# *TEMPORAL CAPACITY TRAITS AT LONG-TERM URBAN WORK ZONE BOTTLENECKS*


By

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## ABSTRACT

Many work zone capacity definitions are currently in use, each with its own assumptions, field-observed and theoretical values. Thus, it is very important to state which definition is being used when designing a work zone configuration. Typically, capacity for work zone locations has been considered to be a single value for any time of the day and for any day of the week. In this paper, three different temporal traffic flow conditions (i.e., weekday morning peak flow, weekday after morning peak flow, and weekend peak flow) were distinguished and used to identify three corresponding "temporal capacities". These temporal traits reflect different flow conditions or regimes for measuring the capacity and they should be analyzed separately.

The study examined two long-term urban freeway work zone locations in Milwaukee, Wisconsin that experienced significant demand throughout daytime hours. Work zone capacity values were evaluated by time of the day and day of the week. The study found that different capacities (sustained maximum flows) may be observed at the same work zone location. Non-queue conditions during the early morning peak periods yielded different capacity in comparison with the period of queue discharge conditions observed after the morning peak hour. Capacity differences were also observed on weekdays and weekends. The apparent loss in capacity due to queuing and congestion was also examined in this paper.

## 1. INTRODUCTION

Researchers and experts who work in the field of traffic operations and capacity start realize recently the need to expand the comprehensibility of the capacity definition and analysis. It has been noticed by those researchers and experts that the HCM procedures of analyzing the concept of capacity and LOS F (or breakdown) conditions are oversimplified and there is a real need to add some more desirable complexity to these procedures. For example, capacity definition and analysis should address, distinguish and handle all different types of freeway sections for multiple daily or weekly time periods. In addition, additional research is needed on the apparent loss of capacity once oversaturated conditions occur, and also on the gradations of LOS F. Moreover, traffic characteristic trends (i.e., occupancy, volume, and speed) during capacity and congestion conditions should be studied and stated clearly.

This study is to provide a more precise understanding and analysis of traffic capacity and operation at work zone locations which are unique types of freeway sections. In particular, the purpose of the study is to introduce a new methodology to analyze work zone capacity by evaluating the capacity for different times of the day and different days of the week. The new methodology associates different work zone capacities for a given location with traffic conditions observed at different times. Capacity drop due to congestion and trends of traffic characteristics at work zones were also investigated. The next section of this paper provides a literature review regarding the definitions of work zone capacity. The third section explains the data collection process. Data analysis process is provided then in the fourth section which is followed by the final section that includes conclusions and future research suggestions.

## 2. DEFINITIONS OF WORK ZONE CAPACITY

Because of the complexity of traffic characteristics at work zones, work zone capacity has been defined in several ways. A Texas Transportation Institute study defined Work Zone Capacity (WZC) as the hourly traffic volume under congested traffic conditions [1]. A study conducted in

California measured volumes for three-minute time intervals during congested conditions; these intervals were averaged and multiplied by 20 to determine the one-hour WZC [2]. These two definitions mirror the definition of "queue discharge flow" offered in the Highway Capacity Manual [3], defined as "…traffic flow that has just passed through a bottleneck and is accelerating back to the FFS of the freeway." Researchers of a North Carolina study defined WZC as the traffic volume immediately before queuing begins [4]. Jiang defines capacity as the flow just before a sharp speed drop followed by a sustained period of low vehicle speed [5]. The latter two definitions are in agreement with the HCM [3] "…Studies suggest that the queue discharge flow rate from the bottleneck is lower than the maximum flows observed before breakdown." The HCM suggests that "…Unlike free flow, queue discharge and congested flow have not been extensively studied, and these traffic flow types can be highly variable… Further research is needed to better define flow in these two regimes." Since traffic conditions vary significantly between queuing and pre-queuing conditions at work zone locations, a more precise WZC analysis may consider two WZC values; one for pre-queuing conditions, and one for queuing conditions.

As defined in the Highway Capacity Manual HCM [3], the capacity of a highway facility is "the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions." All previously mentioned definitions of WZC complied to varying degrees with the general definition of capacity given by the HCM, but none of them matches that definition perfectly.

The HCM general definition of capacity includes two important and sensitive clauses. The first important clause is the "can reasonably be expected" which means that traffic engineers should be reasonably assured to observe in practice any proposed capacity value for a freeway section. The second important clause of the HCM definition is "under prevailing roadway, traffic, and control conditions" which means that the definition is based on an assumption of consistent road geometry, traffic composition and other operating conditions that might affect capacity.

For this study, the following clear and practical definition of WZ "**Service Capacity**" will be used **"Work Zone Service Capacity is the maximum observed hourly traffic flow through the work zone, under prevailing roadway, traffic and control conditions."** This definition mirrors the general HCM definition of capacity; but however, the definition is still general and it is worth mentioning the following important points:

***First:*** The proposed definition accounts for realistic traffic conditions which means it accounts for factors that cause non-ideal utilization of the roadway such as aggressive maneuvers, not relying on the presence of optimal speed, and so on. Therefore, the capacity here is a realistic, not an ideal theoretical capacity.

***Second:*** The proposed definition states the capacity in terms of vehicles per hour (vph). Converting the capacity units from vph into passenger cars per hour (pcph) may be implemented by determining the percentage of Heavy Vehicles (HV) in the traffic stream.

***Third:*** Capacity is measured under prevailing roadway, traffic, and control conditions. The roadway geometry leading to and through the taper should be described in detail and it should be constant for the whole study period. On the other hand, since traffic conditions vary by time of day and day of the week, the following three different capacities observed at different times or different traffic conditions are proposed to be used in this research:

■ *Weekday Morning Peak Flow:* is defined as traffic flow which occurs at weekday morning peak hours and which also precedes queue formation. This flow is characterized by high volume and the absence of queuing conditions.

■*Weekday after Morning Peak Flow:* is defined as queue discharge rate which occurs after weekday morning peak hours and is also prevalent through the whole day until the evening peak hours. This flow is characterized by slightly lower volume and the presence of queuing conditions.

■*Weekend Peak Flow:* is defined as traffic flow which occurs around or after noon and is characterized by high volume and mild queuing conditions.

The study is proposing to handle each of the above periods individually since each period is associated with different prevailing traffic conditions and a sustained traffic flow is present in each period. All of the three above capacity definitions comply perfectly with the two important main clauses in the HCM (i.e., “reasonable expectations” and “prevailing conditions”). Such precise capacity definitions should provide transportation agencies with more accurate and practical capacity values that can be used more efficiently for planning, design, traffic management and operation purposes.

## 3. DATA COLLECTION

All data used in this study were acquired from Wisconsin Department of Transportation (WisDOT) sources. Traffic data were retrieved from the WisTransPortal Project webpage. This WisDOT-supported website maintained by the TOPS laboratory of the University of Wisconsin-Madison provided detailed basic traffic stream characteristics (five-minute occupancy, volume, and speed) at locations of interest during WZ periods, as well as during normal freeway operations periods. The HCM 2000 recommends five-min intervals as the shortest time base for practical purposes. Although 5-min, 15-min, and 60-min time data were used in assessing data quality and data analysis topics, 15-min time aggregation was used for the following two reasons; (1) it avoided the instability associated with shorter time measurements, and (2) it still captured the likely traffic fluctuation during one-hour analysis periods. Therefore, it was felt that the 15-min time aggregation provided a desirable basis for data analysis. Unless otherwise noted, all computations presented in this paper are based on 15-min time aggregations.

**4. DATA ANALYSIS**

The study area was the northbound direction of USH 45 immediately north of the Zoo interchange in Milwaukee County, Wisconsin. As mentioned earlier, two work zone locations were studied. In the following, the analysis for each work zone is introduced.

**4.1 ZOO INTERCHANGE WORK ZONE: LOCATION I**

Figure 1 illustrates the geometry and lane configuration for this location during work zone activities. This freeway segment contained two successive work zones operated together. A 660-foot taper, delineated with evenly-spaced traffic barrels (every 50') was used at each location. The four-lane cross section was first tapered into three lanes at Blue Mound Road and further tapered into two lanes at Wisconsin Avenue. The upstream work zone was favorable to the downstream because it was performing as a metering area that organized traffic entering the downstream work zone. In general, this whole freeway work zone segment was considered to be a four-to-two lane (4-2) work zone.

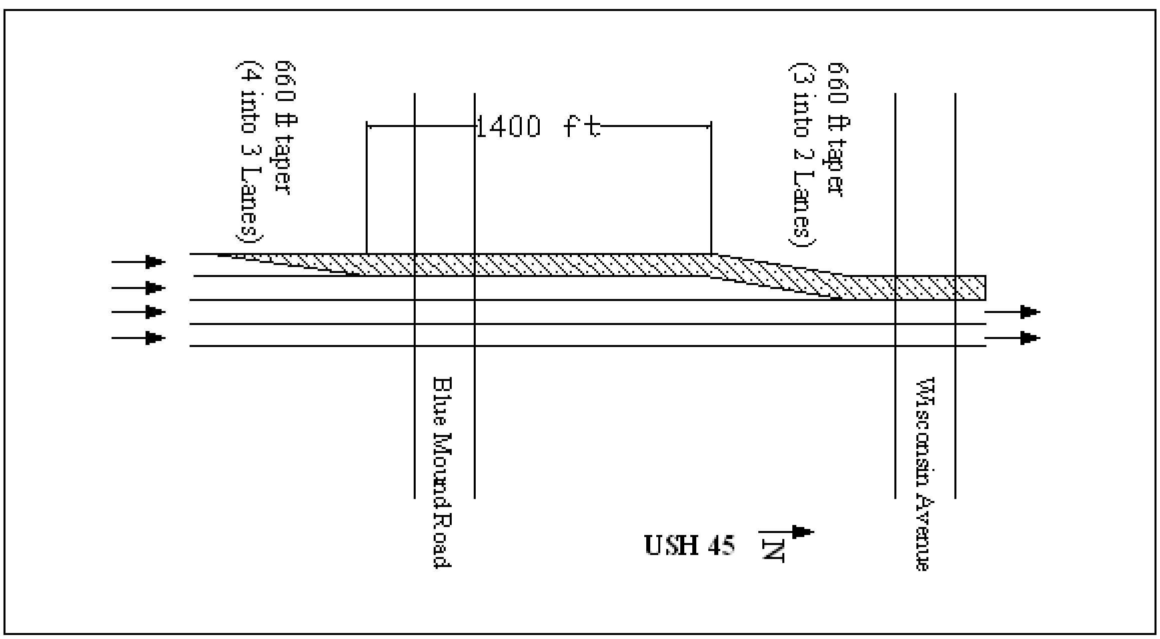



Figure 1. Geometry and lane configuration for work zone at location (I).

## WEEKDAYS

Figure 2 shows traffic occupancy, volume, and speed during the course of a typical normal weekday at this location. The general trend for traffic volumes was a sudden increase between 6:00 A.M. and 7:00 A.M. followed by a sudden decrease. After this decrease, traffic volumes reached relatively constant levels with smaller fluctuations between about 7:00 A.M. and 7:00 P.M. The morning peak conditions are represented by the circled parts of the figure.

One might argue that the sudden morning traffic volume increase is a typical peaking phenomenon, and the sudden decrease afterwards is simply the dissipation of the peak traffic volume. In fact, this argument is not valid because after the sudden pronounced traffic flow peak, traffic stream occupancy gets much higher indicating an increasing congestion level. As congestion levels increase, speeds drop significantly. Therefore, the sudden traffic flow drop is actually attributed to congestion, not to peak volume dissipation. There is no need here to look any further for the source of congestion than the bottleneck created by the downstream taper. In conclusion, prevailing congested traffic conditions lasted about 10 hours, following the sudden drop after the morning flow peak.

### Weekday Morning Peak Flow

As shown in Table 1, a total of 43 15-min observations (10.75 hours) were analyzed for the morning peak periods when sudden increases in the traffic volume (morning flow peaks) were noticed in the traffic stream. During these hours; the average WZC was approximately 3950 vph (in two lanes), the average speed was 34 mph, and the average occupancy was equal to 29.4 %.

**Weekday after Morning Peak Flow (Queuing Conditions)**

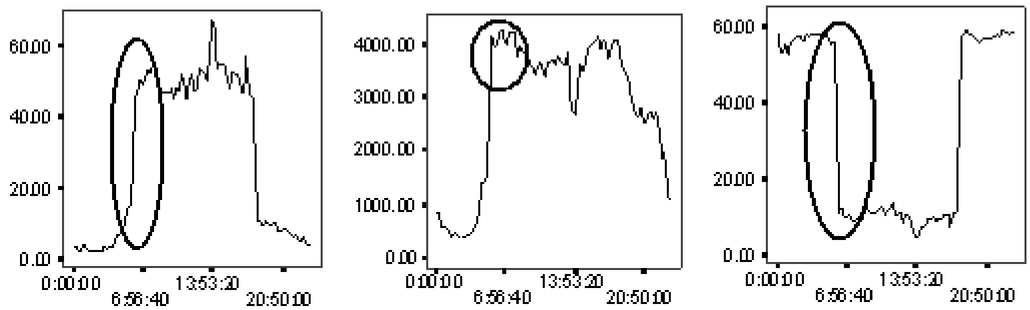
The criterion chosen to reflect congestion was occupancy. In order to ensure that conditions represented maximum WZ throughput (capacity), only hours with intensive continuous congestion conditions (occupancy greater than or equal to 45%) were analyzed. A total of 371 15-min measurements (approximately 93 hours), selected among 10 weekdays satisfied this criterion.

Table 1 summarizes traffic characteristics during the 15-min periods that met the ≥ 45% occupancy criterion. During these time periods; the average WZC was approximately 3793 vph (in two lanes). This might be used as a base capacity for this long-term work zone since it is for the prevalent queuing conditions which last longer than morning peak conditions. In addition, the average speed was 9.5 mph and the average occupancy was equal to 50.5%.

**WEEKENDS**

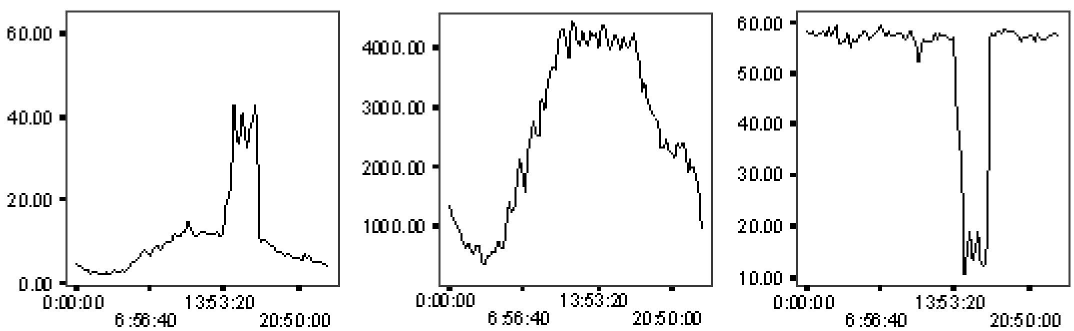
Figure 3 shows work zone traffic occupancy, volume and speed by time of day for weekends. Traffic volume increased gradually until it reached a mild peak around 2:00 P.M.; it remained at this level until around 5:00 P.M. when it started dropping gradually. During the weekend mild peaks, occupancy values did not indicate the severe congestion conditions observed during weekdays, still speeds were quite low.

For measuring WZC during weekends, only measurements with occupancy greater than or equal to 25% were selected. A total of 25 15-min measurements were selected. As illustrated in Table 1, the average WZC was approximately 3975 vph (in two lanes), while the average speed was 19.6 mph and the average occupancy was 33%.




Occupancy (%) Volume (vph in two lanes) Speed (mph)

Figure 2. Weekday traffic characteristics—work zone location (I).
Circles demonstrate morning peaking periods.




Occupancy (%) Volume (vph in two lanes) Speed (mph)

Figure 3. Weekend traffic characteristics—work zone location (I).

| Period | Traffic Characteristics | N | Minimum | Maximum | Mean | Std. Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|---|
| Weekday | OCCUP % (upstream) | 43 | 11.1 | 53.5 | 29.4 | 15.86 | 53.9% |
| Morning | WZC vph (two lanes) | 43 | 3420.0 | 4352.0 | 3949.9 | 216.28 | 5.4% |
| Peaks | Speed mph (upstream) | 43 | 7.5 | 58.2 | 34.1 | 20.61 | 60.4% |
| Weekday | OCCUP % (upstream) | 371 | 45.0 | 59.2 | 50.5 | 2.85 | 5.6% |
| Queuing | WZC vph (two lanes) | 371 | 2528.0 | 4400.0 | 3792.5 | 262.41 | 6.9% |
| Conditions | Speed mph (upstream) | 371 | 6.0 | 14.8 | 9.5 | 1.49 | 15% |
| Weekend | OCCUP % (upstream) | 25 | 20.8 | 43.1 | 33.0 | 6.31 | 19% |
| Congested | WZC vph (two lanes) | 25 | 3464.0 | 4356.0 | 3973.3 | 220.29 | 5.5% |
| Conditions | Speed mph (upstream) | 25 | 10.1 | 37.1 | 19.6 | 7.99 | 40% |

N: number of 15-min observations.

Table 1. Summary of traffic characteristics for different periods — (Location I).

### 4.2 ZOO INTERCHANGE WORK ZONE: LOCATION II

Figure 4 shows the geometry and lane configuration of this location. The work zone taper closed the right northbound lane; only the left northbound lane was opened during the construction period. The configuration for this work zone was a two-to-one lane (2-1). Unfortunately, no weekend data were available for this work zone. Figure 5 shows traffic occupancy, volume and speed by time of day during weekdays. The general trends of WZ traffic characteristics in these graphs are similar to the trends observed in Location I.

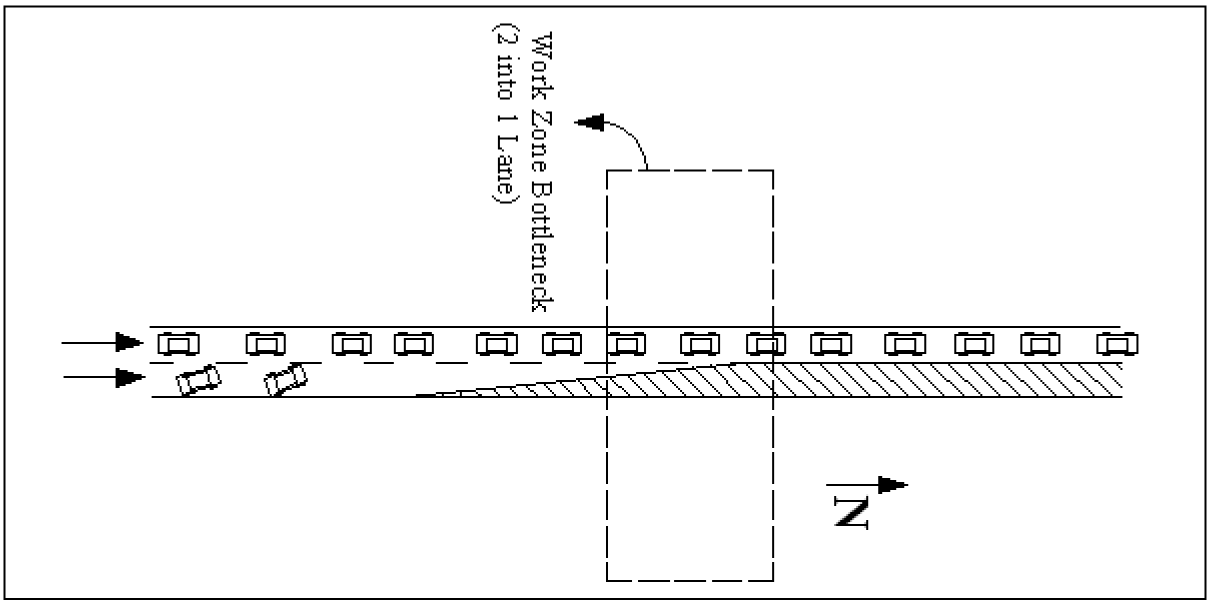
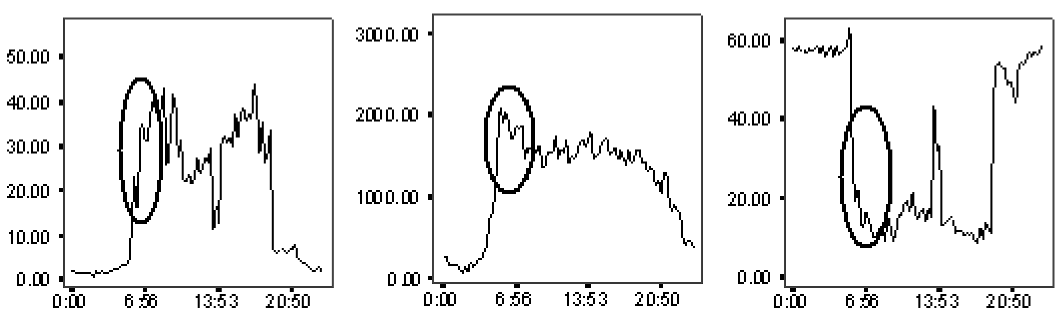



Figure 4. Geomtery and lane configuration for work zone at location (II).




Occupancy (%) Volume (vph in one lane) Speed (mph)

Figure 5. Weekday traffic characteristics—work zone location (II).
Circles demonstrate morning peaking periods.

**Weekday Morning Peak Flow**

A total of 30 15-min observations (7.5 hours) were analyzed for the morning peak periods. As illustrated in Table 2, the average WZC was approximately 1870 vphpl, the average speed was 20 mph, and the average occupancy was equal to 26.8 %.

**Weekday after Morning Peak Flow (Queuing Conditions)**

Prevailing congested conditions or queue discharge conditions were defined as times when occupancy exceeded 45%. The following traffic characteristic ranges were present during periods of prevailing congested conditions (as shown in Table 2); occupancy from 45% to 55%, speed from 8 mph to 11 mph, and finally traffic volume from 1250 vph to 1900 vph. The average WZC was about 1560 vphpl.

| Period | Traffic Characteristics | N | Minimum | Maximum | Mean | Std. Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|---|
| Weekday Morning Peaks | OCCUP % (upstream) | 30 | 8.4 | 44.3 | 26.8 | 9.71 | 36.3% |
| | WZC vph (one lane) | 30 | 1736 | 2088 | 1871.5 | 86.45 | 4.6% |
| | Speed mph (upstream) | 30 | 9.9 | 49.2 | 20.0 | 10.25 | 51% |
| Weekday Queuing Conditions | OCCUP % (upstream) | 18 | 45.4 | 56.8 | 47.8 | 2.66 | 5.6% |
| | WZC vph (one lane) | 18 | 1244.0 | 1908.0 | 1562.2 | 142.13 | 9% |
| | Speed mph (upstream) | 18 | 7.9 | 10.4 | 8.9 | .61 | 6.9% |

N: number of 15-min observations.

Table 2. Summary of traffic characteristics for different periods — (Location II).

### 4.3 DISCUSSION

The following two tables summarize the previously mentioned findings for the two locations and for the three different periods: weekday morning peaks, the 10-hrs after weekday morning peaks and weekend peaks.

| Traffic Characteristic | Weekday morning peaks | After weekday morning peaks | Weekend peaks |
|---|---|---|---|
| Number of 15-min Obs. | 43 | 371 | 25 |
| Occup % (upstream) | 29.4 | 50.5 | 33.0 |
| Speed mph (upstream) | 34.1 | 9.5 | 19.6 |
| WZC vph (two lanes) | 3950 | 3793 | 3973 |
| WZC vph (one lane) | 1975 | 1896 | 1986 |
| Coeff. of variance for WZC | 5.4 | 6.9 | 5.5 |
| Capacity loss after queuing | N/A | 4% | N/A |
| HV (%) | missing | 12.8 | 6.1 |

Table 3. Traffic characteristics—all analyzed periods (Location I: 4-2 work zone).

| Traffic Characteristic | Weekday morning peaks | After weekday morning peaks |
|---|---|---|
| Number of 15-min Obs. | 30 | 18 |
| Occup % (upstream) | 26.8 | 47.8 |
| Speed mph (upstream) | 20.0 | 8.9 |
| Coeff. of variance for WZC | 4.6 | 9 |
| WZC vph (one lane) | 1872 | 1562 |
| Capacity loss after queuing | N/A | 16.7% |

Table 4. Traffic characteristics—all analyzed periods (Location II: 2-1 work zone).

*Comparing weekday morning peak flow with the after peak queuing conditions*

Average WZ exiting volume during morning peaks was considerably higher compared to average volumes under the after peak queue discharge conditions. In the first location, for example, average traffic volume during the morning peak was around 3950 vph. As congestion lasted a longer time, queues start spilling back and the service rate dropped from 3950 vph to around 3790 vph (a reduction of 4%). In the second location, the apparent loss in capacity due to queue formation after morning peaks was much higher (a reduction of 16.7%). The following three interpretations were proposed to explain the variation between the two flows:

- The stochastic nature of capacity and breakdown introduced recently [6,7] indicates that the facility can handle a demand which is equal or even higher than the capacity for a considerable amount of time without breaking down. This means that the examined two work zones can resist breakdown even with high throughput during the early morning peak flows. Afterward, a persistently high demand causes the facility to breakdown and queues to form and spill back.

- Driver population factor during peak hours usually increases the capacity during such hours (a higher percentage of drivers familiar with the location are more likely to travel during this period), and this also helps in explaining the higher traffic flows observed before queue formation.
- The variability of traffic volumes (as indicated by the coefficient of variance in Table 3 and Table 4) was lower for the morning peak conditions in comparison with the after peak queuing conditions. Queuing theory indicates that the variability of the arrival rate adversely affects the utilization of a facility resulting in a significantly lower service rate, longer queues, and more congestion.

*Comparing weekend peaks with weekday non-peaking 10-hours*

The average weekend peak throughput in Location (I) is considerably larger than the WZC computed for weekday after peak hours (3975 compared with 3790, an increase of 5%), so we may assume that this value represents a weekend WZC. A possible explanation for the higher weekend capacity is that during weekends, heavy vehicle percentage drops significantly (from 12.8% to 6.1% at this location), and WZC exhibits a lower variability (coefficient of variance drops from 6.9% to 5.5%). These two factors will tend to increase WZC. The presence of heavy vehicles, as described in the literature, is well known for reducing WZC because these vehicles operate on lower acceleration rates, move at lower speeds and create empty spaces in front of and between them. In addition, as explained before, the utilization of a facility increases when the variability of the arrival rate (traffic flow fluctuation) decreases.

## 5. CONCLUSIONS

This study expanded the set of presently used capacity definitions with the addition of temporally defined WZC definitions. The following are the major conclusions drawn from this research:

- Three major temporal capacity traits can be distinguished at work zone locations: weekday morning peak flow, weekday after morning peak flow (queue discharge rate), and weekend flow. Those definitions complied with the HCM definition of capacity since they were based on the identification of maximum throughput under more accurately defined “sustained traffic conditions”.
- The apparent loss of capacity following weekday peaks at the onset of oversaturated (queuing) conditions was significant. It was found to be equal to 4% for a work zone with a 4 to 2 lane configuration, and 16.7% for a work zone with a 2 to 1 lane configuration.
- It should be noted that the drop in capacity after morning peak is not due to peak dissipation, but is mainly due to queue formation.
- If maintenance activities can be scheduled to be performed only in the first one hour during each two successive hours, then according to the stochastic nature of capacity, morning peak conditions may be repeated and recaptured again every other hour and queues may be eliminated entirely during the whole day.
- The longest-lasting WZ operation at capacity was found to be the weekday after morning peak flow under queuing conditions. This capacity was equal to 1900 vphpl for a work zone with a 4 to 2 lane configuration and 1560 vphpl for a work zone with a 2 to 1 lane configuration.

- Weekend peak work zone capacity was found to be 5% higher in comparison with weekday after morning peak flow and close to the weekday morning peak flow.
- Those comparisons and the associated findings are very useful from a traffic management point of view. If it is possible to manage the traffic stream during weekdays so that the same traffic characteristics are present as are during weekends or during weekday morning peaks, then a higher long-lasting weekday WZC may result. Findings are also useful in design, planning, and traffic operations applications.

More research is recommended to evaluate and analyze the gradations of breakdown and capacity at work zone locations. More specifically, investigations into traffic performance measures (e.g., delay and queue length), time required for the facility to breakdown, speed management strategies, and a detailed investigation of peak hour conditions are all recommended topics that should improve our understanding of traffic operations at work zones.

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