]. Bearing this in mind, and given that this study aims to illustrate the possibility of applying multi-parameter frequency analysis in examining vibrations in motor vehicles, statistical error analysis was not specifically considered.

Therefore, the choice of integration parameters of partial differential equations was made based on the possibility of implementing 2D, 3D, and 4D Fourier transform algorithms on computers of medium configuration. Finally, it should be noted that these transformations require high-performance computer systems both in the realization phase of exploitation research and in the phase of calculating inverse Fourier transformations for laboratory purposes.

CONCLUSIONS

Based on the performed research, it can be concluded that multi-parameter Fourier transforms reliably enable the analysis of experimental data on vibrations of the continuously bodies, indicating the possibility of their application in motor vehicles.

Calculated spectrum magnitude and phase angles, using inverse Fourier transform, enable the generation of identical vibrations both in the laboratory and under operating conditions.

It should be noted that the Fourier transform algorithms used require high-performance computer systems both in the realization phase of exploitation research and in the phase of calculating inverse Fourier transformations for laboratory purposes.

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INVESTIGATION OF THE SINGLE VEHICLE ACCIDENTS SEVERITY BY USING A PROBABILISTIC APPROACH

Drosu Alin [1], Corneliu Cofaru[2], Mihaela Virginia Popescu[3]*

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RESEARCH ARTICLE

ABSTRACT: Single vehicle accidents (SVAs) arouse the interest not only of researchers, but also of the European Commission and other international road safety bodies, since a third part from all road fatalities from Europe are caused by the single vehicle accidents. The aim of this paper is to assess the severity of such accidents by estimating the probability of the fatalities (P_{d1}) and major injuries (P_{d2}) generated by the single vehicle accidents and to identify the factors affecting those probabilities. As for this research, a complex 6 -year-accidents data base has been used and the accidents records have been aggregated on a daily basis. A binary multiple logistic regression has been developed for each type of severity (fatality and major injury) using 86 predictors related to the place of accidents, road category and feature and characteristic, the number and the width of the lanes, horizontal road markings, safety components of the road, road surface characteristics and adherence, weather and lighting conditions, vehicles mileage and drivers' sex. The logistic models have been tested on their statistical significance and their explanatory efficiency was discussed. A descriptive analysis has been conducted for both models in order to discuss the distribution of the probability values. P_{d2} model has a better explanatory power than P_{d1} and its overall percentage of the predictions is 96.10 %. It is also has a very good homogeneity since all its predictors have positive values. An interesting finding is that no other predictors related to weather or lighting conditions do significantly explain the probabilities of a SVA to be of fatality or to generate major injuries. These constraints are to be further researched since the daily level of data aggregation studied in this paper influence the "immediate effect" of random phenomena, as weather or lighting conditions. P_{d2} model has a good applicability in the identifying, prioritizing and treating of the black spots. The Romanian road authority could also use it in driver education and injury risk identification in order to mitigate the severity of the accidents.

KEY WORDS: *Safety, single vehicle accidents, logistic regression, probabilistic*

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ISTRAŽIVANJE JAČINE SUDARA POJEDINAČNOG VOZILA KORIŠĆENJEM PRINCIPA VEROVATNIĆEA

REZIME: Pojedinačne saobraćajne nezgode (SVA) izazivaju interesovanje ne samo istraživača, već i Evropske komisije i drugih međunarodnih tela za bezbednost saobraćaja na putevima, jer trećina svih poginulih na putevima u Evropi su su stradali u pojedinačnim saobraćajnim nezgodama. Cilj ovog rada je da proceni težinu ovakvih nezgoda procenom verovatnoće smrtnih slučajeva (Pd1) i teških povreda (Pd2) izazvanih pojedinačnim saobraćajnim nezgodama i da identifikuje faktore koji utiču na te verovatnoće. Što se tiče ovog istraživanja, korišćena je kompleksna šestogodišnja baza podataka o nezgodama i evidencija o nezgodama na dnevnoj bazi. Razvijena je binarna višestruka logistička regresija za svaku vrstu težine (smrt i teške povrede) koristeći 86 prediktora koji se odnose na mesto nezgode, kategoriju i profil i karakteristike puta, broj i širinu traka, horizontalne oznake na putu, bezbednosne komponente puta, karakteristike površine puta i prijanjanje, vremenski i svetlosni uslovi, kilometraža vozila i pol vozača. Logističkim modelima je ispitana statistička značajnost i diskutovana je njihova efikasnosti. Urađena je deskriptivna analiza za oba modela kako bi se diskutovalo o distribuciji vrednosti verovatnoće. Model P_{d2} ima bolju eksplanatornu sposobnost od P_{d1} i njegov ukupan procenat predviđanja je 96,10 %. Takođe, ima veoma dobru homogenost pošto svi njegovi prediktori imaju pozitivne vrednosti. Interesantan nalaz je da nijedan drugi prediktor koji se odnosi na vremenske uslove ili uslove osvetljenja ne objašnjavaju značajno verovatnoću da SVA bude sa smrtnim ishodom. Ova ograničenja treba dalje istraživati pošto dnevni nivo agregacije podataka koji se proučava u ovom radu utiče na „neposredan efekat“ nasumičnih pojava, kao što su: vremenski uslovi ili uslovi osvetljenja. P_{d2} model ima dobru primenljivost u identifikaciji, određivanju prioriteta i lečenju crnih tačaka. Rumunska uprava za puteve takođe bi mogla da ga koristi u obrazovanju vozača i identifikaciji rizika od povreda kako bi se ublažila težina nesreća.

KLJUČNE REČI: *Bezbednost, nezgoda pojedinačnog vozila, logistička regresija, verovatnoća*

INVESTIGATION OF THE SINGLE VEHICLE ACCIDENTS SEVERITY BY USING A PROBABILISTIC APPROACH

Drosu Alin, Corneliu Cofaru, Mihaela Virginia Popescu

INTRODUCTION

There are many definitions or classifications of the single vehicle accidents. While the American National Safety Council defines the single vehicle accidents (SVA) as collisions that involve pedestrians, fixed objects and wild and domestic animals, in Europe this type of accidents is represented by those collisions where the pedestrians or cyclists are not involved and the driver, rider and/or passengers are killed or seriously injured.

The single vehicle accidents are of interest not only for researchers, but also for the European Commission and other international road safety bodies, since a third part from all road fatalities from Europe are caused by the SVA [1]. At the European level, there is a lack of information in depth collision data focused on SVA and therefore more studies are required in order to find the factors that affect this type of collisions. In Romania, around 20% - 25% of the total number of fatalities is generated by SVA [2] and the Romanian authorities consider SVA as a major problem since the injury index is higher compared with other type of collisions (1.2 – 1.3 for SVA and 1.1 – 1.2 for non SVA). According to the Romanian authorities, the drivers' mood and their actions has a great impact in SVAs causation and injury severity. This fact does not confirm the findings of other international studies which show that the road environment highly impacts are the main factors causing SVA. Therefore, this paper will be focused more on researching the road and environmental factors that have a greater impact on the single vehicle accidents occurring on the Romanian territory.

The SVA are considered to have a higher severity than the multi vehicle accidents [3]. At the same time, the highest fatality percent of the road accidents is generated by the SVA [4]. While in the multi-vehicle accidents the severity of the crashes depends on how the drivers react when they are involved in such an event, in the case of SVA this is more influenced by the road environment and safety devices of the roadway. The hourly traffic volumes do not have a significant influence on the SVA's causational mechanism [5] and are negatively correlated with this type of collisions [6]. Even if the human error is one of the main factors that greatly influence the occurring of SVA, the environmental conditions significantly influence both accidents' probability and victims' severity [7]. The lighting conditions belong to those environmental characteristics which have a great impact on the probability of being involved in a SVA and on the severity of the victims and effects generated in this type of collisions [8]. Moreover, both probability and victims' severity are influenced by the weather conditions from the accident time when the drivers make errors or adopt dangerous decisions in their driving style, due to a poor visibility [9].

The presence of the hard shoulders and the lanes' width strongly influence the severity of a SVA [10]. Therefore, knowing the causational factors of the single vehicle accidents not only mitigate the accident and injury risk, but also will help the road safety authorities to implement appropriate counter measures.

1. DATA PREPARATION

In this paper, a complex accident database was used and all the road crashes occurred between 01.01.2013 – 31.12.2018 were included. According to the SVA's European definition, the collisions with one vehicle have been filtered, regardless the category (personal vehicle, light or heavy commercial vehicle, moped or motorcycle). Those accident records which involved pedestrians or cyclists were removed and all the data were aggregated on a daily basis. Finally, the dataset used for this research has 2.190 rows (corresponding to those 6 years included in this analyze).

2. METHODOLOGY

The severity of a road accident is generally shown by the severity of the victims. Therefore, using the Binary Multiple Logistic Regression (BMLR), two types of probabilities are assessed for predictive purposes by using SPSS: the probability of a SVA to be fatal or not (Pd1) and the probability for a SVA's victims to have or not to have major injuries (Pd2). The road accidents' severity assessed by using BMLR techniques is often found in the literature, as it is shown in other researches [11], [12].

The response variable of a BMLR is a probability P that always takes values between 0 and 1 and its mathematic model can be written as follows:

$$P = \frac{e^y}{1+e^y}, \tag{1}$$

where,

- y represents the odds of an accident to be labelled as a fatal/not fatal or with major injuries/no major injuries and take the values between zero and infinite.

It is also defined as the probability "p" for a SVA to be fatal or to have major injuries divided by the probability "q = 1-p" of a SVA to be not fatal or to have no major injuries. Using the natural logarithms, we can write the following relation:

$$\ln(y) = \ln\left(\frac{p}{q}\right) = \ln\left(\frac{p}{1-p}\right), \tag{2}$$

Mathematically, the relation of *y* (odds) can be written as:

$$y = \exp\left(b_0 + b_1 * X_1 + b_2 * X_2 + ... + b_k * X_k + ... + b_n * X_n\right), \tag{3}$$

where,

- b_0, b_1, b_2, … b_k *are the logit coefficients related to the regression's coefficients and* b_0 *is* the intercept.
- X_1, X_2, …,X_k, …, X_n are the predictors which will be included in the analyses and k = 1, 2,…,n represents the number of these predictors.

In this paper, the logit coefficients b_k of the predictors will be assessed using the odds. In order to do this assessment, an OR odds ratio will be calculated and will show to which extend the odds will be changed for a SVA to be fatal/non-fatal or with major injuries/no major injuries, when a predictor changes its value by own unit, when the other predictors remain constant. The equation for OR odds ratio is the following:

$$QR(\text{odds ratio}) = e^{b_k}, \tag{4}$$

Two kinds of statistical tests will be used in order to check the significance of the logistic models, as SPSS outputs: G^2 chi-square likelihood ratio test and Hosmer and Lemeshow's

Goodness of Fit Test. G^2 test will be used in order to check whether all predictors' logit coefficients, except the intercept, have null values. Its formula is the following:

$$G^2 = \left(-2\text{LLnull}\right) - \left(\text{-2LLmodel}\right). \quad (5)$$

2LLnull shows the errors associated with the model that has the intercept b_o as the only parameter and 2LLmodel shows the errors associated with the model that includes both the intercept b_o and predictors.

In case there are no major differences between the observed and estimated data, then the model is considered a good one. This is shown by the Hosmer and Lemeshow's Goodness of Fit Test's value which should not be statistically of significance ($p>0.05$).

The explanatory power of the estimated logistic models is given by two indicators which are similarly to the R^2 coefficient that is found in the linear regression: Cox & Snell R Square and Nagelkerke R Square. The classification table generated by SPSS will be used in order to check the correctness of the predictions. This shows how high the determination coefficient R^2 for establishing the proportions is. In the other words, R^2 will show the degree of compatibility between the observed and estimated values.

The logit coefficients will be tested in order to see if they significantly influence the values of the dependent variables P_{d1} or P_{d2}. The interpretation and the testing of these coefficients will be done by using the Wald test which tests the null hypothesis when a coefficient has the value of zero. The interpretation of the coefficients will be conducted by using these factors. Their positive values show an increase of the odds for a SVA to be fatal or to generate major injuries, in this case being a direct relationship between the predictor and the correspondent odds. Contrary, the negative values show a decrease of those odds.

In order to interpret the logit coefficients by using the percent, the following formula will be used:

$$Exp\left(B\right)\% = 100 * \left(e^{b_k} - 1\right), \quad (6)$$

3. RESULTS AND DISCUSSIONS

All the predictor variables that are used in this paper are investigated as risk factors related to the road, road environment, vehicle, driver and accident itself, as it is shown in table 1.

Table 1. Risk factors' category and the predictors used in the Binary Logistic Regressions.

Risk factors related to:	Category of the variable	Number of response variables included in this set	Variable's type
Road	Road type	6	Categorical
	Road feature	8	Categorical
	Road feature's configuration	13	Categorical
	Road inclination	4	Categorical
	Number of traffic lanes	8	Continuous
	Lanes' width	4	Categorical
	Roadway condition	5	Categorical
Road environment	Built up area/Outside built up areas	2	Categorical
	Road markings	4	Categorical
	Hard shoulders characteristics	3	Categorical

	Safety devices on the road	9	Categorical
	Roadway adherence	9	Categorical
	Lighting conditions	10	Categorical
	Weather conditions	7	Categorical
Vehicle	Odometer's displaying	7	Categorical
Driver	Male/female	2	Categorical
Crash	Accidents' causes	33	Categorical

As it was specified above at chapter 2, the data were aggregated on daily basis. Due to this aggregation level, all the categorical variables have been automatically transformed in continuous ones and there is no longer need for them to be transformed to dummy variables as it is in the logistic regressions that use this type of predictors. For example, the "Road type" category has 6 response variables that are categorical ones and each of them can take only the values of 0 or 1: street, national road, inter-county road, inter-village roads, highway and other roads. In case of an analysis made on an individual basis, it would have been necessary to transform those 6 variables in 5 dummy variables (k-1 variables). In our case (daily aggregation level), the values of a variable is given by the cumulating the 0 and 1 values of each of the variables counted that precise day. When redundant variables are found by SPSS, meaning that some variables are collinear with others, these are automatically removed by SPSS. Therefore, even if the number of response variables are 134 (Table 1), the total number of predictors taken into analyses are 86 as the figure 1 shows.

3.1 Estimation of P_{d1}

In order to estimate the P_{d1}, a binary multiple logistic regression is developed in SPSS and its primary outputs are shown in Figure 1:

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	413.559	86	.000
	Block	413.559	86	.000
	Model	413.559	86	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	2551.885[a]	.172	.232

a. Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	7.579	8	.476

Figure. 1. Primary outputs for P_{d1} model consisting in G2 test, values of the Cox & Snell R Square and Nagelkerke R Square and Hosmer and Lemeshow test.

As it can be seen in figure 1, P_{d1} model is statistically significant since G2(86) = 413.559, p<0.001. This is also shown by the Hosmer and Lemeshow's Goodness of Fit test which is not significant (p=0.476>0.05), demonstrating an influence of the predictors on Pd1 variance. The Cox & Snell R^2 value is 0.172 and Nagelkerke R^2 value is 0.232, showing that all the predictors have an overall contribution between 17.20 % and 23.20 % to the variation of P_{d1}.

Looking at the classification table from figure 2, we can notice that the overall percentage of the predictions is 58.60 %.

Classification Table[a,b]

Observed			Predicted		
			P_{d1}		Percentage Correct
			0	1	
Step 0	P_{d1}	0	0	905	.0
		1	0	1281	100.0
	Overall Percentage				58.6

a. Constant is included in the model.

b. The cut value is .500

Figure 2. Classification table of the P_{d1} predictions.

After conducting the Wald test, only 14 predictors are of significance, as it is shown in table 2.

Table 2. The significant predictors and their logit coefficients B, Wald test of the individual significance, the exponential values of the coefficients (odds values) and their percentages.

Predictors	b_k	S.E.	Wald	df	Sig.	$Exp(b_k)$	$OR=Exp(b_k)$ %
Outside built-up areas (OBA)	1.527	0.674	5.134	1	0.023	4.605	360.50
Built up areas (BUA)	1.445	0.675	4.591	1	0.032	4.244	324.40
Curve (CRV)	-0.724	0.342	4.496	1	0.034	0.485	-51.50
Intersection (INT)	-0.878	0.367	5.722	1	0.017	0.416	-58.40
Railway crossing (RWC)	-0.922	0.391	5.551	1	0.018	0.398	-60.20
LN = 1	-0.365	0.157	5.395	1	0.020	0.694	-30.60%
LN = 2	-0.198	0.082	5.844	1	0.016	0.820	-18.00%
LN = 3	-0.180	0.073	6.110	1	0.013	0.836	-16.40
Paved hard shoulder (PHS)	0.084	0.040	4.431	1	0.035	1.087	8.70
Safety barriers (STB)	0.668	0.300	4.976	1	0.026	1.951	95.10%
Safety slides (STS)	0.484	0.189	6.525	1	0.011	1.622	62.20%
No road markings (NRM)	0.298	0.131	5.179	1	0.023	1.347	34.70%
Odometer info:							
25000 km – 50000 km (OD25-50)	0.215	0.094	5.217	1	0.022	1.239	23.90%
Female (FML)	-0.167	0.040	17.759	1	0.000	0.846	-15.40%
b_0	-1.419	0.133	113.956	1	0.000	0.242	-

When the number of SVA occurring outside of built-up areas increases by one unit, the odds of them being fatal increase by 360.50 % [OR(OBA) = 360.50 %, Wald(1) = 5.134, p<0.05].

Similarly, for those SVA that occur inside the built-up areas the odds increase by 324.40 % [OR(BUA) = 324.40 %, Wald(1) = 4.591, $p<0.05$], showing that a similar fatality risks is assigned for both types of travels (outside and inside built-up areas), although the travel speed is notably higher outside built-up areas than inside of cities or villages.

Regarding the road's features, the SVAs' number that occurs in curves, intersections and railway crossings significantly explain the variation of P_{d1}. There is an indirect relationship between each of these road's features and the variation of P_{d1}, as it is shown by the negative values of the odds: [OR(CRV) = -51.50 %, Wald(1) = 4.496, $p<0.05$], [OR(INT) = -58.40 %, Wald(1) = 5.722, $p<0.05$] and [OR(RWC) = -60.20 %, Wald(1) = 5.551, $p<0.05$]. In other words, any increase of the SVAs' number that occurs in this type of road's features will lead to a decrease of the probability of SVA of being fatal. The indirect relationship between the P_{d1}'s variation and the SVAs' number that occur in curves is an interesting finding of this paper, since it contradicts other papers in which the curves are considered as risk factors having a high significance in explaining the variation of the severity's increase of a SVA that occurs in these roads' features [4], [13], [14], [15]. When the drivers have to approach a curve, an intersection or a railway crossing, they become more attentive and decrease the travel speed. Apart from this, as it can be seen in the table 2, each SVA that occur on a railway crossing leads to a decrease by 60.20 % of the odds for that collision to be a fatal one. The number of those SVA occurring on roads with 1, 2 or 3 lanes (LN = 1, LN = 2 or LN = 3) significantly explain the variation of P_{d1}, in an indirect relationship, as it is shown by the negative values of the logit coefficients.

Each single vehicle accident that occur on those roads where safety barriers are installed increases by 95.10 % the probability of that SVA to be a fatal one [OR(STB) = 95.10 %, Wald(1) = 4.976, $p<0.05$]. On the roads where safety slides are installed, each SVA increase by 62.20 % the probability of that collision to generate fatalities [OR(STS) = 62.20 %, Wald(1)= 6.525, $p<0.05$]. The safety barriers are usually installed on a those roads that have a high risk of collisions and where the speed is inappropriate to the roadway configuration. When the number of the SVA occurring on those roads where the horizontal marking is missing increases with one unit, this leads to an increase by 34.70 % of the odds that SVA to be a fatal one [OR(NRM) = 34.70 %, Wald(1) = 5.179, $p<0.05$] and this confirms the previous research findings that considered the longitudinal road marking as a risk factor [16]. Usually, the roadway where the horizontal marking is missing can be found on the areas where road works are developing and where the drivers pay more attention simultaneously with a speed diminishing.

Another interesting finding of this paper concerns the number of female drivers involved in single vehicle accidents. This number significantly explains the variation of Pd1 in an indirect relationship and each SVA in which a female driver was involved leads to a decrease by 15.40 % of the odds of that SVA to be a fatal one [OR(FML) = -15.40 %, Wald(1) = 17.759, $p<0.001$]. This statement is in conflict with the conclusions found on [17] in which the female drivers have increased odds to be involved in SVA on the mountain roads and the severity of the accidents caused by the female drivers is higher comparing with the male drivers [15]. The very low p value of this predictor ($p<0.001$) shows that this predictor has the highest explanatory power from all the variables.

Using the predictors presented in table 2, which significantly explain the P_{d1}'s variation, the logistic equation can be written with the formula (3) and the estimated values of P_{d1} will be calculated using formula (1).

A descriptive analysis conducted on the P_{d1} distribution shows a positive asymmetry tendency of the P_{d1} distribution curve as the skewness value (0.73) is a positive one, as it is shown in the table 3.

Table 3: Statistical parameters of the P_{d1} distribution curve.

Pd1 Descriptive Statistics		
N	Valid	2190
	Missing	1
Mean		.585937
Median		.573255
Mode		.0000
Std. Deviation		.2044395
Skewness		.073
Std. Error of Skewness		.052
Kurtosis		-.914
Std. Error of Kurtosis		.105

As it is presented in figure 3, since the skewness value is a positive one, there are many higher P_{d1} values in the detriment of the smaller P_{d1} values. The mean and median have close values and this shows the tendency of the P_{d1} distribution curve towards a normal distribution. This is also confirmed by research [17] that states that any distribution which has the skewness value between [-0.80, 0.80] can be treated as a normal distribution.

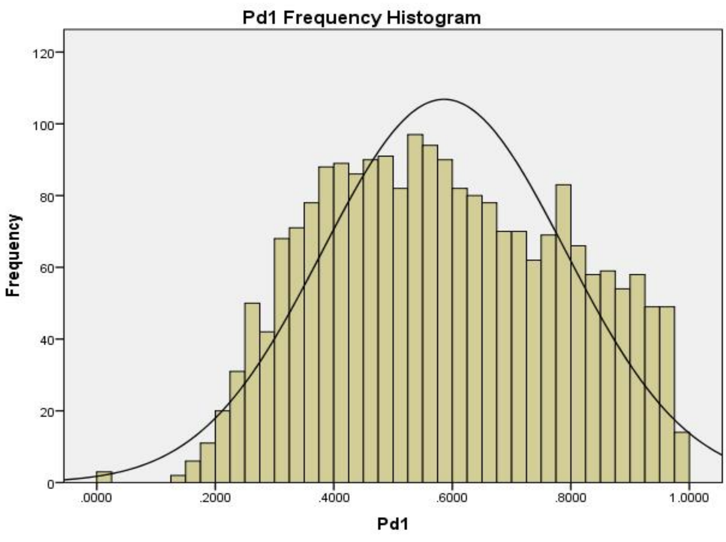

Figure 3. Frequency histogram of the Pd1 valuesAs is it also shown in the table 3 and figure 3, since the kurtosis value (-0.914) is a negative one, the estimated values of Pd1 are scattered and heterogeneous.

4.2 P_{d2} estimation

The primary outputs generated after running a binary logistic regression for P_{d2} model are shown in figure 4 in which we can see that P_{d2} model is also statistically significant, since $G^2(86) = 242.819$, $p<0.001$ and the Hosmer and Lemeshow's Goodness of Fit test is not of significance ($p= 0.983>0.05$).

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	242.819	86	.000
	Block	242.819	86	.000
	Model	242.819	86	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	482.256[a]	.105	.372

a. Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	1.924	8	.983

Figure 4: Primary outputs for P_{d2} model consisting in G2 test, values of the Cox & Snell R Square si Nagelkerke R Square and Hosmer and Lemeshow test.

The following predictors explain the variance of P_{d2} in a proportion of 10.50 % - 37.20 % (as it shown by the Cox & Snell R^2 and Nagelkerke R^2 values): the number of daily accidents that occurred in simple “T” intersections, on those roads with unpaved shoulders, where the lane’s width is over 3.75 m and in which cars having more than 100.000 km are involved, as it is shown in the table 5.

Table 5. The significant predictors and their logit coefficients B, Wald test of the individual significance, the exponential values of the coefficients (odds values) and their percentages.

Predictors	b_k	S.E.	Wald	df	Sig.	Exp(b_k)	OR=Exp(b_k) %
Simple “T” intersections (TIN)	1.314	0.567	5.363	1	0.021	3.721	272.10
Lane width >3.75m (LW3)	0.534	0.255	4.391	1	0.036	1.706	70.60
Unpaved hard shoulder (UHS)	0.276	0.139	3.961	1	0.047	1.318	31.80
Odometer info: 100,000 km – 150,000 km (OD100-150)	0.929	0.212	19.214	1	0	2.532	153.20
Odometer info: >150,000 km (OD>150)	0.329	0.143	5.276	1	0.022	1.389	38.90
b_0	-0.161	0.333	0.233	1	0.629	0.851	-

In case of P_{d2}, the overall percentage of the predictions is 96.10 %, as it is shown in the figure 6.

Classification Table[a,b]

Observed			Predicted P_{d2} 0	Predicted P_{d2} 1	Percentage Correct
Step 0	P_{d2}	0	0	86	.0
		1	0	2100	100.0
	Overall Percentage				96.1

a. Constant is included in the model.

b. The cut value is .500

Figure 6: Classification table of the Pd2 predictions.

The logistic equation can be now written using formula (3) and is as follows:

$$Y_{d2} = exp(-0.161 + 1.314*TIN + 0.534*LW3 + 0.276*UHS + 0.929*(OD100-150) + 0.329*(OD>150)), \quad (7)$$

The estimated values of P_{d2} can be now calculated using formula (1).

The simple "T" intersections are one of the most dangerous road features, since each SVA taking place here increases the major injury probability by 272.10 % [OR(TIN) = 272.10 %, Wald(1) = 5.363, P<0.05]. Most of these intersections can be found on those roads that are situated outside of the built-up areas where the signalization is poor and the travel speeds are higher.

On the roads where the lane's width is >3.75 m, each increase of the SVAs' number with one unit will increase the odds with 70.60 %, this being in line with the findings [19] which states that a high injury risk in single vehicle accidents is predicted on a road with large traffic lanes. P_{d2} variation is also significantly explained by the number of SVA which occur on the roads with no paved hard shoulders [OR(UHS) = 31.80 %, Wald(1) = 3.961, p<0.05].

Other interesting finding of this paper regards the high explanatory power of the number of SVA in which are involved old vehicles whose mileage is between 100,000 km – 150,000 km. Each increase of the SVAs' number which involve this type of vehicles leads to an increase by 153.20 % of the odds that this accident will result major injuries [OR(OD100-150) = 153.20 %, Wald(1) = 5.276, p<0.001]. The Romanian car park has a considerable average age (16.2 years) and most of these vehicles are passenger cars (78.80 %) having these mileages. As these kinds of old vehicles are not equipped with high performance active and passive safety systems, they are associated with a high injury risk of the passengers and drivers as it was stated in [12], [20-23]. The other finding that regards the car's mileage variable is quite contrary to the previously mentioned papers. As we can see from table 5, each increase of a SVA in which a vehicle having the mileage > 150,000 km is involved, will lead to an increase by 38.90 % of the odds of major injuries [OR(OD>150) = 38.90 %, Wald(1) = 5.276, p<0.05]. Most of the vehicles having a mileage > 150,000 km have a considerable age, a small share in the national car park and are often used occasionally, during weekends or summer season.

A descriptive analysis conducted on P_{d2} frequencies generates the statistics presented in table 6.

Table 6. Statistical parameters of the Pd2 distribution curve.

Statistics

Pd2		
N	Valid	2190
	Missing	1
Mean		0.960441
Median		0.995920
Mode		1.0000
Std. Deviation		.0854170
Skewness		-3.688
Std. Error of Skewness		0.052
Kurtosis		16.782
Std. Error of Kurtosis		0.105

As the skewness value is a negative one (-3.688), the P_{d2} distribution curve is a strongly asymmetrical one (its value is far from zero) and there are many higher values in the detriment of the smaller ones, this showing higher values of the major injuries probabilities in the single vehicle accidents. The kurtosis coefficient has a positive value (16.782) and shows a leptokurtic tendency of P_{d2} frequencies distribution curve where homogenous values are found, most of them being grouped around the mean (figure 7).

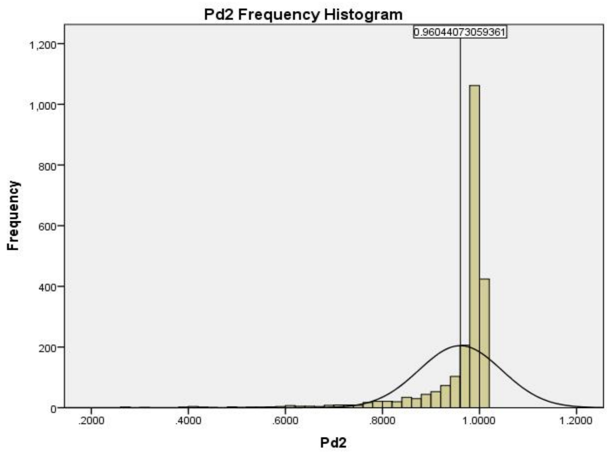

Figure 7. Frequency histogram of P_{d2} values and their grouping compared with the mean.

4. CONCLUSIONS

The probability of a SVA to be of fatality is increased by the number of SVA that occur outside or inside built-up areas, on those roads with paved hard shoulders, safety barriers and slides and no horizontal markings, and those vehicles with mileage between 25,000 km – 50,000 km that are involved in this collisions, as the logit coefficients of these predictors have positive values. Better roads maintenance that would consist in applying of more horizontal markings will decrease the probability of these accidents to be of fatality. As the odds of having a fatal SVA inside and outside the built-up areas are unusually higher, a better law enforcement and development of sustainable mobility plans will play a major role on decreasing the number of fatalities.

The car manufacturers, dealers and the insurance companies, as well, could contribute to the decrease of the number of fatalities as well, by development of educational programs, especially those focused on ADAS (Advanced Driving Assistance Systems) and of awareness campaigns for those who drive relatively new cars with mileages between 25,000 km – 50,000 km.

Other interesting finding of this paper regards the P_{d2} model, where all those 5 predictors included have positive values of the logit coefficients. This means that any decrease of these coefficients will lead to an important decrease of the victims' numbers that are seriously injured in these types of collisions. The simple "T" intersections are the most dangerous, as each SVA occurred in this intersections leads to an increase by 272.10 % of the odds of being seriously injured. The drivers of the those old vehicles whose mileage is between 100,000 km – 150,000 km have a greater risk of being seriously injured in the single vehicle accidents, as the odds values are very high.

Of the two P_{d1} and P_{d2} models, the second one is better significantly explained by the predictors in a proportion of 10.50 % - 37.20 % and has a prediction accuracy of 96.10 %. In addition, all the predictors of P_{d2} have positive values, a thing which gives a practical applicability to this model since any decrease of a predictor's values will lead to a decrease of the serious injuries' probability. Rehabilitation of the simple "T" intersections, reducing the speed around them and improving the lighting during nights, will decrease the number of accidents around these intersections and consequently will lead to a decrease of the numbers of the seriously injured victims.

We should remark that no other predictors related to weather or lighting conditions do significantly explain the probabilities of a SVA to be of fatality or to generate major injuries. These constraints are to be further researched since the daily level of data aggregation studied in this paper influences the "immediate effect" of random phenomena, as weather or lighting conditions.

P_{d2} model has a good applicability in the identifying, prioritizing and treating of the black spots. Knowing the predicted probabilities on the road segments where a higher accident concentration is found would help the road administrators to implement suitable countermeasures in order to mitigate the major injury risk at lower costs. The road features with a higher major injury probability can be improved in terms of safety by implementing different countermeasures or by a better maintenance.

The Romanian road authority could also use it in driver education and injury risk identification in order to mitigate the severity of the accidents, including in the process of road law improvement.

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USE OF ALTERNATIVE INTERSECTIONS IN ORDER TO IMPROVE TRAFFIC SAFETY

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RESEARCH ARTICLE

ABSTRACT: The intersection of two or more roads represents the possibility of a conflict between vehicles. Alternative intersection designs can improve intersection performance by changing the configuration of conflict points by redirecting traffic, reducing the number of signal phases, as well as significantly reducing time losses at intersections. The use of alternative intersections such as continuous flow intersections (CFI) (also known as shifted left turns or DLT), divergent diamond loops (DDI), superstreets (also known as J-turns, restricted crossing U-turns, or RCUTs, reduced conflict intersections, or RCIs, reduced conflict U-turns, and synchronized streets), median U-turns (MUTs) became more common, as traffic demand increases. They are usually more complex than conventional design intersections and they are used when conventional intersection designs do not allow adequate safety improvements or adequate traffic flow. Alternative intersection designs have fewer points of conflict resulting in increased safety for both, drivers and pedestrians.

KEY WORDS: *alternative intersections, traffic safety, divergent diamond loops (DDI), continuous flow intersections , restricted crossing U-turns, median U-turns , superstreets*

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KORIŠĆENJE ALTERNATIVNIH RASKRSNICA U CILJU POBOLJŠANJA BEZBEDNOSTI SAOBRAĆAJA

REZIME: Raskrsnica dva ili više puteva predstavlja mogućnost sudara vozila. Koncepti alternativnih raskrsnica mogu poboljšati performanse raskrsnice: promenom konfiguracije tačaka konflikta preusmeravanjem saobraćaja, smanjenjem broja faza signala, kao i značajnim smanjenjem gubitka vremena na raskrsnicama. Upotreba alternativnih raskrsnica kao što su raskrsnice sa kontinualnim protokom (CFI) (poznate i kao pomerena leva skretanja ili DLT), divergentne dijamantske petlje (DDI), superulice (poznate i kao J-krivine, ograničena polukružna skretanja ili RCUTs, smanjena je konfliktne raskrsnice, ili RCI, smanjena konfliktna polukružna skretanja i sinhronizovane ulice), srednja polukružna skretanja (MUT) su postale sve češće, kako se potražnja za saobraćajem povećava. Obično su složenije od raskrsnica konvencionalnog koncepta i koriste se kada konvencionalni projekti raskrsnica ne dozvoljavaju adekvatna poboljšanja bezbednosti ili adekvatan protok saobraćaja. Koncept alternativnih raskrsnica ima manje tačaka konflikta što dovodi do povećanja bezbednosti i vozača i pešaka.

KLJUČNE REČI: *alternativne raskrsnice, bezbednost saobraćaja, divergentne dijamantske petlje (DDI), raskrsnice sa kontinualnim tokom, polukružna skretanja sa ograničenim ukrštanjem, srednje polukružno skretanje, superulice*

USE OF ALTERNATIVE INTERSECTIONS IN ORDER TO IMPROVE TRAFFIC SAFETY

Bojana Bošković, Saša Babić, Branimir Milosavljević

INTRODUCTION

Traffic problems are more complex than ever. Engineers have a complex task, to meet the needs of a growing population with limited resources. At many intersections, traffic jams are increasing, which results in drivers and pedestrians are wasting a lot of time waiting at such intersections, with an increased risk of being involved in a traffic accident. It is considered that conventional intersection designs are insufficient to alleviate existing transportation problems. Consequently, many engineers are researching and implementing innovative solutions in an attempt to improve both, the mobility of road users and their safety. One of the ways to solve this complex problem is precisely alternative ways of managing intersections.

Traffic is an extremely complex, stochastic phenomenon that cannot be modeled, because it depends on a number of parameters that affect the volume of traffic, and this later entails a number of problems arising from this.

Alternative intersections can reduce the number of major conflict points by redirecting traffic flow, especially left turns and turns at multi-arm intersections. Reducing the number of conflict points leads to the realization of operational and safety advantages for alternative intersections compared to conventional intersection designs under certain traffic and location conditions, often at significant cost savings compared to other more conventional alternatives, such as adding a turning lane or replacing the intersection with a loop, etc.

In the world, one of the most famous and widespread alternative ways of managing intersections is the roundabout. In addition, there are Superstreet, Median U-Turn, Continuous flow intersection, Continuous green-T, Jughandle, Quadrant roadway intersection, Single point diamond interchange, Diverging diamond interchange, etc.

This paper will show the operation of most commonly used listed alternative intersections, their advantages and disadvantages, as well as how each of them influence on traffic safety.

1. ROUNDABOT

A roundabout is an alternative intersection where vehicles move in a counter-clockwise direction around the central island. Although roundabouts have been in use since the early 1900s (USA), the modern roundabout can be traced back to the 1960s in the United Kingdom. What characterizes modern roundabouts is that they can have one or more traffic lanes, and their regulation can be done in several ways. A circular traffic sign is placed on each entrance leg.

The first way to regulate traffic in a roundabout is to place a sign for crossing the road with the right of way along with the sign for the roundabout. This means that the vehicle entering the roundabout is obliged to wait vehicles that are already in this roundabout, and when they pass it can enter in roundabout.

If there is no “crossing the road with right-of-way” sign on the entrance branch, the usual rules apply, namely that vehicles in an intersection that is not regulated by light signals or traffic signs must follow the "right-hand rule" or, as it is otherwise called, the "left-turn rule".

As many alternative intersections, roundabouts move left turns to achieve better operation.

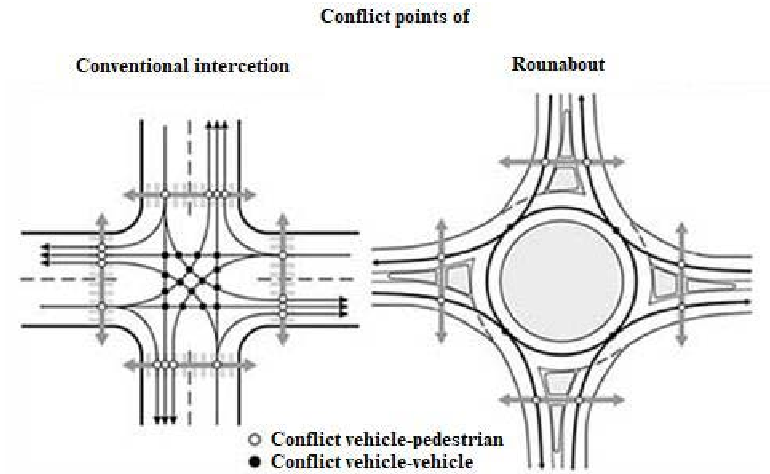

Figure 1. Conflict points: Left - Conventional intersection; Right - Roundaboat

As already mentioned, roundabouts can have one or more traffic lanes. Roundabouts that have only one traffic lane (so-called mini-roundabouts) are extremely safe, because there are no conflicting intersection points, while roundabouts with two or more traffic lanes also have conflicting intersection points due to improper use of the traffic lane and inadequate maneuver conflicts arise.

Advantages of roundabout are improved safety, fewer conflict points (all vehicles within roundabouts travel in the same direction, there are fewer conflict points and the vehicle-to-vehicle contact is limited to the “front-to-back” crashes. A conventional 4-legged signalized intersection has 32 conflict points, whereas a single-lane roundabout has only 8. Roundabout reduces travel speeds (before entering roundabouts, drivers must slow down (speeds in roundabouts often between just 25-40 km/h) and collisions that do occur are generally minor and cause far fewer injuries. Beside that the driver is made more aware of the surroundings with slower speeds. Enhanced efficiency is also one of the advantages of roundabouts (roundabouts provide a more efficient way to move traffic through intersections, since they are continuously flowing, and yield-controlled, they can handle a larger amount of traffic in the same amount of time than a conventional intersection. Roundabouts also reduce congestion on approaching roads and help drivers get to where they need to go in quick timing.). No traffic lights is one of the advantages, too, because there is no flow interrupttion. Since traffic is constantly moving through these intersections, drivers don’t feel the need to accelerate to make it through a traffic light and through the intersection, which made roundaboats safier. Vehicle pollution is decreased because vehicles entering the intersection aren’t required to stop. This opportunity for free-flowing traffic eliminates the stop-and-go movements associated with stop signs or intersections controlled by traffic signals. Reduced stop-and-go traffic leads to fewer idling vehicles and decreased vehicle pollution overall. Reduced maintenance costs is also one big advantage, because traffic signals require electricity 24/7 and the maintenance cost associated with it can become expensive and require a lot of equipment in order to function. If a signal blacks out, the intersection can cause chaos. Increased aesthetic opportunities roundabout, because typical intersections controlled by traffic signals require large, unsightly paved areas to accommodate the full range of turning movements needed. A roundabout provides a welcome opportunity for landscaping and artwork with central space [1].

There are several other disadvantages of roundabouts and they are: As the flow increases and reaches the capacity, weaving generally gives way to a stop and go motion as vehicles force their way into the roundabout, being followed by vehicles waiting in the queue behind them. Under such conditions vehicles, once having got into the rotary, may not be able to get out of it, because the vehicles across their path and the roundabout may lock up. When used on high speed roads, roundabout requires extremely large size. Where the angle of intersection between the two roads is too acute, it becomes difficult to provide adequate weaving length. When provided at close intervals, they make travel troublesome. Traffic turning right has to travel longer distance. A roundabout requires many warning and directional signs for safety. The central island and entrance and exits must be well lighted at night. This tends to make it costly. Roundabouts have a particularly poor safety record for cyclists and motorcyclists because of the geometric design of roundabouts is a major factor in the type of accidents that take place. The design of roundabouts is generally based on maximizing traffic throughput, which often leads to multi-lane approaches with poor entry path curvature and wide circulatory carriageways, encouraging high speed onto and circulating the roundabout) [2].

Very large roundabouts lead to high circulating speeds and cause problems for entering traffic.

2. SUPERSTREET

Unsigned J-turns, limited intersection U-turns, reduced conflict intersection U-turns, reduced conflict U-turns and synchronized streets. Everything listed belongs to Superstreets.

A reduced number of conflicts on Superstreets are achieved by diverting vehicles going straight or turning left to a minor street. Vehicles that want to turn left or want to continue straight cannot do that immediately, they must make so-called U-turn, by turning right, making a U-turn and continuing straight on the main street (if they wanted to turn left) or turn right again (if they wanted to continue straight), as shown in the figure 2). Vehicles turning left and traveling on main street move through the intersection as a conventional intersection, if the median is left open. In a variant of this type of intersection, the median is closed, and vehicles turning left from the main street are redirected to the U-turn section, as indicated.

Figure 2. Left turn in conventional intersection (up) and superstreet (down)

The Superstreet design looks complicated, but it doesn't leave drivers much of a choice. This alternative type of intersection guiding them through the intersection by minimizing intersection conflict points. A typical intersection can have as many as 32 potential conflict points, while a Superstreet has only 14 conflict points, so they are therefore safer for pedestrians.

In addition to these significant advances in increasing the safety of both drivers and pedestrians, there are many other things that make these intersections a good alternative. This type of intersection is efficient, because the number of conflicting points is reduced, there are fewer traffic lights, which allows more vehicles to be served and less waiting time. Also, Superstreets are economically profitable because they require less space compared to interchanges, which are an excellent alternative. The smaller areas required for this type of intersection and the reduced waiting time mean that they are more favorable from an environmental point of view.

One difficulty the authors have observed with bulb-outs is the tendency of drivers to occasionally use them to rest and park [3].

2. 1 Restricted crossing U-turn intersection (RCUT)

Restricted crossing U-turn (RCUT) is among the alternative intersection design used to improve the operation and safety of conventional signalized intersections. It allows larger movements (right turns, through and left turns) on the main road, while prohibiting all these movements for smaller volumes, as well as U-turns (for vehicles on the main and minor roads) on the main intersection. U-turns in the main direction are made downstream of the intersection using U-turn lanes. All vehicles on the secondary road must first turn right and then use the U-turn lanes if the driver wants to pass, turn left or U-turn. Figure 3 shows an example of a signalized RCUT intersection.

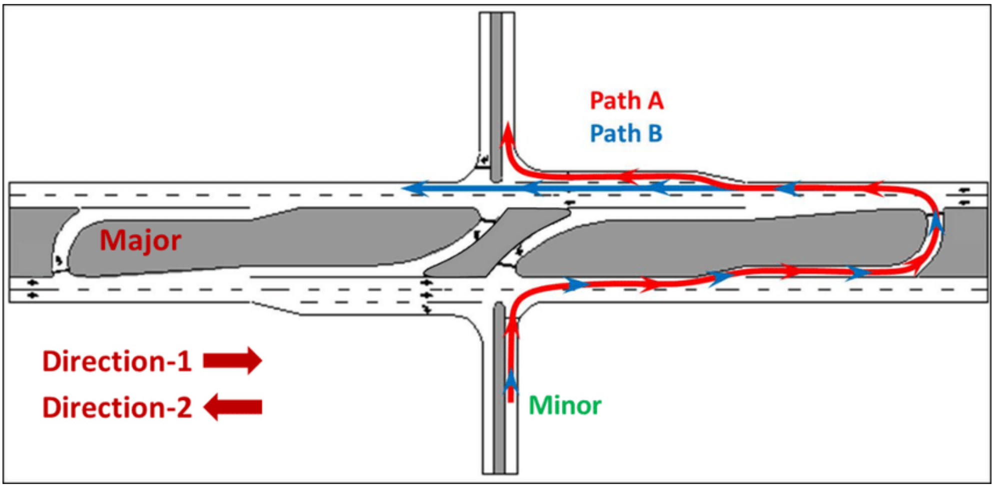

Figure 3. Restricted crossing U-turn (RCUT)

In one of the studies, thirteen RCUT intersections were compared to twenty conventional intersections. Using the cross-sectional method, it was determined that RCUT intersections significantly increase the rush of individual vehicles. On the other hand, the before-and-after method found that RCUT intersections significantly reduced other types of crashes (except vehicle crashes) that did not change significantly with the implementation of the RCUT design [4].

Advantages of RCUT are reduced number and severity of conflicts, reduced signal phases and shorter cycle length (results in decreased intersection delay, congestion, and queuing), – increased intersection capacity, allows installation of additional midblock crossing pedestrian signals, significant cost benefit over grade separation solution.

On the other side disadvantages of RCUT are that without special facilities, crossing bicyclists may have challenges, it increases travel time and distance for movements that are redirected, may require additional right-of-way for loons or wider medians and higher construction cost than conventional intersection due to additional pavement, signs, and signals [5].

2.2. Median U-turn (MUT)

RCUT intersections are a variant of median U-turn (MUT) intersections. Median U-turns (MUT) are the most common type of alternative intersections in Michigan, Florida and Louisiana.

A MUT intersection involves the elimination of direct left turns from major and/or minor approaches (usually both). Vehicles wishing to turn left from the main road onto the intersecting minor road must first pass through the main at-grade intersection and then make a U-turn at the median opening downstream of the intersection. These drivers then turn right at the intersection. Vehicles on the side street who wish to turn left onto the main road must first turn right at the main intersection, make a U-turn at the downstream median and proceed back through the main intersection.

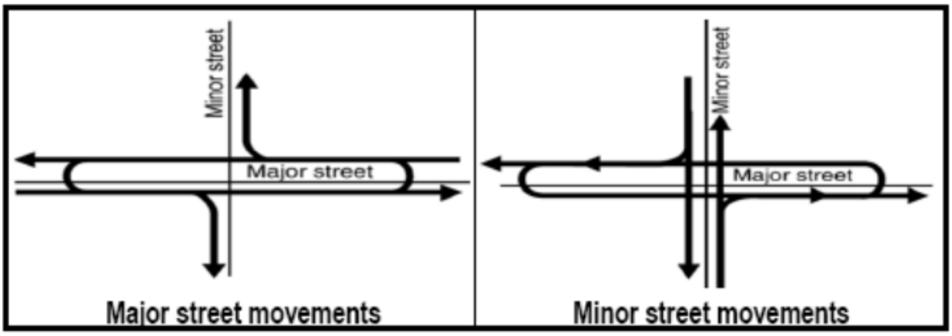

Figure 4. Median U-turn (MUT) movements on major and minor streets

MUT intersection have fewer conflict points compared to conventional intersections with double left turn lanes. An information guide from FHWA shows the number of conflict points at a four-way signalized intersection (32 in total) compared to MUT intersections (16 in total). The MUT intersection, compared to a conventional intersection, reduces crossing conflict points by 75%.

These alternative intersections are sometimes classified as U-turn based intersections. For these reasons, the safety effects of RCUT implementation are somewhat similar to those of MUT intersections.

MUT intersections are often more effective in reducing total, property damage and rear-end crashes; however, RCUT have shown greater effectiveness in reducing minor injuries, fatal injuries, frontal crashes, and corner crashes. Compared to partial MUTs, RCUTs are more effective in reducing the total number of traffic accidents, but less effective in reducing accidents with less material damage.

It should also be noted that MUT intersections are significantly more dangerous for traffic accidents which are involving non-motorized users [4].

3. CONTINIOUS FLOW INTERSECTIONS (CFI OR DLT)

Continuous flow intersections (CFI) are also known as Displaced left turns (DLT) and crossed displaced left turns. They reduce number of conflicts at the main intersection by directing left-turning vehicles to the crossing at a location upstream of the main intersection. In this way, vehicles turning left do not encounter oncoming traffic at the main intersection, that is, they do not have a conflict. In fact, the conventional intersection is split to allow more traffic to flow continuously, as left turns and oncoming vehicles occur simultaneously at the main flow intersection.

In terms of safety, full and partial DLT intersections have 28 and 30 conflict points, respectively, compared to a conventional intersection, which has 32. One of the studies was at Airline Highway and Siegen Lane in Baton Rouge, LA. The results of a simple before-after DLT intersection study showed is a 24 percent reduction in total crashes and a 19 percent reduction in fatal and injury crashes over 2 years after installing a partial DLT.

All of the above referred to vehicle-vehicle conflicts. At DLT intersections, pedestrian and bicycle flows are separated, i.e. there is no pedestrian-vehicle conflict, which significantly increases safety at this type of alternative intersection [6].

Other advantages of DLT are that increases lane capacity by 30 to 70 percent, reduced number of signal phases improves progression and significant cost benefit over grade separation solution.

Disadvantages are potential for wrong-way movements, larger footprint than conventional intersection and longer pedestrian crossing distances and time [5].

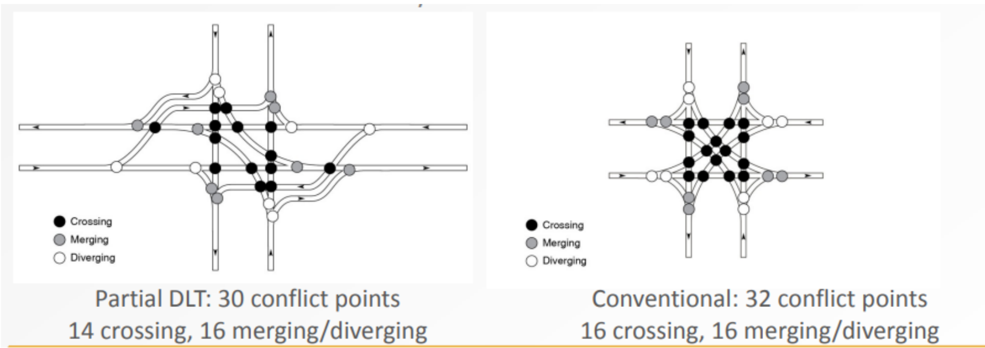

Figure 5. Conflict points of Partial DLT and Convential intersection

There are limited safety-related studies for a small number of existing DLT intersections to infer safety performance based on observed data, so special attention should be paid to this type of alternative intersections.

4. CONTINUOUS GREEN-T INTERSECTIONS (CGT)

Continuous green-T (CGT) intersections, also known as Continuous-T, Turbo-T, High-T, Florida-T, Florida green-T, or Seagull intersections, are usually implemented at three-arm intersections, although there may be a fourth arm in driveway.

This alternative intersection design is controlled by traffic lights, and traffic is traveling in the direction on the upper side of the "T" passes through the intersection without stopping, while the other direction is typically signaled. Vehicles turning left onto main street use the channelized receiving lane to merge onto the main street. By allowing free flow of the main street through one-way traffic, the efficiency of the entire intersection is improved.

Channeling vehicles turning left from a side street reduces the possibility of corner collisions, which is extremely important for safety. Angled collisions are known as having major consequences for drivers, because due to the force acting on the driver from a side impact, the most common injuries drivers sustain are neck injuries, which are mostly fatal.

For example, in Florida, this type of intersection has been used for decades, and certain studies have been conducted and have shown that this type of intersection has proven to be extremely safe for drivers who are not Florida residents. For this reason, the studies conducted in the period from 2003 to 2008 refer to traffic accidents that occurred at Continuous Green-T (CGT) intersections and only in the main lane, where vehicles must stop at the light signal. It was noted that the continuous flow lanes had a statistically significant higher proportion of side impact crashes than the stop lanes. This was probably due to the swerving of vehicles merging into the continuous flow lanes. This analysis did not take into account the overall frequency of collisions or any potential confounding factors. The results of this analysis were based on a comparison of crashes between lane groups, and therefore have limited practical value, as they did not include the types of injuries, which is much more important.

Another study was conducted in Florida between 2000 and 2003 involving five Continuous Green-T (CGT) intersections, where a total of 117 traffic accidents occurred, of which 10 were rear-end collisions caused by the driver's inadvertent stopping in lanes for continuous flow, which, together with side collisions, constitute the most common type of collision at this type of alternative intersection. The side court was reached when drivers turning left from the smaller arm of the intersection turned or merged with passing traffic on the main road [7].

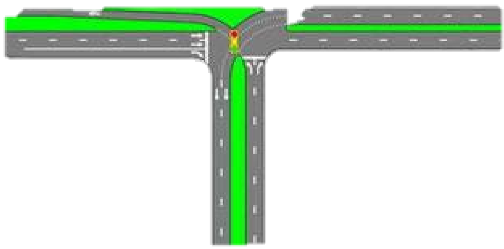

Figure 6. Continuous green-T (CGT) intersection

These data are of great importance when designing this type of alternative intersections because they directly indicate the biggest problems that significantly affect the reduction of safety. Adequate projecting of light signals at this type of intersection and knowledge of pressing problems can have a significant impact on increasing safety.

CGT intersections need to be considered only at intersections with three approaches, which have a moderate or low volume of left turns from the side street and a high flow on the main stream.

One good example of adequate management of Continuous Green-T (CGT) intersections is a study conducted at two rural T-intersections in Colorado (in Grand Junction and Durango), with a high incidence of injuries and angle crashes. The crash reduction results are based on a review of "before and after" data from these intersections over a four-year period. The "before" and "after" observation period was 24 months at both intersections. At both intersections, a large number of crashes were observed, especially at an angle and many with injuries, due to the limited stopping distance. In order to solve these two problems, and thereby improve the efficiency of the intersection. Converting the intersection (US-50 and SH 141, Grand Junction, CO) to a CGT intersection reduced cornering crashes from 16 to 0 (a 100 percent reduction); accidents with injuries reduced from 12 to 2 (a reduction of 83.3 percent); the total number of collisions was reduced from 16 to 7 (a reduction of 56.3 percent).

At another intersection (US-160 and US-550, Durango, CO2) corner crashes decreased from 15 (including 1 fatality) to 1 (average crash reduction of 93.3 percent); injury crashes were reduced from 8 to 4 (an average crash reduction of 50 percent); and the total number of crashes was reduced from 19 to 7 (an average crash reduction of 63.2 percent) [8].

Some of other advantages of CTG are that maximizes throughput, primarily by improving signal efficiency (the use of green time), provides physical separation and a safer and quicker left-turn from a side street, allows installation of a signalized intersection at locations that otherwise couldn't have one, such as intersections that are too close to one another, uses a half-signal (no extra distance driven) and allows one lane of traffic to not stop.

Main disadvantages of CTG are lack of driver familiarity and use due to few installations, left-side merge is a major concern and other safety issues (truck acceleration, pedestrian crossing, traffic control devices etc.) [9].

5. DIVERGING DIAMOND INTERCHANGE (DDI)

Intersections with turnouts are what make DDI different and are very intuitive for the driver, who claim that in cities where DDI is built, they don't even notice this type of alternative intersection. Turnouts gently cross or separate traffic from the right side of the road to the left side of the road and join it again. As traffic flows on the left between intersections, all left turns are made without the need to cross traffic from the opposite direction. Road geometry, road signs and markings help make this very easy.

DDI is worth considering as an alternative especially in locations with the following characteristics: a large number of left turns on and off the freeway ramps; moderate but unbalanced traffic volume at the intersection through the loop, safety issues related to left turns at intersections and when there is a need for additional capacity without roadway and bridge widening.

A separate study comparing DDI designs with conventional diamond interchange designs compared a range of combinations of high and low traffic volumes. For higher traffic volumes, DDI designs showed better overall performance, reducing latency by 15-60 percent and increasing throughput by 10-30 percent. The DDI could accommodate twice as much left-turn traffic as the conventional design.

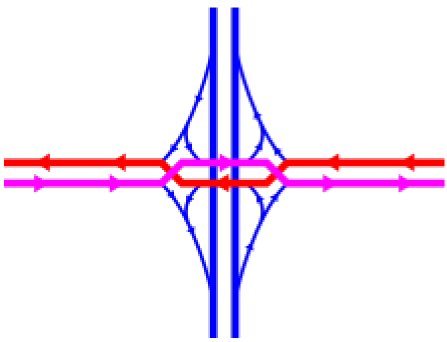

Figure 7. Diverging diamond interchange

A potential collision exists every time a vehicle, pedestrian, or bicycle crosses or turns across the path of another direction of traffic. Compared to a conventional diamond-shaped intersection, DDI reduces collision points between vehicles by nearly 50 percent and eliminates many of the most severe types of collisions. A DDI evaluation in Springfield, Missouri, compared crashes from the first year after construction to the five-year average before DDI and found the following:

- Left turn accidents are completely eliminated,
- Right angle shots are reduced by 72 percent,
- Rear impacts are reduced by 29 percent,
- The total number of crashes was reduced by 46 percent.

For example in 2009 it was opened DDI in Springfield, Missouri, and it was the first in the United States. After that, dozens of others were built in several states and quickly became a popular option. Where they are built, travelers save time, agencies save money, and they are significantly safer.

DDI can cost less – in some cases up to 75 percent less – than a conventional diamond or e.g. one city loop. DDI often require fewer lanes than conventional designs to handle the same amount of traffic. A smaller footprint means less land is needed, resulting in less impact on neighboring areas. All this makes the DDI alternative cheaper, easier and faster to build than some conventional solutions [10].

Disadvantages of DDI are bus stops must operate outside of the interchange, traffic signals in opposite directions will never be green simultaneously, DDI require more pedestrian crossings because of their design, drivers may be confused by driving on the "wrong side" of the road, leading to inadvertent lane changes [11].

6. ADVANTAGES AND DISADVANTAGES OF ALTERNATIVE INTERSECTIONS

Alternative ways of managing intersections, as everything else, are not perfect and they have their advantages and disadvantages. Depending on what is to be achieved, the most adequate alternative solution can be chosen. For this reason, Table 1 shows the good sides, that is, what can be found as a problem when considering the introduction of some of the listed alternative intersection solutions.

Table 1. Advantages and disadvantages of alternative intersections

Name of intersection	**Advantages**	**Disadvantages**
Roundabout	–Mini roundabout are extreamly safe. –Improved safety. –Fewer conflict points. –Reduced travel speeds. –Enhanced efficiency –No traffic lights. –Decreased vehicle pollution. –Reduced maintenance costs. –Increased aesthetic opportunities.	Can be blocked when there is a large amount of traffic. Requires extremely large size. Difficult to provide adequate weaving length between two roads. When provided at close intervals, they make travel troublesome. Traffic turning right has to travel longer distance. A roundabout requires many warning and directional signs for safety. The central island and entrance and exits must be well lighted at night. Roundabouts have a particularly poor safety record for cyclists.
Superstreet	Has only 14 conflict points. There are fewer traffic lights. Economically profitable because they require less space compared to	With bulb-outs is the tendency of drivers to occasionally use them to rest and park.

	interchanges. The smaller areas required for this type of intersection and the reduced waiting time mean that they are more favorable from an environmental.	
RCUT/MUT	MUT intersections are effective in reducing total, property damage and rear-end crashes. RCUT have shown greater effectiveness in reducing minor injuries, fatal injuries, frontal crashes, and corner crashes. Compared to partial MUTs, RCUTs are more effective in reducing the total number of traffic accidents.- Reduced signal phases and shorter cycle length (results in decreased intersection delay, congestion, and queuing). Increased intersection capacity. Allows for installation of additional midblock crossing pedestrian signals. Significant cost benefit over grade separation solution.	Without special facilities, crossing bicyclists may have challenges. Increased travel time and distance for redirected movements. May require additional right-of-way for loons or wider medians. Higher construction cost than conventional intersection due to additional pavement, signs, and signals. MUT intersections are significantly more dangerous for traffic accidents which are involving non-motorized users. RCUT is less effective in reducing accidents with less material damage.
Continious flow intersection (CFI) of Displaced left turn (DLT)	Full and partial DLT intersections have 28 and 30 conflict points, respectively. Reduction in total crashes and in fatal and injury crashes after installing a partial DLT (vehicle-vehicle conflicts).Pedestrian and bicycle flows can be separated, i.e. there is no pedestrian-vehicle conflict, which significantly increases safety. Increased lane capacity by 30 to 70 percent. Reduced number of signal phases improves progression and significant cost benefit over grade separation solution.	Potential for wrong-way movements. Larger footprint than conventional intersection. Longer pedestrian crossing distances and time.
Continuous Green-T	Reduced cornering crashes, accidents with injuries an the total number of collisions. Maximizes throughput, primarily by improving signal efficiency (the use	Lack of driver familiarity and use due to few installations. Left-side merge is a major concern. Other safety issues (truck

	of green time). Provides physical separation and a safer and quicker left-turn from a side street. Allows installation of a signalized intersection at locations that otherwise couldn't have one, such as intersections that are too close to one another. Uses a half-signal (no extra distance driven) and allows one lane of traffic to not stop	acceleration, pedestrian crossing, traffic control devices and driveways).
DDI	Reduced collision points between vehicles and eliminates many of the most severe types of collisions. Left turn accidents are completely eliminated. Right angle shots, rear impacts and the total number of crashes is also reduced. Travelers save time. Costs less – in some cases up to 75 percent less. Require fewer lanes than conventional designs to handle the same amount of traffic. A smaller footprint means less land is needed, resulting in less impact on neighboring areas. All this makes the DDI alternative cheaper, easier and faster to build than some conventional solutions.	Bus stops must operate outside of the interchange. Traffic signals in opposite directions will never be green simultaneously. Require more pedestrian crossings because of their design. Drivers may be confused by driving on the "wrong side" of the road, leading to inadvertent lane changes.

7. CONCLUSION

As shown in this paper, each alternative intersection has its advantages and disadvantages. Depending on the location, intersection geometry, traffic flow structure and traffic conditions, the most favourable solution can be chosen. When everything is summed up, all intersections have the same goals, which are to reduce the number of conflict points, reduce waiting time and, most importantly, increase the safety of road users (drivers, pedestrians, motorcyclists and cyclists). In the Republic of Serbia, roundabouts are the only type of alternative intersections that is represented.

This paper showed a high potential for alternative intersections in order to improve safety in Republic of Serbia by turning some of conventional safety critical intersections into alternative ones.

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