Development of Adjustment Factors for HCM Sixth Edition Freeway Work Zone Capacity Methodology

Final Report
July 2020

Smart Work Zone Deployment Initiative

Center for Transportation Research and Education

Iowa State University Institute for Transportation

Sponsored by
Smart Work Zone Deployment Initiative
(Part of TPF-5(295))
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About the Smart Work Zone Deployment Initiative

Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work Zone Deployment Initiative (SWZDI) in 1999 and Wisconsin joined in 2001. Through this pooled-fund study, researchers investigate better ways of controlling traffic through work zones. Their goal is to improve the safety and efficiency of traffic operations and highway work.

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16. Abstract

This project validated the Highway Capacity Manual (HCM) work zone capacity methodology for urban and rural freeways and provides recommendations for a more accurate estimation of work zone capacity. This study collected data from 16 work zone sites across Iowa in 2018 and 2019. The free flow speeds (FFSs), capacities, and queue discharge rates (QDRs) at these work zones were calculated using the HCM method and compared to field measurements.

For the work zones considered in this study, the key findings are as follows:

- FFSs estimated using the HCM method had a greater variance than the field-measured values. Under free flowing conditions, Iowans generally drove around the work zone speed limits, while the HCM method predicted a wide range of FFSs.
- The field-measured prebreakdown capacities and QDRs were significantly lower than the values computed using the HCM method, indicating that traffic breakdown could happen at a much lower flow level than the capacity predicted by the HCM method.
- With complex work zone configurations, such as narrow lanes, lane shifts, and crossovers, the observed FFS and prebreakdown capacity were significantly lower than typical work zone configurations.

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DEVELOPMENT OF ADJUSTMENT FACTORS FOR HCM SIXTH EDITION FREEWAY WORK ZONE CAPACITY METHODOLOGY

Final Report
July 2020

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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This research was conducted under the Smart Work Zone Deployment Initiative (SWZDI) and Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(295), involving the following state departments of transportation:

- Iowa (lead state)
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- Wisconsin

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EXECUTIVE SUMMARY

The Highway Capacity Manual (HCM), Sixth Edition, introduced a new methodology to estimate freeway work zone capacity. The data used to develop the HCM work zone capacity methodology were collected from 12 work zone sites with different configurations across 6 states including Arizona, Arkansas, California, Maryland, Nevada, and Virginia. It was expected that capacity at work zones in the Smart Work Zone Deployment Initiative (SWZDI) states might be significantly different from the states where the data were collected. Thus, it was crucial to validate the HCM methodology using locally collected data and provide adjustment factors as necessary. In addition, for the special work zone configurations, the queue discharge rate (QDR) adjustment factors were derived from field-calibrated microsimulation models. Validating the capacities at merge, diverge, and weaving segments using field data shed light on the applicability of the simulated results to SWZDI states.

The objective of this project was to validate the HCM work zone capacity methodology for urban and rural freeways in Iowa and provide recommendations for a more accurate estimation of work zone capacity. This study collected data from 16 work zone sites across Iowa in 2018 and 2019. The free flow speeds (FFSs), capacities, and QDRs at these work zones were calculated using the HCM method and compared with the field measurements.

For the work zones considered in this study, the key findings are as follows:

- FFSs estimated using the HCM method had a greater variance than the field-measured values. Under free flowing conditions, Iowans generally drove around the work zone speed limits, while the HCM method predicted a wide range of FFSs.
- The field-measured prebreakdown capacities and QDRs were significantly lower than the values computed using the HCM method, indicating that traffic breakdown could happen at a much lower flow level than the capacity predicted by the HCM.
- With complex work zone configurations, such as narrow lanes, lane shifts, and crossovers, the observed FFS and prebreakdown capacity can be significantly lower than ones of typical work zones.

CHAPTER 1. INTRODUCTION

The Highway Capacity Manual (HCM), Sixth Edition, introduced a new methodology to estimate freeway work zone capacity. The data used to develop the HCM work zone capacity methodology were collected from 12 work zone sites with different configurations across 6 states including Arizona, Arkansas, California, Maryland, Nevada, and Virginia. It was expected that capacity at work zones in the Smart Work Zone Deployment Initiative (SWZDI) states might be significantly different from the states where the data were collected. Thus, it was crucial to validate the HCM methodology using locally collected data and provide adjustment factors as necessary. In addition, for the special work zone configurations, the queue discharge rate (QDR) adjustment factors were derived from field-calibrated microsimulation models. Validating the capacities at merge, diverge, and weaving segments using field data shed light on the applicability of the simulated results to SWZDI states.

The objective of this project was to validate the HCM work zone capacity methodology for urban and rural freeways in Iowa and provide recommendations for a more accurate estimation of work zone capacity. This study collected data from 16 work zone sites across Iowa in 2018 and 2019. Flow rate, speed, and work zone active times and configurations were collected to estimate work zone capacity, discharge flow rate, and free flow speed (FFS). Work zone capacity describes a traffic facility's ability to sustain service flow rates near the operational optimum. Different methods have been used in the literature to estimate work zone capacity based on traffic volume data, including average QDR, maximum QDR, prebreakdown flow rate, and 95th percentile flow rate. In the HCM Sixth Edition, work zone capacity is defined as the prebreakdown flow rate.

As illustrated in Figure 1, the new HCM work zone methodology estimates QDRs and FFSs based on a set of work zone characteristics.

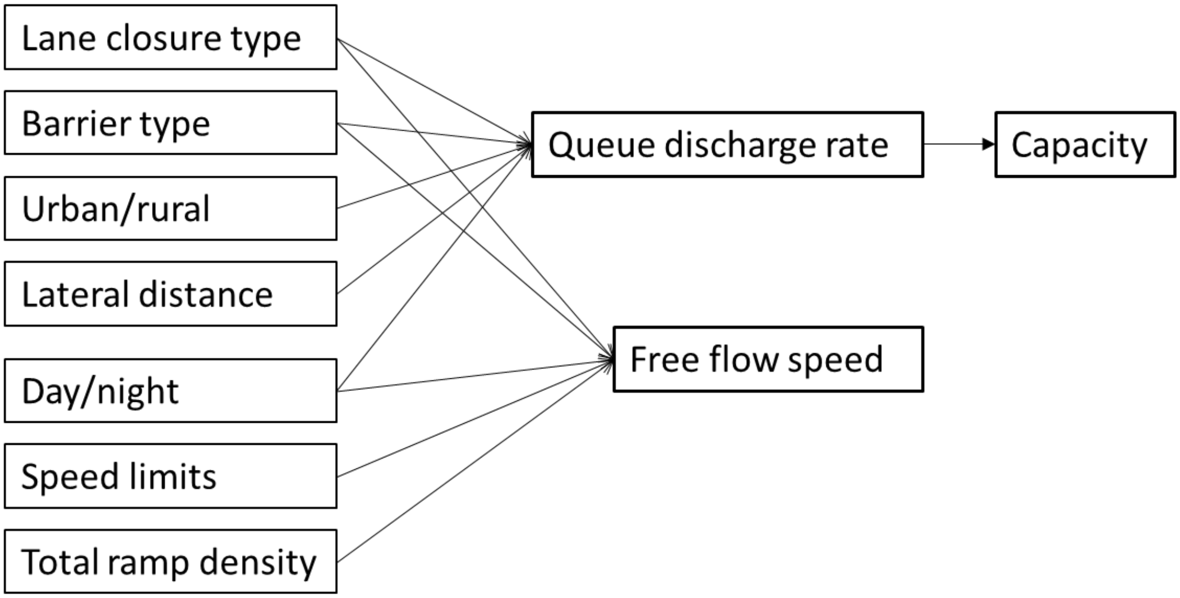


Figure 1. HCM work zone methodology for basic freeway segments

The capacity is then estimated based on the QDR and a pre-determined capacity drop percentage. The QDR model states that additional closed lanes, soft barrier separation (e.g., cones or plastic drums), rural area, less lateral clearance, and night conditions will reduce the queue discharge rates, as well as the work zone capacity. Similarly, the FFS model states that lower work zone speed limits, additional closed lanes, soft barrier separation, night conditions, and higher ramp density will reduce the free flow speed in work zones. Furthermore, for work zones involving merge, diverge, weaving maneuvers, or with directional crossovers, the queue discharge rate estimates are adjusted. In general, more complicated driving conditions result in lower QDRs and lower FFSs.

CHAPTER 2. DATA COLLECTION

2.1. Work Zone Data

The project team explored the archived traffic and work zone data from previous years. Due to incompleteness and discrepancies in the archived work zone data, work zones prior to 2018 were not included in this study. A new dataset was collected during the 2018 and 2019 construction seasons. The dataset includes 10 work zones from 2018 and 6 work zones from 2019 (see Table 1).

Table 1. List of work zones

Year	Project	Location	Construction activity
2018	1J	I-35/80 Douglas Ave, IA 141 (Rider Corner) & 100th St. interchanges	Bridge replacement in 2016 and paving in 2018
	1T/1U	I-35 & US 30 interchange in Ames	PCC pavement - grade and new, bridge new-steel girder
	1AM	I-35 from N of Oralabor Rd. to NE 36th St., including 1st St. and 4 Mile Creek bridge in Ankeny	ITS equipment, grading, bridge replacement, RCB culvert replacement - triple box, reconstruction - bridge widening
	1AQ	NB I-35 bridge over S Skunk River 2.6 mi S of US 30	Northbound bridge replacement-PPCB structures – miscellaneous traffic signs, PCC pavement - grade and replace
	2P	Iowa 58 and Viking Road grade separation in Waterloo	Interchange construction and grade separation
	3B	I-29 (SBL) over SB Frontage Rd./Pierce St./Virginia St./Floyd Blvd./Wesley Pky./Perry Creek in Sioux City	Bridge replacement; new PCC pavement; grade and replace ITS equipment
	4.1	I-29 NB/SB at UPRR b/w Neb Ave. & 9th Ave.; I-29 NB/SB from US 275 to S Expressway; I-80/I-29 from WSI to Madison Ave. (MM 5) in Council Bluffs	New interchange, PCC pavement, grade and replace
	4AH	I-80 bridge over Franklin Ave., 2.3 mi W of US 6 in Council Bluffs	Deck joint repair
	6AA	WB US 30 bridge over CIC RR 0.8 mi W of I-380 in Cedar Rapids	Bridge deck overlay
	6AM	I-80, 1.1 mi E of Y40 to E of IA 130 in Scott County	HMA resurfacing
2019	1J/1BC	I-35/80 Douglas Ave., IA 141 (Rider Corner) & 100th St interchanges; Douglas Ave. to E of 100th St., includes IA 141 interchange, Rider Corner in Urbandale	Grading, bridge-new steel girder
	1AM	In Ankeny at E 1st St. interchange (E 1st St./SE Creekview Dr./Frisk Dr.)	Pavement grade replace
	2Q	IA 21 to the Cedar River in Waterloo	PCC pavement replacement
	3P	US 75 NBL from the Woodbury County Line N to Hinton Stream 1.6 mi N of Co. Rd. C70 (NB)	PCC pavement grade and replace; bridge replacement
	3S	I-29 SB from Missouri Valley to Mondamin: 0.4 mi N of UP PP to 0.5 mi N of IA 127 (SBL)	PCC pavement - grade and replace
	5V	From S of the Decatur Co. Rest Area to IA 2 (SBL)	PCC pavement -grade and replace

Images from video cameras were used to verify the work zone configuration and active work times. The work zone characteristics include lane closure type, barrier type, lateral clearance, project duration, and lane closure times.

2.2. Traffic Data

Traffic conditions including travel speed, volume, and vehicle classification were collected from the Iowa Department of Transportation's (DOT's) permanent sensors and through the temporary sensors deployed by the DOT's Traffic Critical Projects program. The aggregation interval of the data was set to 5 minutes. There are usually several sensors associated with each project. The sensors closest to both ends of the work zone were identified as the upstream and downstream sensors. For some projects, no archived traffic data were available at the closest sensor during the work zone active times. Data from adjacent sensors were used in those instances. As shown in Figure 2, since no data were available at the sensor location I-35/80 milepost 128.5, data from the sensor located at I-35/80 at IA 141 were used. If the next available sensor was too far from the work zone, field measurements of prebreakdown capacity or QDR were not available.

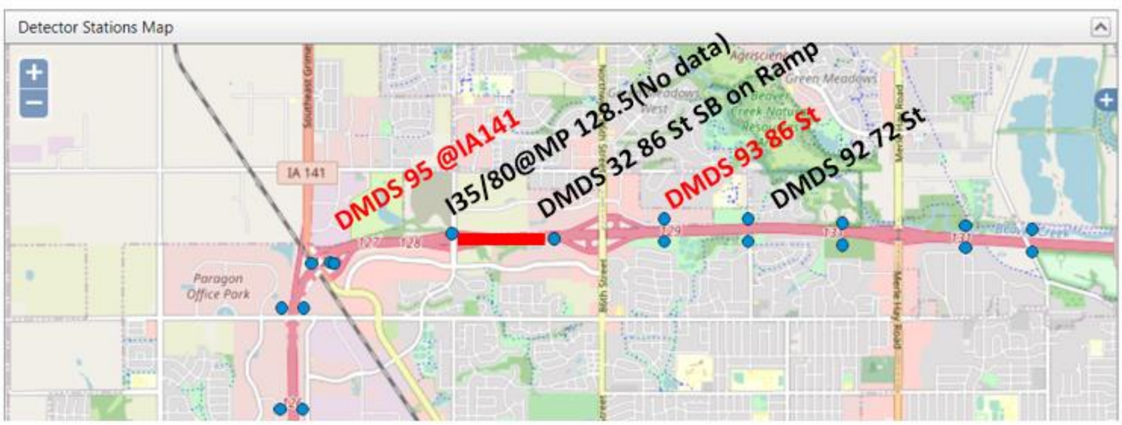


Figure 2. Sensor locations of work zone IJ—I-35/80 at 100th St. in Urbandale

CHAPTER 3. METHODOLOGY

3.1. HCM Work Zone Methodology

3.1.1. Capacity and Queue Discharge Rate

The HCM work zone capacity method estimates the work zone prebreakdown flow and queue discharge flow by accounting for lane closure type, barrier type, area type, lateral clearance, lighting, and speed limit. In particular, for basic freeway segments, the QDR is computed using the following equation:

$$QDR_{wz} = 2{,}093 - 154 \times LCSI - 194 \times f_{Br} - 179 \times f_{AT} + 9 \times f_{LAT} - 59 \times f_{DN}$$

where,

QDR_{wz} = 15 minute queue discharge rate in passenger car per hour per lane (pc/hr/ln) at the work zone bottleneck

LCSI = lane closure severity index; $LCSI = \frac{1}{OR \times N_o}$, OR = open ratio, the ratio of the number of open lanes during road work to the total number of lanes (decimal); N_o = number of open lanes in the work zone

f_{Br} = indicator variable for barrier type; = 0 for concrete and hard barrier separation; =1 for cones, plastic drums, or other soft barrier separation

f_{AT} = indicator variable for area type; = 0 for urban area; =1 for rural area

f_{LAT} = lateral distance from the edge of travel lane adjacent to the work zone barrier, barricades, or cones (0–12 ft)

f_{DN} = indicator variable for daylight or night; = 0 for daylight; =1 for night

In this study, lane closure ($LCSI$), barrier type (f_{Br}), and lateral clearance (f_{LAT}) variables were determined from the archived images of the work zone. The area type (f_{AT}) and indicator variable for daylight or night (f_{DN}) were determined based on the location and the time of work.

The prebreakdown capacity for work zone is then estimated based on the queue discharge rate, as follows:

$$c_{wz} = \frac{QDR_{wz}}{100 - \alpha_{wz}} \times 100$$

where,

c_{wz} = work zone capacity (i.e., prebreakdown flow rate) in pc/hr/ln.

α_{wz} = the percentage drop in prebreakdown capacity at the work zone due to queuing condition (%). The default value of α_{wz} for freeway work zones is 13.4%.

For special work zone configurations, such as merge, diverge, weaving segments, and work zones with directional crossovers, the QDRs need to be adjusted. Table 2 and Table 3 show the adjustment factors for merge and diverge segments based on the acceleration lane length and ramp flow. The acceleration lane lengths were measured using Google Earth Pro, and the ramp flows were obtained from the annual average daily traffic (AADT) map provided by Iowa DOT open data portal.

Table 2. Proportion of work zone QDR (relative to the basic work zone capacity) available for mainline flow upstream of merge area

Work zone lane configuration	On-ramp input demand (pc/hr)	Acceleration lane length (ft)							
		100	300	500	700	900	1,100	1,300	1,500
2 to 1	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	250	1.00	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	500	1.00	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	750	1.00	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	1,000	1.00	0.49	0.45	0.40	0.40	0.40	0.40	0.40
2 to 2	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	250	1.00	0.92	0.92	0.92	0.92	0.92	0.92	0.92
	500	1.00	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	750	1.00	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	1,000	1.00	0.67	0.67	0.67	0.67	0.67	0.67	0.67
3 to 2	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	250	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95
	500	1.00	0.87	0.87	0.87	0.87	0.87	0.86	0.86
	750	1.00	0.78	0.78	0.78	0.78	0.78	0.78	0.78
	1,000	1.00	0.70	0.70	0.70	0.70	0.70	0.70	0.70
4 to 3	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	250	1.00	0.97	0.97	0.98	0.98	0.98	0.98	0.98
	500	1.00	0.91	0.91	0.91	0.92	0.92	0.92	0.92
	750	1.00	0.85	0.85	0.85	0.86	0.86	0.86	0.86
	1,000	1.00	0.79	0.79	0.79	0.79	0.80	0.80	0.80

Source: HCM, Exhibit 25-8

Table 3. Proportion of work zone capacity available for mainline flow downstream of diverge area

Work zone lane configuration	Off-ramp volume percentage	Deceleration lane length (ft)							
		100	300	500	700	900	1,100	1,300	1,500
2 to 1	0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	6.3	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.93
	12.5	0.87	0.88	0.88	0.88	0.88	0.88	0.87	0.87
	18.8	0.79	0.82	0.82	0.82	0.82	0.81	0.81	0.81
	25.0	0.72	0.76	0.76	0.75	0.75	0.75	0.75	0.75
2 to 2	0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	6.3	0.93	0.94	0.94	0.94	0.94	0.94	0.94	0.94
	12.5	0.84	0.87	0.87	0.87	0.87	0.87	0.87	0.87
	18.8	0.76	0.81	0.81	0.81	0.81	0.81	0.81	0.81
	25.0	0.68	0.75	0.75	0.75	0.75	0.75	0.75	0.75
3 to 2	0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	6.3	0.93	0.94	0.94	0.94	0.94	0.94	0.94	0.94
	12.5	0.86	0.87	0.87	0.87	0.87	0.87	0.87	0.87
	18.8	0.78	0.81	0.81	0.81	0.81	0.81	0.81	0.81
	25.0	0.69	0.74	0.74	0.74	0.74	0.74	0.74	0.74
4 to 3	0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	6.3	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
	12.5	0.86	0.87	0.87	0.87	0.87	0.87	0.87	0.87
	18.8	0.76	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	25.0	0.64	0.73	0.73	0.73	0.73	0.73	0.73	0.73

Source: HCM, Exhibit 25-10

3.1.2. Free Flow Speed

The HCM recommends the following equation to compute the free flow speed:

$$FFS_{wz} = 9.95 + 33.49 \times f_{sr} + 0.53 \times SL_{wz} - 5.6 \times LCSI - 3.84 \times f_{Br} - 1.71 \times f_{DN} - 8.7 \times TRD$$

where,

FFS_{wz} = free flow speed at the work zone

f_{Sr} = speed ratio (decimal); the ratio of non-work zone speed limit to work zone speed limit

SL_{wz} = work zone speed limit (mph)

TRD = total ramp density along the facility (ramps/mi)

The Iowa DOT's policy regarding speed limits in temporary traffic control zones is based on the 2009 Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). Specifically, for multi-lane divided highways, the following policies apply:

Four-Lane Divided Highways:

- Existing regulatory speed limit (65 mph, 60 mph, or 55 mph) maintained if all existing lanes are open to traffic and the width between barriers (other than spot locations) is 30 ft or greater
- Regulatory 55 mph speed limit where the roadway width between barriers is less than 30 ft (temporary barrier rail [TBR], 3 ft shoulder, 12 ft lane, 12 ft lane, 3 ft shoulder, TBR) other than spot locations such as bridges
- Regulatory 55 mph speed limit with single lane closure only when workers are present
- Regulatory 55 mph speed limit where construction vehicles must frequently merge into high volume traffic lanes
- Regulatory 55 mph speed limit with single lane closure using temporary barrier rail due to potential side friction from use of barrier rail
- Regulatory 55 mph speed limit for two-lane, two-way operation

Six-Lane or More Divided Highways:

- Existing regulatory speed limit (65 mph, 60 mph, or 55 mph) maintained if all existing lanes are open to traffic
- Existing regulatory speed limit (65 mph, 60 mph, or 55 mph) maintained if at least two existing lanes are open to traffic per direction and the cross section configuration is 30 ft or greater
- Regulatory 55 mph speed limit when cross section configuration is less than 30 ft (TBR, 3 ft shoulder, 12 ft lane, 12 ft lane, 3 ft shoulder, TBR)
- Regulatory 55 mph speed limit with only single lane available to traffic

The non-work zone speed limits and total ramp density were collected from Google Maps. The work zone speed limits were collected from the archived images of the work zone where the speed limit sign was visible; otherwise, 55 mph was used as the work zone speed limit.

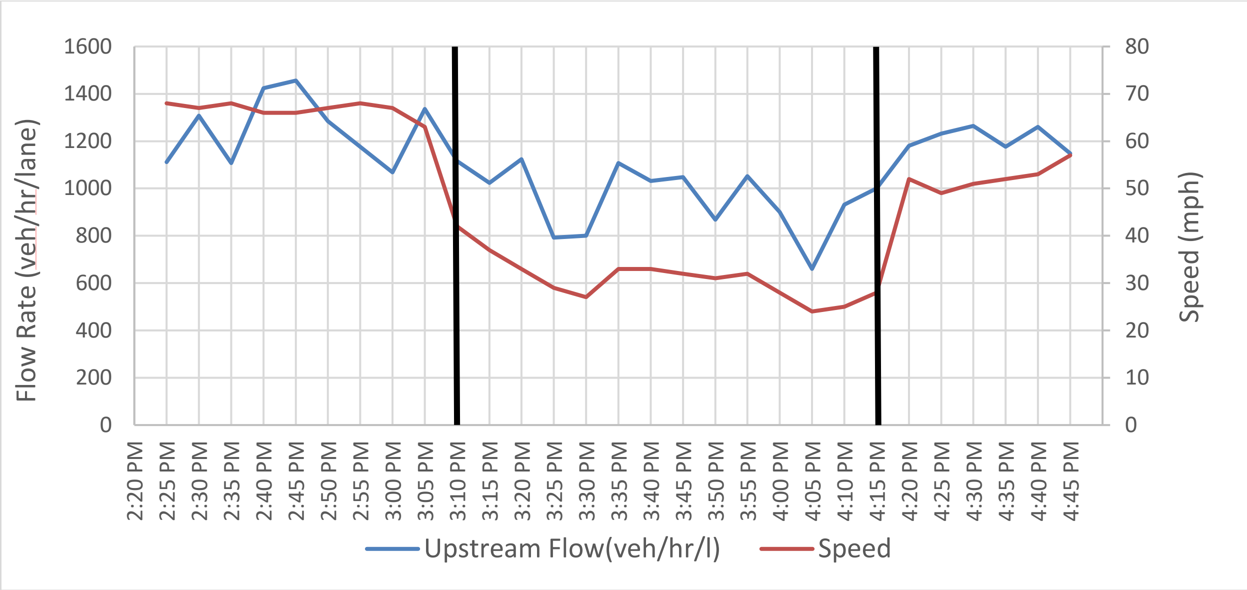
3.2. Field Measurement of Work Zone Capacity

Work zone FFSs, QDRs, and prebreakdown capacity were estimated using the 5 minute aggregated traffic volume and speed data collected by Wavetronix sensors. Work zone FFSs were computed as the average speed when the work zone was active, and the flow rate was less than 1,000 vehicles per hour per lane (veh/hr/ln). Because one work zone site might have different configurations at different times, FFSs were computed for each scenario that was defined by the work zone configuration and time of work.

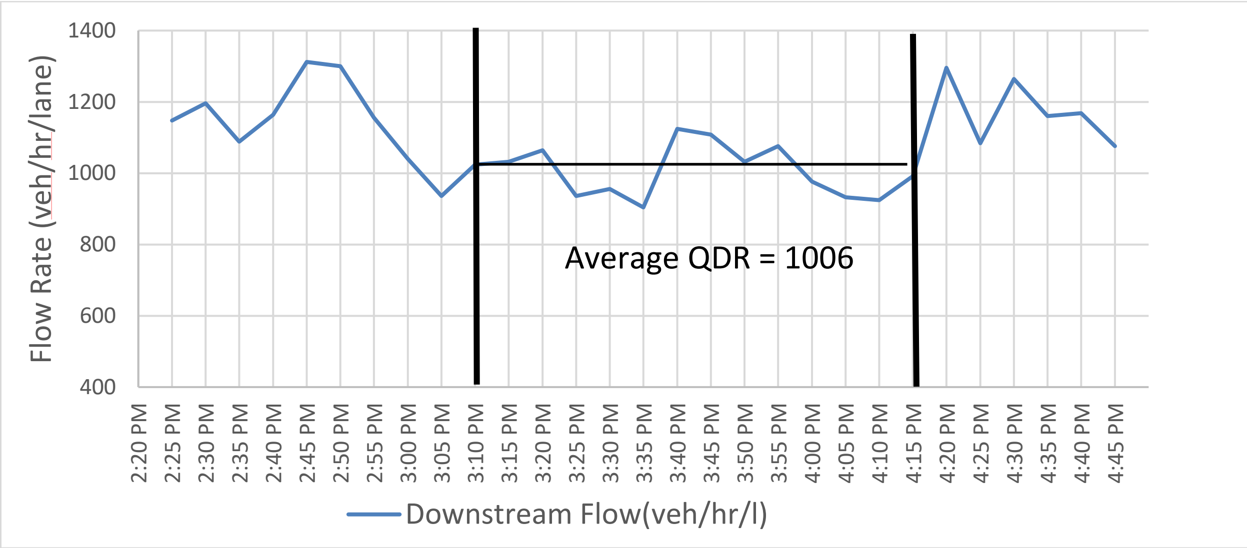
The prebreakdown capacity is defined as the maximum flow rate observed before traffic breaks down. In particular, traffic breakdowns are detected when there is a sudden drop in speed of at least 25% below the FFS for at least 15 minutes that results in queuing upstream of the work zone. The traffic is considered as returning to normal when the speed recovers to greater than 75% of the FFS. After identifying the breakdown, the flow rates observed during the 15 minute period before the breakdown occurred (i.e., 3 flow observations) were compared and the highest flow rate was used as the prebreakdown capacity.

QDR is defined as the average flow rate immediately downstream of an active bottleneck (i.e., the work zone) measured over a 15 minute sampling interval while there is active queuing upstream during oversaturated conditions (i.e., after traffic breaks down and before recovery). The flow data collected from a sensor immediately downstream of a work zone is used to calculate the QDR.

Figure 3 shows the time series plots of flow and speed data collected at the upstream and downstream of work zone 1J on June 28, 2019.



Prebreakdown capacity



Queue discharge rate

Figure 3. Prebreakdown capacity and QDR measured at work zone IJ (westbound traffic) on June 28, 2019

The right shoulder for westbound traffic was closed from 8:51 a.m. to 4:32 p.m. Traffic breakdown occurred at 3:10 p.m. and lasted until 4:15 p.m. The prebreakdown capacity (1,336 veh/hr/ln) was observed at 3:05 p.m., before the traffic breakdown at sensor DMDS93 at 86 St. WB (see previous Figure 2). The QDR is computed as the average flow rate (1,006 veh/hr/ln) observed from downstream sensor DMDS95 at IA 141 WB during the breakdown. In this example, the percentage drop in prebreakdown capacity at the work zone due to queuing condition (i.e., α_{wz}) is 24.7%.

The QDR and capacity are measured in terms of number of vehicles per hour per lane (veh/hr/ln), including trucks and passenger cars. To compare with the HCM estimated values, the field measurements are converted to equivalent passenger car per hour per lane (pc/hr/ln) using the capacity adjustment factor as follows:

$$CAF_{MIX,J} = CAF_{AO} - CAF_{(T.MAX)} - CAF_{G,MIX,J}$$

where,

$CAF_{MIX,J}$= mixed-flow capacity adjustment factor for segment j

CAF_{AO} = capacity adjustment factor for the auto-only case (default = 1)

$CAF_{(T.MAX)}$ = capacity adjustment factor for the percentage of trucks in mixed-flow conditions ($CAF_{(T.MAX)} = 0.53 \times P_{Truck}^{0.72}$)

$CAF_{G,MIX,J}$ = capacity adjustment factor for grade for segment j in mixed-flow conditions, which is assumed to be 0 in this study

The percentage of trucks were computed using the traffic counts by vehicle class during the active work zone time.

CHAPTER 4. RESULTS

This chapter compares the FFS, capacity, and QDR obtained based on the HCM method and from the field measurements. Various scenarios were defined according to the work zone configuration, location, and time of work. In particular, the definition of each component of a scenario is given in Table 4.

Table 4. Scenario definition

Scenario code	Definition
#LC	Number of closed lanes
S/H	Barrier type: S for soft barrier separation, H for hard barrier separation
U/R	Area type: U for urban, R for rural
#	lateral distance from the edge of travel lane adjacent to the work zone to the barrier, in feet
D/N	Work time: D for daylight, N for night
D/M/B	Segment type: D for diverge, M for merge, B for basic

For example, the scenario 1LC-S-U-0-D-D stands for a work zone with one lane closed (1LC), soft barrier separation (S), in an urban area (U), with no lateral distance between the cone and the traveled lane (0), during daytime (D), and at a diverge segment (D).

4.1. Free Flow Speed

The free flow speeds were computed using the HCM method and compared with the field measurements, as shown in Table 5 and Figure 4.

Table 5. Free flow speed comparison: field measurement vs. HCM method

Project	Scenario	Non-work zone speed limit	Work zone speed limit	TRD	HCM method (mph)	Field measurement (mph)
1J	0LC-S-U-0-D-D	65	55	2.00	55.57	66.00
	1LC-S-U-0-N-D	65	55	2.00	51.53	55.27
	2LC-S-U-0-N-D	65	55	2.00	38.93	54.86
	0LC-S-U-0-N-D	65	55	2.00	53.86	65.71
	1LC-S-U-0-D-D	65	55	2.00	53.24	59.46
	0LC-H-U-0-D-D	65	55	2.00	59.41	60.03
	0LC-S-U-0-D-M	65	55	2.00	55.57	68.25
	0LC-S-U-0-N-M	65	55	2.00	53.86	68.93
	1LC-S-U-0-N-M	65	55	2.00	51.53	60.41
	2LC-S-U-0-N-M	65	55	2.00	38.93	52.53
	1LC-S-U-0-D-M	65	55	2.00	53.24	54.41
	0LC-H-U-0-D-M	65	55	2.00	59.41	69.28
1AQ	0LC-S-R-0-D-B	70	55	0.00	75.08	57.49
	1LC-S-R-0-N-B	70	55	0.00	64.97	54.00
	0LC-S-R-0-N-B	70	55	0.00	73.37	64.75
1T	1LC-S-R-0-N-B	55	55	0.67	50.04	55.34
	1LC-S-R-0-N-D	55	55	0.67	50.04	47.51
2P	1LC-H-R-0-D-B	55	55	0.50	57.04	49.19
3B	1LC-S-R-2-D-B	55	55	1.17	47.40	55.68
	0LC-S-R-2-D-B	55	55	1.17	55.80	58.12
	1LC-S-R-2-N-B	55	55	1.17	45.69	54.97
1AM	1LC-S-R-0-N-B	65	55	0.00	53.23	54.72
	1LC-S-R-0-N-B	65	55	0.00	53.23	61.90
4.1_I29	1LC-S-R-2-N-B	55	55	2.50	34.09	28.27
4AH	0LC-S-R-2-D-B	70	55	0.67	69.28	60.62
	1LC-H-R-2-D-B	70	55	0.67	64.72	50.26
6AA	0LC-S-R-2-D-B	65	55	1.67	57.54	59.95
	0LC-S-R-2-N-B	65	55	1.67	55.83	57.84
	1LC-S-R-2-N-D	65	55	1.67	47.43	54.31
6AM	1LC-S-R-2-N-B	65	55	0.33	59.03	64.97
	1LC-S-R-2-D-B	65	55	0.33	60.74	71.48
	0LC-S-R-2-N-B	65	55	0.33	67.43	71.48
2Q	0LC-S-R-0-D-D	55	55	1.67	48.65	58.34
	0LC-S-R-0-N-D	55	55	1.67	46.94	57.78
3P	0LC-S-U-0-D-B	65	55	0.50	64.89	67.09
3S	1LC-S-U-0-D-B	65	55	0.50	51.75	56.20
	1LC-S-U-0-N-B	65	55	0.50	50.04	56.25
5V	1LC-S-U-0-D-B	70	55	1.00	57.98	67.65
	0LC-H-U-0-D-B	70	55	1.00	67.42	59.08

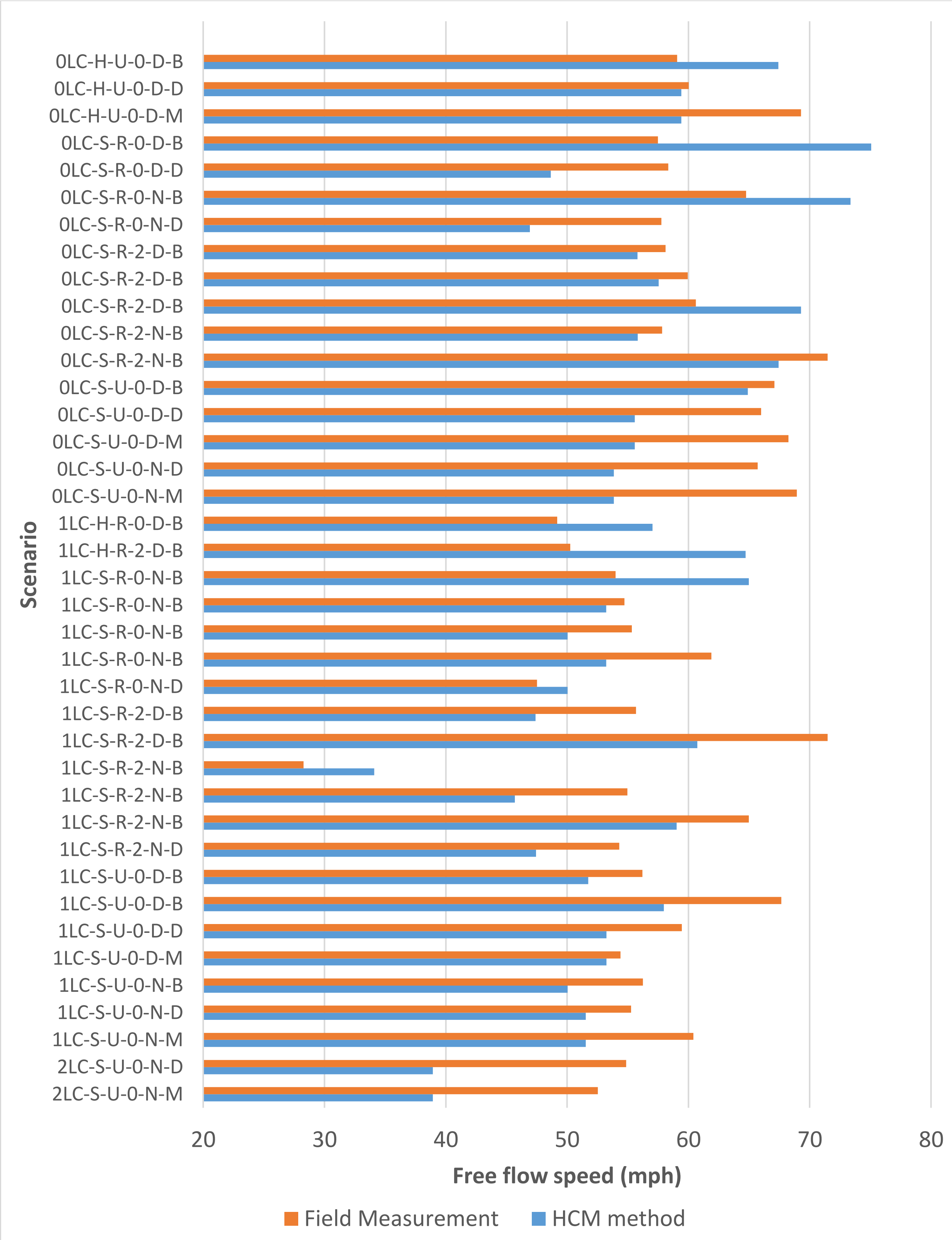


Figure 4. Free flow speed comparison: HCM method vs. field measurement

For the work zones considered in this study, FFSs estimated using the HCM method had a larger variance than the field-measured values. For work zones with an original speed limit of 70 mph and reduced speed limit of 55 mph, the HCM method overestimated FFSs for all but one scenario. For example, the HCM method estimated the FFS for scenario 0LC-S-R-0-D-B (i.e., no lane closure, with soft barrier, in a rural area, no distance from the cones to the traveled lanes, in daytime, on a basic freeway segment) at work zone 1AQ as 75.08 mph. This is unrealistic considering the work zone speed limit is 55 mph. The field-measured FFS was 57.49 mph, which is consistent with the typical driver behavior at work zones. On the other hand, the HCM method underestimates FFSs for scenarios with two lanes closed. In particular, for scenarios 2LC-S-U-0-N-D and 2LC-S-U-0-N-M at work zone 1J, the HCM method estimated the FFS as 38.93 mph, while the field-measured FFSs were 54.86 mph and 52.53 mph, respectively. This indicates that when the traffic is free flowing, Iowans drove only slightly below the speed limit even when two of three lanes were closed.

In Figure 4, one of the obvious outliers is scenario 1LC-S-R-2-N-B at work zone 4.1_I29. The field-measured FFS was 28.27 mph, and the calculated FFS using the HCM method was 34.09 mph. As shown in Figure 5, the speed dropped significantly when the work started around 8 p.m. and remained low until the end of the work at 6 a.m.

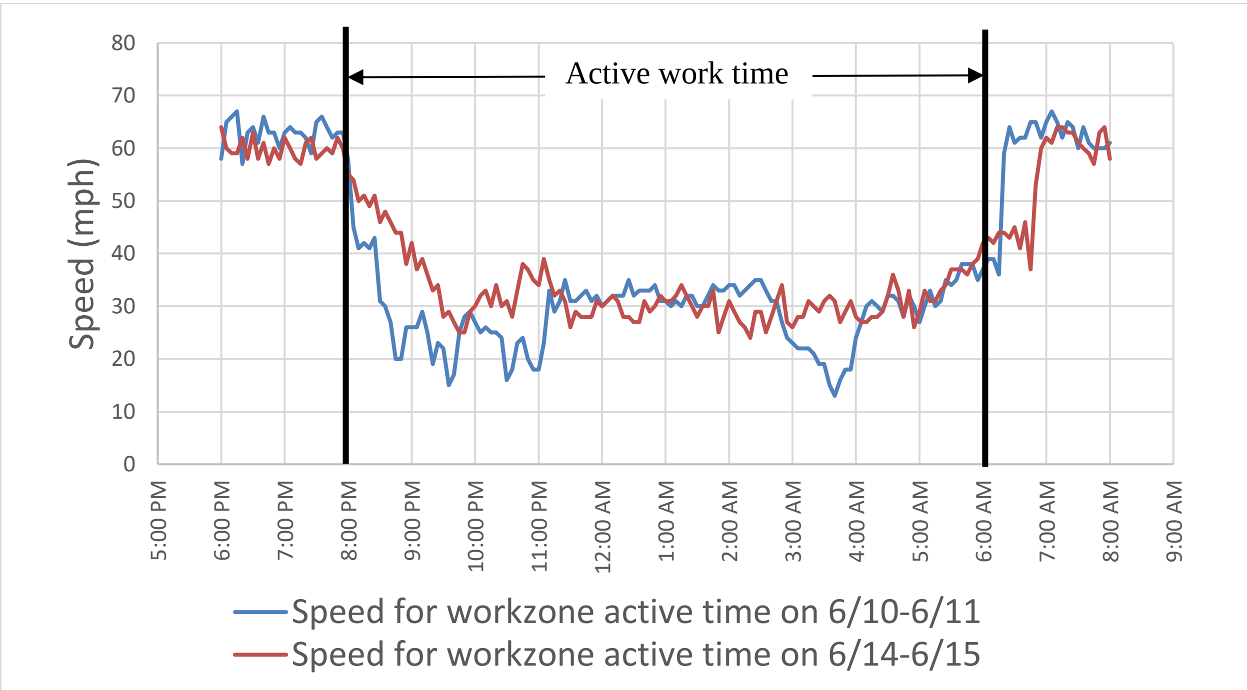


Figure 5. Speed time series of work zone 4.1_I29 on June 10–11 and June 14–15, 2018

Since the flow rate was relatively low, the measured speeds were considered as free flow speeds, although it was significantly below the work zone speed limit of 55 mph. This could be due to several factors, including the presence of multiple workers and the horizontal curve (see Figure 6).

Figure 6. Snapshot of work zone 4.1_I29 at 9:10 p.m. on June 10, 2018

4.2. Capacity and Queue Discharge Rate

To measure prebreakdown capacity and queue discharge rate, traffic breakdowns are identified and summarized in Table 6.

Table 6. Number of breakdowns observed at each work zone

Project	Direction	Scenario	LCSI	f_{Br}	f_{AT}	f_{LAT}	f_{DN}	# of breakdowns
1J	East	0LC-H-U-0-D-D	0.33	0	0	0	0	2
		1LC-H-U-0-D-D	0.75	1	0	0	0	1
	West	0LC-H-U-0-D-M	0.33	0	0	0	0	7
		0LC-S-U-0-D-M	0.33	1	0	0	0	2
1AQ	Both	0LC-S-R-0-D-B	0.5	1	1	0	0	3
3B	Both	1LC-S-R-2-D-B	2	1	1	2	0	15

The field-measured prebreakdown capacity and QDR are compared with the computed values using the HCM method as shown in Table 7.

Table 7. QDR and prebreakdown capacity comparison: HCM method vs. field measurement

Scenario	# of breakdowns	HCM method (pc/hr/ln)		Field data (pc/hr/ln)		
		QDR	Capacity	QDR	Capacity	α_{wz}
0LC-H-U-0-D-D	2	2,042	2,358	1,496	1,519	1.5%
1LC-H-U-0-D-D	1	2,042	2,358	1,582	1,678	5.8%
0LC-H-U-0-D-M	7	1,784	2,059	1,096	1,821	39.8%
0LC-S-U-0-D-M	2	1,848	2,134	893	1,657	46.1%
0LC-S-R-0-D-B	3	1,725	1,991	1,171	1,737	32.6%
1LC-S-R-2-D-B	15	1,378	1,591	1,032	1,482	30.3%

The field-measured capacity and QDR are significantly lower than the values computed using the HCM method. Although the sample size is not large enough to draw definite conclusions, caution should be taken when applying the HCM method to estimate work zone capacity in Iowa.

In addition, the default value of α_{wz} for freeway work zones is 13.4%, as suggested in the HCM. This value is averaged over capacity drop values found in the literature, which included different lane closures and barrier types. The capacity definitions were not consistent in these studies, including prebreakdown flow rate, average or maximum queue discharge rate, and 95th percentile (Yeom et al. 2015). Based on the work zones studied in this project, the percentage drops in prebreakdown capacity (α_{wz}) vary greatly.

The field-measured capacity values were also compared with the default work zone capacity as given in Exhibit 10-14 in the HCM 2010. Since only scenarios with reduced lanes are included in the HCM 2010, Table 8 lists two scenarios with lane closures.

Table 8. Capacity comparison: HCM 2010 vs. field measurement

Scenario	Project	Number of lanes to reduced lanes	HCM 2010 (veh/hr/ln)	Field data (veh/hr/ln)
1LC-H-U-0-D-D	1J	3 to 2	1,450	1,395
1LC-S-R-2-D-B	3B	2 to 1	1,400	1,289

The field measurements are slightly lower than the default values of work zone capacity given in the HCM 2010.

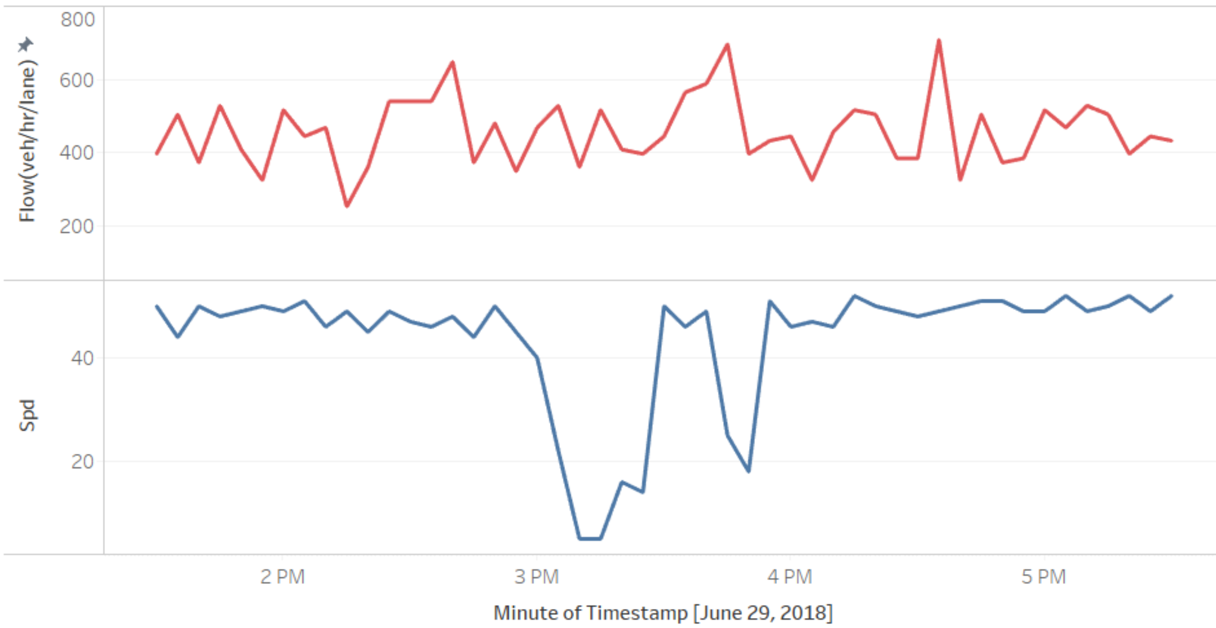
The previous Table 6 lists only traffic breakdowns detected in six scenarios from three work zones. The researchers have also observed sudden speed drops in other scenarios, where flow rates were relatively low before the speed drop (i.e., less than 800 veh/hr/ln). These breakdowns could be due to other disruptions (e.g., crashes) or special configurations of the work zone. For example, Figure 7 shows the configuration of the work zone 2P on IA 58 north of US 20 on June 29, 2018.

(a) Snapshot before traffic breakdown

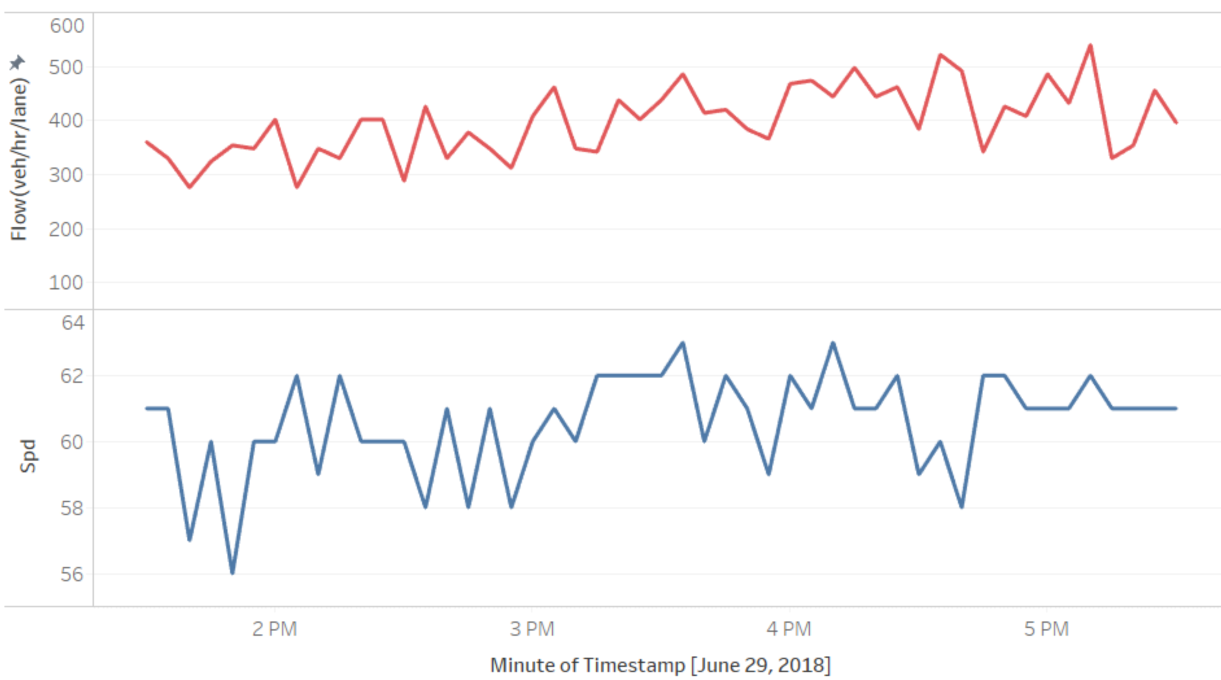
(b) Snapshot after traffic breakdown

Figure 7. Traffic breakdown at work zone 2P on June 29, 2018

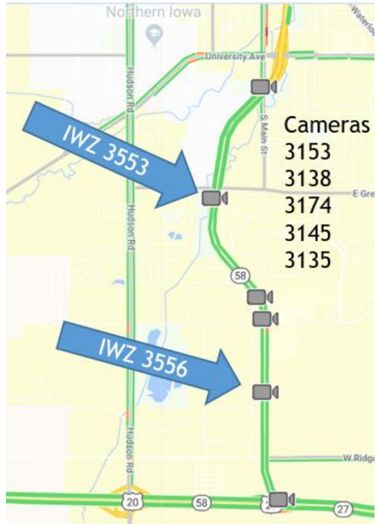
The configuration is classified as a one-lane closure with a TBR when calculating the capacity using the HCM formula. The actual driving condition is more complex than the usual lane closure. Figure 8 shows the speed and flow plots during the active work zone time from 6 a.m. to 6 p.m. The traffic breakdown was detected at 2:55 p.m., and the prebreakdown capacity (648 veh/hr/ln) was observed at 2:40 p.m. The queue discharge rate observed at the downstream sensor was 775 veh/hr over two lanes or 387 veh/hr/ln.



(a) Time series of speed and flow data at upstream sensor (IWZ 3556)



(b) Time series of speed and flow data at downstream sensor (IWZ 3553)



(c) Sensor locations

Figure 8. Time series of speeds and flow rates at work zone 2P on June 29, 2018

In addition, the field-measured capacity and QDR were grouped based on the work type, as defined in the Iowa DOT Lane Closure Planning Tool (LCPT). The results are summarized in Table 9.

Table 9. Queue discharge rate and prebreakdown capacity for different work types

Work type	# of breakdowns	QDR (veh/hr/ln)	Capacity (veh/hr/ln)	QDR (pc/hr/ln)	Capacity (pc/hr/ln)
TC-402, Shoulder closure with cones	3	966	1,376	1,171	1,737
TC-40x: Shoulder closure with TBR	11	922	1,404	1,132	1,736
TC-418, Lane closure	16	929	1,290	1,073	1,488

These capacity values can be used to update the thresholds in the LCPT.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This project compared the results from the HCM work zone capacity methodology with field measurements for urban and rural freeways in Iowa. Work zone activity data and the corresponding traffic data from 16 work zones were collected during the 2018 and 2019 construction seasons. The free flow speeds, capacities, and queue discharge rates at these work zones were calculated using the HCM method and compared with field measurements.

For the work zones considered in this study, the key findings are as follows:

- FFSs estimated using the HCM method had a greater variance than the field-measured values. Iowans generally drove around the work zone speed limits under free flowing conditions, while the HCM method predicted a wide range of FFSs.
- The field-measured prebreakdown capacities and QDRs were significantly lower than the values computed using the HCM method, indicating that traffic breakdown could happen at a much lower flow level than the capacity predicted by the HCM method.
- The HCM work zone capacity method does not account for the effects of complex work zone configurations, such as narrow lanes, lane shifts, and crossovers; thus, the observed FFS and prebreakdown capacity can be significantly lower than typical work zones.

Accordingly, the following recommendations are made for estimating work zone capacity:

- When possible, work zone queue discharge rate and capacity should be estimated using field data to account for the unique features of the work zone.
- If the HCM method estimates a free flow speed that is significantly lower or higher than the posted work zone speed limit, one should consider adjusting the estimated value unless the special configuration of the work zone can justify such discrepancy.
- Recognizing that traffic breakdown might occur at a flow level lower than the HCM estimated capacity, the traffic control target should be set lower than the estimated capacity to avoid slowdowns in work zones.
- The Iowa DOT Lane Closure Planning Tool can use the field-measured capacity in this study as the thresholds for three work types—TC-402: Shoulder closure with cones, TC-40x: Shoulder closure with TBR, and TC-418: Lane closure.

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