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Impact Analyses of Curb-Street Parking Guidance System on Mobility and Environment

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Submitted by

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16. Abstract

The project is proposed to expand the previous effort (by WinLab-Rutgers) performed on Parking Guidance and Information System (ParkNet) and assess the effect of real-time dissemination of on-street parking information using mobile connectivity on the gas emission and consequently the environment pollution. The research team will perform analyses on a hypothetical Central Business District (CBD) roadway network where travelers will be informed on the availability of on-street parking by their mobile devices and directed to the closest available parking spots to their destination points. The vehicle-miles traveled and the pollution produced by these travelers will be compared with other travelers who are not equipped with this service. This assessment will provide evidence on how the mobile connectivity can save energy and reduce the environment pollution.

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EXECUTIVE SUMMARY

Studies revealed that a relatively large number of drivers travelling within central city areas spend a significant amount of their total trip time looking for an on street parking space. This search for parking spaces intensifies the overall amount of traffic congestion and worsens environmental quality within an urban center.

To alleviate this congestion and improve the environment quality in urban centers, the project is introduced Parking Guidance System (PGS) to sense curb-street parking using a drive-by sensing. To quantify the system's benefits, the project has examined the effect of the deployment of this system on network mobility, i.e. travel time and delays, and greenhouse gas (GHG) emitted from vehicles through a design and a development of simulation model replicating one central business district area (Newark, NJ). Different replicated scenarios are developed to explore conditions and operational settings that the highest gains can be achieved from the PGS deployment. The findings demonstrate that PGS has the potential to improve mobility and reduce vehicular emissions at any level of market saturation whether or not near-real-time traffic data is integrated into the route guidance system. The most significant reductions in vehicular emissions and delays are realized under conditions where the demand for parking is much greater than the availability of parking places; suggesting that as cities become more densely populated, PGS will become more necessary to reduce congestion and improve urban air quality. However, the emission reductions enabled by PGS usage are not sufficiently large to completely mitigate the increase in emissions caused by increasing parking demand. The study also analyzes the impacts of simultaneous deployment of near-real-time traffic information system (ATIS) and PGS, as demands increase. The findings suggest that the close integration and coordination of ATIS and PGS is beneficial in order to decrease delays and improve mobility.

INTRODUCTION

Due to the inherent uncertainty associated with public on-street parking spaces, a relatively large number of drivers travelling within central city areas spend a significant amount of their total trip time looking for an on street parking space. A review of sixteen studies performed by Shoup [2006] revealed that between 1927 and 2001 the average cruising time to find a curb-street parking in the central business district areas of eleven cities on four continents was about eight minutes. In recent survey deployed in Chinatown of New York City and performed by Urbitran/Parson Brinckerhoff [2008], 54% (weekday) and 41% (weekend) of parkers spent more than 20 minutes to find curb-street parking space. This search for parking spaces intensifies the overall amount of traffic congestion and worsens environmental quality within an urban center. Based on 2005 statistics [Texas Transportation Institute 2007], motorists waste 4.2 billion hours in congestion resulted to purchase an extra 2.9 billion gallons of fuel for a cost of $78 billion. In his study, Shoup estimated that motorists were cruising 950,000 excess VMT (Vehicle Mile Traveled) in Westwood Village in Los Angeles which equals to 38 trips around the earth, wasting 47,000 gallons of gasoline and producing 730 tons of CO2 emissions.

For this reason, parking guidance systems (PGSs) have been deployed in an effort to reduce car cruising for parking spaces particularly in central business districts (CBD). While early PGSs relied on variable message signs (VMSs) to inform drivers of the number of available parking spaces in garages or parking lots, PGSs have shown potential to go beyond the original scope. For example, a recent trial deployment of a more advanced PGS in San Francisco senses, records, and reports curb-street parking via VMSs, GPS navigation devices, and/or mobile phones. While this PGS test bed has shown good results, high capital costs of sensors, installation, and maintenance are an essential barrier to expand this technology. It is evident more investigations are required to a) design and develop cost-effective sensing technology; b) quantify benefits (e.g. improve mobility, and reduce gas emission) derived from the deployment of this system; c) delineate the scope of PGS deployment in order to achieve the highest gain (considering associated benefits and costs).

To address prohibitive deployment costs, this project introduces a drive-by sensing technology developed and tested by Winlab at Rutgers to sense curb-street parking using innovative low-cost sensors. To quantify the benefits derived from this system, the project has examined the effect of the deployment of this system on network mobility (i.e. travel time and delays) and vehicular greenhouse gas (GHG) emissions through the design and development of a simulation model replicating one CBD area (Newark, NJ). In this model, the most updated information on curb-street parking is presented to drivers via VMSs installed in drivers' paths, which replicates drivers' GPS enabled navigation systems and Smartphones. The simulation model has been built using the Paramics environment and random curb-street parking spots are sited close to office buildings, shops, and parks. For each vehicle type defined in this environment, travel times, delays, and emission rates are estimated in order to quantify the benefits obtained from this deployment. To identify the most efficient level of parking information dissemination, several travel and parking demand scenarios have been defined and the model has been run for each of them. Determination of the information requirements for PGS is critical for transportation agencies who are constantly looking for techniques and approaches to achieve the highest rate of return considering costs' associated with the deployment of this system and benefits derived for this deployment.

This report is organized as follows; the following section presents background and literature review covering the current technologies used in sensing parking locations (on and off-street) and the importance of this system in reducing congestion and GHG emissions in urban areas. The project objectives are noted in the next section. As the simulation technique is utilized to measure the effects of PGS in an urban area, a comprehensive coverage of processes to build the replicated model is described in the section after that. Afterward, the outcomes of assessments are presented and the exploration of key findings is provided. Finally, the report is concluded by summarizing the findings and recommendations' remarks.

LITERATURE REVIEW

While many studies have been reported in the literature that examine the use of different off-street parking capacity detection and presentation technologies, only a handful of studies have been performed to monitor curb-street parking; mainly, because curb-street parking spaces are distributed all over urban centers which are difficult to monitor. Since the cost of curb-street parking is generally less than off-street parking (Arnott 2005, Shoup 2006, and Urbitran 2008), most motorists are willing to drive and search more for parking spots; consequently, they contribute to increased congestion and its associated problems, particularly air pollution. Additionally, while searching for a parking location, motorists drive slower than necessary resulting in a stop-and-go traffic pattern that further exacerbates congestion.

A critical step in facilitating curb-street parking through PGS is the recognition of available curb-street parking in real- or near-real-time. Once available parking can be identified, this information can be used to inform and guide motorists, reducing congestion and ultimately air pollutants such as GHG. The primary technology currently used to identify available parking spaces relies on sensors embedded in asphalt beneath each marked curb-street parking space. For example, SF-Park[1], a PGS deployed by San Francisco Municipal Transportation Agency (SFMTA), utilizes this technology to locate available parking spots and transfers data wirelessly to the public via website, smartphone applications, text message, and eventually 511. A major drawback of this system is the cost including capital, installation, operating, and maintenance of sensors. According to a Department of Transportation report [2007], the installation cost of a sensor per parking space ranges from $250- $800 per spot. Given this cost range, one can estimate the cost of furnishing all marked curb-street parking spaces with sensors in City of San Francisco (for instance) that has 28,800 metered spaces to be between $7.2M and $23M. Furthermore, it is difficult to determine how to deploy fixed sensors on streets without marked parking spaces, a common occurrence in many CBDs (e.g. downtown New York City).

[1] www.sfpark.org

Figure 1: Sensor and sensor installation process –Courtesy of SFpark[2]

A further drawback of such systems is that they require that wireless relay nodes be installed separately on the road side (e.g. in lamp posts) in all areas where sensors are installed in the ground [Mathur, 2010]. SFPark and projects similar to this effort demonstrate the magnitude of the problem in large cities and the agencies' dedication to long-term investments in a smart parking infrastructure.

Considering the drawbacks of current sensing system vehicles, researchers in Winlab at Rutgers University have designed, developed, and tested the ParkNet system. This mobile system collects curb-street parking information using a low-cost ultrasonic sensor. This sensor works by emitting sound waves every 50 ms at a frequency of 42 KHZ to detect the presence or absence of parked vehicles, as depicted in Figure 2. A GPS receiver defines and records the exact location of available parking spots and transfers to the dedicated and centralized parking server.

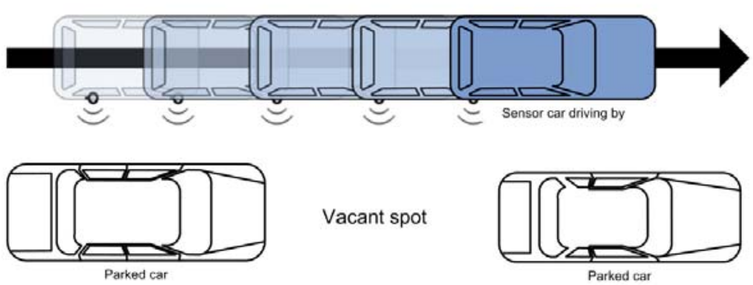

Figure 2: Ultrasonic sensor utilized in Parknet system derived from Mathur, 2010

This ultrasonic sensor can leverage the mobility of vehicles that regularly travel throughout a city such as taxicabs, sweeping machines, parking enforcement, and police cars to reduce the number of sensors required to cover a particular spatial area such as a CBD. The integration of ultrasonic measurements with GPS positioning using environmental fingerprinting provides the system with high accuracies location information required for precise matching of cars with the

[2] http://sfpark.org/resources/mission-sensor-installation-photos/

associated parking slots. Since, the status of parking spaces in a CBD does not change very rapidly in time, continuous sensing through fixed sensors is unnecessary. Thus, the use of a few mobile sensors can provide similar observational capacity as fixed sensors, but at significant cost savings.

While the real-time recognition of off-street and curb-street parking and dissemination of this information are relatively new subjects, many studies have been performed on the dynamic of parking search activity and endeavor to model this phenomenon. Thompson et al. [1998], Arnott et al. [1998] developed a parking search behavior model and defined factors which impacted driver's decision. In another study, Arnott et al. [2006] presented a model to diminish demands for curb-street parking solely by raising parking fee. Chou et al. [2008] used an intelligent agent system to select the optimal car parks for drivers considering negotiate parking pricing. Gallo et al. [2011] proposed an assignment model to simulate the impact of cruising for parking on traffic congestion. Using Intelligent Transportation Systems (ITS), Thompson et al. [2001] developed a model to predict the influence of PGS on the overall performance of the traffic system. Leephakpreeda [2007] presented a fuzzy knowledge-based approach to guide drivers to the best parking slots based on some defined fuzzy linguistic sets.

To analyze the impacts of cruising for parking on the environment, Hoglund [2004] examined the impacts of different types of parking (curb-street parking vs. parking garages) on vehicle emissions and air pollution. Using data derived from a study area, he concluded that underground parking garages produced less gas emission than curb-street parking by 40%.

To the best of the authors' knowledge, no study has been found to investigate the impacts of curb-street parking information dissemination and the spectrum of this dissemination on traffic congestion and air pollution.

PROJECT OBJECTIVES

The overall objective of this study is to investigate the effect of a broad deployment of PGS on traffic congestion and environment pollution. This objective is driven by Winlab's success in developing cost effective sensing technology to record curb-street parking. The results of the study can be used to enable PGS that will:

- Reduce cruising time for parking by informing drivers on available curb-street parking spaces via PGS (e.g. mobile phone)
- Increase higher curb-street parking turnover rate through timely notification of parking availability
- Reduce gas emission via reduction in vehicle mile traveled
- Ease congestion in CBD through diminishing unproductive movements i.e. cruising for parking

PROJECT APPROACH

Road network traffic systems are complex and stochastic systems made up of many interacting components. Although each of these sub-components can be identified as a stand-alone system, analyses of such system that decouple these components are problematic, since they cannot represent the interactions and feedbacks between the subcomponents. Hence, simulation, which is the most common quantitative modeling technique used to design and develop large, complex stochastic systems for forecasting and performance measurement purposes [Flood 1998, Penttinen 1999, and Kennedy 2003], is selected as an appropriate approach to represent a real transportation system that hosts PGS.

Development of Parking Search Model in Microscopic Environment

Study Area

The study area is selected according to the following two criteria: (1) curb-street parking availability is a major problem, (2) curb-street parking spaces located in the study area should not be full at all times or have low turnover rate. These criteria are used to avoid selecting a study site in which PGS has little utility. Using these criteria, downtown Newark is selected to be the study site. This area is a major CBD in the State of New Jersey and home to many retailers and cultural venues. The intersection of Broad Street (the city's widest north/south boulevard) and Market Street, which is one of the busiest in the state and, once, was considered the busiest in the country, is the host to many Newark's retailers, shops, and commercial buildings. Broad Street has many street vendors as well. At night, however, streets are vacant and shops are closed. This pattern is considered in assigning parking spots to curb-street parking with slightly overcrowding in mornings and relieving in afternoons. Curb-street parking spaces are defined based on existing parking spaces and considering the high demands for retailers and office buildings.

Simulation Software

Paramics is a microscopic traffic and pedestrian simulation software, which provides user friendly environment to design efficient and economical transportation infrastructure for drivers and pedestrians allowing operational assessment for current and future year traffic conditions. Paramics offers a number of features to integrate emerging ITS technologies into current models. Paramics has implemented features such as car park signage, Variable Speed Limits (VSL), High occupancy Tolling (HOT), Vehicle Actuated (VA) signals and Incident Management (IM) to provide a more intelligent and dynamic network simulation.

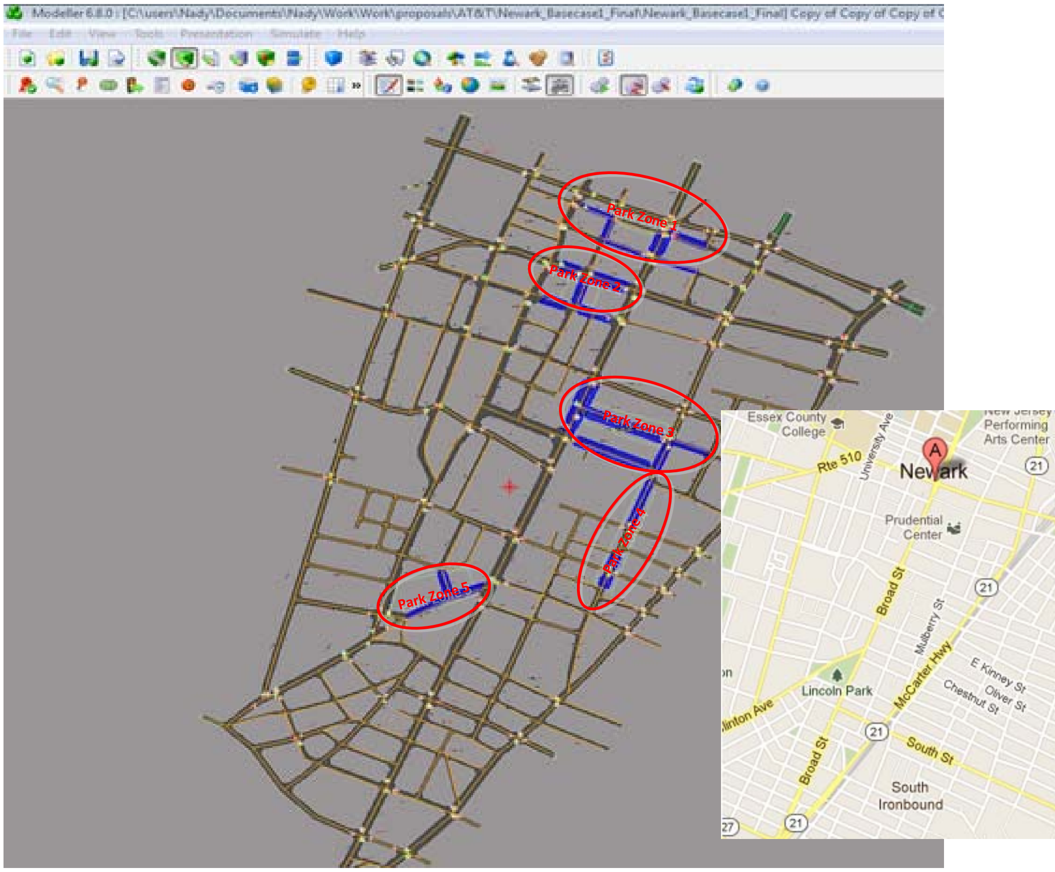

Figure 3: Newark down town – The study area

Simulation Model Development

***Network Creation* -** To build the study area, the "Converter", one of seven Paramics suites, is utilized to take the existing geometric network data into Paramics network. The Converter works with various sources including Mapinfo, ESRI (the project file), Synchro, Corsim, and Cube. Nevertheless, the import procedure could not be performed seamlessly because of exiting flaws in available data (e.g. traffic control data and geometric data) and a complexity in interpreting geospatial data by Converter (i.e. distinguishing between overpassing and intersecting roads). To locate the curb-street parking throughout the study area, satellite images are used and defined in the virtual network. The final network layout is depicted in Figure 3.

***Network Demand* -** Traffic demand captured in Original-Destination (OD) matrix doesn't present the actual network and curb-street parking demands. Demands for each OD zones are assumed for an existing base-demand condition and alternative demand scenarios. To ensure a realistic emissions scenario, the distribution of vehicle types was estimated using roadway information and vehicle count data published by the State of New Jersey Department of Transportation[3] (NJDOT) by first determining the road type (i.e. functional class) distribution in Essex County and multiplying the state-wide vehicle percentage per road type. The estimated vehicle type distribution is show in Table 1.

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[3] http://www.state.nj.us/transportation/refdata/roadway/pdf/hpms2009

Table 1: Motor vehicle class types and associated shares

Motor Vehicle Class	Network Percentage
Motor Cycle	0.70%
Passenger Car	68.36%
School and Commercial Bus	20.26%
Truck with different Axle	9.20%
Trailer Trucks	1.49%
Total	100%

In this study, all cars allotted to curb-street parking are assumed to be passenger car. A prospect study can extend the scope of analysis and dedicate the portion of demand to truck examining the paradigm of PGS in load/unloading goods in CBD.

Replication Period – As the order of arrival is essential for parking, the study defines four operational periods to represent morning peak and afternoon peak hours at which demands for curb-street parking is surged. Two periods are mimicking one hour of non-peak and one hour of peak period in the morning (6:00 – 7:00 and 7:00 – 8:00) and two afternoon periods are determined (16:00- 17:00 and 17:00 – 18:00) capturing one hour of non-peak and one hour of peak period. Morning period has slightly more parking demands. Fifteen minutes are dedicated to warm-up; the statistics associated to this period are not included in analyses.

Curb-Street Parking Deployment - New versions of Paramics have evolved car park and walk time concepts (walking time between car parks and destination points). However, this tool operates and manages the car park capacities using VMSs which inform drivers on how many parking spaces are available in a zone. The research team utilizes car park and walk time functionalities to simulate curb-street parking. In Paramics, “car park” function is defined as a car park garage with the capability of having different capacities. Nevertheless, the car park function works under conditions that do not maintain the study’s purpose adequately. The main reasoning behind this adequacy is the utilization of VMS to inform drivers on car park capacity and divert traffic to other car parks when one car park is full. While, this capability captures PGS operating condition properly, the system is not replicating current conditions in which drivers have no knowledge of parking spot availability. Consequently, the research team models the current condition by manipulating walk time (from parking spot to the destination zone) and information displayed by VMS.

The study has delineated five park zones as illustrated in Figure 3. These zones are selected to replicate actual access demands to retailers (park zone 2), office buildings (i.e. police department- park zone 3, NJDOT- park zone 1), institute of higher education (NJIT- park zone 4), and parks (park zone 5). Based on the estimation of demands for each defined attracting location, demands for curb-street parking are estimated and assigned to each park zone. For instance, as the corner of Raymond Blvd/Broad St, and Market St/Broad St experience high demands, six and five curb-street parking locations (with different capacities) are assigned to cover demands for parking. For each curb-street location, the capacity and explicit walk time (based on the distance between the centroid of parking locations to the centroid of park zone) has been defined. A VMS is assigned to each parking location displaying the capacity of parking location, as required by Paramics to replicate the drivers' visualization of the available parking spaces. As parking spaces are occupied and filled, the parking demands are diverted to other parking locations, which have the shortest walk time. In the base case scenario, in which there is no PGS, the information of one parking location is displayed on the VMS assigned to that location. In alternative scenarios, drivers headed to the specific park zone have the information of all parking locations assigned to that zone. This information is depicted via VMSs in critical locations in which drivers must pass to reach the destination point. By applying this principal, drivers are diverted to parking locations that most likely find parking spots. As a result, it is expected that congestion will ease and gas emission will reduce. The justification of this assertion is investigated and results are presented in the pertinent section.

Base case and Alternative Scenarios – Practice [Waterson et al. 2001, Thompson et al. 2001, Leephakpreeda [2007] demonstrates that the effectiveness of PGS is variant and closely related to a network operational conditions. To delineate these conditions and measure the spectrum of effects, different scenarios are initiated considering the following aspects;

- ***Demands for curb-street parking-*** As much as demand for curb-street parking is increased, clearly the competition for a parking spot gets more intense and accessibility to real-time curb-street parking information has been intuited. However, the effectiveness of PGS is unclear, when demands are significantly more than supplies (curb-street parking spots); to be exact, the system is oversaturated. To capture this circumstance, scenarios have been initiated to detect the effectiveness of PGS in which car park demands exceed supplies.

- ***Data timeliness-*** The frequency of reporting parking data information (availability and the location of curb-street parking) to drivers has strong interconnectivity to traffic volume. While transferring data per minute is not even fast enough in some circumstances, transferring data per five minutes or more may be adequate enough in other situations.

- ***Time of day-*** Time of day and season also impact traffic volume, and gas emissions, which consequently affect the effectiveness of PGS.

- ***PGS availability (Market Saturation)*** - It is expected that a level of accessibility to real-time curb-street parking information impacts the scale of PGS effectiveness; though, the intensity of this impact has not been recognized yet. It is an imprudent claim that there is a deterministic relation between the effectiveness of PGS and the number of drivers equipped with this system. The same observation can be followed in Advanced Traveler Information System (ATIS) when recommending and broadcasting the most apt route is not always ended to the best results. Helbing [2003] studied these circumstances and concluded that traffic congestion might shift to substitute roadways without any major congestion reliefs throughout the network. He suggested that it was essential that only a certain percentage of travelers received this recommendation, in contrast to all in order to achieve some success. With this knowledge, the study endeavors to delineate the circumstances that PGS presents the highest effects considering car park demands and a number of drivers equipping with this system.

Considering the aforementioned discussion, different scenarios are initiated and the effectiveness of PGS in following circumstances is explored:

- Base Demand: This scenario considers the normal situation of traffic demand with normal demand for curbside parking, which happens regularly every day in the study area.
- Network Demand_ 1.50: In this scenario, traffic demand in the network has been increased by 1.50 relative to the base demand without any change in the demand for curb-street parking.
- Car Park Demand_1.25: In this scenario, the demands of curbside parking and network are increased by 1.25 relative to the base demand.
- Car Park Demand_1.5: In this scenario, the demands for curbside parking and network are increased by 1.5 relative to the base demand.
- To evaluate the synergistic effect of near-real-time traffic information on PGS, these scenarios are evaluated with the feedback periods of 3, 5, 7, and 15 minutes.

The feedback period is the period at which link travel times (representing global traffic congestion information) are fed back into the routing calculations and the system modifies the route tables based on the route costs estimated using timely delay per route. Thus, the feedback period represents the level of awareness of the global traffic congestion each motorist has when making route choices. All scenarios are compared with the base operational condition; hereafter is referred to as the base case, which represents the following conditions:

- On-street parking spaces satisfy demands without any overflowing for mornings and afternoons' demands.
- No information on available curb-street parking is on hand.
- Cruising for curb-street parking is performed by all drivers seeking parking spaces considering the closest parking location to the destination.
- Drivers park and leave considering the information defined in the demand table.
- Vehicle's profile is set considering the highest number of vehicle released in the middle to the end of the first hour of mornings' and afternoons' periods (i.e. 6:00, and 16:00); the vehicle releasing rates for the second hour of each period (i.e. 7:00 and 17:00) follow the deterministic distribution.

For each scenario, measure of effectiveness factors defined in following are estimated. The presentation of outcomes will be presented in the pertinent section. It is worth mentioning that the assumption is made that cars designated to park do not impose further delays on traffic flow, while they park. This assumption will definitely bias the results to better statistics; whereas, on-street parking imposes extra delays on other vehicles, interrupt traffic flow, and prolongs travel times and delays in practice.

MOE determinants- The factors measuring PGS performance in different scenarios, Measure of Effectiveness (MOE), are initiated with this notion to probe and delineate the most apt operational circumstances in which PGS has demonstrated the highest gain. MOE indicators are determined under two categories; I) mobility, and II) environment, as illustrated in Figure 4. Two major MOE indicators are determined and estimated using "Analyser" tool in Paramics to quantify mobility; a) sum of links' average travel time per minute, b) sum of average links' delays per minutes. These determinants are estimated for each vehicle types shown in Table 1.

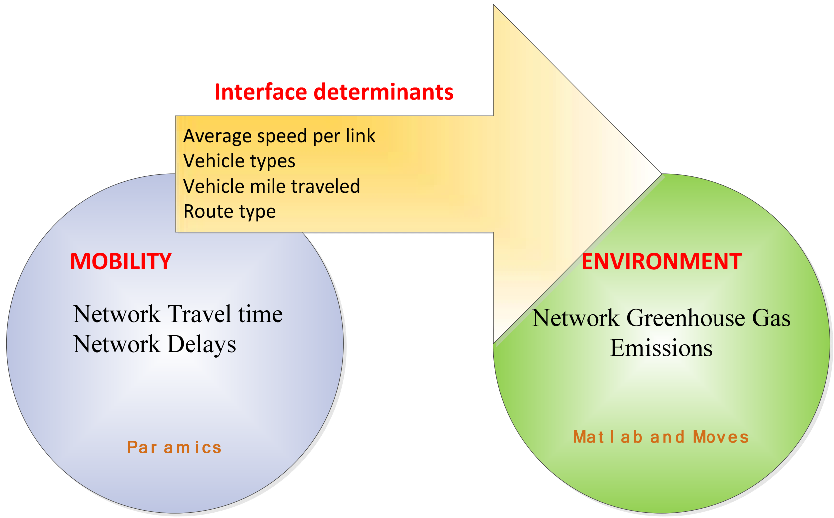


Figure 4: MOE determinants under two classifications

One MOE indicator is defined to represent environmental impacts of PGS, the total GHG emissions for the simulated network. This MOE is computed by integrating Paramics with the United States Environmental Protection Agency's (US EPA's) Mobile Vehicle Emissions Simulator (MOVES) software application. The procedure for integrating Paramics and MOVES to calculate the network GHG emissions is described in the following section.

Inputs to the MOVES software, hereafter referred to as "interface determinants" are extracted from Paramics outputs (speed, vehicle mile traveled) and network setting factors (vehicle types, time of days, road types) defined in Paramics.

Development of Gas Emission Model

Simulation of traffic emission requires a combination of traffic and emission models. The scale of these models should be correspondent. For example, for microscopic emission modeling, a microscopic traffic model is needed, while for the macroscopic emissions modeling, a macroscopic traffic model or averaged results from a microscopic traffic model can be used. The level of aggregation of modeling is dependent on the purpose of the simulation, size of the study area, complexity of network, and data availability.

Since the high-resolution data necessary to perform microscopic emissions modeling on Newark, the study area, a macroscopic model was selected. Newark is a city in Essex County, NJ. Essex is a small, highly urbanized county (population density 6,200 per mi^2). Newark, which has a population density of 11,000 per mi^2, is the largest municipality in Essex County and accounts for 20% of the land area in Essex County. Thus, authors expect that data aggregated at the level of Essex County, which is available in the MOVES software, is representative of Newark.

Therefore, County level MOVES simulation, modeling macroscopic emissions model, has been selected to perform the emissions modeling. Also, the microscopic transportation model, Paramics, has been used to calculate the traffic parameters, required for the MOVES-based emission modeling.

The MOVES software expresses emissions rates in terms of tons/VMT for specific road, traffic, and weather conditions. To compute the emissions for the study area, these emissions rates must be combined with the distance traveled by all of the vehicles in the system under each combination of road, traffic, and weather conditions. The distances are computed by PARAMICS. Although, PARAMICS has a built-in function, named Monitor, which estimates emission using user specified emission rates, the rates computed by MOVES are incompatible with this function. Thus, in order to multiply the rates and VMTs, a Matlab program is developed that reads the rates from MOVES output, parses a PARAMICS output file that contains the VMT and location of each vehicle in the model at defined time intervals, and calculates the emissions for each vehicle during each time interval. A summation of these emissions provides the total emission for the traffic scenario modeled by PARAMICS.

GHG emissions are quantified in terms of carbon dioxide (CO2) equivalents. This metric normalizes each GHG in terms of its potential to warm the planet with respect to CO2, and thus can serve as a univariate measure of GHG emissions. Therefore, the MOVES emissions rates are given in grams CO2 per mile, and are grouped by month, day type, hour of day/temperature, road type, and vehicle type, speed bin, pollutant and process type.

Input parameters for MOVES are sourced from the default data tables supplied by MOVES as well as from external sources. An average speed distribution, fuel supply and formulation, meteorological data, and month/day/hour VMT fractions have been used form the default databases available in MOVES for Essex County. Vehicle age distributions are estimated using the MOBILE6.2 data converter (available through MOVES), which provides representative vehicle age distributions for the US. Since, all roads in the study network are classified as urban, unrestricted access roads; the fraction of road associated with highway entrance/exit ramps is set equal to zero. Furthermore, since detailed information is not available on regulated vehicle inspection and maintenance procedures for vehicles within Essex County, the assumption is made that the effects of such procedures are negligible to the GHG emissions process. The distribution of miles traveled by different vehicle types specified in Table 1 is used.

EVALUATION OF RESULTS

As stated above, Analyser, one of Paramics suites, is utilized to provide the outcomes required for assessing the impacts of PGS on network mobility and GHG emissions. This suite calculates and presents the statistic of MOE determinants for each vehicle class. Since the assessments of mobility and environment impacts of PGS are initiated as focal points of this project, the outcomes are provided in two folds;

- PGS effects on mobility
- PGS effects on urban air quality

Before the presentation of outcomes and key findings, it is important to note that the real-time traffic information (ATIS) is disseminated to all drivers traversing throughout the network simultaneously during each feedback period. Thus, drivers throughout the network may be diverted to less congested routes to avoid traffic congestion. The effect of ATIS is eliminated or diminished by increasing the feedback periods.

Effect of PGS on Mobility

The mobility statistics of the four scenarios defined above using feedback periods of 3, 5, 7, and 15 minutes running in 32 simulation settings are compared to probe and determine circumstances that the network gains the most from the deployment of PGS. The results are analyzed to explore whether:

- PGS benefits from the deployment of ATIS, which diverts traffic to less congested routes. This analysis will be hereafter referred to as the *feedback period* analysis. If this is the case, the study will define the most apt refreshment period.

- The network operational condition (e.g. congestion) improves more for higher levels of PGS usage (e.g. mobile phone, GPS). This analysis will hereafter be referred to as the *Market Saturation* analysis. If this is the case, does it follow a linear trend?

- There are linear increasing trends between the base demand and the increased demand scenarios (25% and 50% increase). This analysis will hereafter be referred to as the *Trends of Impacts* analysis. Particularly, this analysis attempts to examine and determine the system performance in which demands for parking are more than parking supplies.

Feedback period

The study investigates different feedback periods, during which the route table is updated based on the route cost defined by delays in links. Although, the simulated PGS identifies and disseminates the location of available curb-street parking information promptly (in near-real-time), the motorists informed by the PGS select their paths based on the existing version of the route table. It is worth mentioning that the average trip time from all origins to destinations zones is less than 5 minutes. Therefore, the refresh periods of 7 and 15 minutes can be considered as scenarios where the effect of ATIS is minimal, the case where ATIS has not been deployed.

In order to determine the most effective scenario in which the mobility is improved by the deployment of PGS, MOE mobility determinants are calculated and results are presented in Figure 5 and Tables A1 – A4 in Appendix. Each scenario is evaluated for 0, 25, 50, and 100% market saturation of PGS (referred as the percentage usage of PGS by vehicles seeking curbside parking). The statistics are estimated for car park demands and all vehicles traveling throughout the network and outcomes are depicted in tables A5 - A12 in the appendix.

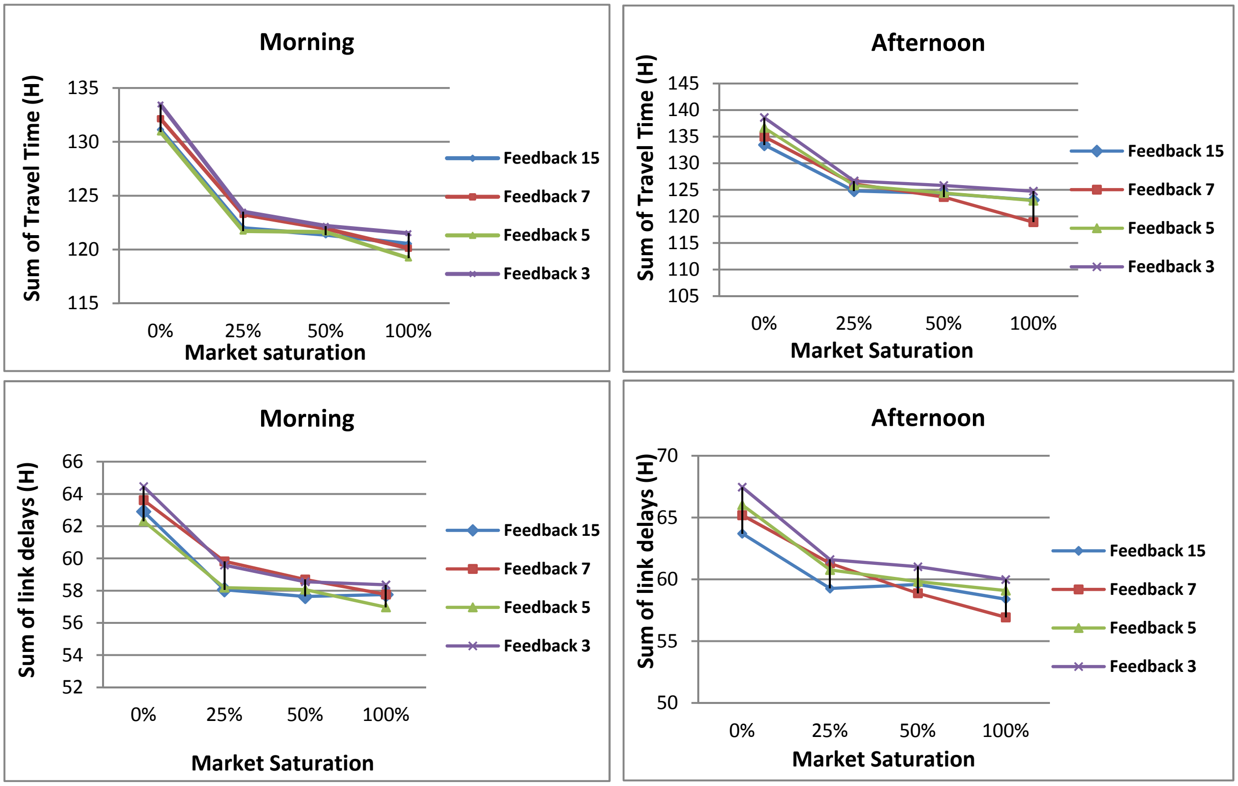


Figure 5: Aggregated travel time and delays for network demands in mornings and afternoons for the base case

As observed in Figure 5 and in the "All or nothing case" row of Table 3A comparing base case settings with 100% market saturation scenario, the feedback period of seven minutes outperforms other scenarios by reducing the travel times by 12.03 and 16.08 hours for all network demands in mornings and afternoons accordingly. Albeit, the feedback period of seven minutes demonstrates the highest saving in delays with 8.26 hours for afternoons, this rate becomes the second highest with 5.85 hours of saving for mornings which is slightly less than the feedback period of three (with 6.1 hours). These assessments have being carried out for the operational conditions that the total demands are increased by 25% and 50%. ***Essentially, the outcomes depict that the solo deployment of PGS (without ATIS utilization) with feedback period of seven improves mobility when demands are more manageable***

The results are less clear in Car Park Demand_1.5 scenario. As demands for parking are more than the existing capacity (demand>supply), the system's outcomes has been affected by this oversaturation and slightly been shifted to the 5-minute feedback period. This shift reveals that the integration of ATIS and PGS may be beneficial in order to decrease delays in the system and improve the network travel times, as demands in network and curb-street parking are being increase. This oversaturation has also been observed in the scenario in which the demands for parking increased by 1.25 in the final minutes of mornings and afternoons simulation periods; though, it doesn't show significant biases.

Market Saturation

To identify whether a linear trend exists between increasing market saturation and reducing travel time and delays, the aggregated network travel times and delays are compared with the immediate next scenario. For instance, the base case is compared with 25% market saturation of PGS and so forth (i.e. comparing 50% with 25% market saturation of PGS; comparing 100% with 50% market saturation of PGS). These investigations are undertaken for all scenarios when 1) demands are set in the existing conditions; 2) demands are increased by 25%; and 3) demands are increased by 50%. Particular attention has been given to the MOE mobility factors of car parks and all vehicles. As illustrated in Figure 6, the aggregated travel time and delays for all vehicles throughout the network are drastically decreased by equipping 25% of car park drivers with PGS. Nevertheless, the same levels of decline in the aggregated travel time and delays are not observed, when the market saturation are increased from 25% to 50% and from 50% to 100%.

For car park demands, while equipping more drivers with PGS improve mobility by decreasing the aggregated travel time and delays, it doesn't follow the linear trend. As depicted in Figure A1, more declines in the aggregated travel time and delays are observed, when the market saturation is increased from 50% to 100%.

These outcomes demonstrate that the mobility throughout the network will improve significantly even when PGS is deployed on a small rate (25%). Clearly, if the target is to improve mobility for car parks' vehicles, more gains can be achieved when more vehicles are equipped with the system (100%). These assessments are carried out when car park's and network's demands are increased by 25% and 50% and the outcomes are illustrated in Figure A2 through A5. ***All results are indicated that the network mobility increases by increasing the level of market saturation; however, this doesn't follow the linear trend.***

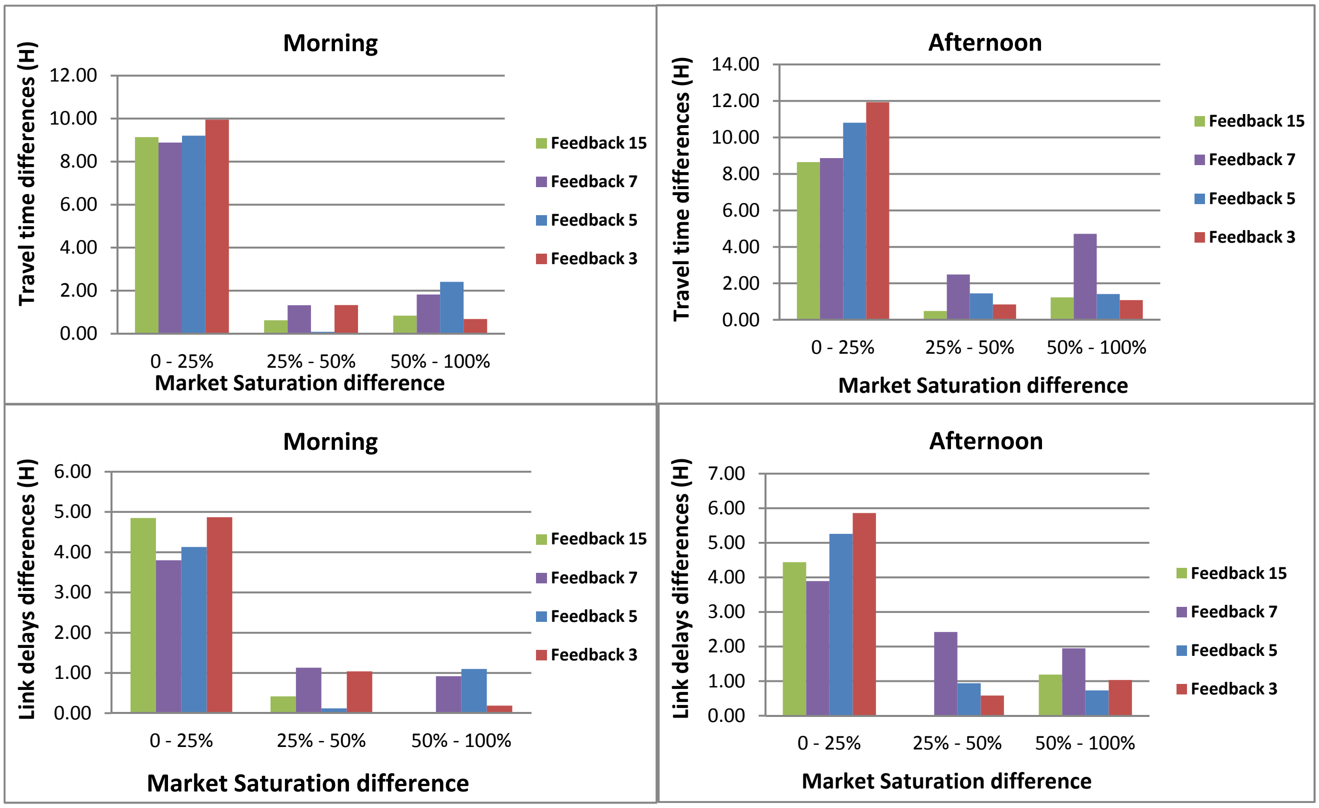


Figure 6: Travel time and delays differences derived from the comparisons of scenarios with different market saturations – Network demand

Trends of Impacts

Since the objective of this analysis is to investigate whether a linear increasing trend between the base demand and the increased demands' scenarios (25% and 50% increase), the proportions of MOE factors obtained from these cases are calculated considering different PGS market saturations (25%, 50%, and 100% of equipped with PGS). To be exact, the values of rows three to six in columns two to five in Tables A5 and A6 are divided by the corresponding rows and columns in Table A1 and A2 for car park demands. The same procedure is carried out for above mentioned rows and columns in Tables A9 and A10 with Tables A3 and A4 for network demands. Again, all processes are followed for 50% increase in network and car park demands. The ratios derived from the comparison of the base demand and 25% increase in demands, and the comparison of the base demand and 50% increase in demands are called hereafter "25% ratio", and "50% ratio" respectively.

The assessments of outcomes are performed for feedback periods of 15 and 7 (represent the solo deployment of PGS), and feedback periods of three and five (represent the concurrent deployment of ATIS and PGS). Findings demonstrate that a 25% increase in all demands (car park and network) increases the total travel time and delays by 13% and 18% respectively throughout the network, when PGS has been deployed solely (feedback periods of 15 and 7). However, the total travel time and delays are increased by 12% and 17% correspondingly for the feedback periods of five and three (concurrent deployment of ATIS and PGS). The same trends have been observed for a 50% ratio. While the total travel time and delays have been increased by 25% and 38% respectively in feedback periods of 15 and 7, the increases of 24% and 37% have been obtained for the aggregated travel time and delays in feedback periods of 5 and 3. These outcomes demonstrate the benefits of ATIS in improving the network mobility particularly when the network operates under or about capacity.

The same examinations are performed for car park demands. The outcomes have revealed while the total travel time in 25% ratio and 50% ratio are increased by 25% and 50%, the total delays in 25% ratio and 50% ratio are increased by 30% and 62% respectively for all feedback periods (a sole deployment of PGS, and concurrent deployment of ATIS and PGS). This increase in delays demonstrates the oversaturation, in which demands for car parks are more than parking spaces (supplies). In this condition (oversaturation), the ratios' comparison of 0% market saturation with 100% market saturation is revealed that the total travel time and delays drop by 15% and 30% respectively, which demonstrate significant reductions comparing with other scenarios for all demands and all ratios (25% ratio and 50% ratio). ***This explains that more gains can be achieved when PGS is deployed in a network with the limited number of parking spaces.***

Effect of PGS on Urban Air Quality

In addition to the above mentioned settings described for base case, scenarios, and simulation time period, each scenario has been evaluated in two extreme weather seasons, summers and winters, to explore the effect of seasonal temperature fluctuations on the emissions. The month of July is selected to be a representative of summer conditions, and the month of February is selected to be a representative of winter conditions. Finally, each scenario is evaluated for 0, 25, 50, and 100% market saturation of PGS. Thus 16 variations of each of the demand scenarios were run for refresh periods of 3, 5, 7, and 15 minutes for a total of 64 emissions simulations.

Figures 7 through 10 illustrate the total emissions generated within the study area for the Base Demand, CarPark Demand 1.25, CarPark Demand 1.50, and Network Demand 1.5 scenarios, respectively. The morning emissions generated in winter and summer are exactly the same, so they have been plotted together. The afternoon emissions for winter and summer are consistently different indicating that the higher temperatures experienced in the summer increase the emissions during afternoon commutes.

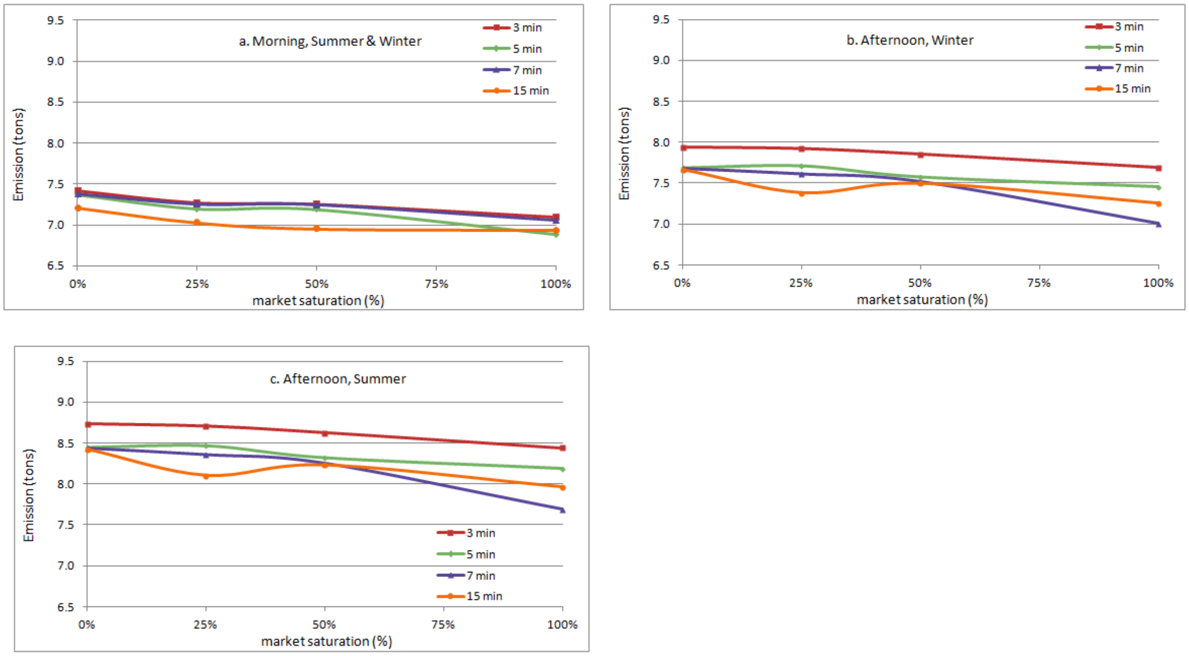


Figure 7: Traffic emission for the Base Demand scenario for (a) morning of summers and winters, (b) afternoon of summers, and (c) afternoon of winters, for various market saturations and feedback periods

These figures show that the usage of PGS, at any level of market saturation, reduces the total emissions generated in the study region relative to the no usage (i.e. 0% market saturation) case. However, the emissions trends do not always decrease monotonically. This implies that optimality of the system in terms of total GHG emissions is sensitive to the market saturation of PGS and the availability of near-real-time traffic information. In general, the emission's rate for similar conditions increases as feedback period decreases. The only exception to this pattern occurs in the base demand scenario, where the 5-minute feedback period outperforms the 7-minute feedback period, and slightly outperforms the 15-minute feedback period with 100% market saturation of PGS. Thus, as the feedback period increases, the influence of this global information on vehicle route selection decreases. Since, 15-minute is larger than the average trip time in the study region, when a 15-minute feedback period is used, most vehicles will not receive route updates during their trips. Thus, the 15 minute feedback period curve can be viewed as being similar to the case where the route is not informed by near-real-time traffic information and is selected by user preference and distance criterion. This result clearly indicates that PGS is much more important than global traffic information for reducing vehicular emissions. However, it also suggests that real-time traffic information may degrade the performance of PGSs. Because the best results are generally achieved using the 15-minute feedback period, and under this condition, vehicle routing is primarily influenced by PGS, the remaining discussion in this section will focus on the emissions generated using a 15-minute feedback period. These data are summarized in Figure 8, and show that morning emissions can be reduced by up to 4%, 4%, 8%, and 6% for the Base Demand, CarPark 1.25, CarPark 1.5, and Network Demand 1.5 scenarios, respectively. These optimal reductions occur with 100% usage of PGS. Under afternoon traffic conditions, emissions can be reduced by up to 5%, 9%, 6%, and 3% for these scenarios under winter weather conditions, and 6%, 9%, 6%, and 3% under summer weather conditions. These optimal results are achieved with PGS usages between 50% and

100%. These results suggest that, in general, more emissions can be reduced as more people adopt PGS.

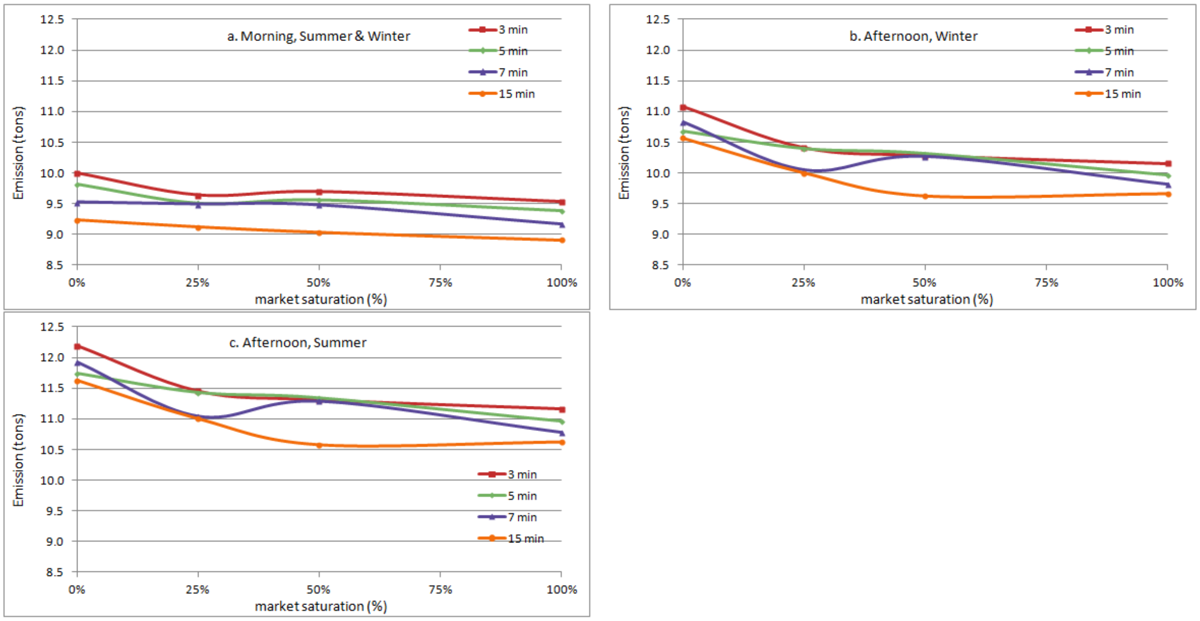


Figure 8: Traffic emission for the Car Park Demand 1.25 scenario for (a) morning of summers and winters, (b) afternoon of summers, and (c) afternoon of winters, for various market saturations and feedback periods

In some of the simulations, ***the minimum emissions are sometimes achieved using a market saturation of less than 100%, especially for the increased demand scenarios*** (i.e. CarPark Demand 1.25, CarPark Demand 1.5, and Network Demand 1.5). This behavior is attribute to the feedback control mechanism of the PGS simulated in this study. In developed model, all PGS users are receiving the same information and using the same routing algorithm to arrive at those destinations. Thus, as more users adopt the PGS, system-wide entropy may be decreased as more drivers converge on the same parking regions along similar routes, resulting in the emergence of vehicle queues. Clearly as demand for travel and parking increases this effect will be more pronounced, which is why, the authors think it is only obvious in the increased demand cases. ***It is also important to note that decreasing the feedback period can shift this optimal point, generally in the direction of decreased market saturation*** as shown, for example in Figure 9 . This figure shows that decreasing the feedback period from 15 to 7 minutes shifts the system optimum for the afternoon from 50% to 25% market saturation. Interestingly though, this behavior is not similarly observed for the morning emissions. This latter result suggests that the effect of global traffic information on vehicle routing has different effects on the morning and afternoon traffic patterns.

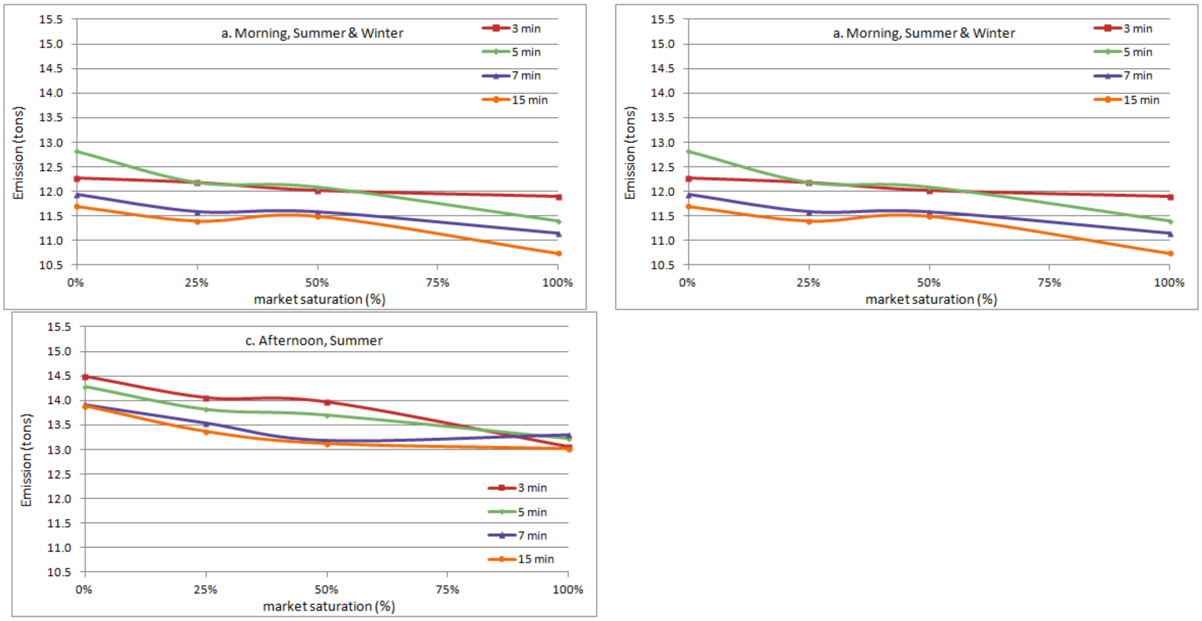
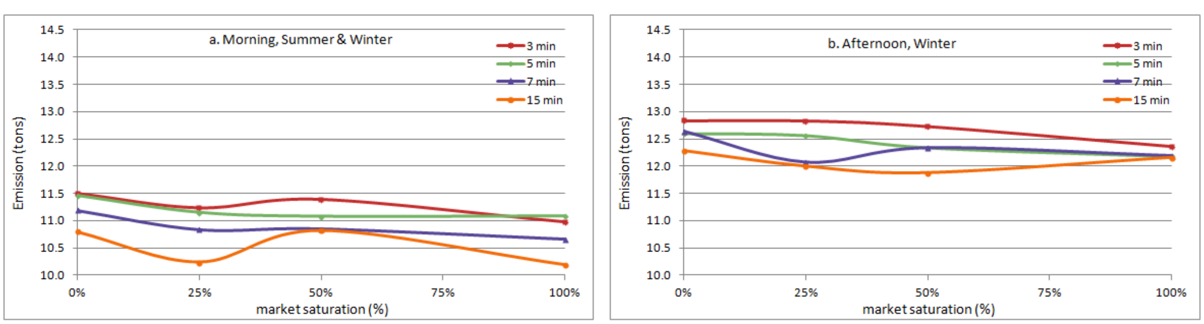


Figure 9: Traffic emission for the Car Park Demand_1.50 scenario for (a) morning of summers and winters, (b) afternoon of summers, and (c) afternoon of winters, for various market saturations and feedback periods

Increasing parking demand increases the emissions reductions realized by the utilization of PGS. In the developed simulation model, increasing the parking demand by 25% and 50% increase the total emissions generated when no PGS is used by 28% and 62% (morning) and 37% and 64% (afternoon), respectively. Thus, the emission's increase is greater than the parking demand increase in all cases. The initiation of PGS, however, decrease this overall emissions increase. Under morning traffic conditions, PGS decreased emissions by 5% and 13% for the CarPark 1.25 and CarPark 1.5 scenarios, respectively. Under afternoon, these reductions are 12% and 10%, respectively. Thus, in the morning, the largest reduction is achieved for the 50% demand increase, whereas, in the afternoon, the largest reduction is achieved for the 25% demand increase. Authors suspect this is due to the larger number of vehicles seeking parking in the morning. Thus, these results suggest that PGS will return increasing gains when parking availability decreases.



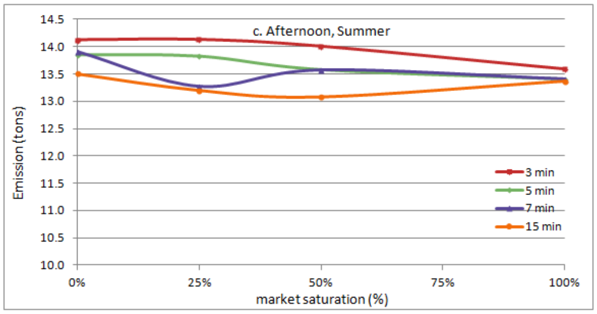


Figure 10: Traffic emission for the Network Demand_1.50 scenario for (a) morning of summers and winters, (b) afternoon of summers, and (c) afternoon of winters, for various market saturation and feedback periods

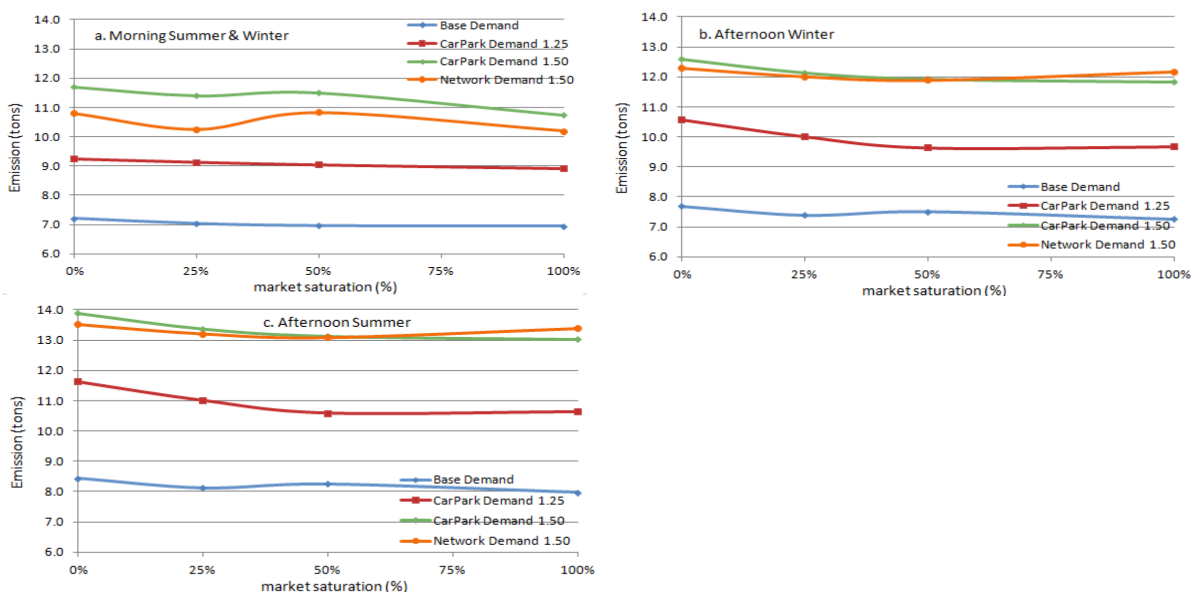


Figure 11: Traffic emission of different demand scenarios using a 15 minute feedback periods for (a) morning of summers and winters, (b) afternoon of summers, (c) afternoon of winters, for various market saturation

When travel demand increases, however, PGS has a little effect on the total emissions generated. In this case, traffic congestion caused by the increased number of vehicles in the system is the primary driver of increasing emissions. Since PGS does improve the efficiency of those vehicles searching for parking, however, small decreases in total emissions are achieved. During the morning period when parking is the most limited PGS usage decreased the emissions generated by 6% over the no-PGI case, whereas in the afternoon, PGS usage only decreases the emissions generated by about 3%. Again, these results suggest that PGS provides the greatest benefit when parking becomes more limited.

Summary of results

The common key findings derived from the mobility and environment assessments of PGS deployed on the study area are as follows;

- The utilization of PGS improves mobility and reduces the total GHG emissions generated in the network regardless of the number of drivers equipped with this system.
- An escalation in increasing urban mobility and decreasing GHG emission has been emerged, when PGS is utilized in areas where parking availability becomes more limited.
- The largest gain in mobility improvement and GHG emission reduction occurs after only a few drivers have adopted the PGS. Incremental improvement continues to occur, however, for all levels of market saturation.

The mobility assessments of PGS with different market saturations and feedback periods representing the ATIS deployment are revealed that

- Not only is the mobility of vehicles cruising for parking improved by the use of PGS, but also, the travel times and delays are reduced for all drivers within the network even when a number of drivers equipped with PGS.
- As demands for travel and curb-street parking increase, the simultaneous use of ATIS and PGS improves mobility throughout the network.
- ATIS has the most impact for improving mobility when the network operates under or close to capacity.
- ATIS is not required to achieve GHG reductions with PGS.

CONCLUSION AND RECOMMENDATIONS

This project examined the impacts of a broad deployment of PGS on traffic congestion and environment pollution. The simulation technique was utilized to assess and quantify these impacts. Different replicated scenarios were developed to explore conditions and operational settings that the highest gains could be achieved from the PGS deployment. The findings demonstrated that PGS had the potential to improve mobility and reduce vehicular emissions at any level of market saturation whether or not near-real-time traffic data was integrated into the route guidance system. The most significant reductions in vehicular emissions and delays were realized under conditions where the demand for parking was much greater than the availability of parking places; suggesting that as cities become more densely populated, PGS will become more necessary to reduce congestion and improve urban air quality. However, the emission reductions enabled by PGS usage were not sufficiently large to completely mitigate the increase in emissions caused by increasing parking demand.

Furthermore, the study analyzed the impacts of simultaneous deployment of near-real-time traffic information system (ATIS) and PGS. The findings suggested that the largest proportion of the improvement in mobility and GHG emissions was achieved after only a few drivers had adopted with PGS. The authors suspect that this result was caused by the diversion of all vehicles heading to the same destination to the same parking spaces (i.e. closest to the destination) along the same path routes, resulting in increased congestion along these routes. To prevent this event, the authors believe that the close integration and coordination of these two systems along with the deployment of more smart diversion technology is essential to increase the benefit of PGS investments. The goal of this integrated route guidance system would be to evaluate the best routes and parking destinations for motorists seeking parking considering the near-real-time traffic and parking information, while directing through traffic along different routes. At the network level, these vehicles will not join the traffic created by car park vehicles. This mixed detouring strategy will increase mobility mutually for car park vehicles and all other vehicles and decrease vehicular emission in the network level.

The project scope can be extended to analyze the effect of parking meter rates (affecting demands), and time limit (influencing turnover rate) on the network mobility and vehicular emissions. Future research can broaden the study's scope and perform economic analyses to justify the investments on PGS through recognizing endogenous and exogenous benefits of this system such as time saving, fuel saving, business prosperity, and reduction in goods delivery time.

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APPENDIX

Table A1: Total travel time in hours aggregated for car park demands

Total Travel Time Sum (H)	Existing Demand			
Morning (6-8)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	43.94	46.37	45.69	45.41
25% market saturation	41.69	42.98	42.49	42.88
50% market saturation	41.24	41.51	41.46	42.34
100% market saturation	37.71	38.04	37.44	39.25
All or nothing case	6.23	**8.33**	8.25	6.16
Total Travel Time Sum (H)				
Afternoon (16-18)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	44.50	45.23	45.40	46.68
25% market saturation	41.84	43.18	43.20	43.01
50% market saturation	40.95	40.72	40.86	42.53
100% market saturation	37.79	36.80	39.30	39.00
All or nothing case	6.71	**8.43**	6.10	7.68

Table A2: Total delays in links in hours aggregated for car park demands

Link Delay Sum (H)	Existing Demand			
Morning (6-8)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	22.61	24.16	23.72	23.71
25% market saturation	21.50	22.45	22.17	22.37
50% market saturation	21.38	21.39	21.45	21.77
100% market saturation	19.60	19.55	19.19	20.27
All or nothing case	3.01	**4.61**	4.53	3.44
Link Delay Sum (H)				
Afternoon (16-18)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	22.73	23.48	23.55	24.41
25% market saturation	21.21	22.53	22.59	22.40
50% market saturation	20.90	20.90	20.99	22.37
100% market saturation	19.24	19.30	20.46	19.94
All or nothing case	3.49	4.18	3.09	**4.47**

Table A3: Total travel time in hours aggregated for network demands

Total Travel Time Sum (H)	Existing Demand			
Morning (6-8)	All Vehicles (Ref15)	All Vehicles (Ref7)	All Vehicles (Ref5)	All Vehicles (Ref3)
Base case (0%)	131.13	132.15	130.93	133.47
25% market saturation	121.99	123.26	121.72	123.52
50% market saturation	121.37	121.94	121.63	122.19
100% market saturation	120.53	120.12	119.22	121.51
All or nothing case	10.60	12.03	11.71	11.96
Total Travel Time Sum (H)				
Afternoon(16-18)	All Vehicles (Ref15)	All Vehicles (Ref7)	All Vehicles (Ref5)	All Vehicles (Ref3)
Base case (0%)	133.45	135.00	136.65	138.59
25% market saturation	124.80	126.13	125.84	126.66
50% market saturation	124.31	123.64	124.39	125.81
100% market saturation	123.08	118.92	122.97	124.73
All or nothing case	10.37	16.08	13.68	13.86

Table A4: Total delays in links in hours aggregated for network demands

Link Delay Sum (H)	Existing Demand			
Morning(6-8)	All Vehicles (Ref15)	All Vehicles (Ref7)	All Vehicles (Ref5)	All Vehicles (Ref3)
Base case (0%)	62.91	63.62	62.32	64.46
25% market saturation	58.06	59.82	58.19	59.59
50% market saturation	57.64	58.69	58.07	58.55
100% market saturation	57.76	57.77	56.97	58.36
All or Nothing	5.15	5.85	5.35	6.10
Link Delay Sum (H)				
Afternoon(16-18)	All Vehicles (Ref15)	All Vehicles (Ref7)	All Vehicles (Ref5)	All Vehicles (Ref3)
Base case (0%)	63.70	65.19	66.02	67.46
25% market saturation	59.26	61.30	60.76	61.60
50% market saturation	59.59	58.88	59.82	61.02
100% market saturation	58.40	56.93	59.09	59.99
All or nothing case	5.30	8.26	6.93	7.47

Table A5: Total travel time in hours aggregated for car park demands increased by 1.25

Total Travel Time Sum (H)	Network and car park demand increased By 1.25			
Morning (6-8)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	55.11	56.40	57.13	55.71
25% market saturation	51.99	52.55	51.57	52.91
50% market saturation	49.96	54.95	51.59	52.08
100% market saturation	45.63	46.19	48.22	47.06
All or nothing case	9.48	10.21	8.91	8.65
Total Travel Time Sum (H)				
Afternoon (16-18)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	55.72	57.75	57.00	58.66
25% market saturation	53.35	51.15	53.17	52.48
50% market saturation	50.10	50.54	51.37	51.93
100% market saturation	47.19	45.98	47.10	48.60
All or nothing case	8.53	11.77	9.89	10.05

Table A6: Total delays in links in hours aggregated for car park demands increased by 1.25

Link Delay Sum (H)	Network and car park demand Increased By 1.25			
Morning	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	29.73	30.86	31.33	29.82
25% market saturation	28.18	28.53	27.63	28.65
50% market saturation	26.54	30.98	27.73	28.01
100% market saturation	23.80	23.99	26.27	24.97
All or nothing case	5.93	6.87	5.07	4.85
Link Delay Sum (H)				
Afternoon	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	30.27	32.15	30.79	32.42
25% market saturation	29.49	27.17	28.97	28.30
50% market saturation	27.00	27.18	27.42	28.27
100% market saturation	25.66	24.35	25.27	25.99
All or nothing case	4.61	7.80	5.52	6.43

Table A7: Total travel time in hours aggregated for network demands increased by 1.25

Total Travel Time Sum (H)	Network and car park Demand Increased By 1.25			
Morning (6-8)	**All Vehicles (Ref15)**	**All Vehicles (Ref7)**	**All Vehicles (Ref5)**	**All Vehicles (Ref3)**
Base case (0%)	146.35	148.96	148.80	147.55
25% market saturation	137.72	136.63	135.41	136.51
50% market saturation	134.24	141.15	137.05	137.71
100% market saturation	130.48	133.58	134.80	135.05
All or nothing case	15.86	15.38	13.99	12.50
Total Travel Time Sum (H)				
Afternoon (16 -18)	**All Vehicles (Ref15)**	**All Vehicles (Ref7)**	**All Vehicles (Ref5)**	**All Vehicles (Ref3)**
Base case (0%)	154.78	154.78	154.49	155.35
25% market saturation	142.69	139.63	141.19	142.71
50% market saturation	139.91	139.63	139.96	141.00
100% market saturation	140.26	137.27	138.94	140.11
All or nothing case	14.52	17.51	15.55	15.24

Table A8: Total delays in links in hours aggregated for network demands increased by 1.25

Link Delay Sum (H)	Network and car park Demand Increased By 1.25			
Morning (6-8)	**All Vehicles (Ref15)**	**All Vehicles (Ref7)**	**All Vehicles (Ref5)**	**All Vehicles (Ref3)**
Base case (0%)	72.86	75.39	75.29	72.69
25% market saturation	69.29	68.22	67.66	68.25
50% market saturation	66.60	72.97	68.79	68.42
100% market saturation	63.60	66.10	67.93	67.44
All or Nothing	9.26	9.29	7.37	5.25
Link Delay Sum (H)				
Afternoon (16 -18)	**All Vehicles (Ref15)**	**All Vehicles (Ref7)**	**All Vehicles (Ref5)**	**All Vehicles (Ref3)**
Base case (0%)	78.58	79.00	77.26	78.52
25% market saturation	72.51	68.98	71.50	71.48
50% market saturation	69.40	69.54	70.01	70.90
100% market saturation	70.29	68.33	69.95	69.81
All or nothing case	8.29	10.67	7.31	8.71

Table A9: Total travel time in hours aggregated for car park demands increased by 1.5

Total Travel Time Sum (H)	Network and car park demand increased By 1.5			
Morning (6-8)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	70.74	70.33	76.85	71.92
25% market saturation	66.14	65.52	69.04	67.53
50% market saturation	61.64	64.61	65.59	65.43
100% market saturation	54.81	54.30	57.66	61.97
All or nothing case	15.93	16.03	19.19	9.95
Total Travel Time Sum (H)				
Afternoon (16 -18)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	68.49	67.49	67.19	66.69
25% market saturation	65.13	60.83	61.64	63.76
50% market saturation	55.84	57.97	59.06	58.84
100% market saturation	50.71	49.72	49.50	49.68
All or nothing case	17.78	17.77	17.69	17.01

Table A10: Total delays in links in hours aggregated for car park demands increased by 1.5

Link Delay Sum (H)	Network and car park demand increased By 1.5			
Morning (6-8)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	40.72	39.73	45.70	40.75
25% market saturation	37.52	36.53	39.92	38.30
50% market saturation	33.65	36.49	37.20	36.59
100% market saturation	29.14	28.88	31.75	35.55
All or nothing case	11.58	10.85	13.95	5.20
Link Delay Sum (H)				
Afternoon (16 -18)	Car Park (Ref15)	Car Park (Ref7)	Car Park (Ref5)	Car Park (Ref3)
Base case (0%)	41.03	40.02	39.37	38.46
25% market saturation	39.43	34.95	35.50	37.22
50% market saturation	31.11	32.89	33.71	33.12
100% market saturation	28.53	27.56	27.39	27.16
All or nothing case	12.50	12.46	11.98	11.30

Table A11: Total travel time in hours aggregated for network demands increased by 1.5

Total Travel Time Sum (H)	Network and car park Demand Increased By 1.5			
Morning (6-8)	All Vehicles (Ref15)	All Vehicles (Ref7)	All Vehicles (Ref5)	All Vehicles (Ref3)
Base case (0%)	167.96	164.82	176.23	167.01

25% market saturation	156.28	149.67	156.81	153.65
50% market saturation	150.28	150.82	151.09	151.23
100% market saturation	144.03	141.45	147.88	153.50
All or nothing case	23.93	23.37	**28.35**	13.51
Total Travel Time Sum (H)				
Afternoon (16 -18)	**All Vehicles (Ref15)**	**All Vehicles (Ref7)**	**All Vehicles (Ref5)**	**All Vehicles (Ref3)**
Base case (0%)	178.57	174.55	171.12	170.87
25% market saturation	165.29	155.45	156.65	157.93
50% market saturation	154.06	151.56	154.37	155.79
100% market saturation	154.86	149.85	150.46	148.33
All or nothing case	23.71	**24.70**	20.66	22.54

Table A12: Total delays in links in hours aggregated for network demands increased by 1.5

Link Delay Sum (H)	**Network and car park Demand Increased By 1.5**			
Morning (6-8)	**All Vehicles (Ref15)**	**All Vehicles (Ref7)**	**All Vehicles (Ref5)**	**All Vehicles (Ref3)**
Base case (0%)	90.07	86.52	97.78	87.32
25% market saturation	83.73	76.66	83.66	80.74
50% market saturation	77.28	78.56	78.92	78.68
100% market saturation	72.51	70.41	76.71	81.88
All or Nothing	17.56	16.11	**21.07**	5.44
Link Delay Sum (H)				
Afternoon (16 -18)	**All Vehicles (Ref15)**	**All Vehicles (Ref7)**	**All Vehicles (Ref5)**	**All Vehicles (Ref3)**
Base case (0%)	99.16	94.62	90.53	89.41
25% market saturation	92.32	81.67	82.86	83.64
50% market saturation	80.64	77.88	81.16	81.80
100% market saturation	82.14	77.70	77.81	75.98
All or nothing case	**17.02**	16.92	12.72	13.43

Figure A1: Travel time and delays differences derived from the comparisons of scenarios with different market saturations – Car park demands

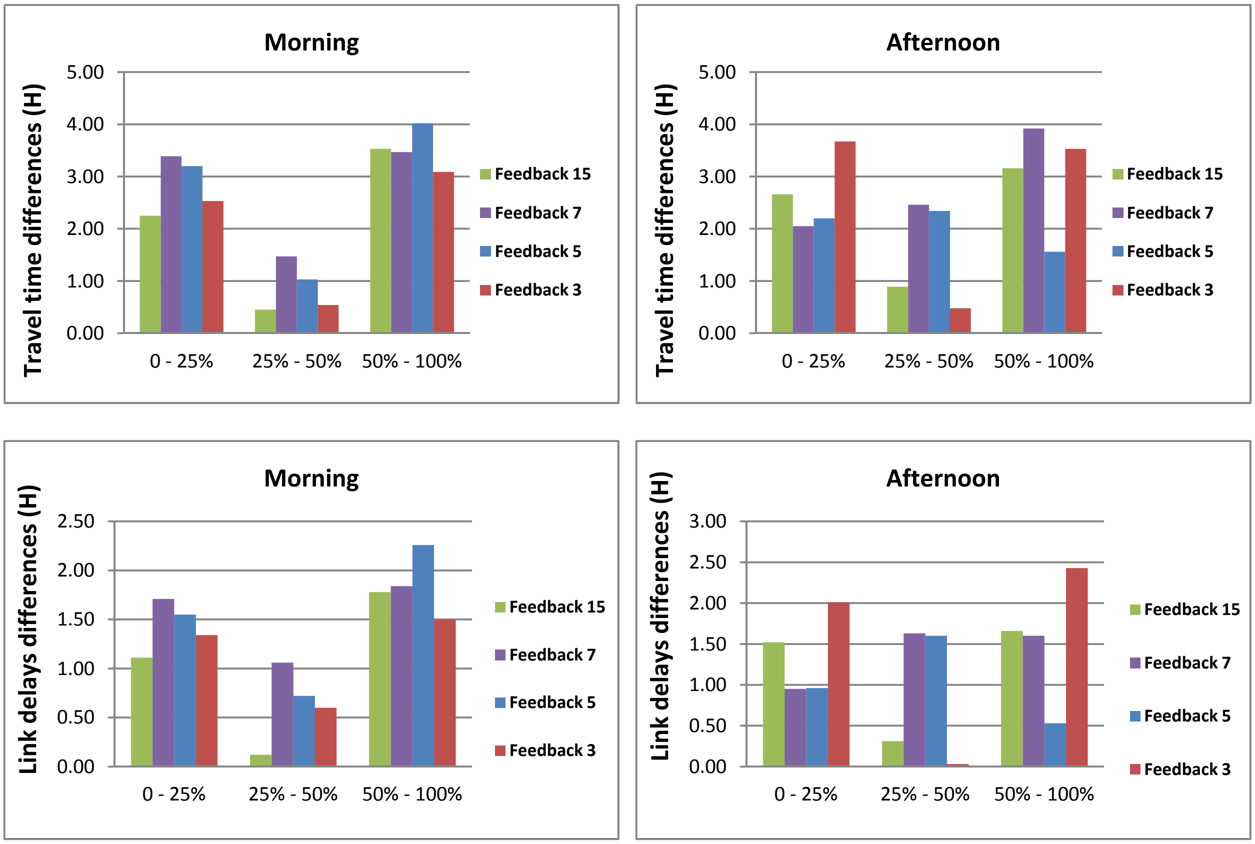

Figure A2: Travel time and delays differences derived from the comparisons of scenarios with different market saturations for network demands increased by 25%

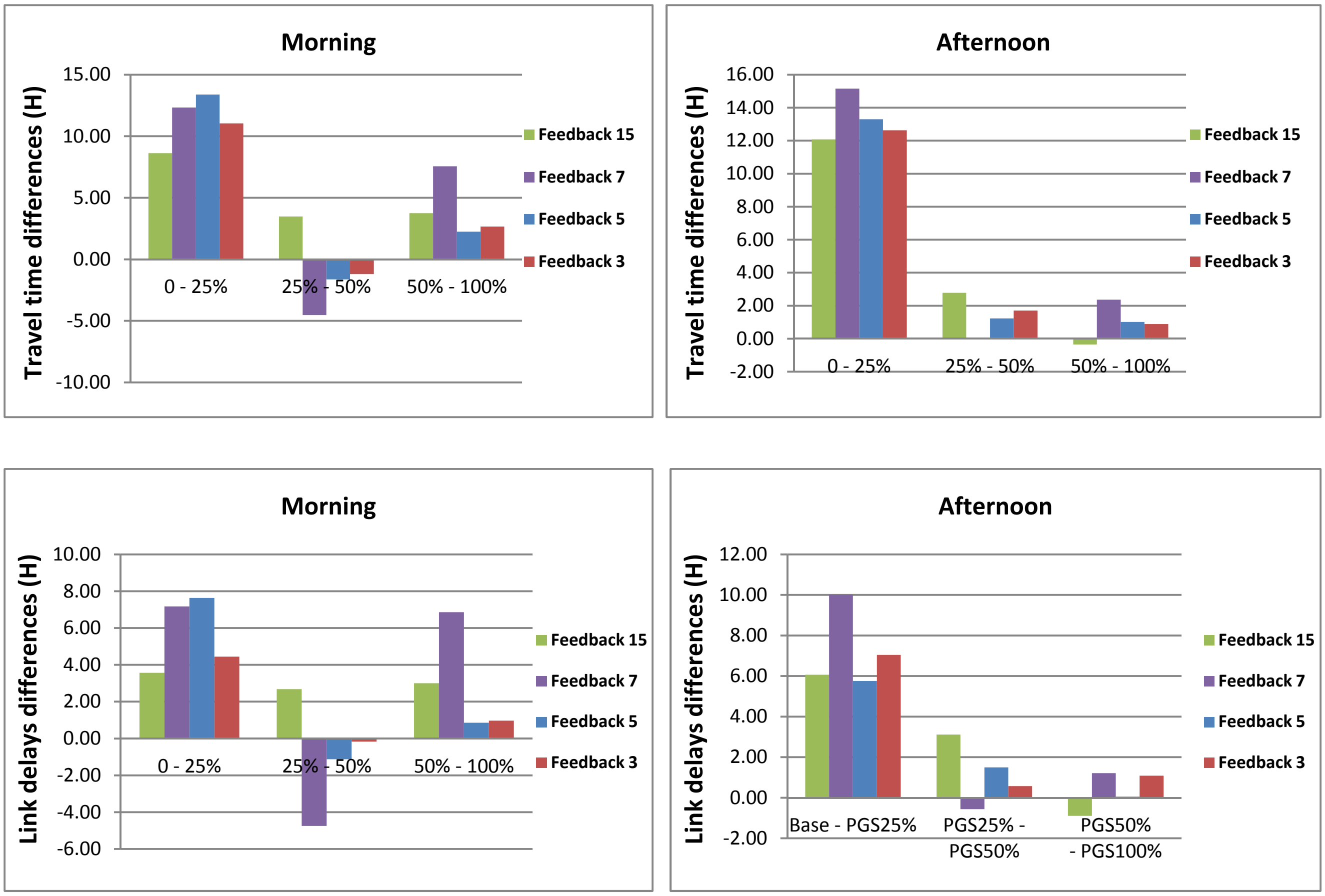

Figure A3: Travel time and delays differences derived from the comparisons of scenarios with different market saturations for car park demands increased by 25%

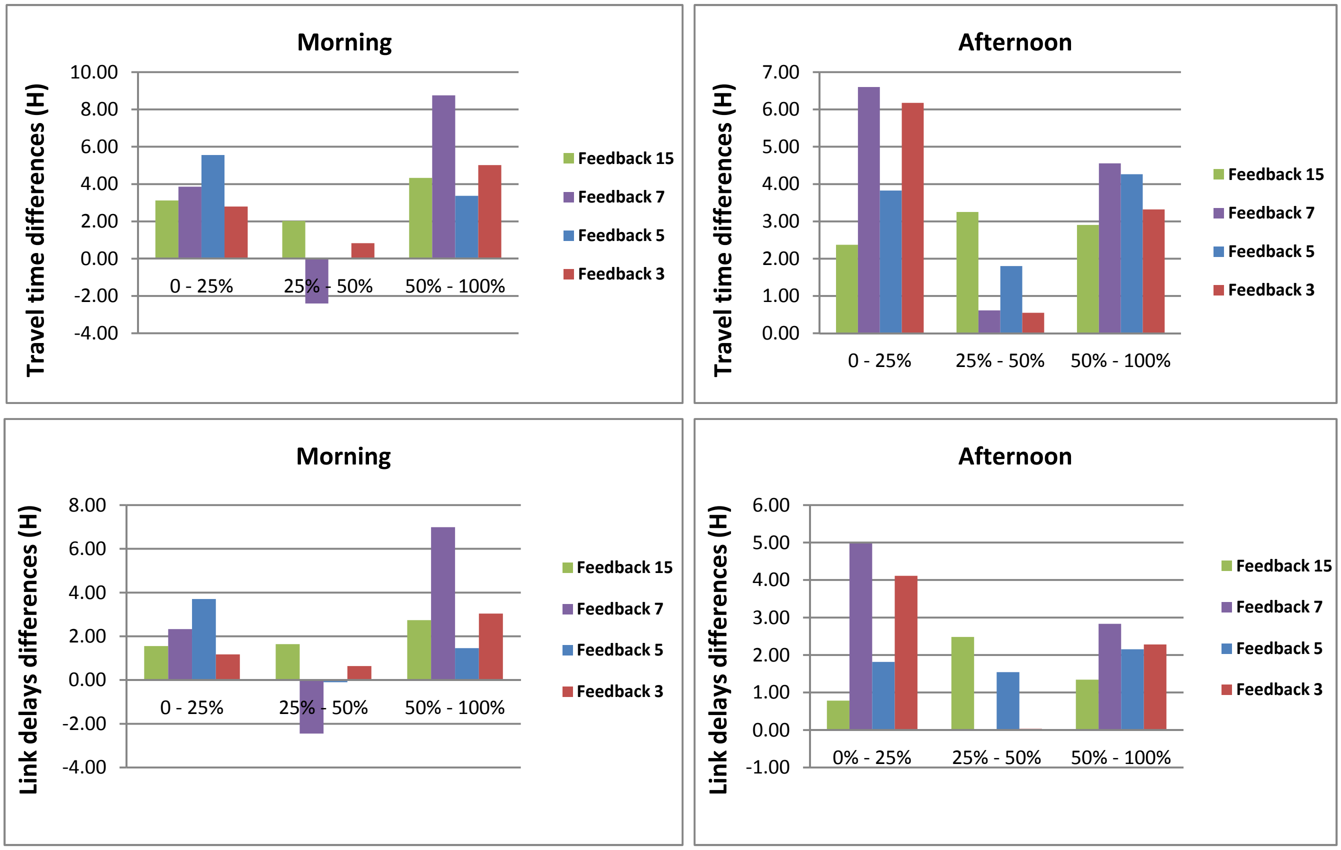

Figure A4: Travel time and delays differences derived from the comparisons of scenarios with different market saturations for network demands increased by 50%

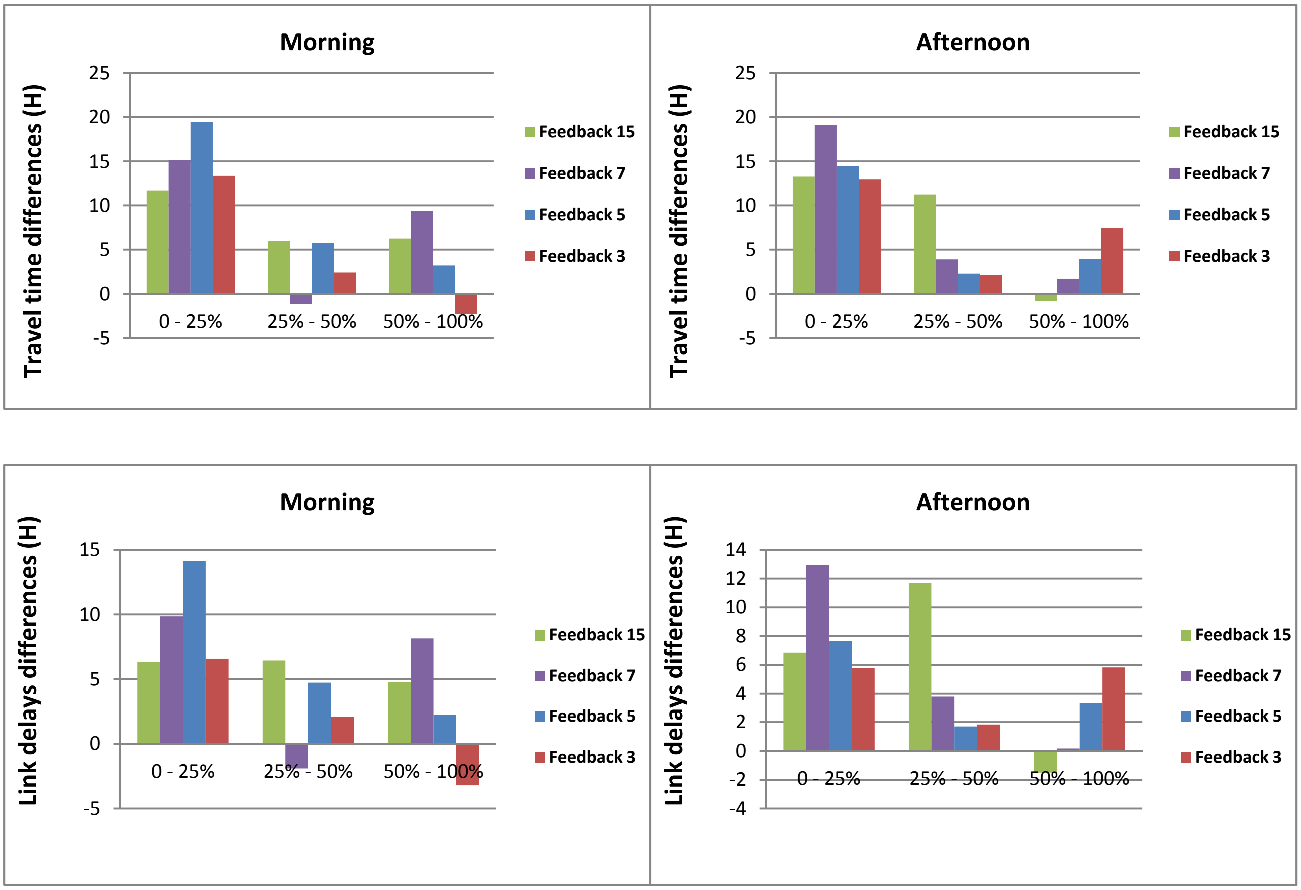

Figure A5: Travel time and delays differences derived from the comparisons of scenarios with different market saturations for car park demands increased by 50%.