TECHNICAL NOTE

MOTORWAY FACILITY ANALYSIS IN THE 2010 HIGHWAY CAPACITY MANUAL

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ABSTRACT

The 2010 edition of the U.S. Highway Capacity Manual provides a macroscopic procedure for developing speed and density contours in the time-space domain for one direction of a motorway with capacity bottlenecks. The FREEVAL spreadsheet implementation, which is driven by a Visual Basic engine, can analyse a maximum of 24 consecutive time periods and 70 segments. It can be used to estimate the relative performance of alternative design and operational solutions in both under- and over- saturated traffic conditions. This technical note introduces the procedure and then a directional motorway corridor applications is briefly presented to exhibit some typical uses such as work zone impact assessment, ramp metering, and improvements to bottleneck capacity.

INTRODUCTION

The Highway Capacity Manual [HCM] provides operational analysis methods to estimate the capacity and other operational measures of effectiveness such as delays, queues and Level of Service for a wide range of transportation facilities (ref.1). The 2010 edition of the Highway Capacity Manual [HCM] will be published later this year. As well as revisions for the methods of analysing individual motorway segments such as basic, ramp and weaving segments in under-saturated conditions, there is an updated freeway facilities chapter which is able to combine these discrete motorway segments into a directional corridor, and now extend the analysis to over-saturated conditions with bottlenecks and their associated queue formation and dissipation patterns over space and time (ref.2).

This technical note will introduce key aspects of the procedure and exhibit some typical uses such as work zone impact assessment, ramp metering and bottleneck elimination on a directional motorway corridor.

FREEWAY FACILITY CONCEPTS

Consistent with other HCM methodologies, the freeway facilities method is a macroscopic deterministic approach to traffic operational analysis. The method is however unique in the HCM in that it encompasses multiple segments and can further be used to analyze operations across multiple time periods. The methodology has been independently validated against field data.

For purpose of analysis, a freeway facility is divided into basic segments, on-ramp or off ramp segments, or weaving segments, defined as a freeway on-ramp followed closely by an off ramp and with two ramps connected by an auxiliary lane. The methodology is directional and the analyst evaluates one direction of traffic at a time. While the two directions on a freeway are largely independent, the effects of onlooker delays that result from an incident occurring in the opposing direction can be modeled.

The methodology can evaluate a facility in an extended time-space domain (Figure 1). In this context it is critical to distinguish between the demand volume that is forecast to travel on a facility and the actual volume served on that facility. In general, an upstream bottleneck will meter traffic and as a result the volume served is less than the demand volume. The constrained volume served is equal to the capacity of the bottleneck itself. Consequently, all downstream segments will experience a consistent reduction in volume served at a level less than or equal to the capacity of the upstream bottleneck.

In the section upstream of the bottleneck, the method tracks the forming and dissipation of queues using a linear flow-density relationship. If the demand volume exceeds the capacity of a downstream section a queue will grow at a shockwave speed calculated from the jam density and the density and flow at capacity.

In an extended time-space domain, the model further tracks any residual demand and processes these un-served vehicles in subsequent time intervals. The resulting volume served can therefore be greater than the demand volume in the periods where queues are clearing. Depending on the configuration of the facility, a downstream bottleneck that is less severe than the metering upstream bottleneck may be inactive or hidden. This effect would not be captured by a single segment-level analysis.

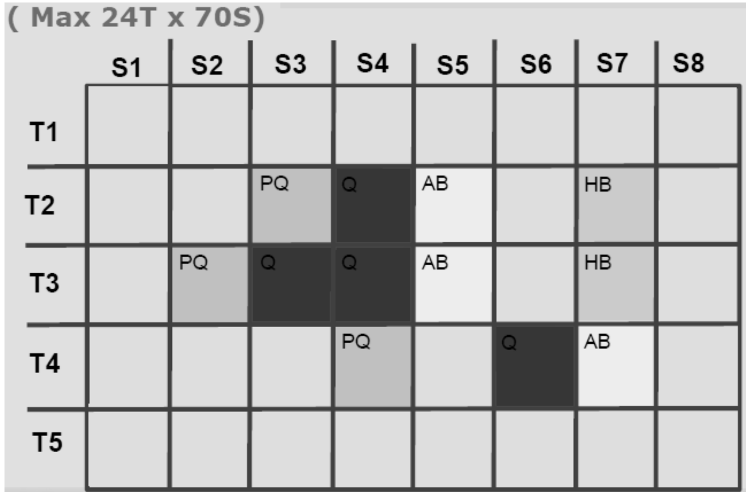

Figure 1 Time-Space Domain Indicating Queuing at Actual Bottlenecks and Hidden Bottlenecks (motorway segmented S1 to S8 left to right, time from top T1 to bottom T5, PQ = pre-queue, Q = in-queue, AB = actual bottleneck, HB = hidden bottleneck)

THE FREEVAL COMPUTATIONAL ENGINE

The computational engine, FREEVAL (FREeway EVALuation) 2010 is a computerised, worksheet based environment designed to faithfully implement the operational analysis computations for undersaturated and oversaturated directional freeway facilities (ref.3). Thus, FREEVAL 2010 is a faithful implementation of the HCM

FREEVAL is executed in Microsoft Excel, with most computations embedded in Visual Basic modules. The environment allows the user to analyze a freeway facility of up to 70 analysis segments (to be defined) and for up to twenty four 15 min time intervals (6 h). The engine can generally handle any facility that falls within these temporal and spatial constraints. However, it is recommended that the total facility length not exceed 15-25 km in length to ensure consistency between demand variability and facility travel time. Further, the analysis boundaries (in time and space) should be uncongested and should allow all queues to form and clear within the facility to assure that performance measures fully encompass the predicted extent of congestion and delay.

Data output in FREEVAL appears at three levels of aggregation: for every 15 minute time period and segment; average segment performance over all time periods and all segments; and graphically for a select number of measures of effectiveness by segment and time period, such as volume to capacity ratio, demand to capacity ratio, segment speed, segment density, and level of service (LOS). All these outputs are used to evaluate the operational performance of a facility.

APPLICATION TO A NEW ZEALAND MOTORWAY

As part of the evaluation process for this new updated procedure and software, a congested 25 km long motorway corridor in New Zealand was coded and the methodology applied. A set of pre-processing and post-processing spreadsheets were used to input scenarios and to summarise and to compare outputs of indicative construction, ramp metering and capacity improvement strategies in metric units. Note that due to time and resource constraints, the model was not calibrated rigorously, as our main purpose was to verify the mechanics of the software engine and provide feedback to the developers. However, the base case corresponded qualitatively with the field conditions in terms of correctly identifying the known bottleneck locations, and the extent and duration of queues during a typical weekday.

The following series of speed contour Figures 2, 3, 4 and 5 show a progression from the existing condition over a typical 24 hour weekday for the base case and daytime periods only for future scenarios. Time flows from top to bottom and traffic direction is from left to right. Black "stop and go" segments are 0% to 50% of free flow speed, dark grey congested segments 50% to 70% ffs, light grey undersaturated segment 70% to 85% ffs, and white uncongested segments 85% to 100% ffs. The four cases shown are:

- Base Case of an existing weekday;
- Evaluation of a long term work zone with speed restrictions and lane closures;
- The post-construction period with decreased ramp metering rates;
- A long term set of capacity improvements aimed at eliminating the major bottlenecks.

Thus, the model was used as an effective macroscopic tool to efficiently evaluate and compare these scenarios at a strategic level.

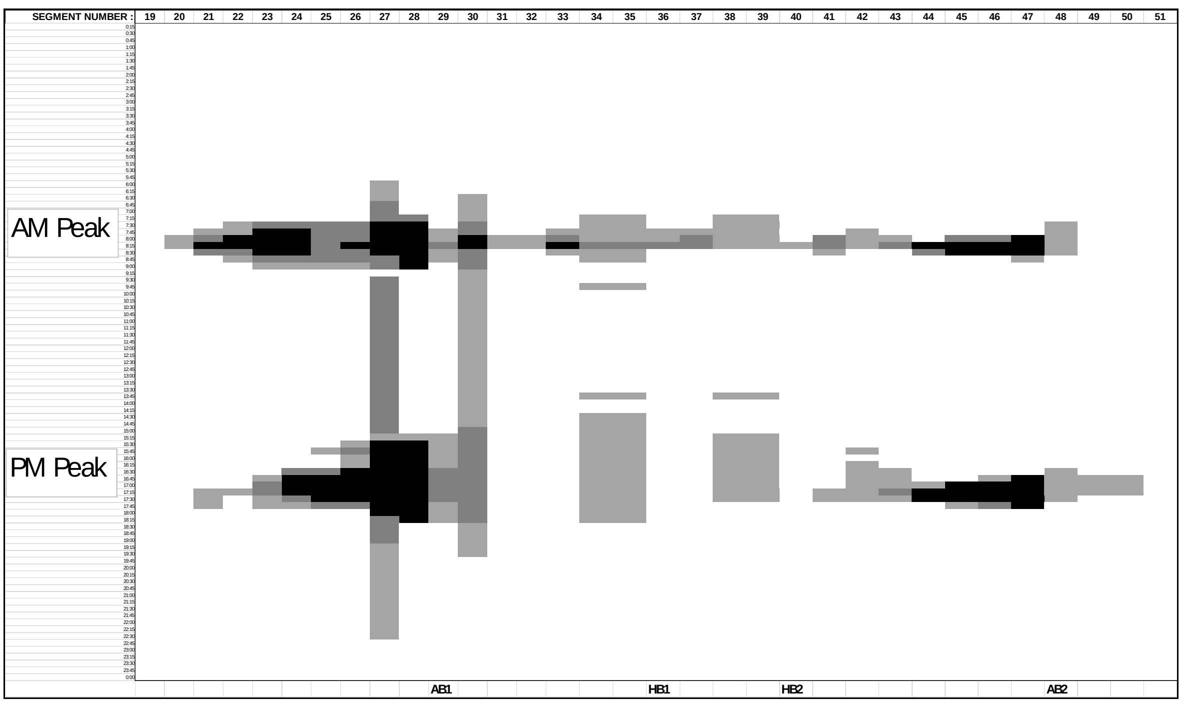

Figure 2 Existing Conditions Base Case Speed Contours (AB = actual bottleneck, HB = hidden bottleneck)

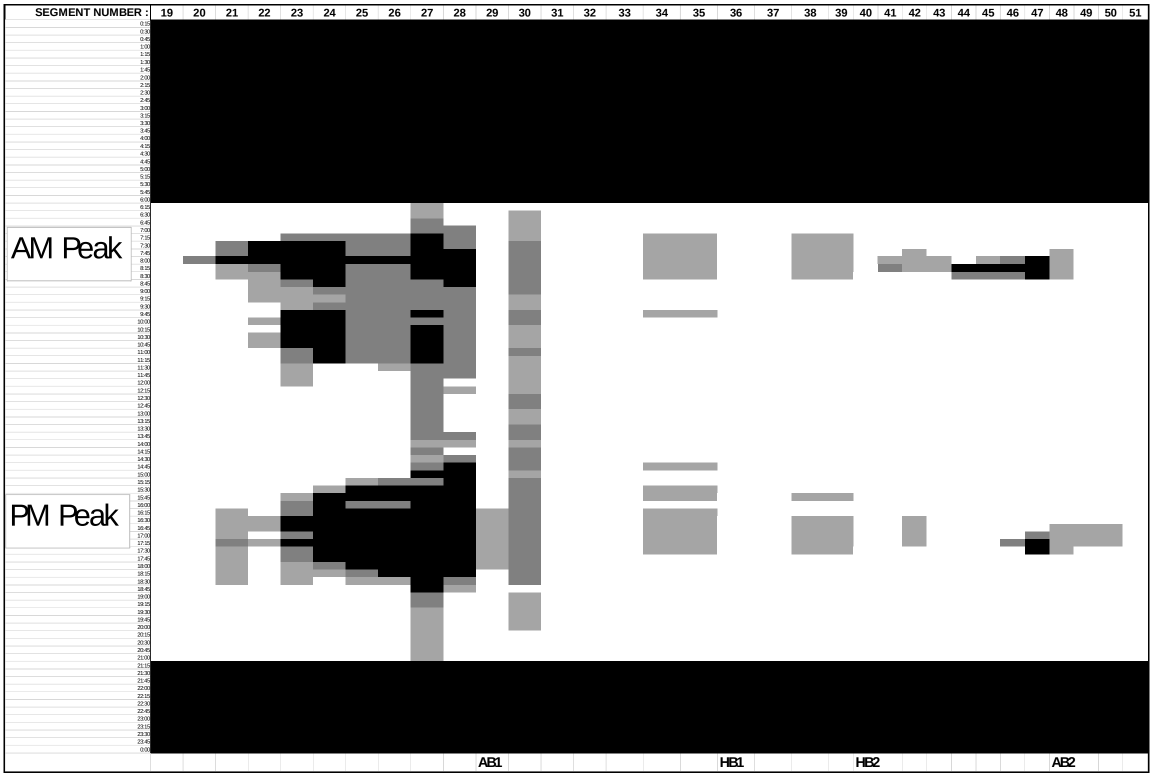

Figure 3 Long Term Work Zone Effects Speed Contours (AB = actual bottleneck, HB = hidden bottleneck)

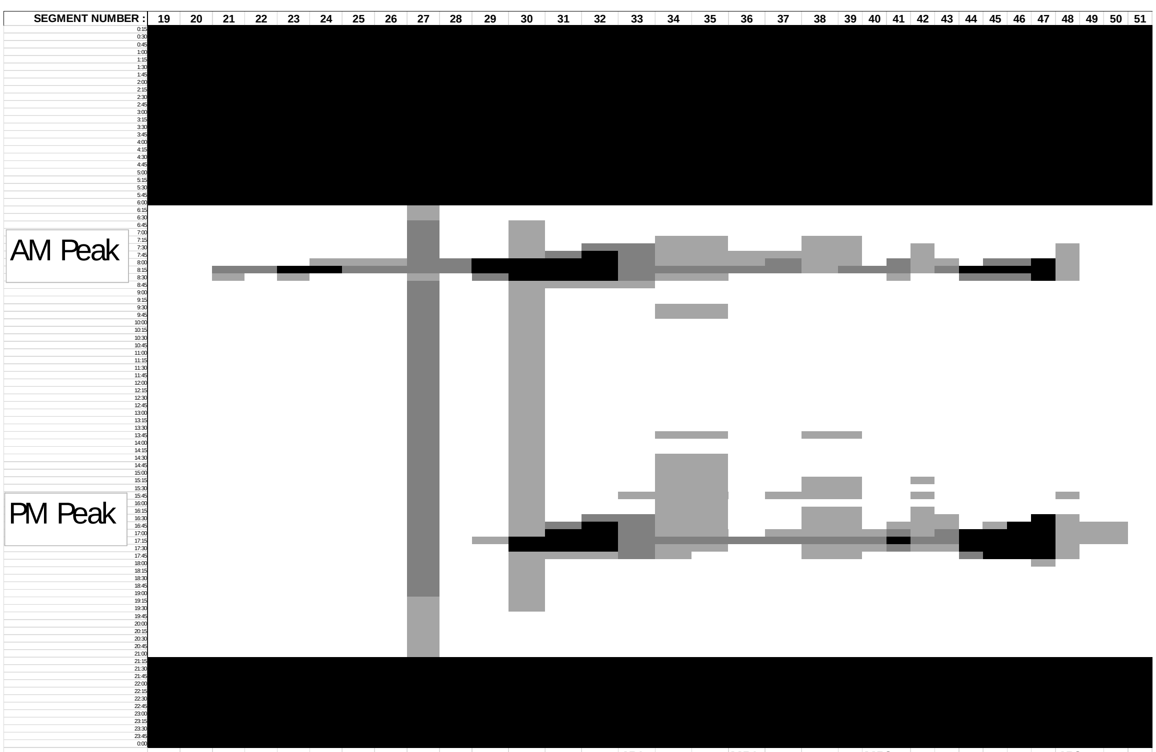

Figure 4 Post-Construction and Decreased Ramp Metering Rate Strategy Speed Contours (AB = actual bottleneck, MB = minor bottleneck)

Figure 5 Long Term Lane Capacity Improvements Speed Contours

CONCLUSIONS

The 2010 HCM will be published later this year. As well as analysing individual motorway segments such as basic, ramp and weaving segments in under-saturated conditions, there is a freeway facilities chapter which is able to combine these elements in a directional corridor, and extend the analysis to over-saturated conditions with bottlenecks and resultant queue formation and dissipation.

This technical note has introduced the procedure and briefly described a directional motorway corridor application to exercise the FREEVAL software implementation. As well as estimating the existing performance of a motorway facility, some typical uses such as work zone impact assessment, ramp metering, and bottleneck capacity improvements were demonstrated.

Our assessment is that that although the HCM is a U.S. document and the Freeway Facilities method is intended for use on U.S. freeways, the computational engine FREEVAL is a promising tool for use on New Zealand motorways to measure or forecast their operational performance, for strategic planning of long-term capacity improvements, evaluation of the impacts of construction work zones, as well as for tactical deployment of ramp metering and other operational strategies.

REFERENCES

1. Transportation Research Board, *Highway Capacity Manual*. 2000

2. Transportation Research Board, *Highway Capacity Manual - Final Draft*. 2010 (unpublished)

3. Transportation Research Board, *Highway Capacity Manual - Draft FREEVAL User's Guide (May 2009)*. 2009 (unpublished)

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