# Inspection of the road surface condition on black spots – Croatia case study

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***Abstract**. In pursuit of a safe road network, adequate design, construction, and maintenance of road surfaces are imperative. However, inevitable wear and tear over time lead to damage. The previous project identifies 23 black spots on the state road network of the Republic of Croatia by analyzing traffic accidents and influential factors. The road surfaces of these black spots were meticulously examined using a specially equipped vehicle, assessing parameters such as international roughness index (IRI), macrotexture, rutting, and cracking. By employing this road surface inspection system, effective road maintenance strategies can be proposed to minimize the risk of traffic accidents.*

**Keywords.** Black spot, traffic safety, road maintenance, road surface inspection, Hawkeye 2000

## 1 Introduction

About 1.3 million people die in road accidents every year (Road Traffic Injuries, 2022), and the most critical factors affecting road safety are the driver, the vehicle, and the road and its surroundings. The road surface is crucial for smooth traffic flow and safety but inevitably sustains damage over time. Proper design, construction, and maintenance are essential for a safe road network. The road surface condition directly affects ride quality and indirectly influences driver distraction, vehicle operation, and traffic accidents. Consequently, it is essential to inspect the condition of the road surface, identify areas with damaged road surface, and promptly repair them to prevent potential negative impact on traffic safety (Vinayakamurthy et al., 2017).

Based on data from the Ministry of Internal Affairs of the Republic of Croatia, an average of 35,386 traffic accidents occurred on Croatian roads in the past decade, with an annual fatality rate of 351 individuals. The analysis further indicates that specific locations, especially shorter road segments, experience a higher frequency of accidents than the rest of the state road network. Potentially dangerous locations on the road network are commonly referred to as black spots. These can be defined as specific or micro-locations on the road that exhibit a higher risk of accidents than other roads in the network with similar traffic and technical characteristics (Road Traffic Safety Bulletin 2021, 2022).

Efforts can be made to treat the road infrastructure to reduce the likelihood and severity of traffic accidents. In line with this objective, the Croatian Ministry of Sea, Transport, and Infrastructure has signed a contract valued at over 9 million euros, which includes more than 7 million euros in grants for a project aimed at rehabilitating dangerous locations and eliminating black spots on state roads. Within this contract and the “Rehabilitation of 23 Dangerous Locations” project, Croatian Roads Ltd., the main road authority in Croatia, utilize these funds to improve road safety on a total of 23 black spots that were determined on state roads (secondary roads) in 12 counties across Croatia. One of the specific objectives is related to the inspection of road surface conditions using a special vehicle equipped with the Hawkeye 2000 ACD system, and the Department of Traffic Signaling, Faculty of Transport and Traffic Sciences has taken on the responsibility of recording, processing data, and creating a report analyzing the condition of pavement structures at the specified locations. This paper aims to present the results of examining the fundamental indicators of road surface conditions at locations identified as black spots by applying the methodology for determining dangerous locations.

## 2 Applied methodology for detecting black spots in Croatia

There are several derivatives of the term “black spot”. Black spots on the road are also referred to as dangerous locations, high-risk locations, accident-prone locations and hotspots. They are defined as points where the number and characteristics of traffic accidents are prominent or where there are potential safety risks compared with other locations over a certain period due to the influence of the road conditions, traffic conditions, climate, environment, etc. Three types of definitions of a dangerous location are generally accepted: numerical definitions, statistical definitions, and definitions based on the prediction of traffic accidents. Identifying black spots, i.e., dangerous locations in road traffic, is one of the most effective ways to reduce and prevent traffic accidents. The most critical activities in the identification phase include recording data on traffic accidents, developing a database on accidents, and defining criteria for identifying black spots (Zovak & Brčić, 2014).

In 2004, Croatian Roads Ltd. collaborated with the Institute of Civil Engineering of Croatia p.l.c. and published the methodology for identifying dangerous locations on roads in the Republic of Croatia titled "Security Approach Methodology of Traffic". It defined three criteria to classify a road section as dangerous: 1) 12 or more injury-related traffic accidents within the past three years, 2) 15 or more traffic accidents, regardless of consequences, within the previous three years, and 3) three or more traffic accidents of the same type involving the same participant groups and movement directions on the same conflict surface within the last three years. However, this methodology solely relied on the number of traffic accidents as a parameter, lacked statistical analysis of accidents at specific locations, and was not aligned with European standards and regulations. Consequently, a new methodology, titled "Methodology for the identification of dangerous locations in the road transport network" was developed in 2016. This revised methodology adhered to European Union laws and regulations and employed the Rate Quality Control (RQC) method, and involved two critical parameters for assessing the occurrence of traffic accidents: the number of traffic accidents and the average annual daily traffic volume (AADT) at the observed location. If the accident rate surpasses the critical level, it indicates that accidents are not random but rather identified black spots. Detailed analysis of accidents at specific locations aims to identify common patterns and contributing factors (Methodology for identification of dangerous locations in road transport network, 2016).

To determine dangerous spots or road stretches, the road was segmented into sections with similar characteristics, such as horizontal curves, bridges, and tunnels, within the same road category. The Croatian methodology employed the three-year period and a "sliding window" method, defining a 300-meter frame around each accident location. If additional accidents occurred within or adjacent to the frame, it could be extended up to a maximum of 1000 meters to encompass those locations. It is essential to note that this method only considered locations with at least one traffic accident, disregarding accident-free areas (Methodology for identification of dangerous locations in road transport network, 2016). The process of black spot identification involved five main steps, as depicted in Figure 1. Following the statistical investigation, identification, and inspection of a potentially dangerous location, a final determination is made to classify it as a genuine dangerous site or a non-genuine one. If a specific road defect or infrastructure issue is identified as a cause or a contributing factor to traffic accidents with severe consequences, the identified dangerous site is confirmed as genuine, leading to the subsequent phase of managing dangerous locations (Methodology for identification of dangerous locations in road transport network, 2016).

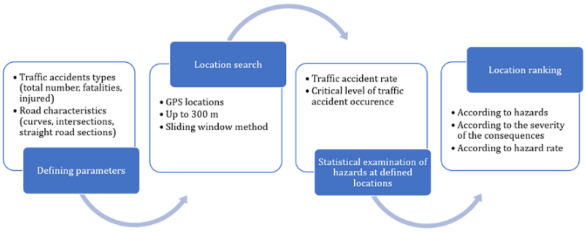

**Figure 1.** The process of black spot identification Source: (Methodology for identification of dangerous locations in road transport network, 2016)

## 3 Road surface inspection methodology

Recording of the road surface condition using a special vehicle equipped with the Hawkeye 2000 ACD system was carried out on 23 black spots on Croatian state roads. In the continuation are listed the inspection locations, i.e., identified black spots, and the essential observed parameters, testing procedure, and equipment used are described.

### 3.1 Observed parameters

The distress parameters collected during the road inspection using a special vehicle equipped with the Hawkeye 2000 ACD system include the International Roughness Index (IRI), macrotexture, surface cracking, and ruts on the road. These parameters measure the roughness, size, and depth of surface irregularities, the presence and severity of cracks, and the depth and severity of wheel ruts. The proposed values of indicators for the "Inspection Work Threshold" (IWT) and "Maximum Acceptable Value" (MAV) levels are provided in Table 1. Proposed values of road surface condition indicators, under the valid Regulations (Regulation on Amendments and Supplements to the Regulation on Road Maintenance, 2021). Defining the intervals within the IWT was done in accordance with recommended criteria within the framework of the COST 354 Action program: Performance Indicators for Road Pavements. Measurement values at the IWT level indicate a road surface condition close to the "Acceptable" state. At this point, more detailed investigative work should be undertaken to determine the need for maintenance work to limit further deterioration. Values at the MAV level represent a road surface in a “Very Poor” or unsatisfactory condition, where extraordinary maintenance will likely be required.

**Table 1**. Proposed values of road surface condition indicators

| **Indicator** | **Unit** | **Inspection work threshold (acceptable)** | **Max. acceptable value (very poor)** |
|---|---|---|---|
| **IRI** | m/km | 2,2 | 3,2 |
| **Rut depth** | mm | 15 | 20 |
| **Macrotexture** | mm | 0,6 | 0,4 |
| **Block cracking** | % | 1% | 20% |
| **Alligator cracking** | % | 25% | 25% |

Source: (Regulation on Amendments and Supplements to the Regulation on Road Maintenance, 2021)

The evenness of the road surface is represented by the International Roughness Index (IRI), which is calculated by summing the vertical oscillations of the vehicle base over a road section (Šimun & Rukavina, 2009). The roughness index represents a measure of driving comfort on a specific road section, and the technical parameters of longitudinal road evenness are measured in the right and left wheel paths (Šimun & Rukavina, 2009).

The macrotexture directly affects the skid resistance of the road surface. It is defined as the deviation of the road surface from an ideally flat surface. The result of macrotexture measurements using non-contact methods is a technical parameter called Mean Profile Depth (MPD).

In mechanical terms, rutting refers to permanent deformations on the road surface that occur at wheel path locations, resulting from the action of traffic loads. Rutting harms driving comfort, safety, and, ultimately, the durability of the pavement. It can be determined in various ways (typically measured in the right and left wheel paths), and in Croatia, it is defined by the technical parameter of rut depth.

Cracking can be divided into four main types: fatigue cracking (alligator cracking), block cracking, longitudinal cracking, and transverse cracking. Fatigue cracks are small irregular areas caused by a single or a series of interconnected cracks. They occur in areas subjected to repeated traffic loads and depend on road surface temperature and vehicle speed. Block cracks are defined as interconnected cracks in an untraveled area that divide the road surface into rectangular blocks of varying sizes (from about 0.1 to 10 m2). They occur across the entire road surface width, not just in wheel lanes. Longitudinal cracks are long cracks that run parallel to the road's centerline. They can occur anywhere between the centerline and the outer edge of the outside wheel lane. Transverse cracks are cracks that run perpendicular to the centerline of the road. They can occur anywhere on the surface, are regularly spaced, and begin as thin hairline cracks that later widen (Ali et al., 2018). The Automatic Crack Detection (ACD) system utilizes two-line lasers to collect data with a crosswise width of up to 5.0 meters and a lengthwise width of up to 1.0 meters. The left side of Figure 3 illustrates the scanning area (ACD laser scan) captured by the two-line lasers. The software processes the data (

Figure **2** – right) based on detected longitudinal road markings. If road markings are absent, the processing range is defined by the width of the road or the width of a single lane. Based on this information, the processing range is established manually or automatically and is used to process detected cracks automatically.

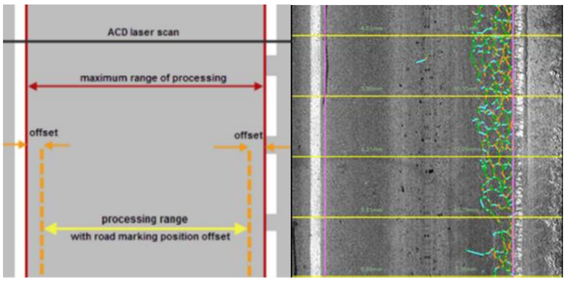

**Figure 2.** Illustration of ACD scanning area (left) and ACD frame with automatic detection of cracks and rut depth (right)

## 3.2 Equipment

The road surface condition was recorded using the Hawkeye 2000 ACD system, installed in a Croatian Roads’ Ltd. specialized vehicle. This system on the vehicle consists of the following components: a laser profiler, an LCMS system for automatic crack detection, video cameras, GPS (GNSS positioning system), GPSI-TRAC 2 (a road geometry examination system), an odometer, an accelerometer, and computer hardware for data processing and storage. The laser profilometer has two lasers that measure IRI, longitudinal profile, and macrotexture. These measurements were executed using a laser bar mounted on a vehicle moving at average speed, ensuring minimal traffic flow disruption during data collection. The LCMS system consists of two 3D lasers mounted on a vehicle perpendicular to the road, emitting infrared radiation from an opening 2.2 m above the ground. Both of these systems are shown in Figure **3**. Other components of the system include a control console, a DMI (Distance Measuring Instrument), an accelerometer, the HEARTBEAT central module, a computer, the Onlooker Live software for data collection, and the Processing toolkit for data processing.

**Figure 3.** Special vehicle with laser profiler (left) and LCMS system (right)

### 3.3 Inspection locations

The recording and data processing included 23 dangerous locations on 14 different state roads, covering 70 kilometers of road that were inspected. The characteristics of each location are presented in Table 1. Out of the 23 of observed locations, 12 were intersections, and the remaining 11 were road stretches.

**Table 2.** Characteristics of 23 inspected locations

| Nr. | State road | Location name | Length (km) | Road section |
|---|---|---|---|---|
| **1** | D8 | Rijeka, intersection DC8-DC304 | 2,08 | intersection |
| **2** | D8 | Bakar | 1,54 | intersection |
| **3** | D8 | Rijeka 1 | 1,28 | intersection |
| **4** | D8 | Rijeka, Krešimirova | 1,61 | intersection |
| **5** | D8 | Jasenova | 6,47 | road stretch |
| **6** | D8 | Rijeka, intersection J. P. Kamova – DC 8 | 0,80 | intersection |
| **7** | D8 | Jadranovo - Klanfari | 9,92 | road stretch |
| **8** | D5 | Filipovac | 2,25 | road stretch |
| **9** | D46 | Ivankovo, Ulica Bošnjaci 180-190 | 1,74 | road stretch |
| **10** | D38 | Dervišaga Kuzmica | 3,01 | road stretch |
| **11** | D55 | Vinkovci, Boškovićeva | 1,95 | intersection |
| **12** | D410 | Split - B. Bušića | 3,66 | intersection |
| **13** | D51 | Baćin Dol | 3,26 | road stretch |
| **14** | D8 | Vodice, Šibenik | 1,17 | intersection |
| **15** | D410 | Split, Spinčićeva | 2,36 | intersection |
| **16** | D3 | Varaždin | 3,27 | intersection |
| **17** | D45 | Garešnica | 1,23 | road stretch |
| **18** | D27 | Intersection, DC 27-DC 59 | 1,90 | intersection |
| **19** | D8 | Zadar, intersection DC 8 - DC 424 | 3,06 | intersection |
| **20** | D106 | Zrće | 1,40 | road stretch |
| **21** | D3 | Dubravci | 5,70 | road stretch |
| **22** | D1 | Rakov Potok | 3,34 | road stretch |
| **23** | D6 | Brajakovo Brdo | 6,73 | road stretch |

### 3.4 Inspection procedure

The field inspection typically involves two individuals: a driver, and an operator. The inspection for the road stretch was conducted in two steps: first, starting with the measurement of one direction of the road stretch and second, the measurement of the opposite direction. If the black spot was an intersection, measurements were performed at all approaches to that intersection. After the field inspection, data processing and analysis were carried out using the Hawkeye Processing Toolkit software. Teams of 1 to 4 individuals were involved in the post-field inspection data processing.

## 4 Results

The processing of the obtained data at 23 dangerous locations on state roads in the Republic of Croatia involved measuring the longitudinal profile expressed by the International Roughness Index (IRI), measuring macrotexture (Mean Profile Depth – MPD), measuring transverse road evenness (RD), detecting road surface crack quantities, and creating georeferenced videos to mark road surfaces and road signaling. The subsequent sections of this article are an overview of each technical parameter, indicating the percentage by which each recorded technical parameter meets, fails to meet, or is acceptable for each dangerous location within the network of state roads in the Republic of Croatia.

### 4.1 International roughness index (IRI)

After road surface inspection and processing of the obtained data, it was determined that 46% of longitudinal profile falls under an unsatisfactory road surface condition (from 2.6 to 3.5 m/km), 22% is considered acceptable (ranging from 1.2 to 2.6 m/km) but bordering on IWT. In comparison, 32% represents satisfactory results (from 0.5 to 1.2 m/km). **Error! Reference source not found.** shows average IRI values for each location and the percentage that is satisfactory, acceptable, or unsatisfactory in terms of the IRI values.

**Table 3.** IRI overview on 23 dangerous locations

| Nr. | International roughness index – IRI | | | |
|---|---|---|---|---|
| | Av. (m/km) | Satisfactory | Acceptable | Unsatisfactory |
| **1** | 2,4 | 13% | 46% | 41% |
| **2** | 2,7 | 29% | 24% | 47% |
| **3** | 3,1 | 25% | 19% | 56% |
| **4** | 4,1 | 22% | 0% | 78% |
| **5** | 1,4 | 87% | 8% | 5% |
| **6** | 4,8 | 0% | 20% | 80% |
| **7** | 1,6 | 85% | 14% | 1% |
| **8** | 3,8 | 8% | 25% | 67% |
| **9** | 2,8 | 0% | 33% | 67% |
| **10** | 2,1 | 31% | 53% | 16% |
| **11** | 1,5 | 81% | 14% | 5% |
| **12** | 3,7 | 21% | 7% | 72% |
| **13** | 1,3 | 94% | 6% | 0% |
| **14** | 3,6 | 0% | 42% | 58% |
| **15** | 4,2 | 18% | 0% | 82% |
| **16** | 2,4 | 39% | 25% | 36% |
| **17** | 2,4 | 38% | 31% | 31% |

| | | | | |
|---|---|---|---|---|
| **18** | 2,7 | 17% | 35% | 48% |
| **19** | 2,9 | 21% | 18% | 61% |
| **20** | 3,2 | 27% | 13% | 60% |
| **21** | 3,2 | 12% | 12% | 76% |
| **22** | 1,5 | 62% | 26% | 12% |
| **23** | 2,7 | 10% | 38% | 52% |

*** Av. – average value**

## 4.2 Macrotexture

After processing the obtained data for macrotexture on the inspected locations, alarming data has been obtained. Specifically, overall results show that 80% of the macrotexture (ranging from 0.6 to 0.3mm) falls into an unsatisfactory range of road surface texture, indicating poor skid resistance of the road surface. Further, 12% of the macrotexture is considered acceptable (ranging from 0.9 to 0.6mm), while only 8% represents a satisfactory level of road surface grip (ranging from 1.1 to 0.9mm). **Error! Reference source not found.** shows the average macrotexture parameter of each inspected location and the proportions of surface area that are satisfactory, acceptable, or unsatisfactory in terms of macrotexture.

**Table 4.** Macrotexture overview on 23 dangerous locations

| **Nr.** | **Macrotexture – MPD (mm)** | | | |
|---|---|---|---|---|
| | Av. (mm) | Satisfactory | Acceptable | Unsatisfactory |
| **1** | 0,57 | 0% | 13% | 87% |
| **2** | 0,73 | 18% | 29% | 53% |
| **3** | 0,64 | 6% | 31% | 63% |
| **4** | 0,52 | 0% | 0% | 100% |
| **5** | 0,65 | 15% | 32% | 53% |
| **6** | 0,54 | 0% | 10% | 90% |
| **7** | 0,66 | 0% | 33% | 67% |
| **8** | 0,55 | 0% | 0% | 100% |
| **9** | 0,43 | 0% | 0% | 100% |
| **10** | 0,59 | 0% | 19% | 81% |
| **11** | 0,44 | 0% | 5% | 95% |
| **12** | 0,53 | 0% | 7% | 93% |
| **13** | 0,68 | 27% | 3% | 70% |
| **14** | 0,44 | 0% | 0% | 100% |
| **15** | 0,50 | 4% | 7% | 89% |
| **16** | 0,52 | 8% | 6% | 86% |
| **17** | 0,57 | 0% | 23% | 77% |
| **18** | 0,49 | 0% | 0% | 100% |
| **19** | 0,43 | 3% | 0% | 97% |
| **20** | 0,74 | 26% | 27% | 47% |
| **21** | 0,68 | 19% | 19% | 62% |
| **22** | 0,23 | 0% | 0% | 100% |
| **23** | 0,94 | 63% | 9% | 28% |

*** Av. – average value**

## 4.3 Surface cracking

The inspection results show that 44% of the road surface at the 23 dangerous locations exhibits an unsatisfactory road surface condition, representing a crack ratio exceeding 20% within a measurement interval of 100 meters. 19% of the road surface falls within an acceptable range, specifically at the IWT (cracking coverage ranging from 15% to 20% within a measurement interval of 100 meters). In comparison, 37% of the surface has a cracking level below 10% and is considered satisfactory. The level of acceptability of the cracking percentage of each inspected location is shown in **Error! Reference source not found.**.

**Table 5.** Cracking percentage overview on 23 dangerous locations

| **Location number** | **Cracking – Cracking Percentage (%)** | | |
|---|---|---|---|
| | Satisfactory | Acceptable | Unsatisfactory |
| **1** | 58% | 21% | 21% |
| **2** | 6% | 29% | 65% |
| **3** | 38% | 25% | 37% |
| **4** | 17% | 17% | 66% |
| **5** | 49% | 28% | 23% |
| **6** | 60% | 20% | 20% |
| **7** | 67% | 28% | 5% |
| **8** | 8% | 8% | 84% |
| **9** | 6% | 6% | 88% |
| **10** | 28% | 25% | 47% |
| **11** | 85% | 10% | 5% |
| **12** | 31% | 33% | 36% |
| **13** | 68% | 3% | 29% |
| **14** | 61% | 8% | 31% |
| **15** | 18% | 32% | 50% |
| **16** | 0% | 0% | 100% |
| **17** | 15% | 23% | 62% |
| **18** | 70% | 26% | 4% |
| **19** | 49% | 30% | 21% |
| **20** | 46% | 27% | 27% |
| **21** | 9% | 7% | 84% |
| **22** | 79% | 15% | 6% |
| **23** | 0% | 4% | 96% |

## 4.4 Ruts on the road

After the road inspection, the data obtained indicate an excellent condition of transverse irregularities, i.e., road rutting. Specifically, 97% of the inspected road surface contains minimal irregularities (up to 4.5mm), while 3% falls within an acceptable range, with irregularities up to a depth of 10mm. The average rut depth of all inspected locations is shown in **Error! Reference source not found.**, as well as the level of acceptability for each location.

**Table 6.** Rutting overview on 23 dangerous locations

| **Nr.** | **Transverse irregularities – Rutting (RD)** | | | |
|---|---|---|---|---|
| | Av. (mm) | Satisfactory | Acceptable | Unsatisfactory |
| **1** | 2,3 | 100% | 0% | 0% |
| **2** | 4,8 | 100% | 0% | 0% |
| **3** | 5,4 | 75% | 25% | 0% |
| **4** | 5,2 | 83% | 17% | 0% |
| **5** | 5,3 | 100% | 0% | 0% |
| **6** | 2,4 | 100% | 0% | 0% |
| **7** | 3,2 | 100% | 0% | 0% |
| **8** | 4,5 | 100% | 0% | 0% |

| | | | | |
|---|---|---|---|---|
| **9** | 5,2 | 100% | 0% | 0% |
| **10** | 2,7 | 100% | 0% | 0% |
| **11** | 2,0 | 100% | 0% | 0% |
| **12** | 3,8 | 100% | 0% | 0% |
| **13** | 1,6 | 100% | 0% | 0% |
| **14** | 3,9 | 100% | 0% | 0% |
| **15** | 4,4 | 96% | 4% | 0% |
| **16** | 4,9 | 89% | 8% | 3% |
| **17** | 3,6 | 100% | 0% | 0% |
| **18** | 3,1 | 100% | 0% | 0% |
| **19** | 4,9 | 100% | 0% | 0% |
| **20** | 5,3 | 93% | 7% | 0% |
| **21** | 4,7 | 95% | 5% | 0% |
| **22** | 5,1 | 97% | 3% | 0% |
| **23** | 3,7 | 100% | 0% | 0% |

*** Av. – average value**

# 5 Discussion

The results of the road surface inspection at 23 dangerous locations on state roads in the Republic of Croatia provide valuable insights into the current condition of the road. The measurements of various technical parameters, including the International Roughness Index (IRI), macrotexture (Mean Profile Depth – MPD), transverse road evenness (RD), and surface cracking, offer a comprehensive overview of the road surface condition.

The analysis of the International Roughness Index (IRI) reveals that the majority of the inspected locations exhibit unsatisfactory road surface conditions, with 46% falling within this category. The acceptable and satisfactory percentages of the IRI are 22% and 32%, respectively, suggesting that some locations show better road surface conditions. However, these numbers are not significant enough to ignore the need for road maintenance and improvement. Among the inspected locations, “D410 Split, Spinčićeva” and “D8 Rijeka, intersection J.P. Kamova - D8” show the highest percentage of unsatisfactory road surface conditions, above 80%. Roughness is closely related to vehicle operating costs, vehicle dynamics, and drainage i.e., ride quality. Cairney and Bennett (2008) conducted a study in Victoria, Australia in which authors measured roadway properties using a multi-laser profilometer and linked them to accident data using the GPS. They found that there was a significant correlation between roughness and accident rate that followed a polynomial relationship (Cairney P, 2008). Another study found that higher road surface roughness is associated with increased accident rates, road surface with rut depths exceeding 23.5 mm and IRI values greater than 3.2 m/km were considered poor and more susceptible to accidents. On the other hand, in their study Tsubota et al. discovered counter-intuitive result showed that higher IRI values were associated with decreased accident risk, likely due to drivers being more cautious and slowing down on rougher sections (Tsubota, Fernando, Yoshii, & Shirayanagi, 2018).

The analysis of macrotexture, expressed by the Mean Profile Depth (MPD), reveals alarming data regarding the skid resistance of the road surfaces. An overwhelming 80% of the inspected locations exhibit unsatisfactory road surface texture, indicating a high risk of reduced friction and increased accident potential. The acceptable level of macrotexture is only present in 12% of locations, while only 8% of locations show satisfactory road surface grip. Of the 23 examined locations, five showed 100% unsatisfactory conditions related to the macrotexture. These results call for immediate attention to improve the skid resistance of the road network. Several studies have examined the relationship between road surface friction and crash occurrence rate, and they share a common finding: There is a higher risk of traffic accidents on road surfaces with lower skid resistance, specifically lower macrotexture values. In other words, the weaker the skid resistance and the lower the macrotexture values of the road surface, the greater the risk of accidents. A study conducted by (Austroads technical report: Road surface characteristics and crash occurrence: A literature review, 2008) suggests that when macrotexture falls below a critical value, typically around 1 mm (MPD), the crash rate increases significantly, sometimes by more than 80%. Another study revealed moderate but consistent increase in crashes when sensor-measured texture depth fell below 0.4 mm (Cairney P. , 2000). Roe et al. (Roe, Webster, & West, 1991) and Gothie (Gothie, 2001) conducted studies that revealed increased accident rates on roads with low friction. Additionally, Roe et al. (Roe, Webster, & West, 1991) and Cairney (Cairney P. , 2005) found increased accident rates at junctions on roads with low macrotexture. However, Cairney (Cairney P. , 2005) did not find any relationship between macrotexture and accidents on wet roads, while Roe et al. (Roe, Webster, & West, 1991) found no difference in effects between dry and wet roads or between different types of accidents. Furthermore, Buddhavarapu et al. (Buddhavarapu, Banerjee, & Prozzi, 2013) suggested a correlation between pavement condition and crash injury severity on two-lane undivided horizontal curves, emphasizing the importance of lateral friction.

The evaluation of surface cracking on the inspected locations indicates that 44% of the road surfaces exhibit unsatisfactory conditions, with a high cracking ratio exceeding 20% within a measurement interval of 100 meters. An additional 19% of locations show acceptable crack percentages, nearing the threshold for inspection work. Only 37% of the surface has a cracking level below 10% and is considered satisfactory. In as many as five inspected locations, the percentage indicating unsatisfactory conditions exceeds 80%. These findings indicate the necessity of proper cracking repair and maintenance to prevent further road deterioration and potential hazards.

The analysis of transverse irregularities, i.e., road rutting, indicates that 97% of the inspected locations have minimal irregularities, suggesting excellent road surface conditions in terms of rut depth. Only 3% of locations fall within an acceptable range, with rut depths up to 10mm. These results demonstrate that the majority of the inspected roads maintain satisfactory transverse evenness. Among the inspected locations, all but one (“D3 Varaždin, intersection”) show excellent transverse evenness, with 100% of locations exhibiting satisfactory or acceptable rut depths. Given that it is about black spots, our results somehow contradict the findings of previous studies which revealed positive correlation between rut depth on road and traffic accidents, suggesting that more parameters should be taken into account when relating to the risk of traffic accidents. For example, Cenek et al. conducted study to develop statistical models to predict the correlation between the rut depth and traffic accidents with fatalities and injured participants on the New Zealand state road network. The results showed that the accident rate increased when the rut depth was 10 mm or more (Cenek, Henderson, Forbes, Davies, & Tait, 2014). Tsubota et al. demonstrated the relationships between the road surface conditions and accident risk through statistical analysis based on the Poisson regression model (Tsubota, Fernando, Yoshii, & Shirayanagi, 2018). The model estimation results suggested that the rut depth has significant impact on increasing the accident risk, particularly under rain conditions. Accumulation of water on the rut surfaces reduces the skid resistance and increase the effect of hydroplaning. Other authors suggested the rutting on highways should be monitored more carefully than the IRI and cracking because rutting which is not maintained can lead to cracking and disintegration from the road surface structure.

Certainly, traffic accidents are caused by more than one factor such as the accident location characteristics, the road condition inclusive of road types and surface condition, driver’s behavior and also weather condition. While traffic accidents are influenced by multiple factors, the condition of the road and its surface plays minor but very important role in their occurrence. Pembuain et al. found in their study that using some RISM tools such as Road Safety Audit (RSA) conducted at the planning, design, construction and early stage of road operation and Road Safety Inspection (RSI) conducted on existing roads has been proven to reduce the rate of traffic accidents by 10-25% and 1-20% respectively (Pembuain A, 2019). The road surfaces wear and tear due to various factors, such as traffic, weather, and ground conditions. Ruts, cracking, and unevenness on the road surface compromise driving comfort and pose potential traffic hazards. Water accumulation in ruts increases the risk of aquaplaning, while cracks and ruts may make it challenging to maintain steady vehicle control. Additionally, large holes in the road surface can cause vehicle damage and potentially lead to the loss of vehicle control. However, the precise impact of road surface conditions on traffic accidents remains to be seen, as well as the extent to which the road surface standard influences accidents. On the other hand, enhancing road surface friction has proven effective in reducing the number of accidents, particularly on wet roads, in sharp bends, and in areas with low initial friction levels. Studies indicate that road surface friction is more significant in accident rates than unevenness. Therefore, prioritizing measures to improve road surface friction can significantly enhance road safety and minimize accident risks in critical driving conditions (Elvik, Høye, Vaa, & Sørensen, 2009). In addition, one study found that resurfacing and a new asphalt layer reduce injuries by 20% in unpopulated areas and 10% in populated areas, and that better skid resistance reduced traffic accidents on wet roads by 40% (Cairney P, 2008).

In summary, based on the obtained results, it is evident that a clear link between the occurrence of traffic accidents and road surface deterioration cannot be established. However, based on the measurements and previous research, it can be concluded that it is possible that on the black spots that were analyzed, there was an influence of bad macrotexture on the occurrence of traffic accidents. Further in-depth analysis is necessary to develop statistical models that establish this connection conclusively. By linking the results to specific black spots, targeted interventions can be planned and implemented to improve road safety on road network.

Future research includes linking the measurements to other factors, such as vehicle speed and weight and the accident type, further to understand the impact of road conditions on road safety. Further, the scientific perspective lies in the continuous improvement of road maintenance and safety through data-driven interventions, i.e., the development of various statistical models that can suggest the correlation between road surface conditions or predict factors that influence road surface deterioration. One of the advantages of regular road surface inspection is the possibility of practical application by road authorities. Continued efforts to monitor road surface conditions and prioritize roads or road parts for maintenance are crucial for ensuring smooth traffic flow and reducing traffic accidents. Limitations and shortcomings of the inspection should also be noted, such as potential measurement errors and the subjective nature of some distress parameters.

# 6 Conclusion

Based on the road surface inspection within the “Rehabilitation of 23 Dangerous Locations” project using a special vehicle equipped with the Hawkeye 2000 ACD system, the Department of Traffic Signaling of the Faculty of Transport and Traffic Sciences in Zagreb, Croatia, inspected and processed data for 23 dangerous locations on the state road network in Croatia, including a total length of 70 kilometers. The results of the road surface inspection provide valuable information for prioritizing road maintenance efforts and improving road safety on state roads in the Republic of Croatia, particularly on the inspected locations that had previously been identified as black spots. Most inspected locations require immediate attention to address the unsatisfactory road surface conditions, particularly regarding the macrotexture. The data also indicate successful maintenance efforts in maintaining satisfactory transverse evenness in most locations. Addressing the identified issues is essential to ensure the road network safety and efficiency and prevent accidents and potential road hazards. Analyzing collected data on road surface conditions helps optimize strategies and systems for maintenance activities to enhance road safety and minimize the risk of traffic accidents.

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