Estimation of Delay using Sensor Data for Reporting through Business Intelligence

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Keywords: Business Intelligence, Delay, Sensor Data, Intelligent Transportation Systems.

Abstract: This study proposes a simple method to estimate delay using sensor data with the final objective of processing and reporting the information through Business Intelligence. The method involves three main tasks: determination of the Peak Period, definition of seasons used by FAST, and the calculation of delay. A small portion of the Las Vegas Roadway network is used to illustrate results. Functional requirements for Business Intelligence are proposed.

1 INTRODUCTION

Congestion and incident management require the involvement of multiple stakeholders who need reliable and easy access to data and analytics to make adequate planning and operational decisions. Business Intelligence (BI) involves the use of informatics to provide access to data and associated analytics. That is, BI involves the processing of data to provide meaningful and easy to use information (NEDELCU, 2013). BI with its real time reporting and automated capabilities at different organization levels has become an important management and tracking tool in developed countries (Nofal and Yusof, 2013). BI solutions have been proposed for transportation systems. Sampaio P., et al. (2011), provided an application to public transportation.

An alternative to BI is the use of traditional standalone applications. As part of the Regional Transportation Commission of Southern Nevada (RTCSN), the Freeway and Arterial System of Transportation (FAST) plays a major role in monitoring and reporting freeway incidents using a web-based dashboard, Performance Monitoring and Measurement System (PMMS) (http://bugatti.nvfast.org/). PMMS data is collected through sensors such as radar detectors, cameras, and Bluetooth devices (Xie and Hoeft, 2012). The information is stored in a databased and retrieved through Structured Query Language (SQL) queries.

This study proposes a simple but very practical algorithm for reporting day using sensor data collected by RTCSN. Currently, there is data available for 449 sensors. Information from four sensors along the US 95 corridor in Las Vegas for the 2014 Spring season was used in this study. The data is constantly updated for display on the dashboard.

With the objective of developing a BI dashboard for the Nevada Department of Transportation (NDOT) the percent of days in a season with a daily peak period delay that does not exceed the average delay by more than 10% is considered in this study. This performance measure is of particular interes to NDOT. The calculation of this measure involves three main tasks: determination of Peak Period, definition of seasons used by FAST, and the calculation of delay.

2 METHODOLOGY

2.1 Determination of Peak Period

Generally, Department of Transportation (DOTs) define two peak periods per day; one in the morning and one in the afternoon. However, this static definition could miss important information about non-recurrent and nocturnal events. In Las Vegas area, it is observed that there are often two or more periods depending on the location and season. Therefore, a more detailed analysis is required for the estimation of the peak periods.

This methodology recommends to define the peak periods based on a definition provided by the

Molano, V. and Paz, A.
Estimation of Delay using Sensor Data for Reporting through Business Intelligence.
In *Proceedings of the International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2016)*, pages 99-103
ISBN: 978-989-758-185-4

Federal Highway Administration (FHWA) Office of Operations, where congestion thresholds are estimated and the duration of the congestion is used as the peak period.

"Measuring congestion by times of the day and days of week has a long history in transportation. A relatively new twist on this is the definition of a weekday "peak period"—multiple hours rather than the traditional peak hour. In many metropolitan areas, particularly the larger ones, congestion now lasts three or more hours each weekday morning and evening. In other words, over time, congestion has spread into more hours of the day as commuters leave earlier or later to avoid the traditional rush hour" (FHWA, 2015).

This phenomena together with the characteristics of the Las Vegas commutes and tourism makes undesirable to define a static peak period. To identify the congested periods, FHWA defines thresholds using the hours in which the speeds are less than 90% of the free-flow speed.

"Congested Hours are computed as the average number of hours during specified time periods in which road sections are congested — speeds less than 90 percent of free-flow speed" (FHWA-UCR, 2015).

To estimate average free flow speed, data from the Highway Performance Monitoring System (HPMS) can be used.

2.2 Definition of Seasons

The definition of seasons used by FAST are: Beginning of year, Holiday, Fall, Summer, Early Summer, and Spring. The detailed definition of the seasons is provided in Table 1. For this study Spring of 2014 is considered.

Table 1: FAST Definition of Seasons.

Season	Description
Beginning of year	First day of CCSD school following holiday break through a Friday in mid-March
Holiday	Monday before Thanks giving to day before CCSD school begins
Fall	First day of CCSD school following summer vacation to Sunday before Thanksgiving
Summer	Final weekend of CCSD high school graduations through Sunday before the new school year begins
Early Summer	A Monday in mid-April through the last weekend of CCSD school activity and graduation ceremonies
Spring	A Saturday in mid-March through a Sunday in mid-April

2.3 Delay Calculation

The National Cooperative Highway Research Program (NCHRP) proposes a methodology to calculate delays for a segment (NCHRP, 2008). Equation 1 provides the corresponding formula.

$$Total\ Delay = [ATT - TT(FFS\ or\ PSL)] \\ x\ Volume\ x\ Occupancy \quad (1)$$

where,
$Total\ Delay$ = the total delay for a segment (persons-minutes)
ATT = Actual travel time in minutes
$TT(FFS\ or\ PSL)$ = Travel time under free flow speed or posted speed (minutes)
$Volume$ = Vehicle volumes (number of vehicles)
$Occupancy$ = Vehicle occupancy (persons/vehicle)

The FAST sensors do not capture the *occupancy* in terms of persons per vehicle. Therefore, from Equation 1, the *occupancy* is removed and the *Total Delay* is reported in vehicle-minutes. This modification does not affect the calculation of the performance measure required by NDOT.

3 TEST SAMPLE

A test example, for a 1.6 miles segment along the US-95 Corridor in Las Vegas, was performed. Information from four sensors for the 2014 Spring season was used in this example. The location of the sensors and the segment is illustrated in Figure 1. The analysis includes only the southbound located sensors.

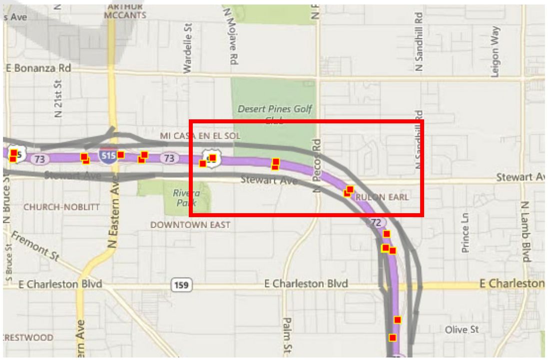

Figure 1: Location of the Test Example Sensors.

The results from the test example are shown in Table 2. The identification number and the length of the segments where the detectors are located is provided. The percent of days in a season that have a daily peak period delay that does not exceed the average delay by more than 10% for each detector is provided in column, 'Percentage'. In total, for the 1.6 miles segment, 39.78 % of days in spring of 2014 have a daily peak period delay that does not exceed the average delay by more than 10%. This value is estimated by calculating a weighted average of percentages using Vehicle Miles Traveled (VMT) as the weights.

Table 2: Sample Test Results.

Detector	Length (mi)	VMT (veh-mi)	Percentage
204_1	0.28	5585837.989	81%
204_2	0.42	8501308.598	28%
210_1	0.52	10940883.45	47%
210_2	0.38	5806442.714	3%
TOTAL	1.60	30834472.75	

In addition to the required performance measure, the data can be queried based on the facility, a selected region, year, month, weekdays, and weekend days. As an example, Table 3 shows the summary of the calculation for the week and weekend days in spring of 2014. These capabilities can be implemented in BI with ease in addition to the requested performance measures.

Table 3: Sample Test Results for Week and Weekend Days.

Detector	Percentage (Week days)	Percentage (Weekends days)
204_1	75%	92%
204_2	0%	75%
210_1	25%	92%
210_2	0%	10%

In total, for the 1.6 miles segment, 22.46% of the weekdays and 71.87% of the weekend days in spring of 2014 have a daily peak period delay that does not exceed the average delay by more than 10%. This value is estimated by calculating a weighted average of percentages using the Vehicle Miles Traveled (VMT) as the weights.

To calculate the required performance measure, the following steps are proposed:

1. Calculate the length of the segments from the network geometry used by FAST.
2. Estimate the free-flow speed using geometrical characteristics from the HPMS database. This step requires integration between the HPMS and FAST networks. The procedure in the 2010 Highway Capacity Manual for basic freeways was used (HCM, 2010) in this study.
3. For each sensor and day in the season, average the speeds and aggregate the volumes to hourly values.
4. For each sensor, determine the peak period's where the actual averaged speeds are less than 90% of the free-flow speed. Using the free-flow speed and the actual speed, a Boolean variable was created to flag the peak periods. Illustrations of the peak period's estimation for different sample days of the season are shown in Figure 2 and 3. Figure 2 shows one peak period interval for the detector 204_1 during April 10th of 2014. Figure 3 shows two peak periods, one in morning and one in the afternoon for detector 204_2 during April 7th of 2014. The algorithm detected days in the season when there was none peak period. In contrast, days where found when the congestion kept constant throughout the day.

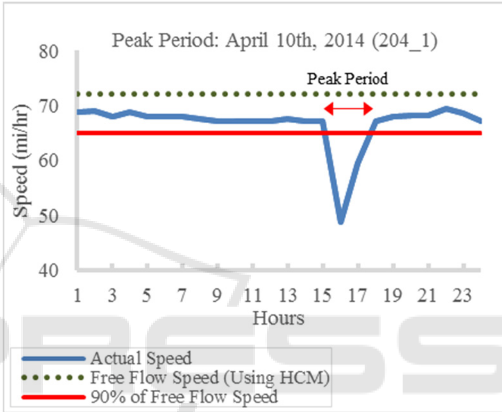

Figure 2: Peak Period Sensor 204_1.

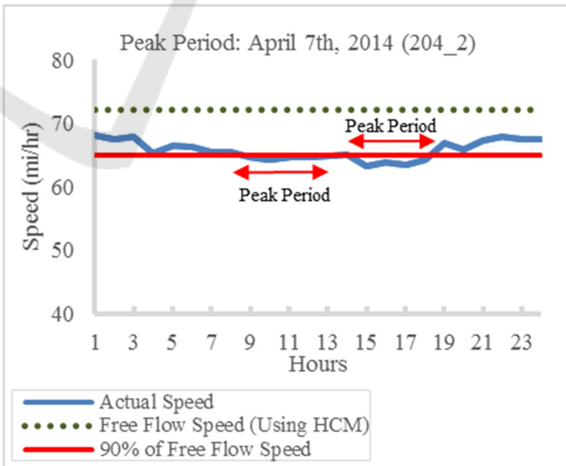

Figure 3: Peak Period Sensor 204_2.

5. For each sensor, determine the average delay in the season. Delays for each hour where calculated using the NCHRP methodology.
6. For the corresponding flagged hours from Step 4, if the hourly delays do not exceed the average

delay by more than 10 %, then flag the day. Figure 4 and Figure 5 shows that for the peak periods, the actual delay exceeded the average delay for at least one hour for the sensor 204_1 and 204_2. For some days in the season the delay exceeded the average delay, however, the speed threshold showed that there was not a peak period.

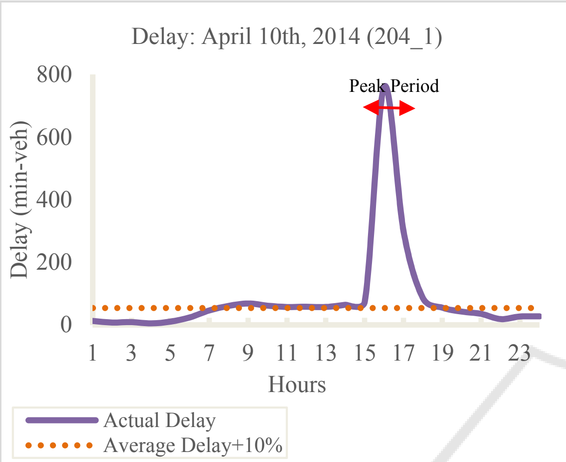

Figure 4: Delay Sensor 204_1.

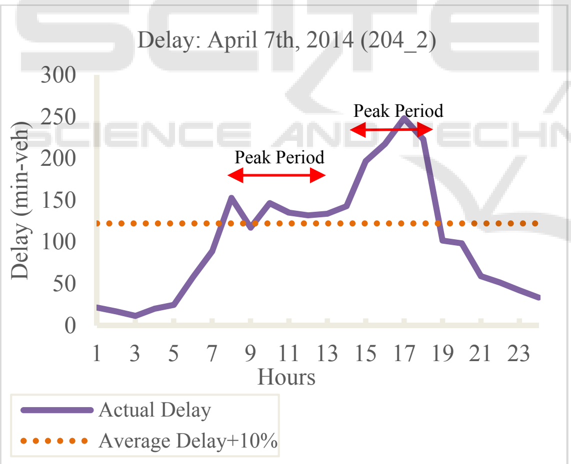

Figure 5: Delay Sensor 204_2.

7. For each sensor, count the number of days that meet the condition in Step 6.
8. Determine the total number of days in the season.
9. For each sensor, using the number of days from Steps 7-8, compute the percentage of days in the season that do not exceed the average delay by more than 10%.
10. Calculate the associated VMT for each sensor and season.
11. Using the VMTs from Step 10, calculate a weighted average of the percentages in Step 9. The average represents the required performance measure.

4 FUNCTIONAL REQUIREMENTS

This study recommends a dashboard to display the results from the proposed methodology. The recommendations for functional requirements of the dashboard proposed in this study are:

1. The BI dashboard will provide pie charts and tables with percentages from the delay analysis.
2. A section be provided with various prompts to allow users to query the data based on corridor, year, month, day, and season.
3. Users have the ability to set the peak hour threshold, using drop down menus or range selectors. This will improve the dynamic functionality of this dashboard. However, this capability is likely to be computationally intensive. Implementation is required to have a better idea about performance.
4. Dashboard should provide a table with detailed information about each day. This table will be filtered based on the selections in a prompts section. The table cells can be color-coded to denote higher delays and peak hours.
5. To have the ability to generate a map using the roadway geometry information. This map will be color-coded to represent the delays for each segment. It can be filtered based on the selections in the prompts section. From this map, users can drill down to a segment or corridor information.
6. To provide charts and tables with aggregated traffic values based on facilities. The aggregated values include speeds, volumes, and travel times. This chart will be filtered based on the selections in the prompts section.
7. To acquire location information to display the sensors on a map in BI. This map will be color-coded to represent the delays for each sensor. It can be filtered based on the selections in the prompt section. From this map, users can drill down to get sensor information.

5 CONCLUSIONS

This paper proposes an algorithm for reporting delay as required by NDOT. Eleven steps were proposed to evaluate dynamically daily peak periods and delays. A test sample from Las Vegas highway system was presented from which the percentage of days in a season that do not exceed the average season delay for more than 10%. The test sample showed that the proposed algorithm is able to define congestion periods for multiple traffic conditions. In addition, the methodology can be extended to multiple corridors by using the average of the performance measures found with the Vehicle Miles Traveled as weight. Moreover, additional performance measures based on volumes or densities can be added to the methodology. A set of seven functionalities are proposed for the implementation of a dashboard. The proposed functionalities consider the capabilities and current available data.

Thresholds and formulation proposed by the Federal Highway Administration were used to define the peak periods and delay (FHWA, 2015; FHWA-UCR, 2015). Future studies involve the development of a methodology for the estimation of recurrent and non-recurrent peak periods and delays using a mathematical framework tailored for the problem.

ACKNOWLEDGEMENTS

The authors are very grateful with the Nevada Department of Transportation for sponsoring this project. Authors would like to express deep gratitude to Regional Transportation Committee of Southern Nevada for providing the data and support during the development and testing component of this study.

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