ABSTRACT

Title of Thesis: ADVANCED DATA ANALYTICS AND MESOSCOPIC DYNAMIC TRAFFIC ASSIGNMENT SIMULATION FOR TRAFFIC IMPACT ANALYSIS OF MARYLAND CASINOS

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Three full-service casinos recently opened in Maryland: Live! Casino at the Arundel Mills Mall (June 2012), Horseshoe in Downtown Baltimore (August 2014), and MGM at the National Harbor (December 2016). The increased travel demand associated with such large entertainment complexes prompted an effort to quantify each facility's impact on regional and local traffic patterns; therefore, a three-pronged analysis was conducted. First, historic vehicle probe data were analyzed to quantify and visualize the observed, local traffic impact for selected months before and after each casino became operational. Subsequently, an open-source mesoscopic DTA simulator named DTALite modeled the regional impact of the before/after scenarios as well as a special

event scenario (e.g. Baltimore Raven's football game). The paper's final component explored two innovative trip generation estimation methods to supplement the ITE Manual's data limitation for casinos by utilizing aggregated mobile device trip data and an origin-demand adjustment system imbedded within DTALite. Ultimately, the data analytics and simulation-based modeling revealed no major traffic impact was generated by any casino. Moreover, upon comparison with ground truth count data, the origin-demand estimation technique out-performed both the ITE-based and location-based trip estimation methods.

ADVANCED DATA ANALYTICS AND MESOSCOPIC DYNAMIC TRAFFIC ASSIGNMENT SIMULATION FOR TRAFFIC IMPACT ANALYSIS OF MARYLAND CASINOS

by

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2019

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Acknowledgements

This research was supported financially by the Maryland State Highway Administration (SHA) under a project titled *Advanced Data Analytics and Mesoscopic Models for Special Event Impact Study at Maryland Casinos*. The project allowed me to improve my analytic and communication skills as project manager, and provided me the opportunity to work with hardworking, intelligent people who all exhibit a desire to advance the fast-evolving field of transportation. I wish to personally thank the other members of the project team, Laura Garrido and Zheng Zhu, who helped me throughout the early stages of the project. I also thank my family for their unwavering support throughout the research effort and life in general. Most importantly, I express sincere appreciation to my advisor Prof. Lei Zhang. His direction, insightfulness, and immense knowledge guided me through my research and graduate studies and opened many doors of opportunity that were seemingly out-of-reach beforehand.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background

A traffic impact analysis (TIA) is essential when planning, developing, and maintaining our transportation system. A TIA is simply defined as an engineering study that estimates the traffic impact of a proposed traffic generator. Upon the approval of a major urban development, newly generated trips can disrupt existing traffic flow and lead to the deterioration in roadway safety and level of service. The findings from a well-executed TIA detail the necessary roadway improvements that may be necessary to ensure site owners have sufficient access to the transportation system and roadway users do not experience significantly worse travel conditions because of an increase in traffic volume.

The stipulation for completing a TIA is subject to the expected number of trips the proposed development will generate, the land-use type and size of development, and other significant development or area traffic characteristics. For example, 50 new trips during any hour of the week or 500 vehicles per day is one warrant set by the Delaware Department of Transportation (DelDOT, 2014). Exceeding a specific traffic volume threshold can be the deciding factor in the decision to request a streamlined review by a licensed transportation professional, or a detailed study that must address a list of analysis criteria established by different state, county, and local government bodies. The Maryland casinos analyzed as part of this paper were estimated to generate thousands of daily trips; therefore, an in-depth traffic impact analysis and full report was completed for each casino prior to construction.

Each state transportation agency typically publishes general TIA guidelines that align with state regulations that control land-use access permitting or rezoning. However, counties and municipalities may enforce additional requirements. In Maryland alone, counties such as Prince George's and Carroll Counties (MNCPPC, 2002; Bureau of Engineering, 1994), and municipalities like Annapolis and Baltimore (Dept. of Planning & Zoning, 2015; Baltimore City DOT, 2007) have their own set of policies and guidelines outlining TIA requirements for development within their political boundaries. Nonetheless, all TIAs encompass several universal reporting components that include the

(1) evaluation of current traffic conditions and the area's transportation infrastructure,

(2) estimation of generator trip generation, distribution, and network assignment,

(3) analysis of the future traffic conditions with and without the proposed generator, and

(4) recommendations for roadway improvements which may be necessary to accommodate the expected traffic.

A more detailed outline of the recommended TIA process published according to the Institute of Transportation Engineers (ITE) is shown in Figure 1.

The ITE community is responsible for publishing a number of useful technical resources for transportation engineers and planners alike. The latest edition of the *Recommended Practice on Transportation Impact Analyses* (2010) describes the traditional TIA procedure observed from numerous government jurisdictions across the U.S. and Canada, and has become an important resource for other jurisdictions to reference in the development of their own TIA guidelines. ITE has also been instrumental in developing

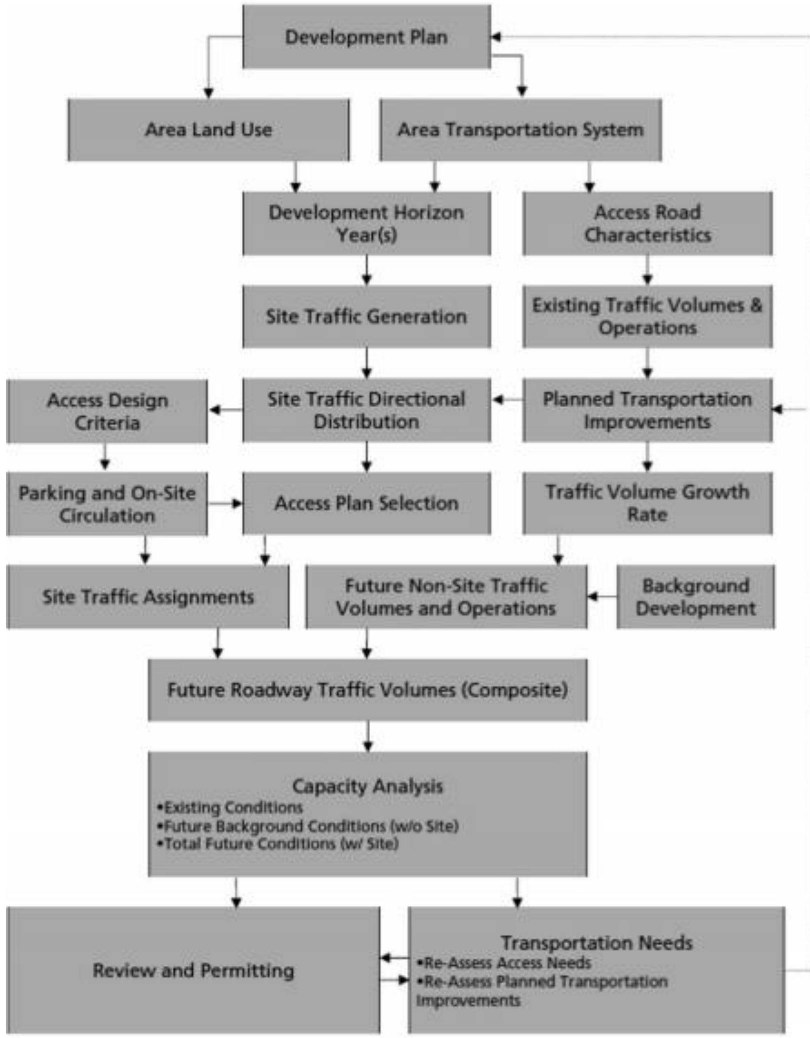


Figure 1: ITE traffic impact analysis flowchart (ITE, 2010)

guidelines for other transportation related topics such as geometric design, planning, safety, and TSM&O; however, there is one topic which ITE has been a leader in for decades and happens to be a focus of this paper: trip generation.

Trip generation is a process that calculates the volume of traffic entering and exiting a proposed site development. The measurement of origin and destination trips are estimated either as vehicle or person trips (e.g. persons in vehicle, bus, bicycle, or pedestrian), then classified as primary, pass-by, diverted, or internal trips (see Figure 2). To aid engineers and planners with the first step of modeling traffic behavior (i.e. trip generation), ITE has published many technical resources that include the most up-to-date *Trip Generation Manual, 10th Edition* as well as the *Trip Generation Handbook, 3rd Edition*. Both resources enable traffic analysts to initiate the traffic impact analysis process for a variety of scenarios based on the time of day, week, or special events.

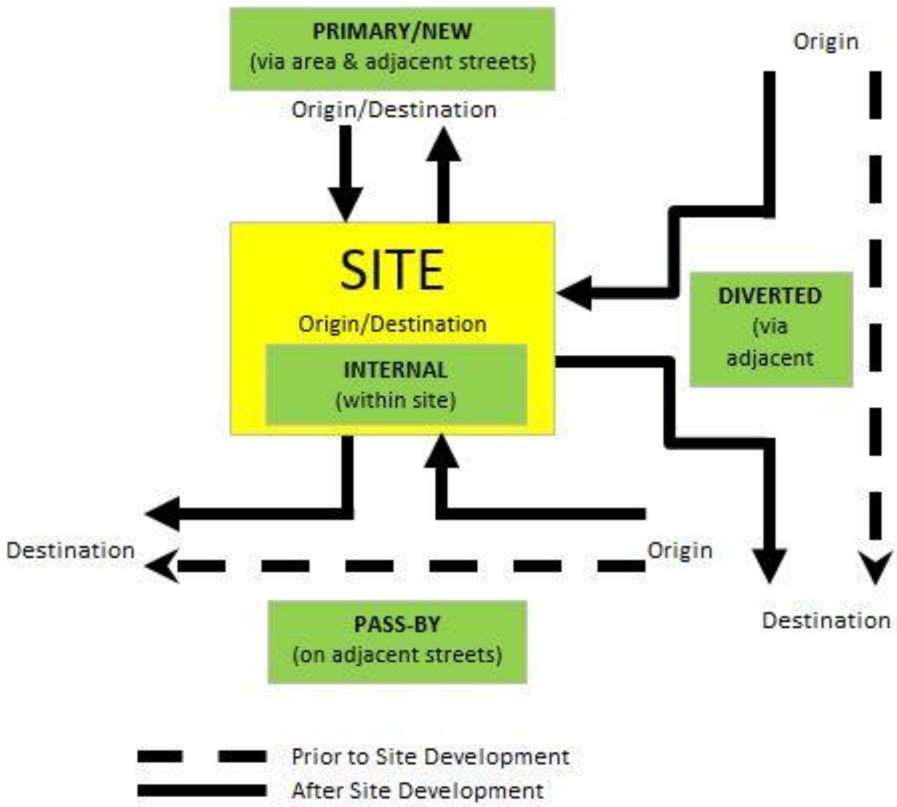


Figure 2: Trip Generation Types **(Ficek, 2017)**

The manual is comprised of two volumes, the Desk Reference and 3,000-page Land Use Data Plots. Users can utilize both resources to estimate trip rates a complete set of land use plots with regression equations that correlate trips with several independent land use and time period variables. A new feature of the manual is the ITETripGen Web-based App.

The desktop application provides electronic access to the trip generation dataset and allows quick-search land use types and filter the independent variables. The *Trip Generation Handbook, 3rd Edition* provides new or improved guidance on appropriate techniques for estimating person and vehicular trip rates, evaluating mixed use developments, and establishing local and pass-by trip rates.

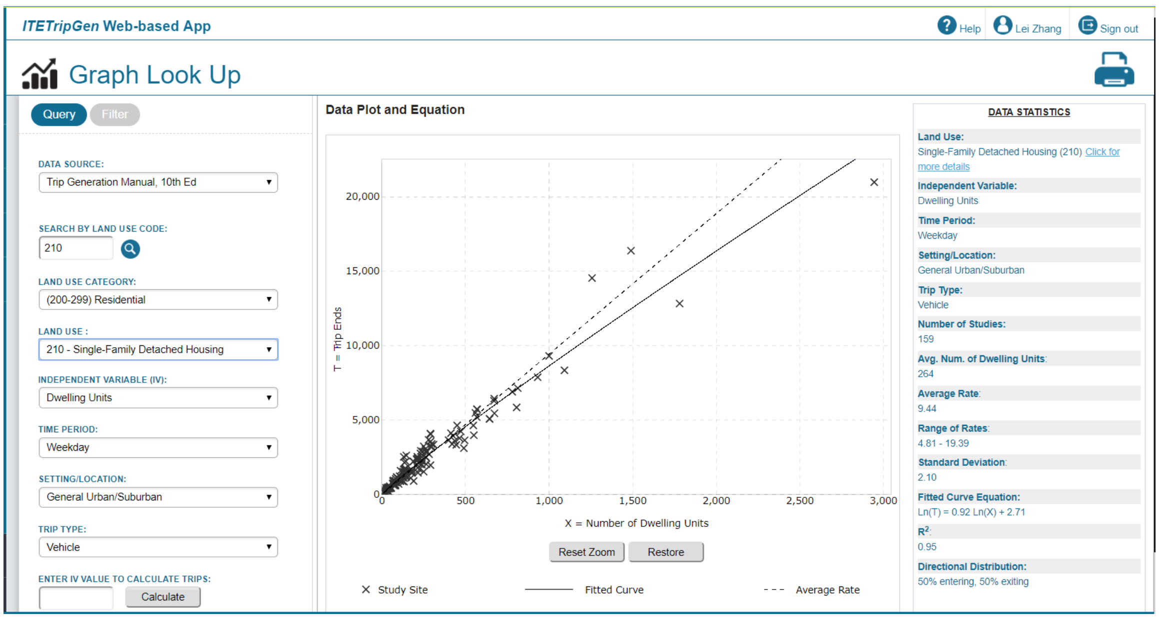


Figure 3: ITETripGen User Interface

Despite the periodic resource improvements in data coverage, access, and guidance for estimating different trip rate types, there are still limitations associated with implementing ITE national trip rates. One of the main limitations continues to be the data variability. The collection of trip data spans over five decades and varies by geographical location, time of year, and the duration of the collection period. Furthermore, either the number of data points for a land use is sparse, or the land category may not be available altogether in the manual (Tripi, 2011). Therefore, land use types with insufficient data are termed special generators and warrant the use of alternative trip estimation methods.

It is no secret the ITE Manual has several limitations. Local trip generation estimation is a common practice implemented across countless traffic studies. What makes each study unique is the approach used to estimate such rates. Over time many state-of-the-art methods have been devised (Currans, 2017). The emergence of more robust traffic analysis tools and probe vehicle data (i.e. GPS, cell phone, smartphone app-based) have attracted more practitioners to develop innovative strategies to estimating trip rates. This paper details a couple innovative approaches to trip generation that incorporate both advanced analysis tools and mobile data sources to investigate one particular special generator, a full-service casino. The same analysis tools and probe data sets are also leveraged to quantify the traffic impact analysis of several full-service casinos recently constructed in Maryland.

1.2 Maryland Casinos

Since 2000, several new casinos have opened throughout the Mid-Atlantic region including Maryland. From 2006 to 2018, more than 30 casinos of various sizes and amenities opened in five Mid-Atlantic states. Three additional casinos are expected to open by 2020.

Table 1: Expansion of Casinos in Mid-Atlantic Region

STATE	# OF NEW CASINOS (2006-18)	# OF CASINOS (In 2005)
Maryland	6	0
Virginia	No Casino Gambling	
District of Columbia	No Casino Gambling	
West Virginia	1	4
Delaware	0	3
Pennsylvania	12	0
New Jersey (Atlantic City)	2*	12
New York	11	14

*Due to increased out-of-state competition, more casinos have closed (6) or renamed during this period.

After casino gaming became legal in Maryland in 2008, several commercial casino licenses were awarded and the first of six casinos opened in 2010. The remaining casinos soon followed, one opening almost every successive year. By 2017, the six Maryland casinos had generated thousands of jobs and millions of dollars in tax revenue. The single-month record of casino gaming revenue collected from all the casinos was totaled at $158M in October 2018 ("Maryland Casinos Generate Record …", 2018). Most of Maryland's casino developments also provide a wealth of amenities that generate additional tax revenue for the state. Restaurants, retail outlets, hotels, and various entertainment venues augment the traditional stand-alone casino into full-scale entertainment facilities that, when combined, generate a significant economic impact on state and local communities.

The increased travel demand associated with any development of a large commercial entertainment complex is a general public concern whenever a new casino license is awarded to a developer. For example, the MGM Casino, the newest Maryland casino, serves as many as 17,000 guests daily. This does not include almost 4,000 personnel employed at the casino. As more people are attracted to the site, the amount of traffic around the casino also increases. A year after opening, an MGM casino representative reported about 800 more vehicles per hour on adjacent streets totaling 2,500 vph (Lazo, 2017).

Existing traffic congestion exacerbated by new casino trips and inadequate infrastructure improvements can cause longer delays for drivers throughout the area. Therefore, determining the traffic impact a new casino imposes on residents and businesses at both the regional and local scale is important. This paper independently analyzes the three largest Maryland casinos with the largest gaming floor areas and amenities to quantify the traffic impact produced by each casino. The three selected casinos are detailed below:

Live! Casino opened as the state's largest casino on June 6, 2012. Located in Anne Arundel County adjacent to the Arundel Mills Mall, the largest mall in the state, the casino currently houses nearly 4,000 slot machines and 189 table games within an approximately 160k square-foot gaming floor. This establishment's amenities are listed below (Live!, 2018):

- 11 Restaurants
- 4 Bars
- 1 Retail store (gift shop)
- Live! Hotel & Event Center*
- Live! Spa*
- Live! Center Stage – 500-seat venue

* These amenities opened after this study commenced; therefore, they are not included in the analysis.

Horseshoe Casino opened as the state's second largest casino (122k square footage for gaming) on August 26, 2014. Located on Russell Street in an industrial zoning district in Baltimore City, the casino is less than half a mile from the iconic M&T Bank Stadium, home of the Baltimore Ravens NFL franchise. Camden Yards, home of the Orioles MLB franchise, and Baltimore's Inner Harbor are nearby as well. Horseshoe Casino supplies 2,200 slots and 178 table games. This establishment's amenities include (Horseshoe Casino, n.d.):

- 9 Restaurants, including a 20,000 square-foot marketplace
- 2 Bars

MGM at the National Harbor opened with a cost of $1.4B on December 8, 2016 ("Maryland Casinos Generate…", 2018). Located just southeast of the I-295/I-495 interchange on National Avenue in Oxon Hill, the casino and hotel overlooks the Potomac River and National Harbor. In 2018, the resort expanded the gaming floor from 125k square feet to 163k square feet of gaming space, surpassing Live! Casino & Hotel to become the largest Maryland casino. The casino boasts 3,085 slot machines, 170 table games, and several amenities including the following ("MGM National Harbor", n.d.):

- 9 Restaurants
- 3 Bars
- 10 Retail stores
- Spa & Salon
- Theater – 3,000 seats
- 23-story hotel – 308 rooms

The size and number of amenities operated among these full-service casinos demonstrates the complexity of this particular special generator. These land use characteristics are instrumental in the estimation of local casino trip rates. The local ITE-based rates are later input into one of the analysis tools employed in this paper.

Figure 4: Maryland Casinos

1.3 Research Objectives & Contribution

There are three distinct traffic impact analysis approaches pursued by this paper:

1. The first analysis approach is data-driven and employs historic vehicle probe data obtained through the Regional Integrated Transportation Information System (RITIS) at the University of Maryland. RITIS is an online data platform that integrates and archives multiple transportation-related data sources. The data sources include INRIX/HERE/TomTom traffic data, event and work-zone records, crowdsourced Waze data, weather data, and surveillance video. RITIS data analytic tools were leveraged to assess the typical weekday, peak-period traffic impact before and after the casino became operational (see **Chapter 3**).

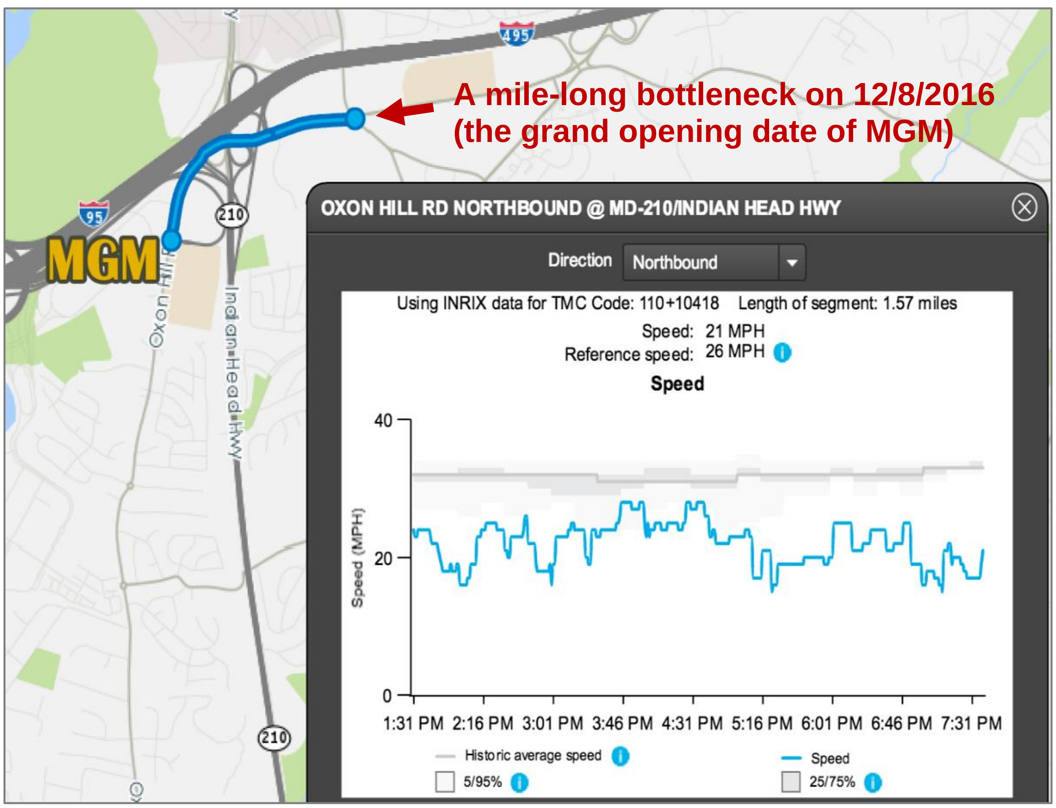


Figure 5: Casino special event congestion.

Second, a model-based approach is taken to forecast the travel impact of casinos at the regional level. The before/after scenarios as well as a casino plus special event scenario are defined and modeled using a mesoscopic dynamic traffic assignment (DTA) simulation model. The casino simulation model is calibrated and validated against observed traffic count and travel time data. The model results are quantified via travel time, speed, and link density performance measures (see **Chapter 4**).

The final analysis approach differs from the previous two approaches by focusing on the trip generation estimation process for full-service casinos. Currently, the state-of-the-practice for trip generation relies upon national rates from the *ITE Trip Generation Manual*. Although the manual is the most comprehensive source of trip generation rates available to practitioners, this national data set contains a lot of variability as well as insufficient data for special generators, especially for large casino entertainment establishments. Therefore, two innovative approaches were devised to estimate the local casino rates (see **Chapter 5**):

(1) Location-based trip estimation

(2) Statistical estimation using the Origin-Destination Matrix Estimation (ODME) system built into the DTA simulation software package.

This paper also aims to help contribute to the modernization of the current traffic analysis state-of-the-practice in several ways.

(1) This is the first study to analyze multiple full-service casinos using innovative traffic analysis tools and data sources. Both a probe data analytic tool that does not rely on the Highway Capacity Manual and mesoscopic simulation model are employed simultaneously to draw conclusions regarding the system and local impact of these casino complexes. Although no direct comparisons are made between the tools and their effectiveness in predicting traffic

performance, the method and data sources employed will provide additional examples of how these unconventional methods can be used to analyze traffic of a special generator traffic in operation.

(2) This is also the first study to introduce and compare two innovative approaches to estimating trip generation for special generators. The first approach highlights the advantages of using aggregated mobile data to determine the casino origin-destination trip pairs for a given time period and estimate the trip generation. The second approach utilizes an integrated traffic assignment and origin-destination demand calibration technique to approximate the casino trips based on site counts. The latter approach provides new insight into the way a mesoscopic simulation model can be used to derive trip rates.

1.4 Research Approach

The flowchart in Figure 3 illustrates the paper's tasks and their interdependencies. The literature review describes the types of analyses and tools that comprise the state-of-the-practice traffic impact analysis (TIA) process, the analysis methods found to be employed for full-service casinos, and the adjusted trip generation rates used for the three Maryland casinos a part of this study. Next, three analysis scenarios were defined, including an after casino + special event scenario to capture the traffic impacts of nearby traffic generators that may generate exceptionally high traffic volumes on rare occasions. Based on data availability, traffic patterns were evaluated using two analysis approaches: data-driven and model-based TIA. The advanced RITIS traffic monitoring data and visualization tools hosted at the CATT Lab at UMD were employed to directly evaluate the before/after traffic impact for each casino. Subsequently, mesoscopic DTALite models were developed based on casino and special event trip rates to evaluate the before/after traffic impact. Finally, two new ways to estimate trip generation were explored for a casino complex using different procured data sets and a mesoscopic modeling tool imbedded with a origin-demand calibration system.

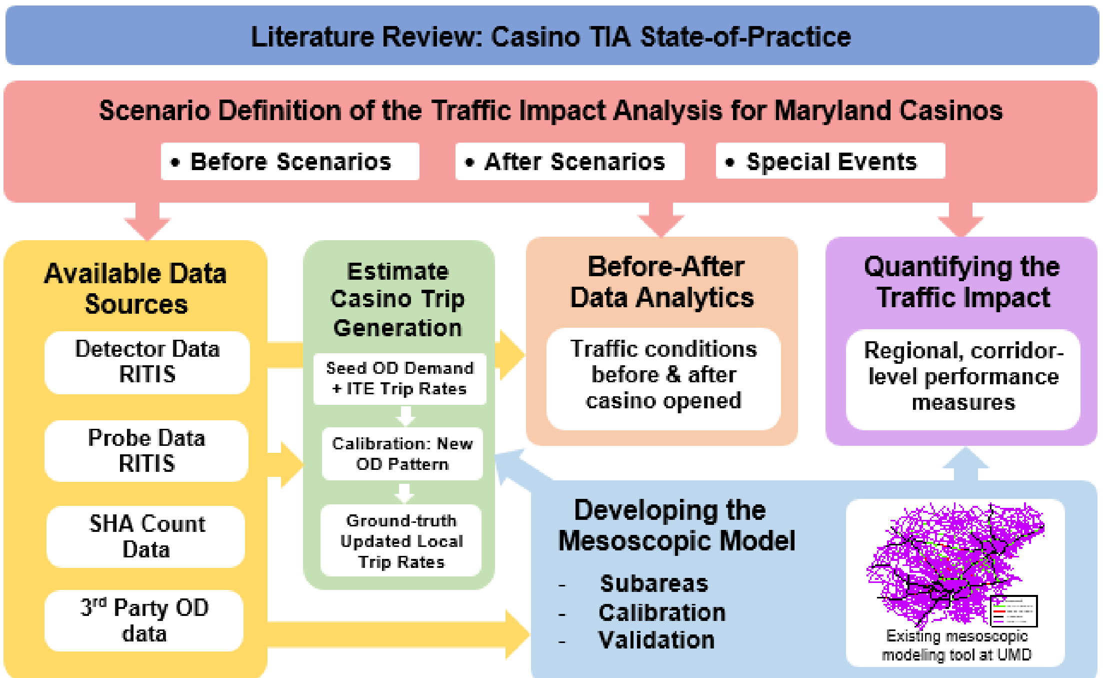


Figure 6: Paper flowchart.

Chapter 2: Literature Review

2.1 TIA Requirements: State of the Practice

Before scanning the literature for methods past impact studies have implemented to analyze the traffic impact of full-service casinos, one should first understand the types of analyses and tools that comprise the traditional TIA process for land use development. After reviewing several state and local TIA guidelines (e.g. DelDOT, 2014; VDOT, 2013; Dept. of Planning & Zoning, 2015; PennDOT, 2017), the general analysis requirements were pooled into three categories:

(1) the evaluation of current traffic conditions and the area's transportation infrastructure,

(2) the estimation of generator trip generation, distribution, and network assignment, and

(3) the analysis of the future traffic conditions with and without the proposed generator.

<u>Current Conditions:</u>

For the first identified general analysis component, after the study area has been determined, the TIA report typically provides an inventory of the existing transportation infrastructure, detailing the roadway characteristics, traffic control devices, and existing bicycle, pedestrian, and transit facilities and movement patterns. Vehicular traffic volume data is also collected and analyzed before any construction at nearby intersections to identify the AM/PM weekday, weekend, and/or special event peak period volume as well as the adjacent street(s) level of service. The collection of signal timings and crash data may also be required for the analysis.

<u>Trip Generation & Distribution:</u>

Next, the development's trip generation, distribution, mode split if applicable, and assignment of trips within the study area must all be estimated. For trip generation, the trip rates are typically calculated for both the peak period of the generator and for the peak period of adjacent street traffic (i.e. 7-9am or 4-6pm) using the latest addition of the *ITE Trip Generation Manual*. The manual is compiled of data spanning over five decades, all of which was voluntarily submitted. The manual develops mathematical relationships between land-use characteristics (e.g. building area, number of employees) and vehicle trip to estimate trip rates for ten primary land-use categories (Tripi, 2011):

- Port & Terminal
- Industrial
- Residential
- Lodging
- Recreational
- Institutional
- Medical
- Office
- Retail
- Service

However, in many cases, reliable trip generation data for complex land uses or special generators located in urban areas with high transit and pedestrian activity may not be available in the manual. Therefore, practitioners must resort to using available local trip rates or calculate weighted average trip rates from collected data representative of operational land-uses similar in size and function.

Other more robust, yet resource intensive generation methods are sometimes pursued as well. These methods are commonly applied to unique infill, mixed use, and transit-oriented development (TOD) land use types. For example, Virginia adopted a model developed by the San Diego Association of Governments (SANDAG), Fehr & Peers, and the U.S. EPA for predicting trip generation for mixed use developments. Named the *Mixed Use Trip Generation Model V 4.0*, the alternative non-ITE method was programmed into an accessible Excel workbook and applies orderly trip reductions associated with internal capture and pass-by trips (VDOT, 2013).

More recent methodology examples have managed to incorporate alternative trip generation data sources that allow multimodal trip generation (Currans, 2017). Person trip counts, visitor intercept surveys, household travel survey data, and site-specific information in addition to the development size (e.g. presence of multimodal and parking facilities, density, design, cost, etc) have been utilized to directly estimate person trip rates by a couple agencies (The Planning Dept…, 2002; DDOT, 2015). Typically, person trip rates are indirectly adjusted from ITE trip rates based on assumed mode split and vehicle occupancy rates. Nonetheless, these alternative approaches demonstrate the industry's determination to surpass the limitations of the conventional ITE trip generation process.

Trip distribution analysis and assignment entails visualizing the flow of trips between origin and destination points on the roadway network within the study area. Investigators can pursue a variety of distribution analysis methods; however, there are primarily two approaches. The simplest, yet widely accepted method to distribute and assign trips is to use engineering judgement based on the knowledge of the area's traffic patterns and freeway access, while accounting for the population centers and proximity of nearby trip producers and attractions that may influence the proposed site's trip distribution. This approach has its obvious limitations yet is commonly pursued when time and analytical tools and/or data are not available. More accurate, but resource-intensive methods involve the use of market area studies, site surveys, and/or regional and statewide planning models that empirically model trip distribution – as well as trip generation, mode choice, and assignment (i.e. 4-step travel demand model) – using both sociodemographic and land-use information. Growth factor methods and synthetic methods are the two basic method types that can be used to empirically estimating the distribution of trips. However, the use of growth factors, although simpler, assumes trip generation patterns will remain largely the same in the future. This may be the case in some sub-urban or rural communities. Contrarily, the gravity model is based on the relative distance between zones and accounts for travel impedances – such as time and cost – that can be updated as the community grows (Bhatt, 2005). Once the distribution analysis is complete, according to loose state TIA guidelines standardizing trip assignment reporting (VDOT, 2013; DelDOT, 2014), the investigator should apply the distribution splits to the existing traffic volumes and present the results using road network diagrams for the appropriate time periods. No guidance on how the distribution of trips should select their routes is usually provided.

Future Conditions Analysis:

The analysis of both background (i.e. without site) and future (i.e. with site) traffic conditions can involve many requirements depending on the scale of the development and the criteria established by the governing jurisdiction. Background conditions account for factors that affect traffic and are not directly associated with the site generator. To analyze such conditions, the analyst must account for the projected growth of traffic and any planned development in the area that may concurrently impact the study area. When available, practitioners apply regional travel demand models based on current traffic conditions that consider travel destination, mode, departure time, and route choices as well as projected household and employment factors to forecast future traffic conditions (Alexiadis , Jeannotte , & Chandra , 2004). Some states have developed statewide travel demand models that integrate regional MPO models to include multimodal travel across sub-regional areas (Xiong & Zhang, 2013). However, due to the complexity and cost to develop such models, the use of growth factors generated from historical series of traffic counts is the most widely acceptable approach to forecasting traffic growth (Liu & Kaiser, 2004).

Similarly, the future conditions analysis forecasts traffic volumes that account for the background traffic and the newly generated site traffic for different future scenarios. PennDOT (2017) requires an analysis for the generator's opening year and a design horizon year, typically five or more build-out years into the future. The actual analysis can involve many sub-analyses that include but are not limited to a capacity or Level of Service (LOS) analysis, safety or crash analysis, and/or signal warrant analysis (VDOT, 2013). Among the TIA guidelines reviewed, every document dedicated the most of the future conditions section detailing the LOS reporting requirements for intersections and roadways, and the appropriate analysis tools recommended to conduct the analysis. Some of the recommended analysis tools recurrently presented in many TIA guidelines include the following:

- Highway Capacity Software
- Synchro
- SIDRA
- Vissim

Due to the abundance of traffic analysis methodologies, these widely adopted software tools have been developed to quantify and predict various traffic characteristics at different levels of resolution and precision across the U.S. The Highway Capacity Manual (HCM) is referenced as the most common standard technical resource for roadway analysis (Alexiadis, et al., 2004). HCM-based tools are used to analyze existing roadway conditions and are best at quickly predicting local Measures of Effectiveness (MOEs) including LOS and intersection delay. Synchro is well-known example of a analytical tool that utilizes HCM methodologies to analyze intersections and interupted flow facilities such as arterials, collectors, and local streets (Maryland State Highway Administration, n.d.). Although the HCM methods are quick and reliable, Synchro and similar HCM-based tools struggle with analyzing system-wide traffic conditions. The static approach of HCM methodologies make it difficult to capture the dynamic changes in traffic over time as well as capture the formation and propagation of traffic congestion across a network.

When HCM procedures do not meet the scope requirements for a given traffic study and sufficient time and resources exist, traffic simulation tools are deployed. The dynamic nature of these tools does allow practitioners to simulate both the temporal and spatial interactions of traffic flows at different resolutions (i.e. Macro, Meso, or Microscopic). Most traffic impact studies utilize microsimulation models, which model individual vehicles and their interactions with one another based on car-following and lane-changing theories (Alexiadis, et al., 2004). Vissim, Sim Traffic, and Corsim are all common microsimulation simulation tools. SIDRA is a microsimulation traffic software recommended to be only used for roundabouts (VDOT, 2013)

With the conventional analysis methods and tools of a TIA state-of-the-practice overviewed, this paper aims to improve aspects of the traditional TIA process by implementing advanced analysis tools and methods to estimate the trip generation for special generators, in this case a full-service casino. This paper also intends to highlight the availability and application of newer data sources. As traffic analytic and simulation tools continue to evolve, so do the available data sources. New, alternative sources of road traffic-related data are substituting conventional traffic data sources obtained from stationary measurement devices and surveys (e.g. household travel survey, traffic sensors such as inductive loops and pneumatic tubes, cameras). Contrarily, new data sources are increasingly mobile and provide larger network sample coverage and information related to users' travel behaviors. In the US, several private sector traffic data providers (e.g. INRIX, AirSage, StreetLight) offer aggregated traffic data that originate from people's cell phones, GPS devices, or smartphone location-based applications (BITRE, 2014).

2.2 TIA for Full-service Casinos

After reviewing many traffic impact studies for full-service casinos in the United States, including the casinos a part of this study, several key approaches in data collection and estimation methods were discovered.

All of the reviewed traffic impact studies for casino complexes with multiple amenities rely on empirical trip generation data either field collected or borrowed from other casino traffic studies completed for sites similar in size and urban context. Several recent examples include Wynn Philadelphia (Keating Consulting, 2014), MGM in Springfield, MA (Maxon Alco Holdings, 2014), Mohawk Harbor Casino in Schenectady, NY (MGM Resorts International Global Gaming Development, LLC, 2012), and Horseshoe Casino in Baltimore, MD (Baltimore City Department of Transportation, 2013). The national rates provided in the ITE Trip Generation Manual were not sufficient to directly estimate the casino trip rates due to the lack of archived full-service casino studies. The ITE manual does include national trip rates for a "Casino/Video Lottery Establishment;" however, the description explicitly states that data statistics for full-service casinos (i.e. those that include food service and entertainment) and casino/hotel facilities are not included (Institute of Transportation Engineers 2017). Therefore, full-service casinos are treated as mixed use land uses due to the number of restaurant, shopping, and entertainment amenities that exist within the casino development.

Furthermore, the majority of studies calculate individual rates based on the ITE Trip Generation Manual for each ancillary land use that may attract trips independently from the casino (Maxon Alco Holdings, 2014; MGM Resorts International Global Gaming Development, 2012; Baltimore City Department of Transportation, 2013). Other studies assume that ancillary facilities support the casino in a way that advocates one bundled trip rate that covers multiple land uses, as indicated in the studies for Nevele Resort (Creighton Manning LLP, 2014) and MGM at National Harbor (Sam Schwartz

Engineering D.P.C., 2013). Among the three Maryland casino studies, both approaches were utilized (see Section 2.3).

Regardless of the approach used to calculate the casino's trip generation, virtually all traffic impact studies conducted an impact analysis based on criteria provided in the Highway Capacity Manual (HCM). These traditional methods often limit the analysis to a small roadway network that consists of a single corridor and several intersections. The generated trips are then assigned to this small network for level of service and intersection delay analysis. Several casino traffic studies utilized the HCM-based tool, Synchro (Maxon Alco Holdings, LLC, 2014; Baltimore City Department of Transportation, 2013).

Overall, several limitations were identified with the methodologies of the casino traffic impact studies. First, the scenarios analyzed often ignore the influence from on-site or nearby special events that generate significant traffic. For example, sports events for the Baltimore Ravens or Orioles were not considered in the impact analysis of the Horseshoe Casino (Baltimore City DOT, 2013). Second, these studies were conducted prior to construction, thus, making the actual traffic impact of a full-service casino less understood. Lastly, both traditional HCM-based and microsimulation tools cannot effectively capture the traffic impact at the regional level. This paper addresses these limitations by deploying advanced data analytic and mesoscopic modeling tools to improve the quantification of traffic impacts, including trip generation, for full-service casinos.

2.3 MD Casino Trip Generation

This section provides a summary of findings related to local trip generation rates for the three Maryland casinos. The trip rates are taken directly from the published traffic impact studies (TIS) for each casino. These same rates are also integrated into the mesoscopic models to determine the after-scenario traffic impact of the casinos (see Section 4.2) and form a base of comparison with the trip estimates generated.

Live! Casino: Unfortunately, no TIS report was publicly available. The weekday PM peak hour trip rates were retrieved from a Mid-Atlantic Section ITE presentation slide deck. One slide presented a comparison table of various casino studies that reported 0.31 trips IN and 0.28 trips OUT per slot position for Live! Casino (Subhani, R., 2014). Moreover, in 2011 MDOT SHA's Travel Forecasting and Analysis Division (TFAD) estimated Friday PM peak of adjacent street and Saturday peak hour of generator trip rates for the Arundel Mills Mall casino. The following TFAD rates were based on trip rates for casino facilities located near large urban centers and major transportation corridors (TFAD-SHA, 2011):

- 0.590 trips per gaming position during the Friday PM peak hour of generator (53% in / 47% out)
- 0.640 trips per gaming position during the Saturday peak hour of generator (53/47)

A pre-construction TIS for **Horseshoe Casino** was completed in 2013 for the City of Baltimore Department of Transportation. Under the "future conditions" section of the report, the author provided the estimated casino trip rates and distributions.

- 0.062 trips per gaming position during the weekday AM peak hour of generator (75% in / 25% out)
- 0.246 trips per gaming position during the weekday PM peak hour of generator (60/40)
- 0.305 trips per gaming position during the Sunday peak hour of generator (53/47)

This study explicitly stated that the national rates provided in the ITE manual were insufficient. Instead, the consultant, WR&A, incorporated a combination of weekday trip rates taken from similar Maryland casinos that were approved by MDOT SHA. The 0.246 and 0.305 rates also appear to be the same rates developed by TFAD for the Friday PM peak of an adjacent street and Saturday peak hour of generator rates of a "video lottery-only facility" without a racetrack (i.e., Hollywood Casino at Perryville, Md). This is an interesting finding given Hollywood Casino is in a rural area. Separate trip rates were developed for restaurant, bar/tavern, and office space land uses. The rates and distributions were acquired from the 9th edition of the ITE manual for the three specified time analysis periods: AM peak, PM peak, & Sunday [10].

A traffic flow study was finalized for **MGM at National Harbor** in December 2013 and produced three MDOT SHA-approved trip rates:

- 0.06 trips per gaming position during the weekday AM peak hour of generator (75% in / 25% out)
- 0.27 trips per gaming position during the weekday PM peak hour of generator (60/40)

- 0.33 trips per gaming position during the Saturday peak hour of generator (53/74)

The report assumed that the various land uses adjacent to the casino “support gambling operations.” Therefore, all restaurants, bars, and retail outlets were bundled with the casino land use to create a single trip rate. Only the hotel and entertainment venue trip rates were generated separately. The Maryland Video Lottery Facility Location Commission approved the decision to bundle food and beverage land use with the casino trip rate; however, the commission commented that bundling nine retail outlets ranging from 1,200 to 9,500 square feet likely underestimates the number of trips generated by these establishments that would not enter the casino. Therefore, the commission recommended additional trips be included in the final trip generation [12].

Chapter 3: Probe Data Analytics

3.1 Methodology

The Probe Data Analytics Suite, a traffic data analysis service supported by the Center for Advanced Transportation Technology (CATT) Lab at UMD, was utilized to compare traffic performance measures for select corridors near each casino. Historic before/after casino average speed and travel time data was collected for Traffic Message Channel (TMC) segments along corridors adjacent to each casino. Table 2 lists the corridors selected for the analysis and Figures.

Table 2: List of Major Corridors included in Analysis

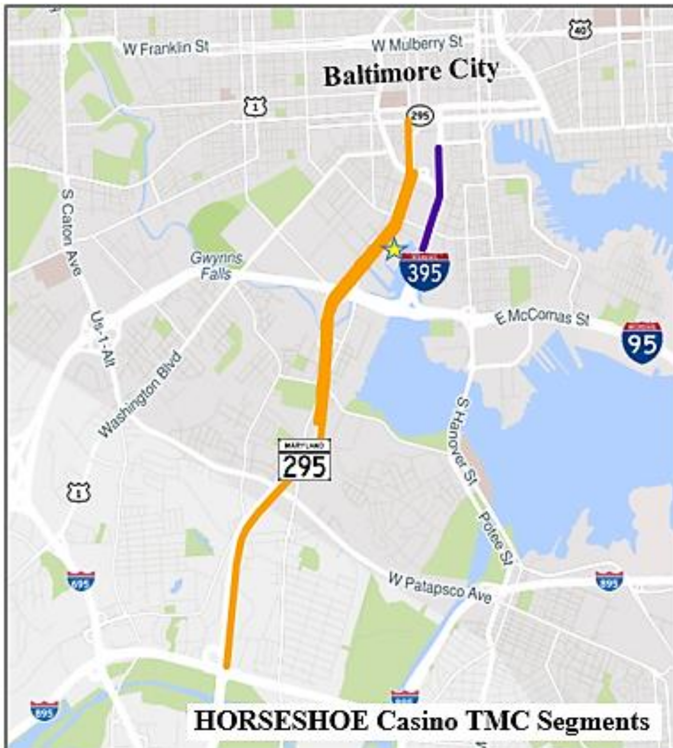
Live! Casino	Horseshoe Casino	MGM at Nat'l Harbor
Arundel Mills Blvd	Russel St / MD – 295	Oxon Hill Rd
MD-100	I-395 Southbound	Indian Head Hwy / MD-210
MD-295		I-95 Exit 2 Ramps 3 & 9

Although casino traffic peaks late evenings on Fridays and weekends, this study focused on the early weekday, evening commuting hours also known as the PM peak period of adjacent streets. This PM peak period typically experiences the greatest decline in traffic mobility when both adjacent-street commuter traffic and casino demand are significant. The exact temporal dimensions of this study equate to a 4-hour weekday PM peak period (3:00 -7:00 PM).

Minute-by-minute INRIX data was aggregated and averaged during the PM peak periods on Tuesdays, Wednesdays, and Thursdays for select one-month periods throughout the year – Mondays and Fridays were excluded to limit the number of data records not representative of a typical weekday. One-month study periods were chosen to formulate average values from an ample sample of weekdays without capturing excessive background noise in the form of non-recurrent traffic incidents. The months of January, April, July, and October were chosen to provide traffic impacts representative of each season. Before/after results are compared for each month and the mean difference between the PM peak speed and travel time values was tested for statistical significance via the paired t-test.

3.2 Traffic Impact Along Major Corridors

The analytic results are organized into one summary table for each casino. Each table presents the before/after average corridor travel time and speed for only the months when the difference in means (shown as Δ) is statistically significant with 95% confidence. Values shown in RED represent unexpected improvements in traffic conditions after the opening of a casino (i.e., increase in average speed and reduced average travel time). Please note that not all before/after years are the same for each month; the years reference the opening casino date shown in the top left corner of each table.



Russell St. / MD-295:

From: Martin Luther King Jr. Blvd.
To: Annapolis Rd. / Waterview Ave.

Northbound: 3.8 miles   Southbound: 2.1 miles

I-395 Southbound:

From: West Conway St.
To: I-95 Interchange

Southbound: 0.7 miles

Note: Inclusion of I-395 SB was necessary due to inaccessibility of I-95 NB from casino via Russel Street.

Arundel Mills Blvd:

From: MD-295 Interchange
To: MD-176 / Dorsey Road

Total: 4.2 miles

MD-295:

From: I-195 Interchange
To: MD-175 Interchange

Northbound: 7.4 miles   Southbound: 6.7 miles

MD-100:

From: West Conway St.
To: I-95 Interchange

Eastbound: 7.4 miles   Westbound: 6.7 miles

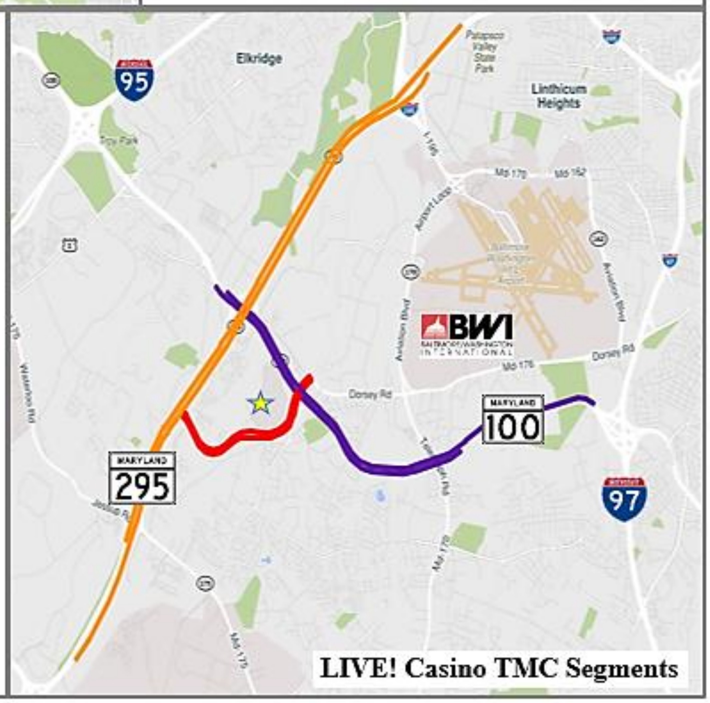


Figure 7: Horseshoe and Live! Casino TMC segments.

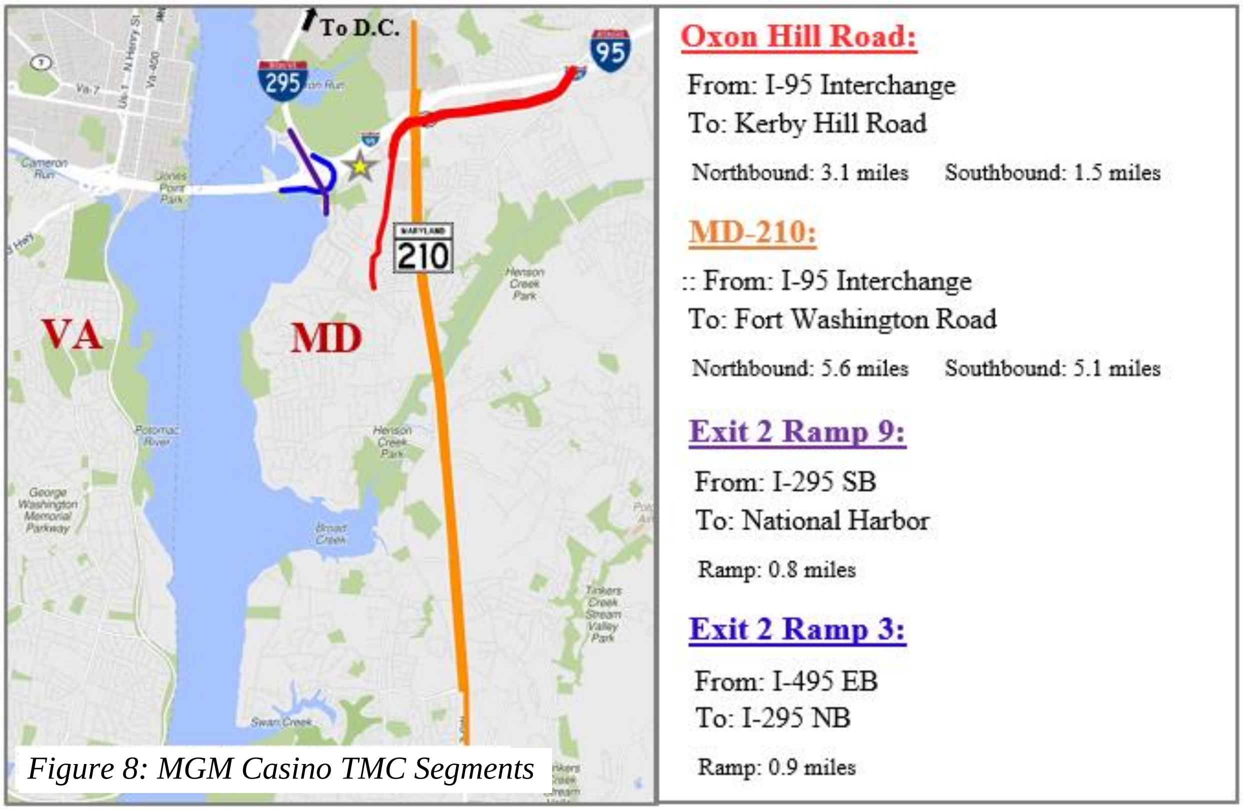


Figure 8: MGM Casino TMC Segments

Before and after travel time comparison charts for each analyzed corridor section are provided in **Appendix I**. The charts are exported from the RITIS Probe Data Analytics Suite. In addition to the charts, statistical tables including the t-stats and p-values for both the average travel time and speed mean differences are provided as well.

Table 3: Horseshoe Casino Data Analytics Summary Table

HORSESHOE Casino (opened Aug 26, 2014)			Russell St. (MD-295)				I-395	
			Northbound		Southbound		Southbound	
TIME PERIOD			Avg. TT (min)	Avg. Speed	Avg. TT (min)	Avg. Speed	Avg. TT (sec)	Avg. Speed
PM Peak Period (3-7 PM)	January	bef 2014	4.64	48.33	4.69	29.52	141	16.59
		aft 2015	5.1	44.15	4.17	32.61	146.4	16.03
		Δ	**0.46**	**-4.18**	**-0.52**	**3.09**	**5.4**	**-0.56**
	April	2014	5.18	43.49	4.04	33.84	NO SIGNIFICANT CHANGE	
		2015	5.71	39.79	4.43	31.08		
		Δ	**0.53**	**-3.7**	**0.39**	**-2.76**		
	July	2014	6.15	36.94	7.41	18.66	163.2	14.37
		2015	6.85	33.7	4.96	27.97	100.2	27.01
		Δ	**0.7**	**-3.24**	**-2.45**	**9.31**	**-63**	**12.64**
	October	2013	4.48	50.05	NO SIGNIFICANT CHANGE		127.2	18.4
		2014	5.36	41.96			169.2	13.84
		Δ	**0.88**	**-8.09**			**42**	**-4.56**
ROAD DISTANCE (mi)			**3.74**		**2.27**		**0.7**	

Observations from the above summary table for Horseshoe Casino are listed below.

- MD 295 NB experienced 10% increase in avg. PM peak period travel time and 8% decrease in avg. speed for each month studied after casino launch
- Inconsistent results for both southbound directions of Russell St. and I-395 – major highway work zone delays on I-95 may be a reason

Only the northbound direction of Russell Street (MD 295), which runs adjacent to the casino, experienced a consistent decline in mobility after the opening of the casino. The after-month of October 2014 revealed the greatest change in mobility with a nearly 20% increase in average travel time and 16% decrease in average speed. Another reason for such significant change may be the deck replacement project for 4.4 miles of elevated highway and ramps between the Fort McHenry Tunnel and Exit 50 at Caton Avenue along I-95, parallel to the target MD 295 segment. The two-year project began in late March 2014 and caused major traffic impacts through Fall 2015. Therefore, it is possible that in October

2014 MD 295 served higher diverted commuting traffic. As an example, according to a *Washington Post* article, the I-395 southbound ramp to I-95 southbound was reduced to one lane during the month of July in 2014 (Thomas, 2014). This information helps explain the significant improvement in average travel time from 2014 to 2015 along I-395 southbound. It is assumed similar conditions impeded traffic traveling southbound on Russell Street. No particular incident was discovered to justify the improved mobility in January for MD 295 South except the fact that January 2015 received 40% more snowfall than in 2014 (NOAA National Weather Service, 2018).

Key observations from Table 4 for **Live! Casino** are listed below:

- MD 295 SB experienced 10% increase in avg. travel time and 9% decrease in avg. speed in January and April following opening;
- MD 100 WB experienced 9% increase in avg. travel time and 6-7% decrease in avg. speed in January, April, and July;
- April: most segments had significantly worse congestion;
- October: unexpected mobility improvement for all segments.

Mobility deteriorated significantly across most segments during the after-months of January and April 2013. Although MD 295 south exhibited the greatest congestion increase during these months, the same section of MD 295 also experienced significant improvements in traffic conditions for July and October. This can be explained by two events. First, MDOT SHA began summer resurfacing work of southbound MD 295 (from Hanover Road to MD 100) in July 2011, closing a single lane for the duration of the work zone (MD State Highway Administration, 2011). Second, in October 2012, Superstorm Sandy caused widespread damage that closed businesses, schools, and government offices for several days. Consequently, travel demand decreased significantly throughout the region during that time. Contrarily, no impact was observed from the completion of the new diverging diamond interchange at MD 295 and Arundel Mills Blvd., which was completed a week after the casino opened.

Key observations from Table 5 for **MGM Casino** are listed below.

- Avg. travel time increases 12-18% and avg. speed decreases 10-15% for 3 of 4 corridors in April 2017
- Oxon Hill Road NB experienced greatest increase in congestion; Relatively little impact on SB traffic
- Exit 2 Ramp 9 (I-295 to National Harbor & Casino) experienced ~13% avg. travel time increase during April and Oct. 2017

Mobility impacts varied for the adjacent corridors and access ramps – nearly half of the study months revealed no significant change. The closest arterial to the casino, Oxon Hill Road, presented several consecutive monthly periods of heightened congestion in the northbound direction likely due to the increase in entering/exiting casino trips. However, in the southbound direction, only the after-month of April exhibited a significant decline in mobility. The reduced impact in this direction may be a result of the widening of Oxon Hill Road between the Capital Beltway and Tanger Outlets as part of a $10M road improvement plan paid for by the casino's parent company (King, 2016). Although capacity was added in both directions, the southbound direction included two dedicated right turn lanes toward the casino and additional thru lane on top of the timing modifications of the existing signal. Of the two access ramps evaluated, Ramp 9 serving traffic south on I-295 toward National Harbor and MGM experienced significantly greater congestion. This observation is likely a result of the new casino.

Table 4: Live! Casino Data Analytics Summary Table

LIVE! Casino (opened June 6, 2012)			Arundel Mills Blvd				MD-100				MD-295			
			Eastbound		Westbound		Eastbound		Westbound		Northbound		Southbound	
TIME PERIOD			Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)
PM Peak Period (3-7 PM)	January	bef 2012	NO SIGNIFICANT CHANGE		3.64	30.74	NO SIGNIFICANT CHANGE		5.56	58.51	7.55	58.47	6.39	61.93
		aft 2013			3.83	29.19			6.09	54.44	8.38	52.97	7.41	53.63
		Δ			**0.19**	**-1.55**			**0.53**	**-4.07**	**0.83**	**-5.5**	**1.02**	**-8.3**
	April	2012	3.15	30.96	3.62	30.9	4.12	56.21	5.58	58.14	NO SIGNIFICANT CHANGE		6.36	62.21
		2013	3.24	30.12	3.83	29.22	4.66	50.79	6.1	54.52			7.01	56.7
		Δ	**0.09**	**-0.84**	**0.21**	**-1.68**	**0.54**	**-5.42**	**0.52**	**-3.62**			**0.65**	**-5.51**
	July	2011	NO SIGNIFICANT CHANGE		NO SIGNIFICANT CHANGE		NO SIGNIFICANT CHANGE		5.27	60.48	NO SIGNIFICANT CHANGE		7.19	55.2
		2012							5.76	56.72			6.8	58.59
		Δ							**0.49**	**-3.76**			**-0.39**	**3.39**
	October	2011	3.25	30	NO SIGNIFICANT CHANGE		5	47.98	6.41	52.35	9.07	49.17	6.61	59.94
		2012	3.15	30.97			4.38	53.44	5.92	55.92	8	55.21	6.33	62.55
		Δ	**-0.1**	**0.97**			**-0.62**	**5.46**	**-0.49**	**3.57**	**-1.07**	**6.04**	**-0.28**	**2.61**
ROAD DISTANCE (mi)			2.1		2.1		2.6		6.8		7.4		6.7	

Shown values significant at 95th confidence level; **RED VALUES** represent **improved** mobility performance.

Table 5: MGM Casino Data Analytics Summary Table

MGM Casino (opened Dec 8, 2016)			Oxon Hill Rd (MD-414)				Indian Head Highway (MD-210)				Exit 2 Ramp 3 (I-95 EB to I-295 NB)		Exit 2 Ramp 9 (I-295 to Nat'l Harbor)	
			Northbound		Southbound		Northbound		Southbound					
TIME PERIOD			Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)	Avg. TT (min)	Avg. Speed (mph)	Avg. TT (sec)	Avg. Speed (mph)	Avg. TT (sec)	Avg. Speed (mph)
PM Peak Period (3-7 PM)	January	bef 2016	9.58	19.49	NO SIGNIFICANT CHANGE		NO SIGNIFICANT CHANGE		12.16	25.39	39.78	52.57	96.6	32.34
		aft 2017	10.24	18.2					10.99	27.89	40.74	51.22	100.8	31.17
		Δ	**0.66**	**-1.29**					**-1.17**	**2.5**	**1.0**	**-1.35**	**4.2**	**-1.17**
	April	2016	8.97	20.75	4.32	21.29	8.06	41.96	NO SIGNIFICANT CHANGE		NO SIGNIFICANT CHANGE		96	32.7
		2017	10.18	18.29	5.08	18.09	8.96	37.69					108	29.14
		Δ	**1.21**	**-2.46**	**0.76**	**-3.2**	**0.9**	**-4.27**					**12**	**-3.56**
	July	2016	9.55	19.49	NO SIGNIFICANT CHANGE		8.63	39.16	NO SIGNIFICANT CHANGE		40.32	51.9	NO SIGNIFICANT CHANGE	
		2017	11.14	16.78			8.89	38.02			39.54	52.79		
		Δ	**1.59**	**-2.71**			**0.26**	**-1.14**			**-0.8**	**0.89**		
	October	2016	NO SIGNIFICANT CHANGE		NO SIGNIFICANT CHANGE		NO SIGNIFICANT CHANGE		10.78	28.46	NO SIGNIFICANT CHANGE		99	31.71
		2017							11.75	26.13			111.6	28.3
		Δ							**0.97**	**-2.33**			**12.6**	**-3.41**
ROAD DISTANCE (mi)			3.1		1.5		5.6		5.1		0.9		0.8	

Shown values significant at 95th confidence level; **RED VALUES** represent **improved** mobility performance.

Chapter 4: Mesoscopic DTA Models

4.1 Scenario Definitions

Three scenarios were modeled for each casino: (1) pre-construction before-scenario (i.e. base model), (2) after-scenario, and (3) after + special event. As shown in Table 6, the opening dates were used to define the before/after scenarios. The average weekday in the year before the casino opened was modeled for the before-scenario and the average weekday in the year after the casino opened was modeled for the after-scenario. The special events modeled in the after + special event scenario are listed as well. Traffic is simulated for all scenarios during the same 3:00 to 7:00 PM weekday peak period (see Section 3.1).

Table 6: Summary of Modeling Scenarios

Maryland Casino	Opening Date	Special Event
Maryland Live!	June 6, 2012	- Black Friday (2-4 PM Peak)
The Horseshoe Casino	Aug. 26, 2014	- Ravens NFL Game (Thursday Night Home Game)
MGM at National Harbor	Dec. 8. 2016	- Large Concert at MGM (Bruno Mars - Dec 21, 2017)

4.2 Model Specification

A mesoscopic dynamic traffic assignment (DTA) traffic simulation model was built for all three scenarios at a sub-regional scale. A DTA model's objective is to solve the dynamic user equilibrium condition (i.e. all routes used by travelers having the same origin/destination and departure time have equal and minimal experienced travel time). The model does so by finding time-dependent shortest paths, assigning traffic to these paths, and then adjusting the number of vehicles along these paths based on link-based travel times that iteratively update as the roadway conditions evolve during the simulation until a dynamic user equilibrium has sufficiently converged.

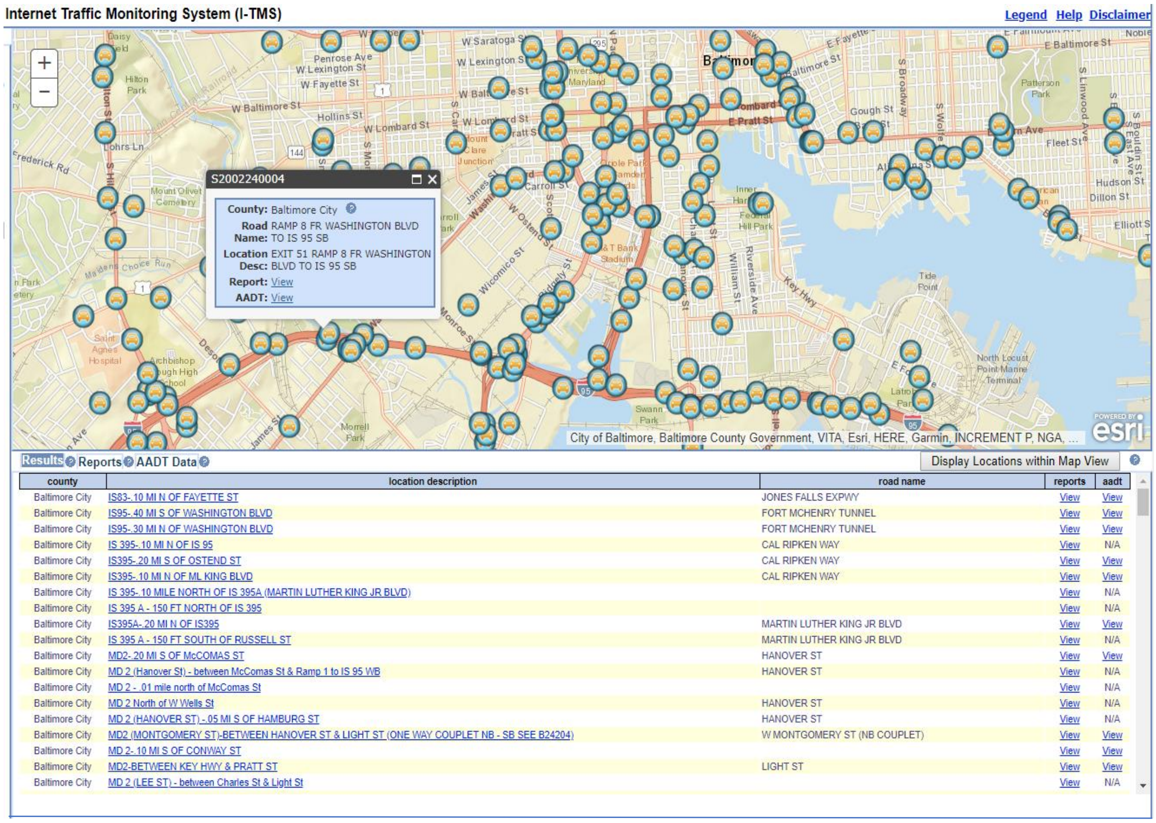
Unlike microsimulation models utilized in past traffic impact studies, a mesoscopic DTA model can simulate individual vehicles and still capture the interactions between vehicles across large networks. It also requires only a fraction of the computing power and time that is necessary to build and calibrate a large-scale microscopic simulation model. Mesoscopic models enable the integration of travel behavior and traffic simulation models that allow visualization and real-time analysis of vehicles' time-dependent route decisions, given various roadway (network) conditions.

Using the open-source mesoscopic DTA model system, DTALite, the author coded, calibrated, and validated mesoscopic models for the three casino sites. DTALite is a light-weight network loading simulator that dynamically assigns traffic based on observed network conditions drawn from historic traffic counts and travel times (Zhou & Taylor, 2014). The modeling process is broken down into five steps:

<u>Step 1. Create Sub-regions:</u> With complete coverage of the Washington-Baltimore metropolitan region provided in the Maryland Statewide Transportation Model (MSTM version 1.0) travel demand model, three sub-regional casino models were clipped from the statewide network that include 3,056 traffic analysis zones (TAZ). The boundaries of the sub-regions were strategically cut to ensure all possible alternative routes a user could take to bypass congestion near the casino were included (see Appendix II). To estimate the time-dependent demand profiles for the PM peak period, the time-independent seed OD matrix from the MSTM 1.0 were transformed into hourly OD demand matrices based on the hour-by-hour distribution of observed traffic volumes measured within each mode2l's sub-region.

Step 2. Collect Field Data: Prior to coding the network model, historic traffic count and travel time data were collected for model calibration. Hourly traffic count data was obtained from count sensors along major corridors throughout each casino network using the MDOT SHA Internet Traffic Monitoring System (I-TMS). Traffic counts collected within three years of the opening day of a casino were included in the model. The author also obtained historic travel time data from the RITIS data system. For each adjacent corridor in the network, minute-by-minute PM peak period travel time values aggregated over a six-month period before the casino opening were gathered.

Step 3. Network Coding: Using Google Maps the author first verified the sub-area stick network had no major issues (i.e., incorrect # of lanes, capacities, and node connections). Next, the author modified the local road network near each casino to capture all local roads in the model and to reflect the before-scenario, supply-side road conditions. Last, signalized intersections were coded into the model. Ideally, real-world signal plans would be imported into DTALite from Synchro; however, such signal data was not readily available. Therefore, DTALite's imbedded phase-based signal representation model generated default pre-timed signal phase plans based on the standard NEMA



county	location description	road name	reports	aadt
Baltimore City	IS83-.10 MI N OF FAYETTE ST	JONES FALLS EXPWY	View	View
Baltimore City	IS95-.40 MI S OF WASHINGTON BLVD	FORT MCHENRY TUNNEL	View	View
Baltimore City	IS95-.30 MI N OF WASHINGTON BLVD	FORT MCHENRY TUNNEL	View	View
Baltimore City	IS 395-.10 MI N OF IS 95	CAL RIPKEN WAY	View	N/A
Baltimore City	IS395-.20 MI S OF OSTEND ST	CAL RIPKEN WAY	View	View
Baltimore City	IS395-.10 MI N OF ML KING BLVD	CAL RIPKEN WAY	View	View
Baltimore City	IS 395-.10 MILE NORTH OF IS 395A (MARTIN LUTHER KING JR BLVD)		View	N/A
Baltimore City	IS 395 A - 150 FT NORTH OF IS 395		View	N/A
Baltimore City	IS395A-.20 MI N OF IS395	MARTIN LUTHER KING JR BLVD	View	View
Baltimore City	IS 395 A - 150 FT SOUTH OF RUSSELL ST	MARTIN LUTHER KING JR BLVD	View	N/A
Baltimore City	MD2-.20 MI S OF McCOMAS ST	HANOVER ST	View	View
Baltimore City	MD 2 (Hanover St) - between McComas St & Ramp 1 to IS 95 WB	HANOVER ST	View	N/A
Baltimore City	MD 2 - .01 mile north of McComas St		View	N/A
Baltimore City	MD 2 North of W Wells St	HANOVER ST	View	N/A
Baltimore City	MD 2 (HANOVER ST) -.05 MI S OF HAMBURG ST	HANOVER ST	View	N/A
Baltimore City	MD2 (MONTGOMERY ST)-BETWEEN HANOVER ST & LIGHT ST (ONE WAY COUPLET NB - SB SEE B24204)	W MONTGOMERY ST (NB COUPLET)	View	View
Baltimore City	MD 2-.10 MI S OF CONWAY ST		View	View
Baltimore City	MD2-BETWEEN KEY HWY & PRATT ST	LIGHT ST	View	View
Baltimore City	MD 2 (LEE ST) - between Charles St & Light St		View	N/A

Figure 9: SHA I-TMS computer Database system (http://maps.roads.maryland.gov/itms_public/).

phasing convention. By default, through and right-turn movements were consolidated and received 45 seconds of green time; all left-turns were assumed to be protected and received 10 seconds of green time. Once all the major signalized intersections were coded, various timing adjustments were made during the model calibration process (Step 4) in locations where the simulated traffic conditions were unrealistic.

<u>**Step 4. Calibration & Validation:**</u> The DTA models were subject to a two-stage quantitative calibration process that utilized the observed traffic count and travel time data.

The first stage calibrated demand-side parameters. A path-flow based optimization model calibrated the OD demand by iteratively minimizing the gap between observed sensor data and simulated volume counts. This OD adjustment process ran for K iterations until the difference between observed and estimated traffic, as well as the difference between estimated path flows and target OD flows, were minimized. The second stage of the process calibrated supply-side parameters. The simulation attempted to minimize the deviation between the simulated travel time along major corridors throughout the network and the historic average travel time obtained from RITIS. Speed is another common supply-side metric used to calibrate DTA models; however, it was not used in this study's model calibration.

To validate the models, an error calculation was performed using a weighted percent root mean square error (%WMSE) formulation:

$$\%\text{WMSE} = \sqrt{\frac{\sum_{i=1}^{N}\sum_{t=14}^{18}\left(Obs_{i,t} - Sim_{i,t}\right)^2}{\sum_{i=1}^{N}\sum_{t=14}^{18} {Obs_{i,t}}^2}} * 100$$

where *N* denotes the total number of sensors and *Obs* and *Sim* denote the observed and simulated traffic volumes at each traffic count station *i* during *t* hours (14:00 to 19:00). The overall hourly traffic count %WMSE should be less than **15%** on all roadways. The error term was also applied to travel time validation, where N denotes the number of travel time intervals. The overall travel time %WMSE should be less than **20%** on all major corridors. Figure 10 visualizes the calibration of the travel time for one major corridor that provides freeway access to Live! Casino. All casino models met the %WMSE threshold criteria and the simulated corridor travel time profiles aligned temporally with the real-world observed data, as shown in Figure 10.

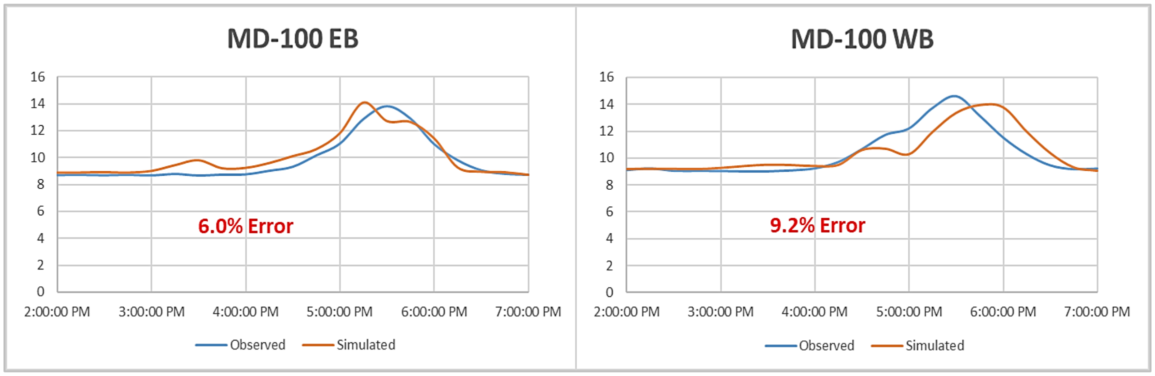
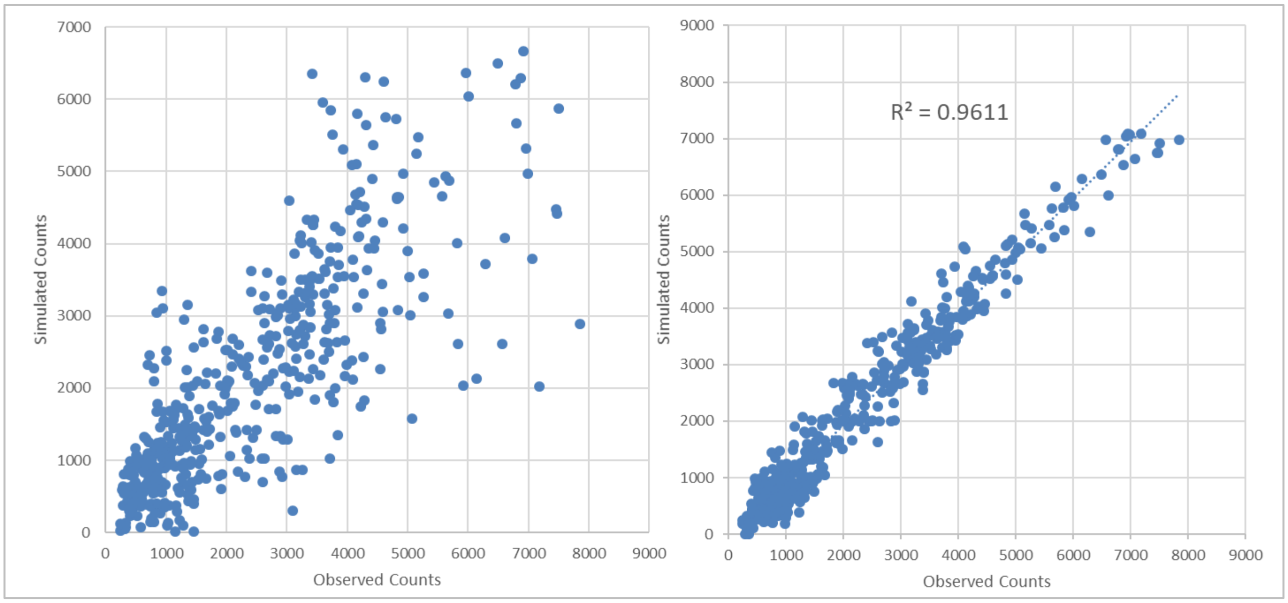


Figure 10: Traffic travel time calibration for major corridor near Live! Casino.

In addition to %WMSE, the comparison of coefficients of determination (R^2 values) is another useful validation approach. According to a FHWA model validation manual, the R^2 for regionwide observed versus simulated traffic counts should exceed 0.88 (Barton-Aschman Associates, 1997). Figure 11 provides a scatter plot comparing the before and after traffic volume calibration for the Live! Casino base model. The after-calibrate R^2 surpassed the 88% threshold. Similar results were obtained for Horseshoe and MGM casino models as shown in Table 7.

Once a base model is calibrated and validated, each traveler's time-dependent trip pattern as well as the overall regional and corridor traffic performance can be measured.



1. (a) Seed OD 2. (b) Calibrated

Figure 11: Traffic volume calibration for sub-regional Live! Casino base model.

Table 7: Validation Statistical Results Summary

CASINO	ALL Sensors	R^2	%WMSE	Freeway Sensors	R^2	%WMSE
LIVE!	96	0.961	12.6	52	0.940	10.1
HORSESHOE	137	0.963	12.8	49	0.969	8.9
MGM	71	0.978	10.7	21	0.966	9.4

Step 5. Add Casino Trip Data: Once the before-scenario models are calibrated and validated, both casino and special event trips were distributed into the hourly OD matrices in order to simulate the after and after + special event scenarios. The casino trip rates were borrowed directly from the existing casino TIS reports (see Section 2.3). For instances where the trip generation for adjacent amenities were estimated with separate trip rates, these rates as well as the directional distributions were updated to reflect the average rates presented in the newest version of the *ITE Trip Generation Manual, 10th ed*. The input variables were also updated (i.e. number of gaming positions and square footage) to

represent the actual values of the now operational casinos. The estimated mode choice and internal capture distributions identified in the TIS reports were not modified.

The total number of PM peak hour trips estimated to enter and exit each casino (considers all land uses at casino complex) along with the corresponding TIS casino trips rates are presented in Table 8. In comparison with the ITE's description of a casino establishment, the weighted average national trip rate for the weekday PM peak hour of generator is 0.4. Neither the ITE Manual nor the Maryland TIS report supplied PM peak hour of adjacent street trip rates, which represent the weighted one-hour trip rate during the morning and late afternoon peak periods. Instead, peak hour of generator rates were provided, which for casinos occurs late in the evening. Ideally, the peak hour of adjacent streets trip rate would be included in the after-scenario models to align with the defined PM peak simulation period from 3:00 to 7:00PM; however, this was not possible due to the lack of national data (see Appendix III for casino trip generation details).

Table 8: After-Scenario Casino Trip Generation (Weekday PM Peak Hour)

CASINO	Gaming Area (SF)	TIS Weekday PM Trip Rate Per Gaming Position	# of Trips Attracted	# of Trips Produced	Peak Hour TOTAL
LIVE!	160k	0.31 IN | 0.28 OUT	886	549	1,435
HORSESHOE	122k	0.322	546	405	951
MGM	163k	0.27	787	552	1,339

The peak hour for casino trips was assigned to the last hour of the PM peak period (6:00 - 7:00pm). Each casino's seed hourly trip patterns were distributed throughout the remaining hours in the model based on the hourly distributions of casino trips estimated from OD demand matrices provided by an independent location data service provider (see Section

5.1). Table 9 provides the estimated seed hourly casino arrival and departure time patterns as percentages of the peak hour casino demand.

Table 9: Casino Hourly Trip Distribution

CASINO	PM HOURLY ARRIVAL PATTERN (6:00 – 7:00PM casino demand peak hour)			
	3:00 – 4:00pm	**4:00 – 5:00pm**	**5:00 – 6:00pm**	**6:00 – 7:00pm**
LIVE!	82.5%	65.5%	73%	**100% (886)**
HORSESHOE	94.5%	81%	84%	**100% (546)**
MGM	79.5%	84%	83%	**100% (787)**
	PM HOURLY DEPARTURE PATTERN			
LIVE!	112%	106%	110%	**100% (549)**
HORSESHOE	94.5%	131%	137%	**100% (405)**
MGM	81%	85.5%	91%	**100% (552)**

Furthermore, trip rates for special events were estimated at or near each casino. A Thursday night Ravens football game near Horseshoe casino and a Black Friday late afternoon shopping event at Arundel Mills Mall adjacent to Live! Casino generate additional trips. The approximate number of special event trips generated are displayed in Table 10. Only Live! Casino was estimated to attract and produce trips for a Black Friday special event during the 3:00 - 7:00 PM peak period. For the other casinos, it was assumed only arrival trips would enter the area to attend an event that typically starts after 7:00 PM. A more detailed breakdown of special event trip generation and arrival/departure time patterns is available in **Appendix III.**

Table 10: After + Special Event Scenario Trip Generation

CASINO	Special Event	Quantity	# of Trips Attracted	# of Trips Produced	TOTAL
LIVE!	Black Friday	1,630,000 sf mall	1,772*	1,697*	3,470*
HORSESHOE	Thursday Night NFL Game	71,008-seat stadium	18,620	0	18,620
MGM	Sold-out Concert	3,000-seat theatre	600	0	600

With all the trip rates and hourly trip patterns determined, the information was integrated into the after-scenario models. Arundel Mills Mall and Live! Casino, as well as the concert special event and MGM casino, share one zone (i.e., the casino site). Only the trip information for the Ravens game special event was combined with a separate zone at the location of the stadium.

4.3 Quantifying the Regional + Corridor Traffic Impact

The mesoscopic DTA models quantify the sub-region, network-wide traffic impacts including total volume, average travel time, average travel time index (mean/FFTT), and average speed. These measures of effectiveness (MoE) for each simulated hour are tabularized in Appendix IV. Additionally, link-based peak-hour density maps as well as travel time profiles for select major corridors near each casino were generated to visualize the regional and corridor-level traffic impact.

4.3.1 Live! Casino

According to the model output, the traffic conditions around Arundel Mills deteriorated significantly after the opening of Live! Casino. For the 6:00 PM hour when the casino demand is at its greatest, a nearly 2% increase in the region-wide traffic volume due to the casino produces a 14% increase in average travel time and a 12% reduction in average speed. A significantly larger traffic impact, 5.4% increase in traffic volume, was measured on Black Friday. The system-wide average travel time is 66% longer and the average speed is almost 40% lower (Appendix III details the special event trip generation methodology).

To help visualize the traffic impact throughout the network, a color-coded comparison figure displaying each link's density (veh/mi/ln) or level of service (LOS) is shown in Figure 12. Green denotes LOS A (6 -10.9 veh/mi/ln), shades of yellow represent LOS B & C (11 – 24.9), orange signifies LOS D & E (25-44.9), and red represents LOS F (>45) or traffic jam. For this casino network, MD 100 revealed the largest change in LOS in both directions near the Arundel Mills interchange. Queue spillback forms at the convergence of the eastbound off-ramp exiting Arundel Mills Boulevard and the MD 100 mainline as well as a separate merging area west of the MD 295 interchange in the westbound direction of MD 100. MD 295 also experienced a decrease in mobility, but the congestion propagation appears to originate around the MD 32/MD 295 interchange. Nonetheless, both corridors exhibit significant mobility impacts as further shown in Figure 13. With the exception of MD 100 EB, the travel time increased marginally along these corridors after the introduction of casino traffic (3-7% increase in travel time; 24% MD 100 EB). As expected, the inclusion of Black Friday traffic causes a spike in trip times by over 25% for each direction of MD 100 (I-95 to I-97) and MD 295 (MD 32 to I-195).

Table 11: 6:00 PM Peak Hour Measures of Effectiveness Region-wide Results for Live! Casino.

LIVE! CASINO	BEFORE CASINO	WITH CASINO	CASINO + BLACK FRIDAY SPECIAL EVENT
MOEs	Value	Value | % Change	Value | % Change
# of Vehicles	80,099	81,619 | 1.9%	84,459 | 5.4%
Average Trip Time	16.03	18.33 | 14.4%	26.58 | 65.8%
Average Trip Time Index	1.90	2.16 | 13.7%	3.12 | 64.2%
Average Speed	25.06	21.96 | - 12.4%	15.17 | - 39.5%

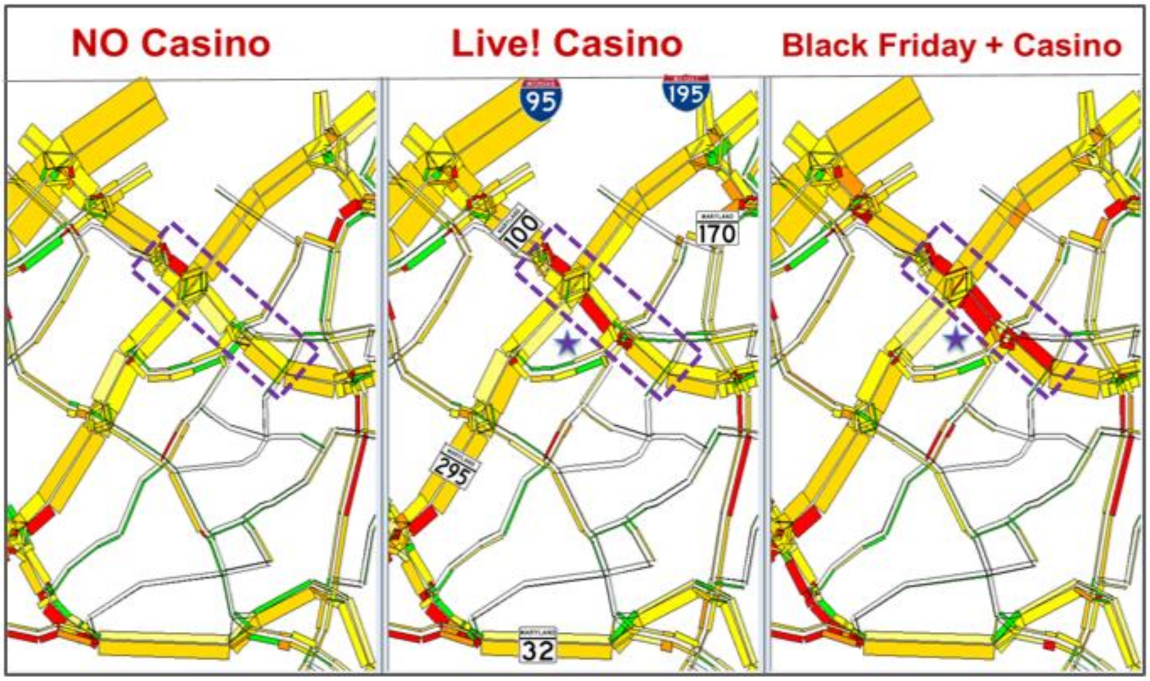


Figure 12: Live! network level of service peak hour snapshot.

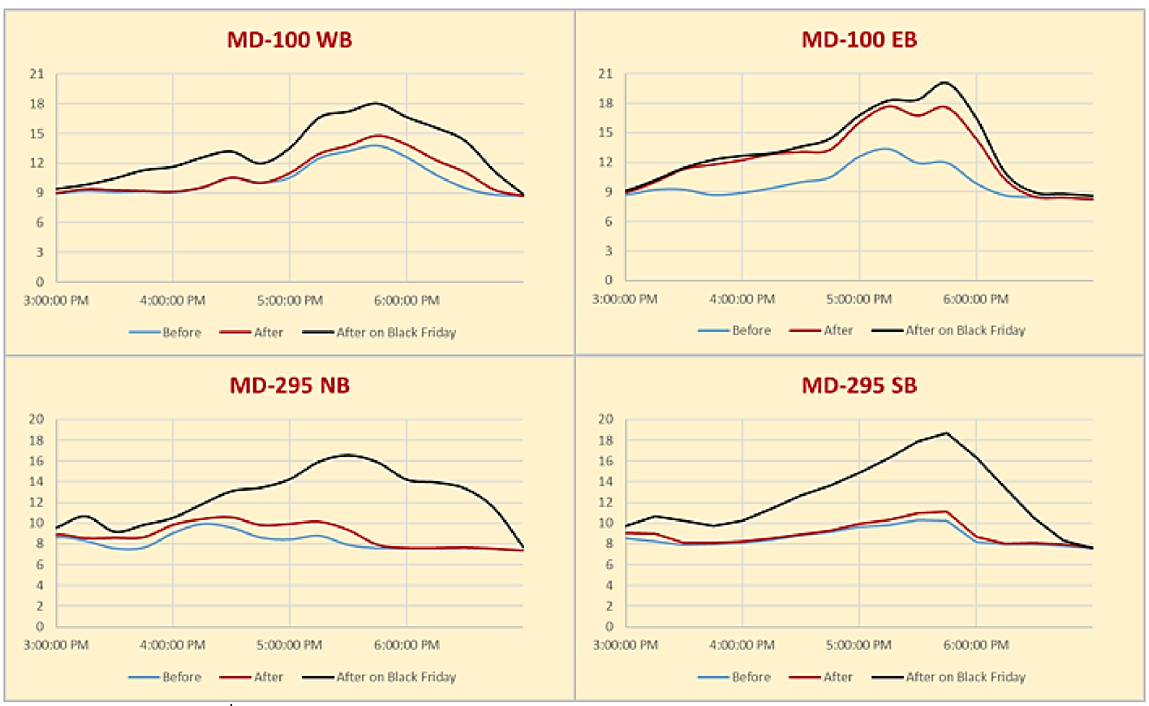


Figure 13: Live! Casino major corridor travel time profiles

4.3.2 Horseshoe Casino

The Horseshoe Casino network is the largest sub-region model in network size and simulated more than twice as many vehicles as the other models. Therefore, a marginal change in the number of vehicles induced a smaller network-wide mobility impact. This notion, combined with the fact that Horseshoe casino has a smaller number of gaming positions, contribute to the overall minimal traffic impact, as shown in Table 12. During the 6:00 PM after-scenario peak hour, an additional 900 vehicles in the system (+0.5%) altered the average travel time and speed by less than 1%. As a result, it is reasoned the addition of Horseshoe Casino alone had no significant impact to mobility network-wide.

The combined casino and special event had a major traffic impact throughout the region. For a Thursday night Baltimore Ravens NFL game, of the over 18,000 game-related trips—including both stadium attendees and staff expected to arrive at the stadium during the hours leading up to the game—approximately 4,500 trips (24%) were predicted to arrive between 6:00 PM – 7:00 PM (the hourly distribution of special event trips is described in Appendix III). Given the influx of vehicles destined for the stadium and casino, the system experienced as much as a 30% decline in regional mobility.

From the density map in Figure 14, the most significant traffic impact is observed along Russell Street, which runs adjacent to the casino (star) and M&T Bank Stadium (ellipsoid). The LOS drops dramatically for both the northbound and southbound directions as well as the exit ramps of the Martin Luther King Jr. Blvd. and Russell Street interchange. A couple minor arterials east of the stadium also appear to experience severe congestion (i.e., W.

Ostend St. and Fort Ave.). The model's density map indicated no major decline in LOS for other major corridors in the vicinity, including I-95, I-395, and MD 295.

With a significant impact recognized along Russell Street from the I-95 interchange to Martin Luther King Jr. Blvd., time-of-day profiles are prepared in Figure 15 to provide details regarding the corridor's simulated travel time impact for each scenario. After the casino opened, the simulated travel time increased significantly in the southbound direction (27% during the 3:00 – 7:00 PM peak period and 64% during 5:00 – 6:00 PM when travel time peaks along this corridor). Simulated game traffic also caused an 80% increase in travel time during the 3:00 – 7:00 PM peak period (156% during 5:00 – 6:00 PM) in the southbound direction. Contrarily, no travel time impact was estimated for after-scenario traffic approaching the stadium from the south; however, for game days, both southbound (80%) and northbound (550%) travel times increased greatly.

Table 12: 6:00 PM Peak Hour Measures of Effectiveness Region-wide Results for Horseshoe Casino

HORSESHOE CASINO	BEFORE CASINO	WITH CASINO	CASINO + RAVEN'S GAME SPECIAL EVENT
MOEs	**Value**	**Value | % Change**	**Value | % Change**
# of Vehicles	178,044	178,970 | 0.5%	183,302 | 3.0%
Average Trip Time	10.07	10.15 | 0.8%	13.12 | 30.3%
Average Trip Time Index	1.50	1.51 | 0.7%	1.94| 29.3%
Average Speed	24.29	24.08 | - 0.9%	18.74 | - 22.8%

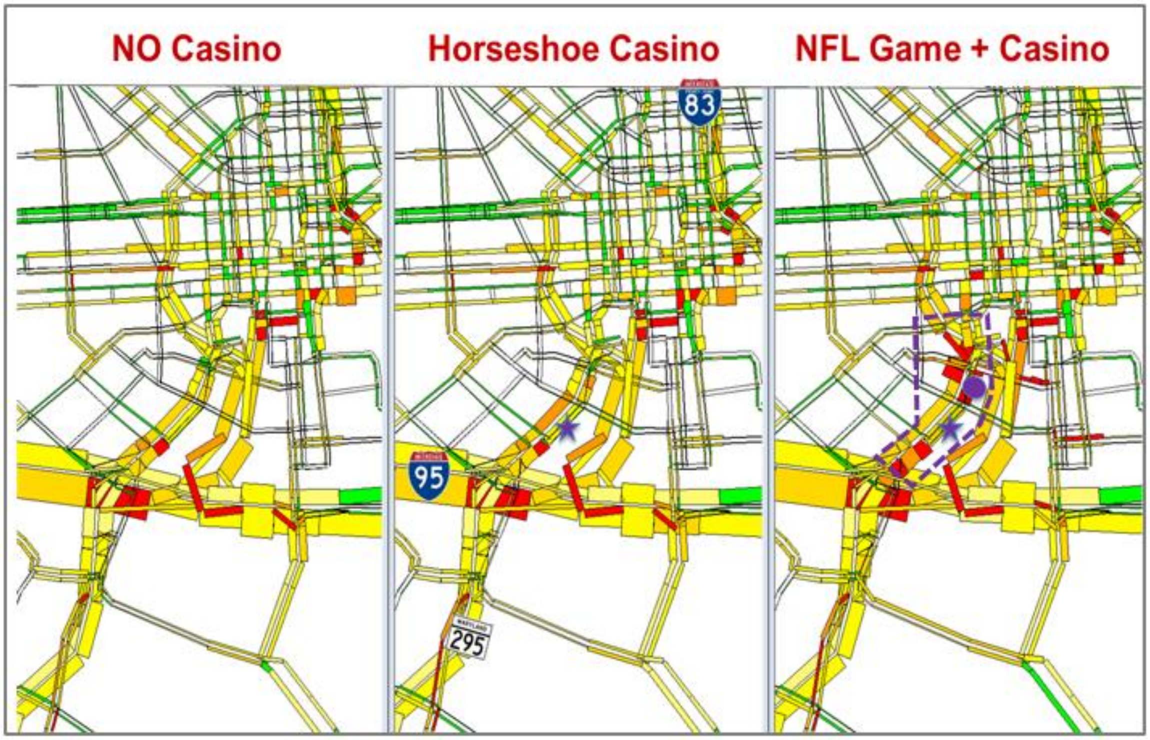


Figure 14: Horseshoe network level of service peak-hour snapshot.

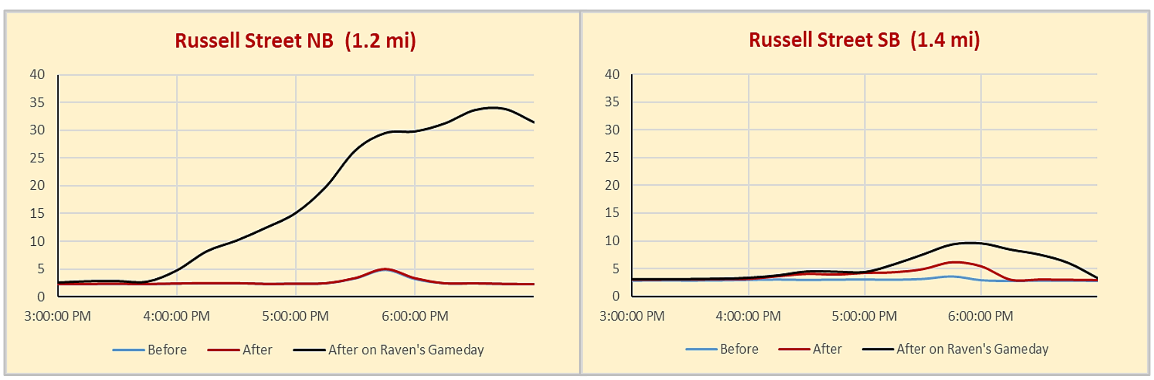


Figure 15: Horseshoe Casino major corridor travel time profiles.

4.3.3 MGM Casino

The MGM Casino model results predicted a moderate impact to regional mobility for the after-scenario. During the 6:00 – 7:00 PM hour of greatest system-wide impact, about a 6% increase in average travel time and decrease in average speed was estimated given a 2.2% increase in traffic volume (~1,400 peak-hour casino trips). The sold-out concert special event had no significant impact on system-wide traffic. A concert at the casino's 3,000-seat theater was assumed to start at 7:00 PM. All attendees driving to the concert were assumed to arrive within an hour before the concert began. 600 additional vehicle trips were produced as estimated in the Schwartz Engineering TIS report (Sam Schwartz Engineering 2013) (see Appendix III for additional info regarding the special event's trip generation). The regional roadway mobility impact was marginal (< 0.5% change).

Table 13: 6:00 PM Peak Hour Measures of Effectiveness Region-wide Results for MGM

MGM CASINO	BEFORE CASINO	WITH CASINO	CASINO + MGM CONCERT SPECIAL EVENT
MOEs	**Value**	**Value | % Change**	**Value | % Change**
# of Vehicles	64,021	65,449 | 2.2%	66,083 | 3.2%
Average Trip Time	14.99	15.9 | 6.1%	15.55 | 6.3%
Average Trip Time Index	1.69	1.79 | 5.9%	1.75| 5.9%
Average Speed	23.97	22.57 | - 5.8%	22.50 | - 6.1%

The peak-hour density map in Figure 13 shows locations outside the casino's immediate area where queue spillback occurs, notably I-295 and several spots along MD 210 (Indian Head Highway). No major decline in LOS was modeled on the adjacent streets around the casino. This finding could be a direct result of the $10M in infrastructure upgrades installed with the intent to alleviate the expected increase in traffic demand induced by the new casino. As a result, new capacity was added to the adjacent access roads, including Harborview Ave., National Ave., and Oxon Hill Road between the Capital Beltway and the Tanger Outlets intersection. The improvement plan also included a new signal as well as updated signal coordination on Oxon Hill Road (King, 2016).

The time-of-day travel time profiles were analyzed for three major corridors that were expected to have significant travel time impacts (Figure 14). The first, Oxon Hill Road from Kerby Hill Road to St. Barnabus Road exhibited a large increase in simulated travel time in the southbound direction only (12%). The cause of the impact is due to a historic bottleneck located south of Tanger Outlets where the road narrows from two to one lane. Northbound traffic during the after-scenario for both Oxon Hill Road and MD 210 unveiled no significant mobility changes as those directions are opposite of the direction of peak flow. However, the southbound direction of MD 210 from the Beltway to Old Fort Road experienced a 28% increase in simulated peak-hour travel time for the after-scenario. For the final corridor analyzed, I-295 south, the after-scenario casino demand impacted simulated travel time modestly by 7% for the 6:00 PM peak hour. Similar to the regional traffic impact peak-hour results, the difference in travel time associated with the addition of special event traffic across all analyzed corridors is negligible.

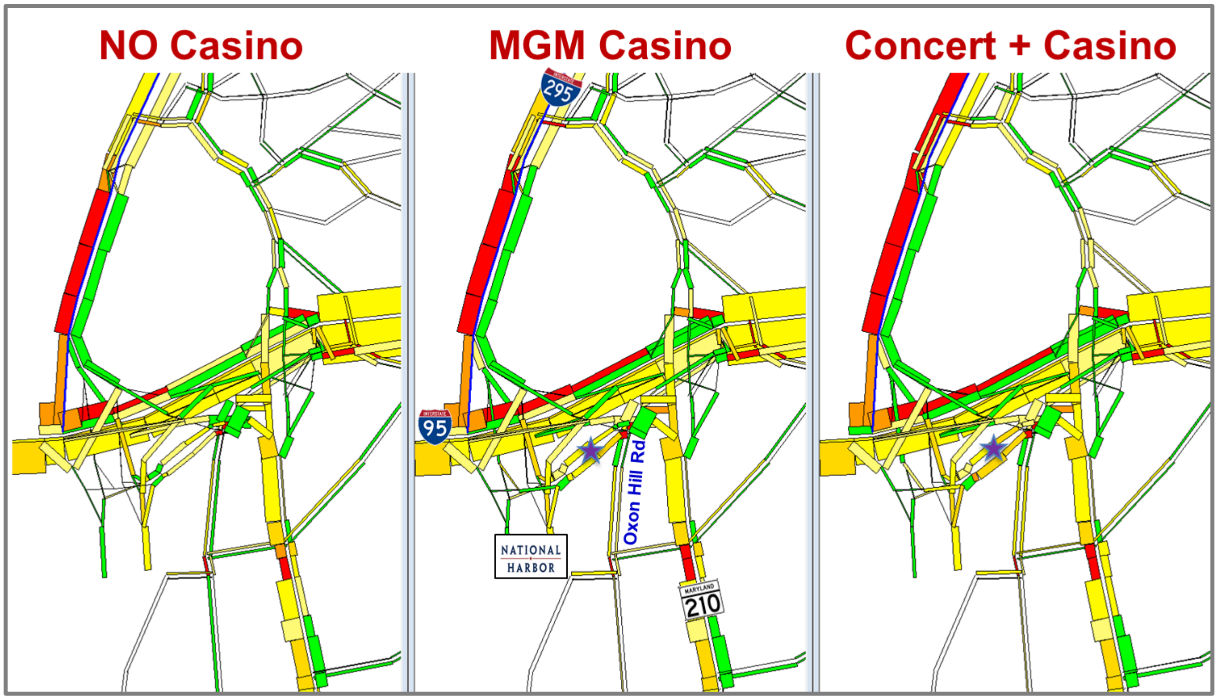


Figure 16: MGM network level of service peak-hour snapshot.

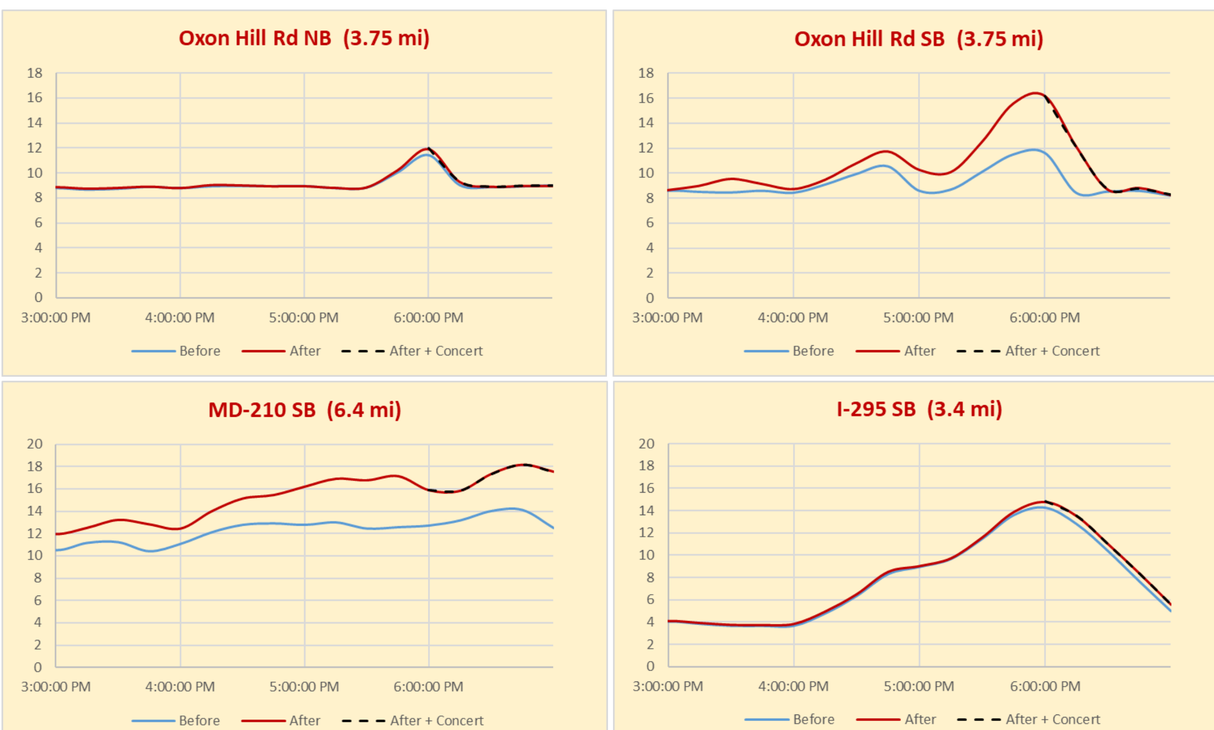


Figure 17: MGM Casino major corridor travel time profiles.

Chapter 5: Alternative Trip Generation Estimation

5.1 Method 1: Location-based Data

The growing availability of mobile data in transportation is reshaping the way the industry analyzes and manages traffic-related problems. As telecommunication and location-based technologies provide increasingly larger and more sophisticated datasets, transportation agencies can now manage large-scale, complex traffic demand and operations with the aid of location-based data suppliers and analytic services.

In search of regional origin-destination demand data to estimate casino trip rates, this study procured statewide OD trip matrices from Airsage, a national leading location data service provider. Airsage offers both accurate and secure trip information used for modeling and forecasting trip patterns, point of interest trip generation, and traveler behavior through the collection and analysis of real-time mobile phone and GPS data. The spatiotemporal qualities and coverage of the Airsage data permitted the estimation of casino trip rates that do not rely on ITE-based rates.

The acquired OD demand matrices capture trips to and from each casino from zones (i.e. census tracts) that cover the state of Maryland, D.C., and northern Virginia. Separate casino zone areas were drawn to encompass the casino building and parking garage footprints. The trip matrices were weighted to represent the resident population of the census tracts that produced casino trips and aggregated for the month of April 2017, during the weekday

PM peak period. With this dataset, the author compared the Airsage casino OD demand with the ITE-based casino trip volumes as shown in Table 14.

Upon comparison, it is apparent that the location-based peak hour estimates (6-7pm) greatly differ from the ITE-based trip values. Among the three casinos studied, the number of arrival trips aggregated from the Airsage dataset averages about 30% the total number of trips estimated in their respective TIS reports – about 36% for trips exiting the casinos. The largest difference was observed for Live! Casino where more than four times as many arrival peak hour trips were estimated using the ITE-based method versus the Airsage trip data (182 vs 886).

Table 14: Airsage OD Trip + MGM Counts Summary

2017	LIVE!					HORSESHOE		
Weekdays 4/1 - 4/27	Airsage Trip Estimates					Airsage Trip Estimates		
	IN	OUT	Internal	FROM MALL	TO MALL	IN	OUT	Internal
3-4PM	150	140	28	0	8	136	104	21
4-5PM	119	202	16	0	0	117	144	8
5-6PM	133	137	20	0	0	121	151	7
6-7PM	**182**	**125**	16	3	4	**144**	**110**	5
TOTAL	**584 (49%)**	**604 (51%)**	**80**	**3**	**12**	**518 (50%)**	**509 (50%)**	**41**
***Default Trips**	**886**	**549**				**546**	**405**	

2017	MGM NATIONAL HARBOR						
Weekdays 4/1 - 4/27	Airsage Trip Estimates					SHA Counts (Sept. 2018)	
	IN	OUT	Internal	FROM NAT'L HBR	TO NAT'L HBR	IN	OUT
3-4PM	292	271	31	0	2	418	418
4-5PM	296	281	35	2	7	436	436
5-6PM	281	305	24	6	0	517	517
6-7PM	**353**	**336**	29	32	15	**571**	**571**
TOTAL	**1222 (51%)**	**1193 (49%)**	**119**	**40**	**24**	**1942**	**1942**
***Default Trips**	**787**	**552**					

* Default trip volumes represent the peak hour of generator and are based on trip generation rates from casino impact studies

Consequently, it is observed that the TIS casino rates, already modified lower from the ITE manual's average trip rate of 0.4 for casino establishments (see Section 4.3 step 5), significantly overestimate the trip generation estimated from the location-based OD data. It is important to note that the overestimation can be somewhat attributed to the Maryland casino rates representing the peak hour of generator traffic, which occurs outside the analyzed time period (i.e. late evening). Moreover, the data provided by Airsage has not been validated and should not be assumed to be the true values. Details surrounding the extraction and post-processing of location data from telecommunication devices are unknown, but it is suspected the final data product may contain inaccuracies that would affect the trip estimates. For example, the added casino zones were relatively small in comparison with typical zonal structures (i.e. census blocks/tracts, TAZs); therefore, it is likely not all cell phone devices that entered the casino zone were detected, resulting in an underestimate of trips. This notion is also supported by the small number of internal trips reported during the analyzed time period.

Also included in Table 14 are 2018 ground truth counts for MGM Casino provided by the Maryland State Highway Administration. With tube counters installed at the start and end of both National and Harborview Avenue, the author estimated casino trips based on MDOT SHA hourly count data with the intention to ground-truth the results of both trip analysis methods (see Appendix V for details). Although the counters were not placed at the direct access points of the casino complex (author had to assume the distribution of tips entering and exiting the site to be 50/50), this estimation is likely the most accurate representation of the casino's trip generation for the weekday PM peak period in comparison with all other trip estimations presented in this paper. Upon review, the count-based 6-7 PM trip estimate (1,142 total) is significantly closer to the total number of estimated trips based on the default ITE-based method (1339 total) than Airsage's OD data (718 total including internal trips). Table 15 compares the peak hour count totals in a clearer way for MGM Casino. Therefore, with the ground truth counts considered, the ITE-based trip generation out-performs the location-based trip estimates procured from Airsage based on the total number of peak hour trips.

Table 15: MGM Peak Hour Trip Estimates

[April 2017]	**Airsage Location-based Trip Estimates**			**ITE-based TIS Trip Rates**		**Ground Truth Counts**		
	IN	OUT	Internal	IN	OUT	IN	|	OUT
6-7 PM Pk Hr	353	336	29	787	552	571	|	571
TOTAL	718			1339		1142		

5.2 Method 2: Statistical Estimation Based on ODME

The second trip rate estimation approach incorporates a module embedded within the mesoscopic DTA model: Origin Demand Matrix Estimation (ODME). ODME is the same path-flow optimization model used in calibration of the DTA models to match the observed and simulated traffic counts. After vehicle shortest paths are assigned based on a user's experienced travel time which accounts for dynamic traffic conditions as time progresses, ODME is performed to adjust the OD demand along these paths to satisfy the dynamic user equilibrium condition. For the purpose of estimating local trip rates, ODME is introduced to attempt to match the number of estimated trips based on ITE rates (MDOT SHA approved casino rates for this study) with ground-truth data such as local traffic counts or OD probe data.

Figure 18 displays the illustrative framework of the ODME trip rate analysis. The procedure begins with preparing a calibrated and validated before-scenario, sub-region model with supplemental OD demand (i.e. seed OD demand). Next, a new OD pattern based on national trip rates is generated and integrated into the base model via a newly created TAZ. The new zone's trip distribution can be determined from an adjacent network zone with a similar land use. Using traffic counts obtained for years after the site began operation, the sub-region model is again calibrated, and the OD demand is re-estimated in an attempt to match the model's simulated local traffic with post-construction ground-truth data. Finally, the adjusted peak hour OD trip volumes supplant the default ITE trip rates and provide the opportunity to augment the ITE trip generation database. In short, the analysis starts with a base scenario OD pattern based on existing trip generation rates, then updates the trip generation rates using after-scenario count data through the implementation of a DTA simulation-based model. This analysis procedure was completed for the MGM casino network using the calibrated before-scenario MGM model and after-scenario traffic counts (i.e. counts collected 2017-18 after casino opened). Volume estimates produced from hourly MDOT SHA traffic count data collected in September 2018 were used to ground-truth the results.

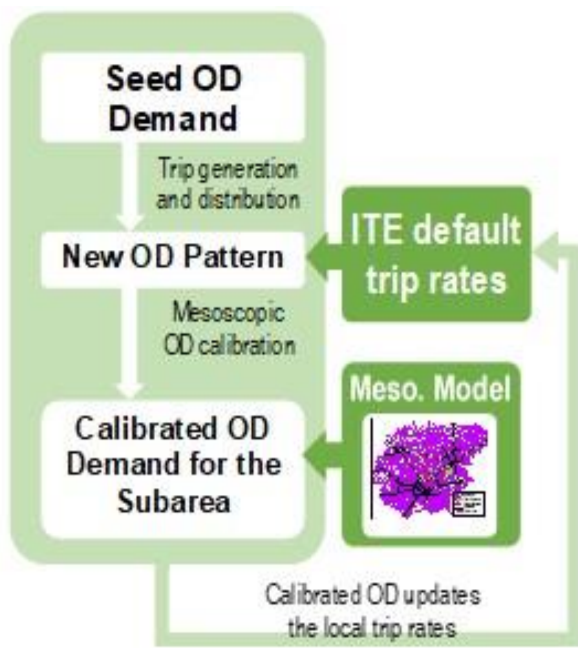


Figure 18: Trip Rate Estimation Framework

Figure 19 presents the analysis results. Starting with seed ITE-based casino volumes of 886 trips in and 549 trips out of the casino, both entering/exiting casino trip volumes converge to a smaller value after applying ODME using after-scenario sensor count data. Originally, all 96 count sensors throughout the network were included in the ODME procedure to adjust the local casino trip volumes; however, due to both the variability and unavailability of volume data at many of the sensor locations, the initial results were inconclusive. Therefore, the number of sensors used in the estimation procedure was narrowed to approximately ten sensors within the casino vicinity. After completing twelve runs of ODME with the reduced number of sensors, the final estimated trip volumes equated to 565 and 410. The updated volumes adjusted by over 35%; however, the end results underestimated the casino traffic counts provided by MDOT SHA. The number of 6-7 PM peak hour trips entering and exiting the casino area based on 2018 count data totaled at 1,142. The ODME method estimated a total of 975 trips, a 14.6% difference. Interestingly, the ODME results fell closer to the MDOT SHA counts than the trip estimates provided by Airsage and the ITE-based default trip rates. It is important to note that the author was not able to obtain an accurate IN/OUT distribution of the casino trips, so a 50/50 distribution was assumed for the MDOT SHA counts.

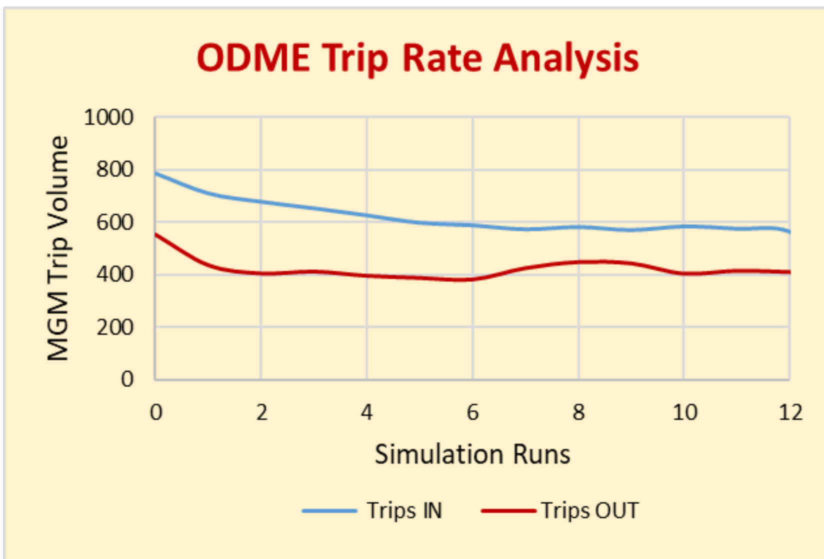


Figure 19: Trip Rate Analysis Results

Table 16: Trip Rate Estimation Results Comparison Summary

MGM CASINO	Peak Hr Trips		TOTAL	% Change
Estimation Method	**IN**	**OUT**		
Default Rates (ITE-based)	787 (59%)	552 (41%)	1,339	**17.3%**
Airsage OD Matrices	353 (51%)	336 (49%)	689	**-39.7%**
ODME (DTA Model)	565 (58%)	410 (42%)	975	**-14.6%**
SHA Counts*	**571 (50%)**	**571 (50%)**	**1,142**	-

*** Trip Distribution assumed to be 50/50**

Chapter 6: Discussion

With the recent opening of three full-scale casinos in Maryland, this traffic impact study evaluated regional and local traffic conditions at each casino for three different scenarios: before casino, after casino, and after casino during a special event (e.g. an NFL football game). Two methodological approaches were implemented to perform the analysis: (1) before/after-scenario probe data analytics and (2) mesoscopic DTA simulation-based modeling. Both approaches yielded different results due to the disparities in data sources and methodological framework. The first method analyzed raw traffic data which averaged over an entire month and likely contained abnormal traffic patterns (i.e. crashes or work zone delays). The DTA model controls for the untypical travel behaviors, but is influenced more by the accuracy of the model's network features and availability of count data. The result summaries for both methods are described below.

6.1 Data Analytics

The traffic impact results varied widely depending on the corridor under review and the month from which aggregated INRIX data was analyzed (i.e., January, April, July, or October). For example, I-395 South, the average travel time decreased during the month of July by 38%, one year after the casino opened and increased 33% for the month of October. Another important finding was the large number of months that exhibited no significant impact (21 months) or improved traffic performance (11 months) after the opening of the casinos. The improvement in mobility could sometimes be attributed to temporary work zones, large-scale disruption like Superstorm Sandy, and roadway improvement projects.

Nonetheless, it was discovered that probe data aggregated for the month of April presented consistent performance results for all corridors. The results relayed a worsening of the average travel time and speed performance along all studied corridors except I-395 South and Exit 2 Ramp 3 near the MGM casino. For the remainder of the corridors, the traffic impact resulted in an approximate 8 to 14% increase in average travel time and a 6 to 12% decrease in average speed; these changes account for any roadway improvements that were completed in conjunction with the casino. Therefore, the author concludes the casinos did create additional congestion on roadways near the casinos after they became operational, but the impact was moderate.

6.2 Mesoscopic DTA Modeling

According to the model outputs, the traffic conditions around Arundel Mills deteriorated the most after the opening of Live! Casino in comparison with the model results for Horseshoe and MGM casinos. The Horseshoe Casino model simulated no major impact to regional mobility; the MGM Casino model simulated a moderate impact of 6% for the after-scenario. However, the after-scenario for the Live! Casino model – this model is about the same size as the MGM model in terms of number of simulated vehicles – estimates a 14% increase in average travel time and 12% decrease in average speed system-wide.

The significant differences in traffic impact for each casino can be explained by the size of the network, after-scenario network changes, and number of casino gaming positions. Horseshoe Casino simulated almost twice as many vehicles and introduced about a third less casino demand based on the Maryland casino trip rates; hence, the result of adding only a couple hundred vehicles per hour to the entire network had little effect on the system's performance. The only significant impact realized was at the corridor level along Russell Street. Although the MGM and Live! Casino models are similar in size and load roughly the same number of casino trips into the network, the MGM Casino model includes network changes that reflect the $10M worth of infrastructure improvements completed on all the adjacent streets to the casino. This network difference could help explain why the Live! Casino exhibited the largest traffic impact among the three casinos studied.

For the after-scenario + special event, again Live! Casino model estimates the largest regional impact (+66% average travel time and -40% average speed) after an additional 16,600 Black Friday trips were loaded into the model. It should be noted that Black Friday is a holiday for most, so the increase in traffic congestion may not be a major concern for those who travel to the Live! Casino or the shopping mall (compared to commute trips). The Horseshoe Casino added approximately 18,500 Raven's NFL game-day special event trips, yet the regional impact was less (+30% average travel time and -26% average speed), likely due to the larger size of the network. A sold-out concert at MGM Casino would have no significant regional traffic impact according to the model.

6.3 Alternative Trip Generation Estimation

Chapter 5 introduced two trip generation estimation approaches in search for an alternative estimation method to the *ITE Trip Generation Manual*. The location-based data approach utilized Airsage mobile device data to extrapolate OD pairs from cell phone devices that entered one of the casinos during April 2017. This data provided weighted trip estimates that significantly underestimated both the default ITE-based casino rates and the volume estimates based on the September 2018 Maryland SHA count data. As discussed in Section 5.1, the trip generation estimates produced by Airsage have not been properly validated, and may explain the degree of underestimation. Mobile sourced data encompasses several known technical issues that include spatial accuracy, data penetration, and expansion factoring. Therefore, the location-based data approach requires further validation before this data form can assert itself as a reliable alternative to the ITE trip generation manual.

The second estimation method, the ODME statistical procedure embedded within the mesoscopic DTALite model, provided trip estimates more parallel with the ground truth data. The testing of this method resulted in a trip estimate that slightly underestimates the total PM peak hour trip volume provided by SHA by less than 200 trips. The ODME estimates out-performed both the ITE-based and Airsage trip estimates. Although ODME requires after-scenario traffic count data, this method is potentially more appropriate for developing calibration/adjustment factors for trip generation of special generators.

6.4 Conclusion

Traffic impact analyses are programmed and guided by government jurisdictions with the intention to provide straightforward, easy-to-replicate procedures for practitioners to estimate the changes in demand and travel behavior in response to land use development. However, many complex transportation problems warrant the use of more quantitatively advanced analysis methods than the current methods in practice. Fortunately, the development of more modern analysis tools as well as the expanse in data coverage and accessibility has allowed practitioners and researchers to surpass the limitations of conventional analysis methods. As a result, new analysis strategies can be effectively implemented to quantify the traffic impact for complex development scenarios (i.e. special generators) such as a full-service casino.

This research effort is the first to analyze a special generator, namely a full-service casino, using innovative traffic analysis tools. Both a vehicle probe data analytic tool and mesoscopic DTA simulation model successfully measured and predicted MGM at National Harbor to produce a moderate impact on the existing system-wide and local traffic patterns. The study also evaluated traffic conditions across three different scenarios: before casino, after casino, and after casino plus special event, the latter of which is not typically incorporated in conventional TIAs. Furthermore, this study also introduced and compared two innovative approaches to estimating trip generation for special generators. The estimation techniques revealed surprising results. With the advantages of using aggregated mobile data to determine the travel demand, the authors did not expect to see the location-based results underestimate the ground-truth trip counts by large margin. This outcome should encourage researchers to investigate the accuracy of such data. Contrarily, the ODME method assignment produced quality results, and provides new insight into the way a mesoscopic simulation model can be used to derive trip rates.

Overall, the implementation of these alternative analysis methods can serve as a building block in the endeavor to improve the methods in practice that are used to conduct a TIA, including special generator trip generation estimation, for complex land use developments.

Modern analysis tools can improve the evaluation quality and simultaneously reduce time and costs. Perhaps with further investigation, the state-of-the-art trip generation approaches can be improved upon to augment the ITE Manual.

Appendices

APPENDIX I:

PROBE DATA ANALYTICS COMPARISON CHARTS + TABLES

HORSESHOE CASINO

MD-295 / Russell Street (1/3)

3.8 miles NB; 2.2 miles SB

Opened in August 2014

Table 17: Probe Data Analytic Results for Russel St. (January + April)

Avg Travel Time (min)		January 2014	January 2015	Difference	t-stat	p-value		April 2014	April 2015	Difference	t-stat	p-value	
NB	(3 - 7PM)	4.64	5.10	**0.46**	-5.78	0.000	***	5.18	5.71	**0.53**	-2.90	0.011	**
	PM Peak Hr	4.69	5.50	**0.81**	-20.49	0.000	***	5.06	6.44	**1.37**	-13.70	0.001	***
SB	(3 - 7PM)	4.69	4.17	**-0.51**	4.33	0.001	***	4.04	4.43	**0.39**	-6.17	0.000	***
	PM Peak Hr	5.57	4.42	**-1.15**	16.87	0.000	***	4.56	5.06	**0.50**	-9.81	0.002	***
Avg Speed (mph)													
NB	(3 - 7PM)	48.33	44.15	**-4.18**	6.10	0.000	***	43.49	39.79	**-3.69**	2.82	0.013	**
	PM Peak Hr	47.82	40.75	**-7.06**	28.23	0.000	***	40.63	34.86	**-5.77**	3.68	0.035	**
SB	(3 - 7PM)	29.52	32.61	**3.09**	-4.76	0.000	***	33.84	31.08	**-2.77**	6.87	0.000	***
	PM Peak Hr	24.42	30.70	**6.28**	-16.10	0.001	***	29.80	26.90	**-2.90**	10.65	0.002	***

Note: PM Peak Hour comprises 4 consecutive 15-min intervals that yield overall highest average travel time value within 3-7pm period.

Table 18: Probe Data Analytic Results for Russell St. (July + October)

Avg Travel Time (min)		July 2014	July 2015	Difference	t-stat	p-value		Oct 2013	Oct 2014	Difference	t-stat	p-value	
NB	(3 - 7PM)	6.15	6.85	**0.70**	-4.92	0.000	***	4.48	5.36	**0.88**	-14.13	0.000	***
	PM Peak Hr	7.28	8.70	**1.42**	-11.47	0.001	***	4.56	5.64	**1.07**	-10.79	0.002	***
SB	(3 - 7PM)	7.41	4.96	**-2.45**	11.21	0.000	***	4.13	4.01	**-0.12**	1.26	0.228	
	PM Peak Hr	8.04	6.10	**-1.95**	20.35	0.000	***	4.83	4.18	**-0.65**	9.14	0.003	***
Avg Speed (mph)													
NB	(3 - 7PM)	36.94	33.70	**-3.24**	5.63	0.000	***	50.05	41.96	**-8.09**	16.85	0.000	***
	PM Peak Hr	30.89	25.89	**-5.01**	13.42	0.001	***	49.17	39.85	**-9.32**	12.96	0.001	***
SB	(3 - 7PM)	18.66	27.97	**9.31**	-9.72	0.000	***	33.35	33.96	**0.61**	-0.83	0.417	
	PM Peak Hr	16.82	22.36	**5.54**	-7.69	0.005	***	28.19	32.55	**4.36**	-9.00	0.003	***

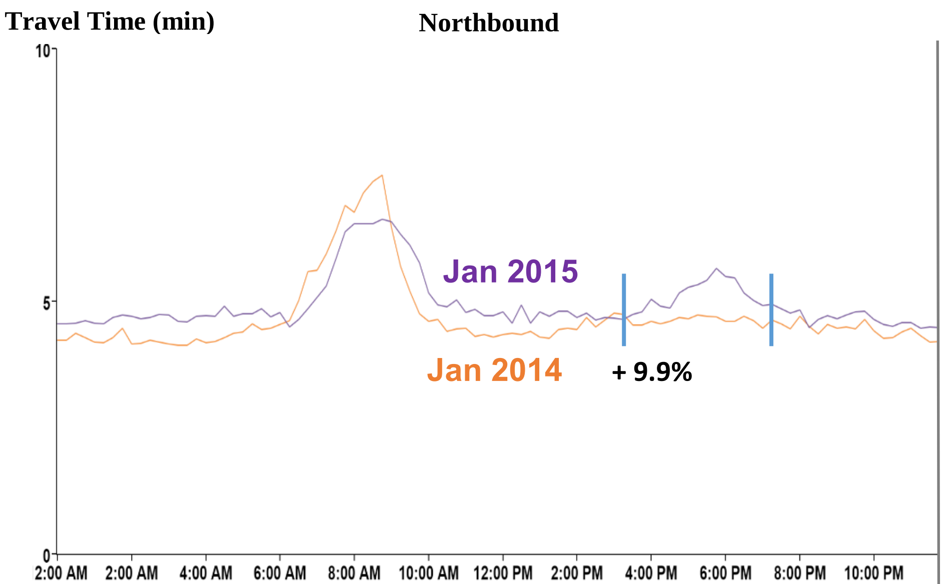
***Significant at p < 0.01 **Significant at p < 0.05 *Significant at p < 0.1 ; **RED VALUES** represent improved mobility performance.

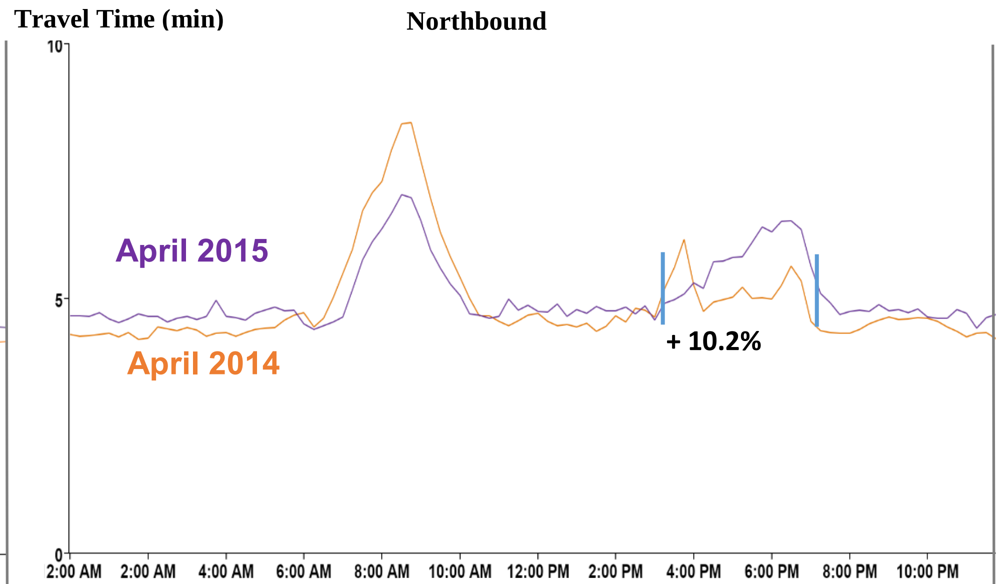
HORSESHOE CASINO

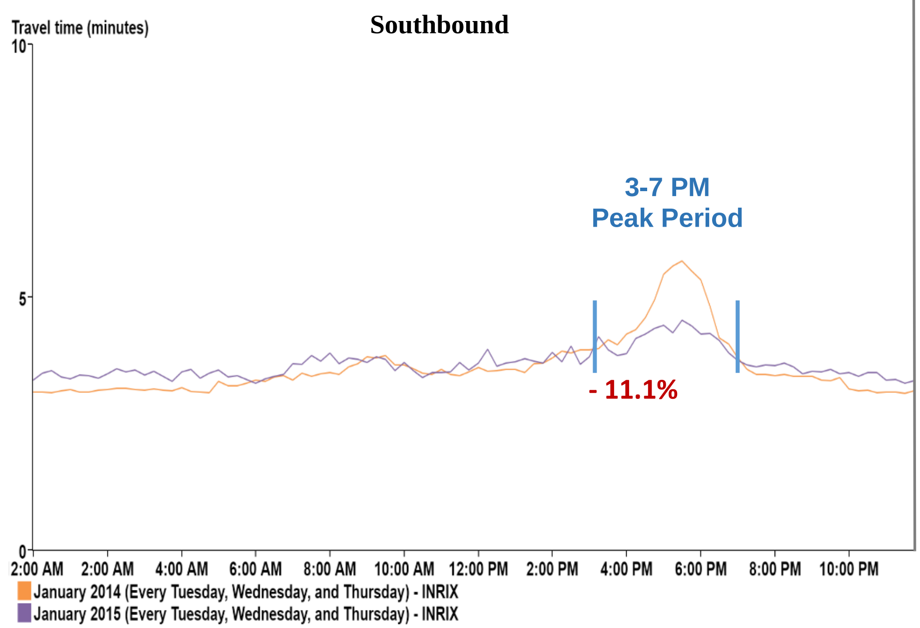
MD-295 / Russell Street (2/3)

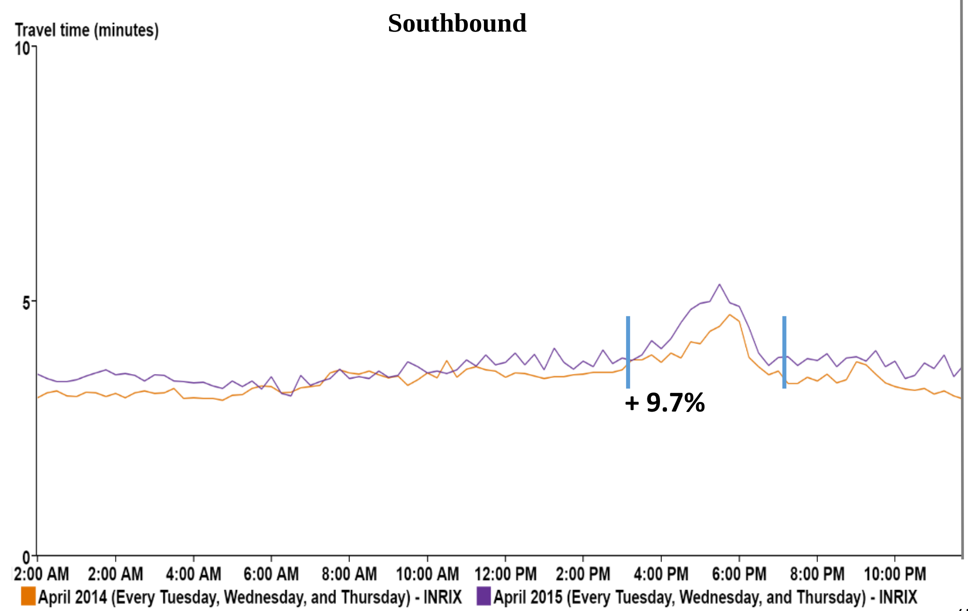
3.8 miles NB; 2.2 miles SB

Opened in August 2014







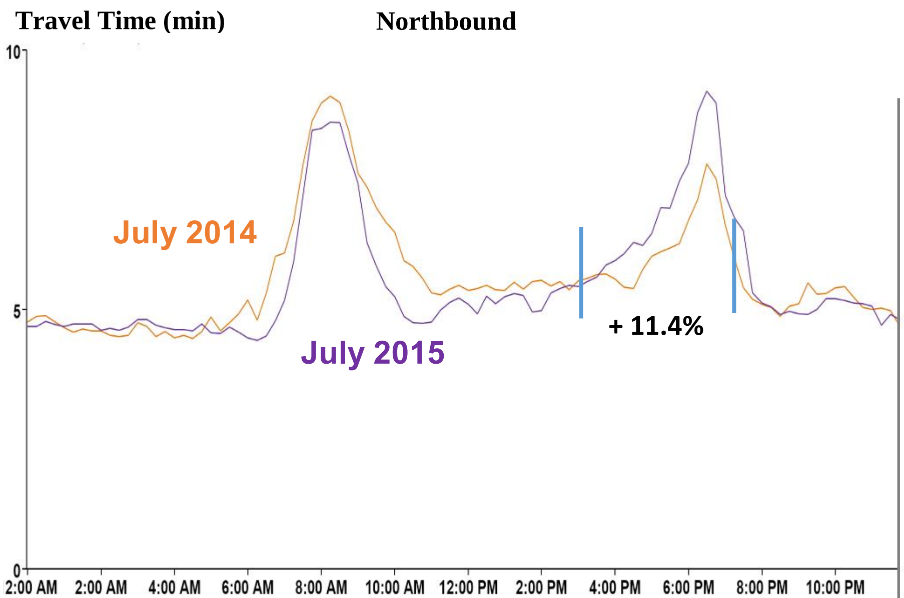


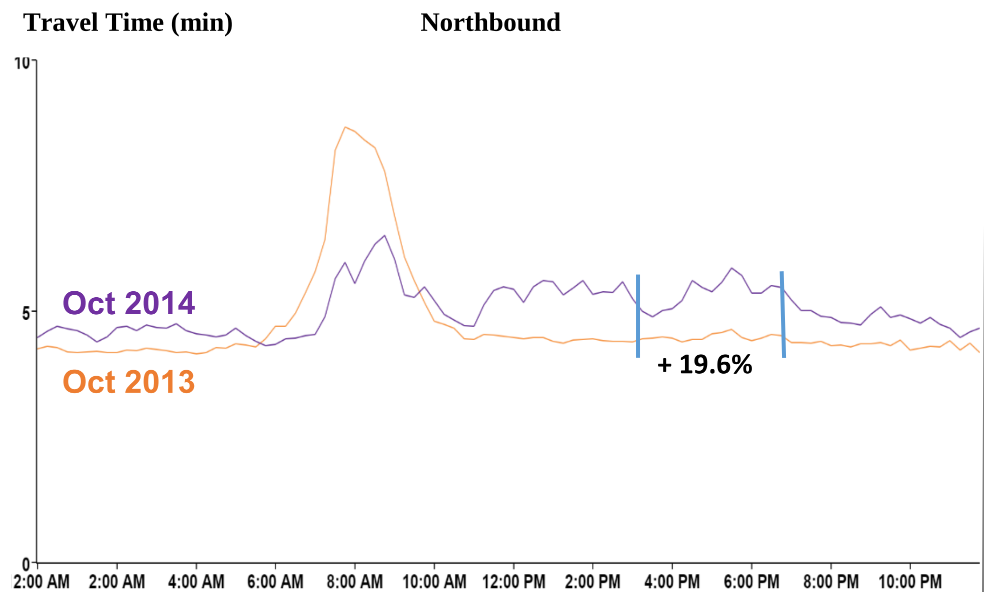
HORSESHOE CASINO

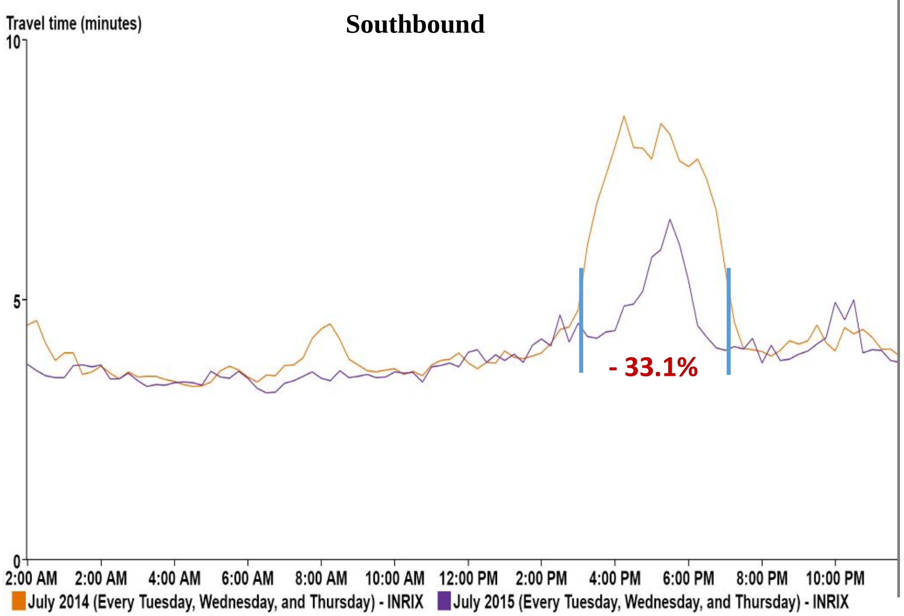
MD-295 / Russell Street (3/3)

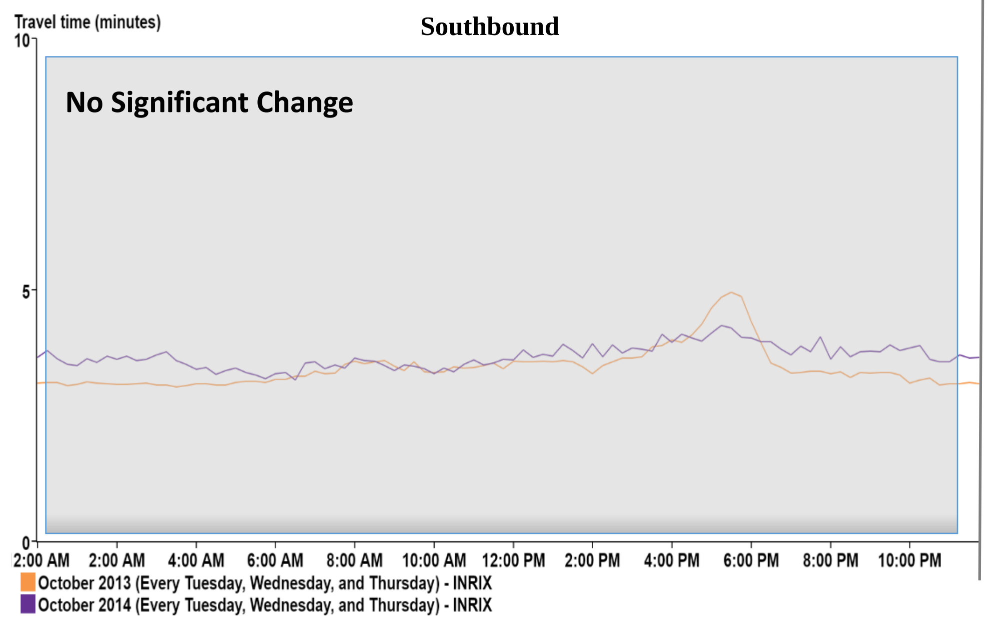
3.8 miles NB; 2.2 miles SB

Opened in August 2014









HORSESHOE CASINO

I-395 SB (1/2)

0.7 mile

Opened in August 2014

Table 19: Probe Data Analytic Results for I-395 (January + April)

Avg Travel Time (min)		Jan 2014	Jan 2015	Difference	t-stat	p-value		April 2014	April 2015	Difference	t-stat	p-value	
SB	(3 - 7PM)	2.35	2.44	**0.08**	-3.22	0.006	***	2.36	2.42	**0.05**	-1.20	0.248	
	PM Peak Hr	2.43	2.52	**0.09**	-1.88	0.157		2.49	2.78	**0.29**	-4.08	0.027	**
Avg Speed (mph)													
SB	(3 - 7PM)	16.59	16.03	**-0.56**	3.15	0.007	***	16.54	16.29	**-0.25**	0.90	0.384	
	PM Peak Hr	16.04	15.47	**-0.58**	7.44	0.005	***	15.70	14.08	**-1.62**	4.23	0.024	**

Note: PM Peak Hour comprises 4 consecutive 15-min intervals that yield overall highest average travel time value within 3-7pm period.

Table 20: Probe Data Analytic Results for I-395 (July + October)

Avg Travel Time (min)		July 2014	July 2015	Difference	t-stat	p-value		Oct 2013	Oct 2014	Difference	t-stat	p-value	
SB	(3 - 7PM)	2.72	1.67	**-1.04**	6.79	0.000	***	2.12	2.82	**0.70**	-30.65	0.000	***
	PM Peak Hr	2.78	2.50	**-0.29**	1.57	0.214		2.24	2.92	**0.69**	-20.27	0.000	***
Avg Speed (mph)													
SB	(3 - 7PM)	14.37	27.01	**12.64**	-4.80	0.000	***	18.40	13.84	**-4.56**	30.98	0.000	***
	PM Peak Hr	14.14	15.89	**1.75**	-1.47	0.237		17.46	13.37	**-4.10**	22.97	0.000	***

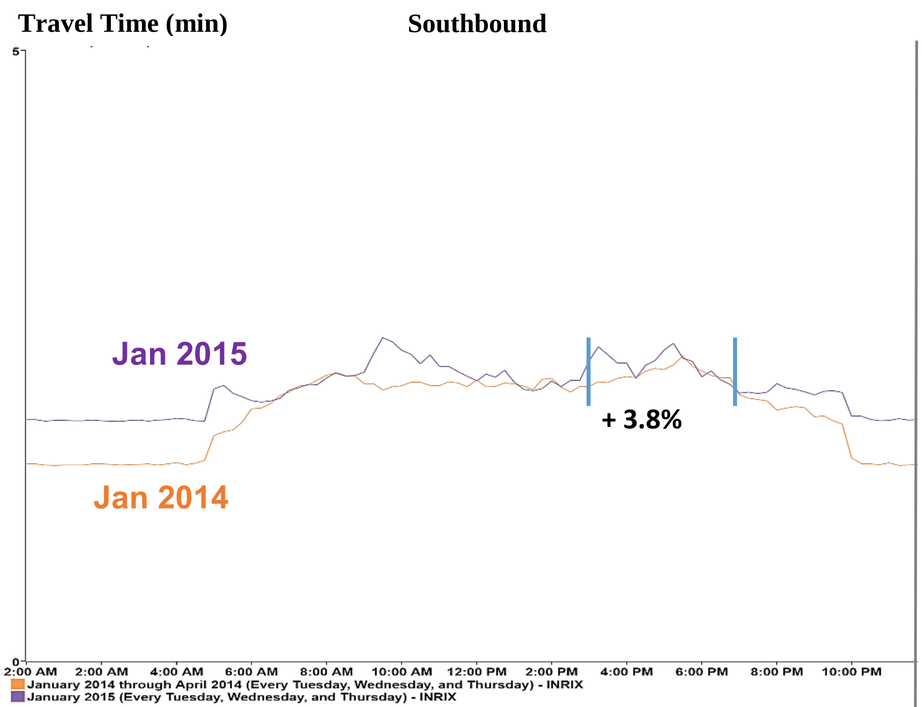
***Significant at $p < 0.01$ **Significant at $p < 0.05$ *Significant at $p < 0.1$; **RED VALUES** represent improved mobility performance.

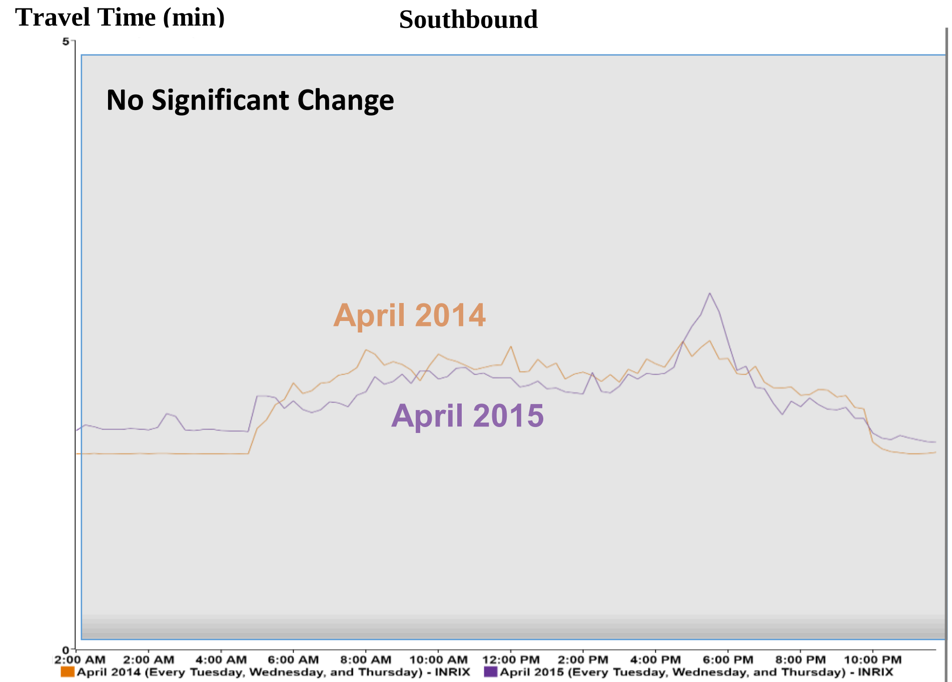
HORSESHOE CASINO

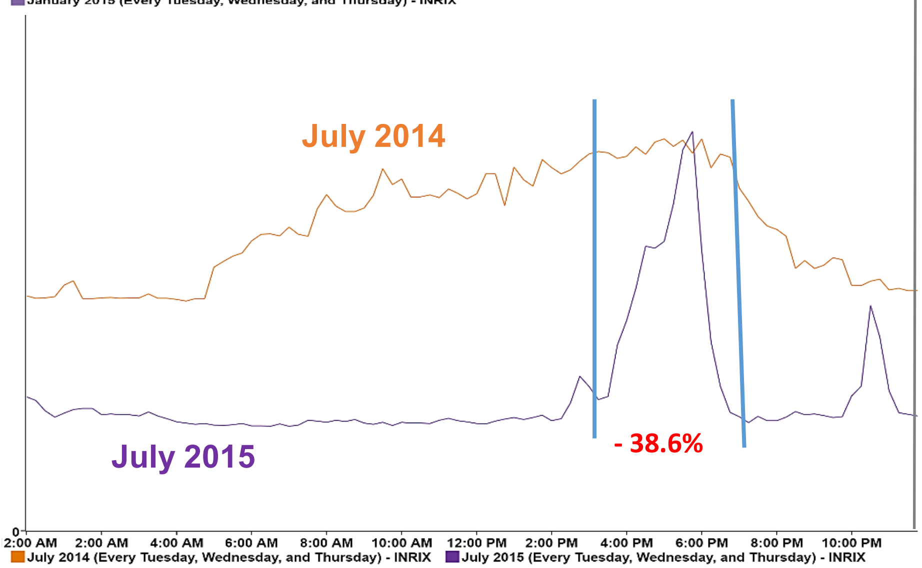
I-395 SB (2/2)

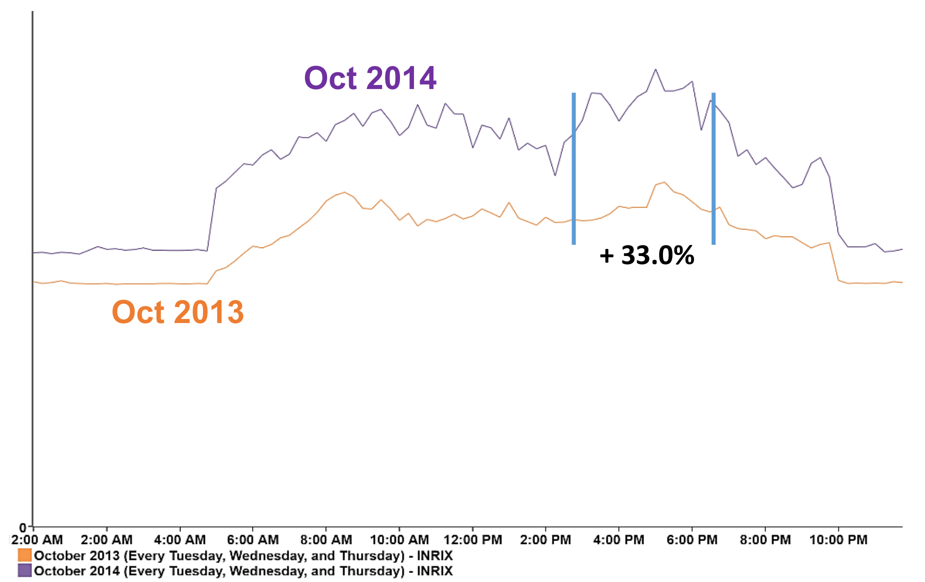
0.7 mile

Opened in August 2014









LIVE! CASINO

MD-100 (1/3)

2.5 miles EB; 5.3 miles WB

Opened in June 2012

Table 21: Probe Data Analytic Results for MD-100 (January + April)

Avg Travel Time (min)		Jan 2012	Jan 2013	Difference	t-stat	p-value		April 2012	April 2013	Difference	t-stat	p-value	
NB	(3 - 7PM)	4.19	4.10	**-0.10**	1.27	0.222		4.12	4.66	**0.54**	-4.52	0.000	***
NB	PM Peak Hr	5.33	4.89	**-0.44**	2.62	0.079	*	4.99	6.03	**1.04**	-10.95	0.002	***
SB	(3 - 7PM)	5.56	6.09	**0.52**	-3.56	0.003	***	5.58	6.10	**0.52**	-3.09	0.007	***
SB	PM Peak Hr	7.11	8.16	**1.05**	-3.99	0.028	**	6.97	8.31	**1.34**	-2.80	0.068	*
Avg Speed (mph)													
NB	(3 - 7PM)	55.57	56.18	**0.62**	-0.83	0.418		56.21	50.79	**-5.43**	4.43	0.000	***
NB	PM Peak Hr	42.84	46.51	**3.67**	-2.97	0.059	*	45.69	37.70	**-7.99**	7.20	0.006	***
SB	(3 - 7PM)	58.51	54.44	**-4.08**	3.63	0.002	***	58.14	54.52	**-3.61**	3.34	0.004	***
SB	PM Peak Hr	45.09	39.41	**-5.68**	4.27	0.024	**	45.94	38.72	**-7.22**	2.89	0.063	**

Note: PM Peak Hour comprises 4 consecutive 15-min intervals that yield the highest average travel time value within 3-7pm period.

Table 22: Probe Data Analytic Results for MD-100 (July + October)

Avg Travel Time (min)		July 2011	July 2012	Difference	t-stat	p-value		Oct 2011	Oct 2012	Difference	t-stat	p-value	
NB	(3 - 7PM)	4.33	4.38	**0.05**	-0.56	0.586		5.00	4.38	**-0.62**	4.72	0.000	***
NB	PM Peak Hr	5.36	5.73	**0.37**	-3.30	0.046	**	6.55	5.55	**-1.00**	4.08	0.027	**
SB	(3 - 7PM)	5.27	5.76	**0.49**	-2.49	0.025	**	6.41	5.92	**-0.50**	4.22	0.001	***
SB	PM Peak Hr	5.72	7.39	**1.67**	-5.00	0.015	**	8.97	8.04	**-0.94**	3.58	0.037	**
Avg Speed (mph)													
NB	(3 - 7PM)	53.73	53.70	**-0.03**	0.03	0.979		47.98	53.44	**5.46**	-5.19	0.000	***
NB	PM Peak Hr	42.51	39.69	**-2.82**	2.87	0.064	*	34.76	41.03	**6.28**	-4.08	0.027	**
SB	(3 - 7PM)	60.48	56.72	**-3.76**	2.37	0.031	**	52.35	55.92	**3.57**	1.75	0.000	***
SB	PM Peak Hr	55.64	43.13	**-12.52**	5.15	0.014	**	35.59	39.92	**4.33**	2.35	0.066	*

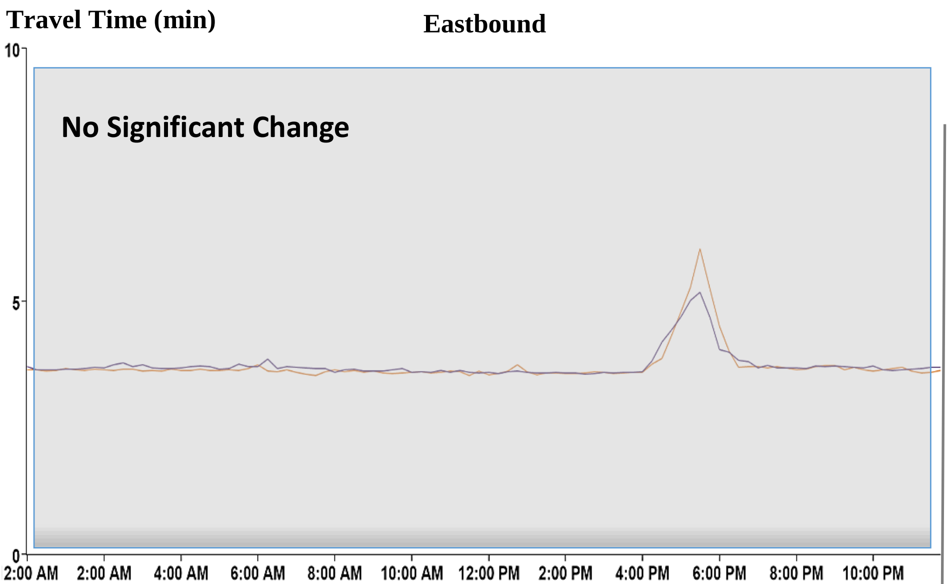
***Significant at $p < 0.01$ **Significant at $p < 0.05$ *Significant at $p < 0.1$; **RED VALUES** represent improved mobility performance.

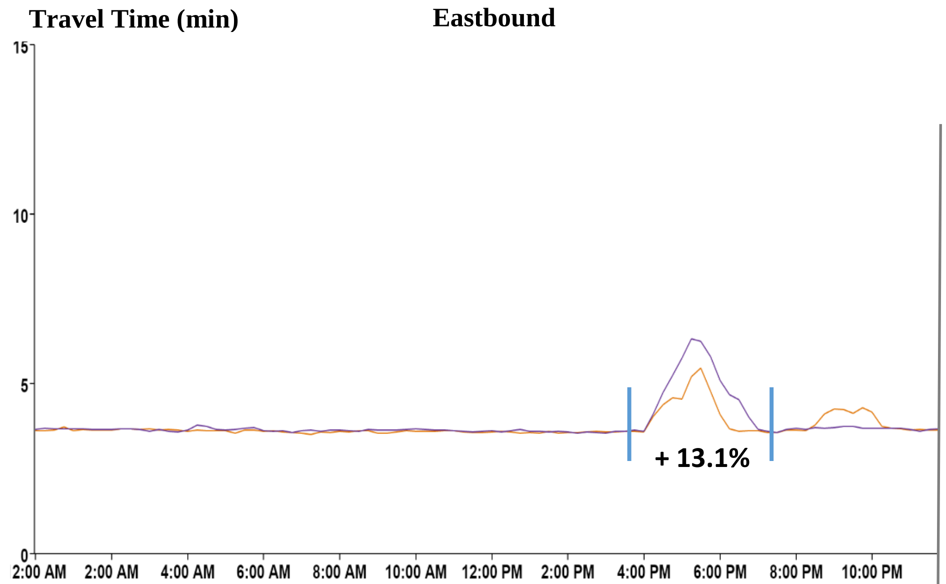
LIVE! CASINO

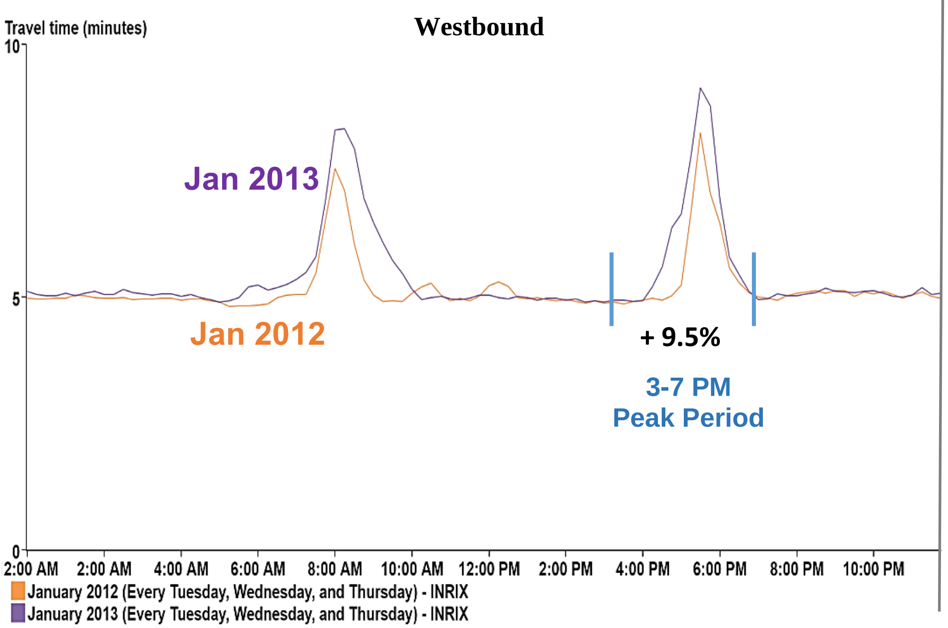
MD-100 (2/3)

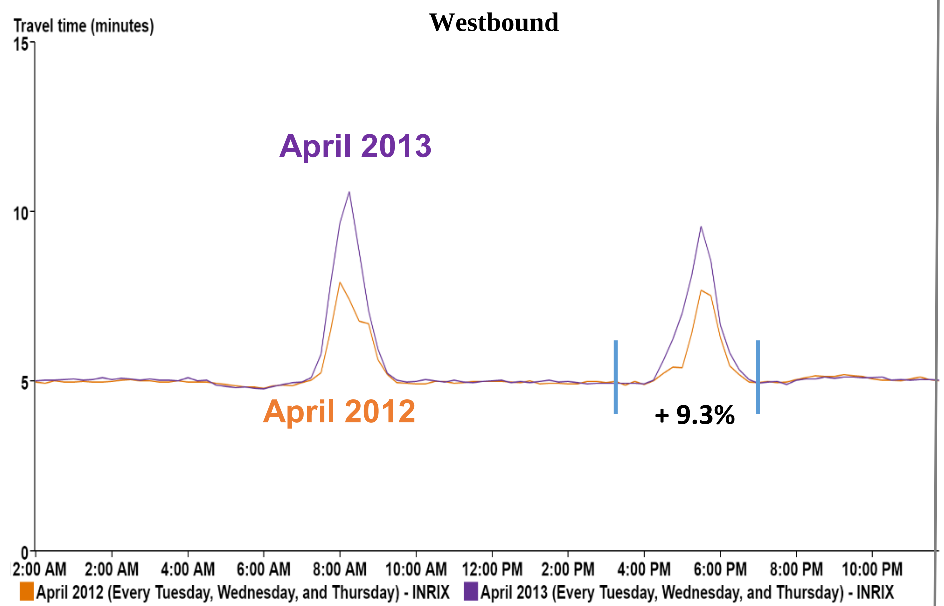
2.5 miles EB; 5.3 miles WB

Opened in June 2012







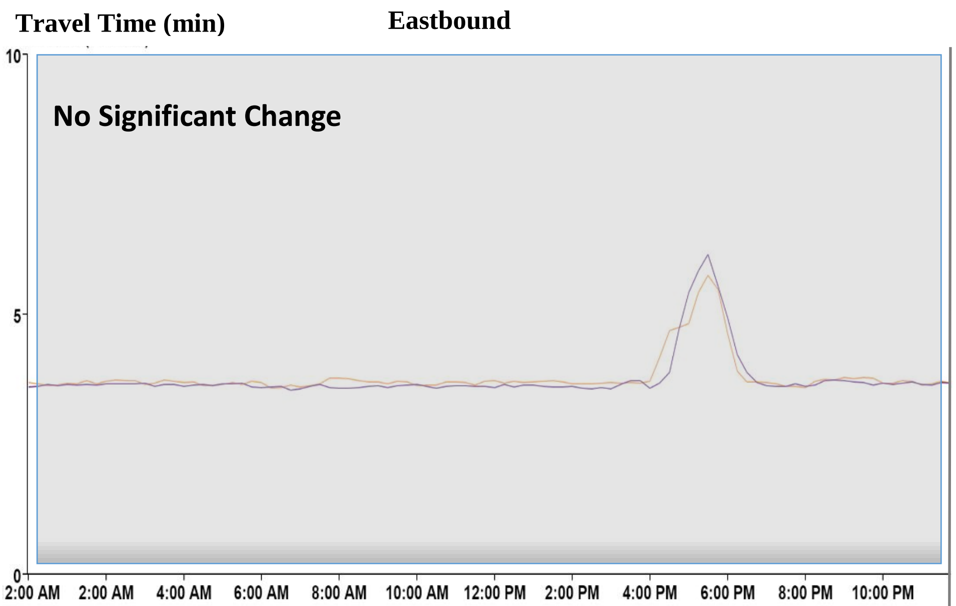


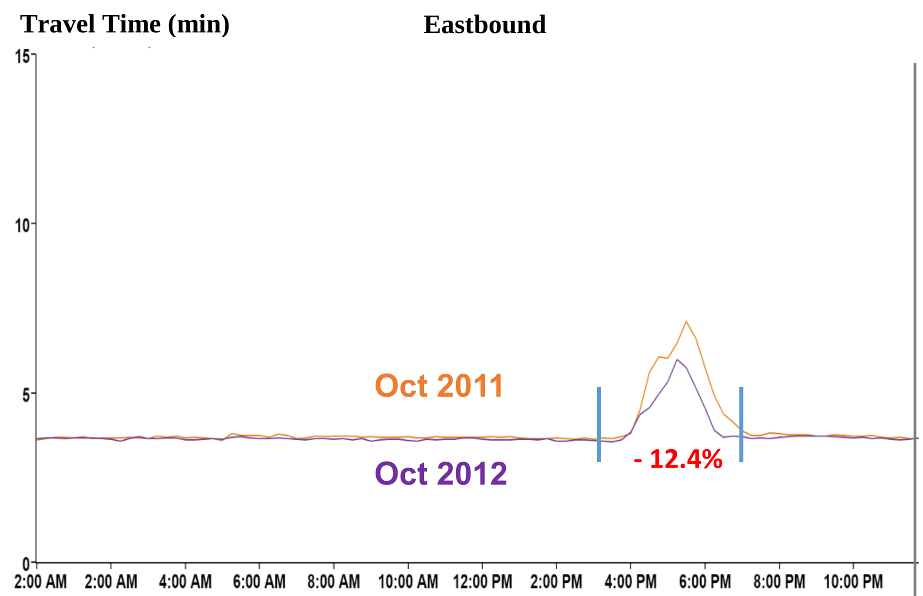
LIVE! CASINO

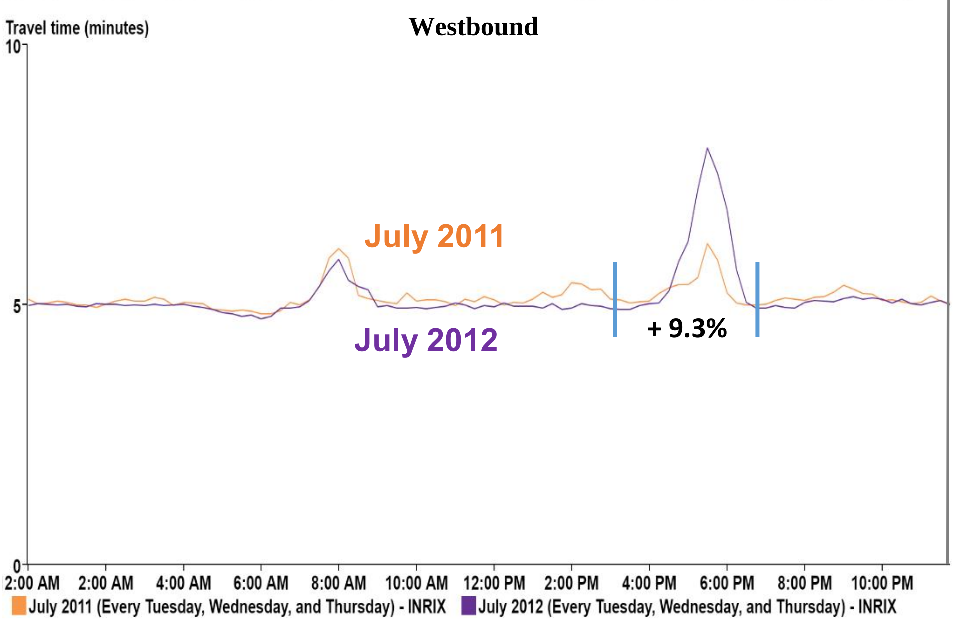
MD-100 (3/3)

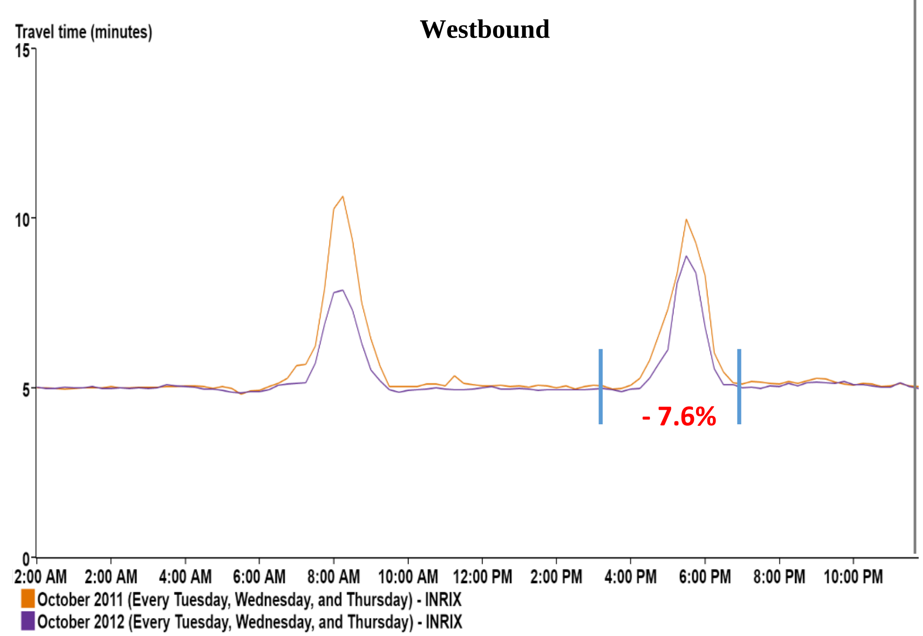
2.5 miles EB; 5.3 miles WB

Opened in June 2012









LIVE! CASINO

MD-295 / Baltimore & Washington Parkway (1/3)

7.4 miles NB; 6.7 miles SB

Opened in June 2012

Table 23: Probe Data Analytic Results for MD-295 (January + April)

Avg Travel Time (min)		Jan 2012	Jan 2013	Difference	t-stat	p-value		April 2012	April 2013	Difference	t-stat	p-value	
NB	(3 - 7PM)	7.55	8.38	**0.83**	-5.90	0.000	***	8.34	8.38	**0.04**	-0.26	0.795	
	PM Peak Hr	7.91	9.30	**1.39**	-4.37	0.022	**	8.69	9.51	**0.82**	-14.24	0.001	***
SB	(3 - 7PM)	6.39	7.41	**1.01**	-8.46	0.000	***	6.36	7.01	**0.64**	-6.57	0.000	***
	PM Peak Hr	6.77	7.89	**1.12**	-9.35	0.003	***	6.72	7.56	**0.84**	-4.23	0.024	**
Avg Speed (mph)													
NB	(3 - 7PM)	58.47	52.97	**-5.51**	7.14	0.000	***	52.98	53.17	**0.18**	-0.22	0.832	
	PM Peak Hr	55.76	47.57	**-8.18**	4.89	0.016	**	50.34	46.46	**-3.89**	1.93	0.149	
SB	(3 - 7PM)	61.93	53.63	**-8.30**	9.05	0.000	***	62.21	56.70	**-5.51**	6.89	0.000	***
	PM Peak Hr	58.46	50.17	**-8.29**	10.54	0.002	***	58.96	52.30	**-6.66**	4.01	0.028	**

Note: PM Peak Hour comprises 4 consecutive 15-min intervals that yield overall highest average travel time value within 3-7pm period.

Table 24: Probe Data Analytic Results for MD-295 (July + October)

Avg Travel Time (min)		July 2011	July 2012	Difference	t-stat	p-value		Oct 2011	Oct 2012	Difference	t-stat	p-value	
NB	(3 - 7PM)	8.17	8.08	**-0.09**	1.40	0.183		9.07	8.00	**-1.07**	5.75	0.000	***
	PM Peak Hr	8.79	8.55	**-0.24**	3.68	0.035	**	10.47	8.32	**-2.15**	15.21	0.001	***
SB	(3 - 7PM)	7.19	6.80	**-0.40**	3.76	0.002	***	6.61	6.33	**-0.28**	4.73	0.000	***
	PM Peak Hr	7.67	7.78	**0.11**	-1.26	0.296		7.04	6.56	**-0.47**	2.90	0.063	**
Avg Speed (mph)													
NB	(3 - 7PM)	54.20	54.76	**0.56**	-1.31	0.210		49.17	55.21	**6.03**	-7.02	0.000	***
	PM Peak Hr	50.17	51.60	**1.43**	-3.77	0.033	**	42.13	53.02	**10.89**	-16.34	0.000	***
SB	(3 - 7PM)	55.20	58.59	**3.39**	-4.19	0.001	***	59.94	62.55	**2.60**	-5.09	0.000	***
	PM Peak Hr	51.52	50.80	**-0.71**	1.32	0.277		56.21	60.27	**4.06**	-2.94	0.061	*

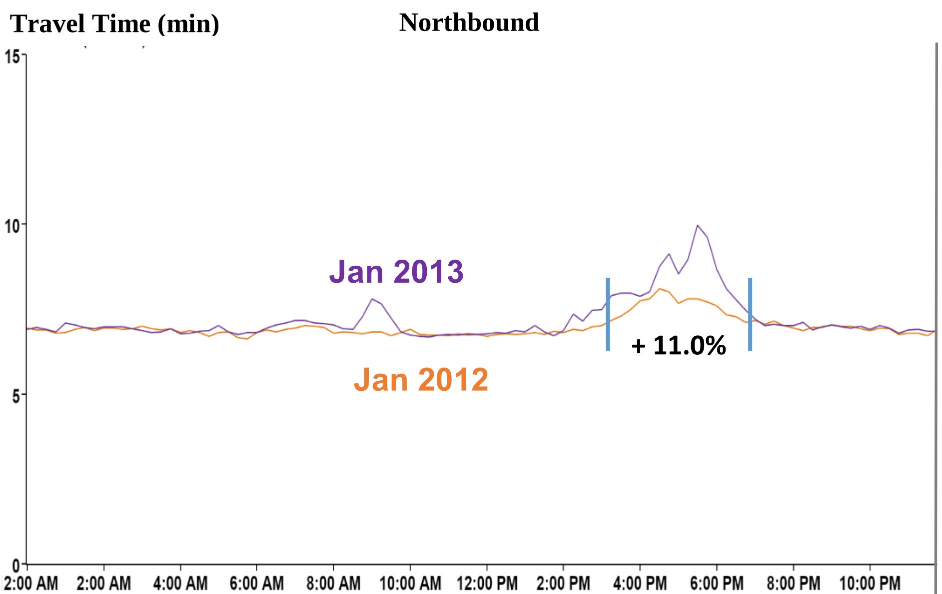
***Significant at $p < 0.01$ **Significant at $p < 0.05$ *Significant at $p < 0.1$; **RED VALUES** represent improved mobility performance.

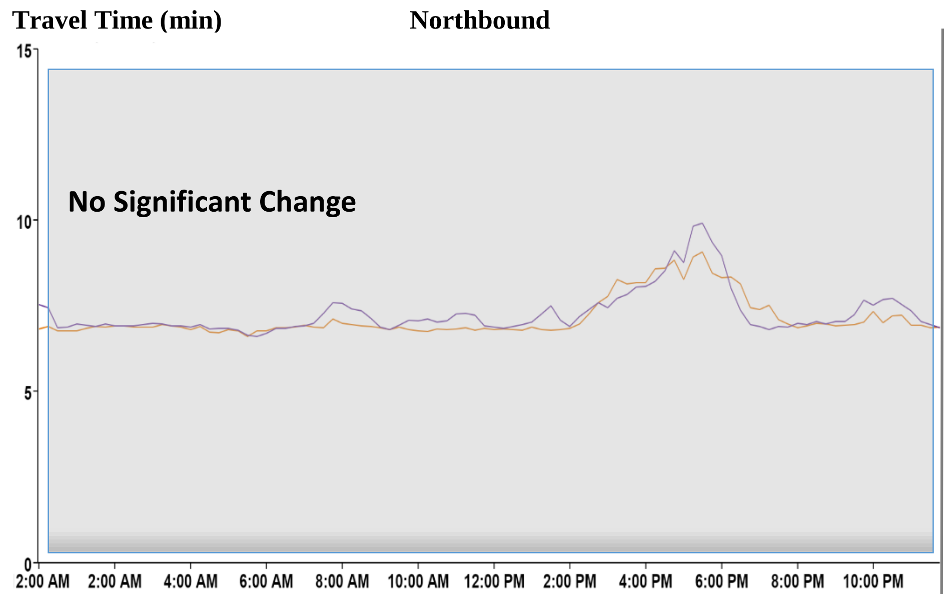
LIVE! CASINO

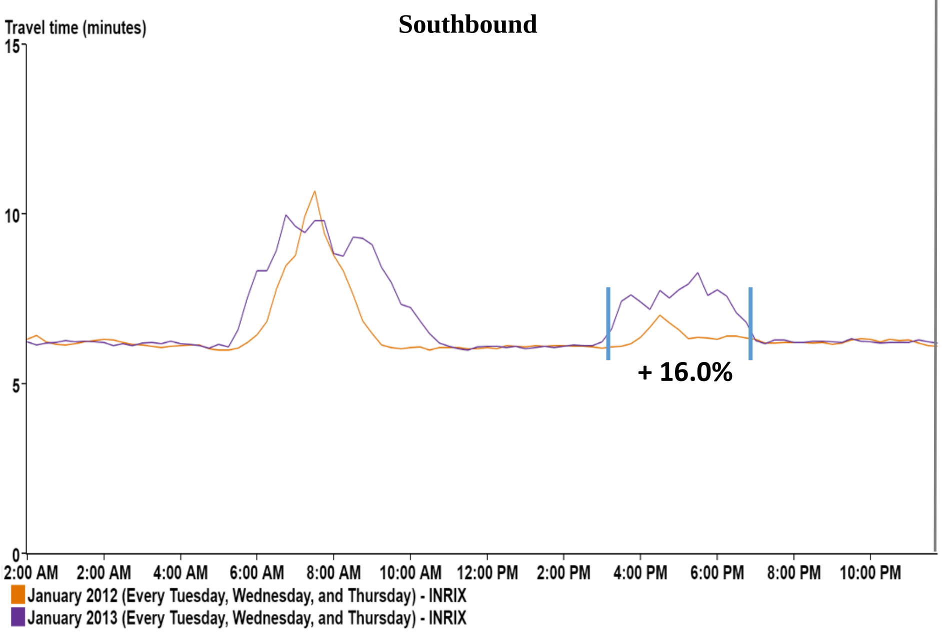
MD-295 / Baltimore & Washington Parkway (2/3)

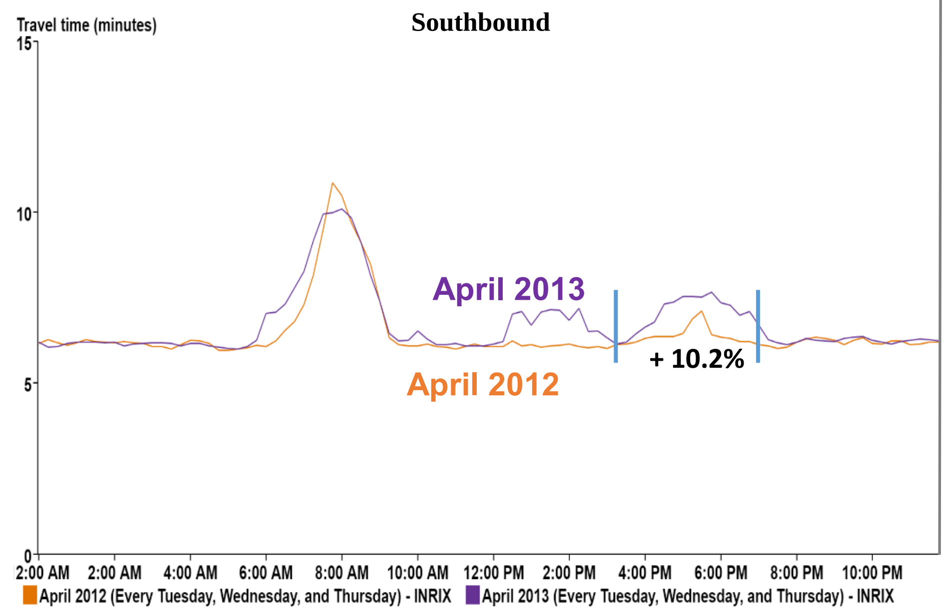
7.4 miles NB; 6.7 miles SB

Opened in June 2012







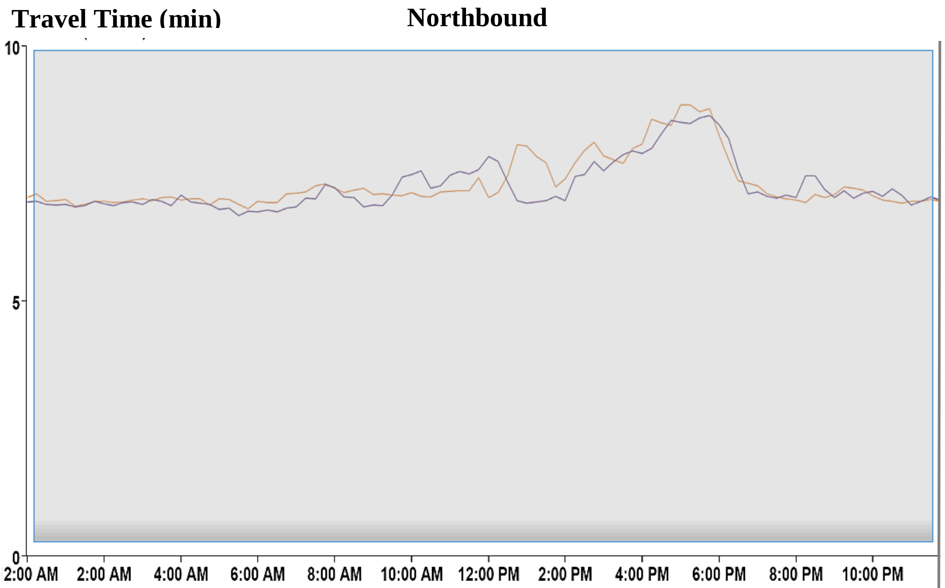


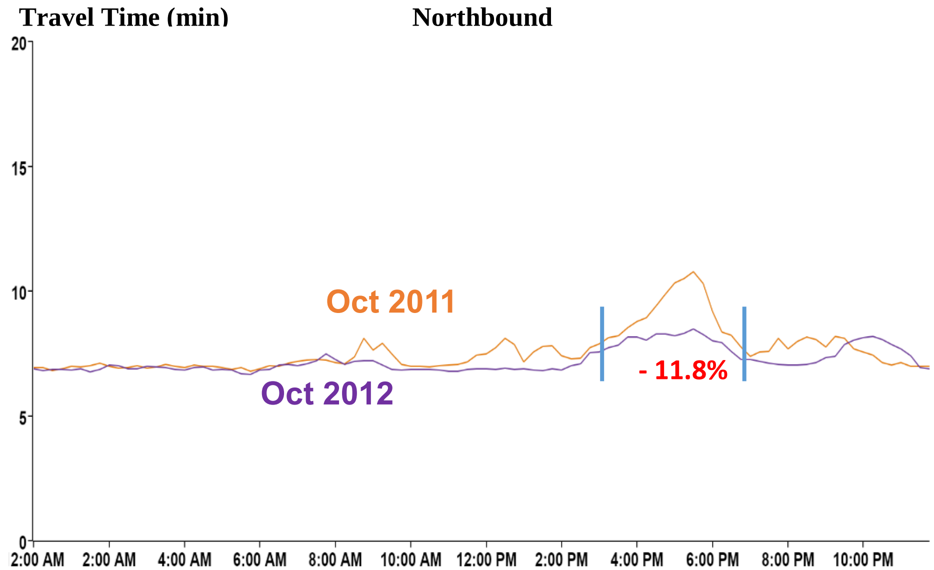
LIVE! CASINO

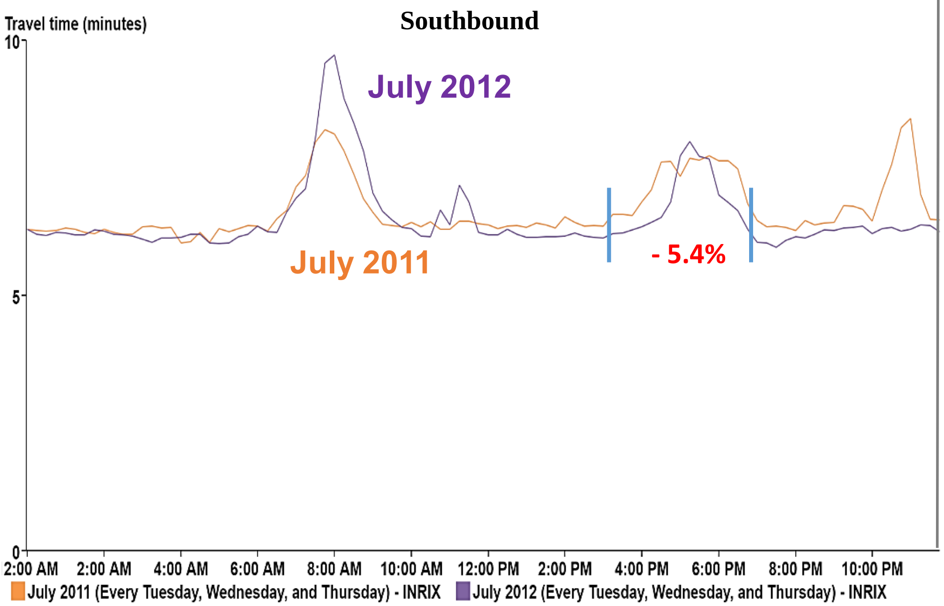
MD-295 / Baltimore & Washington Parkway (3/3)

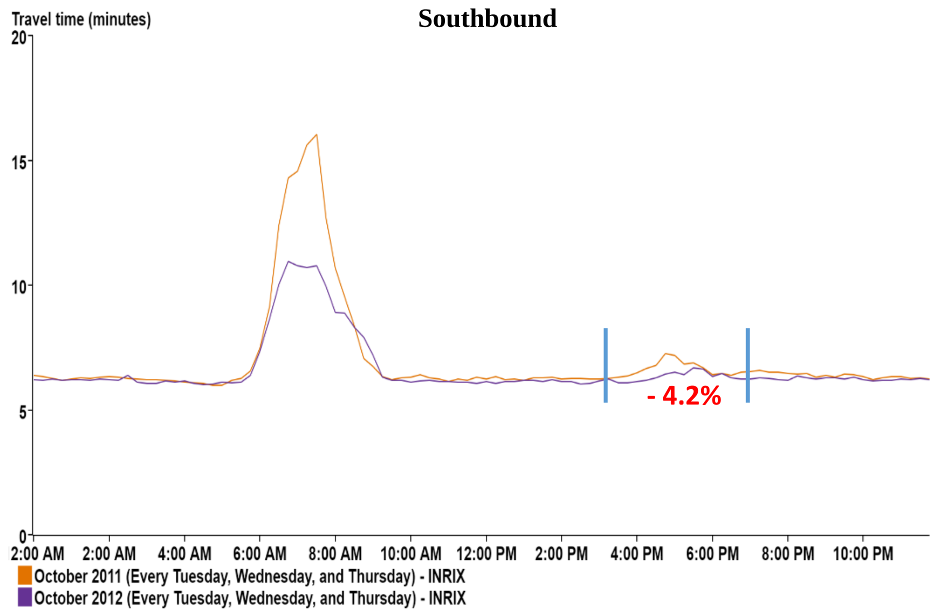
7.4 miles NB; 6.7 miles SB

Opened in June 2012









LIVE! CASINO

MD-713 / Arundel Mills Blvd (1/3)

4.2 miles

Opened in June 2012

Table 25: Probe Data Analytic Results for Arundel Mils Blvd. (January + April)

Avg Travel Time (min)		Jan 2012	Jan 2013	Difference	t-stat	p-value		April 2012	April 2013	Difference	t-stat	p-value	
NB	(3 - 7PM)	3.18	3.24	**0.06**	-2.05	0.058	*	3.15	3.24	**0.09**	-2.64	0.019	**
	PM Peak Hr	3.23	3.32	**0.09**	-1.04	0.377		3.19	3.37	**0.18**	-2.45	0.091	*
SB	(3 - 7PM)	3.64	3.83	**0.20**	-5.03	0.000	***	3.62	3.83	**0.21**	-11.33	0.000	***
	PM Peak Hr	3.71	3.99	**0.28**	-2.59	0.081	*	3.66	3.95	**0.29**	-18.57	0.000	***
Avg Speed (mph)													
NB	(3 - 7PM)	30.72	30.14	**-0.58**	2.01	0.062	*	30.96	30.12	**-0.83**	2.63	0.019	**
	PM Peak Hr	30.17	29.41	**-0.76**	1.03	0.380		30.63	29.01	**-1.62**	2.51	0.087	*
SB	(3 - 7PM)	30.74	29.19	**-1.55**	5.21	0.000	***	30.90	29.22	**-1.67**	11.99	0.000	***
	PM Peak Hr	30.09	28.00	**-2.09**	8.99	0.003	***	30.47	28.31	**-2.16**	5.00	0.015	**

Note: PM Peak Hour comprises 4 consecutive 15-min intervals that yield overall highest average travel time value within 3-7pm period.

Table 26: Probe Data Analytic Results for Arundel Mils Blvd. (July + October)

Avg Travel Time (min)		July 2011	July 2012	Difference	t-stat	p-value		Oct 2011	Oct 2012	Difference	t-stat	p-value	
NB	(3 - 7PM)	3.10	3.14	**0.04**	-1.63	0.124		3.25	3.15	**-0.10**	4.72	0.000	***
	PM Peak Hr	3.15	3.20	**0.05**	-0.95	0.411		3.29	3.21	**-0.08**	1.89	0.156	
SB	(3 - 7PM)	3.67	3.71	**0.04**	-1.48	0.159		3.74	3.70	**-0.04**	1.04	0.315	
	PM Peak Hr	3.79	3.77	**-0.02**	0.51	0.647		3.81	3.83	**0.02**	-0.15	0.893	
Avg Speed (mph)													
NB	(3 - 7PM)	31.51	31.10	**-0.41**	1.62	0.126		30.00	30.97	**0.97**	-4.74	0.000	***
	PM Peak Hr	30.98	30.47	**-0.52**	0.99	0.397		29.69	30.38	**0.69**	-0.89	0.440	
SB	(3 - 7PM)	30.46	30.12	**-0.34**	1.55	0.142		29.91	30.26	**0.35**	-1.27	0.224	
	PM Peak Hr	29.52	29.64	**0.11**	-0.22	0.843		29.32	29.26	**-0.06**	0.06	0.955	

***Significant at p < 0.01 **Significant at p < 0.05 *Significant at p < 0.1 ; **RED VALUES** represent improved mobility performance.

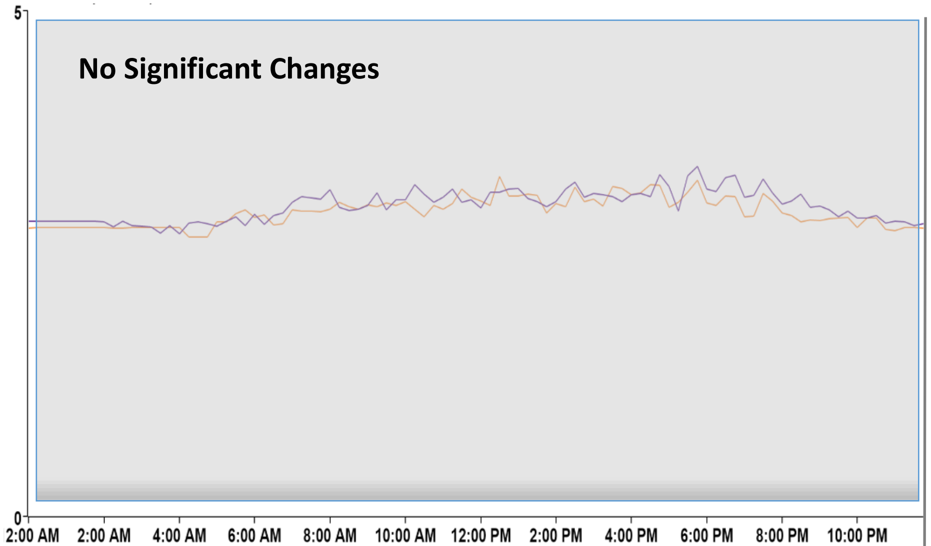
LIVE! CASINO

MD-713 / Arundel Mills Blvd (2/3)

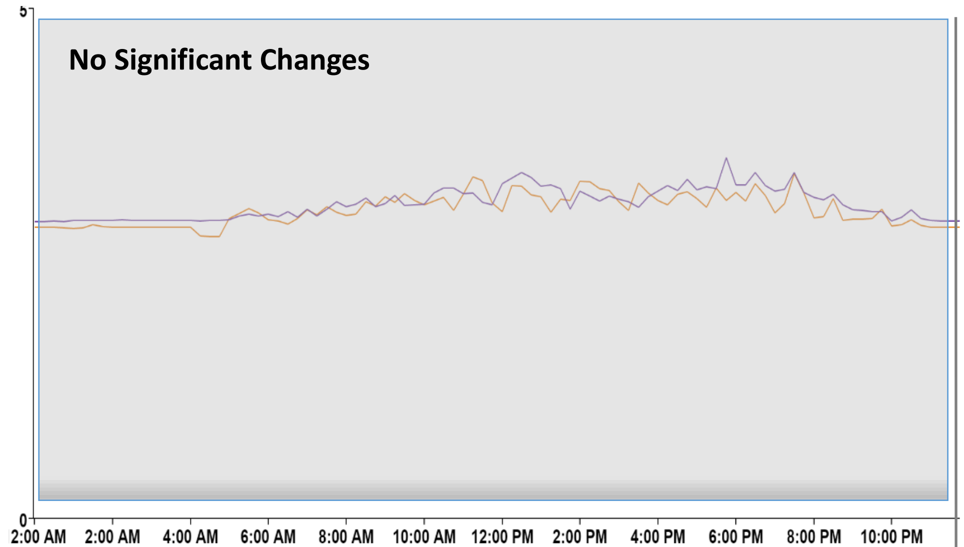
4.2 miles

Opened in June 2012

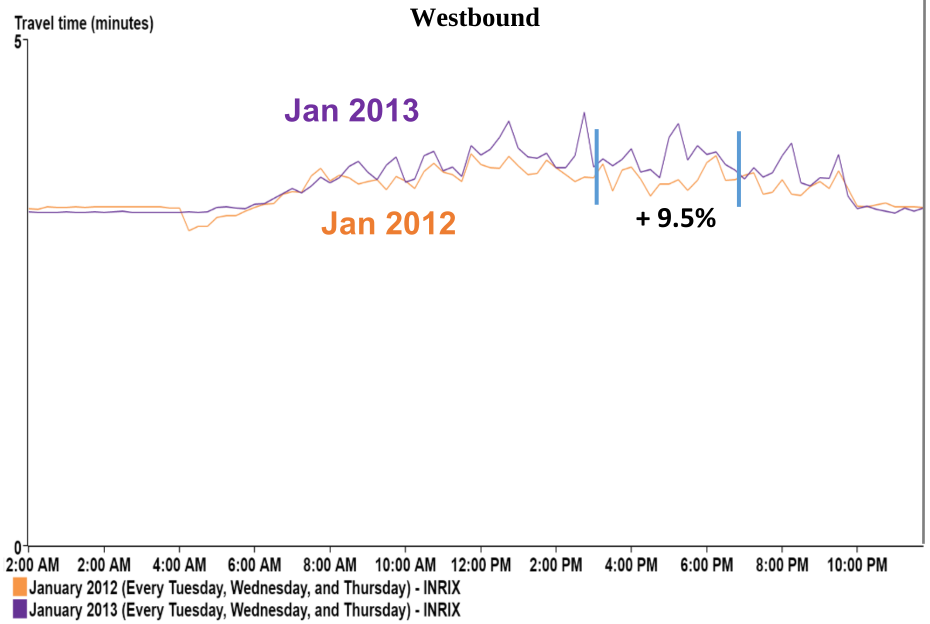
Travel Time (min) **Eastbound**



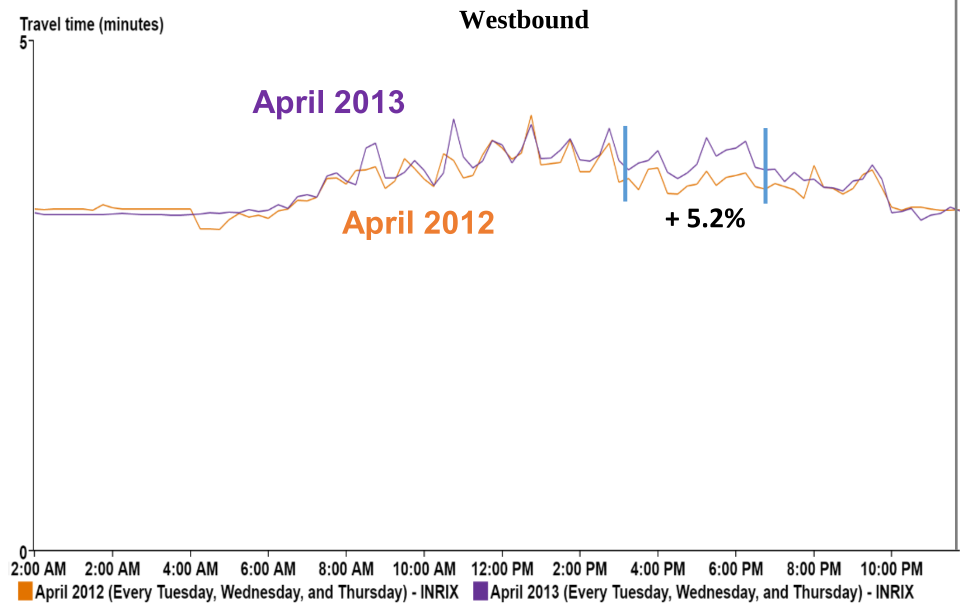
Travel Time (min) **Eastbound**



Westbound



Westbound

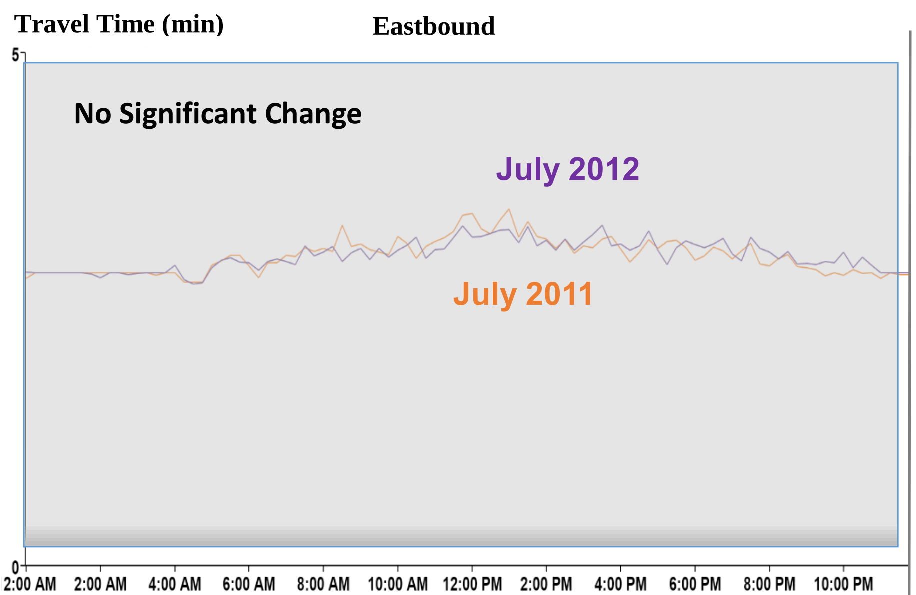


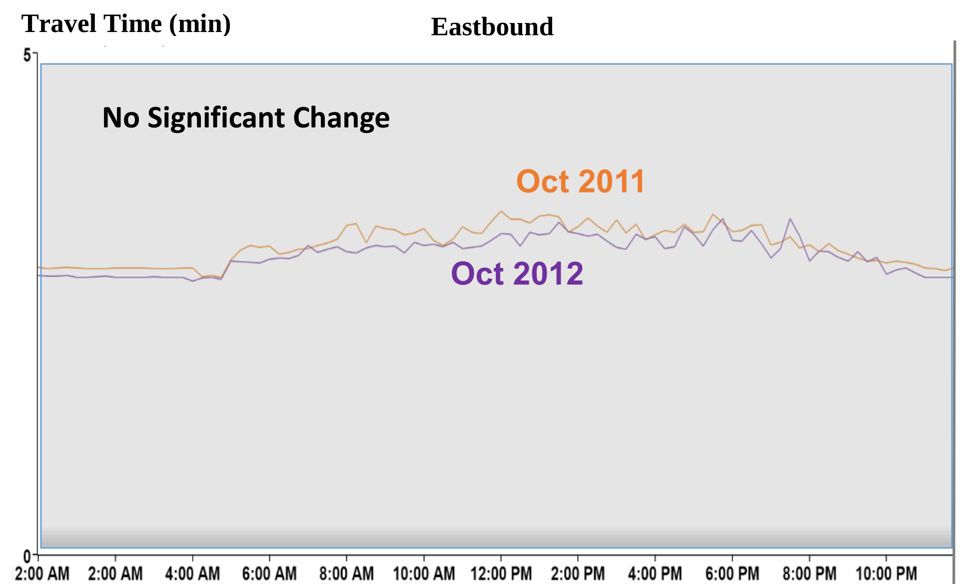
LIVE! CASINO

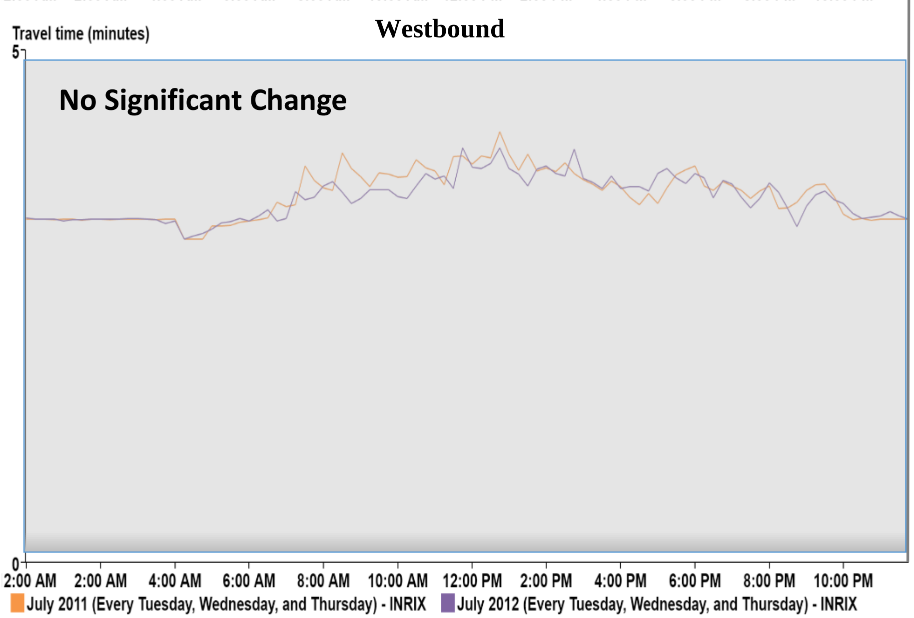
MD-713 / Arundel Mills Blvd (3/3)

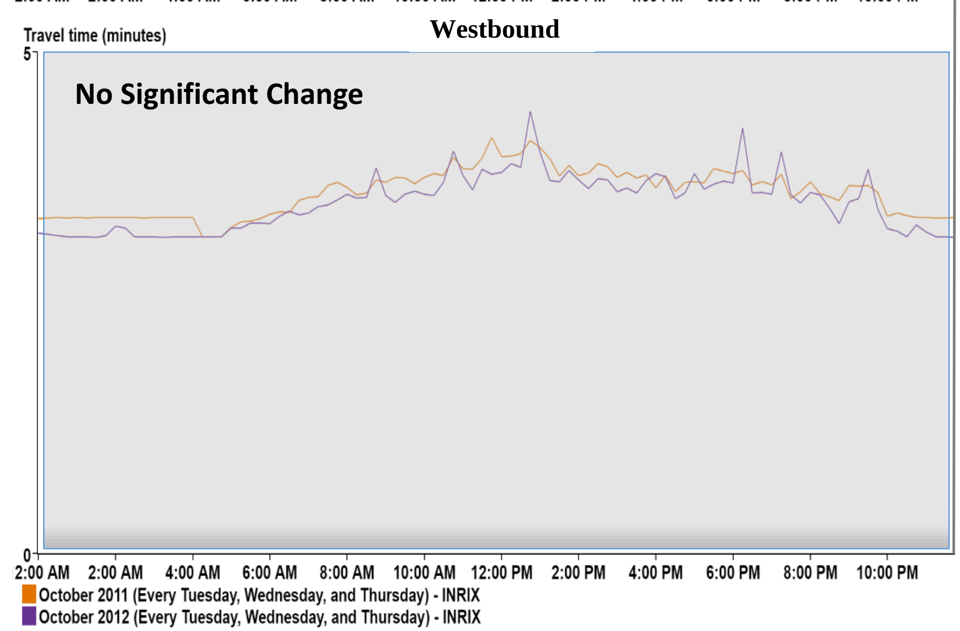
4.2 miles

Opened in June 2012









Oxon Hill Road (1/3)

3.1 miles NB; 1.5 miles SB

Opened in December 2016

Table 27: Probe Data Analytic Results for Oxon Hill Road (January + April)

Avg Travel Time (min)		Jan 2016	Jan 2017	Difference	t-stat	p-value		April 2016	April 2017	Difference	t-stat	p-value	
NB	(3 - 7PM)	9.58	10.24	**0.65**	-5.50	0.000	***	8.97	10.18	**1.21**	-8.24	0.000	***
	PM Peak Hr	10.27	10.66	**0.39**	-1.74	0.180		9.25	10.73	**1.48**	-7.25	0.005	***
SB	(3 - 7PM)	5.39	5.22	**-0.17**	1.45	0.168		4.32	5.08	**0.76**	-14.96	0.000	***
	PM Peak Hr	5.78	5.44	**-0.34**	1.15	0.335		4.54	5.25	**0.71**	-12.58	0.001	***
Avg Speed (mph)													
NB	(3 - 7PM)	19.49	18.20	**-1.29**	5.31	0.000	***	20.75	20.75	**-2.46**	8.35	0.000	***
	PM Peak Hr	18.13	17.47	**-0.66**	1.72	0.184		20.11	20.11	**-2.77**	7.86	0.004	***
SB	(3 - 7PM)	17.12	17.58	**0.46**	-1.32	0.205		21.29	21.29	**-3.20**	14.19	0.000	***
	PM Peak Hr	15.99	16.87	**0.89**	-1.04	0.375		20.21	20.21	**-2.73**	17.11	0.000	***

Note: PM Peak Hour comprises 4 consecutive 15-min intervals that yield overall highest average travel time value within 3-7pm period.

Table 28: Probe Data Analytic Results for Oxon Hill Road (January + April)

Avg Travel Time (min)		July 2016	July 2017	Difference	t-stat	p-value		Oct 2016	Oct 2017	Difference	t-stat	p-value
NB	(3 - 7PM)	9.55	11.14	**1.59**	-9.44	0.000	***	10.60	10.77	**0.16**	-0.98	0.343
	PM Peak Hr	9.84	12.09	**2.25**	-60.79	0.000	***	11.28	11.36	**0.08**	-0.35	0.748
SB	(3 - 7PM)	5.07	5.20	**0.12**	-1.75	0.101		5.29	5.25	**-0.03**	0.62	0.547
	PM Peak Hr	5.16	5.34	**0.18**	-1.48	0.235		5.51	5.42	**-0.09**	0.83	0.466
Avg Speed (mph)												
NB	(3 - 7PM)	19.49	16.78	**-2.71**	10.54	0.000	***	17.60	17.32	**-0.28**	1.06	0.307
	PM Peak Hr	18.91	15.38	**-3.53**	44.68	0.000	***	16.49	16.38	**-0.12**	0.37	0.737
SB	(3 - 7PM)	18.11	17.68	**-0.43**	1.65	0.120		17.40	17.48	**0.08**	-0.45	0.659
	PM Peak Hr	17.85	17.19	**-0.66**	1.90	0.154		16.67	16.92	**0.24**	-1.67	0.193

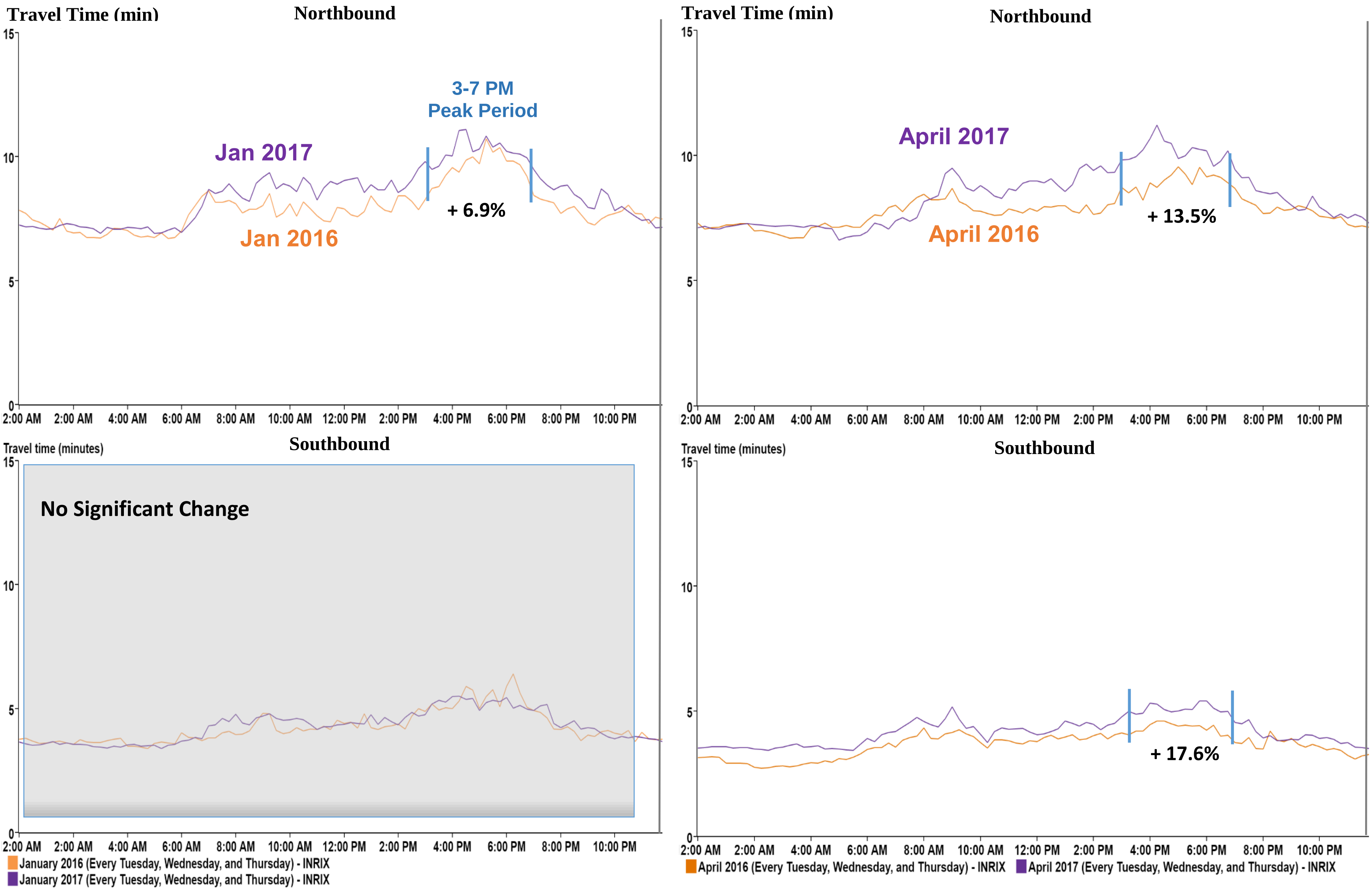
***Significant at $p < 0.01$ **Significant at $p < 0.05$ *Significant at $p < 0.1$; **RED VALUES** represent improved mobility performance.

MGM at NAT'L HARBOR

Oxon Hill Road (2/3)

3.1 miles NB; 1.5 miles SB

Opened in December 2016

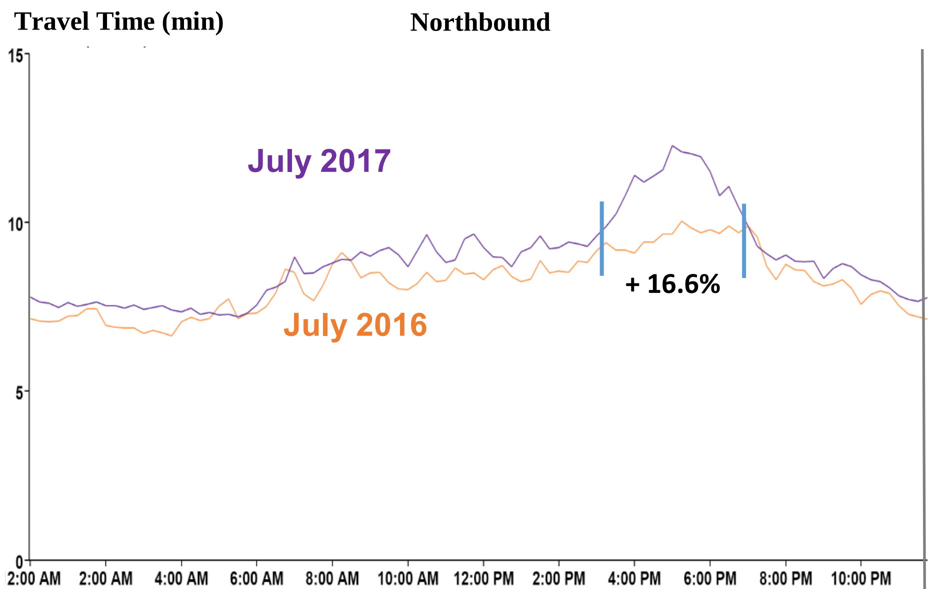


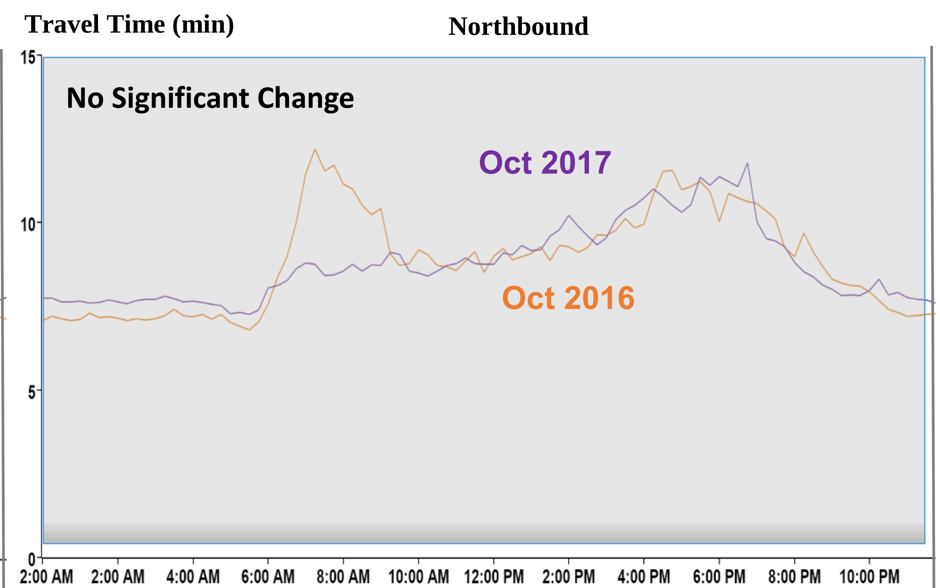
MGM at NAT'L HARBOR

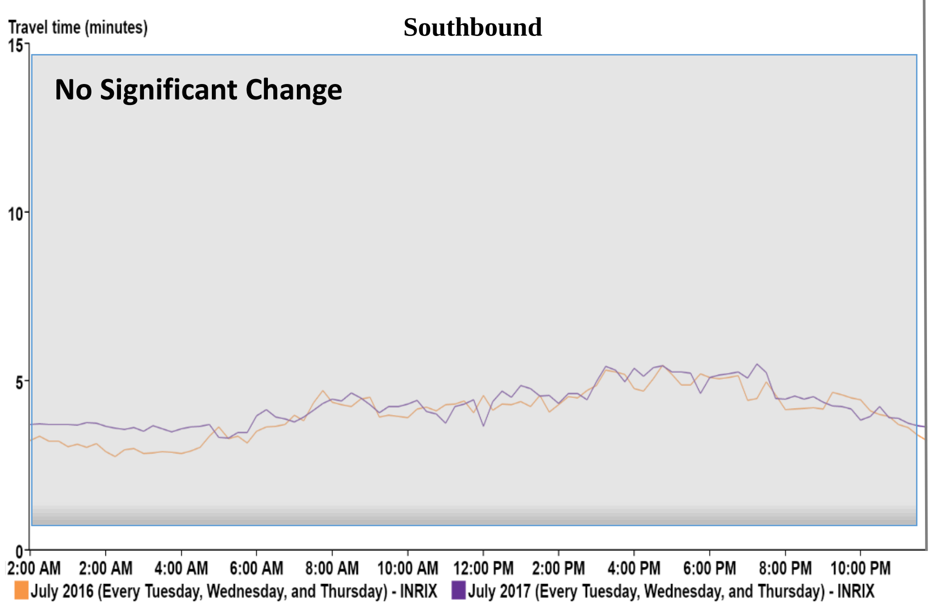
Oxon Hill Road (3/3)

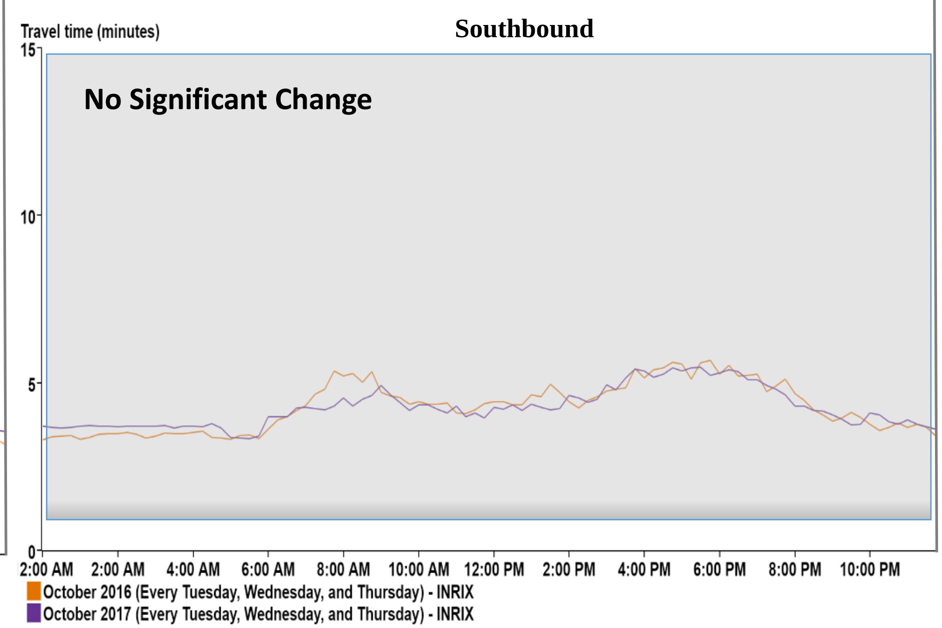
3.1 miles NB; 1.5 miles SB

Opened in December 2016









MGM at NAT'L HARBOR

MD-210 / Indian Head Highway (1/3)

5.6 miles NB; 5.1 miles SB

Opened in December 2016

Table 29: Probe Data Analytic Results for MD-210 (January + April)

Avg Travel Time (min)		Jan 2016	Jan 2017	Difference	t-stat	p-value		April 2016	April 2017	Difference	t-stat	p-value	
NB	(3 - 7PM)	8.93	8.90	**-0.03**	0.53	0.603		8.06	8.96	**0.90**	5.99	0.000	***
	PM Peak Hr	9.03	9.04	**0.01**	-0.09	0.936		8.25	9.02	**0.77**	-10.06	0.002	***
SB	(3 - 7PM)	12.16	10.99	**-1.17**	6.56	0.000	***	10.64	10.80	**0.16**	-2.02	0.062	*
	PM Peak Hr	13.32	11.70	**-1.62**	6.19	0.008	***	11.26	11.38	**0.12**	-0.70	0.535	
Avg Speed (mph)													
NB	(3 - 7PM)	37.86	37.99	**0.13**	-0.55	0.589		41.96	37.69	**-4.27**	5.95	0.000	***
	PM Peak Hr	37.45	37.39	**-0.06**	0.10	0.926		40.96	37.47	**-3.49**	10.07	0.002	***
SB	(3 - 7PM)	25.39	27.89	**2.51**	-7.26	0.000	***	28.80	28.35	**-0.45**	2.07	0.056	*
	PM Peak Hr	22.92	26.07	**3.15**	-6.70	0.007	***	27.13	26.83	**-0.30**	0.71	0.527	

Note: PM Peak Hour comprises 4 consecutive 15-min intervals that yield overall highest average travel time value within 3-7pm period.

Table 30: Probe Data Analytic Results for MD-210 (July + October)

Avg Travel Time (min)		July 2016	July 2017	Difference	t-stat	p-value		Oct 2016	Oct 2017	Difference	t-stat	p-value	
NB	(3 - 7PM)	8.63	8.89	**0.26**	-5.07	0.000	***	8.82	8.78	**-0.04**	0.59	0.566	
	PM Peak Hr	8.76	8.95	**0.19**	-3.07	0.054	*	8.96	8.89	**-0.07**	0.69	0.542	
SB	(3 - 7PM)	10.53	10.55	**0.02**	-0.16	0.872		10.78	11.75	**0.97**	-17.46	0.000	***
	PM Peak Hr	10.78	11.04	**0.26**	-2.20	0.115		11.50	12.72	**1.22**	-15.73	0.001	***
Avg Speed (mph)													
NB	(3 - 7PM)	39.16	38.02	**-1.14**	5.00	0.000	***	38.31	38.49	**0.18**	0.36	0.727	
	PM Peak Hr	38.57	37.74	**-0.84**	1.55	0.219		37.69	38.02	**0.32**	0.73	0.520	
SB	(3 - 7PM)	28.99	29.03	**0.04**	-0.10	0.925		28.46	26.13	**-2.33**	7.83	0.000	***
	PM Peak Hr	28.35	27.64	**-0.71**	2.29	0.106		26.53	23.99	**-2.54**	14.42	0.001	***

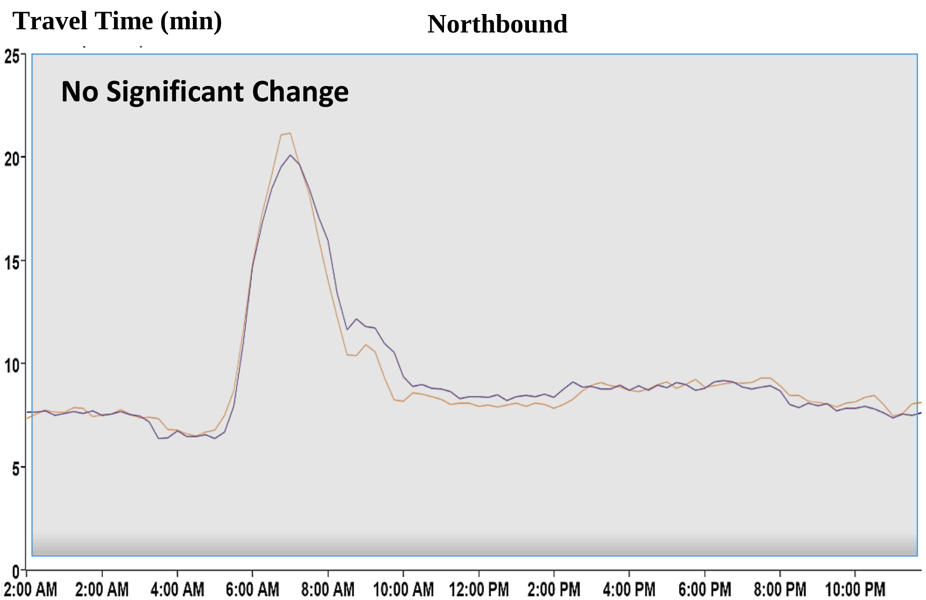
***Significant at $p < 0.01$ **Significant at $p < 0.05$ *Significant at $p < 0.1$; **RED VALUES** represent improved mobility performance.

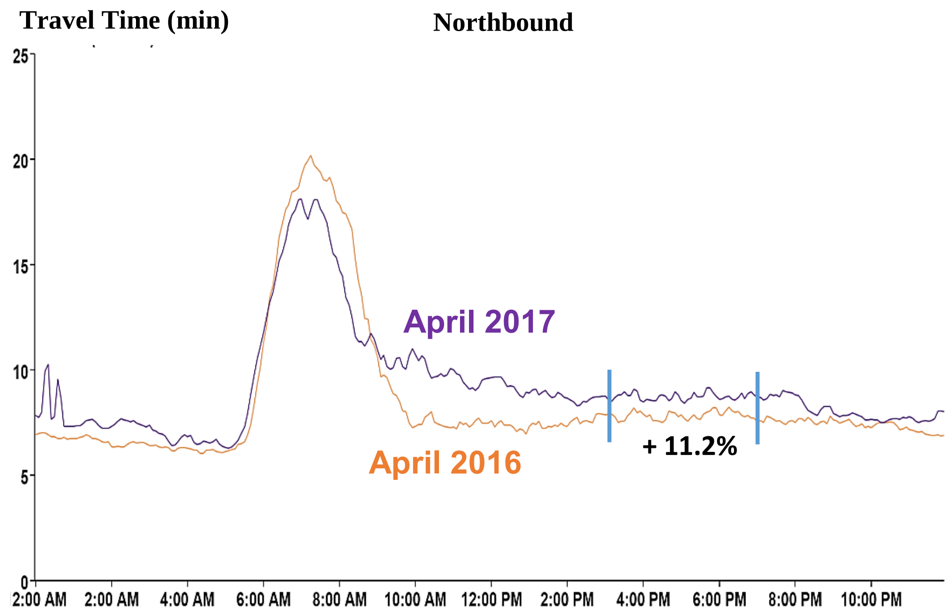
MGM at NAT'L HARBOR

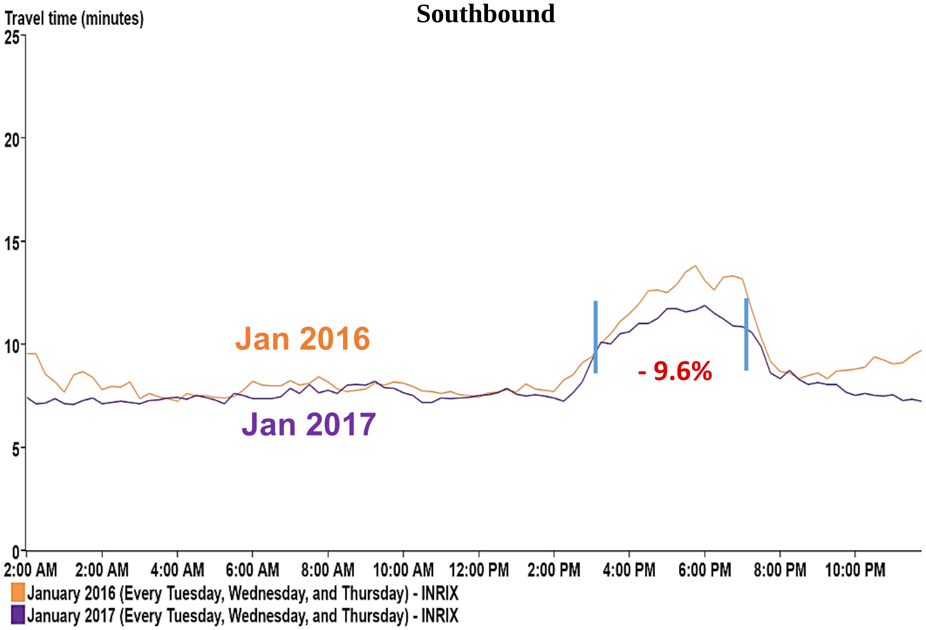
MD-210 / Indian Head Highway (2/3)

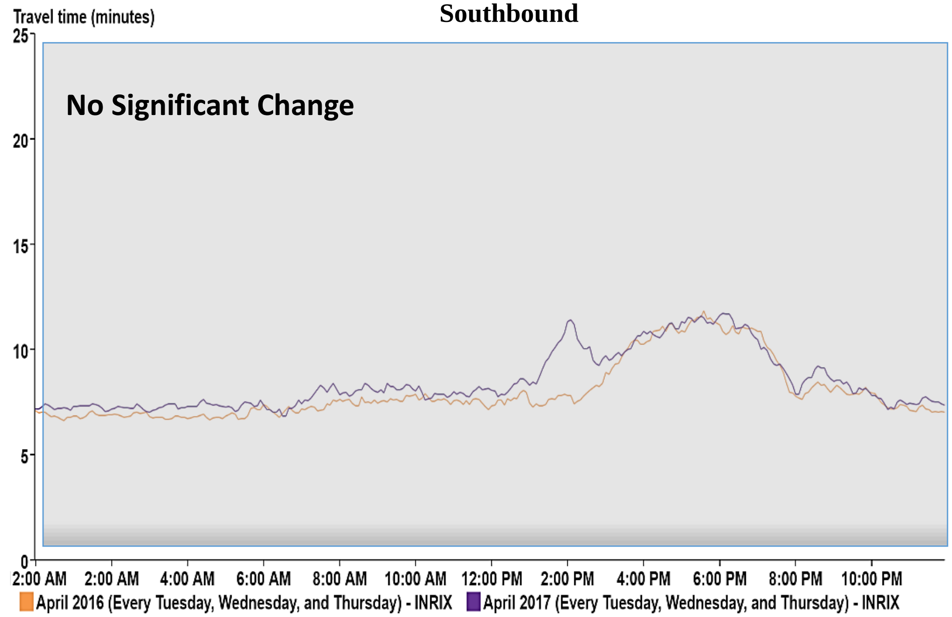
5.6 miles NB; 5.1 miles SB

Opened in December 2016









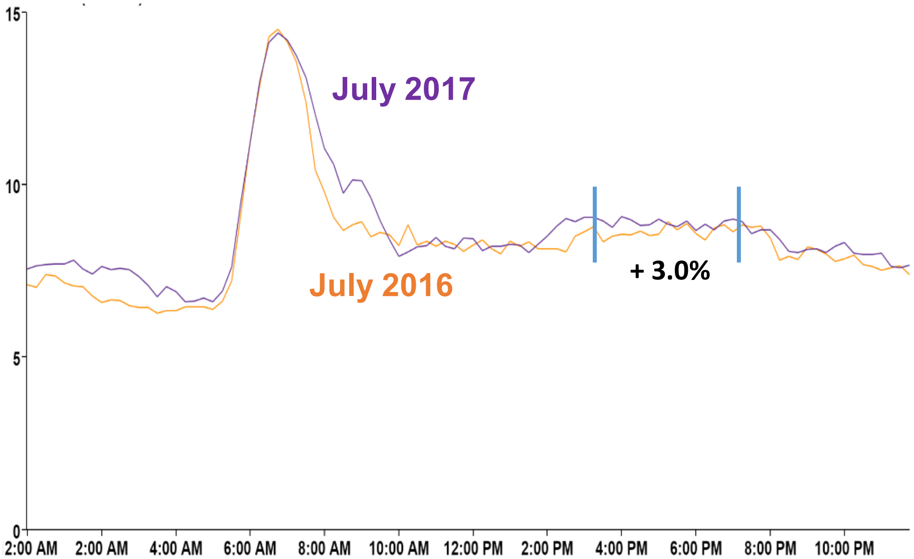
MGM at NAT'L HARBOR

MD-210 / Indian Head Highway (3/3)

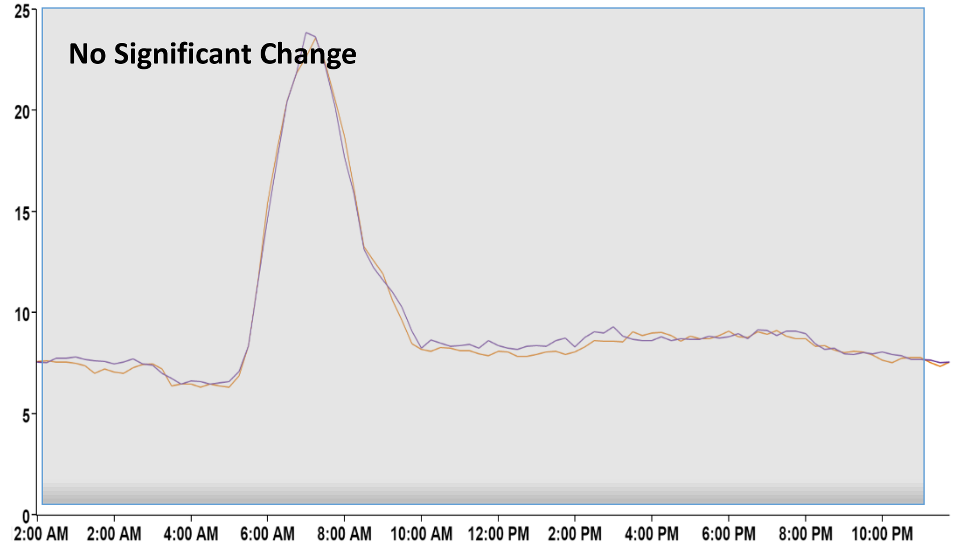
5.6 miles NB; 5.1 miles SB

Opened in December 2016

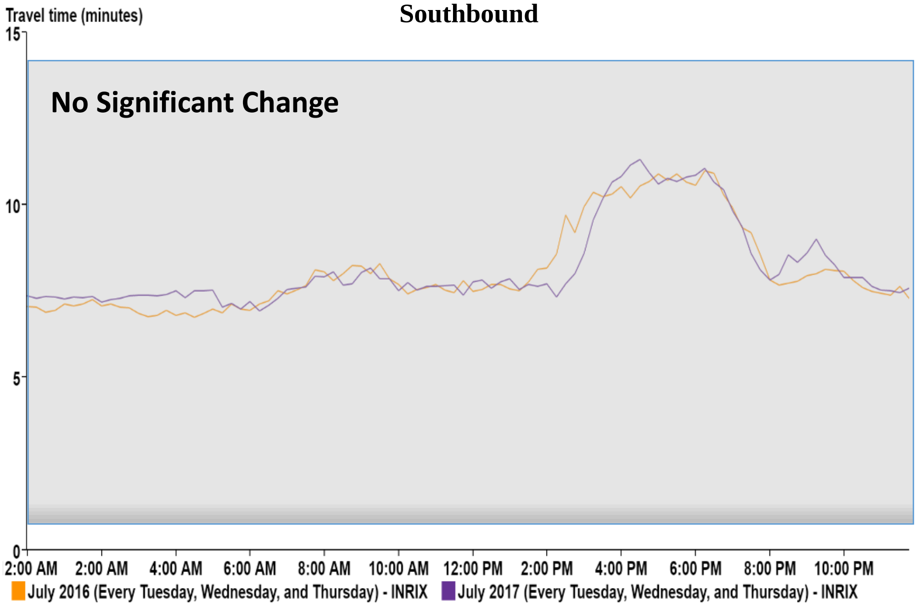
Travel Time (min) Northbound



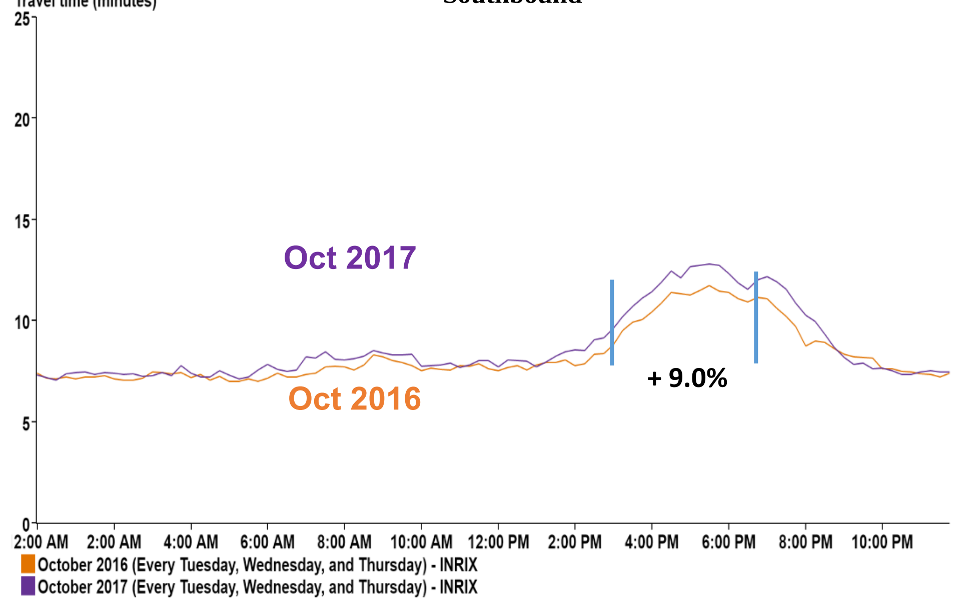
Travel Time (min) Northbound



Travel time (minutes) Southbound



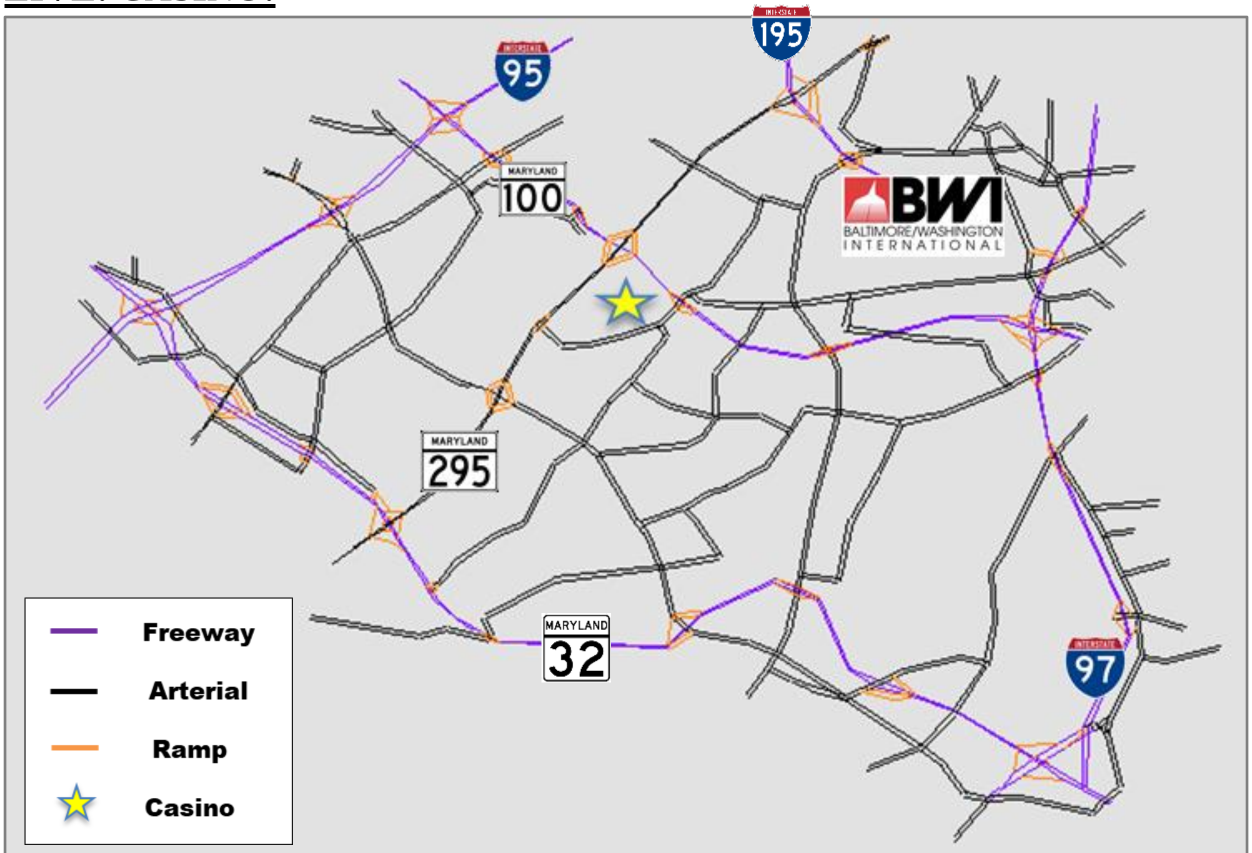
Travel time (minutes) Southbound



APPENDIX II:

MESOSCOPIC DTA MODEL SUB-REGIONS

LIVE! CASINO:



MAJOR CORRIDORS:

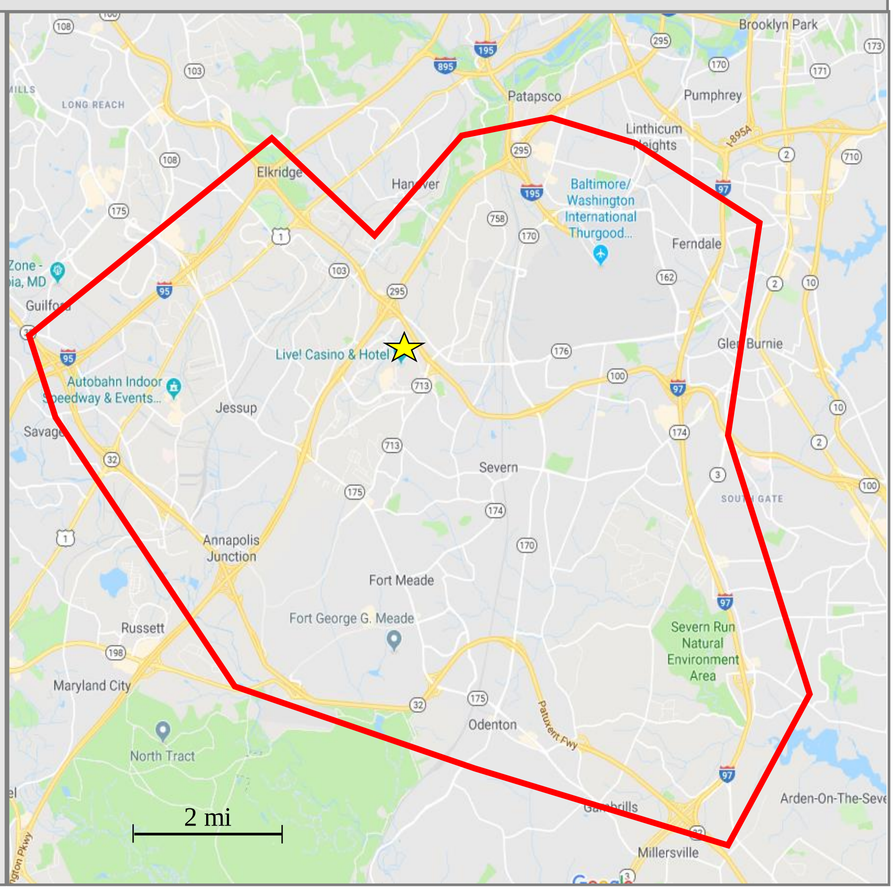
- I-95
- I-97
- I-195
- MD-295
- MD-100
- MD-32

\# of TAZs:
- **100**

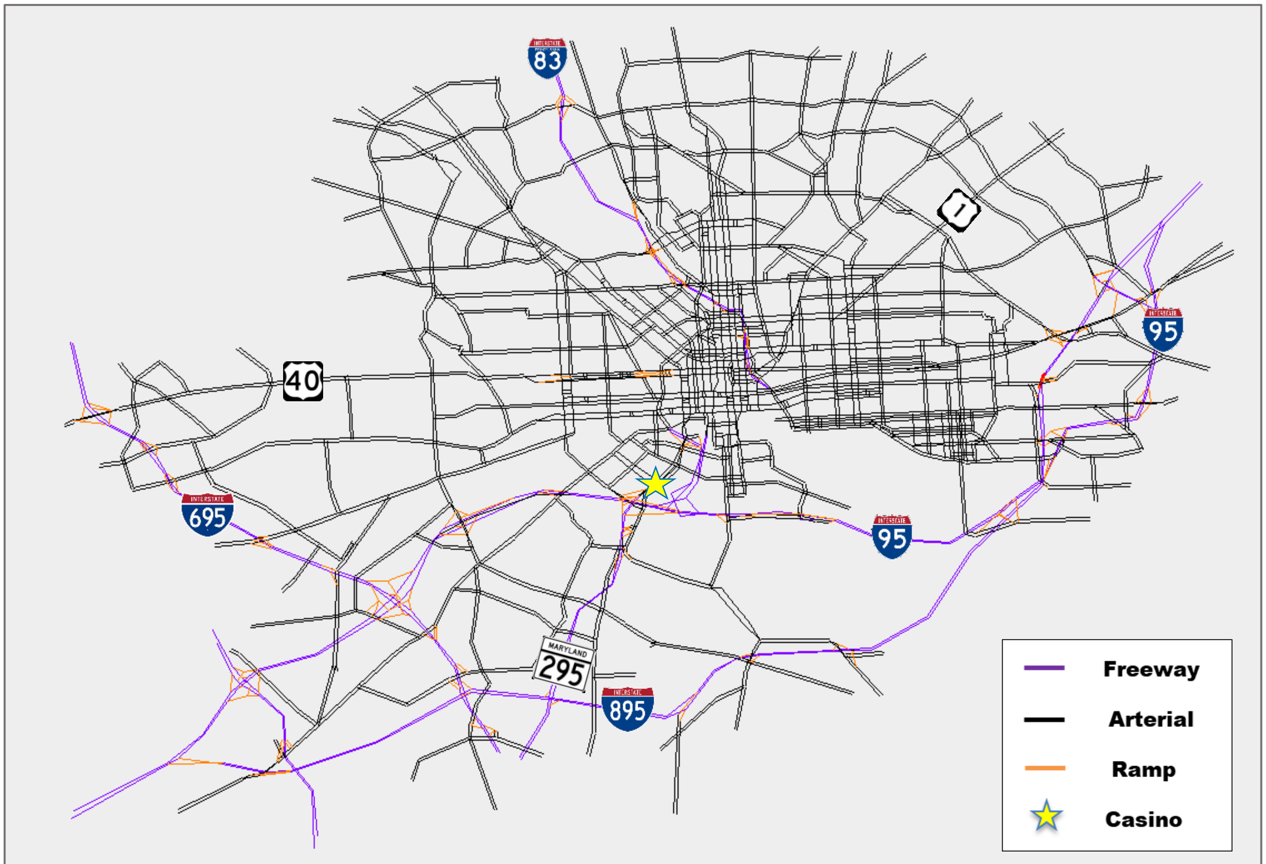
\# of Links:
- **1,048**

\# of Nodes:
- **626**

\# of Signalized Nodes:
- **39**



HORSESHOE CASINO:



MAJOR CORRIDORS:

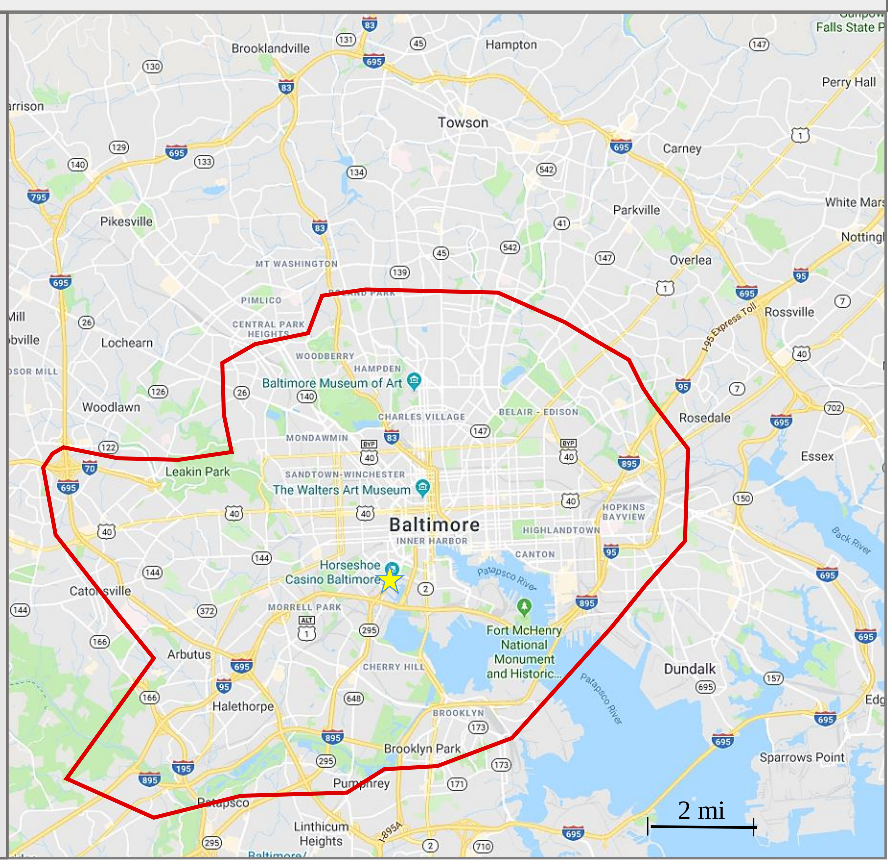
- I-95
- I-395
- I-83
- I-695
- I-895
- MD-295 / Russell Street
- US-40
- US-1

\# of TAZs:
- **179**

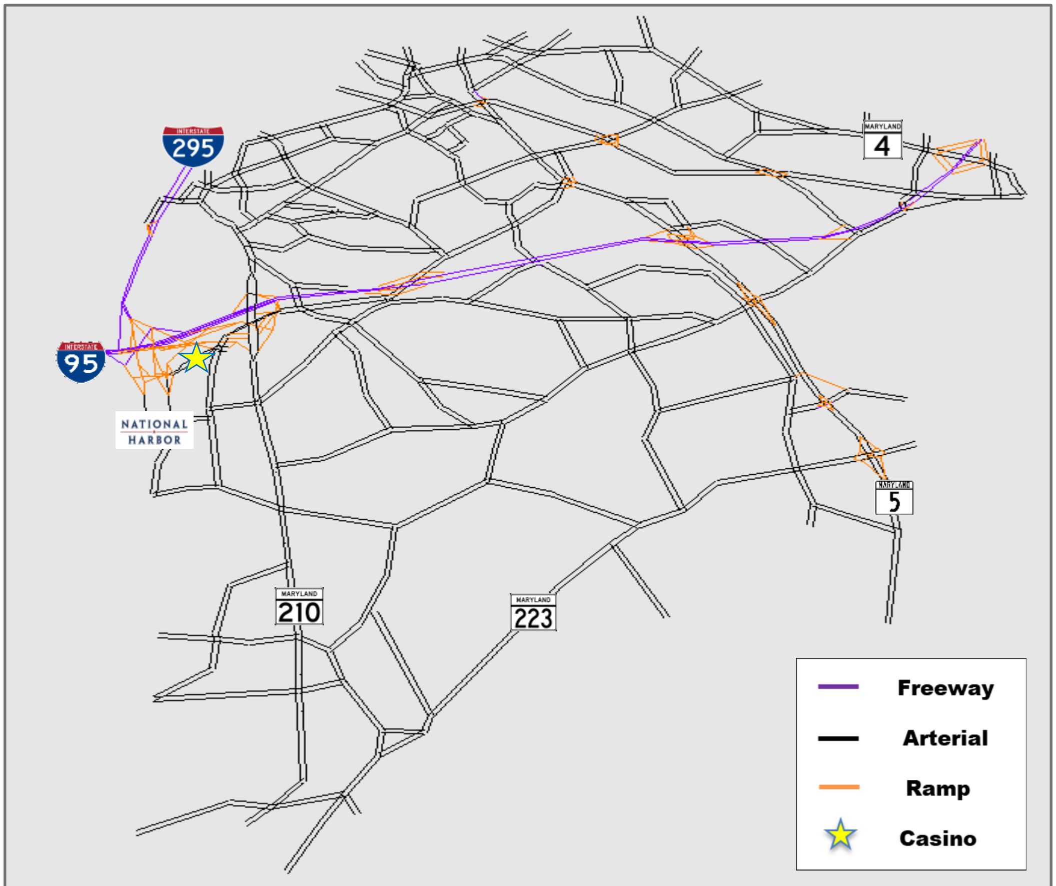
\# of Links:
- **4,272**

\# of Nodes:
- **2,127**

\# of Signalized Nodes:
- **191**



MGM at NAT'L HARBOR:



MAJOR CORRIDORS:

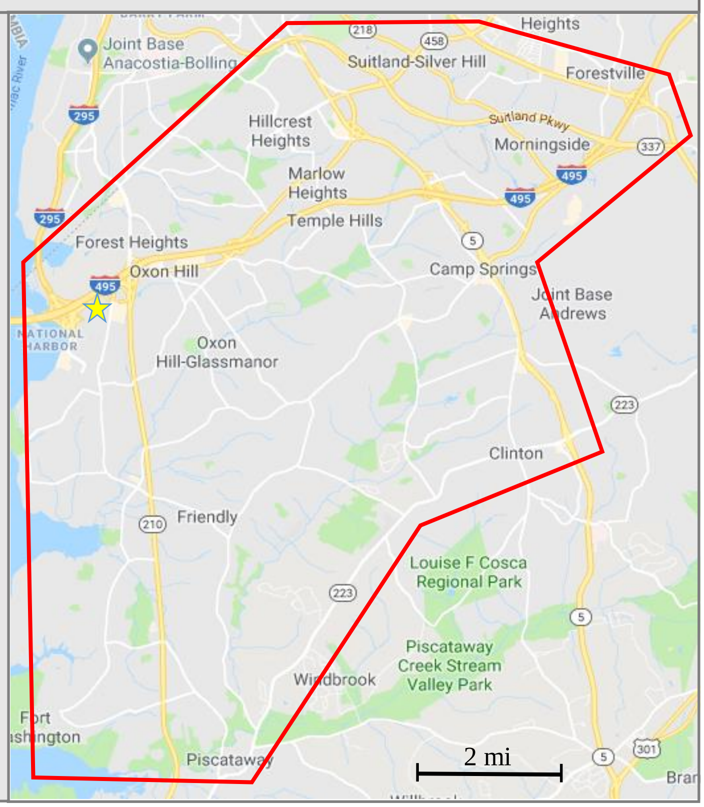
- I-95 / I-495
- I-295
- MD-210
- Oxon Hill Rd
- MD-5
- MD-4
- Suitland Parkway

# of TAZs:
- **104**

# of Links:
- **1,084**

# of Nodes:
- **561**

# of Signalized Nodes:
- **48**



APPENDIX III:

ITE-BASED CASINO TRIP GENERATION

HORSESHOE CASINO:

Table 31 details the trip generation for Horseshoe Casino. The total trip estimates rely on information presented in the 2013 casino traffic impact study (TIS), which derive from PM peak hour of generated values recorded in the 9th edition of the ITE Trip Generation Manual. Peak hour of adjacent street traffic values were not used in the calculation due to this study's analysis time period extending outside the designated 4:00 – 6:00 PM peak hour time restraint. Furthermore, the shown number of gaming positions of 3,446 is lower than the original estimate of 3,750 estimate provided in the TIS. The updated estimate accounts for 2,200 slot machines and 178 poker tables, assumed to have seven seats each.

Table 31: Horseshoe Casino ITE-based Trip Generation

Land Use:	Quantity	Unit	Avg Trip Rates	Trips	PM Directional Distribution		Internal Capture	Non-Auto	TOTAL TRIPS	
					IN (%)	OUT (%)	(%)	(%)	IN	OUT
Full-Scale Casino	3,446	# of Seats	0.246*	842	60*	40*		20*	407	271
Restaurant (LUC 931)	40,858*	1000 sq ft	7.49*	306	67*	33*	40*	20*	82	40
Bar/Tavern (LUC 925)	15,089*	1000 sq ft	11.34*	171	66*	34*	40*	20*	45	23
Office (LUC 710)	72,735*	1000 sq ft	1.49*	108	17*	83*		20*	15	72
							TOTAL		**549**	**407**

* Values taken directly from 2013 Horseshoe Casino traffic impact study

Figure 20 presents the arrival trip patterns for special event trips generated by a Baltimore Ravens NFL Thursday night game (distribution percentages are based on study for proposed NFL stadium in San Diego[1]). The capacity of M&K Bank Stadium in Baltimore is approximately **71,000**. A Thursday night game's start time is around **8:30pm**; therefore, only arrival trips are simulated. The estimated total number of game-day trips is based on a sold-out game managed by **2,500 staff** as well as several assumptions taken from transportation impact studies conducted for other exiting/proposed NFL football stadiums. The assumptions include the following:

- **Mode split**: automobile mode share varied widely (i.e. 57 – 76%) among all NFL stadium sites compared in a Las Vegas[2] site study. Therefore, the author assumed **67%** or two-thirds of attendee trips are taken by automobile (**60%** for stadium staff trips).

[1] Qualcomm Stadium, San Diego Chargers (AECOM 2015)

[2] Las Vegas Stadium, Las Vegas Raiders (CH2M 2016)

- **Passengers per vehicle**: based on the San Diego study, an average of **2.7 game attendees** were assumed to arrive per automobile for a weekday game; **1.5 game staff** per auto.

TOTAL SPECIAL EVENT TRIPS: 17,620 Attendee Trips by Auto | 1,000 Staff Trips by Auto

Hour	Attendees	Staff
7:30 - 8:30pm	0%	40%
6:30 - 7:30pm	10%	20%
5:30 - 6:30pm	40%	15%
4:30 - 5:30pm	30%	15%
3:30 - 4:30pm	15%	10%
2:30 - 3:30pm	5%	5%

Interpolation

Hour	Attendees	Staff	A Trips	S Trips
7 - 8pm	5.0%	30.0%	881	300
6 - 7pm	**25.0%**	**17.5%**	**4405**	**175**
5 - 6pm	**35.0%**	**15.0%**	**6167**	**150**
4 - 5pm	**22.5%**	**12.5%**	**3965**	**125**
3 - 4pm	**10.0%**	**7.5%**	**1762**	**75**
2 - 3pm	2.5%	2.5%	441	25

Figure 20: Trip Arrival Patterns for Horseshoe Casino Special Event

LIVE! CASINO:

Table 32 displays the trip generation for Live! Casino. With the TIS report unavailable to the research group, the Maryland casino trip rates were found in a Mid-Atlantic Section ITE presentation slide deck[1]. The author estimated the restaurant and bar square footage quantities using a basic floor plan[2]. Designated office space was not delineated on the plan; therefore, the quantity was derived from the proportion of casino employees in comparison with Horseshoe Casino. Again, PM peak hour of generator trip rates from the 9th edition of the ITE Trip Generation Manual were employed. The number of gaming positions (5,323) includes 4,000 slot machines and 189 poker tables.

Table 32: Live! Casino ITE-based Trip Generation

Land Use:	Quantity	Unit	Avg Trip Rates		Trips		PM Directional Distribution		Internal Capture	Non-Auto	TOTAL TRIPS	
			IN	OUT	IN	OUT	IN (%)	OUT (%)	(%)	(%)	IN	OUT
Full-Scale Casino	5,323	# of Seats	0.31	0.28	1650	1490	60	40		0.2	792	477
Restaurant (LUC 931)	40,000	1000 sq ft	7.49		300		67	33	0.4	0.2	80	40
Bar/Tavern (LUC 925)	2,500	1000 sq ft	11.34		28		66	34	0.4	0.2	7	4
Office (LUC 710)	58,000	1000 sq ft	1.49		86		17	83		0.2	6	29
									TOTAL		**886**	**549**

[1] Subhani, R. – WR&A, & Silberman, P. – SW&A. (2014). *Casino Trip Generation* [Powerpoint Slides].

[2] https://adc3ef35f321fe6e725a-fb8aac3b3bf42afe824f73b606f0aa4c.ssl.cf1.rackcdn.com/staticmaps/5201.gif

The estimation of Black Friday special event trips required a different approach. Using a combination of the ITE rates, Airsage location data, and independent Black Friday shopping trend analytics, the author estimated the trip generation and hourly arrival and departure patterns for trips entering and exiting the Arundel Mills Mall during the PM peak period on Black Friday. Starting with 10th edition ITE trip volumes for a Shopping Center (LUC 820), the 1.6 million square-foot mall – the largest in Maryland - would generate approximately **4,287** (48% In; 52% Out) during the weekday PM peak hour and **5,614** (52% In; 48% Out) during the Saturday peak hour. It is assumed Black Friday aligns more with the traffic patterns of a busy Saturday rather than a typical weekday due its designation as a state holiday.

According to a ShopperTrak analysis[1] of historic Black Friday trends, the shopper traffic peaks at 3:00 PM. Therefore, the author utilized Airsage trip estimates for 3:00 PM to determine the Black Friday trip generation for the mall and surrounding outlets. The total estimate equaled 2,132 (51% in; 49% out). The Saturday peak hour volume was estimated to be 2,800 based on a 1.31 multiplication factor derived from the ITE peak hour estimates (5,614 / 4287). To estimate the total number of Black Friday peak hour trips, the Saturday peak hour trip estimates were conservatively doubled to **5,602**. This decision was based on a ShopperTrak volume profile of Thanksgiving weekend shopping traffic showing about twice as many people shop on Black Friday than on the following Saturday. The final number of added trips due to Black Friday was obtained by subtracting the typical weekday trip volumes from the overall number of Black Friday trips (Table 33). The hourly distribution of trips follows a similar distribution to the time-of-day chart shown in the ShopperTrak analysis article.

TOTAL SPECIAL EVENT TRIPS: 3,470

[1] McCarthy, Bill. (2016). *What Store Traffic Data Reveals about Black Friday Shopping Trends*. https://www.shoppertrak.com/article/traffic-reveals-black-friday-shopping-trends/

Table 33: Live! Casino Special Event Trip Generation

	AIRSAGE Weekday Trip Estimates(3pm)	Sat. Peak Hr. Trip Estimates	TOTAL Black Friday Trip Estimates	ADDED Black Friday Trip Estimates
TRIPS	A	B = A * 1.31	C = 2*B	D = C-A
IN	1089	1431	2861	1772
OUT	1043	1370	2740	1697
TOTAL	**2132**	**2801**	**5602**	**3470**

MGM at Nat'l Harbor:

Table 34 details the trip generation for MGM Casino. The total trip estimates utilize information published in a 2013 final review of a TIS. The TIS presents a single trip generation rate that represents traffic to all types of facilities within the casino complex except the hotel (PM peak hour rate = 0.27). With the bundled rate, the estimated vehicle trips is still determined by the number of gaming positions. Similar to Horseshoe Casino, the TIS overestimated the number of gaming positions to be 4,580. Currently, 4,275 positions spread out between 3,085 slot machines and 170 tables exist at the casino.

The special event assumed to be a sold-out concert at the casino's 3,000-seat theatre. For a 7:00 PM or later weeknight show, it is assumed all vehicle trips will arrive within the 6:00 – 7:00 PM hour. The number of vehicle trips (600 or 20% of theatre capacity) is taken directly from the TIS report. The report states "10% would be occupied by MGM hotel guests, 10% would be occupied by persons coming from National Harbor on shuttle buses, and 40% would be occupied by casino guests and would not generate new traffic." The report also assumes a vehicle occupancy of 2.0.

Table 34: MGM Casino ITE-based Trip Generation

Land Use:	Quantity	Unit	Avg Trip Rates	TRIPS	PM Directional Distribution		TOTAL TRIPS	
					IN (%)	OUT (%)	IN	OUT
Casino/Restaurant/Shops (TIS)	4275	# of Seats	0.27	1154	60	40	693	462
Hotel	308	# of Rooms	0.6	185	51	49	94	91
						Sub-Total	**787**	**552**
Theater (special event)	3000	# of Seats	0.2	100	0	600	600	0
					TOTAL		**1387**	**552**

APPENDIX IV:

MESOSCOPIC DTA MODEL RESULTS

Table 35: Live! Casino Model Hourly Measures of Effectiveness Results

LIVE! CASINO MODEL MOE RESULTS			
TIME (PM Peak Period)	BEFORE CASINO	WITH CASINO	CASINO + BLACK FRIDAY SPECIAL EVENT
	# of Vehicles	# of Veh | % Change	# of Veh | % Change
3:00 - 4:00	90,242	91,676 | 1.59%	95,134 | 5.42%
4:00 - 5:00	103,011	104,871 | 1.81%	107,696 | 4.55%
5:00 - 6:00	104,672	106,023 | 1.29%	109,214 | 4.33%
6:00 - 7:00	80,099	81,619 | 1.90%	84,459 | 5.44%
	Average Trip Time	Avg. TT | % Change	Avg. TT | % Change
3:00 - 4:00	10.77	11.12 | 3.25%	15.04 | 39.64%
4:00 - 5:00	12.97	14.09 | 8.64%	20.5 | 58.06%
5:00 - 6:00	15.44	17.58 | 13.86%	25.15 | 62.9%
6:00 - 7:00	16.03	18.33 | 14.35%	26.58 | 65.81%
	Average Trip Time Index	TTI | % Change	TTI | % Change
3:00 - 4:00	1.31	1.35 | 3.05%	1.81 | 38.17%
4:00 - 5:00	1.57	1.70 | 8.28%	2.46 | 56.69%
5:00 - 6:00	1.84	2.09 | 13.59%	2.98 | 61.96%
6:00 - 7:00	1.90	2.16 | 13.68%	3.12 | 64.21%
	Average Speed	Avg Speed | % Change	Avg Speed | % Change
3:00 - 4:00	36.25	35.16 | - 3.01%	26.09 | - 28.03%
4:00 - 5:00	29.80	27.44 | - 7.92%	18.94 | - 36.44%
5:00 - 6:00	25.30	22.25 | - 12.06%	15.59 | - 38.38%
6:00 - 7:00	25.06	21.96 | - 12.37%	15.17 | - 39.47%

Note: Model simulates greatest mobility impact during 6:00 - 7:00PM for both after scenarios.

Table 36: Horseshoe Casino Model Hourly Measures of Effectiveness Results

HORSESHOE CASINO MODEL MOE RESULTS			
TIME (PM Peak Period)	BEFORE CASINO	WITH CASINO	RAVEN'S GAME SPECIAL EVENT
	# of Vehicles	# of Veh | % Change	# of Veh | % Change
3:00 - 4:00	182,190	183,221 | 0.57%	184,980 | 1.53%
4:00 - 5:00	232,809	233,820 | 0.43%	237,841 | 2.16%
5:00 - 6:00	227,465	228,499 | 0.45%	234,904 | 3.27%
6:00 - 7:00	178,044	178,970 | 0.52%	183,302| 2.95%
	Average Trip Time	Avg. TT | % Change	Avg. TT | % Change
3:00 - 4:00	9.15	9.16 | 0.11%	9.19 | 0.44%
4:00 - 5:00	9.29	9.34 | 0.54%	9.73 | 4.74%
5:00 - 6:00	10.42	10.51 | 0.86%	12.48 | 19.77%
6:00 - 7:00	10.07	10.15 | 0.79%	13.12 | 30.29%
	Average Trip Time Index	TTI | % Change	TTI | % Change
3:00 - 4:00	1.32	1.32 | 0.0%	1.33| 0.76%
4:00 - 5:00	1.45	1.46 | 0.69%	1.52| 4.83%
5:00 - 6:00	1.56	1.57 | 0.64%	1.86| 19.23%
6:00 - 7:00	1.50	1.51 | 0.67%	1.94| 29.33%
	Average Speed	Avg Speed | % Change	Avg Speed | % Change
3:00 - 4:00	27.93	27.84 | - 0.32%	27.76 | - 0.61%
4:00 - 5:00	25.11	24.97 | - 0.56%	24.06| - 4.18%
5:00 - 6:00	23.28	23.06 | - 0.95%	19.50| - 16.24%
6:00 - 7:00	24.29	24.08 | - 0.86%	18.74 | - 22.85%

Note: Model simulates greatest mobility impact with casino during 5:00 - 6:00PM and casino + Raven's game during 6:00 - 7:00PM.

Table 37: MGM Casino Model Hourly Measures of Effectiveness Results

MGM CASINO MODEL MOE RESULTS			
TIME (PM Peak Period)	BEFORE CASINO	WITH CASINO	THEATER CONCERT SPECIAL EVENT
	# of Vehicles	# of Veh | % Change	# of Veh | % Change
3:00 - 4:00	71,671	72,817 | 1.60%	-
4:00 - 5:00	76,577	77,720 | 1.49%	-
5:00 - 6:00	78,060	79,186 | 1.44%	-
6:00 - 7:00	64,021	65,449 | 2.23%	66,083 | 3.22%
	Average Trip Time	Avg. TT | % Change	Avg. TT | % Change
3:00 - 4:00	10.65	10.82 | 1.60%	-
4:00 - 5:00	12.01	12.34 | 2.75%	-
5:00 - 6:00	14.60	15.21 | 4.18%	-
6:00 - 7:00	14.99	15.9 | 6.07%	15.94 | 6.34%
	Average Trip Time Index	TTI | % Change	TTI | % Change
3:00 - 4:00	1.30	1.33 | 2.31%	-
4:00 - 5:00	1.46	1.5 | 2.74%	-
5:00 - 6:00	1.68	1.75 | 4.17%	-
6:00 - 7:00	1.69	1.79 | 5.92%	1.79| 5.92%
	Average Speed	Avg Speed | % Change	Avg Speed | % Change
3:00 - 4:00	30.87	30.37 | - 1.62%	-
4:00 - 5:00	27.50	26.76 | - 2.69%	-
5:00 - 6:00	23.80	22.84 | - 4.03%	-
6:00 - 7:00	23.97	22.57 | - 5.84%	22.50 | - 6.13%

Note: Model simulates greatest mobility impact during 6:00 - 7:00PM for both after scenarios.

APPENDIX V:

MGM CASINO SENSOR COUNT DATA COMPARISON

Table 38: Before/After Sensor Counts Comparison (MGM Casino)

Hour (PM peak pd.)	Sensor Location: Adjacent to Casino	BEFORE Count	BEFORE Year	AFTER Count	AFTER Year	% Change	Sensor Location: Nearby Corridors	BEFORE Count	BEFORE Year	AFTER Count	AFTER Year	% Change
2 - 3:00	Harborview Ave (EB)	226	Jan-14	591	Dec-17	161.5%	I-295 (NB)	1910	Oct-15	2243	Nov-18	17.4%
3 - 4:00		294		791		169.0%		1760		2131		21.1%
4 - 5:00		496		979		97.4%		1618		1780		10.0%
5 - 6:00		641		866		35.1%		1660		1570		-5.4%
6 - 7:00		395		790		100.0%		1669		1653		-1.0%
2 - 3:00	National Ave (WB)	136	Jan-14	432	Dec-17	217.6%	I-295 (SB)	4467	Oct-15	2972	Nov-18	-33.5%
3 - 4:00		139		406		192.1%		4799		4110		-14.4%
4 - 5:00		240		406		69.2%		4327		4694		8.5%
5 - 6:00		277		401		44.8%		4183		4489		7.3%
6 - 7:00		173		410		137.0%		4283		3913		-8.6%
2 - 3:00	Exit 2 Ramp 9 from I-295 to Nat'l Harbr	278	Mar-16	388	Jul-17	39.6%	MD-210 (NB)	1808	Aug-15	1933	Jun-18	6.9%
3 - 4:00		446		537		20.4%		1727		1818		5.3%
4 - 5:00		569		574		0.9%		1702		1839		8.0%
5 - 6:00		587		656		11.8%		1649		1913		16.0%
6 - 7:00		417		569		36.5%		1606		1935		20.5%
2 - 3:00	Oxon Hill Rd (NB)	354	Jun-15	405	Aug-18	14.4%	MD-210 (SB)	3070	Aug-15	2584	Jun-18	-15.8%
3 - 4:00		327		372		13.8%		3251		3201		-1.5%
4 - 5:00		317		352		11.0%		3284		3462		5.4%
5 - 6:00		336		404		20.2%		3174		3437		8.3%
6 - 7:00		356		396		11.2%		3142		2967		-5.6%
2 - 3:00	Oxon Hill Rd (SB)	600	Jun-15	801	Aug-18	33.5%	I-95 W of MD-414 (NB)	5691	Oct-15	5808	Jan-18	2.1%
3 - 4:00		918		779		-15.1%		6823		7154		4.9%
4 - 5:00		1150		720		-37.4%		6928		7061		1.9%
5 - 6:00		1005		878		-12.6%		6562		6823		4.0%
6 - 7:00		942		708		-24.8%		6547		6439		-1.6%
2 - 3:00							I-95 W of MD-414 (SB)	4426	Oct-15	4372	Jan-18	-1.2%
3 - 4:00								4978		5035		1.1%
4 - 5:00								5467		5319		-2.7%
5 - 6:00								5595		5225		-6.6%
6 - 7:00								4885		4758		-2.6%

Note: Change in volume after MGM Casino opened varies significantly at different count sensor locations

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