Effects of Road Construction Intensity and Operations on Rural Freeway Work Zone Capacity

Final Report
November 2014

SWZDI
Smart Work Zone Deployment Initiative

Missouri S&T
University of Science & Technology

Sponsored by
Smart Work Zone Deployment Initiative
(TPF-5(081))
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(InTrans Project 06-277)

About SWZDI

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

Capacity is affected by construction type and its intensity on adjacent open traffic lanes. The effect on capacity is a function of vehicles moving in and out of the closed lanes of the work zone, and the presence of heavy construction vehicles. Construction activity and its intensity, however, are not commonly considered in estimating capacity of a highway lane. The main purpose of this project was to attempt to quantify the effects of construction type and intensity (e.g. maintenance, rehabilitation, reconstruction, and milling) on work zone capacity. The objective of this project is to quantify the effects of construction type and its intensity on work zone capacity and to develop guidelines for MoDOT to estimate the specific operation type and intensity that will improve the traffic flow by reducing the traffic flow and queue length commonly associated with work zones. Despite the effort put into field data collection, the data collected did not show a full speed-flow chart therefore extracting a reliable capacity value was difficult. A statistical comparison between the capacity values found in this study using either methodologies indicates that there is an effect of construction activity on the values work zone capacity. It was found that the heavy construction activity reduces the capacity. It is very beneficial to conduct similar studies on the capacity of work zone with different lane closure barriers, which is also directly related to the type of work zone being short-term or long-term work zones. Also, the effect of different geometric and environmental characteristics of the roadway should be considered in future studies.

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EFFECTS OF ROAD CONSTRUCTION INTENSITY AND OPERATIONS ON RURAL FREEWAY WORK ZONE CAPACITY

Final Report
November 2014

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- Iowa (lead state)
- Kansas
- Missouri
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INTRODUCTION

Capacity has been defined and measured by many researchers. Capacity is dependent on many variables that can be broadly categorized as traffic, geometric and traffic control conditions. Capacity is also affected by construction type and its intensity on adjacent open traffic lanes. The effect on capacity is a function of vehicles moving in and out of the closed lanes of the work zone, and the presence of heavy construction vehicles. Construction activity and its intensity, however, are not commonly considered in estimating capacity of a highway lane.

The main purpose of this project was to attempt to quantify the effects of construction type and intensity (e.g. maintenance, rehabilitation, reconstruction, and milling) on work zone capacity. The intensity of construction activity can be defined as the frequency of work zone vehicles ingress/egress from the open traffic lane, the presence of heavy construction vehicles like milling machines, etc., number of workers present at the work site. The objective of this project is to quantify the effects of construction type and its intensity on work zone capacity and to develop guidelines for MoDOT to estimate the specific operation type and intensity that will improve the traffic flow by reducing the traffic flow and queue length commonly associated with work zones. The results of the study can be used to help the State Departments of Transportation in improving customer satisfaction.

Project Objectives and Tasks

The objective of this research project is to study the effects of construction type and intensity on work zone capacity. Field data (volume and speed of vehicles) will be collected to analyze the capacity of different work zones and to find how various construction activities and their intensities affect work zone capacity. The objectives are:

1. Collect and analyze field data (volume and speed)
2. Quantify the effects of:
    a. Construction vehicle ingress/egress from the open traffic lane(s)
    b. Different types of construction operations adjacent to open lane(s)
    c. Presence of workers and heavy equipment operation next to open traffic lane(s)
3. Propose recommendations to minimize the effects of the above factors on the work zone capacity, and increase the throughput of the open lane.

The project involves the following tasks. First, existing information on how to account for construction activity and methodology used in estimating capacity will be collected from state highway agencies in the USA and a detailed review of the literature will be performed. An experiment will be designed and field data will be collected from work zones (duration of project and budget permitting) on rural interstate highways with construction projects. The traffic volume and speed data will be analyzed using statistical analysis to quantify the effects of different variables including construction type and intensity on capacity. Finally, recommendations to minimize the undesirable effects of the above factors will be proposed and a report will be prepared which will include the details of data collection, the methodology used for estimating capacity, the results, interpretations, conclusions and recommendations. If existing

methods are not found to provide realistic results, a new methodology will be proposed to estimate work zone capacity affected by various types of construction activities. To accomplish the objectives of this research, the following tasks will be carried out:

Task 1 – Review of the Research and Practice Literature (including DOT survey),
Task 2 – Collect and Analyze Field Data, and
Task 3 – Preparation of final report and develop strategies to reduce the effects of construction type and intensity of work zone capacity.

This project was conducted as a part of the Smart Work Zone Deployment Initiative pooled-fund study, as administered by the Iowa State University, Institute for Transportation.

LITERATURE REVIEW

Traffic stream models that are commonly used to estimate the highway capacity explain the relationship between traffic flow characteristics such as flow rate, speed, and density. Currently, several traffic stream models are being practiced. The earliest models assumed a single-regime relationship over both uncongested and congested states of flow conditions like Greenshields model (Greenshields et al., 1935). Later, other recognized single-regime models are those developed by Greenberg (1959), Underwood (1961) and Drake et al. (1967). May (1990) applied the aforementioned models to freeway data set and found them unable to replicate the near capacity data with reasonable accuracy.

(Edie, 1961) proposed the first multi-regime model in which he used Underwood's model for the free-flow condition and Greenberg's model for the congested-flow condition. Later on, (Drake et al., 1967) proposed three new model formulations: a two-regime model, a three-regime model, and a modified Greenberg model. Other multi-regime models also have been proposed by other researchers. The key point about a multi-regime model is that it provides a higher degree of freedom in calibration which results in a better fit to different traffic flow conditions and therefore, is considered an improved model over single-regime models. However, calibration of the multi-regime models usually involves engineering judgments to determine the break-points between the regimes and the capacity occur at one of the break-points in the multi-regime models. Rouphail and Tiwari (1985) used numerical values for various work activities and names the sum of those values as *activity index (AI)*. They studied the effect of work activity on vehicles' speed by measuring the activity indices for different 5-min intervals together with observing the speed-flow conditions. Persaud and Hurdle (1991) indicated that mean queue discharge rate is the most suitable suggestion for freeway capacity since the queue discharge rate determined the flow condition during congestion. Krammes and Lopez (1994) and Al-Kaisy and Hall (2003) computed work zone capacity as the mean queue discharge flow rate averaged over consecutive hour volumes collected from a site.

Krammes and Lopez (1994) studied the effect of heavy vehicles, construction intensity, and presence of ramps on work zones capacity by adjusting the base capacity value of 1600 pcphpl (passenger cap per hour per lane). The capacity of work zones fell within ±10% (160 pcphpl) of the base capacity -Equation (1)-, which eventually became part of HCM (2000). For short-term work zones, they developed the following capacity estimation model by using data collected at 33 sites in Texas between 1987 and 1991 for three-to-one, two-to-one, four-to-two, and five-to-three lane configurations.

$$C = (1600\ pcphpl + I - R) \times H \times N \tag{1}$$

Where,

C = estimated work zone capacity,

I = adjustment for type and intensity of the work activity, range (-160 to +160) depending on type, intensity, and location of work activity,

R = minimum average entrance-ramp volume during lane closure period for ramps located within lane reduction taper or within 152 m (500 ft.) downstream of beginning of full

lane closure, or one-half of capacity of one lane open through work zone (i.e. $1600\,pcphpl/2N$),

H = heavy vehicle adjustment factor (vehicle per passenger car), and

N = number of open lanes through work zone.

Dixon et al. (1996) defined and determined short-term capacity of freeway work zones for rural and urban freeways by taking into account work time (night or day), intensity of work activity (heavy, moderate, or light), and work zone configuration. They suggested a capacity of 1,200 vphpl (vehicle per hour per lane) for the rural work zone and 1,500 vphpl for the urban work zone. They computed the 95th percentile flow from all 5-min flow observations after the beginning of queue. This flow value was then converted to equivalent hourly rate and reported as the work zone capacity. They also defined capacity as the 95th percentile flow value of 5-min volume observations within-a-queue. They also compared the capacity at transition and at activity area of the work zone. Jiang (1999) defined work zone capacity as the flow before a sharp drop in speed followed by low speeds and fluctuating traffic flows. Such a drop can be determined through the time-speed and time-flow graphs. Work intensity were classified into three levels of low, medium, and high and determined the capacity of four work zones in the taper and construction activity area; however, he found no statistical difference between the capacity values. Maze et al. (2000) determined the work zone capacity as the average of 10 maximum traffic volumes before and after queuing conditions. Al-Kaisy et al. (2000) developed a generic multiplicative model to estimate capacity in long-term work zones as the queue discharge rate under congested conditions. He measured the average value of capacity on such work zones to be 1943 vphpl:

$$C = C_b \times f_{HV} \times f_d \times f_w \times f_s \times f_r \times f_l \times f_i \tag{2}$$

Where,

C_b = based workzone capacity (2,000 passenger cars per hour per lane),

f_{HV} = adjustment factor for heavy vehicles,

f_d = adjustment factor for driver population,

f_w = adjustment factor for work activity,

f_s = adjustment factor for side of lane closure,

f_r = adjustment factor for rain,

f_l = adjustment factor for light condition, and

f_i = adjustment factor for nonadditive interactive effects.

Kim et al. (2001) developed a multiple regression model that takes into account the number of closed lanes, percentage of heavy vehicles, grade, and work intensity to estimate capacity for short-term freeway work zones:

$$C = 1857 - 168.1NUMCL - 37.0LOCCL - 9.0HV + 92.7LD - 34.3WL - 106.1WI - 2.3WG \times HV \tag{3}$$

Where,

$NUMCL$ = number of closed lanes,

$LOCCL$ = lane closure location (right =1, left =0),
HV = heavy vehicle percentage,
LD = lateral distance,
WL = work zone length,
WI = work intensity, and
WG = work zone grade.

Schnell et al. (2002) computed capacity as the average hourly flow rate during the queuing conditions. Al-Kaisy and Hall (2003) examined the capacities of six reconstruction sites in Ontario, Canada, and then developed a generic multiplicative model for estimating the capacity of long-term work zones. The effect of heavy vehicles, driver population, weather, lane configuration, work intensity, and lighting conditions on capacity was investigated; heavy vehicles and driver population were determined to be the most significant factors affecting work zone capacity. Karim and Adeli (2003) used a neural network-based tool to estimate capacity by considering 11 different parameters affecting the capacity including construction intensity. Sarasua et al. (2004) defined capacity as the maximum flow of the hourly traffic flows computed by the sum of 12 consecutive 5-min flows. A linear regression was then used to model speed by density and the equation was used to find capacity.

Benekohal et al. (2004) presented a step-by-step methodology to develop speed-flow curves and estimates work zone capacity for the two-to-one lane closure configuration by establishing the relationship between capacities and operating speed. They used the data obtained from 11 work zones and formulated the operating speed in a work zone as a function of work intensity, lane width, lateral clearance, and other factors. In other words, they proposed a methodology for estimating operating speed and capacity in work zones by determining speed reduction due to work intensity, lane width and lateral clearance. They defined the capacity as the discharge flow of platoons of vehicles (headway between vehicles less than 4 s or spacing between vehicles less than or equal to 250 ft.). Capacity was calculated as the inverse of average headway of the vehicles in the platoon. Speed-flow curves were generated by fitting the congested part of the data. The HCM procedure was used to fit the uncongested part. Large headways in data set can affect the capacity using either queue discharge flow or maximum flow rate (Benekohal et al., 2004). Since removal of these large gaps from the data improves the estimate for capacity, they decided to determine the platoons of vehicles and remove the headways more than 4 seconds within platoons (based on spacing). To make sure about the continuous demand over specific time periods, they used the 15-min interval for sites with queuing and 5-min interval for sites without queuing.

Ping and Zhu (2006) used CORSIM to derive capacities for short-term freeway work zones under various network configurations. Sarasua et al. (2006) developed a model to estimate the capacities for the two-to-one, three-to-two, and three-to-one lane closure configurations of interstate work zones. In their study, the base capacity depended on the lane closure configuration, and the passenger car equivalent value varied with the traffic speed. They proposed two methods to estimate capacities at short-term work zones in South Carolina:

(i) a curve fitting method to establish speed-density-flow relationship in work zones and derive capacity as the maximum flow from the speed-flow curve;

(ii) an alternative method that considered the 85th percentile volume as capacity.

Chitturi et al. (2008) proposed a methodology for computing delay from the speed-flow curves for work zones. They estimated capacity from the field data:

(i) for work zones with queuing, the highest 15-min departure volume was identified and the average headway for that time interval was determined and reversed to estimate the service capacity;

(ii) for work zones without queuing, the 5-min interval was used instead of the 15-min interval.

Heaslip et al. (2009) proposed analytical models and procedures for estimating the capacity of long-term work zones by considering geometric, traffic, and work zone factors. They trained the analytical models with simulation data from CORSIM and validated with field data.

$$C = f_l \times f_d \times f_r \times (C_{unadj} - V_R) \tag{4}$$

Where,

f_l = adjustment factor for light condition,
f_d = adjustment factor for driver population,
f_r = adjustment factor for rain,
V_R = ramp volume, and
C_{unadj} = the unadjusted capacity (vphpl) that can be estimated with the regression models developed for three lane closure configurations shown in Figure 1.

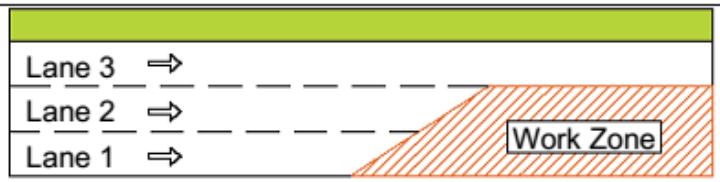
Lane Closure Type	CAPACITY MODEL FOR OPERATIONAL PROCEDURE
2 TO 1	 $R^2 = 0.915$ $C_{unadj}^{2\text{-}to\text{-}1} = 1855 - 693 * SignDist + 191 * f_{HV\text{-}F} - 12.3 * Rubber\% - 467 * DistrLan1(6,7) + 829 * DistrLan1(6,7) * SignDist + 7.43 * SpeedLan1(6,7)_{adj} * SignDist$
3 TO 2	 $R^2 = 0.932$ $C_{unadj}^{3\text{-}to\text{-}2} = 917 + 461 * SignDist + 854 * f_{HV\text{-}F} - 20.4 * Rubber\% - 611 * DistrLan1(6,7) * SignDist - 4.03 * SpeedLan1(5,6)_{adj} * SignDist$
3 TO 1	 $R^2 = 0.895$ $C_{unadj}^{3\text{-}to\text{-}1} = 1177 + 550 * f_{HV\text{-}F} - 14.5 * Rubber\% + 157 * DistrLan3(6,7)$
ALL	$C_{adj} = f_l * f_d * f_r * (C_{unadj} - v_R)$

Figure 1. Unadjusted capacity models for different work zone configurations (Heaslip et al., 2009)

The speed-flow curves suggested by HCM (2010) have been modified over time since 1965 as extensive sets of data became available. Roess (2011a) has conducted a review of the historical development of speed-flow curves in HCM (2010). The regimes in speed-flow curves of the capacity analysis procedure for basic freeway segments presented in HCM (2010) are (1) the *free-flow* regime in which speed is maintained equal to the free-flow speed (FFS), and (2) the *transition* regime in which speed is reduced with increasing flow until capacity (maximum flow) is reached. The capacity values found from this procedure were also proposed by the Highway Capacity and Quality of Service Committee (HCQSC). The HCM (2010) is not concerned with the congested regime in the speed-flow curve.

Xing et al. (2010) analyzed the work zone capacities of expressways in Japan. They used two definitions of capacity:

(1) breakdown flow or the 15-min flow rate immediately before the 5-min space mean speed decreased below 25 mph at a point immediately upstream of a bottleneck, and
(2) queue discharge flow or the average flow rate discharged during the congested conditions at a bottleneck.

Nikolic et al. (2010) used three methods to estimate work zone capacity:

(i) direct estimation of capacity by identifying the maximum 5-min flows during queuing conditions,
(ii) estimation using time headways for different vehicle type combinations and proportions, and
(iii) estimation from the VISSIM microscopic simulation model. The primary focus of most studies was to develop a model that could adequately estimate work zone capacities without requiring the collection of actual flows. Each study assumed a certain definition of capacity in estimating its model.

Pringle et al. (2010) used 5-minute flow observations to evaluated the capacity of three-to-one lane work zones and the effects of the percentage of heavy vehicles on Ontario area highways with consideration of queues present in the highway. They have also reviewed previous studies and identified the factors that might affect the work zone capacity:

- Percentage of heavy vehicles
- Grade
- Configuration of work zone:
  - Lane width
  - Shoulder width
  - Taper length and angle
  - Entry and exit ramps upstream of work zone
- Construction intensity
- Weather, lighting and road condition
- Driver population

They found that the general relationship showed that capacity tends to decrease as heavy vehicle percentage increases (Figure 2). The maximum capacity values estimated was about 1200 vph which is much less than the 1750-1800 vph value of capacity normally used.

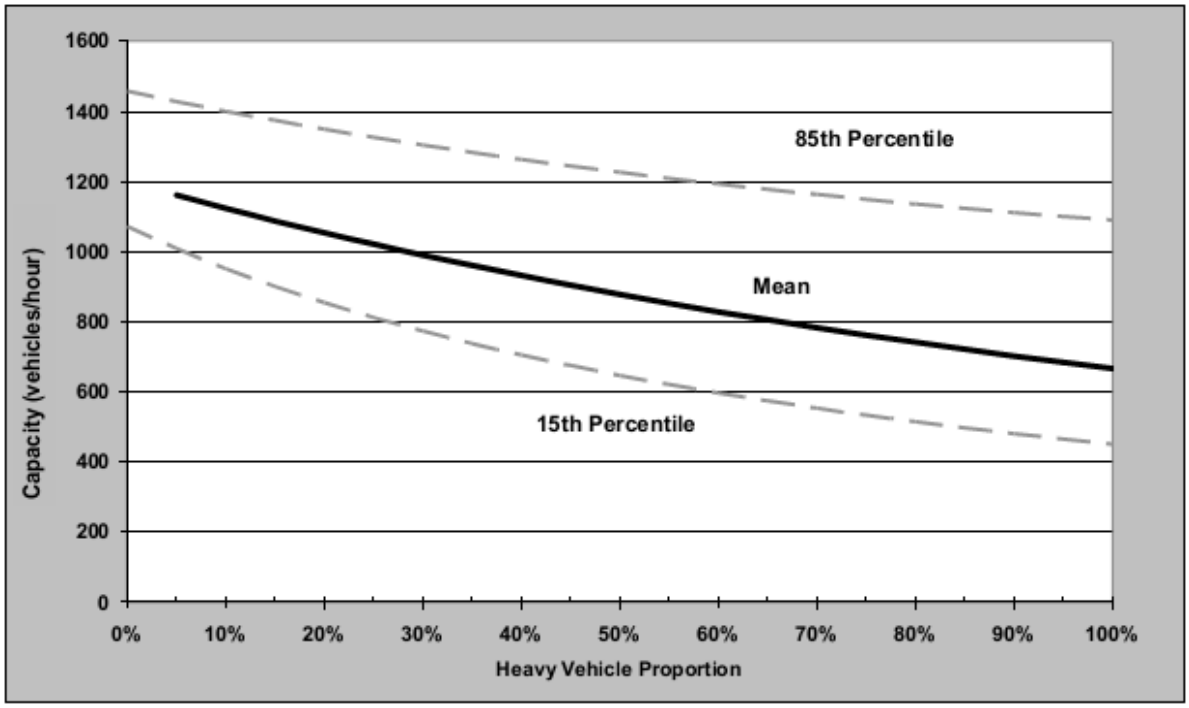


Figure 2. Variation in capacity versus heavy vehicle percentage (Pringle et al., 2010)

Avrenli et al. (2011) examined the speed-flow relationship of a selected work zone with no lane closure and presented a step-by-step procedure to develop the work zone speed-flow curve as a three-regime model: free flow, transition, and congestion regimes. They defined the transition regime as the condition of flow between 800 pcphpl and the maximum flow (work zone capacity) and fit a nonlinear regression model to the data in the transition regime to determine the speed-flow relationship. The 800 pcphpl chosen based on the scattered data which is different from the HCM's suggestion of 1600 pcphpl for the upper bound of the free flow regime. They also argue that the work zone capacity should be lower than the 2300 pcphpl value suggested by HCM due to the interactions of the vehicles. They found the capacity value of the work zone to be 1900 pcphpl. This value had to be compared with the maximum sustained 15-min flow rate suggested by HCM 2000.

Edara et al. (2012) studied the work zone capacity using field data from four short-term work zones in Missouri. They investigated the extent of the effects of definition on the value of capacity. They determined the capacity value using three different definitions of capacity: (1) maximum sustained flow, (2) rescaled cumulative flow curves (used for the first time in this area), and (3) 85th percentile flow. The average capacity values were found to be 1149, 1267, and 1301 vehicle per hour per lane (vphpl) determined by QDF, 85th percentile flow, and 15-min sustained flow methods, respectively. The speeds of vehicles approaching the work zone were captured using three methods: (1) a radar speed gun, (2) speeds derived from video processing, and (3) speeds derived from virtual speed traps. For the accuracy purposes they used the virtual speed traps for the analysis and the 5-minute radar speed were used for calibrating speeds. The maximum sustained flow rate could have occurred before or after the formation of queues (pre-queue flow and queue discharge flow) at freeway bottlenecks. Moving time windows of 15-min,

10-min, and 5-min were obtained by grouping 1-min traffic counts over the size of the respective time window. The maximum sustained flow rate was then obtained by aggregating counts within a group. The truck percentages observed at each site were used in conjunction with passenger car equivalents (PCE) to convert capacities to equivalent passenger cars per hour per lane (pcphpl). For max 15-min flow rate, they used a moving window to find the max flow. Also truck percentage was used to convert the flow to pcphpl. For the 85th percentile flow, 5-min flow values were used.

Edara et al. (2012) found that the queue discharge flow (QDF) is the most conservative estimate of capacity. Instead of developing a new technique for estimating capacity, Edara et al., (2012) tried to compare the existing methods to evaluate the effect of the various definition of work zone capacity on the values obtained by each method. This way the definition-related variation in the value of capacity obtained/predicted can be determined. They also did a survey of the US DOTs on capacity definition and measurement, and factor affecting capacity in which, only 30% said work zone intensity affects the capacity. Major factors were mentioned to be the work zone configuration (number of open/closed lanes) (74%), work zone length (74%), lane width (70%), and heavy vehicles (65%). Congested time was defined when speeds are less than the threshold speed lasting more than 5 minutes. QDF exists upstream of the work zone whenever there is congestion upstream of the work zone but not inside the work zone. They have used the methodology of Banks (2009) to find the pre-queue flow (PQF). To generate the cumulative flow curves the data from the camera looking upstream of taper were used. This field-of-view was used to capture the onset of the queue at the taper area. The beginning of the taper is where the capacity is measured.

Dudek and Richards (1982) computed capacity as the maximum full hour traffic count observed when queues existed upstream of the lane closure. They recommended that a value of 1,600 vphpl be used as the base capacity for short-term work zones, regardless of lane closure configurations.

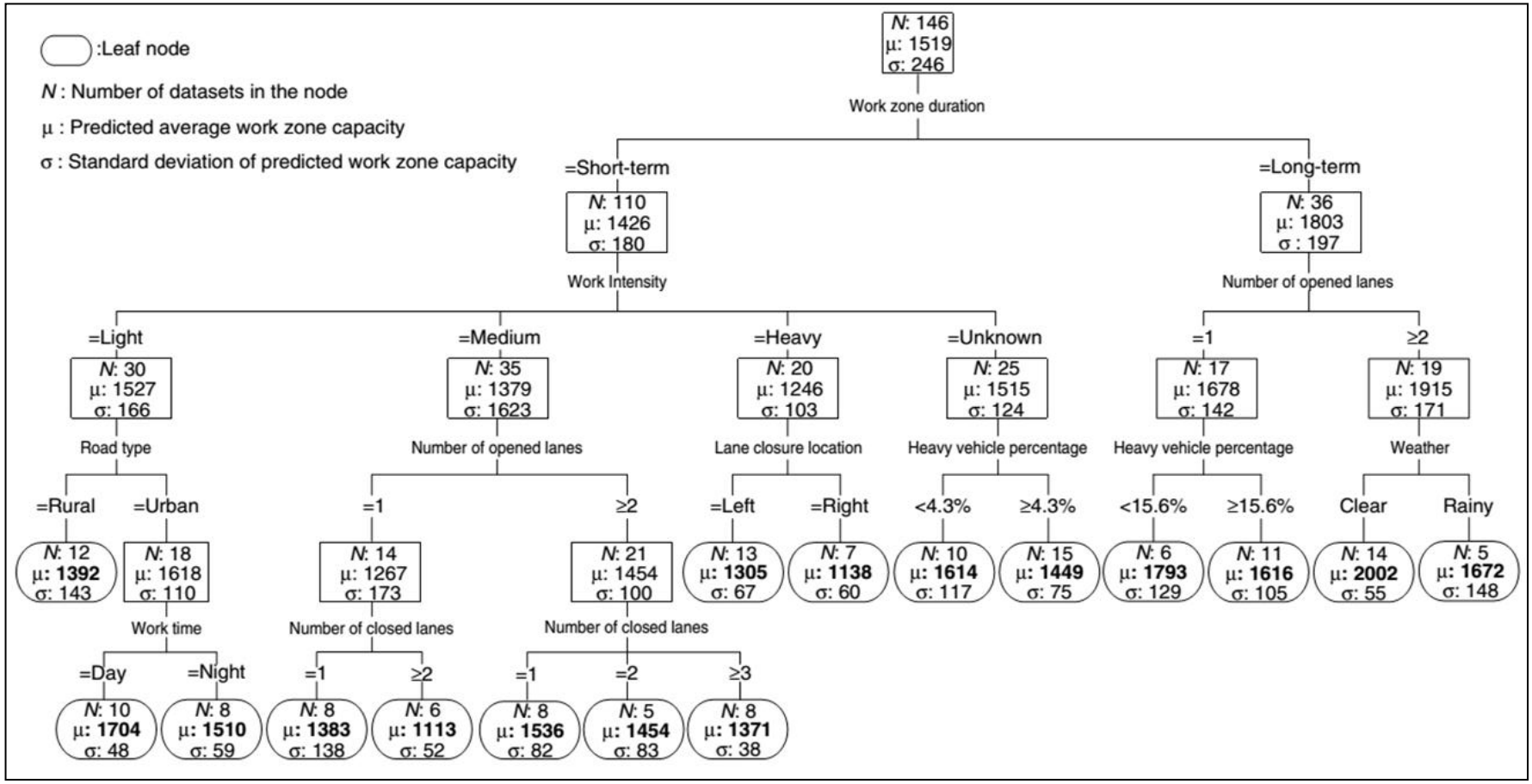


Figure 3. Optimal decision tree for work zone capacity estimation (Weng and Meng, 2011)

Weng and Meng (2011) presented a decision tree based model for short-term and long-term work zones (Figure 3); However, Maclin and Opitz (2011) found this decision tree to be unstable because the tree structure and estimation accuracy could be altered significantly by a slight change in the training and checking samples. Weng and Meng (2012) suggested an ensemble tree approach for short- and long-term work zones. The ensemble tree approach (presented in Figure 4) is an effective method for reducing instability and improving estimation accuracy because it combines all individual decision trees based on training and checking data into one mode. They also presented several factors affecting work zone capacity in their study, including work zone duration, percentage of heavy vehicles, work time, work intensity, weather, configuration of lane closures, lane width, and road grade (see Figure 5). Although various models and guidelines have been proposed for estimating work zone capacity, none incorporate all important factors, which could lead to low accuracy of estimates. They used bootstrap aggregation method in an ensemble tree approach to estimate work zone capacity. They incorporated 182 data sets of previous work zone projects from 14 states and cities in a case study to build and evaluate the ensemble tree. A comparison with the 2010 Highway Capacity Manual indicates that the ensemble tree can provide more accurate estimates of work zone capacity and is a good alternative for estimating work zone capacity, especially for inexperienced users. The work zone capacity from the ensemble tree comprising n individual trees is estimated by:

$$T = \sum_{i=1}^{n} w_i T_i \ = \frac{1}{n} \sum_{i=1}^{n} T_i \tag{5}$$

Where,

T_i = estimated work zone capacity from the ith decision tree, and

$w_i = 1/n,\ i\ = 1, \ldots, n\ - 1$ is the weight value of T_i.

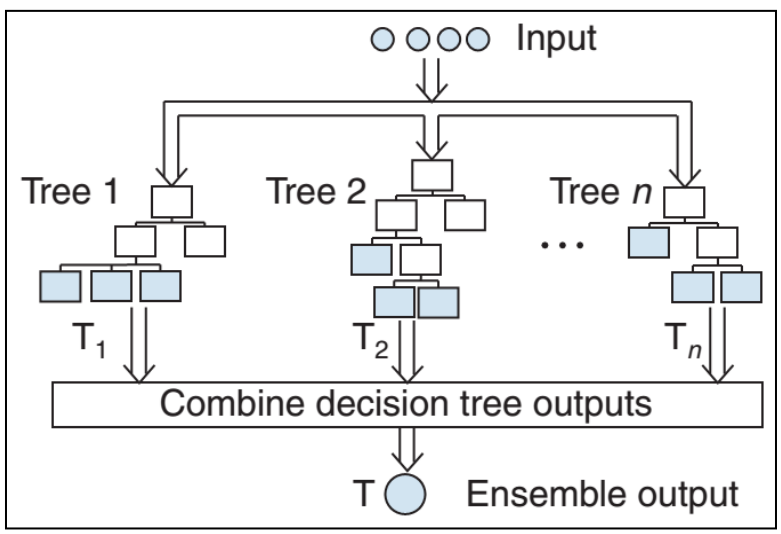


Figure 4. Schematic framework of the ensemble tree model (Weng and Meng, 2012)

Weng and Meng (2012) divided work intensity into three classes: (a) light, for barrier or guardrail installation or repair and pavement repair; (b) medium, for resurfacing or asphalt removal and striping removal; and (c) heavy, for pavement marking and bridge repair. Work

zone capacity on urban freeways is usually greater than that of rural freeways. Long-term work zones usually have larger capacities than short-term work zones because commuters and frequent travelers become familiar with the configuration of the long-term work zone. Enforcement of a lower speed limit improves safety and decreases work zone capacity. Time of day is also important because night construction or maintenance can decrease the capacity of a work zone because of reduced traveler attention.

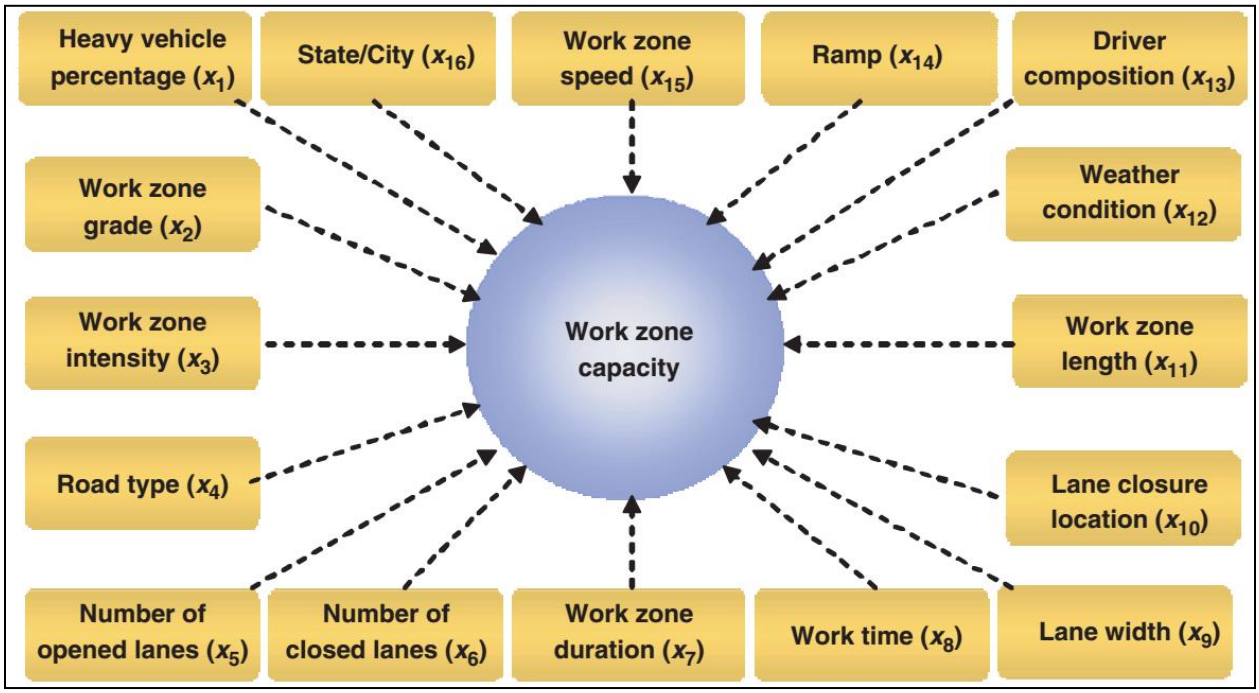


Figure 5. Major factors affecting work zone capacity (Weng and Meng, 2012)

Most models of work zone capacity apply only to a specific type of work zone. Models are applicable only to either long-term work zones or short-term work zones. Capacity estimation models for short-term work zones may greatly underestimate the capacity of long-term work zones, and models for long-term work zones may overestimate the capacity of short-term work zones. Because many factors can affect capacity, it is inappropriate to use a simple model to estimate freeway work zone capacity. For long-term work zones, the HCM (2010) provides an average capacity of 1,750 vphpl for two-to-one lane closure and 1,860 vphpl for three-to-two lane closure work zones. HCM (2010) assumes that the maximum flow rate can be reached at the end of the work zone taper when a queue is formed upstream of the construction area. Chapter 25 of HCM presents a functional relationship (equation 6) that presents the speed of drivers as a function of free-flow speed, flow and the capacity of the road segment. The relationship ensures a constant ideal density of 45 pcpmpl at capacity as indicated in Chapter 11 of HCM-Basic Freeway Segments.

$$S = FFS + \left[a - e^{\ln\left(FFS+1-\frac{C\times CAF}{45}\right)\frac{v_p}{C\times CAF}}\right] \tag{6}$$

Where,

S = segment speed (mph),
FFS = segment free-flow speed (mph),
C = original segment capacity (pcphpl),
CAF = capacity adjustment factor
v_p = segment flow rate (pcphpl)

It can be seen in equation 6 that as $v_p$approaches zero, S approaches to FFS, and as v_p approaches $C \times CAF$, S approaches the speed at capacity. Figure 6 shows the speed-flow graphs for various levels of capacity adjustment factors.

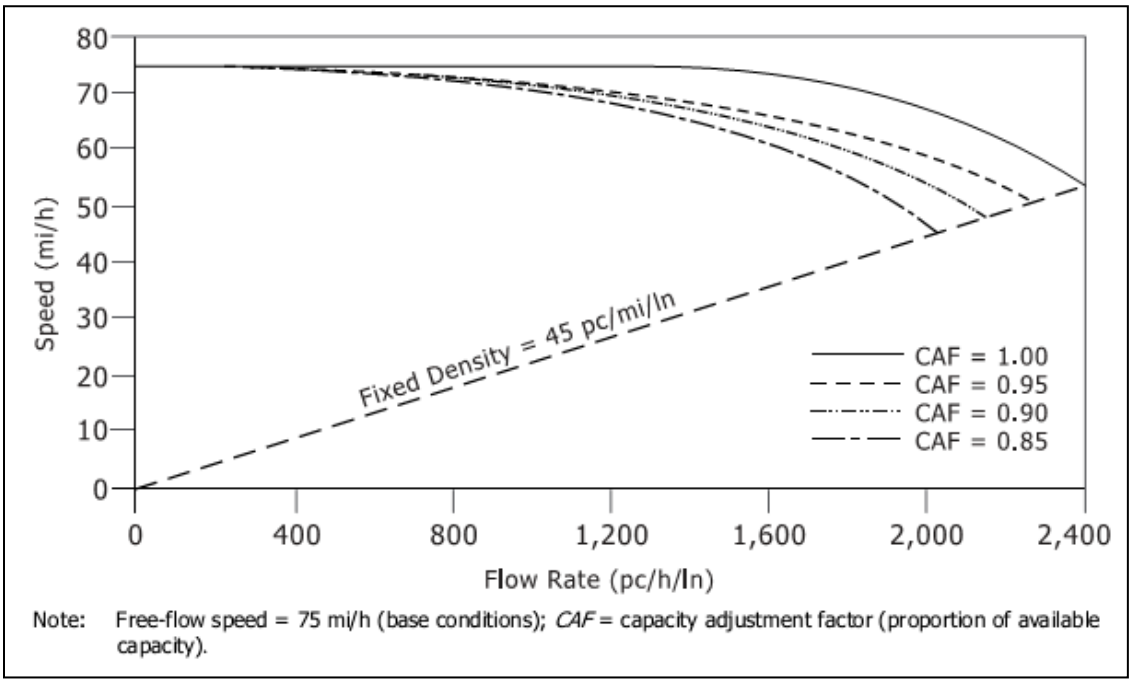


Figure 6. Speed-flow graphs for various levels of capacity adjustment factors (HCM, 2010)

DATA COLLECTION

Data Types

The data used in the study consisted of several types of documentations:

- The video data recorded from the field were in the form of digital with the format of .AVCHD (Advanced Video Coding High Definition) and QuickTime Videos.
- Recording and measurements from the field were in the form of writing in the note books.
- The sensor data acquired from the ASTI sensors were in the form of digital format stored into .CSV files that were opened in EXCEL spreadsheets.
- The work zone diaries received from the work zone contractors were in the digital format of .PDF files.

Description of Data Collected

The data used in this project is categorized in two classes: 1) traffic flow characteristics, and 2) work zone characteristics. The traffic flow data includes the traffic volume and speed during the implementation of the work zone. Work zone data contains the properties of the work zone such as location, configuration, and the personnel data.

Despite the effort put into field data collection, the data collected did not show a full speed-flow chart therefore extracting a reliable capacity value was not possible. Additionally, the selected work zones for this study had a concrete barrier, median or space between the construction zone and the moving traffic. In some instances these conditions where combined and the construction activities were too far from the traffic to result in any measurable impact on work zone traffic capacity. It is suggested that in future projects of this nature, construction zones are identified by the DOT with enough additional time to be reviewed by investigators prior to data collection.

Field Data Collection at Selected Construction Sites

The research team started collecting the traffic data by visiting the work zone at various occasions to video the flow. The video data capturing was carried out from a higher standpoint of view such as an overpass bridge and filming in the direction of passing vehicles. The camera was fixed on a tripod, on the side of the bridge that was not visible to the drivers and as they leave the shooting point their movement is captured in the video. Figure 7 illustrates the method used to film the traffic. The reason the video was shot from an overpass and not from the side of the roadway is because the processing software results in higher accuracy if the video has an overhead view.

For validation purposes, a speed gun[1] was also used at specific times known to the recording person to capture the exact speed of vehicles. This task could be performed on specific vehicles that are distinguishable later in the video with taking notes on the vehicles characteristics and the recording time. The speed gun records the speed of the vehicle and stores it in its digital memory but since, the research approach for this project needs specific vehicles' speed, each recorded speed was written down with the information related to the vehicle. This helps to find and match the vehicles' speed extracted from the video with their real speed to validate the accuracy of the software outputs.

Figure 7. Video camera captures traffic directly above a bridge overpass

During these visits the construction activity was manually recorded in a notebook for the time of video capturing. This data was later used along with the capacity values to evaluate the effect of different construction activity/intensity on the capacity values. Table 1 presents the properties of each one of the work zone sites considered for video data collection. More details of each of the sites are presented in the next sections.

Table 1. The work zone sites considered for field data collection

Site	Road	Mile Marker	Dir.	Date	Day	Time	Duration	WZ activity
1) Rolla	US 63	at Lowe's	SB	Jul. 13	Fri.	1:55-5:40 pm	225 min	Asphalt paving
2) Eureka	I-44	MM 268	WB	Aug. 13	Mon.	1:40-5:15 pm	215 min	No activity
3) Eureka	I-44	MM 268	WB	Aug. 17	Fri.	2:40-5:35 pm	175 min	No activity
4) Eureka	I-44	MM 268	WB	Aug. 24	Fri.	6:40-10:40 am	240 min	Installing dowel bars
5) Eureka	I-44	MM 268	EB	Aug. 24	Fri.	6:40-10:40 am	240 min	Installing dowel bars*
6) Eureka	I-44	MM 271	EB	Sep. 6	Thu.	8:00-12:00 am	240 min	Excavation/surveying

* This direction separated from the activity by two more lanes of traffic (WB) and a concrete barrier in between.

[1] A speed gun, also called radar gun is a device used (usually by law-enforcement) to measure the speed of moving objects (e.g., vehicles).

Also several measurements were also conducted for calibration purposes. The calibration data included the length of the open lanes (the calibration element across the roadway) and the length between two to three markers along the open lane from where the video was being shot (the calibration element along the roadway). To point out the markers along the open lane, traffic cones and spray painting was used to be clearly visible in the video.

The traffic flow video was then imported into a video image processing software Autoscope (2006) and the measured geometric properties of the view were used to calibrated the snapshot image of the video on the software main screen. After the calibration process was completed, several different types of virtual detectors such as *presence detectors* and *speed detectors* were positioned on the calibrated view. All the detectors were then linked to a virtual polling station where the detection outputs could be stored. The presence detectors were used to measure the traffic volume and the speed detectors to measure the speed of the vehicles.

The speed detectors algorithm works in a simple way. It detects the presence of a vehicle at the beginning of the detector and then at the end of the detector and records their times and calculates the time difference. The length of detector (distance between the beginning and end of detector) is divided by the time difference and calculates the speed. This indicates that the extracted speed is in fact the *space mean speed* which is desirable for the roadway capacity studies.

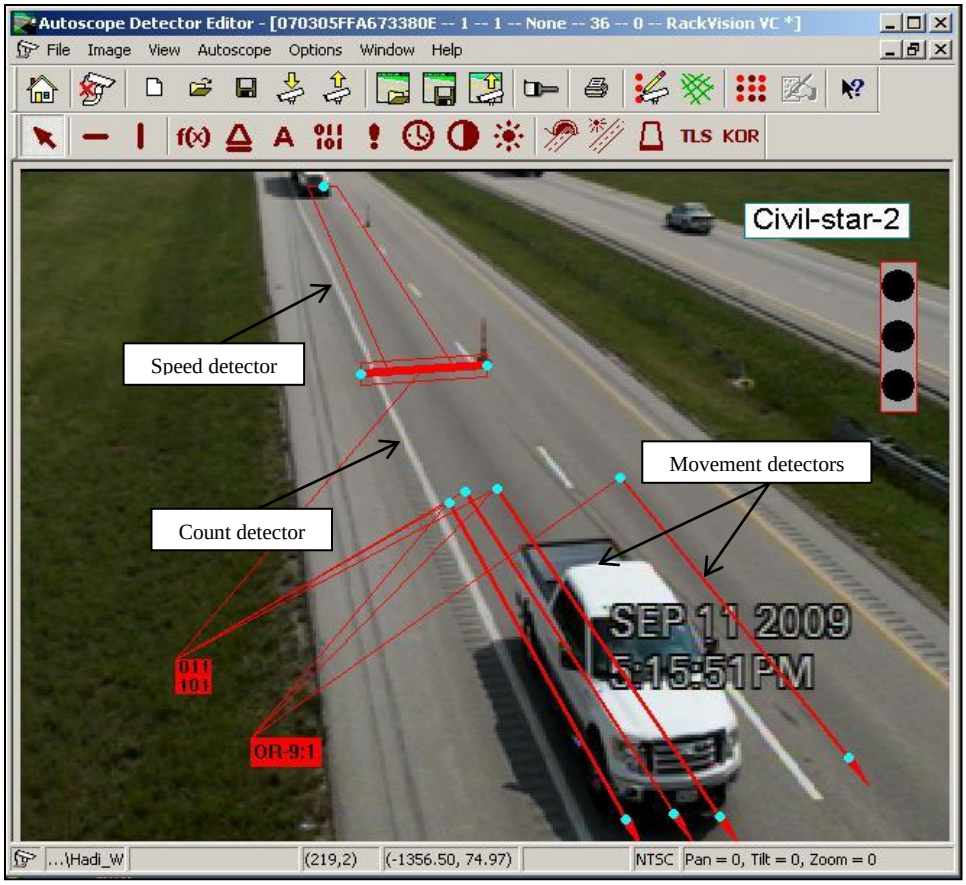


Figure 8. Screenshot of the Autoscope video image processing software (Autoscope, 2006)

The software is run to capture the speed of the specific vehicles whose speeds were previously recorded during the field trips using the speed guns. The on-site recorded speed values is compared with the corresponding speed values extracted by the software and if there was significant differences (more than ±2 mph) between them, the calibration of the view was adjusted. This process was repeated until the extracted speed values could be validated with the speed gun values with 95% level of confidence. The validated view of the captured location within the work zone was then used to extract all the traffic flow characteristics into an Excel file for the complete video.

Site 1) Rolla Work Zone at Lowe's – July 13 (Friday)

Figure 9 shows the location of data collection at the Rolla work zone site. Construction activity included adding a layer of asphalt (paving construction). Since there was no overpass or bridge at the area of work zone to ease the process of filming, a portable overhead surveillance trailer (POST) trailer was used and the camera was set and filmed the southbound direction of the Route 63 (

Figure 9). The view calibration lines drawn on the pavement in yellow are visible in the figure as well. An example of a POST is shown in Figure 10.

Figure 9. Location of the data collection at Rolla site

Figure 10. Video camera mounted on post

The work zone crew was stopping each direction sequentially for 10-15 minutes (depending on the traffic) and stopping traffic in each direction to pass through the open lane in the work zone. The southbound left lane was being constructed. The trailer was positioned on the southbound shoulder. Every 10-15 minutes that the traffic was released upstream of the work zone, to travel through the open lane a queue discharge flow (QDF) was observed and filmed by the trailer video camera. At times there was no construction and for about 1-1.5 hours there was construction activity going on right in the filming area with the queue discharge flow. The queue was not generated as a result of the construction but the traffic being stopped by the work zone crew. During the time of the construction the activity properties was recorded manually on a paper including the exact time and the number of equipment pieces and workers, etc.

Site 2) Eureka Work Zone WB – August 13 (Monday) mm 268

For this location video data was collected (from top of the bridge located at mileage 263) in the westbound direction toward Rolla between 1:40- 5:15 pm (3 hours and 35 min).

Figure 11 presents the photos of the data collection location. There was no activity at the time of video collection. There have been excavations and the next phase of the construction would have probably been the construction of the base layer of the pavement.

Figure 11. Location of the data collection at Eureka site westbound

According to the construction crew, the westbound direction had the heaviest traffic between 2:30 to 7:00 pm. The video data collection was set up at 1:00 pm. When the traffic was becoming heavy during the afternoon rush hour, one more lane was opened on the right side of the traffic in westbound in an effort to minimize congestion.

Site 3) Eureka Work Zone WB - August 17 (Friday) mm 268

On this trip to the Eureka site again video data was collected in the westbound direction toward Rolla between 2:40 – 5:35 pm (2 hours and 55 min). There was no activity at the time of video collection. There was no construction going on. This was the same location as the one for August 13th and was chosen to setup up the camera as the calibration measurements were already available. The data from this trip was combined with the data from the August 13 as there was no difference between them. The combined data was stored as one data set.

Site 4) Eureka Work Zone WB- August 24 (Friday) mm 268

The same location as the previous two attempts was chosen for setting up the camera as the calibration measurements (and configurations) were already available. The difference this time was that there was construction activity, which provided and opportunity to compare the results for with/without construction. Video data was collected in the westbound direction toward Rolla between 6:40 – 10:40 am (4 hours).

Figure 12 presents some pictures of the data collection location. The construction crew was installing the steel reinforcing bars on the base of the pavement. The activity progress in terms of time and location was recorded in a notebook.

Figure 12. Eureka site westbound on August 24

Site 5) Eureka Work Zone EB- August 24 (Friday) mm 268

Figure 13 presents some photos of the data collection location. The only difference in this dataset with the dataset from trip 4 (same trip as trip 5) is that the video was taken from the eastbound direction. The open lane in this direction is farther away from the location of the construction activity. The construction activity had no effect on eastbound traffic, because there are two lanes of traffic flow on the westbound direction and a concrete barrier between the construction activity area and the eastbound direction. Filming started at 6:40 and continued to 10:40 am.

Figure 13. Eureka site eastbound on August 24

Site 6) Eureka Work Zone EB- September 6 (Thursday) mm 271

This trip was also made to the Eureka area but the work zone was located on the eastbound direction. One right lane was closed and the construction activity expanded about 1000 ft., where there were excavators, bulldozers, trucks (dumpers) and loaders were observed. Video data was collected in the eastbound direction toward Saint Louis between 8:00am – 12:00pm (4 hours).

Figure 14 presents the pictures of the data collection location. The video data collection was conducted using the POST equipment. The work zone activity included a surveyor at the job site using a standalone GPS, excavation and hauling the material. Heavy traffic observed in the morning rush hour but no congestion observed. Concrete barriers separated the construction work activity area from the open lane during this entire period.

Figure 14. Eureka site eastbound on September 6 at mile marker 271

ASTI Data from Permanent Sensors

Another set of data was obtained from the permanent sensors placed at fixed locations along I-44 in Missouri. One of these permanent sensors was located within the construction activity area of the Eureka work zone of interest. Advanced Sensor Technologies, Inc. (ASTI) implemented these sensors for the MoDOT for the purpose of traffic management and control. The lane-by-lane data could be polled and extracted from their website with permission. The advantage this data was that sensors record traffic data non-stop for the entire time the work zone was in place, capturing all the different traffic conditions from free-flow conditions to congestion. This provides the opportunity to determine the capacity of the highway during construction activity by the use of congested time data.

The data for each lane and each direction recorded by the sensors were used to draw the time-speed and time-flow to determine the breakdown flow time and incorporate it in separating the free-flow regime from the congested regime in speed-flow graphs. Speed-flow graphs were generated for the different days, lanes, and directions and using the different definitions and methodologies, capacity values were found.

In order to compare the capacity values for different days where the construction intensity values are different, a measure of the construction activity was also needed. Since the research team was not present at the work zone location during all times, the ASTI sensor data was used. To make the construction intensity data available for analysis, the work zone contractors were contacted to obtain the work zone diary that records for the various activities taking place during the work time. A work zone diary was received that included recorded information about the construction activity, personnel, equipment, etc. and was sorted and classified into a spreadsheet in an easy-to-follow format. This work zone data was then used in combination with the traffic data to understand the effects of construction intensity on the work zone capacity. The following report section explains the work zone diary data.

After scanning the work zone diary data, and determining specific days with low, medium and high construction intensity from the number of personnel present at work, the traffic data was extracted for those specific days of interest from the ASTI website. The data was aggregated and recorded for every one minute and some of the minute's data were missing from the data set (e.g. minute 01:11-00:12 am). Data was then aggregated for 15-minute intervals (HCM, 2010) for the capacity analysis and filtered by westbound and eastbound and five lanes, three located in westbound and two located in the eastbound. Table 2 shows the days for which the sensor data was extracted initially. For each sensor during each day a set of data in a comma separated values (CSV) format was extracted.

Table 2. The initial extracted data sets at mile marker 267.4 along I-44

1. September 5, 2012
2. September 6, 2012
3. September 11, 2012
4. September 12, 2012
5. September 13, 2012
6. September 18, 2012
7. September 19, 2012
8. September 20, 2012
9. September 25, 2012
10. September 26, 2012
11. September 27, 2012
12. August 21, 2012
13. August 22, 2012
14. August 23, 2012
15. August 28, 2012
16. August 29, 2012
17. August 30, 2012

Table 3 shows an example of the CSV data file extracted from ASTI. The data set included the sensor name, mileage location, lane number, direction, time, volume, speed, and occupancy.

Table 4 shows the personnel data for light and heavy construction days. The weight of construction was only determined based on the judgment of the number of personnel. For these sets of extracted data, only the eastbound was analyzed because it reaches the congestion and westbound data for all days fell only in the free-flow regime of the speed-flow graphs. Since the data was aggregated into 15-min interval, to increase the number of data points in the speed-flow graphs and consequently, increase the reliability for the curve fitting methodology by more data, the data in the same direction for those days with similar characteristics in terms of traffic and construction activity properties were combined with each other. For example, the traffic flow data for both lanes in August 28th and 29th were combined with each other (see

Table 4).

Table 3. The initial extracted data sets for the mile marker 267.4

Item Name	Mile Marker	Location Name	Lane Number	Lane Group	Check In Time	Volume (per min)	Speed (mph)	Occupancy (%)
Q04	267.4	I-44 EB	1	E	8/28/2012 0:00	10	59	6
Q04	267.4	I-44 EB	1	E	8/28/2012 0:02	6	64	4
Q04	267.4	I-44 EB	1	E	8/28/2012 0:03	9	61	5
Q04	267.4	I-44 EB	1	E	8/28/2012 0:04	13	59	8
Q04	267.4	I-44 EB	1	E	8/28/2012 0:05	12	62	6
Q04	267.4	I-44 EB	1	E	8/28/2012 0:06	9	62	6
Q04	267.4	I-44 EB	1	E	8/28/2012 0:07	9	60	9
Q04	267.4	I-44 EB	1	E	8/28/2012 0:08	13	62	6
Q04	267.4	I-44 EB	1	E	8/28/2012 0:09	10	61	6
Q04	267.4	I-44 EB	1	E	8/28/2012 0:10	10	60	6
Q04	267.4	I-44 EB	1	E	8/28/2012 0:11	8	61	7

Table 4. The number of personnel data for both light and heavy construction activity

Days	Total	Operators	Laborer	Heavy equipment
August 21, 2012	5	2	3	0
August 22, 2012	5	2	3	0
August 23, 2012	3	2	1	0
August 28, 2012	49	6	11	31
August 29, 2012	48	7	10	30
August 30, 2012	47	7	11	28
September 05, 2012	44	6	11	26
September 06, 2012	40	10	11	17
September 12, 2012	28	10	16	2
September 18, 2012	5	1	4	0
September 19, 2012	24	4	10	5
September 20, 2012	3	1	2	0

Note: The shaded rows are for the days with heavy construction.

Work Zone Diary

There were two (2) files provided by the contractor that contained information about the work zone. They consisted of two PDF files, including the following information:

1. Personnel data for the dates August 16th – October 25th. The type of data in the personnel file includes the number of operators, number of laborers, and number of heavy equipment for various contractors of the project.
2. Other types of information in addition to the personnel data; however there are some

inconsistencies for the dates and number of personnel between the two files. The latter file includes the data for dates August 15th – October 15th. Other information includes the following:

a) Temperature quality (hot, cold, etc.)
b) Weather: Clear, Cloudy, Rain.
c) General nature of work: Excavation, Breaking and Digging, Hauling and Removing, Installing and Finishing (Pouring, Filling, Tying Steel).
d) Law enforcement
e) Construction Vehicles:
    - Truck for supply of water and/or light.
    - Breaking and digging: dozers, milling machine, and skid steer.
    - Hauling and removing: dump trucks, truck hoe, truck mounted, tack trunk, pickups, tire crane, and concrete trunk.
    - Finishing: paving machine, spreading, brooms, sweepers, rollers, and rubber tired.
f) Pavement condition: wet or dry.

Detailed recorded data of the work zone diary is presented in the Appendix A in CD form, but an example of a table is shown in Table A1.. From the work zone diary data presented above, the nature of type of work and presence of construction vehicle was examined to determine the intensity of the work zone construction activity.

METHODOLOGY

Speed-time, flow-time, and speed-flow graphs were first generated for each lane/direction available in the ASTI dataset. These graphs were generated using the 5-minute aggregated SMS and flow data from the raw data. This step was to exclude those lanes/directions for which the flow data does not reach congestion and no ascending or descending trend can be observed in the flow-time and speed-time graphs, respectively. Figure 15 and Figure 16 show examples of two sets of data excluded and included in the analysis, respectively.

It can be observed that the horizontal axis of speed-time and flow-time does not end at 24:00. This is because the dataset includes a few random minutes of missing data and those missing minutes expose themselves in reducing the overall time of observation. This does not affect the analysis as the missing minutes are consistent for both volume and speed data.

Two methodologies have been used in this study to determine the capacity values in the work zone:

- An indirect approach using equation 25-1 of HCM (2010)
- The three regime speed-flow graph

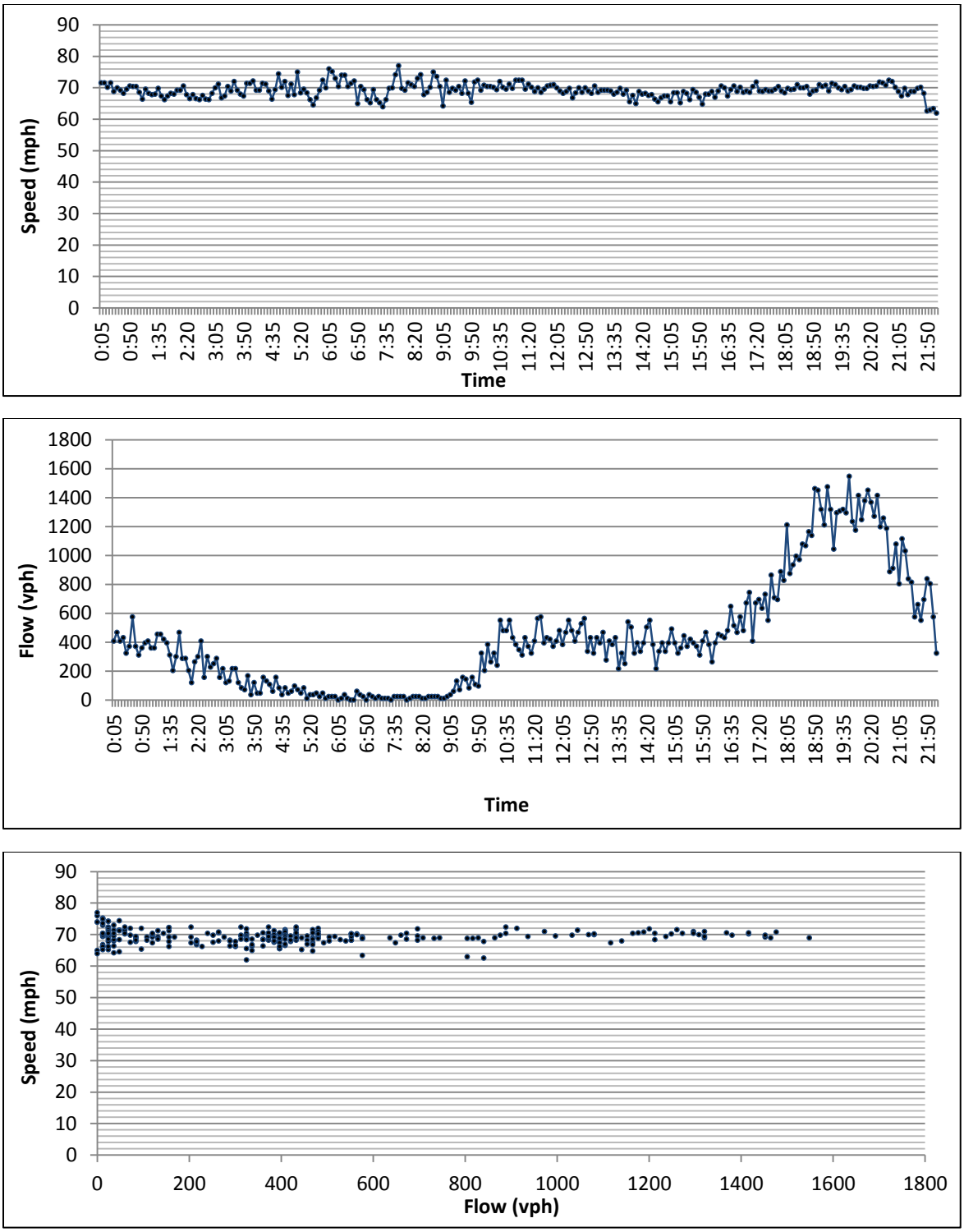


Figure 15. Graphs of speed-time (top), flow-time (middle), and speed-flow (bottom) for Lane 3 of the westbound direction at mile marker 267.4 on August 28, 2012

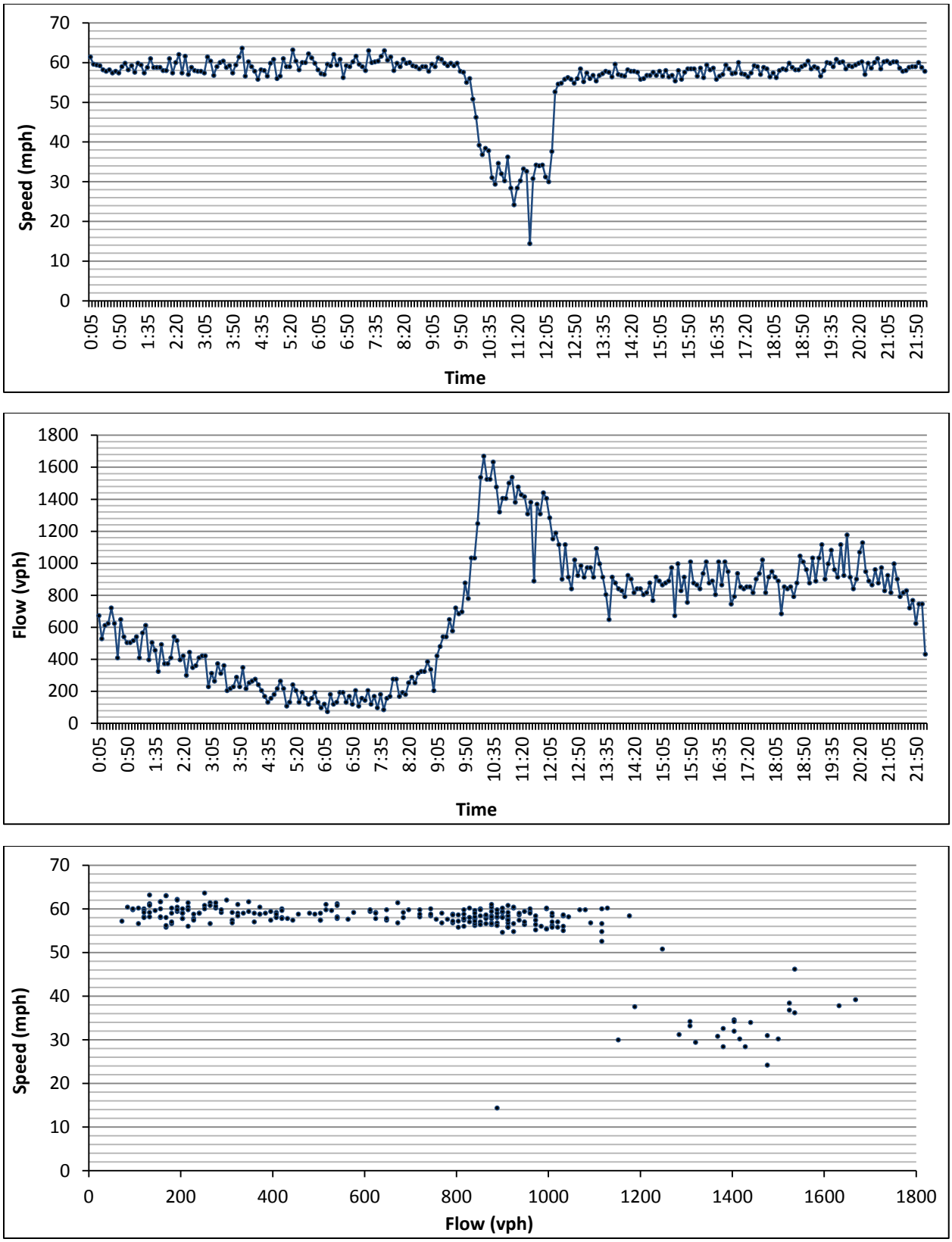


Figure 16. Graphs of speed-time (top), flow-time (middle), and speed-flow (bottom) for Lane 1 of the eastbound direction at mile marker 267.4 on September 20, 2012

Conversion of TMS to SMS

The ASTI data is recorded using a sensor, which is point data (resulting in time mean speed, TMS) with regards to the speed of the vehicles; while the methodology for determining the highway capacity uses the space mean speed (SMS) that takes into account the speed of the vehicles over a length of travel. The ASTI data includes the aggregate volume and speed data for every minute. The best way to convert TMS to SMS is to have individual vehicles data. Therefore, if we want to convert the aggregate TMS provided for 1-minute periods into SMS values, we need to (unavoidably) assume that all the volume (every vehicle) in each recorded minute were traveling with the same speed (namely the recorded TMS). With this assumption the 1-minute TMSs were converted into 5-minute SMS values. The SMS data was then used in speed-flow graphs and led to the calculation of the work zone capacity.

HCM Chapter 25

The HCM has suggested speed-flow curves since 1965. These curves have been modified over time with the availability of extensive sets of data. A historical review of development of speed-flow curves in HCM can be found in a recent paper by (Roess, 2011a).

According to the HCM (2010) Chapter 25: Freeway Facilities Supplemental, the capacity in any occasion of the time and space can be reduced to represent incident situations such as construction and maintenance activities, adverse weather, traffic accidents, and vehicle breakdowns; Although, it is important to use an alternative speed–flow relationship for analyzing the adjusted capacity situations. Equation (7) calculates the predicted speed for the alternative speed–flow model (HCM, 2010). This equation was used in this study to find the adjusted capacity value of the work zone having all the parameter values known except the adjusted capacity in work zone (C × CAF), results in determining the adjusted value of capacity within the work zone.

$$S = FFS + \left[1 - e^{\ln\left(FFS+1-\frac{C\times CAF}{45}\right)\frac{v_p}{C\times CAF}}\right] \tag{7}$$

Where,

S = segment speed (mph)
FFS = segment free-flow speed (mph)
C = original segment capacity (pcphpl)
CAF = capacity adjustment factor
v_p = segment flow rate (pcphpl)

It can be observed that in Equation (7), as v_p approaches zero, the speed segment S approaches the free flow speed FFS. Also, when v_p approaches the adjusted capacity (C × CAF), S approaches the speed at capacity. Figure 17 illustrates how the changes in capacity using different capacity adjustment factors.

Chitturi and Benekohal (2005) found that the free-flow speed of vehicles dropped by about 10 mph for a lane width of 10 ft. Following their approach in this study, given the 60 mph speed limit of the work zone studied, the 50 mph speed threshold seemed reasonable, and it was used in the definition of breakdown from the free-flow regime toward the congested regime. Visual inspection of the speed profile, a speed boundary of approximately 50 mph exists between the congested and uncongested regions. The minute after which there are 5 consecutive minutes with average speed of less than 50 mph shows the breakdown (Chitturi and Benekohal, 2005). Figure 18 presents an example in which the time of the breakdown flow can be determined using the speed-time graph. This graph was also previously presented in Figure 16.

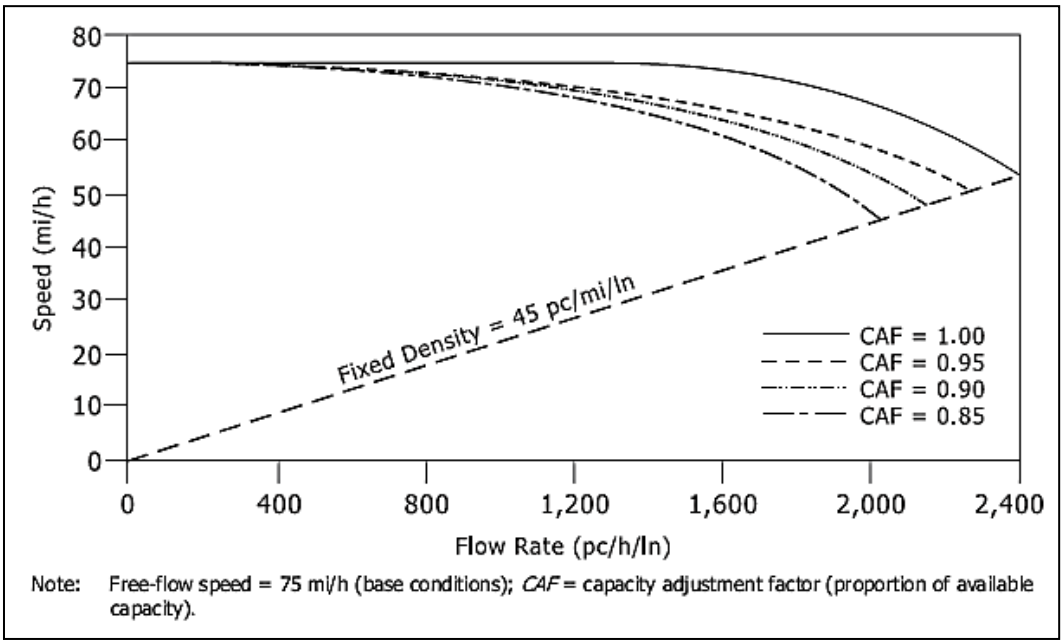


Figure 17. Alternative speed-flow curves for the capacity adjustment factors (HCM, 2010)

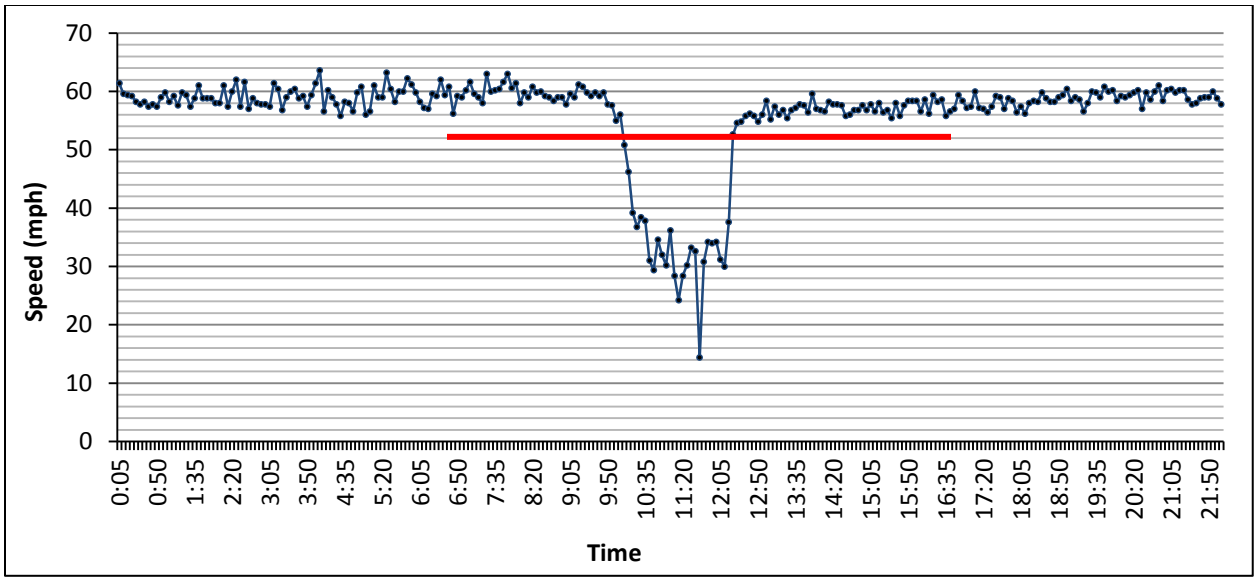


Figure 18. Speed-time graph to determine the time of the breakdown for equation 7

The unit of the flow in Equation (7) is based on the passenger car per hour (pcph) and the available data is based on the vehicle per hour (vph). In order to be able to convert the vehicles into passenger cars the HCM (2010) equation 11-2 is used:

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \tag{8}$$

Where,

v_p = demand flow under equivalent base condition (pcphpl),
V = demand volume under equivalent condition (vph),
PHF = peak-hour factor,
N = number of lanes,
f_{HV} = adjustment factor for presence of heavy vehicles in traffic stream, and
f_p = adjustment factor for unfamiliar driver population.

Using the average volume from the peak hours for the analysis of each set of data the demand volume was determined. f_p was assumed to be 1.0 considering the unfamiliar driver population was negligible in the area. PHF in the peak hour (congested region) was assumed to be one.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \tag{9}$$

Where,

f_{HV} = adjustment factor for presence of heavy vehicles in traffic stream,
P_T = proportion of trucks and busses in the traffic stream,
P_R = proportion of RVs in the traffic stream,
E_T = passenger car equivalent for trucks and busses

E_R = passenger car equivalent for RVs

The E_T at level terrain was determined from chapter 11 of (HCM, 2010) to be equal to 1.5. The percentage of trucks was found as the average value of truck percentage manually determined from the field video data equals 15% truck and assuming no RVs, the adjustment factor for presence of heavy vehicles found to be 0.93.

Therefore, all the parameters in equation (7) is known except the adjusted capacity which is in fact the work zone capacity (CAF x C). Using excel solver the cases were analyzed and the capacity values were determined for the different days of available data (having different intensity values) found based on the methodology described above.

Three Regime Speed-Flow

Due to the importance of HCM and the extensive amount of data used for development of its speed-flow curves, this study is consistent with the format suggested by the latest version of the HCM, released in 2010. The HCM (2010) capacity analysis procedure for basic freeway segments is based on calibrated speed-flow curves for sections with various free-flow speeds (presented in Exhibit 11-6, p.11-8). These speed-flow curves, based on a study by Roess (2011b), consist of two segments (regimes): the free-flow regime in which speed is maintained equal to the free-flow speed (FFS), and the transition regime in which speed is reduced with increasing flow until capacity (end-points) is reached. These end-points (capacity values) are based on the HCM (2010) and were proposed by the Highway Capacity and Quality of Service Committee (HCDSC).

The HCM (2010) does not model the congested (lower) part of the speed-flow curve. In this study, the two-regime model in HCM is complemented with a third regime representing congested conditions i.e., the lower part of the speed-flow relationship. The main reason for fitting the congested regime is to determine capacity based on field data, defined as the intersection between the congested and transition regimes. Figure 19 shows the common relationship between the speed and flow of the traffic. As it can be observed the capacity which is the highest flow discharge happens in the area of the intersection of free-flow and congested flow, the queue discharge area (that is, two regimes).

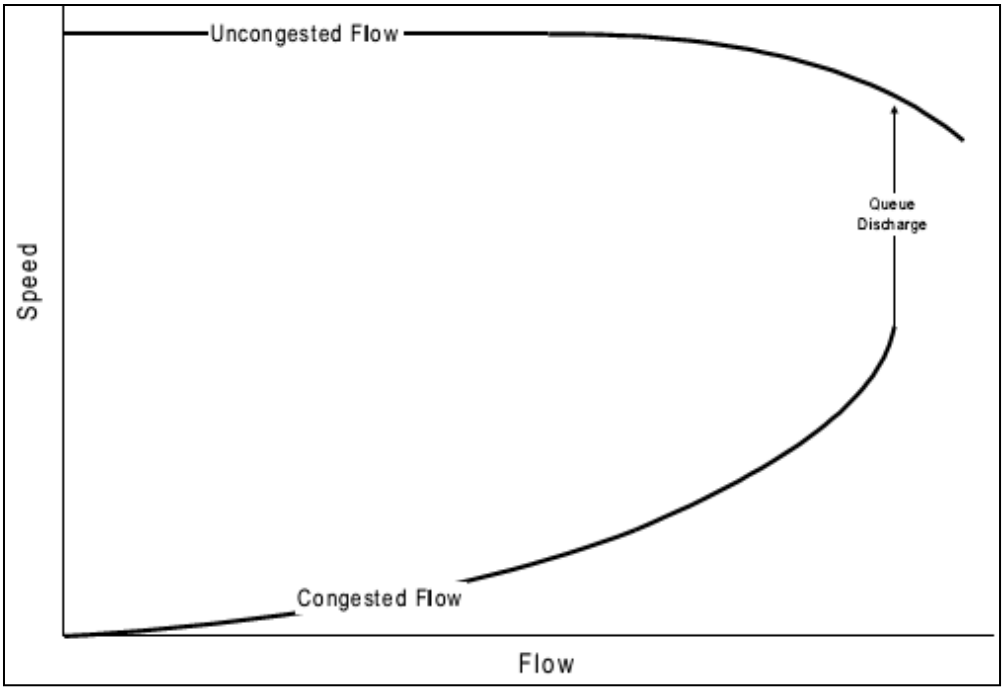


Figure 19. Traffic speed-flow relationship (HCM, 2010)

In the three-regime analysis, the graph is divided into three distinct regimes: free-flow regime, transition regime, and congested regime. In order to be able to make the distinction between the different regimes, the first step is to identify the flow where the behavior of the traffic flow changes from freely flowing and increases until it reaches congestion. This flow is named the "break point" flow (Figure 20).

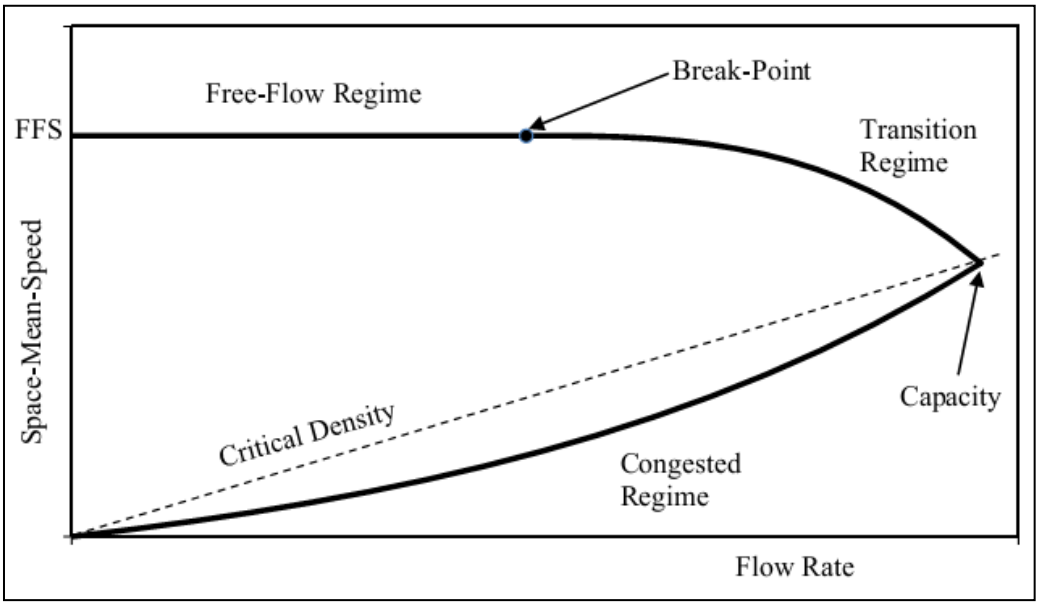


Figure 20. The three regimes identified in the speed-flow graph (Bham and Khazraee, 2011)

The break point flow was found with an iterative process. First assume a flow value as the break point flow and slowly increasing the value in each step. The flow in which the change in the standard deviation of the speed is the highest in ascending order is determined as the break point flow. Figure 21 shows an example of the change trend in the standard deviation of speed over various break point flow values assumed. For this example the break point flow was determined to be 1200 vph. The break-point flow separates the free flow regime from the other two regimes in the speed-flow graph. Figure 22 shows an example where the free-flow condition is distinguished by a break-point flow of 1120 vph.

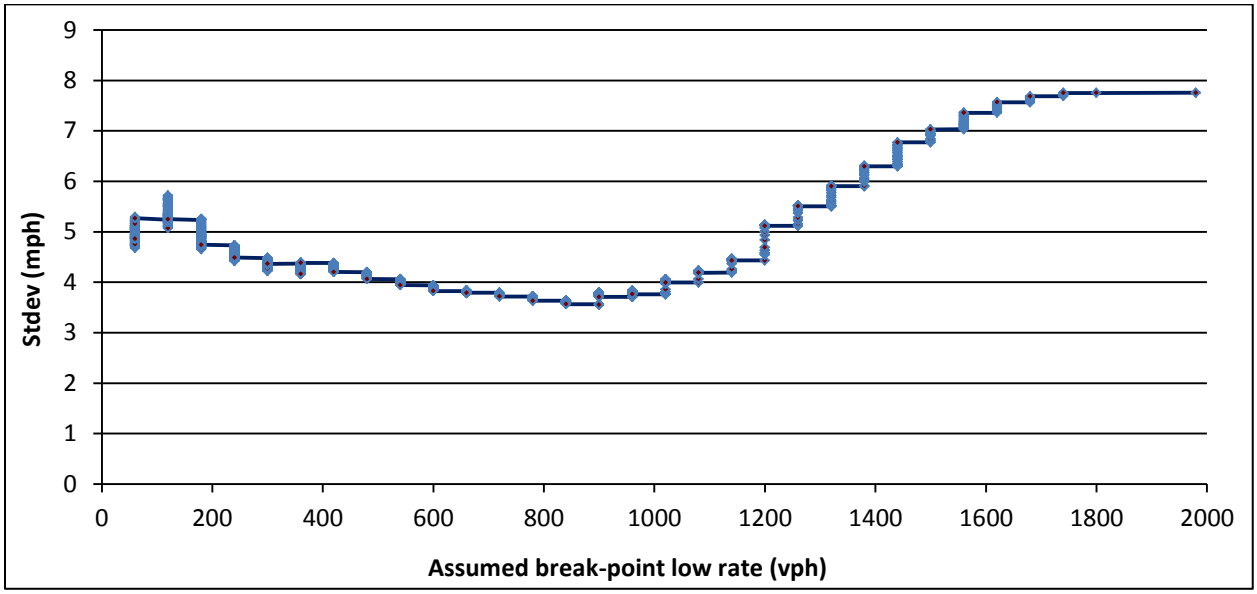


Figure 21. The change in standard deviation of speed with assumed break-point flow

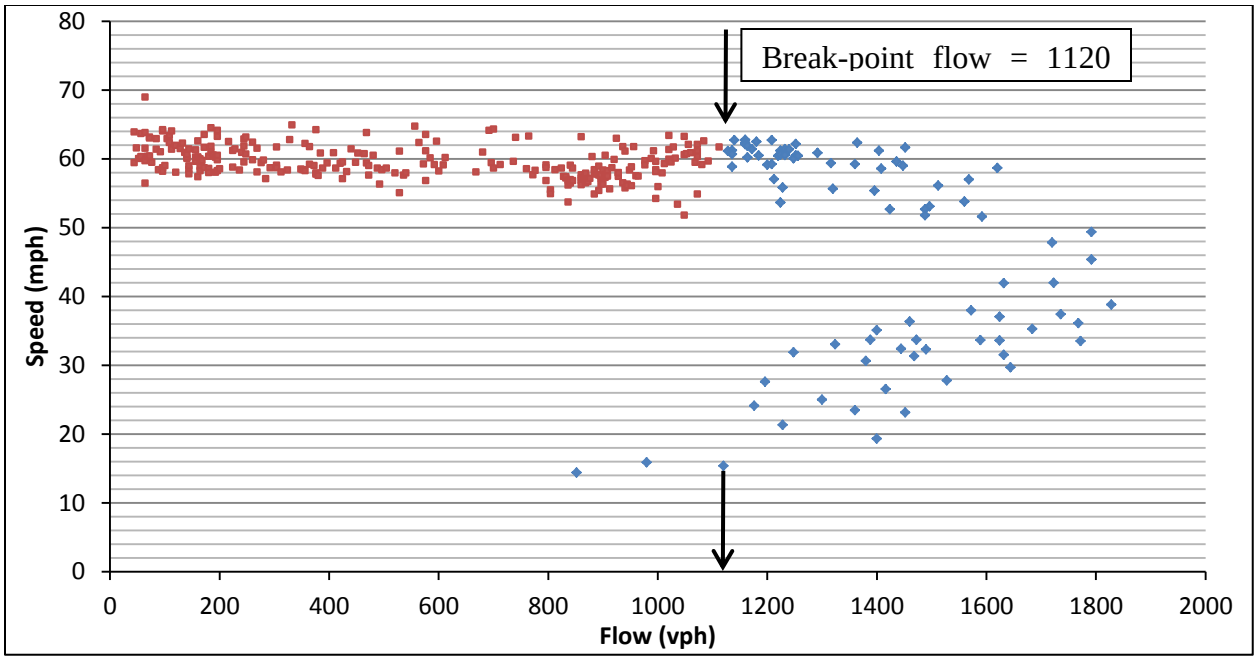


Figure 22.

The transition regime and the congested regime are identified using a critical density that occurs at the value of capacity (HCM, 2010). It is called transition as the area includes those data points that represent the transition between the free-flow conditions to the congested condition. Figure 23 shows the relationship between speed and flow, where, V is flow (vph), D is density (vpm), and S is the speed.

$$V = D \times S \tag{10}$$

For example assume the critical density is 33 vpm and draw the equation in the speed-flow graph. Figure 23 shows the separation of the transition area from the congested area by the dashed-line that represents the 33 vpm density value. Using Equation (11), a quadratic function is then fit to the transition data. The free flow speed in this equation is the average of the speed values in the free-flow regime. Each data point in the transition regime provides a coordinate of speed and flow that is used in the iterative process of curve fitting to minimize the sum of the squared error value of the fit. Using the determined break-point flow as BP and an iterative process the parameters α and β are estimated. Figure 24 shows an example of the fit to the transition regime.

$$S = FFS - \alpha(v - BP)^{\beta} \tag{11}$$

Where,

S	= speed at transition area (mph)
FFS	= free flow speed (mph)
v	= flow at transition area (vph)
α, β	= estimable parameters

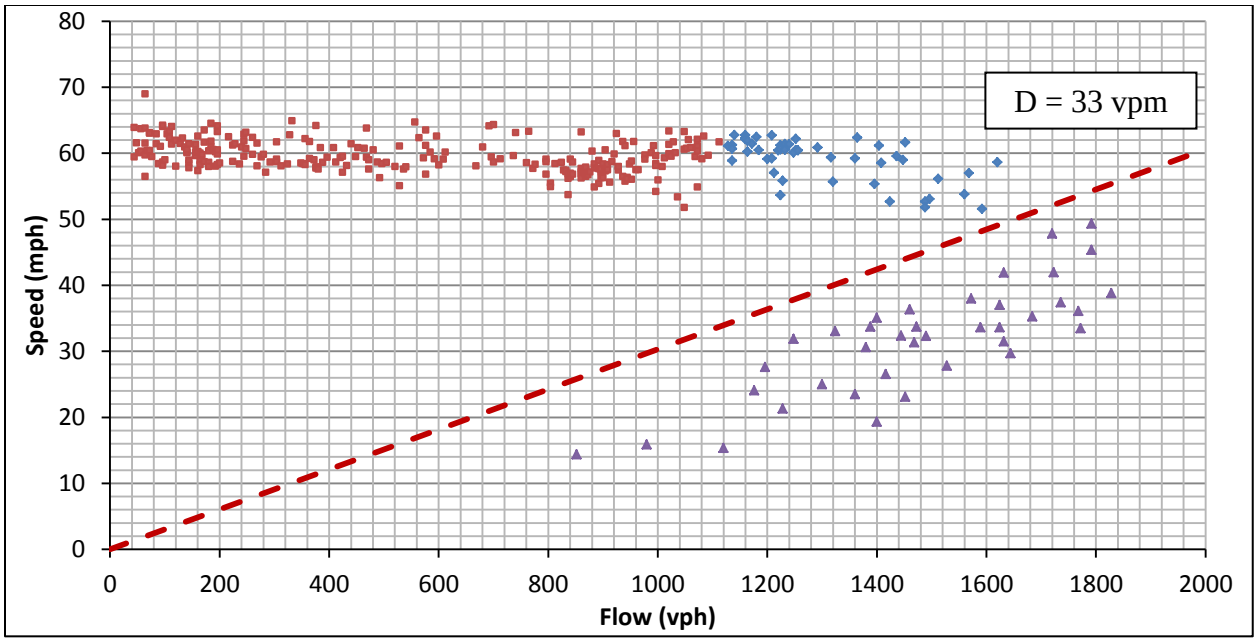


Figure 23. Separating transition area from the congested area in speed-flow graph

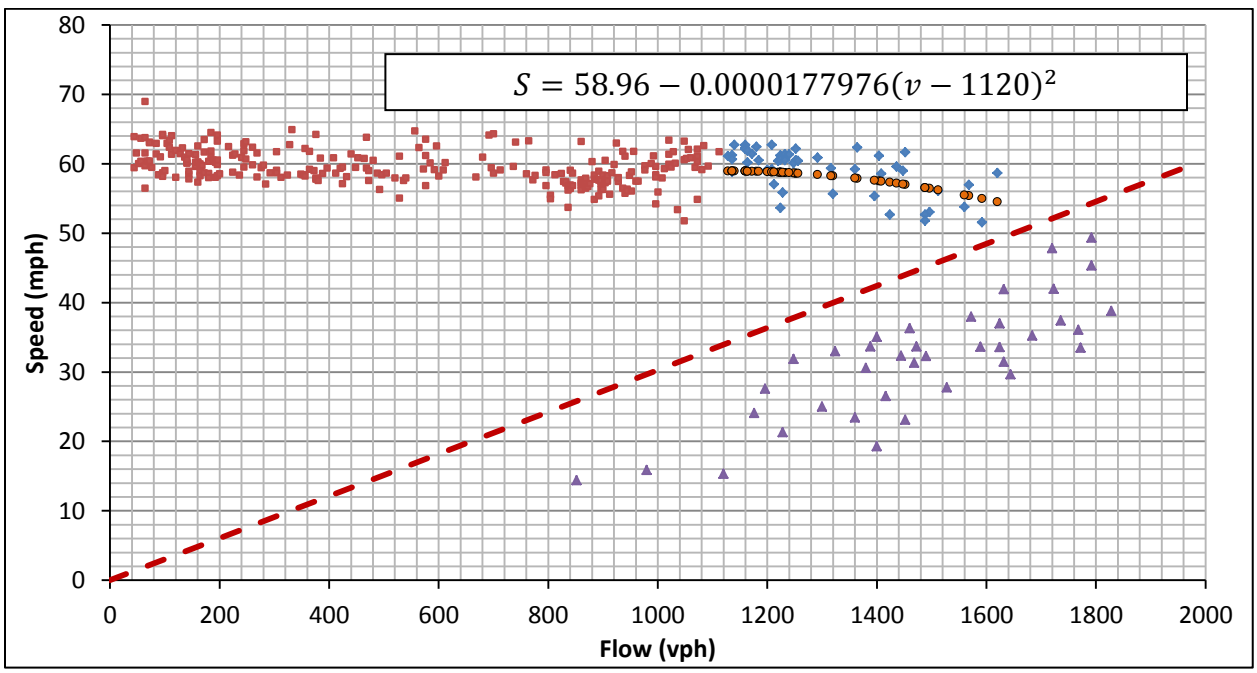


Figure 24. Fitting the data in transition area

Three functions were chosen to fit to the congested regime: 1) power 2) exponential, and 3) quadratic. These functions were also fit to the data points so that it minimizes the sum of the squared error terms of the fit. All these curve fitting was conducted using MATLAB software (Jiade, 2008). Figure 25 shows an example of the three functions fitted as curves to the data points in the congested regime. The final step in this procedure is to make sure that all the curves fitted to the congested regime intersect with the quadratic function fitted to the transition regime

at the same point and on the line of the critical density value (see Figure 26). According (HCM, 2010) capacity happens at the critical density after which the flow decreases and there will be queue back up and congestion. So both of the fits to the sets of data on the sides of the density line is fit considering this constraint. It is obvious that the error sum square value will not be the same as when there is no constraint, although, it will take the minimum possible value to determine the best fits.

Another critical density is chosen and the above process is continued until the best fit for the congested and transition was found and that would be the capacity. The range of the critical density values examined was between 35 to 45 vpm (see Figure 27). Figure 28 shows an example of the procedure using only two critical density values of 40 and 42.

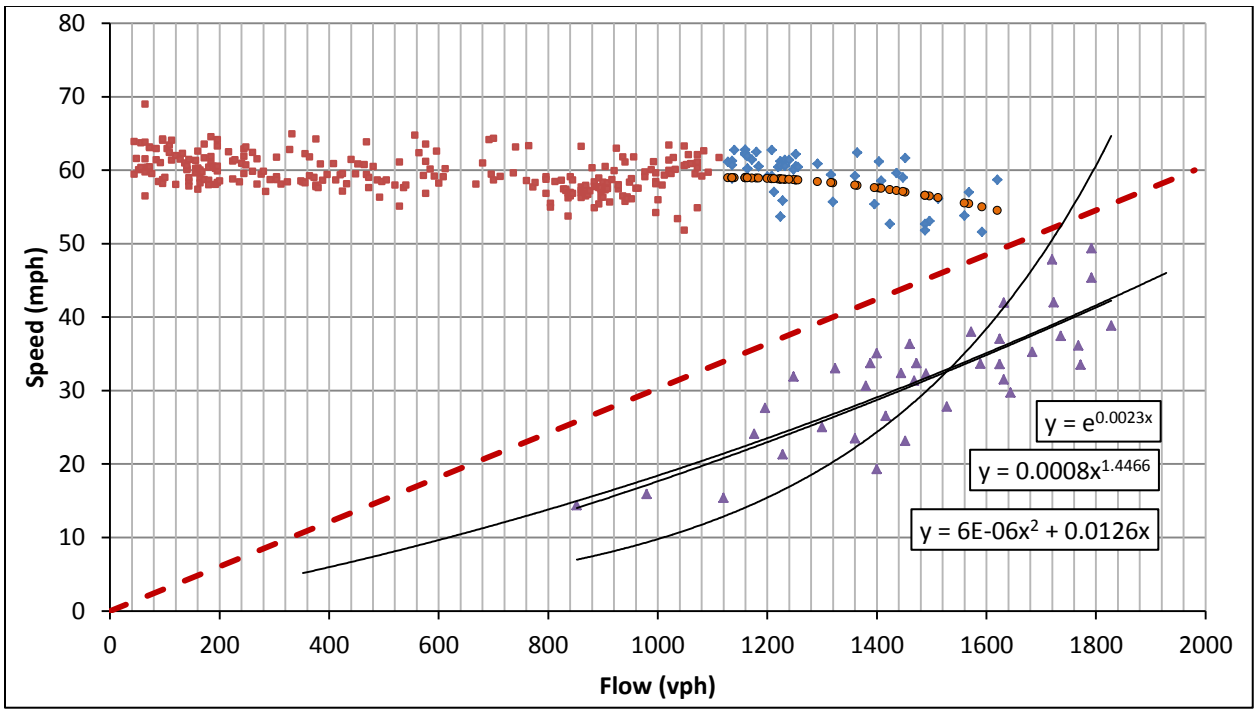


Figure 25. Fitting to the transition and congested regime

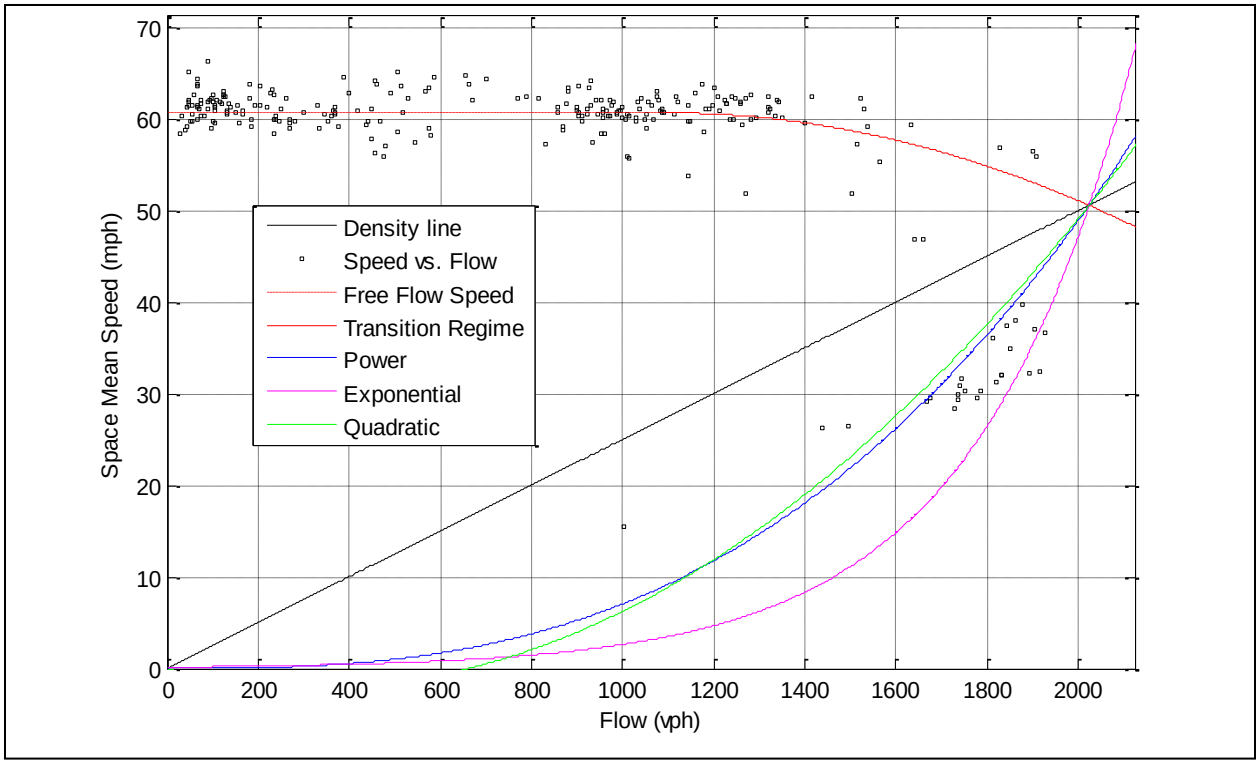


Figure 26. Fitting to the transition and congested regimes intersecting at one point

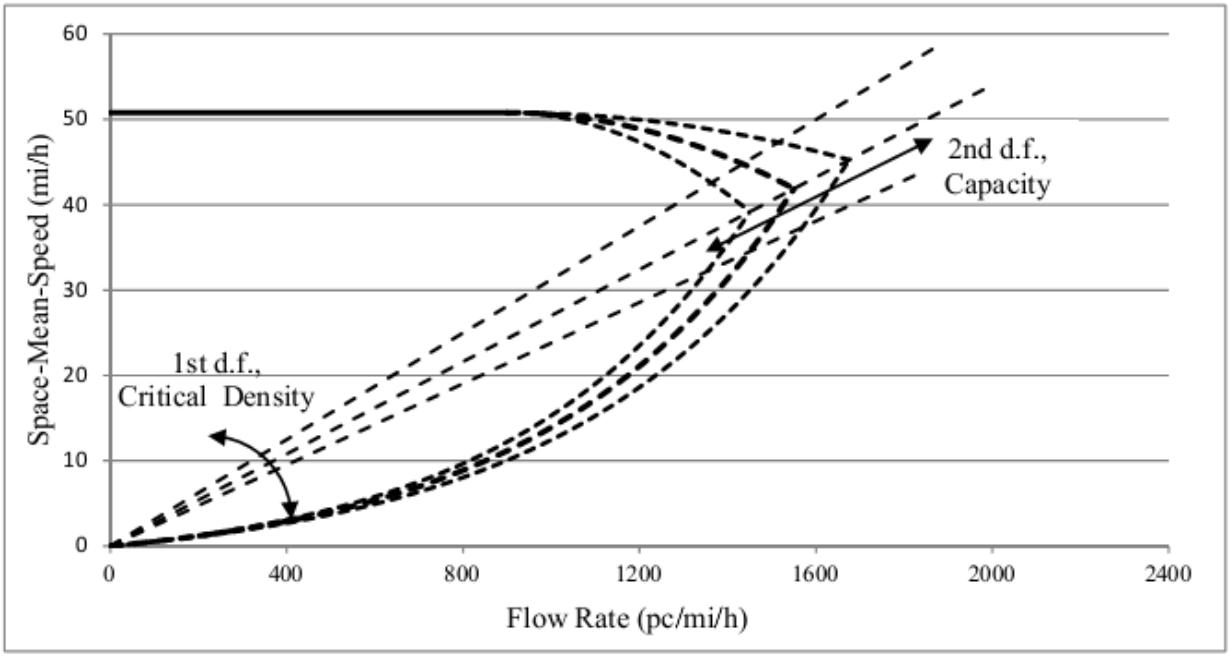


Figure 27. Changing the value of critical density and repeating the capacity approach

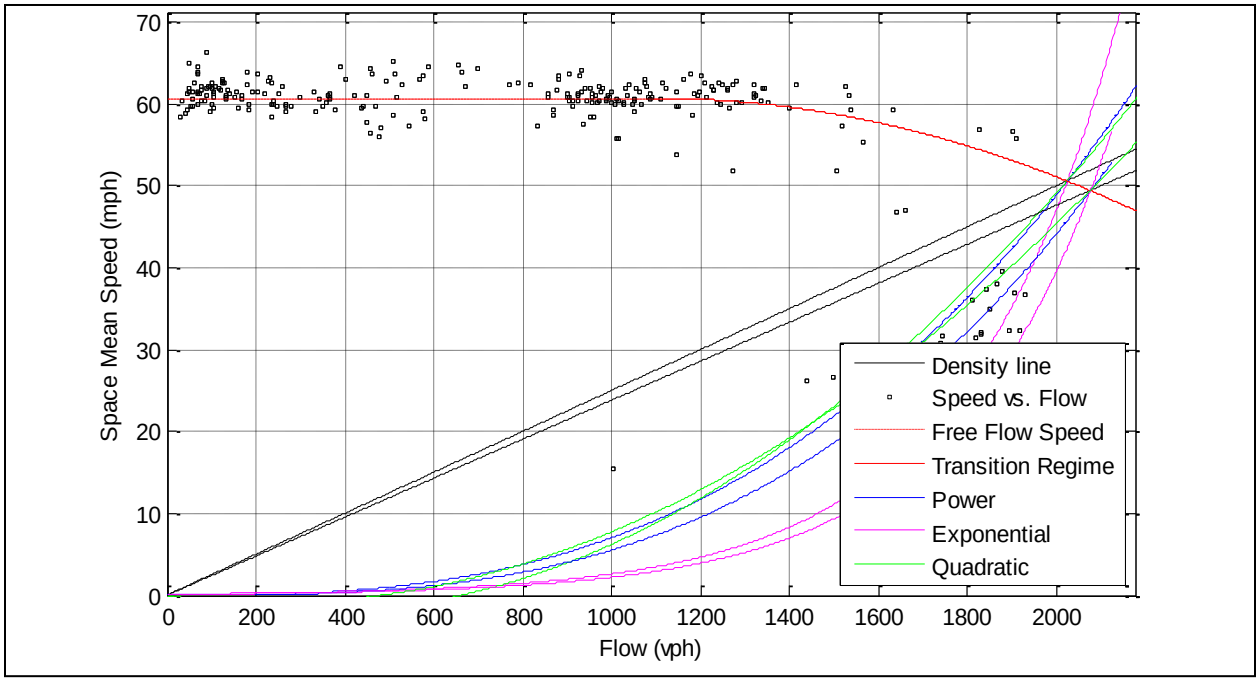


Figure 28. Fitting to the congested regime using critical densities of 40 and 42 vpm

After the methodology was completely established and the programming in MATLAB completed, the data was examined to divide it to days with low and high construction intensity. The only source that was available to do this task was the data from the work zone diary provided by the contractors. The type of data available in the work zone diaries are presented in the "Data" section.

It was assumed that the number of personnel present in the work zone could be an appropriate representative of the amount of work being conducted through the construction area in each day. There was other information also recorded for the work zone but there was not much change in them such as the grade of the highway that remained the same over the period of work. The number of different types of personnel and the number of equipment used was tabulated and organized for each day. This simplifies the categorization of days/activity into light and heavy activity days and consequently dubbing days with low and high intensity works.

The speed and flow data were then combined for the intervals of 15 minutes. The data from the lanes in the same direction and similar days (similar intensities) were combined to achieve a higher power and more accurate fitted equation to the various regimes. This also prevents small sample size for generating the data points in the speed-flow graphs.

STATE DOT SURVEY

Fifty DOTs were contacted to complete a survey on their current and/or previous practices on work zone capacity. Twenty one (21) states took the survey and responses were recorded. The DOTs were surveyed on the following factors:

- Conceptual methodology and/or formula(s) used to estimate work zone capacity
- Definitions of short/ long work zones and work zone capacity,
- Best time interval to aggregate traffic flow
- How field collected data was used in their procedure
- Properties of field data collected in terms of the roadway geometry, work zone configurations, construction activity, construction intensity, time, and other measured factors.
- How the effect of construction activity on capacity was considered into the methodology
- Capacity properties of short/long term work zones, and
- Strategies undertaken to increase the capacity or reduce the effect of various factors on capacity

Most of the states said they use the equation and methodology provided by the HCM to estimate the work zone capacity. Those states were New Jersey, Delaware, Iowa, North Carolina, New York, Minnesota, California, and Maryland. Other states such as Missouri, Alaska, Michigan, Connecticut, Washington, Idaho, Wisconsin, and District of Columbia mentioned that they use software such as Vissim, Synchro, Quickzone, lane closure analysis tool, and charts and spreadsheets found from MUTCD, HCM, and also developed from the local knowledge.

Most of the responding states follow the guidelines of MUTCD chapter 6 on the definition of the short term/long term work zones. Missouri, Georgia, and North Carolina regards those work zones that are in place for less than three days as short term while similarly Iowa, Washington, and North Dakota for when it is less than one hour, Connecticut for less than eight hours, Minnesota and Maryland for less than 12 hours, New York and Idaho for less than one day, and New Jersey for less than four days. If a work zone was not considered as short term, it is treated as a long term work zone.

The factors that were mentioned by the states as the main differences in considering a work zone as short or long term work zone was the temporary traffic control devices such as signs, lighting, and pavement markings, but most of all the duration of the construction activity. For those of short term, construction activity in daytime is very little and most of the time would happen during the night time. Also, the capability of removing the work zone during rush hours is mentioned as a characteristic of short term work zones.

Also, various definitions were used by agencies in defining the work zone capacity but the most common definition were identified to be maximum hourly flow rate, followed by max hourly flow rate before queue discharge, and mean queue discharge. The 95th percentile of mean queue discharge flow was the least common definition used by the highway agencies. Alaska also

mentioned they use local knowledge and Michigan mentioned the reduced work zone capacity as a result of work activity and reduced lane width is determined.

For the desired time interval for flow rate aggregation, 15 minute was found to be the most commonly used time interval, some of the state also mentioned they use 1 (Missouri, Alaska, Michigan, Iowa, Mississippi, and North Dakota) and 10 minutes intervals (New jersey and Minnesota).

Traffic volume and speed were the two main factors mentioned in the field data recorded for the work zone capacity analysis conducted by the states if there was any. Various lane delineation methods used by the states such as portable cones, drums, and other channelization objects, but from those who responded the corresponding question most mentioned concrete barriers. Light construction activities were usually classified by installing temporary guardrails and median barriers and concrete barriers were used for more permanent and long term work zones. It was also found from a few responses that they consider a higher capacity to prevail for the long term work zones.

Regarding the DOTs actions toward classification of construction activity and whether they consider it as a factor affecting the work zone capacity, New Jersey mentioned that there is a difference between road and bridge construction, North Dakota differ the construction between short and long term work zones, North Carolina by the traffic impact and Washington based on whether it is a mobile work zone or not. The rest which were the majority mentioned that they do not use any classification of construction activity to modify the value of capacity as a result of it.

The capacity values that the states reported vary depending on the type of the work zone (short term or long term), construction barriers, truck percentage, grade, lane width, local knowledge, etc. but mainly they reported that they use the values of HCM and they adjust it according to the local conditions and the above factors. North Carolina reported a value of 1300-1600 vphpl for work zones in urban areas and 500-900 vphpl in rural areas. Minnesota reported 1800 vphpl for long-term work zones in urban and 1500 vphpl in rural areas. Similarly, Connecticut reported a general capacity value of 1500-1800 vphpl for all the work zones.

The responses of the state DOTs, although not very comprehensive, helped us understand the way other states deal with work zones and consider the capacity values in their construction policies. The study conducted in this project examining the effect of work zone construction intensity on the capacity has been a unique study which dealt with an important factor that certainly affects the behavior of drivers through the work zone and as a result of that the capacity of work zone would change. However, there is always room for improvements of the analysis by acquiring more quality data from different classes of work zone exhibiting different construction intensities. A detailed questionnaire designed for this purpose and the responses are presented in the Appendix A of this report. Above, we have presented a summary of the responses of the DOTs and their strategies.

RESULTS AND DISCUSSION

Field Data Analysis

Despite of all the effort put in the field data collection, the data collected did not show a full speed-flow chart including all the areas of free-flow regime and the congested area and therefore, extracting a reliable capacity value was not possible. For example, Figure 29 shows the speed flow graph for the data collected on eastbound of Eureka work zone on September 6th. The flow is calculated from the traffic volume aggregations over 5 minute time periods. This set of data was collected during the time construction activity was underway. From this speed-flow graph it is not possible to point to the area where capacity might have occurred.

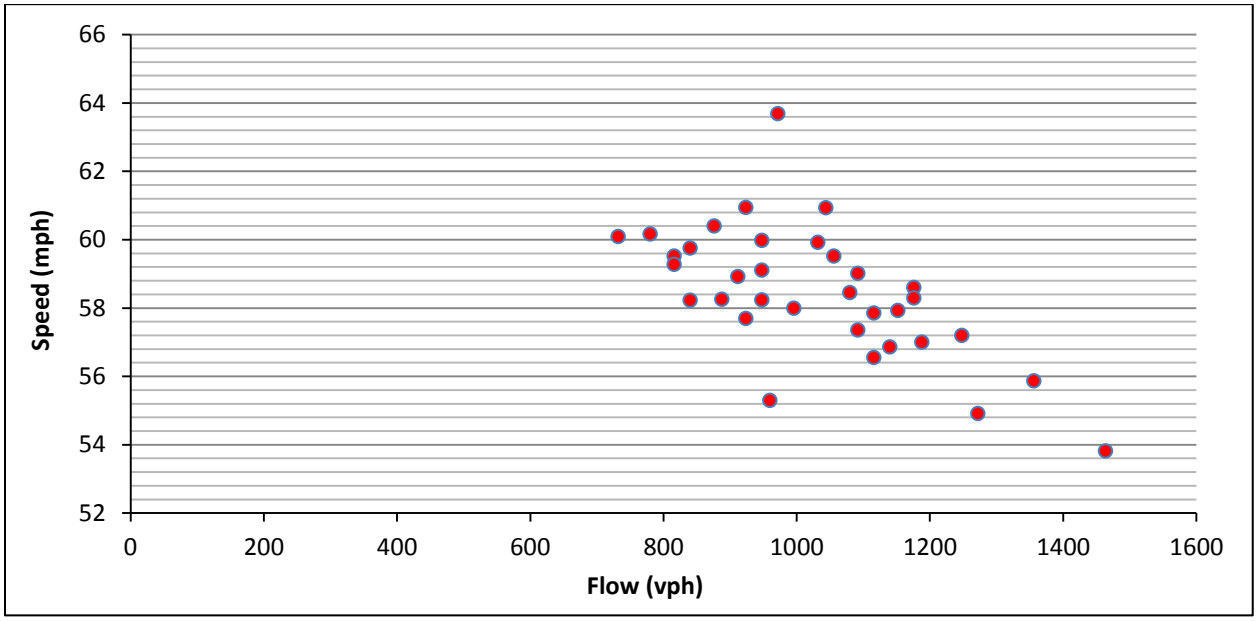


Figure 29. Speed flow graph for the field data collected on Site 6

ASTI Data Analysis

HCM 25-1 Methodology

The data from the eastbound direction of the interstate highway 44 (I-44) was used to find the capacity as the westbound direction did not exhibit any congestion during the time of data collection or from the ASTI data acquired.

Table 5 shows the results of the capacity values found using the HCM equation 25-1. In order to increase the accuracy of the procedure, the data for lanes 1 and 2 were combined and aggregated over 15-minutes time intervals. The shaded cells are for the days with heavy construction. Back calculation was also conducted to convert the values of capacity from pcph to vph. From the

methodology it was found that the $f_{HV} = 0.93$ assuming level terrain with $E_T = 1.5$, 15% trucks and no RV.

It can be observed that the average value of capacity for the days with light construction intensity (1704 vphpl) is higher than that for days with heavy intensity (1683 vphpl). This was also statistically analyzed to see if the difference is statistically significant based on the available data set. The statistical test however, showed that there is no significant difference between the two average values. Consequently, we cannot conclude that the construction intensity results in a significant difference in the work zone capacity. Although, it should be noted that the work zone considered in this analysis was a long-term work zone and the construction area was separated from the open lane using concrete barriers. Additionally, this conclusion was found using one definition of capacity which is the queue discharge flow using the HCM equation 25-1. The capacity values obtained using this procedure were found to be consistent with the range of the values suggested by the HCM for long term work zones and also with the capacity values reported by the other DOTs in the survey.

Table 5. Values of capacity found by equation 25-1 from HCM 2010

Day	Capacity value (pcphpl)	Capacity value (vph)
August 21	1879	1747
August 22	1780	1655
August 23	1841	1712
August 28	1833	1705
August 29	1836	1707
August 30	1804	1678
September 5	1837	1708
September 6	1825	1697
September 12	1692	1574
September 18	1824	1696
September 19	1840	1711
September 20	1839	1710

Note: The shaded rows are for the days with heavy construction.

Three-Regime Speed-Flow Curve

Using this methodology, separate tables and graphs were generated for the two construction intensities (light and heavy construction, see

Table 4) considered and for different data combination levels (lanes and days). In each analysis, capacity values were obtained using a range of different density values to separate the transition and congestion flow regimes. An attempt was made to combine all the days with light construction intensity and find the capacity value. Similarly, the capacity was found for all the heavy construction intensity days.

Table 8 shows the final results that were found for each of the light and heavy construction days combined to find the capacity values. Figure 31 presents a graphical comparison between the capacity values found for each of the construction activity classes (the values that are also shown in). The overall results indicate that heavy construction decrease the capacity values as those days with heavy constructions show lower capacities calculated using the three-regime method although, this difference has to be statistically compared too. An analysis of variance (ANOVA) was conducted to see if this difference (effect of construction activity on work zone capacity) is statistically significant as well.

Table 6 shows an example of the procedure and capacity values found for each day using only one day and one lane of data. Shaded areas represent those days with heavy construction activity. For each day the capacity value that resulted from the best fit was considered as the final value of capacity considered for that day. The fitting criterion used was the root sum square error (RSSE) of the fit; the lower it is the better the fit. In each iteration, three different functions (power, exponential, and quadratic) were used to fit the data.

Table 7 shows an example of the different RSSE values found for the three functions using each density values. Figure 30 also shows an example of the speed-flow graph with the three types of functions fitted to the data. An attempt was made to combine all the days with light construction intensity and find the capacity value. Similarly, the capacity was found for all the heavy construction intensity days.

Table 8 shows the final results that were found for each of the light and heavy construction days combined to find the capacity values. Figure 31 presents a graphical comparison between the capacity values found for each of the construction activity classes (the values that are also shown in). The overall results indicate that heavy construction decrease the capacity values as those days with heavy constructions show lower capacities calculated using the three-regime method although, this difference has to be statistically compared too. An analysis of variance (ANOVA) was conducted to see if this difference (effect of construction activity on work zone capacity) is statistically significant as well.

Table 6. Capacity values found by three-regime method only for one lane (Lane 2)

Day	Capacity value (pcphpl)										
	D=35	D=36	D=37	D=38	D=39	D=40	D=41	D=42	D=43	D=44	D=45
21-Aug	1894	1924	1953	1980	2006	2031	2054	1835	1846	2141	2164
22-Aug	1655	1665	1674	1683	1691	1698	1705	1712	1718	1723	1728
23-Aug	1838	1861	1883	1903	1922	1939	1956	1972	1987	2001	2014
28-Aug	1838	1870	1859	1886	1911	1936	1960	1921	1858	1874	1856
29-Aug	1951	1914	1946	1976	2005	2033	2060	2086	2112	2136	2160
30-Aug	1911	1946	1981	2014	2046	2077	2107	2136	2164	2191	2218
5-Sep	1946	1859	1880	1900	1919	1936	1953	1968	1983	1997	2103
6-Sep	1887	1918	1948	1977	2005	2032	2058	2083	2106	2130	2152

Day	Capacity value (pcphpl)										
	D=35	D=36	D=37	D=38	D=39	D=40	D=41	D=42	D=43	D=44	D=45
12-Sep	1789	1807	1824	1840	1731	1743	1756	1767	1778	1788	1798
18-Sep	1926	1956	1984	2010	2034	2058	2080	2100	1992	2010	2027
19-Sep	2003	2038	2038	2068	2096	2123	2149	2173	2196	2218	2239
20-Sep	2142	2203	2265	2326	2387	2448	NaN	2211	2236	2261	2284

Table 7. Capacity values during heavy construction, data for 1 day August 28, 2012 (Lanes 1-2 combined)

Density (vpmpl)	RSSE			Best fit	Capacity (vphpl)
	1(power)	2(exponential)	3(quadratic)		
35	72.10	161.78	54.60	3	1838
36	64.82	142.68	49.04	3	1870
37	61.18	140.58	45.21	3	1859
38	55.71	126.10	40.54	3	1886
39	51.49	114.18	36.31	3	1911
40	48.44	104.63	32.56	3	1936
41	46.45	97.20	29.29	3	1960
42	44.39	100.66	27.33	3	1921
43	38.47	109.52	25.36	3	1858
44	34.97	100.95	22.58	3	1874
45	31.79	101.81	20.35	3	1856

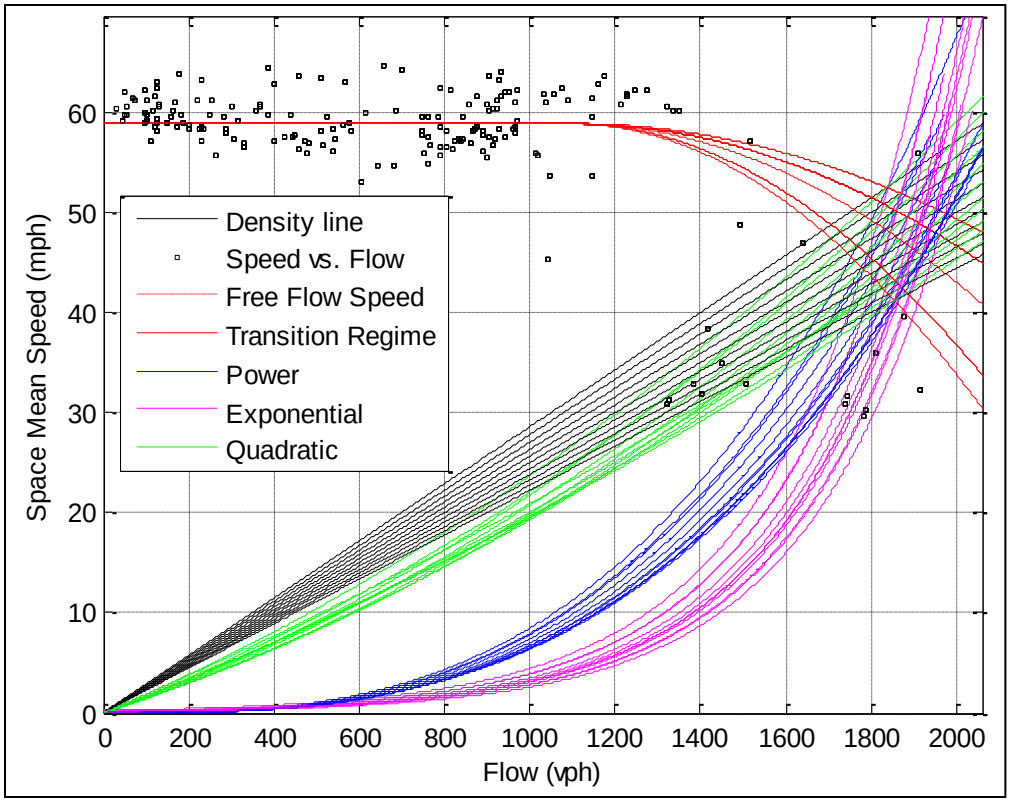


Figure 30. An illustration of the functions fitted to the 15-minute aggregated data for one day

Table 8. Capacity values, all days combined for each construction activities

Construction	Density (vpm)	RSSE			Best fit	Capacity (vphpl)
		1(power)	2(exponential)	3(quadratic)		
Light 8/21/2012 8/22/2012 8/23/2012 9/18/2012 9/20/2012	30				3	1760
	31	188.81	304.22	170.56	3	1819
	32	158.17	247.25	146.40	3	1877
	33	135.37	207.89	125.33	3	1936
	34	120.48	186.18	108.16	3	1995
	35	105.64	170.87	91.06	3	2053
	36	85.44	172.51	80.04	3	2112
	37	104.34	177.05	70.42	3	2171
	38	110.78	186.00	63.74	3	2229
	39	116.87	193.11	57.75	3	2288
	40	98.79	168.57	56.79	3	2155
	41	88.08	151.99	58.21	3	2024
	42	80.43	139.97	53.05	3	2011
	43	74.52	132.47	51.34	3	1949
	44	53.27	116.23	42.49	3	2002
	45	60.26	108.84	38.36	3	1993
Heavy 8/28/2012 8/29/2012 8/30/2012 9/05/2012 9/06/2012 9/12/2012 9/19/2012	30	271.31	443.46	235.71	3	1767
	31	224.46	359.56	204.98	3	1825
	32	188.33	295.59	175.53	3	1884
	33	163.34	254.19	151.72	3	1937
	34	162.14	259.45	145.84	3	1913
	35	151.30	243.59	132.57	3	1931
	36	145.67	237.39	123.34	3	1930
	37	133.81	216.78	108.63	3	1975
	38	113.10	207.08	98.09	3	2000
	39	121.66	201.34	91.67	3	1984
	40	114.16	195.38	85.86	3	1956
	41	105.95	185.41	77.27	3	1965
	42	100.55	178.94	70.52	3	1966
	43	93.03	173.69	65.51	3	1938
	44	87.36	174.43	61.81	3	1897
	45	76.08	161.31	55.03	3	1891

Table 9 shows the results of the ANOVA. The p-value calculated is less than the significance level alpha equal to 0.05 and indicates that the difference is found to be statistically significant. A pair-wise T-test was conducted controlling the density values and comparing the capacities found for each density used in the methodology. A p-value of 0.0009 was found for the paired t-test that also indicates the statistical significance of the differences between the capacity values found for the two construction activity classes.

Table 9. ANOVA analysis for the comparison of the capacity values between light and heavy construction

Source	DF	Sum of Squares	Mean Square	F Value	p-value
Model	1	81507.0313	81507.0313	6.73	0.0145
Error	30	363069.6875	12102.3229		
Corrected Total	31	444576.7188			

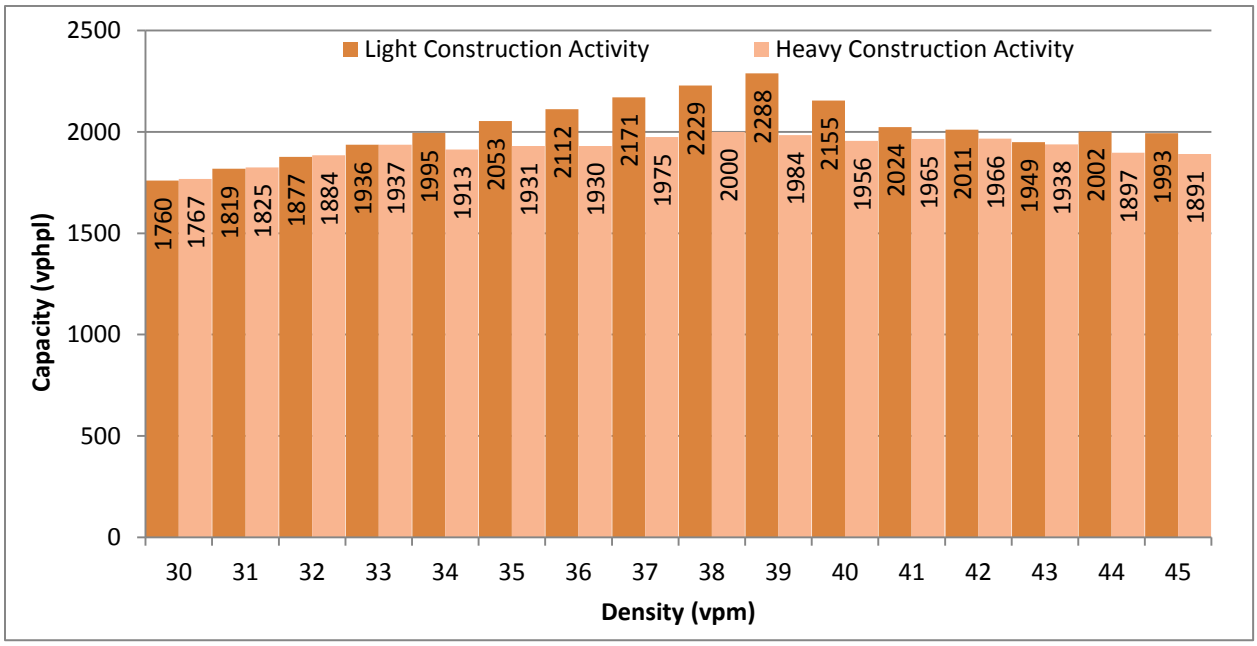


Figure 31. Capacity values, all days combined for for light and heavy construction activities

DISCUSSION OF THE RESULTS

The data collected in this study included both the field data collection and the data acquired from the permanent sensors implemented at several locations on the interstate highway 44. Most of the field data collected by the videos of the traffic stream were during times where there was no or little construction activity underway and, anyhow the traffic flow did not reach a congested condition. Therefore, determining the capacity during those times was not possible. Fortunately, the data acquired from the permanent ASTI sensors was more thorough and covered the whole period of the work zone in place. This data was used to determine the capacity along with the evaluation of the effects of construction activity on capacity.

The construction activity data was acquired from the work zone diaries recorded by the contractors, which included the number of personnel and construction equipment. A search in the previous related works on the quantification of the work zone construction intensity did not provide any information on the use of this construction data in order to calculate an index representing the intensity of construction. Therefore, the number of personnel was used as the criterion to assign two levels of light and heavy construction activity for the available data. The days with fewer than 10 personnel present in the work zone were considered to have lower (light) construction intensity compared to the other days (with more than or equal to 10 work zone personnel); the other days were considered to have higher (heavy) construction intensity. The work zone intensity data may be reviewed in

Table 4.

Two methodologies were used to determine the capacity values, i.e. two different definitions of capacity were considered to develop the steps of the approach toward finding capacity: 1) an indirect approach using equation 25-1 of the HCM (2010), and 2) a three-regime speed-flow model. The capacity values found using the 1st approach fell in the range of 1655-1747 vph with a mean value of 1704 vph for light construction intensity and 1574-1708 vph with mean value of 1682 vph for heavy intensity. The capacity values found using the 2nd approach fell in the range of 1760-2288 vph with a mean of 2023 vph for light construction intensity and 1767-2000 vph with a mean of 1922 vph for heavy intensity.

The values found using the two regimes are different from each other and that is because of the two different approaches toward determining capacity. The first approach uses the concept of the queue discharge flow as is used in the different versions of the highway capacity manual through the years. The second approach, however, uses all the data in both queue discharge area and congested area of the speed-flow graph to find the best fit to the data and the intersection of the two fits will result in capacity value. This does not consider the average queue discharge flow in right after the break down and it is reasonable to expect higher values of capacity using this method.

The capacity of the work zone was found to be lower during heavy construction; however, the difference between the values for the two intensity classes was only found to be statistically significant for the 2nd approach, the three-regime model. This finding leaves the conclusion of

the effects of construction intensity on work zone capacity open to further investigations. Although, one method provides enough evidence to believe that there is an effect of construction activity in reducing the capacity but such a conclusion cannot be supported by the statistical results of the second approach.

The work zone considered in this study was a long-term work zone and was in place for more than two months. The open lane was separated from the work zone activity area by concrete a median barrier which means there is no potential of direct diversion of the road by the travelers into the work area or for the construction crew to accidentally get too close to the traveling public. This reduces the risk of getting involved in an accident with the workers or the machinery and enhances the driving confidence of the travelers, which results in a higher capacity value compared to short-term work zones or the roadway capacity at locations where the lane closure is conducted using cones and more basic separators.

The objectives defined in this study may be very appealing in the area of traffic control and management but on the other site, capturing the appropriate and sufficient data from work zones depend much on the availability of different types of work zones (short-term and long-term) with various characteristics. It may be intuitive to suspect less effect on roadway capacity when the open lane is completely separated from the construction area using concrete barriers compared to the common traffic control devices in short-term work zones like cones and tubular markers. This presumption however, can be further investigated by acquiring more real data from the work zones with different characteristics. One of the limitations that prevailed in this study was access to the data collected from several different work zones in which traffic stream would reach break down. In that case a comparison between different capacity values would have been straight forward, no matter what definition of capacity is used. Furthermore, the effect of construction intensity can be quantified more reliably based on more data from different sources.

EVALUATION OF STRATEGIES

In conjunction with the MoDOT traffic experts, the traffic control strategies before the work zones were evaluated. The current strategies being implemented by the DOT were discussed in the context of the construction activities along interstates (EPG 616.13); a summary is presented below:

- Early Warnings
- Dynamic late merge zones
- Backup queuing
- Changeable or dynamic message signs (CMS or DMS)
- Maintain same number of lanes

Not all of these strategies are available for work zones located in rural interstate highways, for example, permanent or portable dynamic message signs are not always available and it depends on the policies of the construction agency or the department of transportation. For the work zones available and studied in this project only the last one listed above "Maintain same number of lanes" was implemented. According to the EPG (2014) this strategy consists of "the capacity of the roadway can be restructured by maintaining the same number of lanes by reducing the lane and/or the shoulder widths". Unfortunately, there were no different strategies implemented in the work zones studied to evaluate one versus the other.

It is recommended that in future studies several work zones with different strategies implemented be studied and that permanent cameras and traffic count data collection points are installed. This way a longer period of traffic flow can be studied and the different levels of congestion may be measured to compare the different capacities determined for each work zone strategy.

CONCLUSIONS AND RECOMMENDATIONS

Two different definitions were considered to determine the value of work zone capacity: 1) an indirect approach using the equation 25-1 of the HCM (2010), and 2) three-regime speed-flow model. The values of capacity were determined using the available data for a long-term work zone located near Eureka, Missouri. The work zone was in place for about three months and the open lane was separated from the activity area using concrete barriers.

To determine the intensity of construction activity, the number of personnel and the heavy equipment present in the construction area were used as criteria. Light construction was defined as if there were less than 10 personnel in the work area and as a result less construction equipment and work were present. Otherwise, it was defined as heavy construction activity within the work zone.

Using equation 25-1 of the HCM (2010), for the two conditions of light and heavy construction activity, capacity values were found to be in the range of 1655-1747 with a mean value of 1704 vphpl, and 1574-1708 with a mean value of 1682 vphpl, respectively. Using the three-regime model approach the capacity values were found to be in the range of 1760-2288 with a mean of 2023 vphpl, and 1767-2000 with a mean of 1922 vphpl for light and heavy construction intensities, respectively.

A statistical comparison between the capacity values found in this study using either methodologies indicates that there is an effect of construction activity on the values work zone capacity. It was found that the heavy construction activity reduces the capacity value by 22-288 with a mean value of 101 vphpl. This comparison, however, is made for only the one work zone data available in this study. The capacity values found in this study are subjective depending on the definition of capacity used. This shows how the perception of capacity affects the results of a study and emphasizes a careful evaluation of the methodologies used in the analysis of capacity. This matter shows even greater importance as traffic characteristics are being considered in the work zone areas because these construction areas exhibit different conditions to the travelers and affect their behavior, compared to basic freeway segments with no lane closures.

It is very beneficial to conduct similar studies on the capacity of work zone with different lane closure barriers, which is also directly related to the type of work zone being short-term or long-term work zones. Also, the effect of different geometric and environmental characteristics of the roadway should be considered in other studies.

It is recommended to collect traffic data from different work zones with break downs and therefore, a comparison between the effects of construction intensity on work zone capacity would be feasible. In such cases, when there are several quality data sets are available from different work zones, a regression analysis would be one of the best choices on evaluating the effects of various factors existing in the work zone area such as types of traffic control devices, number and types of different work zone machinery, number of personnel, time of construction activity, etc.

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APPENDIX

A list of the files contained in the electronic media is listed in Table 10.

Table 10. Files contained in the electronic media

Folder/ File Name	Description/ Type
CD - St Louis ASTI data	Includes complete raw ASTI data received in a CD / Excel files
Google map pictures of the work zone area	Incudes pictures of the work zone area/ jpeg
Initial ASTI data downloaded from website	Includes initial raw ASTI data for a few days downloaded at from their website / CSV files
Traffic data extracted from video	Includes the raw data extracted from the work zone videos captured during data collection and analyzed / Excel files
DWR from 8-15 to 10-15 for RTE 44 EB and WB rebuild Project.pdf	Work zone diary provided by the work zone contractor / Adobe pdf file

Table 11 presents a sample of the raw ASTI data. Included with this project is a CD, which contains related data and analysis results.

Table 11. Sample ASTI raw data

QDID	Change Time UTC	Check-in Time UTC	Lane Count	Avg. Occupancy	Avg. Speed	Total Volume	Lane Group	Avg. Volume	Record Change Time UTC
Q08	5/15/2012 20:36	5/15/2012 20:35	1	13	35	11	W	11	5/15/2012 20:36
Q08	5/15/2012 20:36	5/15/2012 20:35	1	13	35	11	W	11	5/15/2012 20:36
Q08	5/15/2012 20:38	5/15/2012 20:36	3	25	25	57	W	19	5/15/2012 20:38
Q08	5/15/2012 20:39	5/15/2012 20:38	3	26	29	62	W	20.66666667	5/15/2012 20:39
Q08	5/15/2012 20:40	5/15/2012 20:39	3	24	29	59	W	19.66666667	5/15/2012 20:40
Q08	5/15/2012 20:42	5/15/2012 20:40	3	25	32	67	W	22.33333333	5/15/2012 20:42
Q08	5/15/2012 20:43	5/15/2012 20:42	3	34	18	44	W	14.66666667	5/15/2012 20:43
Q08	5/15/2012 20:44	5/15/2012 20:43	3	28	22	53	W	17.66666667	5/15/2012 20:44
Q08	5/15/2012 20:45	5/15/2012 20:44	3	26	27	61	W	20.33333333	5/15/2012 20:45
Q08	5/15/2012 20:46	5/15/2012 20:45	3	28	32	76	W	25.33333333	5/15/2012 20:46
Q08	5/15/2012 20:47	5/15/2012 20:46	3	27	22	56	W	18.66666667	5/15/2012 20:47
Q08	5/15/2012 20:48	5/15/2012 20:47	3	39	14	40	W	13.33333333	5/15/2012 20:48
Q08	5/15/2012 20:49	5/15/2012 20:48	3	24	25	50	W	16.66666667	5/15/2012 20:49
Q08	5/15/2012 20:50	5/15/2012 20:49	3	21	31	56	W	18.66666667	5/15/2012 20:50