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# MOTORWAY WORK ZONES CAPACITY ESTIMATION USING FIELD DATA FROM SLOVENIA

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## Abstract

Work zones represent typical bottlenecks on motorway sections. Due to aging of Slovenian motorway network, roadworks and the corresponding delays are becoming a major issue. While the majority of roadworks is planned, it is not straightforward to predict the delays they will cause even with a good prediction of the traffic volumes. The problem is to determine the work zone capacity, which is affected by several work zone characteristics, road elements and traffic structure. Besides, the stochastic nature of capacity cannot be ignored, since the same traffic values can result in different traffic conditions. This paper presents work zone capacity estimation based on the data of the recent work zones on Slovenian motorways. We collected data of various short- and long-term work zones that were recently present on Slovenian motorway network. We have studied the effect of heavy vehicles, longitudinal grade, crossovers and lane narrowing on the work zone capacity. Two statistical methods were applied to study those factors, namely regression analysis and survival analysis combined with maximum likelihood method. For each work zone type we have estimated the Weibull cumulative distribution function of capacity and queue discharge rate. The estimated capacity can provide an estimate of breakdown probabilities, delays and levels of service of motorway sections in work zones and as such it provides a useful tool in planning maintenance of the motorway network.

*Keywords: capacity, cumulative distribution function, maximum likelihood method, regression analysis, work zone*

## 1 Introduction

Safe and reliable motorway network requires regular maintenance resulting in common work zones, i.e. part of the motorway sections under roadworks. While different parts of a work zone can have different capacity, the capacity of a road zone is considered the part of the work zone with the lowest capacity. Several factors appear to affect the capacity; however, determination of their effect can be a difficult task. Researchers also note that no appropriate model has been developed to accurately determine the impact of various factors on work zone capacity, as different studies take into account different factors ([1], [2]).

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The potential work zone capacity affecting factors can be divided into five categories:

- Work zone configuration: number of opened/closed lanes, work zone length, grade, speed limit, distance to side barriers, type of side barriers, lane narrowing, traffic signalization and presence of construction site sight blocking equipment.
- Road conditions: area urbanization, presence of on- and off-ramps in work zone area, lane width.
- Road works conditions: intensity of roadworks, working hours (day/night) and work duration (short-term/long-term work zones).
- Weather conditions: rain, snow, visibility etc.
- Traffic conditions: traffic structure and driver population (heavy vehicle percentage, percentage of drivers unfamiliar with the network), presence of ITS for traffic management upstream of the work zone and in the work zone.

Length of the work zone is shown in some studies not to affect the work zone capacity [3]. Some studies also show that the capacity of long-term work zones does not increase with time, eliminating the effect of work zone duration ([4], [5], [6]). In [6], it turns out that the most influencing factors are: heavy vehicle percentage, intensity and type of roadworks, traffic lanes width and presence of a crossover. A crossover can represent a bottleneck, especially under inappropriate traffic management and signalization. The negative impact of work zone on section capacity can be reduced by appropriate signalization and construction site sight blocking equipment. According to [6], those measures can increase work zone capacity by 10 %.

The capacity can be considered as an exact value (deterministic approach) or as a random variable (stochastic approach). Stochastic methods for capacity estimation are more accurate and therefore suitable for assessing traffic flow stability and probability of traffic breakdown under certain conditions. However, less accurate deterministic methods enable some insight in capacity-affecting factors due to their simplicity and input data requirements.

Deterministic models for capacity estimation are usually based on regression analysis of queue discharge rates (QDR) as the capacity estimate (more accurate capacity estimate is the pre-breakdown capacity PBC). However, short-term work zones often cause a breakdown immediately after the work zone setting up, making determining PBC impossible.

Stochastic approach considers capacity as the maximum flow while traffic is still stable, i.e. does not cause a traffic breakdown. If the demand exceeds the capacity, traffic breakdown occurs. However, the measured pre-breakdown flow rates usually differ even in case of several measurements on the same section. This confirms that the breakdown is a random phenomenon, which depends on driver behaviour and specific traffic conditions [7]. The survival analysis is able to take into account these maximum pre-breakdown flows.

The objective of this paper is estimating work zone capacity and capacity-affecting factors based on the data of the recent work zones on Slovenian motorway network. We aim to determine Weibull distribution of capacity, as several researchers [7], [8] as well as HCM [9] claimed it to be a good estimate of the actual capacity distribution.

# 2 Methodology

This chapter consists of describing the data collection and methodology, used for analysis of short-term and long-term work zones.

## 2.1 Data collection

We collected data about work zones and motorway sections in the zones (road geometry and grade, presence of tunnels), precipitation and traffic data (traffic volumes, speeds, structure). 151 short-term work zones (less than 24 hours) and 5 long-term work zones (more than 3 weeks) with congestions were analysed. They were classified by types, described in Table 1. All the analysed long-term work zones were on the same motorway section.

**Table 1** Types of work zones in analysis

| Type | Description | Right lane width | Left lane width | No. of different WZ, duration | No. of congestions |
|---|---|---|---|---|---|
| 0 | No workzone | 3,75 m | 3,75 m | 1, long-term | 10 |
| A | Right lane closed | 0 | 3,75 m | 89, short-term | 103 |
| B | Left lane closed | 3,75 m | 0 | 62, short-term | 70 |
| C | Narrowed lanes 1 | 3,25 m | 2,75 m | 1, long-term | 32 |
| D | Narrowed, deviated lanes | 3,25 m | 2,75 m | 1, long-term | 54 |
| E | Narrowed lanes 2 | 3,00 m | 2,30 m | 1, long-term | 33 |
| F | Narrowed lanes, crossover | 3,05 m | 2,50 m | 1, long-term | 40 |
| G | Shoulder lane closed | 3,75 m | 3,75 m | 1, long-term | 12 |

## 2.2 Analysing traffic flow

Traffic flow data from automatic traffic counters were provided by traffic manager DARS, d.d. We analysed the data of traffic counters that were located upstream of the work zone. All the 15-minute intervals were qualified by traffic stability type (stable traffic, period with capacity reached – C and period with traffic jam – QDR) An example is shown in Table 2.

**Table 2** An example of traffic counter data and determination of interval types.

| Time interval | Avg speed [km/h] | Rel speed change | Flow [PC/h/ln] | Interval type |
|---|---|---|---|---|
| 08.06 13:15 | 85 | 5% | 1440 | stable |
| 08.06 13:30 | 96 | -3% | 1456 | stable |
| 08.06 13:45 | 93 | -32% | 1486 | C |
| 08.06 14:00 | 63 | -17% | 1298 | QDR |
| 08.06 14:15 | 52 | 15% | 1430 | QDR |
| 08.06 14:30 | 60 | 33% | 1544 | QDR |
| 08.06 16:30 | 80 | 10% | 1510 | stable |

QDR data were used in both short-term and long-term work zones. For short-term work zones, QDR was used as a capacity measure for a regression model. Least-squares multiple regression analysis was performed for each work zone type. QDR data for long-term work zones was used in a different manner as a better capacity estimate could be obtained (PBC). Therefore, we calculated the average QDR values for long-term work zones to compare QDR and PBC. To estimate PBC, we used survival analysis [7] to obtain capacity cumulative distribution function:

$$F_c(q) = P(c \leq q) \tag{1}$$

where:
$F_c(q)$ - capacity cumulative distribution function,
$P(c \leq q)$ - probability, that traffic demand exceeds capacity.

All the periods with stable traffic and periods with traffic jam were furtherly analysed. The transition between stable and congested traffic was determined based on occurrence of a breakdown regarding multiple criteria; breakdown is followed by a sudden drop in speed (at least 25 %), speed drops below a certain threshold (50 – 75 km/h, depending on the work zone type). The transition between stable traffic and traffic breakdown occurs when speed reaches 70 to 80 km/h on motorway sections without work zones [8]. However, this speed is usually lower in work zones, therefore flow-speed diagrams were used to determine the thresholds (see diagram on Figure 1 for comparison).

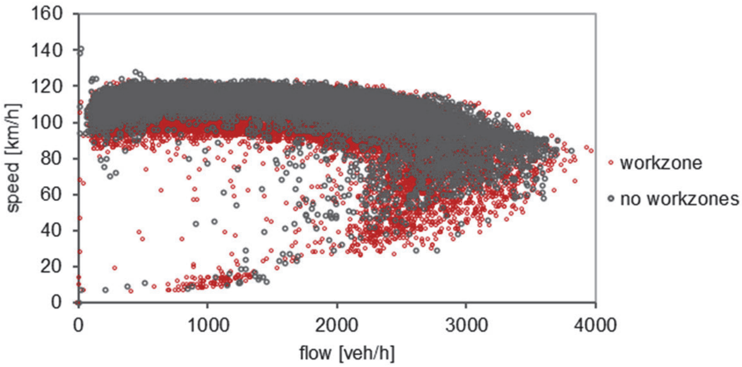


**Figure 1** low rates and average speed data in roadwork period (red) and comparable period without work zones (gray)

We will determine Weibull cumulative distribution function of capacity represent the relationship between flow and probability of traffic breakdown:

$$F_C(q) = 1 - e^{-\left(\frac{q}{\beta}\right)^{\alpha}} \tag{2}$$

where:

$F_c(q)$ - cumulative distribution function of capacity,
$q$ - flow (veh/h),
$a$ - Weibull shape parameter,
$\beta$ - Weibull scale parameter.

Parameters $a$ and $\beta$ were estimated using maximum likelihood method. The resulting capacity cumulative distribution function estimates the probability of a traffic breakdown for a given flow (demand) value. Therefore, it can be used as an estimate of the effect of a work zone on traffic flow under certain traffic conditions. The capacity is estimated as the flow, under which the traffic remains stable with a certain (high) probability, i.e. the probability of the breakdown for such flow is low (for example 5 % or 15 % according to HCM).
The maximum likelihood method analysis for determining Weibull capacity distribution functions can be used in work zones, where sufficient pre-breakdown data can be collected, i.e., we are not able to determine PBC values for short-term work zones that caused a breakdown immediately after the work zone setting up.

# 3 Results and discussion

Results of the analyses are hereby summarized. The first part consists of results of the regression analysis of QDR for short-term work zones, whereas Weibull cumulative capacity distribution functions for each work zone type and average QDR values for each long-term work zone are shown in the second part.

## 3.1 QDR in short-term work zones and factors affecting capacity

Several possible capacity affective factors were studied in the regression analysis. Besides the factors that were identified as statistically significant (light goods vehicle percentage, heavy goods vehicle percentage, grade, high share of drivers unfamiliar with the network – weekend/seasonal traffic), we studied several factors that turned out to be insignificant and were excluded from the model (presence of a shoulder lane, precipitation, time of day (day/night) and tunnel area). The results of the regression analysis are shown in equations (3) and (4) for work zones of type A A ($QDR_A$ in equation (3)) and B ($QDR_B$ in equation (4)).

$$QDR_A = 1596 - 1345 \cdot GV - 17800 \cdot I \cdot HGV - 230 \cdot WE \tag{3}$$

$$QDR_B = 1591 - 1419 \cdot GV - 28000 \cdot I \cdot HGV - 180 \cdot WE \tag{4}$$

where:
GV - percentage of commercial goods vehicles (light goods vehicles and heavy goods vehicles),
I - longitudinal grade,
HGV - percentage of heavy goods vehicles,
WE - weekend or seasonal traffic (drivers unfamiliar with the network).

Longitudinal grade only reduces capacity when heavy goods vehicles are present. Grade shows a bigger effect for work zones of type A than B (17800 compared to 28000), however, both equations don't differ significantly. QDR for work zones type A and B can therefore be determined as an average of both equations (also HCM [9] doesn't differ between both types of work zones). The effect of negative grades was further analysed; the effect is the best described if we set negative grades to 0, unless they are long and steep (≥3 % in ≥ 700 m), where they act similar as a positive grade (represent a capacity reduction in presence of heavy vehicles).
Factors, that turned out to be statistically insignificant may still have some effect on the capacity, however, their effect can be difficult to measure due to insufficient data. For example, daily precipitation data may not be sufficient and may lead to a false result, since most of the short-term work zones were probably implemented during dry hours, even though it may have rained earlier/later in the day.

## 3.2 Cumulative distribution functions

We performed stochastic analysis for both short- and long-term work zones. Short-term work zones on steep (grade › 2 %, length › 800 m) and non-steep (grade ‹ 2 %) motorway sections were analysed separately, with the same heavy vehicle equivalent factor ($E_T$=2). This clearly shows the effect of a steep grade (Figure 2), with up to ten times higher probabilities for a breakdown with the same flow. Curve "one ln closed (HCM 2016)" on Figure 2 shows cumulative distribution function of capacity, where HCM [9] heavy vehicle equivalent factors were used ($E_T$=2) for non-steep and $E_T$=3 for steep roads). Clearly, the HCM methodology with the homogenous traffic flow concept captures the grade effect well.

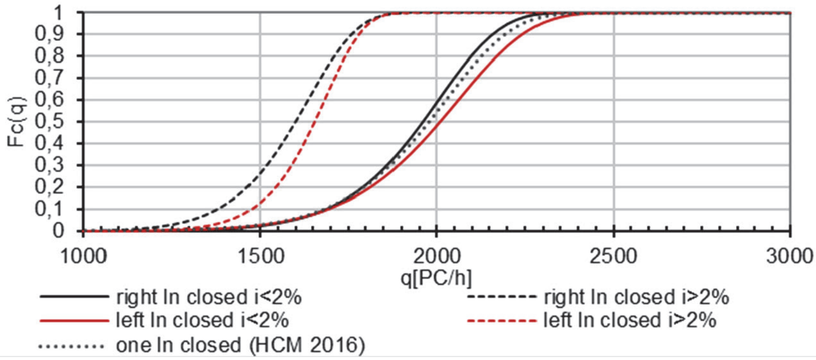


**Figure 2** Weibull distribution functions for work zones of types A and B for steep/nonsteep grades (‹2 % and ›2 %).

The results of stochastic analysis of long-term work zones (Figure 3) show, as expected, that capacity is the highest for type G work zone (closed shoulder lane, no lane narrowing). The capacity for type G work zone is approx. 100 100PC/h/lane lower than in the case with no work zone (type 0). Work zones with crossovers (type D and F) and work zone with the narrowest lanes (type E) achieve the lowest capacity.

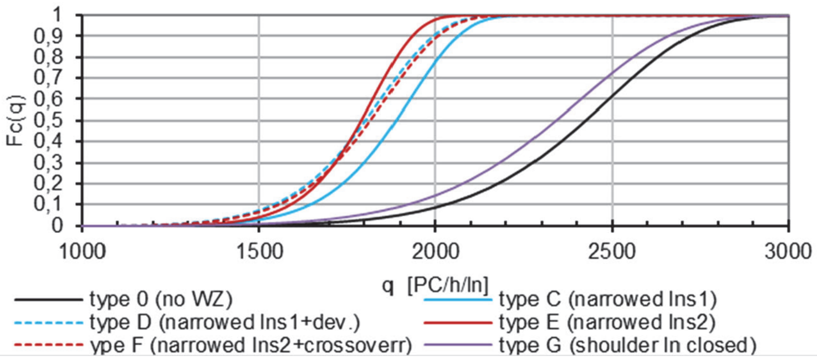


**Figure 3** Weibull capacity distribution functions for various long-term work zone types

Table 3 shows summary of results with estimated capacity PBC as 15th percentile of capacity distribution function ($C_{15}$), whereas QDR is the average value of QDR data. Hereby, values for work zones with similar results are averaged. It should be noted that QDR values in work zones of type G can be underestimated, since breakdowns were rarely reported in this type of work zone and additionally, when they were reported, they commonly lasted less than 15 minutes (time period of data).

**Table 3** Estimated work zone capacity $C_{15}$ [PC/h/lane] and capacity drop $\alpha_{wz}$

| **Work zone type** | **A or B One ln closed** | **G Shoulder ln closed** | **C Narrowed lns (3,25; 2,75)** | **E Narrowed lns (3,00; 2,30)** | **D or F Narrowed lns + crossover** |
|---|---|---|---|---|---|
| $C_{15}$ [PC/h/lane] | 1754 | 2004 | 1694 | 1630 | 1600 |
| QDR [PC/h/lane] | 1594 | 1572 | 1600 | 1474 | 1445 |

Results of the analysis are comparable of those proposed in HCM only in case of work zones with no lane narrowing and no crossovers. In case of lane narrowing and crossover, HCM methodology does not provide good fit, as already noted in HCM [9].

# 4 Conclusions

The presented research shows analysis of 151 short-term work zones of two types (left or right lane closed) and long-term work zones of five types (various lane narrowing and crossovers). QDR values and 15th percentile of capacity distribution function ($C_{15}$) were calculated for the work zones. The presented analyses show that the work zone capacity is strongly affected by heavy vehicle percentage, grade, high share of drivers unfamiliar with the network – weekend/seasonal traffic, lane narrowing and crossovers. While some other factors might also affect capacity (daylight, precipitation etc.), their effect cannot be measured due to work zone planning/insufficient data (e.g. short-term work zones only in sunny days).
The results are useful as an orientational estimates for capacity values of different types of work zones and helpful for planning work zone configurations in the future. Furthermore, the estimated capacity values can provide an estimate of breakdown probabilities, delays and levels of service of motorway sections under work zones and as such they enable the motorway managers to be better prepared for possible scenarios during roadworks.

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