Investigating Time and Distance Halo Effects due to Mobile Photo Enforcement on Urban Roads

by

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ABSTRACT

This thesis investigated time and distance halo effects of Mobile Photo Enforcement (MPE) on urban roads. Speed data was recorded at different distances for several locations during an eight-week time period in the summer of 2015 in Edmonton, Canada. A time series intervention analysis using speed limit violations was conducted in order to determine the time halo effects of MPE. To study the distance halo effects, a two-sample *t*-test was used to compare speed limit violations during the enforcement site-visits and the corresponding times without enforcement. The results of the analysis indicated that both time and distance halo effects existed at the study locations and there were significant reductions in speed limit violations due to the presence of MPE. It was concluded that, on average, if a MPE unit was deployed eight times during a week for a total of 22 hours (which translates to approximately 2.7 hours per visit), it would produce a i) time halo effect that would extend for a period of approximately five days, and reduce speed limit violation rates by almost 19% and ii) a drop in violations ranging from 10-to-17% over a distance of 500 meters upstream and downstream of the enforcement unit. In addition, a correlation analysis was performed to study the relationship between different enforcement intensity variables, time and distance halo effects, and reductions in speed limit violations. It was found that the number of enforcement visits per week, the total enforcement hours per week, and the average hours per visit were strongly correlated to the longevity of the time halo effects and the reduction of speed limit violations. Moreover, the analysis also revealed that the total enforcement hours per week and the average hours per visit were strongly correlated with the reduction in speed limit violations at different distances upstream and downstream of the MPE unit. The findings of this study can be utilized to significantly increase the coverage of MPE programs and the safety benefits associated with MPE operations. It can also support decision makers with valuable information that help them in their planning and scheduling decisions.

PREFACE

Work presented in this thesis has been accepted for presentation at the 96th Annual Meeting of Transportation Research Board, Washington, DC, January 8-12th, 2017.

Gouda, M. and El-Basyouny, K. (2017) "*Investigating Time Halo Effects of Mobile Photo Enforcement on Urban Roads*".

Gouda, M. and El-Basyouny, K. (2017) "*Investigating Distance Halo Effects of Mobile Photo Enforcement on Urban Roads*".

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1 Introduction

1.1 Background

Traffic safety is a major worldwide problem. Recent statistics shows that the number of road traffic deaths due to traffic collisions has been estimated at 1.25 million deaths per year, and the number of non-fatal injuries was estimated at 50 million injuries annually *(1)*. In 2014, the total number of motor vehicle fatalities and injuries in Canada was 1,834 and 159,547, respectively *(2)*. In order to prevent such fatalities and collisions, different countries around the world including Canada, Sweden, Netherlands, the United States, and the United Kingdom adopted a global initiative known as Vision Zero *(3–6)*.

Vision Zero is an initiative that targets the goal of zero traffic fatalities and major injuries on transportation networks and can be summarized in one sentence: No loss of life is acceptable *(3, 4)*. The basic principle of Vision Zero is that humans make mistakes, and the loss of life or fatal injury should not be the price for these mistakes. It is unacceptable to trade off human life for other benefits of the transportation system such as mobility. As such, transportation networks must be designed to account for the human error. So far, the adoption of Vision Zero has been proven successful worldwide *(3–5)*. The goals of Vision Zero are achieved through the adaption of what is known as the Safe System Approach *(4, 7)*.

The Safe System Approach provides a framework to evaluate, guide, and improve road safety and involves the use of engineering, education, enforcement, evaluation, and engagement (the five E's of traffic safety) to achieve the vision of zero fatalities and fatal injuries on transportation networks *(4)*. Engineering solutions involve improving the design and operation of roads to prevent collisions from happening and to minimize the severity of crashes (e.g., improved right-turn design, using prohibited and protected left-turn signals, introducing speed limits). Education involves enhancing the current educational programs and developing new programs based on traffic safety culture surveys and research findings. Evaluation aims at assessing and improving the effectiveness and efficiency of using the available road safety and enforcement resources. Engagement includes using new technologies and public involvement initiatives in order to further understand and improve the traffic safety culture. Lastly, enforcement targets changing driver behaviors that increase the risk of getting involved into a crash and increase collision severity such as speeding and impaired driving *(4, 8)*.

One of the main causes of traffic collisions is speeding and it is strongly correlated with the severity of crashes and the likelihood of being involved into a crash *(9–11)*. Thus, enforcing speed limits is an important countermeasure to manage speeds and improve drivers' compliance *(1, 9, 10)*. Enforcement is one of the 5 E's of traffic safety in the Safe System Approach and enforcing speed limits is one of its targets in order to achieve the goals of Vision Zero *(4)*. Automated speed enforcement (ASE) is recognized as one of the most effective methods to manage speeds by reducing speed limit violations *(10)*. Automated speed enforcement can be performed using mobile speed cameras, also known as mobile photo enforcement, or fixed enforcement cameras. In mobile photo enforcement (MPE), an enforcement vehicle manned by enforcement personnel and equipped with a mobile speed camera is deployed at a specific location to detect speed limit violations and then citations are issued to offenders.

Li et al. *(12, 13)* evaluated the safety benefits of mobile photo enforcement (MPE) in Edmonton, Canada. It was found that MPE was effective in reducing collision severities on urban arterial roads by 14% to 20%. Carnis et al. *(14)* reported that the speed camera program in France successfully reduced both fatal and non-fatal traffic injuries by 21% and 26.2%, respectively. In Australia, Champness et al. *(15)* found that mobile overt speed cameras reduced mean speeds by 6 km/h, 85th percentile speed by 7 km/h, and speed limit violations by 37%. Retting et al. *(16)* compared vehicle speeds before and after the implementation of the speed camera enforcement program in Washington, DC. The study concluded that mean traffic speeds dropped by 14%, and violations in excess of the speed limit by more than 10 mph decreased by 82%. Chen et al. *(17)* studied the effectiveness of MPE in British Columbia, Canada. The results indicated that MPE significantly reduced mean speed by 2.8 km/h and collisions by 16% along the entire studied corridor.

Speed enforcement, however, is associated with a substantial economic cost in terms of equipment and staffing. Consequently, many recent studies attempted to improve the efficiency of speed enforcement operations by studying the potential of producing distance and time halo effects. Halo effects are the lasting effects in time and distance on the change in driver behavior produced by speed enforcement units (e.g., MPE units). These effects could be utilized to increase the coverage of speed enforcement programs (such as MPE programs), and hence, optimize the use of limited available resources to improve MPE operations. A relationship between MPE program coverage and the expected safety benefits (e.g., decrease collisions, increase compliance, etc.) has been proven in recent studies *(13)*.

Li et al. *(13)* studied the relationship between different MPE program performance indicators (e.g., number of enforced sites and number of issued tickets) and the associated safety benefits from MPE in Edmonton, Canada. Results indicated that as the number of enforced locations and issued tickets increased, speed-related collisions decreased. Li et al. *(18)* assessed the success of the City of Edmonton’s MPE program deployment decisions in meeting several qualitative criteria that were commonly identified in several enforcement guidelines. Quantitative measures were proposed to help enforcement agencies better identify high-priority deployment locations. GIS maps were used to assess the spatial coverage and enforcement intensity. It was found that the majority of the MPE program resources were allocated to locations that met one or more of the identified criteria. Further, the spatial coverage and intensities were reassessed for the high collision and high speed violation locations while accounting for the distance halo effects of MPE units. Results suggested that both the spatial coverage and enforcement intensity greatly increased. However, the study did not account for the time halo effects of MPE, which the authors claimed would improve the effectiveness and efficiency of MPE programs.

Earlier studies provided limited insight into MPE program resource management and utilization. In fact, only a recent study by Kim et al. *(19)* developed a practical and replicable framework that could be used to operate MPE programs. The proposed framework optimized the allocation and scheduling of limited enforcement resources for a set of pre-identified locations with safety issues. Results indicated that the new framework can reduce the travel distance between dispatches by 8%, increase the detection of speed limit violations by 33%, and increase the program coverage by 24%. The study urged that further optimization of deployment frequencies is possible through the utilization of the time halo effects of MPE dispatched squads. The proposed framework, however, did not account for time and distance halo effects.

Evidence from the literature suggests that understanding the halo effects of MPE could help improve the program's coverage, and thus maximize the safety benefits using the limited resources available for enforcement operations *(19)*. Such an improvement could help enhance the feasibility of enforcement operations and justify its considerable costs and efforts *(20)*. In addition, by increasing the MPE program coverage, an increase in the general citywide deterrence is expected *(15)*.

1.2 Research Motivation

A better understanding of the halo effects of MPE is expected to help optimize the use of limited resources available for enforcement operations by increasing the coverage of MPE programs and enhancing the expected safety benefits associated with enforcement operations (e.g. reduce traffic collisions, improve compliance, and reduce speeding). This can be achieved by redeploying MPE units at more locations during the time halo period and by avoiding deploying MPE units at locations that falls within the distance halo of another MPE squad. The improvements in coverage should improve the entire program's efficiency and effectiveness.

Only a limited number of studies have investigated the halo effects of MPE on urban roads. Most previous work used small sample sizes in terms of the number of locations studied. Moreover, the findings were typically inconsistent. This thesis proposes a study that accounts for most of the recommendations from previous research. These recommendations include using a realistic enforcement schedule that is designed as per the regular working hours of enforcement personnel, performing sufficient hours of enforcement during weekends, and using a large sample size in order to be able to generalize the findings of the study.

1.3 Research Objective

The objectives of this thesis is to explore the potential of producing time and distance halo effects from MPE units. In general, the goals can be summarized as follows:

1. Study the possibility of producing time halo effects from MPE site-visits and assessing the expected time length of the halo effect.
2. Study the possibility of producing distance halo effects from MPE site-visits at different distances upstream and downstream of the MPE unit.
3. Study the relationship between different enforcement intensity variables (e.g., total number of enforcement hours, etc.) and the expected time and distance halo effects as well as the reductions in speed limit violations.

1.4 Thesis Structure

The reminder of this thesis is organized as follows. Chapter two discusses previous studies on the time and distance halo effects. Chapter three presents detailed information about the study areas, enforcement intensity, and data description. Chapter four introduces the methodology used for data analysis. Chapter five presents the analysis results and discusses the findings of the study. Chapter six summarizes the main conclusions of the study and research contributions. Further, study limitations and recommendations for future research are also presented.

2 Literature Review

2.1 Overview

Several studies in the literature discussed the time and distance halo effects of various enforcement techniques with the majority of these studies being conducted in suburban or rural areas. In these studies, the effect on driver behavior is measured through changes in different performance measures that can be categorized into two groups:

1. Speed variables:
    - Odds of drivers exceeding the speed limit
    - Mean speed
    - 85th percentile speed
2. Traffic collisions:
    - Fatal collisions
    - Injury collisions
    - PDO collisions (Property-Damage-Only)

The different enforcement techniques studied in the literature include the following speed enforcement units:

- Mobile Photo Enforcement (MPE)
- Fixed speed enforcement cameras
- Stationary unmarked police vehicles equipped with mobile radar
- Stationary unmanned police vehicles parked on the side of the road
- Enforcement police patrols
- Marked police vehicles (stationary or patrolling the highway section)

The following subsections will discuss the different studies in the literature that explored the possibility of producing time and distance halo effects using the aforementioned techniques.

2.2 Time Halo Effect

Time halo effect is the length of time that the effects of enforcement on drivers' behavior (measured through changes in collisions, speeds, or speed-related measures) continue after enforcement operations have ended. Tay et al. *(21)* was one of the earliest studies to theorize the time halo effect. Figure 1 shows the hypothesized relationship between violation rates and time. First, when enforcement is active, violation rates are expected to decrease until it reaches a lower level of violation rates "steady-state" and this stage shall be called the adaptive learning stage. Second, the violation rates would continue on in the steady state stage as long as enforcement is active or sustained. On the other hand, when enforcement is discontinued, the violation rates are expected to increase as drivers learn that the location is not being enforced and the likelihood of violations will also increase. This period is related to maladaptive learning and it corresponds to the time required for driver behavior to return to its pre-enforcement levels or for violation rates to stabilize at a higher threshold. Consequently, the length of this stage is the time halo effect of enforcement.

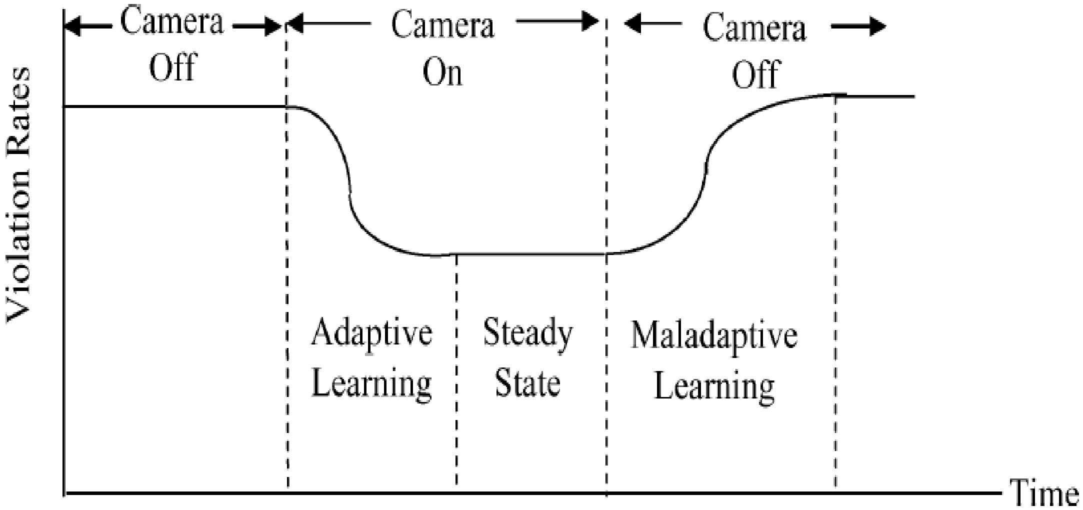


Figure 1: Relationship Between Violation Rates and Time *(21)*

Wilmots et al. *(22)* investigated the safety effects of stationary unmarked police vehicle presence at two locations in the province of Limburg in the Flemish region of Belgium. The stationary unmarked police vehicles were equipped with mobile radar to detect vehicles' speeds and violations. The objective of the study was to compare the effects of enforcement on driver behavior with and without the existence of advance warning signs and to study the time halo effect produced by stationary unmarked police speed control. General linear regression models were used to study the change in the 85th percentile speed, the average speed and speed limit violations. It was found that the different speed indicator values significantly reduced with and without the use of advance warning signs due to exposure to mobile radar enforcement. Further, results suggested that there was a time halo effect of up to three weeks in only one of the experiments, and no time halo effect in the other experiment. The authors argued the limitations of their study. The two studied locations had different initial speeding problems and speed limits (70 and 90 km/h). Enforcement was scheduled at the two locations for one week, with visits only occurring during the morning hours and with limited hours during the weekend. Hence, the authors recommended that further studies should consider a larger number of locations with the same speed limit and similar initial conditions. Moreover, the authors urged that enforcement schedules should include enough enforcement hours during other times of the day and on weekends in order to generalize the effects of enforcement.

Champness et al. *(15)* conducted a study on the halo effects of mobile overt speed cameras at one location in the city of Queensland, Australia. The studied corridor was a multilane highway section with a speed limit of 100 km/h and high traffic volume. It was hypothesized that there would be a significant reduction in vehicle speeds at the location of the deployed mobile camera in comparison to the corresponding times without enforcement activities. Moreover, it was anticipated that there would be a lasting time halo effect at the enforcement location after the camera is withdrawn from the enforcement location. Tickets were issued to offenders as per the normal procedures in enforcement operations. In order to study the lasting time halo effects of enforcement, speed measures were compared in the two hours before enforcement, the two hours after removal of the speed camera, and the hours when the speed camera was in operation. Results suggested that enforcement with speed camera was successful in reducing mean speeds by 6 km/h, 85th percentile speeds by 7 km/h, and the number of vehicles violating the speed limit fell from 53% to 16%. It was found that there were no time halo effects as there was no significant difference in speed measures between the two hours after removal of the speed camera and the two hours before camera deployment. It is worth mentioning that the different speed measures yielded similar results and findings. However, the study considered only one study location. Moreover, the number of enforcement hours was only three hours and during one enforcement site-visit. Consequently, it could be postulated that the enforcement intensity was not high enough to produce a lasting time halo effect and a longer enforcement period with more than one enforcement site-visit might result in producing a lasting effect in time on driver behavior.

Tay et al. *(21)* estimated the time halo effect of intersection safety cameras. The project team used historical data from the red light camera program in Alberta, Canada. A preliminary analysis, to determine the expected time halo effect of intersection safety cameras, was performed. Four locations had an enforcement schedule that experienced an “on-off-on” periods for the enforcement camera. The goal of the study was to determine the length of the time halo effect in order to utilize it to maximize the coverage of a specific number of intersection safety cameras.

The results showed that a significant difference in violation rates between the times when the camera has been removed and times when the camera was turned on again. The time halo effect was estimated by visually inspecting the changes in violation rates without any statistical testing and it was suggested to be less than one month. In order to quantify the time halo effect, four intersection safety cameras at four intersections were turned off, and the change in violation rates with time was investigated at the four locations to determine the time halo effect. Despite the fact that these cameras were turned off, they were kept in their boxes to record the speeds of vehicles and capture violations to estimate the violation rates. The main differences between these cameras and the active cameras were that their flashers were inactive, which means that drivers did not receive any feedback about running the red light safety camera. Second, no tickets were issued to offenders for red light running at the studied intersections. Based on the preliminary estimated time halo effect from the historical data, it was assumed that the time halo effect is less than one month. Results indicated that a significant portion of drivers was found to learn that an intersection was not being enforced within one to two weeks after a camera had been removed. Interestingly, it was found that drivers took longer to learn that a camera was installed than learning that a camera was removed. As such, the lasting time halo effect of intersection safety cameras was found to range from one to two weeks.

Vaa *(23)* studied the time halo effect developed by a set of stationary enforcement controls all together in Oslo, Norway. These stationary controls included stationary enforcement with police vehicles, police patrols and parked unmanned police vehicles. The studied corridor was a 35-km section of an undivided two-lane highway that was located in a semi-rural and agricultural area. The enforcement period extended for six consecutive weeks and enforcement intensity reached a daily level of nine hours. The stretch of the road selected for the study consisted of two sections in different speed limit zones. In total, 12 measurement locations were selected for the study. Six measurement locations were located on the studied highway and six measurement locations were selected on another highway for comparison. Speed data was recorded for two weeks before enforcement, six weeks of enforcement, and eight weeks after enforcement. Data collection process was continuous throughout the day (24 hours) and the sixteen weeks of data collection. An average of nine hours of enforcement comprising 5.56 hours of stationary visible speed controls, 2.10 hours of enforcement with mobile surveillance with marked vehicles, and 1.38 hours of enforcement with unmanned police vehicles parked on the side of the highway. The total hours of enforcement on the studied location during the entire study period was 380 hours. All enforcement visits on the studied corridor were random. Results indicated that mean speed of vehicles were reduced by 0.9-4.8 km/h during enforcement visits in both speed limit zones and through all times of the day. Violations to speed limit were significantly reduced through all times of the day except for the morning rush hours (6:00 to 9:00 A.M.). All results were significant at the 99% confidence interval. Figure 2 shows the relationship between average speed and time for the morning rush hours between 6:00 A.M. and 9:00 A.M. The figure clearly shows the reduction in average speeds of vehicles during the enforcement period and that the effect lasts for some time after enforcement activities had ended on the highway section.

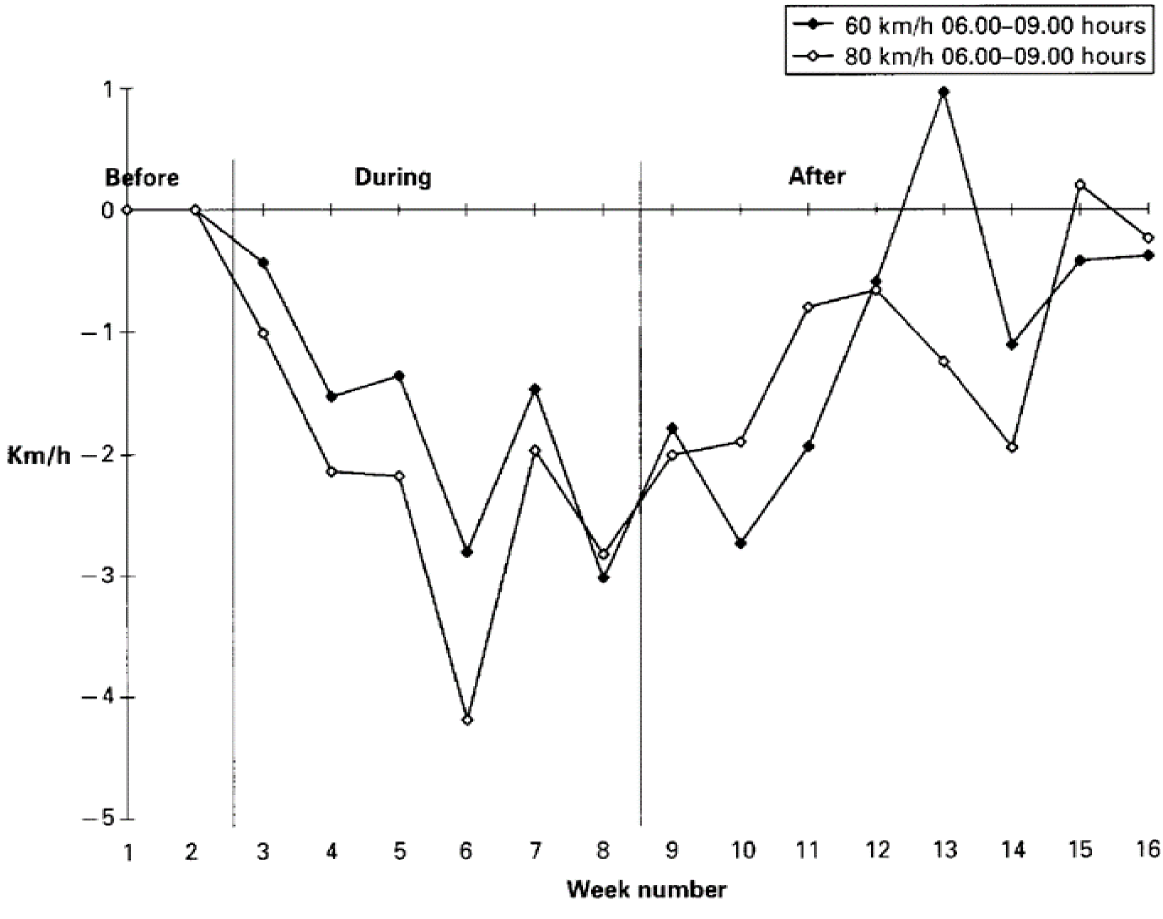


Figure 2: Average Speed vs. Before, During, and After Enforcement Time Periods *(23)*

The figure shows that the time halo effect existed for a couple of weeks after enforcement. In general, the time halo effects ranged from six to eight weeks after enforcement was suspended. In addition, it was also found that enforcement effects on speed and violations reached a significant level of reduction within the first or second week of enforcement. The author discussed some limitations and considerations for future research. The average of nine hours of enforcement at one location is extremely high and difficult to accomplish within the regular working hours of enforcement personnel. Hence, it was suggested that the time halo effects may be produced by a realistic enforcement schedule with short site-visits (maximum five hours per day).

Sisiopiku and Patel *(24)* evaluated the halo effects of marked police vehicles along a 45-km long highway segment located on Interstate 96 in Ionia county, Michigan. The speed limit on the studied corridor was 113 km/h for cars and 88 km/h for trucks, while the minimum speed was 72 km/h. The enforcement police vehicles circulated along both directions of the studied highway segment and became temporarily stationary when an offender was stopped to receive a proper penalty.

Enforcement patrols were implemented by the Ionia County Police Department using two police patrol vehicles that circulated around the two directions of the highway. Enforcement was performed during pre-selected time intervals and extended for a total period of six days. In order to assess the effects of enforcement, the speed characteristics of drivers traversing the highway in the control condition of no enforcement activities were compared with the case when there has been a stationary marked police vehicle close to the data collection counter. For the evaluation of the time halo effect, the average speeds of vehicles while police stopped a vehicle for verbal warning or issuing a ticket (temporarily stationary) were compared to several hours (i.e., 1, 2, and 3 hrs) after the police resumed patrolling the highway segment at four counters. However, there was no statistical testing to assess the significance of the results. Results showed that police presence was effective in significantly reducing the mean speeds of vehicles by approximately 8 km/h. In addition, it was found that there was no lasting time halo effect after police presence ended. The authors suggested limiting the length of the studied corridor for future studies since a 45-km study segment was considered too long for consistent enforcement effects to be established. Further, the authors recommended that future studies might consider using police vehicles as a treatment for specific locations with safety issues rather than police patrols over the entire transportation network that targets managing driving speeds in general.

Armour *(25)* investigated the immediate and lasting effects of deploying an enforcement symbol at two locations in the eastern suburbs of Sydney, Australia. The enforcement symbol was a stationary police car manned by a police officer holding a radar unit. The enforced locations were two-lane sub-arterials in a suburban area with a speed limit of 60 km/h and the traffic volume reached a maximum of 10,000 vehicles per day. Data collection was performed through speed surveys at the two study locations and at a third location that was selected as a control. The speed surveys were implemented before, during, and after enforcement activities had ended at the study locations. Due to the difference in the highways horizontal alignment, the enforcement vehicle was visible for upstream road users at one location while it was not visible for drivers on the other location. Results of the data analysis revealed that enforcement presence at a suburban location reduces the number of vehicles exceeding the speed limit by approximately 66%. In addition, it was found that a memory effect could be produced by enforcement symbols for at least two days once the enforcement symbol was removed. The author argued that increasing the level of enforcement (enforcement intensity) would produce stronger halo effects on urban roads.

Hauer et al. (*20*) published an early study on time and distance halo effects of enforcement. The study was implemented on semi-rural two-lane roads in the counties of Halton and Peel west of Metropolitan Toronto in the province of Ontario, Canada. The study locations were enforced by means of a marked police cruiser equipped with a window mounted radar unit. The enforcement vehicles were highly visible and recognizable by motorists. Four experiments were carried out and each of these experiments had a specific enforcement configuration. In experiment 1, the police cruiser was clearly recognizable well in advance of the enforcement location while in the rest of the experiments the enforcement vehicle became visible to motorists at 200 to 300 meters upstream of the study location. Experiments 1 and 2 had only one day of enforcement. The difference between experiments 1 and 2 was that the police cruiser became evident suddenly for the road users in experiment 2. Experiment 3 involved five consecutive days of enforcement (2.5 hours per day), and experiment 4 involved only two days of enforcement separated by three days without enforcement. The length of each site-visit was 2.5 hours of enforcement. Data collection was conducted before, during, and after enforcement vehicles had withdrawn from the experiment locations. In addition, four control locations have been chosen as a control sample. In order to determine the effects during enforcement site-visits and to quantify the produced time halo effect, changes in mean speeds of vehicles before, during and after exposure to enforcement were visually investigated without any statistical testing. Results indicated that the average speed of the traffic stream was reduced when enforcement was in place, and the average speed was estimated to be approximately equal to the posted speed limit at the study locations. In addition, it was found that the time halo effect produced by five consecutive days of enforcement extended for up to six days after the last day of enforcement, and that a single enforcement visit produced a halo effect for three days.

2.3 Summary of Time Halo Effect Studies

Table 1 shows a summary of the studies exploring the time halo effects of enforcement. The table includes the authors of the study, location of the study, number of study locations, surrounding setting classification (urban or rural), highway classification, information about the enforcement method, information about the enforcement intensity, and the time halo effects results found in each study.

In summary, only a limited number of studies discussed the time halo effects of MPE on urban roads. Most previous work used a fairly small sample size in terms of the number of locations being studied. Moreover, the findings from various studies were sometimes inconsistent. This thesis proposes a study that accounts for most of the recommendations from previous research. In terms of enforcement intensity, this study accounted for the recommendations of Vaa *(23)* and Sisiopiku and Patel *(24)*. Vaa *(23)* reported that the average of nine hours of enforcement per day is extremely high to achieve within the regular working hours of enforcement personnel and suggested that time halo effects may be produced by realistic enforcement schedules with shorter visits. Sisiopiku and Patel *(24)* suggested limiting the study to specific locations as a 45-km highway corridor was very long for consistent enforcement effects to be established due to exposure to a temporally stationary police vehicle. As such, this study was performed according to a practical, realistic and non-continuous enforcement schedule that was designed as per the regular working hours of enforcement personnel, and at specific study locations. Moreover, all studied locations had the same speed limit (50 km/h), and site-visits covered different times of the day and during weekends as recommended by Wilmots et al. *(22)*. In terms of the sample size, the study involved collecting speed data at 14 different urban arterial and collector roads for a total duration of eight weeks, which is significantly larger than sample sizes in previous studies. Further, the analysis was performed using speed limit violation rates, which is a common measure of MPE performance in previous studies *(15, 16, 21–23, 25)*.

Table 1: Summary of Studies on the Time Halo Effects of Enforcement

Authors	Location	Number of Study Locations	Rural /Urban	Roadway Classification	Enforcement Method	Enforcement Intensity	Time Halo Effect
Wilmots et al. *(22)*	Limburg, Belgium	2	Suburban	NA	Unmarked police vehicles with and without an advance warning sign	One week of enforcement with a daily site-visit only during the morning hours	There was a time halo effect for up to three weeks in one experiment only
Champness et al. *(15)*	Queensland, Australia	1	Rural (Speed limit =100 km/h)	Multilane highway with a speed limit of 100 km/h	Mobile overt speed cameras	One site-visit and three hours of enforcement	No time halo effects were found

Authors	**Location**	**Number of Study Locations**	**Rural /Urban**	**Roadway Classification**	**Enforcement Method**	**Enforcement Intensity**	**Time Halo Effect**
Tay et al. *(21)*	Alberta, Canada	4	NA	Intersections	Intersection safety cameras	Continuous historical enforcement using fixed cameras	One to two weeks after removal of the intersection safety camera
Vaa *(23)*	Oslo, Norway	35-km section of a two-lane highway with six speed measurement sites	Semi-rural	Undivided two-lane highway	Stationary enforcement vehicles, police patrols, and parked unmanned police vehicles	Six consecutive weeks of enforcement (an average of 9 hours per day)	Time halo effects extended for six to eight weeks after enforcement activates has ended

Authors	**Location**	**Number of Study Locations**	**Rural /Urban**	**Roadway Classification**	**Enforcement Method**	**Enforcement Intensity**	**Time Halo Effect**
Sisiopiku and Patel *(24)*	Ionia County, Michigan, USA	45-km long highway segment (four counters)	NA (Speed limit was 113 km/h)	NA	Marked police cars circulating in the two directions of the studied segment	NA	No time halo effects were observed
Armour *(25)*	Sydney, Australia	2	Suburban	Two-lanes sub-arterials	Stationary enforcement vehicle manned by a police officer holding a radar unit	Pre-selected times during the months of February and March in 1982	Time halo effects extended for two days once the enforcement symbol was removed

Authors	Location	Number of Study Locations	Rural /Urban	Roadway Classification	Enforcement Method	Enforcement Intensity	Time Halo Effect
Hauer et al. *(20)*	Ontario, Canada	4 (2 failed)	Semi-rural	Two-lane highways	Marked police cruiser equipped with a window mounted radar unit	Different enforcement configurations	Five consecutive enforcement days produced time halo effects that extended for up to six days and a single enforcement visit produced time halo effects that extended for three days after the last day of enforcement

NA = Not applicable

2.4 Distance Halo Effect

Distance halo effect is the space upstream and downstream that the effects of an enforcement operation would extend as a driver passes through the MPE enforcement location. Medina et al. *(26)* investigated the downstream effects of MPE and other speed reduction treatments (e.g., police vehicles with emergency lights on) on two work zones on interstate highways in Illinois, USA. Three datasets were collected at the two work zones, and the measurement site was 1.5 miles downstream of the enforcement location. Separate data sets were collected for both cars and trucks. In order to maximize the visibility of all treatments, trailers and enforcement vehicles were deployed outside of the roadway away from any fixed obstructions and on highway stretches without horizontal or vertical curves. In general, the effect of the following speed reduction treatments was studied:

1. Mobile Photo Enforcement (MPE).
2. Police vehicle with emergency lights on.
3. Police vehicle with emergency lights off.
4. Speed feedback trailer.
5. A combination of speed feedback trailer and police vehicle with emergency lights on.
6. A combination of speed feedback trailer and police vehicle with emergency lights off.

The speeds and violations to the speed limit in a base condition prior to exposure to speed reduction treatments were compared to speeds and violations during the enforcement site visits (1 hour in length). MPE was found to have the most significant effects on vehicle speeds and violation reduction compared to other treatments. Results indicated that, for the general traffic stream, MPE reduced the average downstream speed by 1.1-2.9 mph for cars and by 0.9-3.3 mph for trucks, and reduced the percentage of speeding vehicles by 2.9-28.6% for cars and by 7.5-36.1% for trucks. For the free-flowing conditions, MPE reduced the downstream speeds by 2-3.8 mph for cars and by 0.8-5.3 mph for trucks and reduced violations to speed limit by 7.1-23.4% for cars and 4.2-48.3% for trucks. However, the study only considered three MPE site visits at two locations in work zones, and each MPE site visit lasted one hour. Table 2 shows a summary of the study results.

Table 2: Summary of Study Results

	Free-flowing conditions	General traffic stream
Speed reduction in cars	2-3.8 mph	1.1-2.9 mph
Speed reduction in trucks	0.8-5.3 mph	0.9-3.3 mph
Violations reduction for cars	7.1-23.4%	2.9-28.6%
Violations reduction for trucks	4.2-48.3%	7.5-36.1%

Another study on work zones in Illinois showed mixed results, where MPE was effective at reducing the speeds of heavy vehicles but not effective in reducing the speeds of cars *(27)*.

Champness et al. *(15)* evaluated the distance halo effects of mobile overt speed cameras at one location in the city of Queensland, Australia. The studied corridor was a multilane highway section with a speed limit of 100 km/h. Vehicle speeds were recorded every 500 meters over a 3.5-km section of the highway during one site visit and during the same hours in the day before and the day after enforcement. Distance halo effects were evaluated by investigating the relationship between the distance and a set of speed-related measures during the deployment of the speed camera and the corresponding times in the day before and the day after enforcement. The results suggested that there were no distance halo effects upstream of the camera location, but there was a significant halo effect for 1.5 km downstream of the deployed camera. However, the study considered only one location with three hours of enforcement and one site visit.

Ha et al. *(28)* analyzed the effects of automated speed enforcement (ASE) in Korea. For each ASE location, a warning sign was posted one kilometer upstream of the speed camera informing drivers of the presence of an ASE station. The change in the average speed of vehicles over distance near an ASE station was visually investigated and compared to the speed limit. It was found that drivers tended to reduce their speeds at the warning sign located one kilometer upstream of the ASE location; however, drivers accelerated back to their normal speeds after passing the enforcement location.

Sisiopiku and Patel *(24)* evaluated the halo effects of marked police cars patrolling in the two directions of a highway segment in Ionia County, Michigan. The speed limit on the studied corridor was 113 km/h for cars, and 88 km/h for trucks. For evaluating the distance halo effect, the average speeds of vehicles at four counters were compared to pre-enforcement levels while police stopped a vehicle to deliver a verbal warning or issue a ticket (temporarily stationary) at different distances upstream and downstream of the counter (1.6, 3.2, and 4.8 km on each side). Further, the increase in the average speed of vehicles at a counter as the police patrol moved further away, using the same distances, was also investigated. It was found that drivers tended to reduce their speeds as they approached the police vehicle, but as soon as they passed the police vehicle, drivers accelerated back to their normal speeds or higher. The authors suggested limiting the length of the studied corridor for future studies since a 45-km study segment was considered too long for consistent enforcement effects to be established.

Shinar et al. *(29)* studied the effects of conspicuously marked stationary and moving military police units on a 17-km stretch of a straight freeway. The speed limit of the freeway was 90 km/h; however, there was a legal speed limit for different types of vehicles. The targeted population was military vehicle drivers and the sample size included 541 speeding drivers who exceeded the speed limit specified for their vehicle type by 2 km/h. Speed data were collected at three measurement sites: one site at the enforcement location, one site 1.5 km upstream of the enforcement location, and one site located 4 km downstream of the enforcement location. The behavior of the 541 speeding drivers over distance was investigated and compared to the speed limit. It was found that the moving police unit was effective in producing a distance halo effect at the downstream location. However, the study mainly focused on military personnel, and the moving police vehicle had to be heading in the same direction as the speeding vehicles.

Armour *(25)* investigated the halo effects of manned enforcement at two locations in the eastern suburbs of Sydney, Australia. The enforcement vehicle was a stationary police car manned by a police officer holding a radar unit. Speed surveys were conducted at two measurement sites. One measurement site was located 300 meters downstream of the police vehicle, and the other site was located 200 meters upstream of the police vehicle. Speed limit violations during enforcement were compared to their pre-enforcement levels using a *t*-test. Results suggested that drivers return to their normal behavior (as in the pre-enforcement period) as soon as they are out of the sight of the enforcement symbol. However, the study suggested that increasing the level of enforcement would produce a spill-over effect.

Hauer et al. *(20)* investigated the distance halo effects of marked police vehicles. The study was implemented on semi-rural two-lane roads in Ontario, Canada. The study locations were enforced using marked police cruisers equipped with a window-mounted radar unit, and four experiments were carried out. In order to determine the distance halo effect, changes in mean speeds of vehicles before and after exposure to enforcement were visually investigated without any statistical testing at the enforcement location as well as at various distances upstream and downstream of the enforced locations. It was found that there was a significant distance halo effect upstream and downstream of the police vehicle. While no value was suggested for the distance upstream, the reduction in mean speed was found to decay exponentially with distance downstream and the effect was found to reduce by half for every 900 meters downstream.

A study in the Dutch province of Friesland *(30)* demonstrated that MPE had spill-over effects at the surrounding locations on rural non-motorway roads, and reduced speeds and speed limit violations. Walter et al. *(31)* also studied the effects of increasing the level of policing along a route in south London, and reported that enforcement had spill-over effects on speeds and violations in the surrounding locations.

2.5 Summary of Distance Halo Effect Studies

Table 3 summarizes the findings from previous studies on the distance halo effects of enforcement. Again, only a limited number of studies attempted to investigate the distance halo effects of MPE on urban roads. A relatively small sample size in terms of the number of locations studied was again a common shortcoming with sometimes mixed and inconsistent results. Therefore, this study investigates the distance halo effects of MPE while accounting for several of the abovementioned limitations. The site visits were selected to cover various times of the day and during both weekdays and weekends, and all locations had the same speed limit (50 km/h) as recommended by Wilmots et al. *(22)*. The enforcement intensity in this study was higher compared to the intensities reported in previous studies. This was a major shortcoming since a limited number of enforcement hours might not be enough to produce a strong halo effect *(15, 25)*. In addition, the sample size involved collecting speed data at 14 urban roads during four enforcement site-visits (two to four hours each) and the corresponding hours without enforcement, which is a much larger dataset compared to previous studies.

Table 3: Summary of Studies on the Distance Halo Effects of Enforcement

Authors	Location	Number of Study Locations	Rural /Urban	Roadway Classification	Enforcement Method	Enforcement Intensity	Distance Halo Effect
Medina et al. *(26)*	Illinois, USA	2 locations with three datasets	Work-zones located on Interstate highways	Interstate highway	Mobile photo enforcement and other speed reduction treatments	Three enforcement site-visits (one hour each)	Distance halo effects existed at a distance of 1.5 km downstream of the enforced location
Champness et al. *(15)*	Queesland, Australia	1	Rural (Speed limit =100 km/h)	Multilane highway with a speed limit of 100 km/h	Mobile overt speed cameras	One site-visit and three hours of enforcement	No distance halo effects were found upstream of the enforcement location. There was a distance halo effect for 1.5 km downstream of the enforcement camera

Authors	**Location**	**Number of Study Locations**	**Rural /Urban**	**Roadway Classification**	**Enforcement Method**	**Enforcement Intensity**	**Distance Halo Effect**
Ha et al. *(28)*	Korea	NA	NA	NA	Automated speed enforcement with fixed cameras and advance warning signs	Continuous historical enforcement using fixed cameras	Upstream effects extended to the warning sign location but no distance halo effects were observed downstream
Sisiopiku and Patel *(24)*	Ionia County, Michigan, USA	45-km long highway segment (four counters)	NA (Speed limit was 113 km/h)	NA	Marked police cars circulating in the two directions of the studied segment	NA	Drivers tended to reduce their speeds as they approached the enforcement location. No distance halo effects existed downstream

Authors	Location	Number of Study Locations	Rural /Urban	Roadway Classification	Enforcement Method	Enforcement Intensity	Distance Halo Effect
Shinar et al. *(29)*	Highway connecting Tel Aviv and Ashkelon, Israel	1	Rural	Freeway	Conspicuously marked stationary and moving military police vehicles	Moving vehicles patrolled the highway section and the speeds of 541 vehicles were recorded	Moving police units produced distance halo effects downstream of the enforcement location
Armour *(25)*	Sydney, Australia	2	Suburban	Two-lanes sub-arterials	Stationary enforcement vehicle manned by a police officer holding a radar unit	Pre-selected times during the months of February and March in 1982	Drivers returned to their pre-enforcement speed levels as soon as they were out of the sight of the enforcement vehicle

Authors	**Location**	**Number of Study Locations**	**Rural /Urban**	**Roadway Classification**	**Enforcement Method**	**Enforcement Intensity**	**Distance Halo Effect**
Hauer et al. *(20)*	Ontario, Canada	4 (2 failed)	Semi-rural	Two-lane highways	Marked police cruiser equipped with a window mounted radar unit	Different enforcement configurations	Significant distance halo effects existed upstream and downstream of the enforcement locations

NA = Not applicable

3 Data

3.1 Study Locations

The study was implemented in the months of July and August in 2015 in Edmonton, Alberta. Location selection was based on specific guidelines that were recommended in previous studies *(32)*. In order to minimize the effect on drivers' speed choice and to eliminate any disruption to the traffic stream, selected locations satisfied most of the following guidelines:

- Suitable for collecting speed data at upstream and downstream locations
- Straight and uniform section of the road
- Section with small gradient (< 3%)
- Away from junctions
- Away from speed calming devices
- Appropriately far from pedestrian crossings
- Away from work zones, parking zones, and roadside developments

Based on the abovementioned criteria, 14 locations (i.e., four on collector roads and ten on arterial roads) were selected. All locations were in an urban setting and within the urban limits of the city of Edmonton. Three locations were located in downtown Edmonton, five locations in the west side of the city, two locations in the southwest region, three in north Edmonton, and one location southeast of the city. Figure 3 shows the six police divisions as specified by Edmonton Police Service *(33)*. The speed limit on all locations was 50 km/h, and the number of lanes was two lanes per direction. Table 4 shows all of the selected locations, and the different characteristics of each study location (location description, neighborhood, direction of travel, speed limit, trigger speed, roadway classification, and the number of travel lanes).

Figure 3: Map of the Six Edmonton Police Service Divisions *(33)*

Table 4: Study Location Summary Information

Location Description	Neighborhood	Direction	Speed Limit (km/h)	Roadway Classification	No. of Lanes
156 St. btw. 94 - 92 Ave.	West	SB	50	A	2
101 Ave. btw. 67 - 70 St.	Southeast	EB	50	A	2
142 St. btw. 104A - 105 Ave.	West	NB	50	A	2
Saskatchewan Dr. btw. 107 - 105 St.	Southwest	EB	50	A	2
142 St. btw. 106 - 104 Ave.	West	SB	50	A	2
127 St. btw. 137 - 135 Ave.	West	SB	50	A	2
127 St.at 135 Ave.	West	NB	50	A	2
97 St. btw. 115 - 117 Ave.	Downtown	NB	50	A	2
109 St. btw. 110 - 108 Ave.	Downtown	SB	50	A	2
109 St. btw. 108 - 110 Ave.	Downtown	NB	50	A	2

Location Description	Neighborhood	Direction	Speed Limit (km/h)	Roadway Classification	No. of Lanes
132 Ave. btw. 123 - 121 St.	North	EB	50	C	2
Riverbend Rd btw. 43 - 45 Ave.	Southwest	NB	50	C	2
144 Ave. btw. 77 - 79 St.	North	EB	50	C	2
144 Ave. btw. 77 - 79 St.	North	WB	50	C	2

A stands for Arterial roads
C stands for Collector roads
SB stands for Southbound
NB stands for Northbound
EB stands for Eastbound
WB stands for Westbound

3.2 Enforcement Information and Schedules

The study was implemented in the eight weeks starting Monday, July 6th and ending on Sunday, August 29th, 2016. All study locations were subjected to MPE, using unmarked enforcement vehicles in overt operation, according to a predefined schedule that was designed according to the regular working hours of the MPE program. The regular working hours start at 7:00 A.M. to 3:00 P.M. as well as from 5:00 P.M. to 2:00 A.M. It is important to note that Edmonton drivers are familiar with these unmarked enforcement vehicles. Although the vehicles are unmarked, their operation is considered overt rather than covert because they are typically parked in the same spot and in most cases within visible ranges to drivers. In addition, citations were issued and offenders were notified within five days from being captured. The second, fourth, sixth, and eighth weeks of the study were enforcement weeks, while the first, third, fifth, and seventh weeks had no enforcement. In general, enforcement visits were short (2-4 hours long). Table 5 shows the number of visits per week, the total enforcement hours per week, and the average number of enforcement hours per visit for all locations.

3.3 Control Locations

Five control locations that share the same operational and geometric characteristics as the study locations were selected to account for changes due to any confounding factors, such as weather conditions or events that might affect driver behavior. Note that there were no enforcement activities at the five control locations. Table 6 shows the characteristics of the five control locations.

Table 5: Enforcement Schedules Summary

Location ID	Number of visits per Week	Total number of enforcement hours per week	Average hours per visit
1	13	42	3.23
2	14	28	2.00
3	8	26	3.25
4	6	23	3.83
5	9	22	2.44
6	6	16	2.67
7	5	14	2.80
8	5	12	2.40
9	5	10	2.00
10	13	43	3.31
11	8	18	2.25
12	7	14	2.00
13	6	12	2.00
14	5	10	2.00

Table 6: Control Location Summary Information

Location Description	Neighborhood	Direction	Speed Limit (km/h)	Roadway Classification	No. of Lanes
142 St. btw. 95 - 96 Ave.	West	NB	50	A	2
142 St. btw. 97 - 95 Ave.	West	SB	50	A	2
Riverbend Rd btw. Heath Rd - Falconer Rd	Southwest	NB	50	C	2
159 St. btw. 81 Ave. and Whitemud Dr. NW	West	SB	50	A	2
Saskatchewan Dr. btw. 91 - 92 Ave.	Southwest	EB	50	A	2

A stands for Arterial roads
C stands for Collector roads
SB stands for Southbound
NB stands for Northbound
EB stands for Eastbound
WB stands for Westbound

3.4 Data Collection

Data collection was carried out for eight weeks starting Monday, July 6th and ending on Sunday, August 29th. Vehicle speeds and headways were recorded at different distances up to 500 meters upstream and downstream of the MPE units using NC-200 devices. Drivers were unaware of the data collection process, and the NC-200 device was hardly noticeable by road users. All enforcement activities were suspended at the study locations and the surrounding historical deployment locations for four-to-six months prior to the start of the study to avoid any effects due to site learning.

Site learning occurs as a result of drivers becoming familiar with the enforcement activities at a location, which could influence their driving behavior. Such a case might prevent detecting a base condition in which the normal driving behavior without intervention may be explored.

To ensure that drivers were freely choosing their speeds and to account for the effects of high traffic volume, vehicles following at headways of less than two seconds were excluded from the dataset. Thus, any reductions in speed and speed-related measures can be attributed to enforcement and not to the high traffic volume *(20)*.

Figure 4 shows the locations of the NC-200 devices and the surrounding historical enforcement locations at Saskatchewan Drive between 107 and 105 Streets. Appendix A shows the placement of the NC-200 devices at all locations.

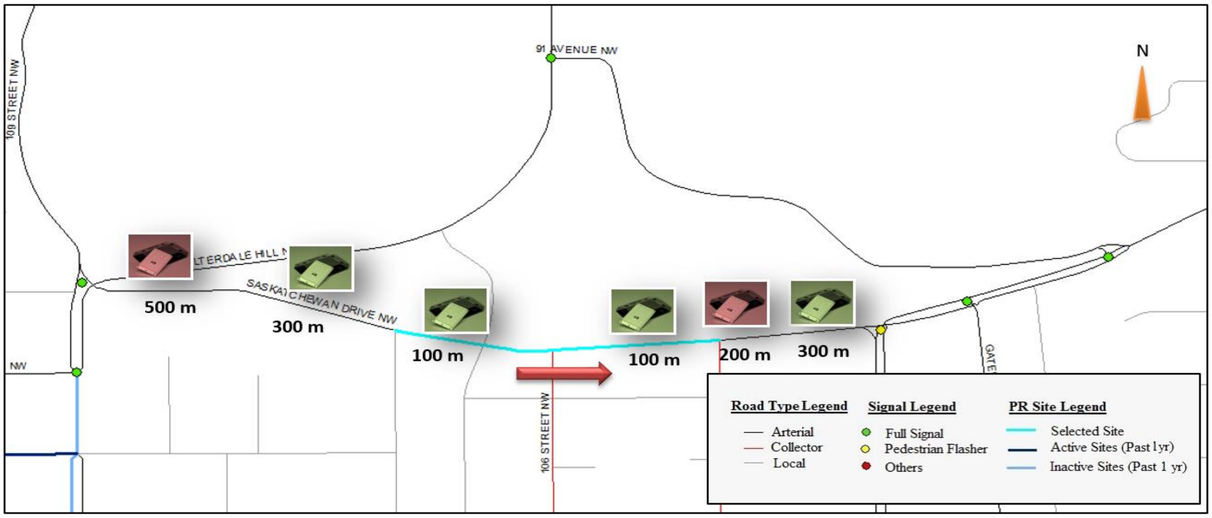


Figure 4: Locations of the NC-200 Devices and the Surrounding Historical Enforcement Locations at Saskatchewan Drive Between 107 and 105 Streets

3.4.1 Data Collection Devices

NC-200 devices were used for the purpose of data collection. The NC-200 device is a portable traffic analyzer that is directly installed in traffic lanes to accurately detect vehicle count, speed, and headways *(34)*. Devices calibration, installment, charging and changing were all performed by well-trained personnel on a weekly basis. NC-200 devices have many advantages. The NC-200 device is hardly noticeable by road users, and hence results in more accurate data. It can be covered by a specially developed extruded aluminum housing to protect it from vehicles and minimize the possibility of device failure. The device is equipped with a long-life and rechargeable batteries. It can be connected to any computer or work station to transfer and retrieve the recorded traffic data. Finally, a straightforward software is easily used to view and transfer the collected data. It is worth mentioning that the NC-200 device has a speed detection range from 13 km/h to 193 km/h (8 mph to 120 mph). The dimensions of the NC-200 device are 181×118×12.7 millimeters (7.125×4.625×0.5 inches). Further, it has an ultimate bearing strength of up to 88,000 psi.

Vehicle Magnetic Imaging technology (VMI) is used to detect vehicles count, speed and headways and the data is then exported to Highway Data Management Software (HDM).

The software can generate reports, charts and graphs based on the recorded data. Enforcement personnel used the NC-200 devices to generate Excel reports that had the vehicles count, headways, and speeds, and reports were sent to researchers at the University of Alberta for processing on a weekly basis.

3.5 Data Reduction

3.5.1 Time Halo Effect

In an attempt to determine the time halo effects, the percentage of speed limit violations was extracted from the recorded data at all locations to perform a time series intervention analysis. The Excel reports retrieved from the NC-200 devices and received from the City of Edmonton were used for data reduction. Excel Visual Basic for Applications (VPA) was used to develop a macro to extract the time series of violations for each location. Figure 5 shows a time series of violations to speed limit that was extracted at 101 Avenue between 67 and 70 Streets.

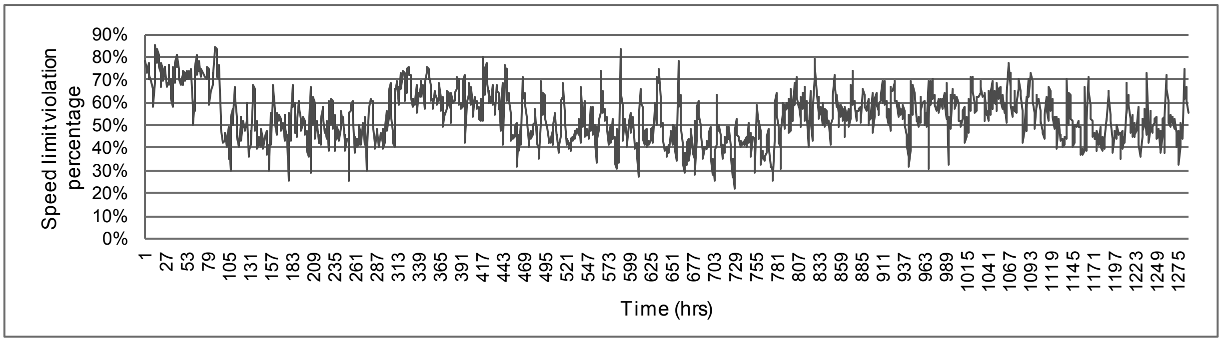


Figure 5: Time Series of Violations at 101 Ave. btw. 67 and 70 St.

3.5.2 Distance Halo Effect

The percentage of speed limit violations was extracted from the data at the different devices located upstream and downstream of each enforcement location during four enforcement site-visits and the corresponding hours without enforcement. In an attempt to study the distance halo effects, the violations to speed limit during four enforcement site-visits were compared to violations in the corresponding days without enforcement.

4 Research Methodology

4.1 Time Halo Effect

4.1.1 Box-Jenkins Time Series Modeling

The time series of speed limit violation percentages was extracted from devices located 100 meters away from the MPE unit. The extracted data was analyzed using time series intervention modeling based on the methodology developed by Box and Jenkins in 1976. First, Autoregressive Integrated Moving Average (ARIMA) models are used to tentatively identify a model for pre-intervention data, and then interrupted time series analysis is performed in order to evaluate the magnitude and significance of the effects of interventions on the time series *(35, 36)*.

4.1.2 ARIMA Models

A seasonal ARIMA model is denoted as ARIMA$(p, d, q)(P, D, Q)_{\mathrm{m}}$. *p*,*d*,*q* are parameters related to the non-seasonal operators of the model, where, *p* is the order of the autoregressive model; *q* is the order of the moving average model; and *d* is the degree of differencing required in the case of a non-stationary series. *P*, *D*, *Q* are parameters related to the seasonal operators of the model, and m is identified as the number of periods in each season. The general form of the ARIMA model is as follows:

$$\begin{aligned}&(1-\emptyset_1 B-\emptyset_2 B^2-\cdots-\emptyset_p B^p)\ (1-\emptyset_{1,L}B^L-\emptyset_{2,L}B^{2L}-\cdots-\emptyset_{P,L}B^{PL})\ (1-B^L)^D(1-B)^d\, y_t^* \\ &= (1-\theta_1 B-\theta_2 B^2-\cdots-\theta_q B^q)\ (1-\theta_{1,L}B^L-\theta_{2,L}B^{2L}-\cdots-\theta_{Q,L}B^{QL})\ a_t \qquad (1)\end{aligned}$$

where, y_t^* is the time series variable; $\emptyset_1$ to $\emptyset_p$ are the non-seasonal autoregressive operator parameters; $\emptyset_{1,L}$ to $\emptyset_{P,L}$ are the seasonal autoregressive operator parameters; θ_1 to θ_q are the non-seasonal moving average operator parameters; $\theta_{1,L}$ to $\theta_{Q,L}$ are the seasonal moving average operator parameters; *D* is the degree of seasonal differencing; d is the degree of non-seasonal differencing; a_t is the random shock and B is a backshift operator that shifts the subscript of a time series observation inversely in time by one period *(36)*.

4.1.3 Advantages of ARIMA Models

ARIMA modeling has many advantages. It accounts for the autocorrelation between observations at different lags or time periods. Thus, it is suitable when time series observations are not independent, which is the case in our study. A strong autocorrelation was found between time series observations at different time periods. Moreover, in the ARIMA intervention analysis, covariates are added to the developed ARIMA model to evaluate the intervention effects in the post-intervention data. These covariates are known as intervention parameters or terms.

4.1.4 Development of ARIMA Models

In ARIMA intervention analysis, an ARIMA model is first developed to explain as much variation as possible in a time series before attributing any changes to an intervention, which is MPE in our case. Second, the developed model is combined with dummy variables such as pulse functions or step functions, to carry out intervention analysis. Before developing an ARIMA model, a time series must be stationary, that is to say, the time series should have no trend. If the time series is not stationary, specific differencing (seasonal, non-seasonal or both) can transform a non-stationary time series into a stationary one. Next, there are three main stages to develop an ARIMA model that best fits a stationary time series:

1) Tentative identification: in this stage a model is tentatively identified based on the behavior of the sample autocorrelation (SAC) and sample partial autocorrelation (SPAC) plots (SAC and SPAC at different lags) at the seasonal and non-seasonal levels.
2) Estimation of the model parameters: different methods can be used to estimate the model parameters. These methods include the maximum likelihood

method, the unconditional least squares method, and the conditional least squares method.

3) Diagnostic checking: this assesses the adequacy of the tentatively identified model.

4.1.4.1 Tentative identification of the model

Based on the pre-intervention time series values available, a tentative model should be identified. Tentative identification of a model that adequately fits a time series can be done through the following steps:

1) Plotting the sample autocorrelation and partial sample autocorrelation functions (SAC and SPAC) at different lags. SAC and SPAC measure the linear relationship between time series observations separated by a specific time lag. The difference between SAC and SPAC is that SPAC eliminates the effects of the intervening observations.
2) Checking the time series stationarity: in order to develop a model for a time series, it must be stationary. In case the original data set is nonstationary, a specific differencing can result in a stationary time series. Moreover, if the time series is seasonal, pre-transformation of the original time series might be required. In general, a time series can be considered stationary if the SAC of the time series dies down or cuts off fairly quickly. This happens when the ratio between the SAC value and the standard deviation become less than or equal to 2.
3) Identifying the nonseasonal operators that should be utilized in the model: based on the behavior of the SAC and SPAC on the nonseasonal level, the parameters of the nonseasonal operators should be identified. These operators are the nonseasonal moving average (q) and autoregressive (p) operators.
4) Identifying the seasonal operators that should be utilized in the model: based on the behavior of the SAC and SPAC on the seasonal level, the parameters of the seasonal operators should be identified. These operators are the seasonal moving average (Q) and autoregressive (P) operators.

4.1.4.2 Estimation of the model parameters

After the tentative model has been identified. The model parameters are estimated. There are different methods that can be used to estimate the model parameters. These methods include the maximum likelihood method, the unconditional least squares method, and the conditional least squares method.

4.1.4.3 Diagnostic checking

Each of the following indicates that the identified model is adequate and fits the time series:

1) Autocorrelation check for white noise for the original time series: If p-value < 0.05 at all lags, then we may reject the null hypothesis that there is white noise in the time series.
2) The t-value for the estimated moving average and autoregressive parameters must be more than two to be considered significant at the 95% confidence level.
3) The lower the AIC value the better the model. AIC value is the Akaike Information Criterion, which is a measure of the quality of a developed statistical model for a set of data relative to other possible models.
4) Correlation between the estimated parameters should be less than 0.85 for any two of the estimated parameters.
5) Autocorrelation check of residuals for the identified model: If the p-value is higher than 0.05 at all lags, then we may accept the null hypothesis that the residuals are not correlated and random (white noise).

4.1.4.4 Forecasting

The final best fit model developed through the previous steps could be used to predict future values of the time series.

4.1.5 Development of Intervention Models

The effects of interventions on a time series can lead to different responses. These responses can be modeled by what is known as a transfer function. These transfer functions can be simple dummy variables, such as step and pulse functions, or might take more complicated forms. Moreover, the effects of an intervention might change the behavior of a time series abruptly, or in few cases after some delay. There are different types of interventions that could be modeled. These types can be summarized as follows:

a) Abrupt start and permanent effect
b) Gradual start and permanent effect
c) Linearly changing without limit
d) Abrupt start and abrupt decay
e) Abrupt start and gradual decay
f) Abrupt start and gradual decay to a permanent level

If we add a dummy intervention variable to an ARIMA model, the form previously shown in equation (1) becomes as follows:

$$(1-\emptyset_1 B-\emptyset_2 B^2-\cdots-\emptyset_p B^p)\ (1-\emptyset_{1,L} B^L-\emptyset_{2,L} B^{2L}-\cdots-\emptyset_{P,L} B^{PL})\ (1-B^L)^D (1-B)^d\ y_t^*$$
$$= (1-\theta_1 B-\theta_2 B^2-\cdots-\theta_q B^q)\ (1-\theta_{1,L} B^L-\theta_{2,L} B^{2L}-\cdots-\theta_{Q,L} B^{QL})\ a_t+\omega I_t \qquad (2)$$

where, I_t is the intervention function representing a change in the level of the time series either abruptly or during a specific period of time t, and ω is the intervention parameter. The combination of ωI_t is known as a transfer or response function. In general, the responses to MPE found in this study were in the form of step functions, as in equation (3). The intervention parameters are used to make inferences about the magnitude and significance of the effects of intervention.

$$I_t = \begin{cases} 0 & if\ t < T_1 \\ 1 & if\ T_1 \leq t < T_2 \end{cases} \qquad (3)$$

4.1.6 Modelling

In this study, the time series of the percentage of speed limit violations was analyzed for all of the study locations. Basically, the first week of data was considered pre-intervention data that was used to develop an ARIMA model, and then, an intervention analysis, also called interrupted time series analysis, was carried out to detect and quantify the significant responses in the time series due to exposure to MPE. First, an autocorrelation check for white noise was carried out to check the autocorrelation between observations at different lags. It was found that the time series at all locations had a strong autocorrelation between observations ($p < 0.01$), and not white noise (random). Table 7 shows the check for white noise for the first week of data at 142 Street between 106 and 104 Avenues, generated by SAS 9.4 software. Second, the SAC plots for pre-intervention time series at all locations were investigated and found to cut off or die down fairly quickly, suggesting a stationary time series. Hence, no differencing was required. Also, the variability of the time series was fairly constant with time (variance), and no pre-differencing transformation was required *(36)*. As such, the analysis was performed using the original values of the percentage of speed limit violations. Figure 6 shows the SAC (ACF) plot for 142 Street between 106 and 104 Avenues.

After accounting for stationarity, the behavior of the SAC and SPAC plots was investigated to determine the appropriate parameters to be included in the seasonal and non-seasonal moving average and autoregressive operators of a tentatively identified ARIMA model. The model parameters were then estimated, and different diagnostics were performed to assess the adequacy of the tentatively identified ARIMA model. These diagnostics include the following:

1) Checking the significance of the estimated moving average and autoregressive parameters. The *t*-value for these parameters must be more than 2 to be considered significant at the 95% confidence level. Table 8 shows the parameters estimation for the pre-intervention ARIMA model developed for the

first week of data at 142 Street between 106 and 104 Avenues as generated in SAS 9.4.

Table 7: Check for White Noise for the First Week of Data at 142 Street Between 106 and 104 Avenues

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	38.85	6	<.0001	0.425	0.272	0.200	0.138	0.101	-0.022
12	45.37	12	<.0001	-0.021	-0.084	-0.152	-0.134	-0.046	0.005
18	59.72	18	<.0001	-0.124	-0.202	-0.152	-0.100	-0.064	-0.113
24	66.57	24	<.0001	-0.044	-0.009	-0.019	0.044	0.052	0.198
30	70.62	30	<.0001	0.058	-0.015	-0.106	0.017	-0.036	-0.098
36	95.04	36	<.0001	-0.134	-0.151	-0.217	-0.214	-0.103	-0.060
42	99.00	42	<.0001	-0.085	-0.097	-0.037	0.008	0.067	0.004
48	107.10	48	<.0001	-0.030	-0.024	0.009	0.033	0.117	0.155
54	112.33	54	<.0001	0.107	0.042	0.015	0.108	0.006	-0.010
60	114.73	60	<.0001	-0.078	-0.029	-0.042	-0.030	0.007	-0.030
66	119.30	66	<.0001	-0.038	-0.014	0.050	0.096	0.048	0.041
72	150.56	72	<.0001	0.115	0.121	0.140	0.128	0.180	0.098
78	154.46	78	<.0001	0.073	0.049	-0.016	-0.026	-0.045	-0.033

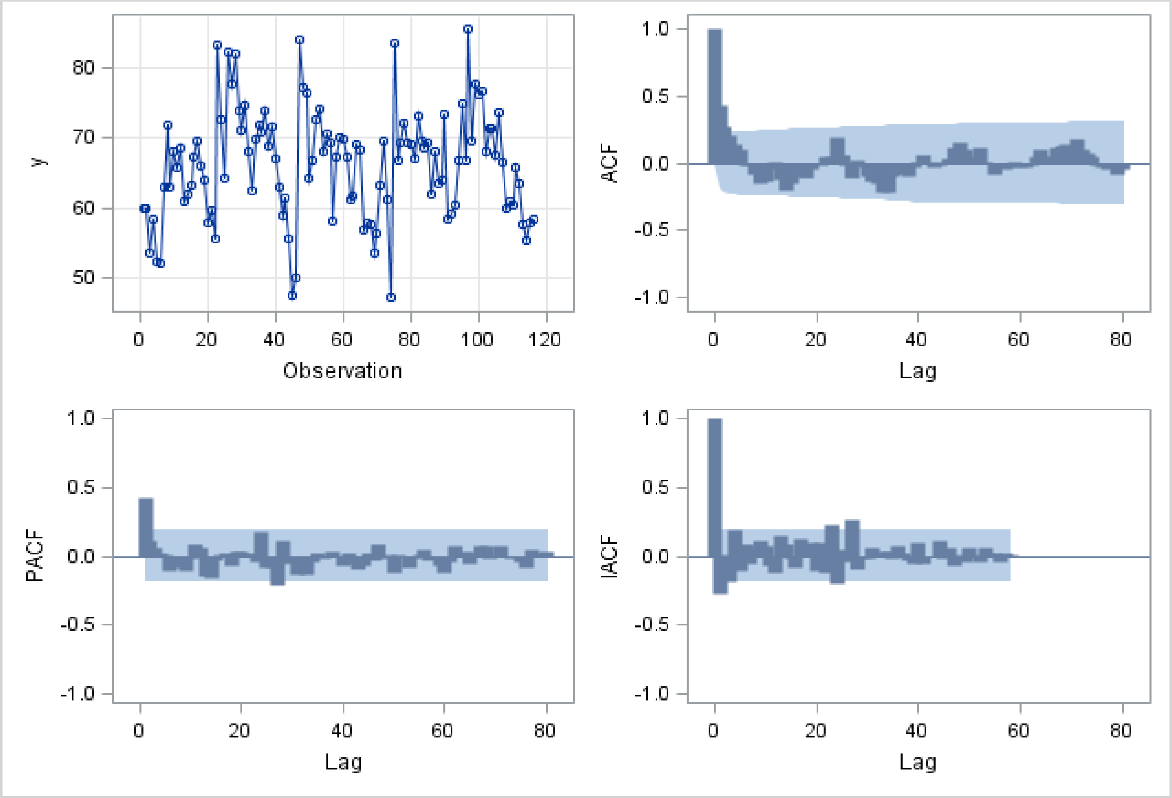


Figure 6: SAC (ACF) Plot for the Location at 142 Street Between 106 and 104 Avenues

Table 8: Parameters Estimation for the Pre-Intervention ARIMA Model Developed for the First Week of Data at 142 Street Between 106 and 104 Avenues

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag
MU	66.21021	1.38186	47.91	<.0001	0
AR1,1	0.40652	0.08740	4.65	<.0001	1
AR2,1	0.28793	0.10125	2.84	0.0053	24

2) Correlation between the estimated parameters should not be high. When two parameters were highly correlated, one of them was dropped from the model based on which would further improve the model quality. Table 9 shows the correlation between the estimated parameters for the pre-intervention ARIMA

model developed for the first week of data at 142 Street between 106 and 104 Avenues as generated in SAS 9.4 software.

Table 9: Correlation Between the Estimated Parameters for the Pre-Intervention ARIMA Model Developed for the First Week of Data at 142 Street Between 106 and 104 Avenues

Parameter	MU	AR1,1	AR2,1
MU	1.000	-0.019	-0.003
AR1,1	-0.019	1.000	0.005
AR2,1	-0.003	0.005	1.000

3) Autocorrelation check of residuals for the identified model using the Ljung-Box statistic at different lags: if the *p*-value is higher than 0.05 at all lags, then we may accept the null hypothesis that the residuals are not correlated and are random (white noise). Moreover, the model adequacy is checked by investigating the SAC and SPAC plots for the residuals to identify spikes (values exceeding ± 2 standard error). Table 10 shows the autocorrelation check of residuals for the pre-intervention ARIMA model developed for the first week of data at 142 Street between 106 and 104 Avenues. Figure 7 shows the SAC and SPAC plots of residuals at different lags for the pre-intervention ARIMA model developed for the first week of data at 142 Street between 106 and 104 Avenues.

Table 10: Autocorrelation Check of Residuals for the Pre-Intervention ARIMA Model Developed for the First Week of Data at 142 Street Between 106 and 104 Avenues

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.99	4	0.4078	-0.038	0.037	0.123	-0.011	0.118	-0.039
12	5.44	10	0.8600	0.050	-0.029	-0.059	-0.036	0.009	0.058
18	9.87	16	0.8735	-0.083	-0.126	-0.031	-0.031	-0.036	-0.086
24	11.29	22	0.9704	-0.051	0.043	-0.050	0.037	-0.038	-0.019

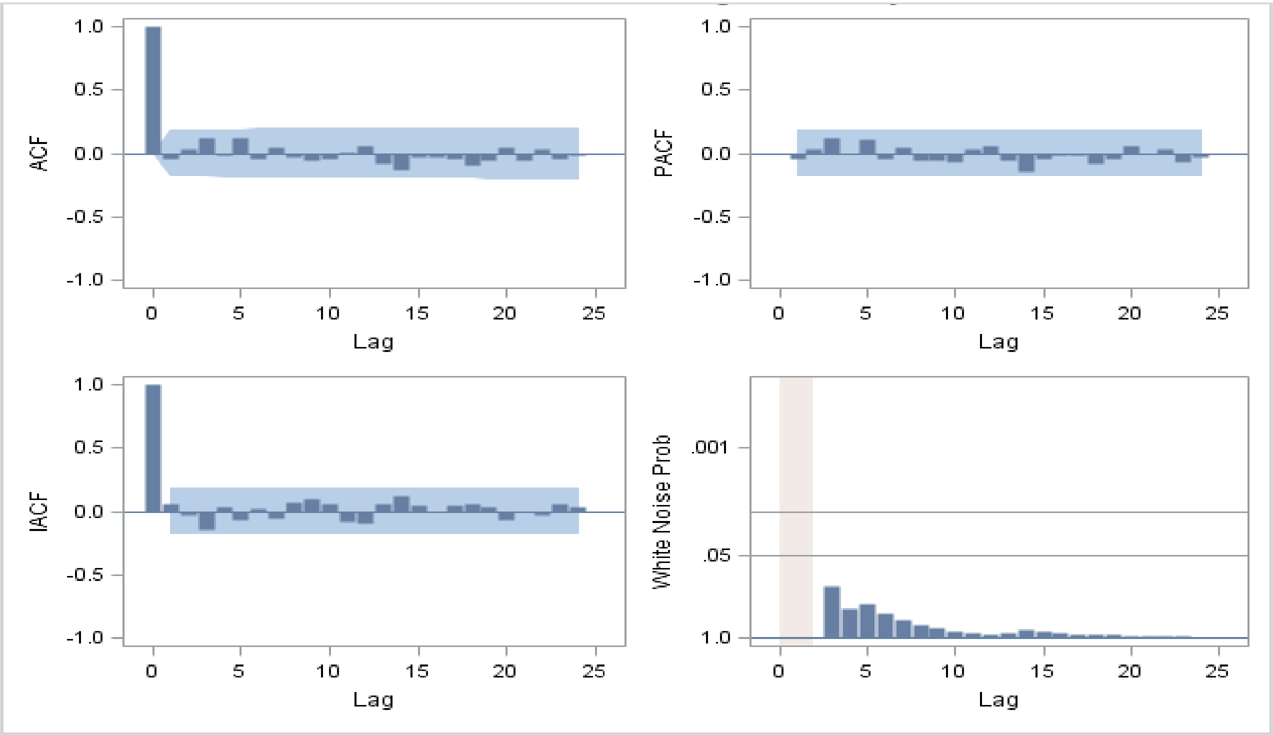


Figure 7: SAC and SPAC Plots of Residuals at Different Lags for the Pre-Intervention ARIMA Model Developed for the First Week of Data at 142 Street Between 106 and 104 Avenues

4) Checking the Akaike Information Criterion (AIC), and comparing it for different models. The model with the minimum AIC value was used. Table 11 shows the Akaike Information Criterion for the pre-intervention ARIMA model developed for the first week of data at 142 Street between 106 and 104 Avenues.

Table 11: Akaike Information Criterion for the Pre-Intervention ARIMA Model Developed for the First Week of Data at 142 Street Between 106 and 104 Avenues

Constant Estimate	27.98041
Variance Estimate	47.54677
Std Error Estimate	6.895416
AIC	760.0132
SBC	768.1954
Number of Residuals	113

5) Normality check for residuals is performed to verify that it is approximately true for the developed model. Figure 8 shows the distribution of residuals for the pre-intervention ARIMA model developed for the first week of data at 142 Street between 106 and 104 Avenues.

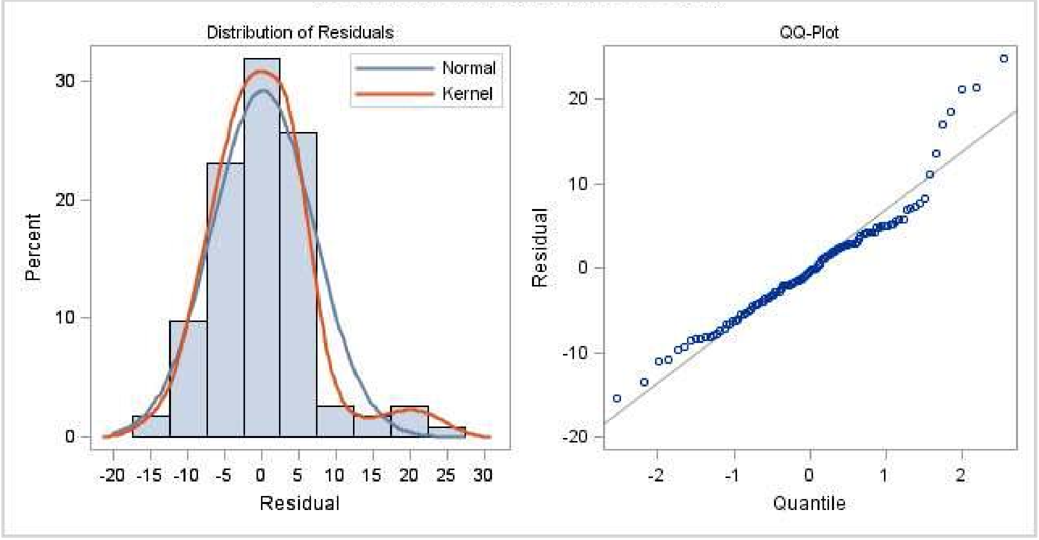


Figure 8: Distribution of Residuals for the Pre-Intervention ARIMA Model Developed for the First Week of Data at 142 Street Between 106 and 104 Avenues

Several iterations were performed in an attempt to determine the ARIMA model that best met the aforementioned diagnostics for the pre-intervention data. The ARIMA models were then combined with step functions to study the intervention effects. The combined model is known as the ARIMAX model. The same steps for parameter estimation and diagnostics were applied to the ARIMAX model, and models were improved whenever possible. Finally, the value and significance of the intervention parameters were used to assess the effects of interventions. It is worth mentioning that it was not possible in some cases to develop one ARIMAX model for the whole time series of eight weeks. In that case, the time series was divided into more than one part and more than one ARIMAX model was developed. SAS 9.4 software was used to conduct all stages of the analysis. Table 12 shows the parameters estimation for the ARIMAX model developed for the data between the first and fourth weeks at 142 Street between 106 and 104 Avenues as generated in SAS 9.4. The table shows two significant intervention parameters (NUM1 and NUM2).

Table 12: Parameters Estimation for the ARIMAX Model Developed for the Data Between the First and Fourth Weeks at 142 Street Between 106 and 104 Avenues

Parameter	Estimate	Standard Error	t-Value	Approx Pr > |t|	Lag	Variable	Shift
MU	65.74002	1.10701	59.39	<.0001	0	y	0
AR1,1	0.36269	0.04477	8.10	<.0001	1	y	0
AR2,1	0.22736	0.04790	4.75	<.0001	24	y	0
NUM1	-26.88470	1.52678	-17.61	<.0001	0	s	0
NUM2	-5.21490	2.16587	-2.41	0.01	0	s2	0

Table 13 shows the correlation between the estimated parameters for the ARIMAX model developed for the data between the first and fourth weeks at 142 Street between 106 and 104 Avenues as generated in SAS 9.4. As shown in the table, low correlation is observed between the different parameters used in the ARIMAX model. Table 14 and Figure 9 shows the autocorrelation check of residuals and the SAC and SPAC plots of residuals at different lags for the same ARIMAX model, respectively.

Table 13: Correlation Between the Estimated Parameters for the ARIMAX Model Developed for the Data Between the First and Fourth Weeks at 142 Street Between 106 and 104 Avenues

Variable Parameter	MU	AR1,1	AR2,1	NUM1	NUM2
MU	1.000	-0.005	-0.012	-0.690	-0.507
AR1,1	-0.005	1.000	-0.125	0.023	-0.044
AR2,1	-0.012	-0.125	1.000	0.037	-0.006
NUM1	-0.690	0.023	0.037	1.000	0.400
NUM2	-0.507	-0.044	-0.006	0.400	1.000

The flow chart shown in Figure 10 summarizes all the steps followed in order to develop an ARIMAX model for a time series of data. Table 15 shows all of the developed ARIMA and ARIMAX models for nine study locations. It is worth mentioning that five of the study locations have been excluded from the analysis due to failures in the data collection devices. Each new row indicates the start of developing a new ARIMAX model. Appendix B includes all of the parameters estimation tables for all of the developed ARIMAX models at all locations. Appendix C shows all of the autocorrelation check of residuals for all of the developed ARIMAX models at all locations. Appendix D shows all the SAC and SPAC plots of residuals at different lags for all of the ARIMAX models at all locations.

Table 14: Autocorrelation Check of Residuals for the ARIMAX Model Developed for the Data Between the First and Fourth Weeks at 142 Street Between 106 and 104 Avenues

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	5.75	4	0.2184	-0.028	0.044	0.078	0.028	0.040	-0.038
12	8.08	10	0.6212	0.012	-0.019	-0.064	-0.006	-0.018	-0.009
18	15.72	16	0.4727	0.024	-0.022	-0.044	-0.064	-0.089	-0.038
24	27.47	22	0.1941	-0.018	0.086	-0.047	-0.012	0.119	-0.025
30	30.86	28	0.3231	0.034	0.063	-0.035	-0.002	0.000	-0.029
36	36.26	34	0.3636	-0.049	-0.022	-0.007	-0.053	0.054	-0.049
42	37.32	40	0.5913	0.001	-0.004	0.023	0.006	-0.024	-0.031

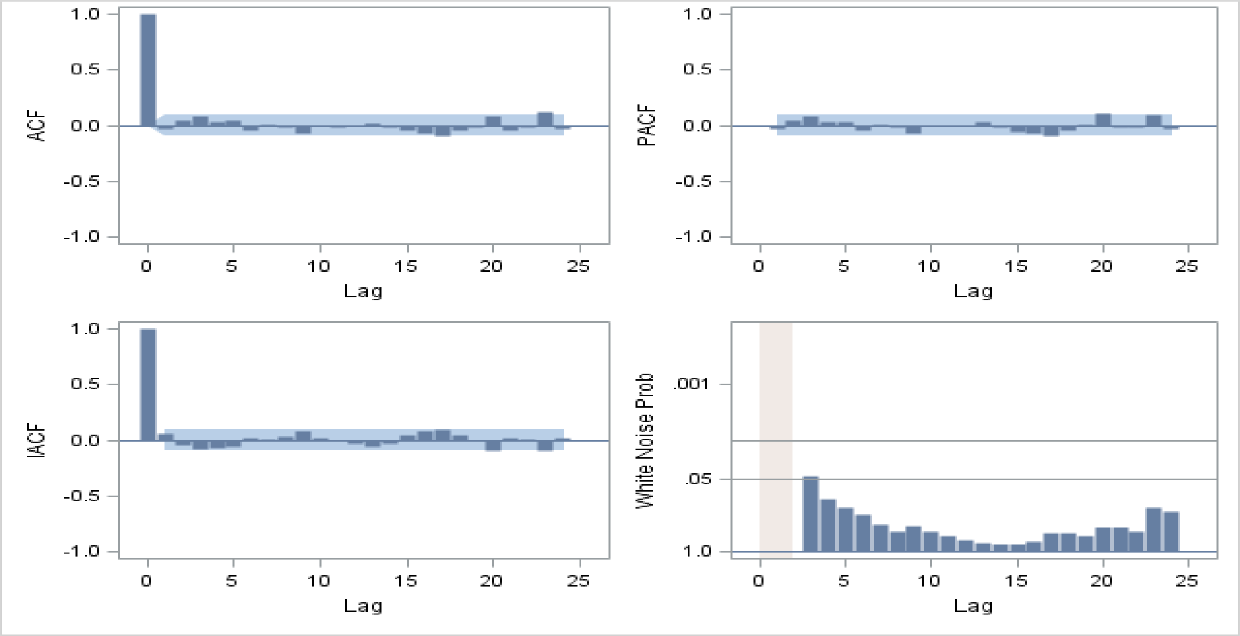


Figure 9: SAC and SPAC Plots of Residuals at Different Lags for the ARIMAX Model Developed for the Data Between the First and Fourth Weeks at 142 Street Between 106 and 104 Avenues

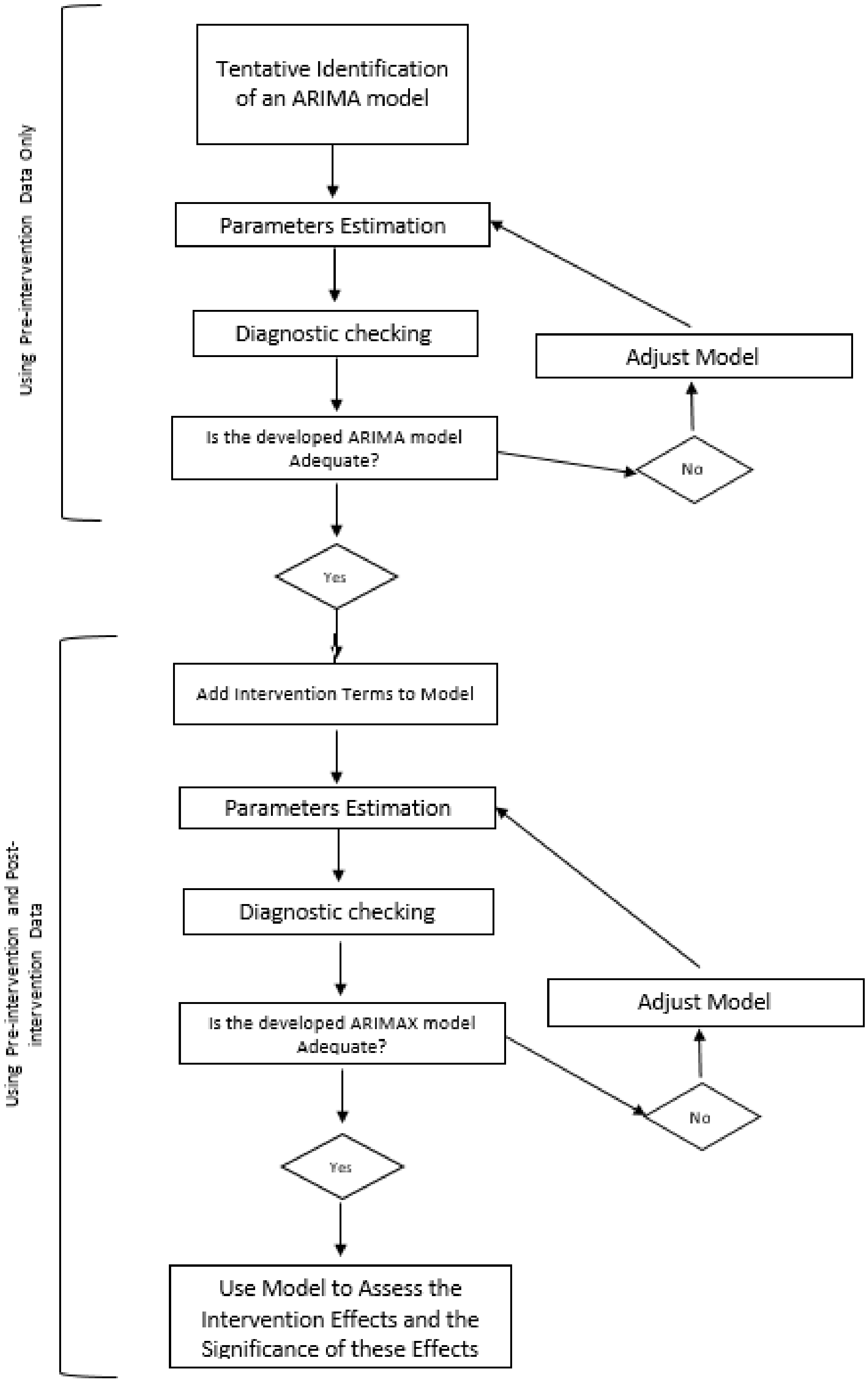


Figure 10: Flow Chart Showing All the Steps Followed in Order to Develop an ARIMAX Model for a Time Series of Data

Table 15: Developed ARIMA and ARIMAX Models for the Study Locations

Location	Period (Week)	ARIMA Models	ARIMAX Models
142 St. btw. 106 - 104 Ave.	1	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
	4	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(9,0,0) $(1,0,0)_{24}$
	4	ARIMA(9,0,0) $(1,0,0)_{24}$	ARIMAX(9,0,0) $(1,0,0)_{24}$
	5	ARIMA(2,0,0) $(1,0,0)_{24}$	ARIMAX(7,0,0) $(1,0,0)_{24}$
	6	ARIMA(2,0,0) $(1,0,0)_{24}$	ARIMAX(6,0,0) $(1,0,0)_{24}$
	7	ARIMA(4,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
101 Ave. btw. 67 - 70 St.	1	ARIMA(1,0,0)	ARIMAX(4,0,0) $(1,0,0)_{24}$
	2	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(18,0,0) $(1,0,0)_{24}$
	3	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
	4	ARIMA(5,0,0) $(1,0,0)_{24}$	ARIMAX(17,0,0) $(1,0,0)_{24}$
	7	ARIMA(6,0,0)	ARIMAX(17,0,0) $(2,0,0)_{24}$
142 St. btw. 104A - 105 Ave.	1	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
	2	ARIMA(2,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
	4	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(3,0,0) $(1,0,0)_{24}$
Saskatchewan Dr. btw. 107 - 105 St.	1	ARIMA(6,0,0) $(1,0,0)_{24}$	ARIMAX(6,0,0) $(1,0,0)_{24}$
	4	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(5,0,0) $(1,0,0)_{24}$
	6	ARIMA(5,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
	7	ARIMA(17,0,0) $(1,0,0)_{24}$	ARIMAX(17,0,0) $(2,0,0)_{24}$
	8	ARIMA(1,0,0) $(2,0,0)_{24}$	ARIMAX(1,0,0) $(2,0,0)_{24}$

Location ID	Period (Week)	ARIMA Models	ARIMAX Models
132 Ave. btw. 123 - 121 St.	1	ARIMA(5,0,0) $(1,0,0)_{24}$	ARIMAX(5,0,0) $(1,0,0)_{24}$
	4	ARIMA(2,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(2,0,0)_{24}$
127 St. btw. 137 - 135 Ave.	1	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(4,0,0) $(1,0,0)_{24}$
	3	ARIMA(4,0,0) $(1,0,0)_{24}$	ARIMAX(4,0,0) $(1,0,0)_{24}$
	4	ARIMA(4,0,0) $(1,0,0)_{24}$	ARIMAX(2,0,0) $(1,0,0)_{24}$
	6	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(3,0,0) $(1,0,0)_{24}$
	7	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(2,0,0) $(1,0,0)_{24}$
109 St. btw. 108 - 110 Ave.	1	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
	5	ARIMA(2,0,0) $(1,0,0)_{24}$	ARIMAX(14,0,0) $(1,0,0)_{24}$
	7	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(2,0,0) $(1,0,0)_{24}$
144 Ave. btw. 77 - 79 St.	1	ARIMA(1,0,0) $(1,0,1)_{24}$	ARIMAX(1,0,0) $(1,0,1)_{24}$
	4	ARIMA(1,0,0) $(1,0,0)_{24}$	ARIMAX(1,0,0) $(1,0,0)_{24}$
156 St. btw. 94 - 92 Ave.	1	ARIMA(3,0,0) $(1,0,0)_{24}$	ARIMAX(15,0,0) $(1,0,0)_{24}$

For the five control locations, the time series of speed limit violations was investigated to account for any confounding factors before attributing the variation of the time series at the enforced locations to MPE effects. Moreover, the time series of traffic volume at the nine locations was also checked to see if there were any variations that could possibly indicate the need to include traffic volume in the developed models.

4.2 Distance Halo Effect

Hypothesis testing using a two-sample *t*-test was performed to test the hypothesis that the percentage of speed limit violations during four MPE site-visits (3-4 hours each) is significantly low compared to the same hours on days without enforcement. The null hypothesis is that the average percentage of speed limit violations during the four MPE site-visits (12 to 16 hours in total) is not significantly different from the average value during corresponding hours on days without enforcement (12 to 16 hours in total). The alternative hypothesis is that the average percentage of violations during MPE site-visits is significantly lower compared to the average during corresponding hours on days without enforcement. First, the pooled standard deviation of the two samples is estimated, and then the *t*-statistic is calculated, as shown in equations (4) and (5). Finally, the *df* and *t*-statistic are used to determine the corresponding p-value, which represents the area under the curve of the t-distribution *(37)*. If the calculated p-value is lower than 0.05, then the alternative hypothesis is accepted and the difference is considered significant at the 95% confidence level.

$$s_p = \sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2}} \tag{4}$$

$$t = \frac{\bar{x}_1-\bar{x}_2}{s_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \tag{5}$$

$$df = n_1 + n_2 - 2 \tag{6}$$

where, n_1 and n_2 are the sample sizes; $\bar{x}_1$ and $\bar{x}_2$ are the sample means; $s_1$and s_2 are the sample standard deviations; s_p is the pooled standard deviation of the two samples; t is the t-statistic; and *df* is the degree of freedom.

The two-sample *t*-test was performed for all 50 devices upstream and downstream of the nine urban locations to compare the percentages of speed limit violations during enforcement hours with those during non-enforcement hours. Selected enforcement visits lasted from three to four hours. The reductions in violations and significance at the different devices were used to make inferences about how far the effects of MPE extended upstream and downstream from the enforcement location. The normality assumption of the *t*-test was validated for the tested samples using the Anderson–Darling test, and the equal-variance assumption was met for the tested samples *(37)*.

For the five control locations, the time series of speed limit violations was investigated to account for any confounding factors before attributing the reduction in violations at the enforced locations to MPE effects. Moreover, the changes in traffic volume at the nine enforced locations were also checked to see if there were any variations in traffic volume that might affect driver behavior.

5 Modelling Results and Discussion

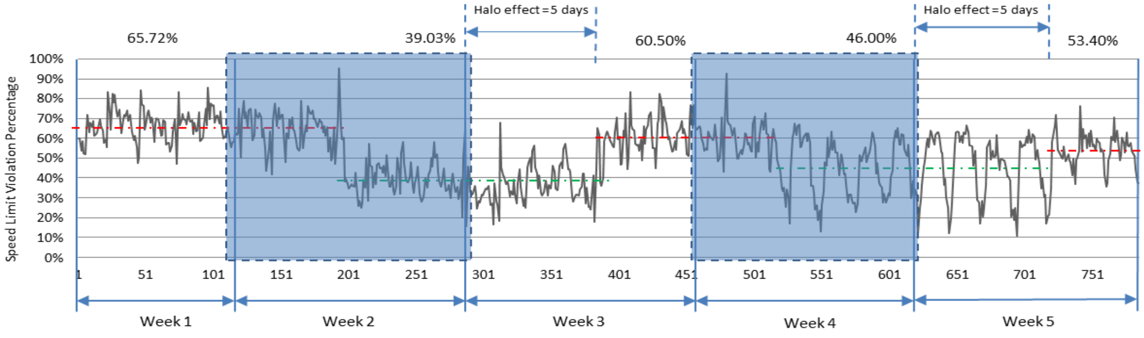
5.1 Time Halo Effect

Figures 11 to 14 show the time series of speed limit violation percentages at the nine study locations (time in hours). Figures 11 and 12 show the time series between the first and fifth weeks for arterial and collector roads, respectively. Similarly, Figures 13 and 14 show the time series between the fifth and eighth weeks for arterial and collector roads. Significant changes that were detected in the time series and described by the intervention parameters are shown in the figures by dotted lines, and the corresponding percentage of violations is shown above the plot of each location. Shaded squares show the weeks with enforcement, and hatched parts show times when there has been a failure in the collection device. In addition, the time halo effect results are shown above the plots for the third, fifth and seventh weeks. For arterial roads, as shown in Figures 11 and 13, it was found that speed limit violations during the first week ranged from 65.72% to 83.23%, except for the location at Saskatchewan Drive between 107 - 105 Streets that showed only 41.1% of violations. After the first round of MPE (during the second week), there were significant reductions in violations at all locations, ranging between 12.73% and 26.72%. These reductions in violations were found to last for some time after enforcement has ended, before increasing and stabilizing at a slightly higher violation percentage. This slight increase in violation rates was found to be lower than the rate of violations during the first week (before the first round of enforcement). The time period during which enforcement had a lasting effect on violation percentages is known as the time halo effect. It was determined to range between three and seven days during the third week.

After the second round of enforcement (during the fourth week), significant reductions in violations ranged from 11.37% to 14.50%, which is lower than the reductions observed after the first round of enforcement. Again, a lasting time halo effect of enforcement was observed during the fifth week (after the second round of enforcement). The time halo effect during the fifth week ranged between four to seven days at the seven arterial locations.

After the third round of enforcement during the sixth week, significant reductions in the percentage of violations ranged between 3.34% to 5.07% at five locations, which is lower than the observed reductions in the preceding two rounds. However, the percentage of violations was found to significantly increase by approximately 13% at two locations (101 Ave. btw. 67 - 70 St., and 109 St. btw. 108 - 110 Ave.) compared with the recorded violations in week 5. The time halo effect in the seventh week ranged between four and seven days. Similar mixed results were found during the fourth round of enforcement in the eighth week. Reductions in violations at four locations ranged from 1% to 12.8%, and a significant 8.67% increase in violations was found at one study location.

Moreover, it was found that during the enforcement weeks, the reduction in violations became significant after some delay and not directly after the first visit of enforcement. This delay is consistent with the findings of Vaa *(23)*, who found a delay in the effect of enforcement, and that the effect of enforcement became significant anytime during the first or second week. It is also consistent with the findings of Tay et al. *(21)*, who found that drivers took time to learn that a location is being actively enforced. As evident from Figures 11 to 14, the observed time delay varied widely between the study locations and this variation may be attributed to multiple factors. For instance, the existence of a parked vehicle close to the enforcement location might have limited the visibility of the MPE unit, and affected the time it takes drivers to adopt to the existence of enforcement activities.



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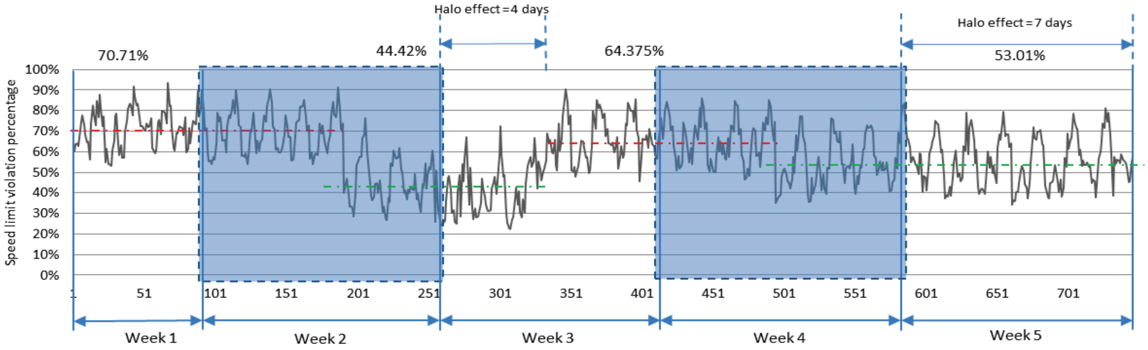
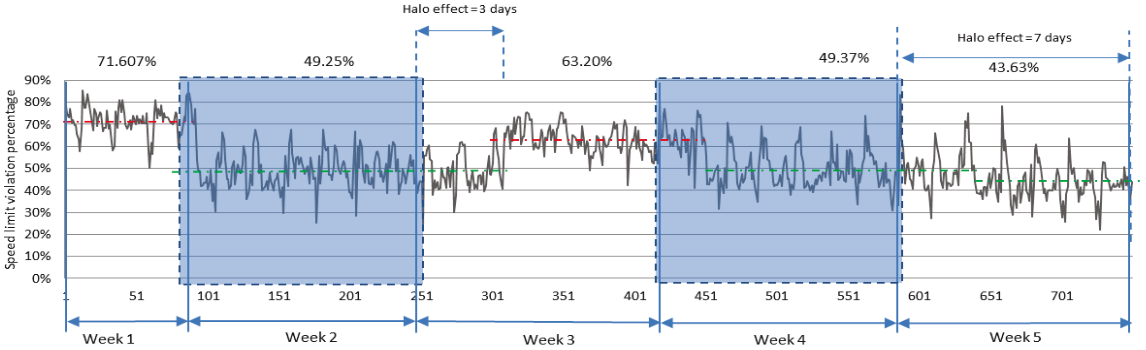


127 St. btw. 137 - 135 Ave.



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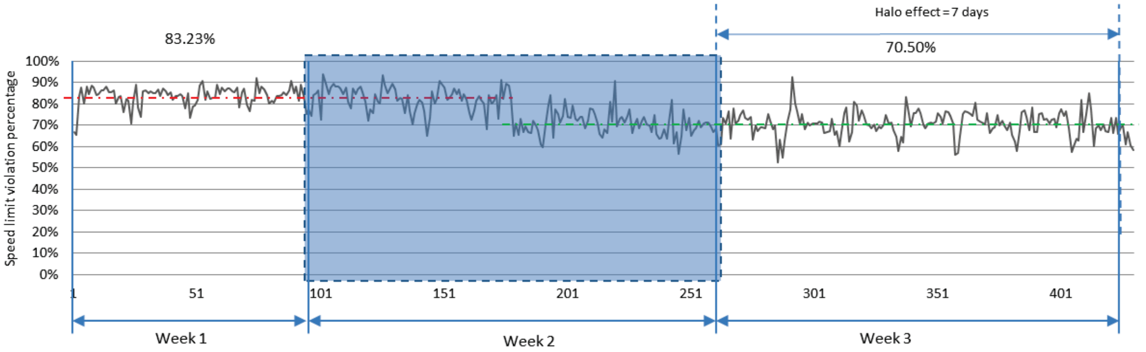

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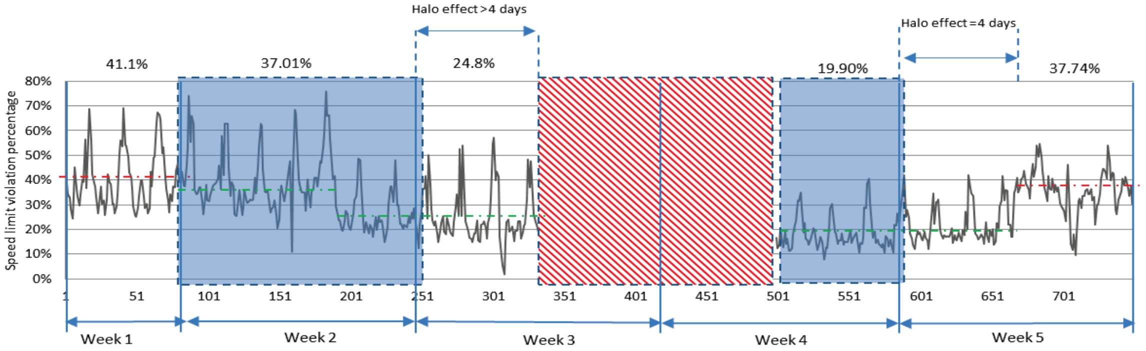

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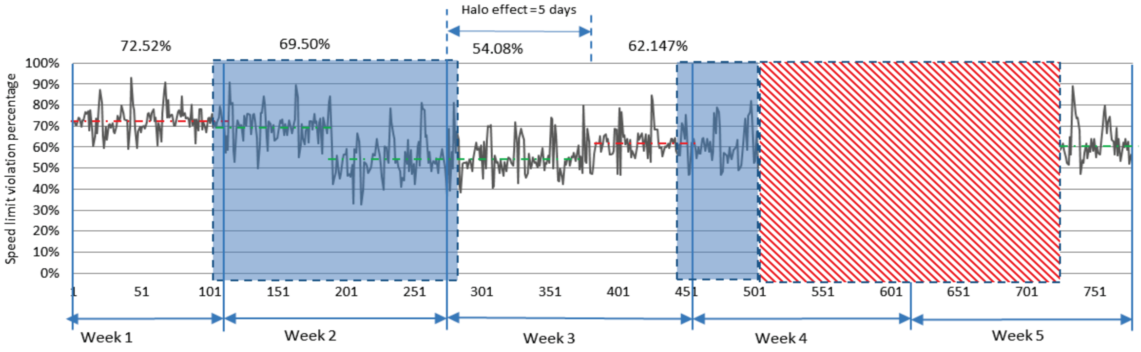

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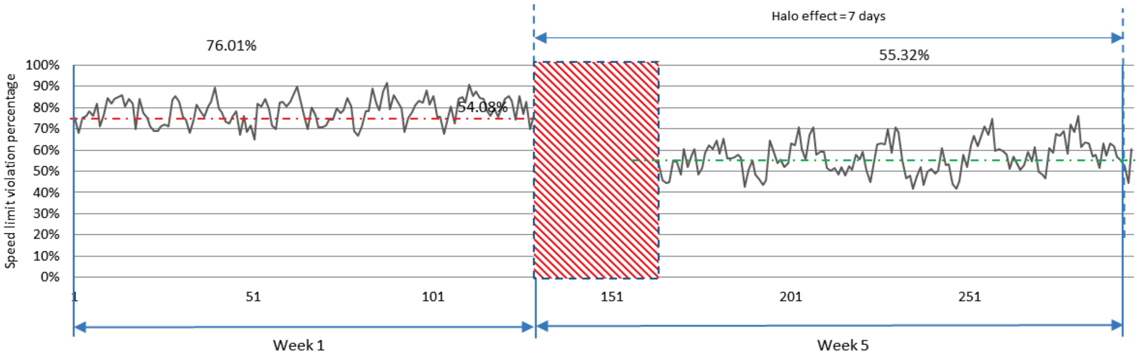
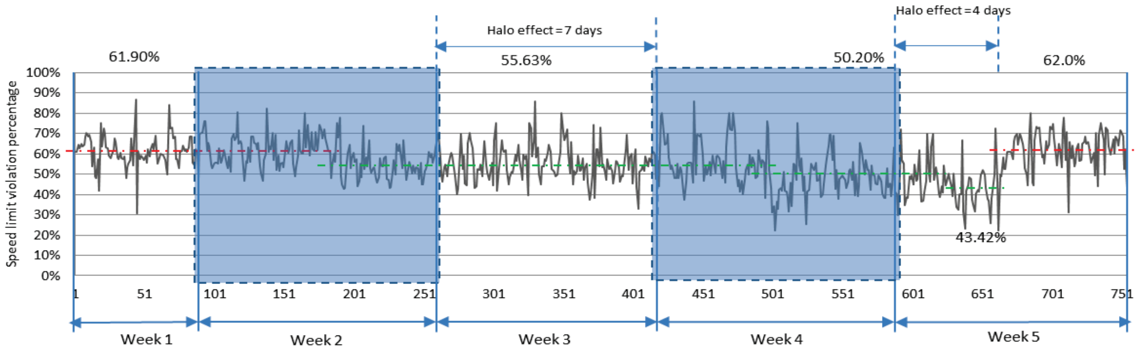
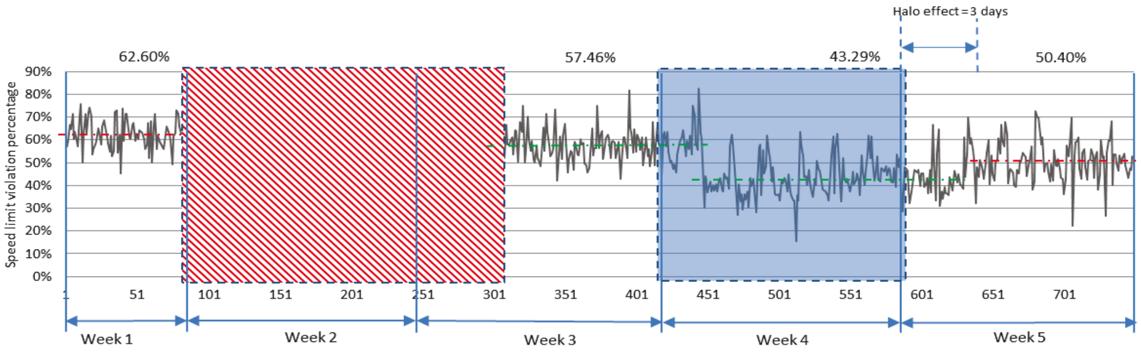


109 St. btw. 108 - 110 Ave.

Figure 11: Time Series of Speed Limit Violation Percentages for Arterial Roads (Weeks 1 to 5)

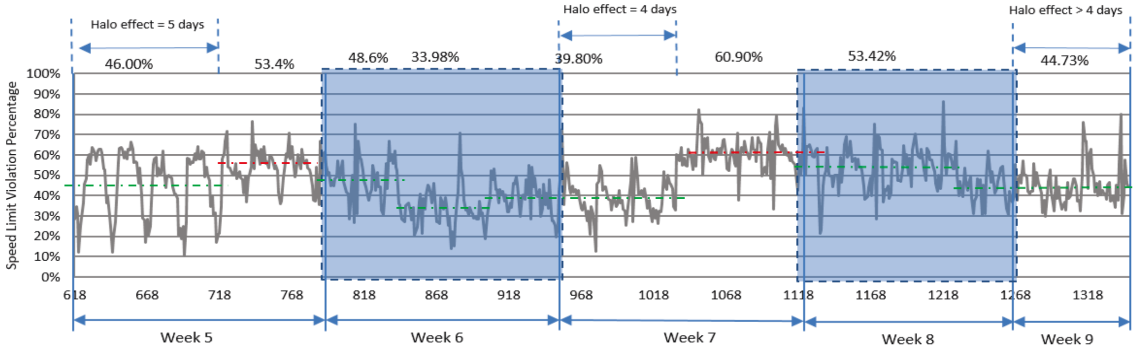


132 Ave. btw. 123 - 121 St.

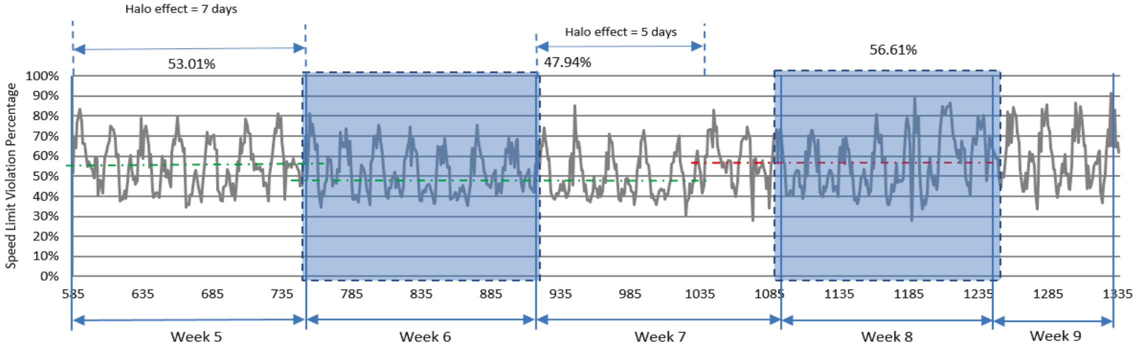


144 Ave. btw. 77 - 79 St.

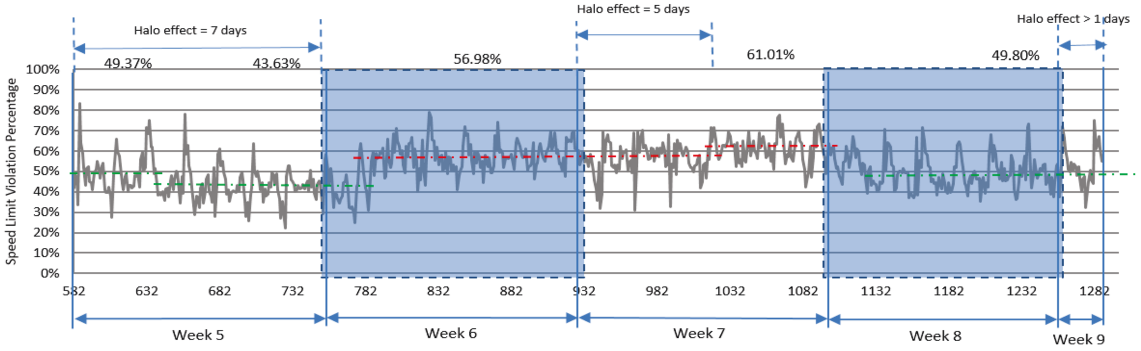
Figure 12: Time Series of Speed Limit Violation Percentages for Collector Roads (Weeks 1 to 5)



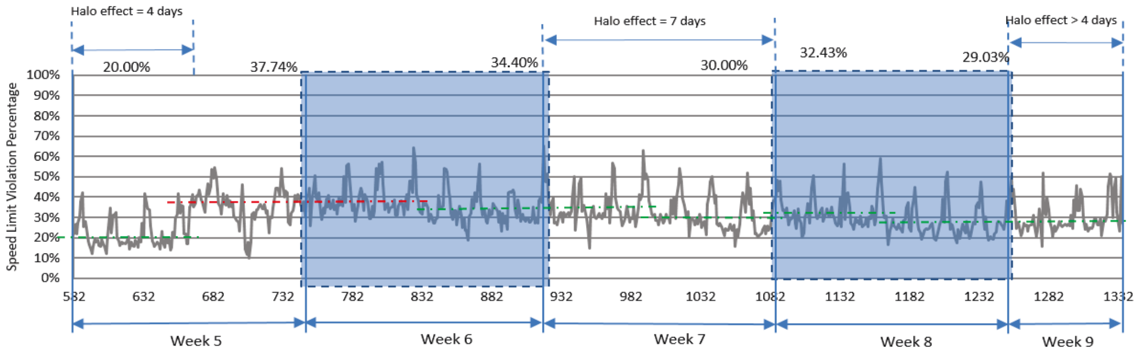
142 St. btw. 106 - 104 Ave.



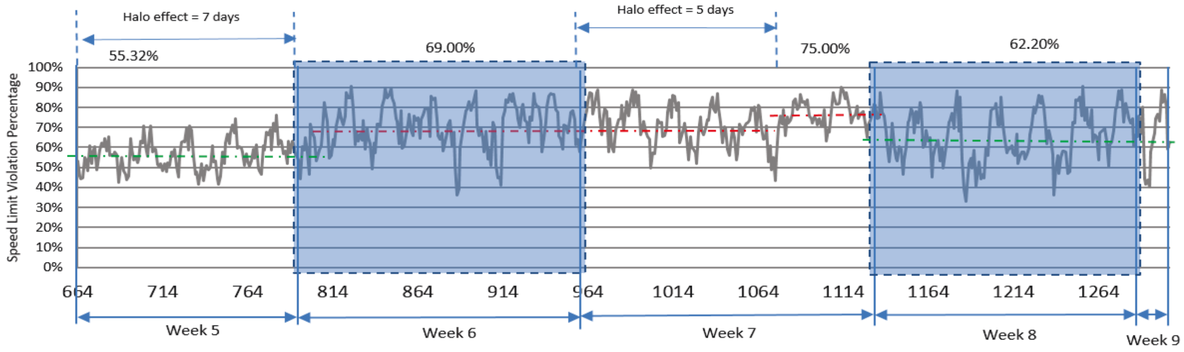
127 St. btw. 137 - 135 Ave.



101 Ave. btw. 67 - 70 St.

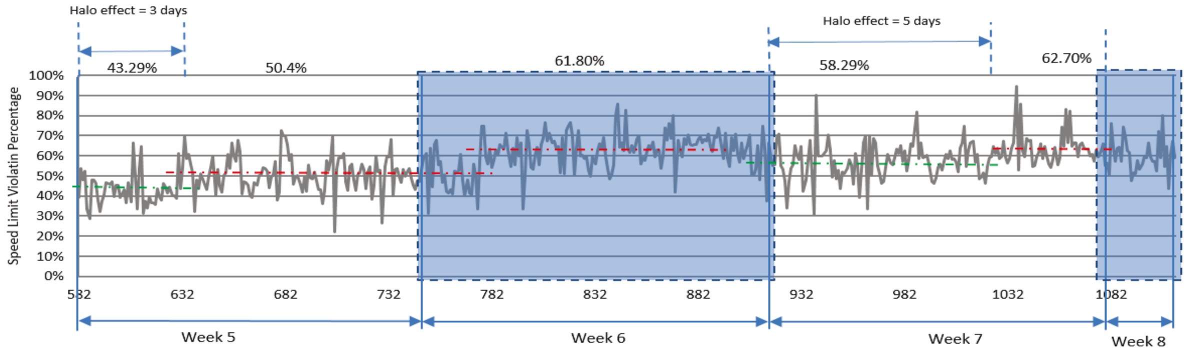


Saskatchewan Dr. btw. 107 - 105 St.



109 St. btw. 108 - 110 Ave.

Figure 13: Time Series of Speed Limit Violation Percentages for Arterial Roads (weeks 5 to 8)



144 Ave. btw. 77 - 79 St.

Figure 14: Time series of Speed Limit Violation Percentages for Collector Roads (weeks 5 to 8)

Similar results were found for collector roads, as shown in Figures 12 and 14. The violations in the pre-enforcement period (during the first week) ranged from 61.90% to 62.60%. The average reduction in violations after the first round of enforcement was 5.8%. The time halo effect during the third week was seven days. The average reduction in violations after the second round of enforcement was 10.0%. The time halo effect during the fifth week ranged from three to four days. After the third enforcement round in the sixth week, a significant 11.4% increase in violations was observed. The time halo effect in the seventh week was five days.

There were no similar changes detected at the five control locations, but rather, the time series of violations at the control locations showed consistent behavior over time. In addition, the time series of traffic volume also showed consistent behavior at the nine study locations and the five control locations throughout the entire study period. As such, the significant changes detected in the time series of violations at the study locations were reasonably attributed to the effect of MPE and not to any effects due to other confounding factors or traffic volume changes. Intervention parameters related to the discussed results were significant at the 99% confidence interval (p-value < 0.01).

5.2 Relationship Between Enforcement Intensity, Time Halo Effect and Reductions in Violations

A correlation analysis was conducted between violations reductions and time halo durations on various enforcement-intensity variables. The enforcement-intensity variables included the number of visits per week, the total number of enforcement hours per week, and the average hours per visit. The violation reduction variables included the reductions in the percentage of violations between the first and second weeks (reduction 1-2), the reductions in the percentage of violations between the third and fourth weeks (reduction 3-4), the reductions in the percentage of violations between the first and fourth weeks (reduction 1-4), the average value of the reductions from 1-2 and 3-4, and the average value of the reductions from 1-2 and 1-4.

The time halo effect variables included the time halo effect in the third week (week 3 halo), the time halo effect in the fifth week (week 5 halo), and the average halo effect (average halo) for both weeks. Due to device failures and sample sizes, similar variables in the period between the sixth and eighth weeks were not developed.

Table 16 presents the above-mentioned variables for the nine locations. The shaded cells could not be estimated due to a failure in the data collection devices. Table 17 shows the results of the correlation analysis including the correlation coefficients and their statistical significance. The time halo effect in the fifth week was found to be strongly correlated to the total hours of enforcement per week and the average hours per visit. The number of visits per week had strong positive correlations with the reduction 1-2, the average value of reductions 1-2 and 1-4, and the average value of reductions 1-2 and 3-4, with correlation coefficients of 0.6, 0.60, and 0.70, respectively. The same three variables were statistically correlated to the total hours of enforcement at a location with correlation coefficients of 0.70, 0.70, and 0.80, respectively. These results indicate that the different enforcement-intensity variables were found to strongly affect the longevity of the time halo effects and reductions in violations. More specifically, the results of this study suggest that, on average, if an urban road is to be visited by a MPE unit at least eight times in a week with at least 22 hours of enforcement per week, a 19% drop in violation rates is to be expected with a time halo effect extending for approximately five days. These findings can help MPE program managers optimize the allocation of limited resources by redeploying MPE units at other locations with known safety issues during the time halo period. This can significantly increase MPE program coverage, expected safety benefits, and the overall efficiency of MPE programs.

Table 16: Enforcement Intensity Variables, Time Halo Effect Variables, and Violation Reduction Variables

Location Number	Number of visits per Week	Total number of enforcement hours per week	Average hours per visit	Week 3 halo	Week 5 halo	Average halo	Reduction 1-2	Reduction 3-4	Reduction 1-4	Average reduction 1-2 & 3-4	Average reduction 1-2 & 1-4
1	13	42	3.23		7				20.68		
2	14	28	2.00	5	5	5	26.72	14.5	19.72	20.61	23.22
3	8	26	3.25	4	4	4	16.3		21.2		18.75
4	6	23	3.83	3	7	5	22.35	13.83	22.24	18.09	22.295
5	9	22	2.44	5			18.44				
6	6	16	2.67	4	7	5.5	26.29	11.365	17.7	18.828	21.995
7	5	14	2.80	7	4	5.5	8.47	5.63	11.69	7.05	10.08
8	5	12	2.40	7			12.73				
9	5	10	2.00		3		5.14	14.17	19.31	9.655	12.225
Average	7.89	21.44	2.74	5.00	5.29	5.00	17.06	11.90	18.93	14.85	18.2

Table 17: Correlation Analysis Results (Time Halo)

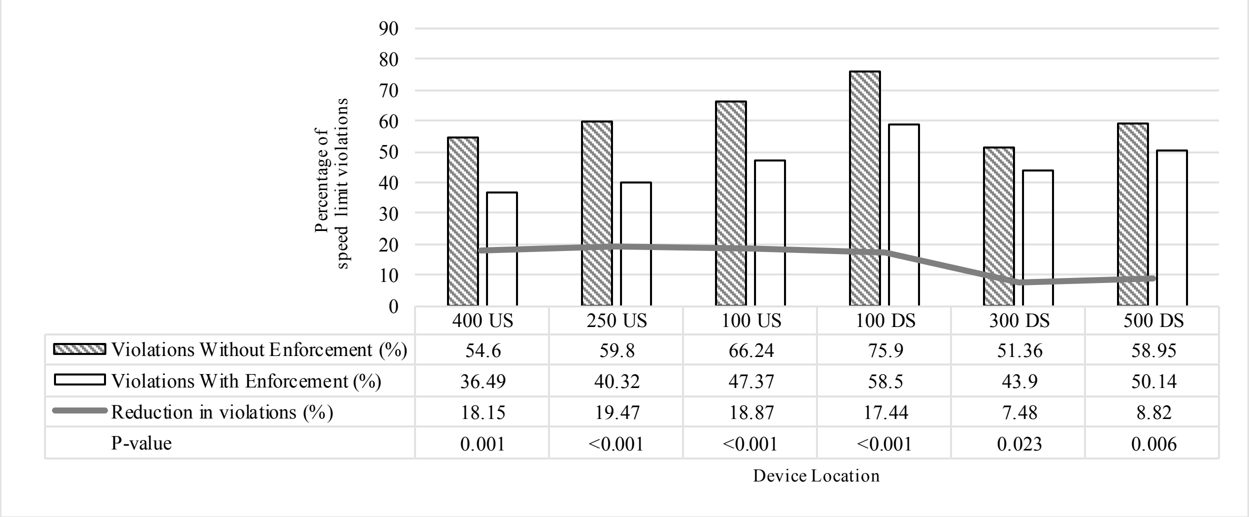
Variable 1	**Variable 2**	**Correlation coefficient**	**Significance**
Total number of enforcement hours per week	Week 5 halo	0.6	0.07
Average hours per visit	Week 5 halo	0.6	0.07
Number of visits per week	Reduction 1-2	0.6	0.05
Number of visits per week	Average reduction 1-2 & 3-4	0.7	0.08
Number of visits per week	Average reduction 1-2 & 1-4	0.6	0.09
Total number of enforcement hours per week	Reduction 1-2	0.7	0.02
Total number of enforcement hours per week	Average reduction 1-2 & 3-4	0.8	0.06
Total number of enforcement hours per week	Average reduction 1-2 & 1-4	0.7	0.06

5.3 Distance Halo Effect

Figures 15 and 16 show the results of the analysis at the nine urban locations. The vertical axis represents the percentage of speed limit violations and the horizontal axis represents the distance of the device upstream (US) and downstream (DS) of the MPE unit in meters (500 US, 300-400 US, 200-250 US, 100 US, 100 DS, 200-250 DS, 300 DS, and 500 DS). The table and the bars show the percentage of speed limit violations during the hours with and without enforcement, and the line represents the reductions in violations due to MPE exposure at the different devices. In addition, the *p*-value is also shown in the table for each location. For arterial roads, as shown in Figure 15, it was found that, on average, the percentage of violations during the hours without enforcement at all locations ranged from 42.36% to 66.83%, and during the MPE visits ranged from 30.51% to 57.65%. There were significant reductions at 38 devices out of 39 devices at all locations, suggesting that MPE had a distance halo effect that extended along the entire studied corridor at all locations. Only at 142 Street between 104A and 105 Avenues the effect was not significant at 300 meters US of the MPE location. On average, the reductions in violations ranged between 10% and 23.61% for all locations. The reductions were highest at 100 meters upstream (100 US) and downstream (100 DS) of the MPE unit.

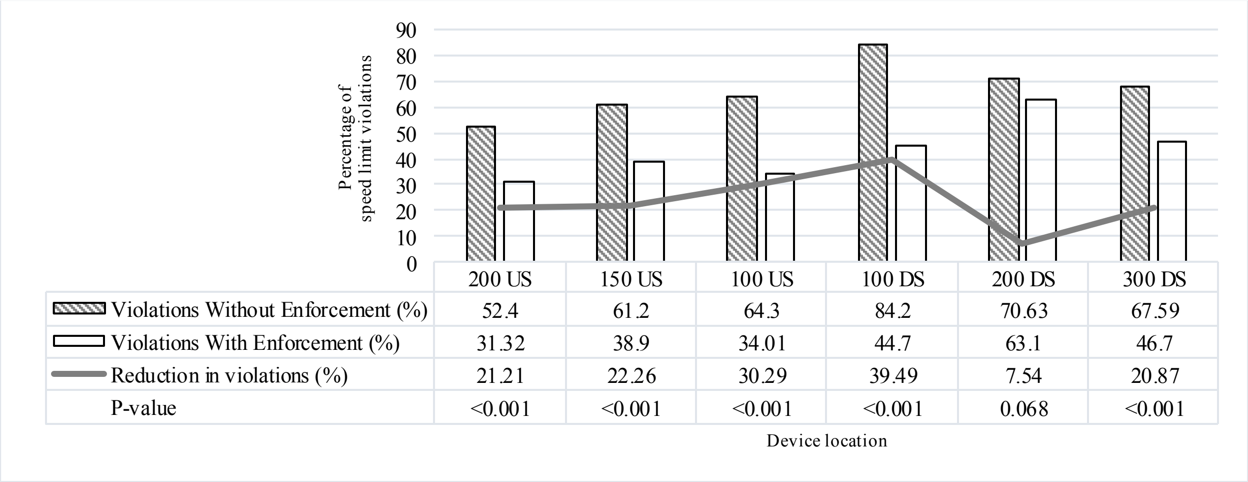
Similar results were found for collector roads, as shown in Figure 16. On average, the violations in the hours without enforcement ranged from 50.76 to 58%, and during MPE visits ranged between 34.64% and 45.35%. Reductions were significant at all devices and, on average, ranged between 12.62% and 16.15%, suggesting that MPE had a distance halo effect that extended along the entire studied corridor. No similar changes were detected at the five control locations, but rather, the percentage of violations at the control locations showed consistent behavior over time. In addition, the traffic volume was consistent at the nine study locations and the five control locations. As such, the significant reductions detected at the study locations were reasonably attributed to the effects of MPE and not to any effects of other confounding factors or traffic volume changes.

Interestingly, the observed overall pattern of reductions in speed limit violations, represented by the line, varied between the different study locations. This variation may be attributed to multiple factors such as the existence of a parked vehicle close to the enforcement location, which might have limited the visibility of the MPE unit.



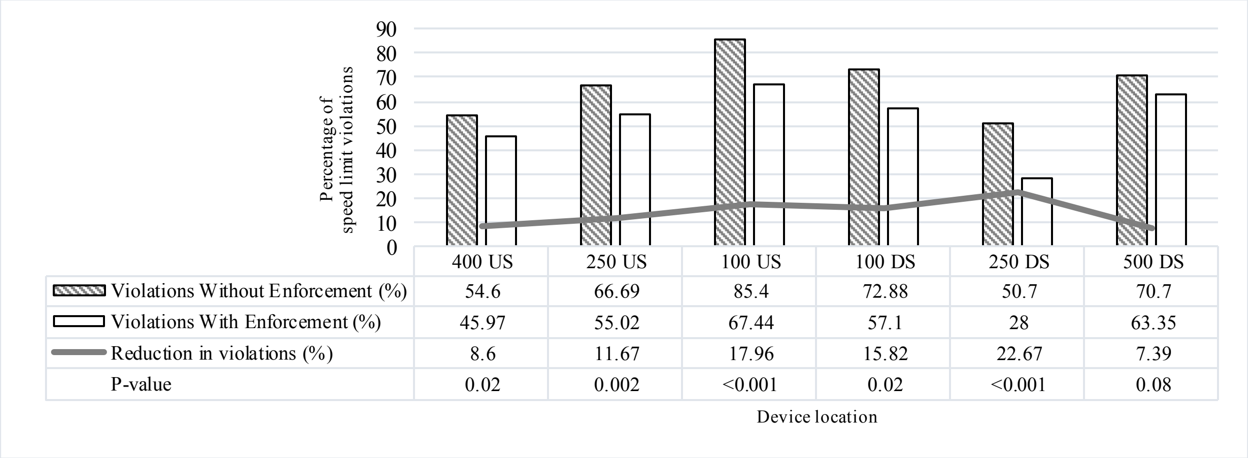
	400 US	250 US	100 US	100 DS	300 DS	500 DS
▨ Violations Without Enforcement (%)	54.6	59.8	66.24	75.9	51.36	58.95
☐ Violations With Enforcement (%)	36.49	40.32	47.37	58.5	43.9	50.14
— Reduction in violations (%)	18.15	19.47	18.87	17.44	7.48	8.82
P-value	0.001	<0.001	<0.001	<0.001	0.023	0.006

101 Ave. btw. 67 - 70 St.



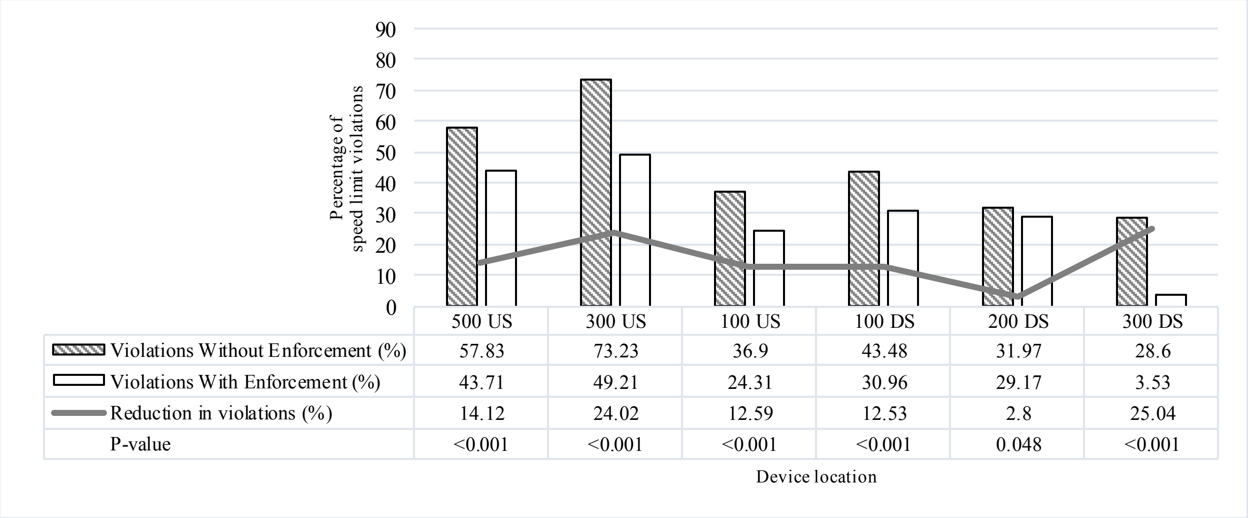
	200 US	150 US	100 US	100 DS	200 DS	300 DS
▨ Violations Without Enforcement (%)	52.4	61.2	64.3	84.2	70.63	67.59
☐ Violations With Enforcement (%)	31.32	38.9	34.01	44.7	63.1	46.7
— Reduction in violations (%)	21.21	22.26	30.29	39.49	7.54	20.87
P-value	<0.001	<0.001	<0.001	<0.001	0.068	<0.001

109 St. btw. 108 - 110 Ave.



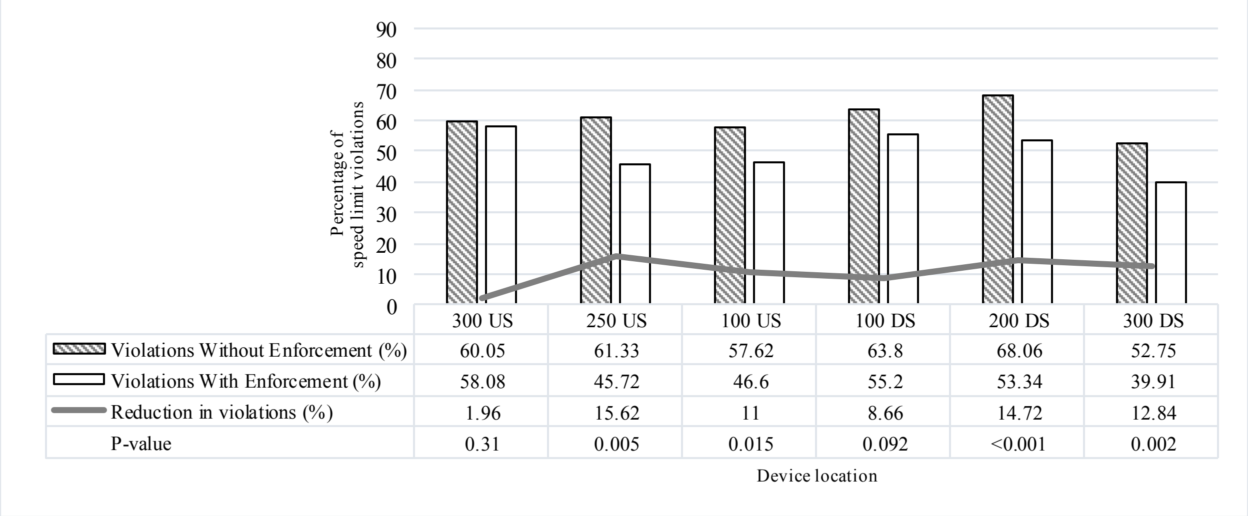
	400 US	250 US	100 US	100 DS	250 DS	500 DS
▨ Violations Without Enforcement (%)	54.6	66.69	85.4	72.88	50.7	70.7
☐ Violations With Enforcement (%)	45.97	55.02	67.44	57.1	28	63.35
— Reduction in violations (%)	8.6	11.67	17.96	15.82	22.67	7.39
P-value	0.02	0.002	<0.001	0.02	<0.001	0.08

156 St. btw. 94 - 92 Ave.



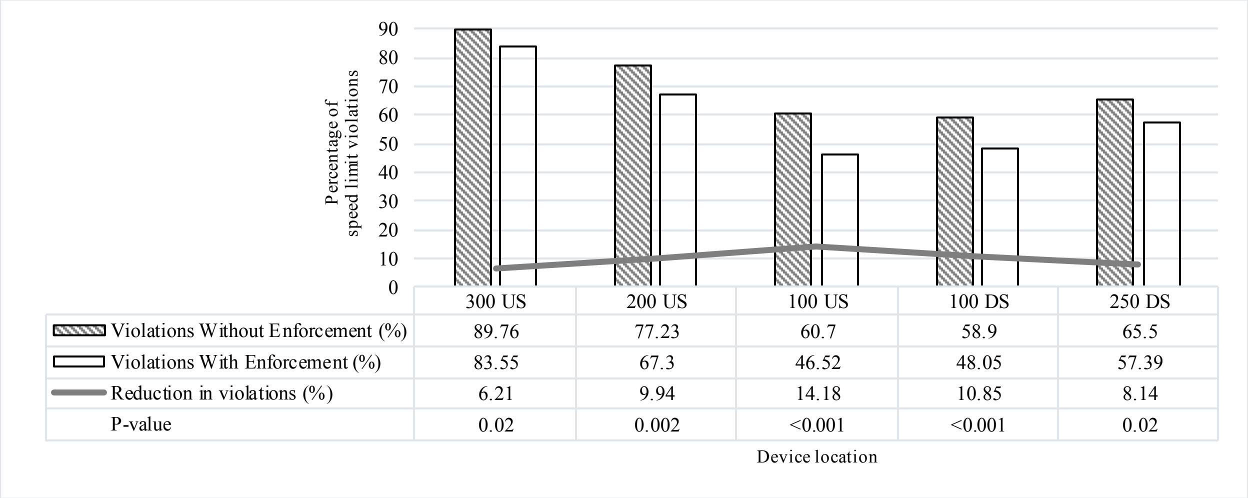
	500 US	300 US	100 US	100 DS	200 DS	300 DS
▨ Violations Without Enforcement (%)	57.83	73.23	36.9	43.48	31.97	28.6
☐ Violations With Enforcement (%)	43.71	49.21	24.31	30.96	29.17	3.53
— Reduction in violations (%)	14.12	24.02	12.59	12.53	2.8	25.04
P-value	<0.001	<0.001	<0.001	<0.001	0.048	<0.001

Saskatchewan Dr. btw. 107 - 105 St.



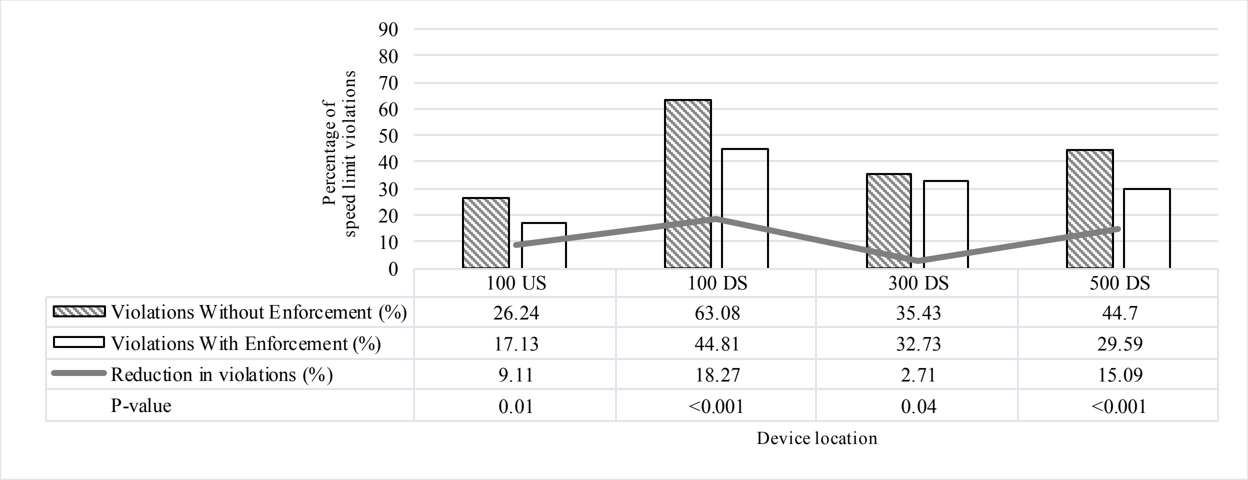
	300 US	250 US	100 US	100 DS	200 DS	300 DS
▨ Violations Without Enforcement (%)	60.05	61.33	57.62	63.8	68.06	52.75
☐ Violations With Enforcement (%)	58.08	45.72	46.6	55.2	53.34	39.91
— Reduction in violations (%)	1.96	15.62	11	8.66	14.72	12.84
P-value	0.31	0.005	0.015	0.092	<0.001	0.002

142 St. btw. 104A - 105 Ave.



	300 US	200 US	100 US	100 DS	250 DS
▨ Violations Without Enforcement (%)	89.76	77.23	60.7	58.9	65.5
☐ Violations With Enforcement (%)	83.55	67.3	46.52	48.05	57.39
— Reduction in violations (%)	6.21	9.94	14.18	10.85	8.14
P-value	0.02	0.002	<0.001	<0.001	0.02

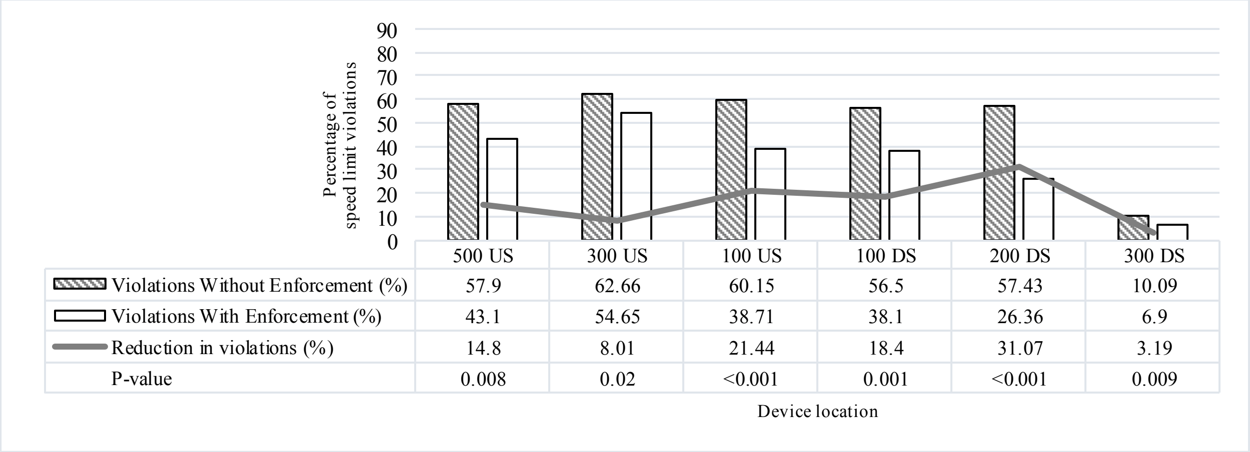
142 St. btw. 106 - 104 Ave.



	100 US	100 DS	300 DS	500 DS
▨ Violations Without Enforcement (%)	26.24	63.08	35.43	44.7
☐ Violations With Enforcement (%)	17.13	44.81	32.73	29.59
— Reduction in violations (%)	9.11	18.27	2.71	15.09
P-value	0.01	<0.001	0.04	<0.001

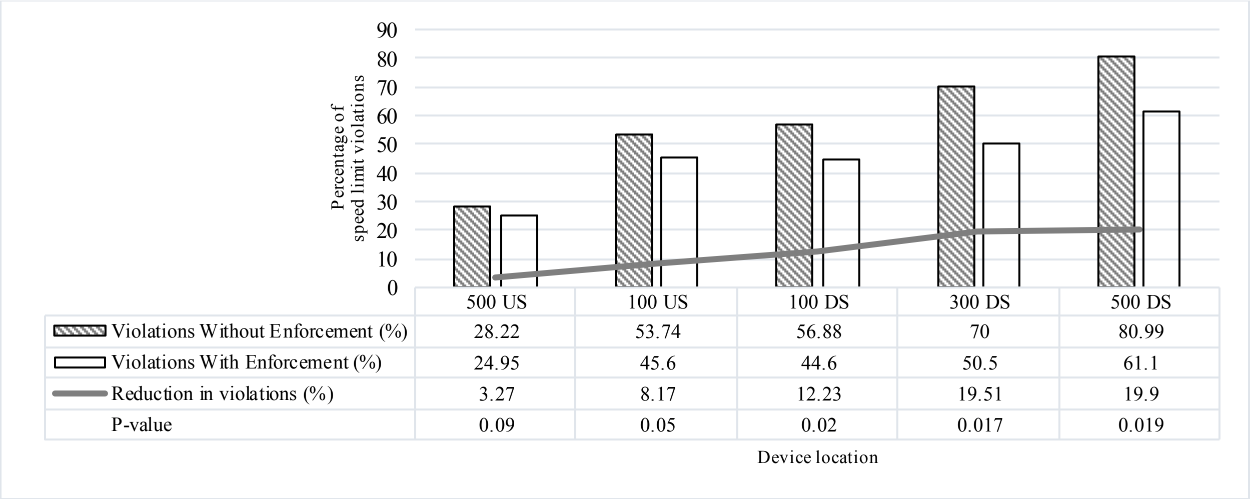
127 St. btw. 137 – 135 Ave.

Figure 15: Distance Halo Effect Analysis Results for Arterial Roads



	500 US	300 US	100 US	100 DS	200 DS	300 DS
▨ Violations Without Enforcement (%)	57.9	62.66	60.15	56.5	57.43	10.09
☐ Violations With Enforcement (%)	43.1	54.65	38.71	38.1	26.36	6.9
— Reduction in violations (%)	14.8	8.01	21.44	18.4	31.07	3.19
P-value	0.008	0.02	<0.001	0.001	<0.001	0.009

144 Ave. btw. 77 - 79 St.



	500 US	100 US	100 DS	300 DS	500 DS
▨ Violations Without Enforcement (%)	28.22	53.74	56.88	70	80.99
□ Violations With Enforcement (%)	24.95	45.6	44.6	50.5	61.1
— Reduction in violations (%)	3.27	8.17	12.23	19.51	19.9
P-value	0.09	0.05	0.02	0.017	0.019

132 Ave. btw. 123 - 121 St.

Figure 16: Distance Halo Effect Analysis Results for Collector Roads

5.4 Relationship Between Enforcement Intensity and Violations Reductions at Different Distances Upstream and Downstream of the MPE Location

In order to further understand the effects of MPE, a correlation analysis was carried out between different enforcement-intensity variables and violation reductions at the various distances upstream and downstream of the MPE location. The enforcement-intensity variables included the number of visits per week, the total number of enforcement hours per week, and the average hours per visit. The violation-reduction variables included the reductions in the percentage of speed limit violations at all devices at different distances (in meters) upstream and downstream of the MPE unit at all locations (500 US, 300-400 US, 200-250 US, 100 US, 100 DS, 200-250 DS, 300 DS, and 500 DS), and the average reduction for each location.

Table 18 presents the above-mentioned variables for the nine locations. The shaded cells indicate that the data was unavailable for that specific location. Table 19 shows the results of the correlation analysis, including the correlation coefficients and statistical significance. It was found that the total number of enforcement hours is significantly correlated with the percentage reductions in violations at all devices between 250 US and 300 DS of the MPE unit. In addition, the total number of enforcement hours had a strong correlation with the average reduction in violations at each location, with a correlation coefficient of 0.60. The average hours per visit had a very strong positive correlation with the reduction in violations upstream of the enforcement unit at the devices between 200 US and 400 US. The average number of hours per visit was also statistically correlated with the average reductions in violations at all locations.

These results indicate that the total number of enforcement hours and the average hours per visit strongly affect the reductions in violations at the different distances upstream and downstream of the MPE unit. In fact, the results of this study suggest that, on average, the reductions in speed limit violations for urban locations, due to exposure to MPE, would be highest (16%) at distances 100 meters upstream and downstream of the enforcement location, and it would gradually drop at further distances reaching a value of approximately 11% at 500 meters upstream and downstream of the MPE unit. These findings can help enforcement agencies better estimate the MPE program coverage, expected safety benefits, and the overall efficiency of the MPE program.

Table 18: Enforcement Intensity Variables and Violation Reduction Variables

Location number	Number of visits per week	Total number of enforcement hours per week	Average hours per visit	Violations reduction at 500 US	Violation reduction at 300 US - 400 US	Violation reduction at 200 US - 250 US	Violation reduction at 100 US	Violation reduction at 100 DS	Violation reduction at 200 DS - 250 DS	Violation reduction at 300 DS	Violation reduction at 500 DS	Average reduction %
1	13	42	3.23	▨	▨	21.21	30.29	39.49	7.54	20.87	▨	23.61
2	14	28	2.00	▨	6.21	9.94	14.18	10.85	8.14		▨	10
3	8	26	3.25	14.12	24.02	▨	12.59	12.53	2.8	25.04	▨	15.18
4	6	23	3.83	▨	18.15	19.47	18.87	17.44	▨	7.48	8.82	15.04
5	9	22	2.44	▨	1.96	15.62	11	8.66	14.72	12.84	▨	10.8
6	6	16	2.67	▨	▨	▨	9.11	18.27	▨	2.71	15.09	11.3
7	5	14	2.80	3.27	▨	▨	8.17	12.23	▨	19.51	19.9	12.62
8	5	12	2.40	▨	8.6	11.67	17.96	15.82	22.67	▨	7.39	14.02
9	5	10	2.00	14.8	8.01	▨	21.44	18.4	31.07	3.19	▨	16.1
Average	7.89	21.44	2.74	10.73	11.16	15.58	15.96	17.08	14.49	13.09	12.80	14.30

Table 19: Correlation Analysis Results (Distance Halo)

Variable 1	Variable 2	Correlation Coefficient	Significance
Total number of enforcement hours per week	Violation reduction at 200 US - 250 US (%)	0.6	0.1
Total number of enforcement hours per week	Violation reduction at 100 US (%)	0.5	0.08
Total number of enforcement hours per week	Violation reduction at 100 DS (%)	0.6	0.04
Total number of enforcement hours per week	Violation reduction at 300 DS (%)	0.6	0.07
Total number of enforcement hours per week	Average reduction (%)	0.6	0.04
Average hours per visit	Violation reduction at 300 US - 400 US (%)	0.8	0.02
Average hours per visit	Violation reduction at 200 US - 250 US (%)	0.9	0.01
Average hours per visit	Average reduction (%)	0.5	0.08

6 Conclusion and Recommendations

This thesis investigated the possibility of producing distance and time halo effects using mobile photo radar enforcement units deployed in Edmonton, Canada. A total of 14 locations on urban arterial and collector highways were subjected to MPE according to a pre-defined enforcement schedule that was designed as per the regular working hours of MPE personnel. However, five of the study locations were excluded from the analysis due to failures in the data collection devices. NC-200 traffic analyzers were used to collect the speeds and headways of vehicles during the eight weeks of the study.

Time series intervention analysis using ARIMA models was performed in order to estimate the effects of MPE on violations to speed limit and to quantify its time halo effects. First, ARIMA models were developed for pre-intervention periods and then ARIMAX intervention models were developed for the full time series of violations at each location. Finally, the values and significance of the intervention parameters were used to make inferences about the time halo effects produced by MPE operations. In addition, a correlation analysis was performed to study the relationship between enforcement intensity variables and the produced time halo effects and reductions in violations during the enforcement site-visits. The enforcement intensity variables included the number of site-visits at a location per week, the total number of enforcement hours per week, and the average number of enforcement hours per visit per week at a location.

In order to determine the distance halo effects, a two-sample *t*-test was used to compare between speed limit violations percentage during four enforcement site-visits and the corresponding times in days without enforcement at different distances upstream and downstream of the MPE units at nine study locations. Further, a correlation analysis between different enforcement intensity variables and the reductions in violations at different distances upstream and downstream of the MPE units was also carried out. Results of this analysis provided further insight into the effects of enforcement intensity on the produced distance halo effects.

6.1 Time Halo Effect

Results of the time series intervention analysis provided empirical evidence that MPE can produce time halo effects on urban roads that ranged from three to seven days after the last enforcement visit. It was concluded that, on average, if a MPE unit was deployed eight times during a week for a total of 22 hours (which translates to approximately 2.7 hours per visit) at an urban location, it would produce a time halo effect that would extend for a period of approximately five days, and reduce speed limit violation rates by almost 19%. In addition, the number of enforcement visits per week, the total enforcement hours per week, and the average hours per visit were found to be strongly correlated to the longevity of the time halo effects and the reduction of speed limit violations.

6.2 Distance Halo Effect

The results of this study suggested that MPE produced a distance halo effect at all of the studied locations over the entire studied corridor (500 meters upstream and downstream of the enforcement location). On average, if a MPE unit is deployed at an urban location eight times during a week for a total of 22 hours, with an average visit length of approximately 2.7 hours, reductions in speed limit violations that range from 10.73% to 17% are expected over a distance of 500 meters upstream and downstream of the MPE location. In addition, the reductions are expected to be highest at distances 100 meters away from the MPE unit and to gradually drop at further distances. Further, it was found that the total hours of enforcement per week and the average hours of enforcement per visit are statistically correlated to the expected reductions in speed limit violation percentages at various distances upstream and downstream of the enforcement location and the average reduction at a location.

6.3 Research Contributions

This study provides a valuable contribution to the enforcement and traffic safety literature. A significant gap exists in the literature in studying the time and distance halo effects of MPE, in general, and its effects on urban roads, in particular. But perhaps the biggest advantage of this study was in its ability to apply a robust statistical technique to empirically investigate the time and distance halo effects. Most previous work used a relatively small sample size in terms of the number of locations studied. More so, findings from different studies provided inconsistent and sometimes mixed results. Consequently, this study investigated the time and distance halo effects of MPE while accounting for several recommendations from previous studies. For instance, previous studies involved the use of very low (one site visit with two hours of enforcement) or very high (nine hours of enforcement per day) enforcement intensities. As a result, this study was designed to use a practical and realistic enforcement schedule based on the regular working hours of enforcement personnel. The relationship between different enforcement intensity variables and the halo effects produced and reductions in violations was studied, which was identified as another gap in previous research.

In terms of the practical contributions of this thesis, results found in this study can greatly assist enforcement agencies to optimize the use of limited resources allocated for MPE operations and design appropriate enforcement schedules that account for the halo effects of MPE units. This can be done by redeploying MPE units at more locations during the time halo effect period and by avoiding deploying MPE units at locations that fall within the distance halo effect of another MPE squad. As a result, enforcement agencies can improve the coverage of MPE programs by increasing the number of locations covered by MPE site-visits and maximize the expected safety benefits (e.g., increase compliance, reduce speeding). Further, the significant relationships found between different enforcement intensity variables and MPE halo effects and reductions in violations can provide decision makers with valuable information that help them in estimating the safety benefits associated with enforcement operations.

6.4 Research Limitations and Future Recommendations

6.4.1 Research Limitations

Limitations of this study can be summarized as follows:

1. Failures in the data collection devices at some locations limited the scope of analysis. This includes failures at the five locations that were excluded from the analysis as well as failures during specific time periods for the remaining locations.

2. Due to the study design, it was not possible to quantify time halo effects that were longer than seven days. This was due to the fact that the maximum unenforced time between rounds of enforcement was set at seven days.

3. Similarly, the distance halo effects were found to extend over the entire studied corridors, reaching 500 meters upstream and downstream of the enforcement locations. As no data collection devices were used at distances larger than 500 meters, it was not possible to determine the exact length of the distance halo effects.

4. Study results are valid for similar conditions (e.g., summer weather, dry pavement condition, and a citation delivery time of five days).

6.4.2 Future Recommendations

Future studies should try to minimize failures in data collection devices by considering less intrusive data collection technologies. Further, it is advisable to increase the unenforced time between enforcement rounds to more than seven days in order to quantify the effects of longer time halos. Moreover, using data collection devices at distances larger than 500 meters is recommended to explore the distance halo effects. In general, using a larger sample size with more locations and longer data collection periods are suggested in order to study the learning behavior of road users. In addition, studying the effects of changing the time difference between capturing the violation and delivering the citation, or replicating the study in different weather and pavement conditions is advisable. Finally, studying the site-learning and halo effects of using variable enforcement schedules rather than a fixed repeated schedule is worth future investigation.

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Appendix A– Placement of the NC-200 Devices at the study Locations

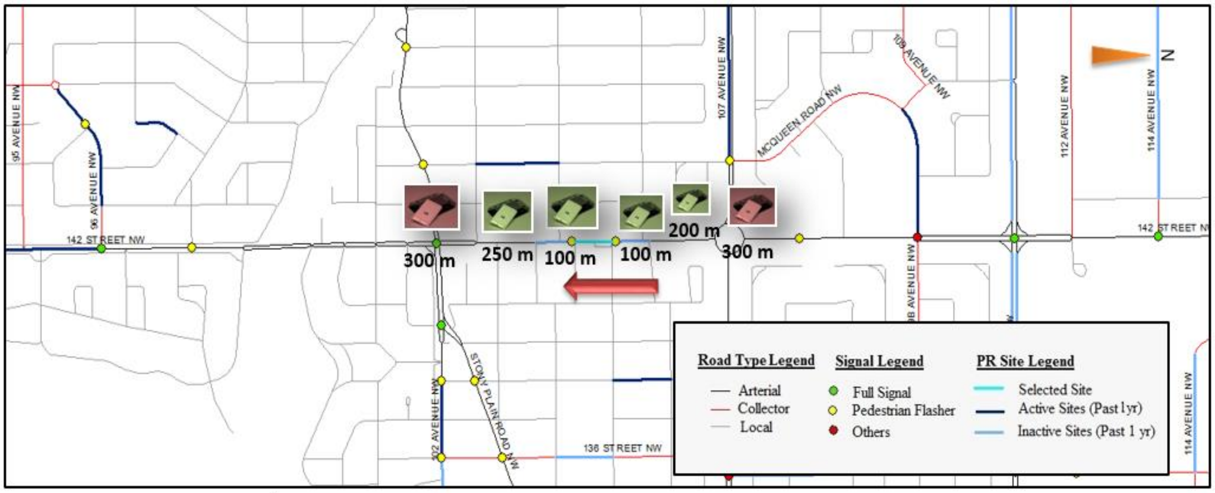

Figure 17: Locations of the NC-200 Devices at 142 St. btw. 106 - 104 Ave.

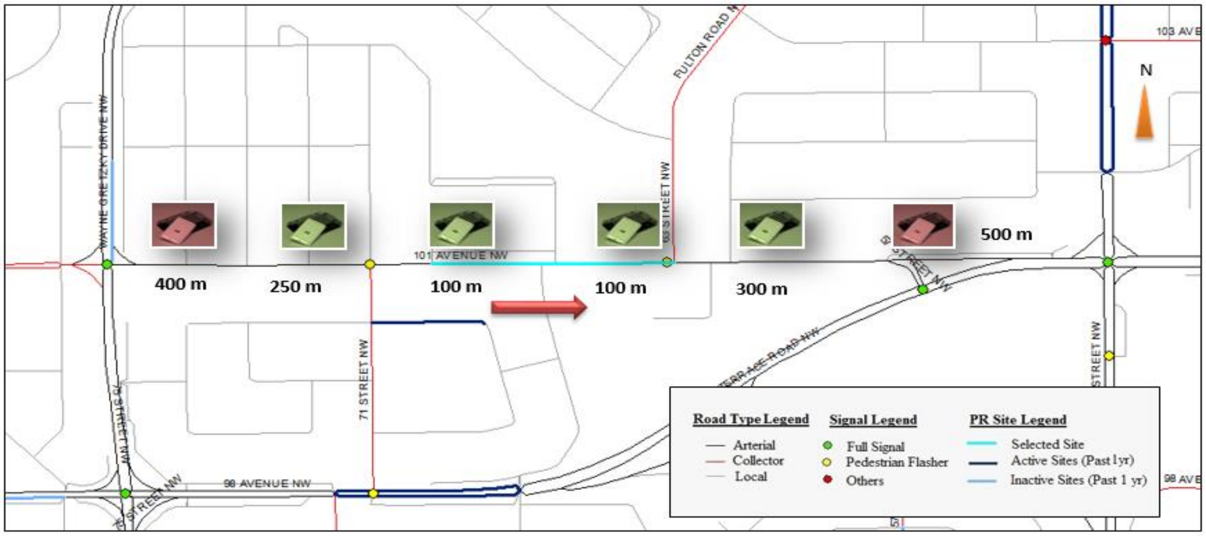

Figure 18: Locations of the NC-200 Devices at 101 Ave. btw. 67 - 70 St

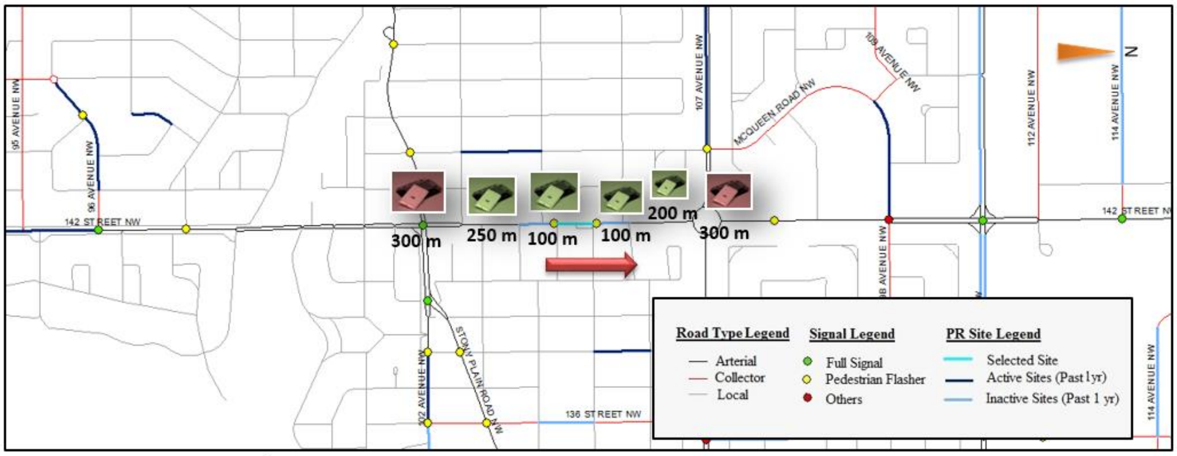

Figure 19: Locations of the NC-200 Devices at 142 St. btw. 104A - 105 Ave.

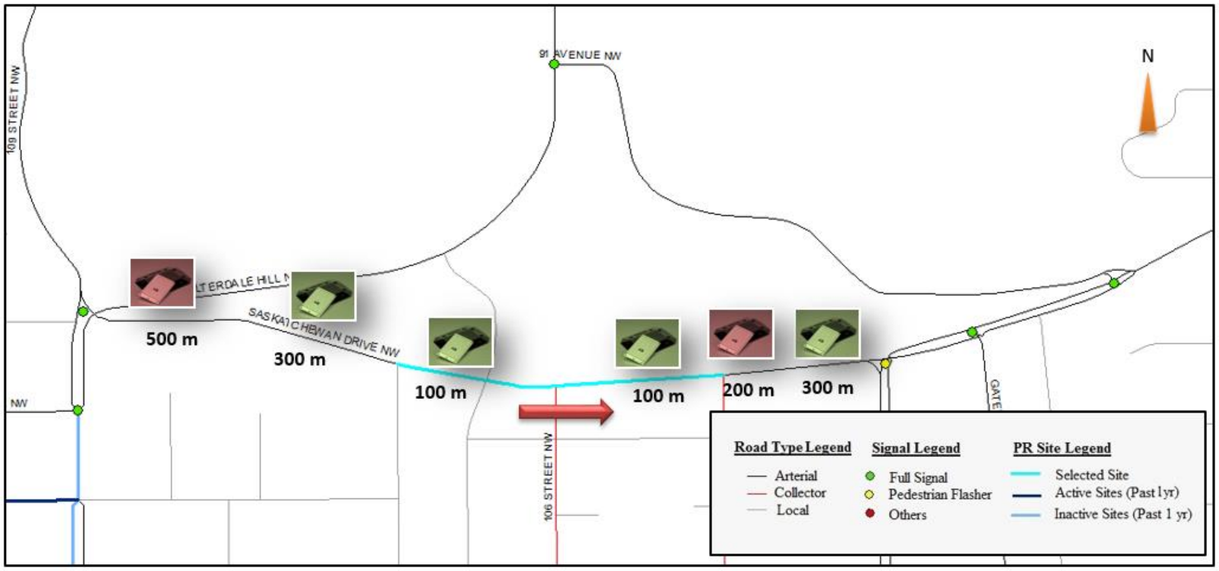

Figure 20: Locations of the NC-200 Devices at Saskatchewan Dr. btw. 107 - 105 St.

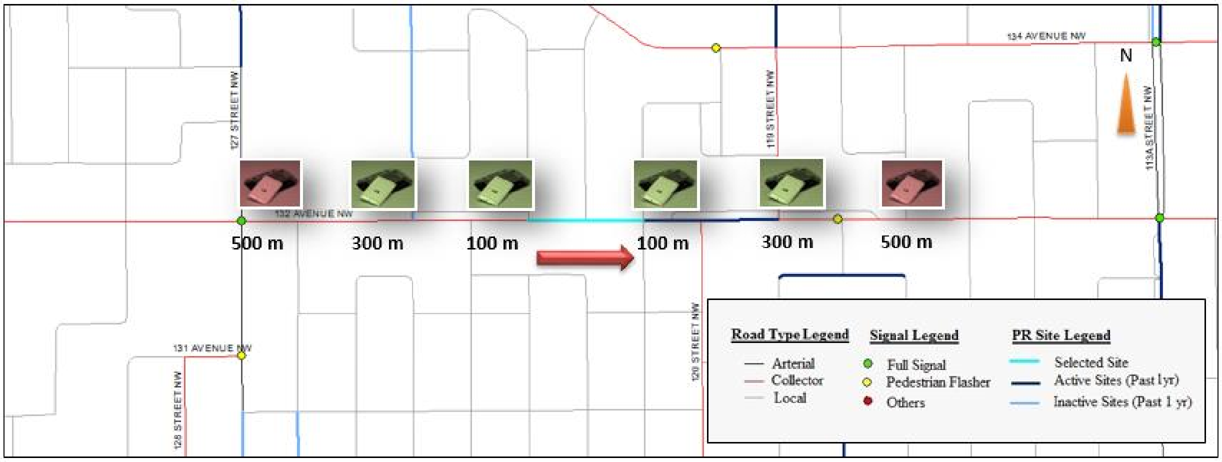

Figure 21: Locations of the NC-200 Devices at 132 Ave. btw. 123 - 121 St.

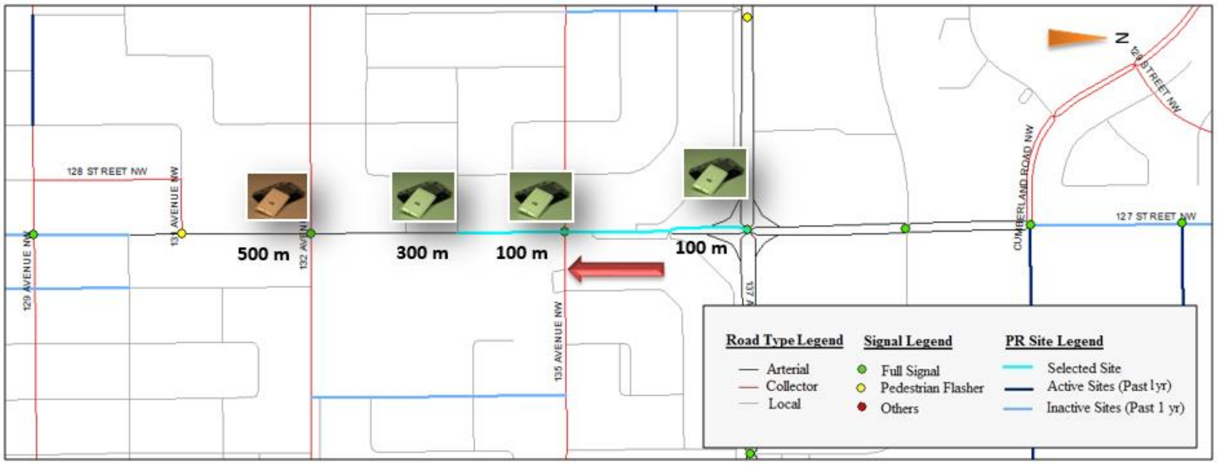

Figure 22: Locations of the NC-200 Devices at 127 St. btw. 137 - 135 Ave.

Figure 23: Locations of the NC-200 Devices at 109 St. btw. 108 - 110 Ave.

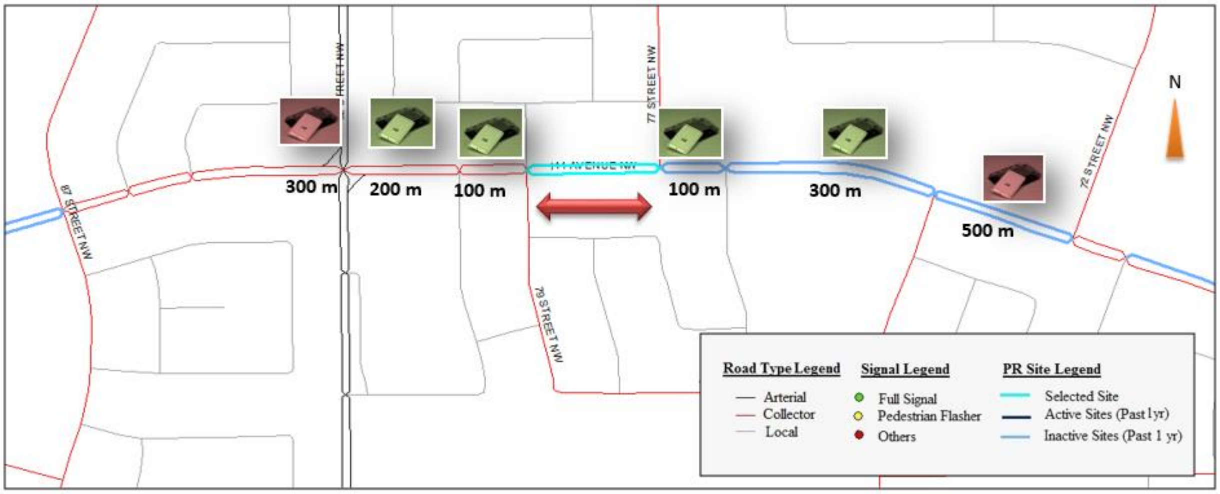

Figure 24: Locations of the NC-200 Devices at 144 Ave. btw. 77 - 79 St.

Figure 25: Locations of the NC-200 Devices at 156 St. btw. 94 - 92 Ave.

Appendix B– Parameters Estimation for ARIMAX Models Developed at All Locations

B1. Location 142 St. btw. 106 - 104 Ave.

Tables' titles are written in the form of (Location– (Period of the ARIMAX model)). For instance, a title written as Parameters Estimation- Location X- (1-4) would show the developed ARIMAX model parameters estimation table at location X for the period between weeks 1 and 4.

Table 20: Parameters Estimation- Location 142 St. btw. 106 - 104 Ave.- (1-4)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	65.74002	1.10701	59.39	<.0001	0	y	0
AR1,1	0.36269	0.04477	8.10	<.0001	1	y	0
AR2,1	0.22736	0.04790	4.75	<.0001	24	y	0
NUM1	-26.88470	1.52678	-17.61	<.0001	0	s	0
NUM2	-5.21490	2.16587	-2.41	0.01	0	s2	0

Table 21: Parameters Estimation- Location 142 St. btw. 106 - 104 Ave.- (4-5)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	44.18499	2.20236	20.06	<.0001	0	y	0
AR1,1	0.69410	0.04373	15.87	<.0001	1	y	0
AR1,2	-0.09206	0.04545	-2.03	0.0438	9	y	0
AR2,1	0.26799	0.05913	4.53	<.0001	23	y	0
AR2,2	0.27828	0.06006	4.63	<.0001	24	y	0
NUM1	11.95483	3.08673	3.87	0.0001	0	s	0

Table 22: Parameters Estimation- Location 142 St. btw. 106 - 104 Ave.- (5-6)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	53.02615	1.56165	33.96	<.0001	0	y	0
AR1,1	0.39017	0.08695	4.49	<.0001	2	y	0
AR1,2	-0.16288	0.09067	-1.80	0.0751	7	y	0
AR2,1	0.45442	0.09873	4.60	<.0001	24	y	0
NUM1	-4.79284	2.03781	-2.35	0.0204	0	s	0

Table 23: Parameters Estimation- Location 142 St. btw. 106 - 104 Ave.- (6-7)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	48.44042	1.65253	29.31	<.0001	0	y	0
AR1,1	0.21709	0.06327	3.43	0.0007	1	y	0
AR1,2	0.23740	0.06208	3.82	0.0002	2	y	0
AR1,3	-0.18510	0.05967	-3.10	0.0022	6	y	0
AR2,1	0.19186	0.06714	2.86	0.0046	24	y	0
NUM1	-14.81771	2.18044	-6.80	<.0001	0	s	0
NUM2	-9.05903	2.40536	-3.77	0.0002	0	s1	0
NUM3	-9.21052	2.17247	-4.24	<.0001	0	s2	0

Table 24: Parameters Estimation- Location 142 St. btw. 106 - 104 Ave.- (7-8)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	38.99597	1.74920	22.29	<.0001	0	y	0
AR1,1	0.31818	0.04598	6.92	<.0001	1	y	0
AR2,1	0.23039	0.04914	4.69	<.0001	24	y	0
NUM1	21.74014	2.20152	9.88	<.0001	0	s	0
NUM2	14.41716	2.31830	6.22	<.0001	0	s1	0
NUM3	5.72610	2.12683	2.69	0.0074	0	s2	0

B2. Location 101 Ave. btw. 67 - 70 St.

Table 25: Parameters Estimation- Location 101 Ave. btw. 67 - 70 St.- (1-2)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	71.60774	1.10955	64.54	<.0001	0	y	0
AR1,1	0.30984	0.06429	4.82	<.0001	1	y	0
AR1,2	-0.13715	0.06333	-2.17	0.0314	4	y	0
AR2,1	0.30146	0.06758	4.46	<.0001	24	y	0
NUM1	-18.03245	4.25319	-4.24	<.0001	0	s1	0
DEN1,1	0.35703	0.15187	2.35	0.0196	1	s1	0
NUM2	-22.36054	1.38070	-16.20	<.0001	0	s2	0

Table 26: Parameters Estimation- Location 101 Ave. btw. 67 - 70 St.- (2-3)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	48.73807	1.04727	46.54	<.0001	0	y	0
AR1,1	0.35522	0.05420	6.55	<.0001	1	y	0
AR1,2	-0.14618	0.05456	-2.68	0.0078	18	y	0
AR2,1	0.20388	0.05817	3.50	0.0005	22	y	0
AR2,2	0.11411	0.05746	1.99	0.0480	23	y	0
AR2,3	0.20190	0.05754	3.51	0.0005	24	y	0
NUM1	14.4986	1.57256	9.22	<.0001	0	s2	0

Table 27: Parameters Estimation- Location 101 Ave. btw. 67 - 70 St.- (3-4)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	63.07391	1.43599	43.92	<.0001	0	y	0
AR1,1	0.52146	0.05374	9.70	<.0001	1	y	0
AR2,1	0.24256	0.06396	3.79	0.0002	24	y	0
NUM1	-10.56800	3.11254	-3.40	0.0008	0	s1	0
DEN1,1	-0.88535	0.05528	-16.02	<.0001	1	s1	0
NUM2	-13.71136	2.03543	-6.74	<.0001	0	s2	0

Table 28: Parameters Estimation- Location 101 Ave. btw. 67 - 70 St.- (4-7)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	48.98749	0.84672	57.86	<.0001	0	y	0
AR1,1	0.30104	0.03939	7.64	<.0001	1	y	0
AR1,2	0.19634	0.03907	5.03	<.0001	2	y	0
AR1,3	-0.12790	0.03622	-3.53	0.0004	6	y	0
AR1,4	-0.13523	0.03674	-3.68	0.0003	17	y	0
AR2,1	0.29553	0.03989	7.41	<.0001	24	y	0
NUM1	-5.37660	1.30269	-4.13	<.0001	0	s1	0
NUM2	7.98243	1.16691	6.84	<.0001	0	s2	0
NUM3	12.07886	1.59578	7.57	<.0001	0	s3	0

Table 29: Parameters Estimation- Location 101 Ave. btw. 67 - 70 St.- (7-8)

Paramete	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	61.12917	0.76843	79.55	<.0001	0	y	0
AR1,1	0.31248	0.05791	5.40	<.0001	1	y	0
AR1,2	-0.11020	0.06005	-1.84	0.0676	6	y	0
AR1,3	-0.16510	0.06078	-2.72	0.0070	8	y	0
AR1,4	-0.19023	0.06081	-3.13	0.0020	17	y	0
AR2,1	0.14355	0.06420	2.24	0.0262	23	y	0
AR2,2	0.38497	0.06678	5.77	<.0001	48	y	0
NUM1	-16.81846	1.56801	-10.73	<.0001	0	s2	0
DEN1,1	-0.74278	0.07820	-9.50	<.0001	1	s2	0
NUM2	-11.29064	1.00927	-11.19	<.0001	0	s3	0

B3. Location 142 St. btw. 104A - 105 Ave.

Table 30: Parameters Estimation- Location 142 St. btw. 104A - 105 Ave.- (1-2)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	72.51629	1.06002	68.41	<.0001	0	y	0
AR1,1	0.23333	0.07219	3.23	0.0015	1	y	0
AR2,1	0.44208	0.07256	6.09	<.0001	24	y	0
NUM1	-3.02981	1.45786	-2.08	0.03	0	s	0

Table 31: Parameters Estimation- Location 142 St. btw. 104A - 105 Ave.- (2-3)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	71.21877	1.39532	51.04	<.0001	0	y	0
AR1,1	0.14853	0.05568	2.67	0.0080	1	y	0
AR2,1	0.17106	0.05337	3.20	0.0015	23	y	0
AR2,2	0.36112	0.05333	6.77	<.0001	24	y	0
NUM1	-17.06550	1.55441	-10.98	<.0001	0	s	0
NUM2	-9.07311	2.03587	-4.46	<.0001	0	s1	0

Table 32: Parameters Estimation- Location 142 St. btw. 104A - 105 Ave.- (4-5)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	63.72912	0.99868	65.82	<.0001	0	y	0
MA1,1	-0.29132	0.05567	-5.23	<.0001	1	y	0
MA1,2	-0.11575	0.05554	-2.08	0.0380	3	y	0
MA2,1	-0.18572	0.05855	-3.17	0.0017	23	y	0
MA2,2	-0.15093	0.05911	-2.55	0.0112	24	y	0
NUM1	0.84585	1.31813	0.64	0.5215	0	s	0

B4. Location Saskatchewan Dr. btw. 107 - 105 St.

Table 33: Parameters Estimation- Location Saskatchewan Dr. btw. 107 - 105 St.- (1-4)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	41.08055	1.91111	21.50	<.0001	0	y	0
AR1,1	0.52707	0.04370	12.06	<.0001	1	y	0
AR1,2	-0.12416	0.04276	-2.90	0.0040	6	y	0
AR1,3	0.26720	0.04826	5.54	<.0001	23	y	0
AR2,1	0.22504	0.06204	3.63	0.0003	24	y	0
NUM1	-4.12610	2.28775	-1.80	0.0723	0	s	0
NUM2	-16.23648	2.55264	-6.36	<.0001	0	s1	0

Table 34: Parameters Estimation- Location Saskatchewan Dr. btw. 107 - 105 St.- (4-6)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	19.67532	1.40537	14.00	<.0001	0	y	0
AR1,1	0.52778	0.04852	10.88	<.0001	1	y	0
AR1,2	0.18657	0.05025	3.71	0.0002	2	y	0
AR1,3	-0.13416	0.04061	-3.30	0.0010	5	y	0
AR2,1	0.16270	0.04861	3.35	0.0009	23	y	0
AR2,2	0.24842	0.04889	5.08	<.0001	24	y	0
NUM1	17.76349	1.84125	9.65	<.0001	0	s	0
NUM2	14.33273	2.29856	6.24	<.0001	0	s1	0

Table 35: Parameters Estimation- Location Saskatchewan Dr. btw. 107 - 105 St.- (6-7)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	33.37774	1.65453	20.17	<.0001	0	y	0
AR1,1	0.47398	0.07494	6.32	<.0001	1	y	0
AR2,1	0.44367	0.08454	5.25	<.0001	24	y	0
NUM1	2.41437	2.13317	1.13	0.2596	0	s	0

Table 36: Parameters Estimation- Location Saskatchewan Dr. btw. 107 - 105 St.- (7-8)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	31.09237	0.89441	39.24	<.0001	0	y	0
AR1,1	0.38650	0.05938	6.51	<.0001	1	y	0
AR1,2	-0.19531	0.05994	-3.26	0.0013	11	y	0
AR1,3	-0.15207	0.05984	-2.54	0.0117	17	y	0
AR2,1	0.26290	0.06690	3.93	0.0001	24	y	0
AR2,2	0.21727	0.07325	2.97	0.0033	48	y	0
NUM1	-5.17837	1.19372	-4.34	<.0001	0	s	0
NUM2	-2.67125	1.29081	-2.07	0.0396	0	s1	0

Table 37: Parameters Estimation- Location Saskatchewan Dr. btw. 107 - 105 St.- (8)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	33.15067	1.20795	27.44	<.0001	0	y	0
AR1,1	0.23218	0.06443	3.60	0.0004	1	y	0
AR2,1	0.42890	0.06863	6.25	<.0001	24	y	0
AR2,2	0.30484	0.07338	4.15	<.0001	48	y	0
NUM1	-4.11299	1.29134	-3.19	0.0016	0	s	0

B5. Location 132 Ave. btw. 123 - 121 St.

Table 38: Parameters Estimation- Location 132 Ave. btw. 123 - 121 St.- (1-4)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	61.97197	0.88426	70.08	<.0001	0	y	0
AR1,1	0.20066	0.04495	4.46	<.0001	1	y	0
AR1,2	0.10895	0.04520	2.41	0.0163	2	y	0
AR1,3	-0.09216	0.04451	-2.07	0.0389	5	y	0
AR1,4	-0.12195	0.04457	-2.74	0.0064	16	y	0
AR2,1	0.11750	0.04582	2.56	0.0106	23	y	0
AR2,2	0.22638	0.04571	4.95	<.0001	24	y	0
NUM1	-8.78812	1.56165	-5.63	<.0001	0	s	0
NUM2	-6.07381	1.18111	-5.14	<.0001	0	s1	0

Table 39: Parameters Estimation- Location 132 Ave. btw. 123 - 121 St.- (4-5)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	56.46897	1.71963	32.84	<.0001	0	y	0
AR1,1	0.24831	0.05540	4.48	<.0001	1	y	0
AR2,1	0.11320	0.05528	2.05	0.0414	21	y	0
AR2,2	0.19436	0.05773	3.37	0.0009	24	y	0
AR2,3	0.18504	0.06005	3.08	0.0022	48	y	0
NUM1	-8.58681	2.01992	-4.25	<.0001	0	s1	0
NUM2	-12.99535	2.54746	-5.10	<.0001	0	s2	0
NUM3	6.11026	2.48248	2.46	0.0144	0	s3	0

B6. Location 127 St. btw. 137 - 135 Ave.

Table 40: Parameters Estimation- Location 127 St. btw. 137 - 135 Ave.- (1-3)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	70.71346	1.89644	37.29	<.0001	0	y	0
AR1,1	0.45957	0.04978	9.23	<.0001	1	y	0
AR1,2	0.19571	0.05208	3.76	0.0002	2	y	0
AR1,3	-0.15112	0.04601	-3.28	0.0011	4	y	0
AR2,1	0.16880	0.04456	3.79	0.0002	23	y	0
AR2,2	0.51435	0.04440	11.58	<.0001	24	y	0
NUM1	-26.28623	2.25659	-11.65	<.0001	0	s	0
NUM2	-6.33459	2.95374	-2.14	0.0326	0	s1	0

Table 41: Parameters Estimation- Location 127 St. btw. 137 - 135 Ave.- (3-4)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	65.52643	2.06935	31.67	<.0001	0	y	0
AR1,1	0.49072	0.06478	7.58	<.0001	1	y	0
AR1,2	0.11242	0.06754	1.66	0.0974	2	y	0
AR1,3	-0.13967	0.05907	-2.36	0.0189	4	y	0
AR2,1	0.17159	0.05994	2.86	0.0046	22	y	0
AR2,2	0.18468	0.06011	3.07	0.0024	23	y	0
AR2,3	0.39787	0.05958	6.68	<.0001	24	y	0
NUM1	-12.53028	2.41940	-5.18	<.0001	0	s1	0

Table 42: Parameters Estimation- Location 127 St. btw. 137 - 135 Ave.- (4-6)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	54.17282	2.10240	25.77	<.0001	0	y	0
AR1,1	0.41307	0.04916	8.40	<.0001	1	y	0
AR1,2	0.15283	0.04937	3.10	0.0021	2	y	0
AR2,1	0.32726	0.04376	7.48	<.0001	23	y	0
AR2,2	0.43072	0.04343	9.92	<.0001	24	y	0
NUM1	-5.16150	2.51187	-2.05	0.0405	0	s	0

Table 43: Parameters Estimation- Location 127 St. btw. 137 - 135 Ave.- (6-7)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	49.36674	2.04243	25.15	<.0001	0	y	0
AR1,1	0.40991	0.05261	7.79	<.0001	1	y	0
AR1,2	0.09027	0.05333	1.69	0.0915	3	y	0
AR2,1	0.40941	0.05128	7.98	<.0001	23	y	0
AR2,2	0.37997	0.05081	7.48	<.0001	24	y	0
NUM1	9.77655	2.43890	4.01	<.0001	0	s	0

Table 44: Parameters Estimation- Location 127 St. btw. 137 - 135 Ave.- (7-8)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	55.89047	2.85571	19.57	<.0001	0	y	0
AR1,1	0.31943	0.08452	3.78	0.0002	1	y	0
AR1,2	0.23501	0.08477	2.77	0.0064	2	y	0
AR2,1	0.24172	0.08264	2.93	0.0040	23	y	0
AR2,2	0.49374	0.08364	5.90	<.0001	24	y	0
NUM1	-1.57914	3.01911	-0.52	0.6018	0	s	0

B7. Location 109 St. btw. 108 - 110 Ave.

Table 45: Parameters Estimation- Location 109 St. btw. 108 - 110 Ave.- (1-5)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	76.0111	1.66351	42.49	<.0001	0	y	0
AR1,1	0.56600	0.05241	10.80	<.0001	1	y	0
AR2,1	0.33731	0.06374	5.29	<.0001	24	y	0
NUM1	-20.6912	2.17805	-6.69	<.0001	0	s	0

Table 46: Parameters Estimation- Location 109 St. btw. 108 - 110 Ave.- (5-7)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	56.83392	1.50753	37.70	<.0001	0	y	0
AR1,1	0.49936	0.04686	10.66	<.0001	1	y	0
AR1,2	0.10052	0.04635	2.17	0.0306	2	y	0
AR1,3	-0.10276	0.03863	-2.66	0.0081	14	y	0
AR2,1	0.33202	0.04528	7.33	<.0001	24	y	0
NUM1	14.25220	1.82371	7.81	<.0001	0	s	0
NUM2	19.16286	2.63049	7.28	<.0001	0	s2	0

Table 47: Parameters Estimation- Location 109 St. btw. 108 - 110 Ave.- (7-8)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	72.29035	3.57521	20.22	<.0001	0	y	0
AR1,1	0.55016	0.06745	8.16	<.0001	1	y	0
AR1,2	0.12937	0.06784	1.91	0.0579	2	y	0
AR2,1	0.21424	0.07066	3.03	0.0027	23	y	0
AR2,2	0.30850	0.07082	4.36	<.0001	24	y	0
NUM1	-10.06422	3.91112	-2.57	0.0107	0	s	0

B8. Location 144 Ave. btw. 77 - 79 St.

Table 48: Parameters Estimation- Location 144 Ave. btw. 77 - 79 St.- (1-5)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	61.06752	1.28117	47.67	<.0001	0	y	0
MA1,1	0.93473	0.07617	12.27	<.0001	24	y	0
AR1,1	0.28001	0.04380	6.39	<.0001	1	y	0
AR2,1	1.00000	0.05583	17.91	<.0001	24	y	0
NUM1	-3.10198	1.45653	-2.13	0.0337	0	s	0
NUM2	-18.26871	1.51178	-12.08	<.0001	0	s1	0
NUM3	-12.78533	1.49943	-8.53	<.0001	0	s2	0

Table 49: Parameters Estimation- Location 144 Ave. btw. 77 - 79 St.- (4-7)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	43.78907	1.13973	38.42	<.0001	0	y	0
AR1,1	0.20940	0.03935	5.32	<.0001	1	y	0
AR2,1	0.11482	0.03966	2.89	0.0039	22	y	0
AR2,2	0.12903	0.03961	3.26	0.0012	23	y	0
AR2,3	0.14148	0.03970	3.56	0.0004	24	y	0
NUM1	7.33455	1.63165	4.50	<.0001	0	s	0
NUM2	18.03352	1.84571	9.77	<.0001	0	s2	0
NUM3	15.22923	1.71886	8.86	<.0001	0	s3	0
NUM4	19.31957	2.20011	8.78	<.0001	0	s4	0

B9. Location 156 St. btw. 94 - 92 Ave.

Table 50: Parameters Estimation- Location 156 St. btw. 94 - 92 Ave.- (1-3)

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	83.23420	0.67059	124.12	<.0001	0	y	0
AR1,1	0.26939	0.04609	5.84	<.0001	1	y	0
AR1,2	-0.10071	0.04594	-2.19	0.0289	15	y	0
AR1,3	0.25203	0.04839	5.21	<.0001	23	y	0
AR2,1	0.12571	0.05347	2.35	0.0192	24	y	0
NUM1	-12.73112	0.85336	-14.92	<.0001	0	s	0

Appendix C– Autocorrelation Check of Residuals for ARIMAX Models Developed at All Locations

C1. Location 142 St. btw. 106 - 104 Ave.

Table 51: Autocorrelation Check of Residuals- Location 142 St. btw. 106 - 104 Ave.- (1-4)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	5.75	4	0.2184	-0.028	0.044	0.078	0.028	0.040	-0.038
12	8.08	10	0.6212	0.012	-0.019	-0.064	-0.006	-0.018	-0.009
18	15.72	16	0.4727	0.024	-0.022	-0.044	-0.064	-0.089	-0.038
24	27.47	22	0.1941	-0.018	0.086	-0.047	-0.012	0.119	-0.025
30	30.86	28	0.3231	0.034	0.063	-0.035	-0.002	0.000	-0.029
36	36.26	34	0.3636	-0.049	-0.022	-0.007	-0.053	0.054	-0.049
42	37.32	40	0.5913	0.001	-0.004	0.023	0.006	-0.024	-0.031
48	46.99	46	0.4317	-0.057	0.009	-0.006	0.062	0.055	0.095

Table 52: Autocorrelation Check of Residuals- Location 142 St. btw. 106 - 104 Ave.- (4-5)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.28	2	0.1943	-0.068	0.065	0.018	-0.020	0.021	-0.043
12	10.47	8	0.2336	-0.084	0.018	0.038	0.026	0.043	-0.117
18	17.00	14	0.2559	-0.009	-0.045	-0.128	-0.013	0.034	-0.051
24	20.35	20	0.4360	-0.025	0.007	0.075	0.051	-0.030	-0.038
30	27.33	26	0.3922	0.078	0.058	-0.041	0.085	-0.064	0.012
36	30.39	32	0.5479	-0.044	-0.002	-0.068	-0.028	-0.042	-0.027
42	36.71	38	0.5291	0.014	-0.012	-0.048	-0.083	-0.024	-0.097
48	40.23	44	0.6341	-0.011	0.018	-0.059	0.031	0.018	0.073

Table 53: Autocorrelation Check of Residuals- Location 142 St. btw. 106 - 104 Ave.- (5-6)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	6.59	3	0.0863	-0.044	0.068	0.145	-0.088	-0.081	-0.109
12	13.01	9	0.1623	-0.074	-0.073	0.132	0.057	-0.077	0.111
18	16.26	15	0.3653	0.026	-0.088	-0.040	-0.056	-0.103	-0.007
24	24.34	21	0.2767	-0.051	-0.153	0.061	0.108	0.120	-0.008

Table 54: Autocorrelation Check of Residuals- Location 142 St. btw. 106 - 104 Ave.- (6-7)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.12	2	0.2106	0.010	0.036	-0.066	-0.044	-0.068	0.006
12	6.95	8	0.5418	-0.103	-0.036	0.016	0.008	-0.047	0.022
18	16.66	14	0.2749	-0.083	-0.135	0.002	-0.044	-0.097	-0.015
24	31.21	20	0.0525	-0.055	-0.031	0.154	0.108	0.116	-0.030
30	37.16	26	0.0722	0.013	0.063	0.099	-0.046	-0.063	-0.037
36	40.54	32	0.1430	-0.008	-0.011	-0.052	-0.057	-0.069	-0.027
42	42.88	38	0.2700	0.031	0.012	0.021	-0.051	-0.021	-0.057
48	57.14	44	0.0883	-0.015	-0.016	0.061	-0.025	0.149	0.139

Table 55: Autocorrelation Check of Residuals- Location 142 St. btw. 106 - 104 Ave.- (7-8)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	5.95	4	0.2029	-0.019	0.025	0.101	0.012	0.041	0.025
12	9.46	10	0.4894	-0.023	-0.013	-0.040	-0.066	-0.024	-0.025
18	15.93	16	0.4577	-0.060	-0.068	-0.033	-0.026	0.007	-0.066
24	24.95	22	0.2997	0.004	-0.108	-0.033	0.039	-0.067	-0.032
30	31.89	28	0.2789	0.044	0.042	-0.037	-0.098	-0.016	-0.008
36	34.43	34	0.4472	-0.027	0.039	0.036	-0.002	-0.042	-0.005
42	36.63	40	0.6226	-0.034	-0.016	-0.006	-0.008	-0.048	-0.029
48	50.09	46	0.3145	0.007	0.036	0.047	-0.002	0.060	0.143

C2. Location 101 Ave. btw. 67 - 70 St.

Table 56: Autocorrelation Check of Residuals- Location 101 Ave. btw. 67 - 70 St.- (1-2)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.67	3	0.2995	-0.036	0.058	0.072	0.016	-0.017	-0.069
12	8.47	9	0.4876	-0.112	0.042	-0.053	-0.038	0.031	0.003
18	15.94	15	0.3864	-0.054	-0.062	0.038	-0.071	-0.060	-0.111
24	23.94	21	0.2958	-0.033	-0.015	-0.061	0.134	0.069	-0.053
30	30.38	27	0.2974	0.112	0.063	-0.025	-0.008	-0.076	0.031
36	36.95	33	0.2912	-0.017	-0.102	0.068	0.028	0.007	-0.087
42	47.47	39	0.1656	0.102	-0.037	-0.036	-0.042	-0.015	-0.147

Table 57: Autocorrelation Check of Residuals- Location 101 Ave. btw. 67 - 70 St.- (2-3)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	1.71	1	0.1914	-0.032	0.041	0.029	-0.006	-0.016	0.040
12	6.13	7	0.5241	0.037	0.090	0.028	-0.018	0.042	0.041
18	12.34	13	0.4996	-0.076	-0.048	0.070	-0.037	-0.064	0.026
24	15.38	19	0.6979	-0.013	-0.051	-0.070	0.039	-0.007	0.002
30	20.71	25	0.7087	0.101	0.036	-0.032	-0.025	-0.026	0.044
36	27.01	31	0.6718	-0.051	-0.066	0.097	0.006	-0.039	-0.020
42	36.53	37	0.4909	0.104	0.027	-0.001	0.048	0.043	-0.105
48	49.53	43	0.2290	-0.049	-0.046	0.041	-0.112	0.120	0.051

Table 58: Autocorrelation Check of Residuals- Location 101 Ave. btw. 67 - 70 St.- (3-4)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	6.34	4	0.1752	-0.057	0.061	0.104	0.027	-0.059	-0.035
12	7.69	10	0.6593	-0.058	0.013	-0.017	-0.018	-0.026	0.007
18	13.10	16	0.6656	-0.002	-0.070	-0.011	-0.073	0.004	-0.091
24	17.66	22	0.7258	-0.052	-0.044	-0.020	0.087	0.029	-0.046
30	24.73	28	0.6423	0.077	0.080	0.017	-0.028	-0.021	-0.099
36	27.32	34	0.7847	-0.040	-0.067	-0.022	0.006	0.028	0.033
42	35.41	40	0.6767	-0.041	-0.029	-0.052	-0.051	0.023	-0.131
48	54.62	46	0.1798	0.025	0.095	-0.039	0.053	0.114	0.178

Table 59: Autocorrelation Check of Residuals- Location 101 Ave. btw. 67 - 70 St.- (4-7)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.84	1	0.10	0.004	0.009	0.018	-0.006	-0.075	0.001
12	6.98	7	0.4308	0.013	0.032	-0.053	0.025	-0.018	-0.006
18	9.77	13	0.7126	0.009	-0.017	0.019	-0.056	0.014	0.018
24	12.79	19	0.8489	-0.049	0.001	0.007	0.001	0.036	-0.030
30	21.47	25	0.6663	0.061	-0.059	0.030	-0.037	-0.046	-0.041
36	28.21	31	0.6104	-0.067	-0.045	0.013	-0.040	0.042	-0.010
42	33.67	37	0.6258	-0.009	0.004	-0.033	-0.003	-0.027	-0.079
48	49.23	43	0.2380	-0.049	-0.057	0.088	0.006	0.079	0.058

Table 60: Autocorrelation Check of Residuals- Location 101 Ave. btw. 67 - 70 St.- (7-8)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	.	0	.	-0.019	0.003	0.026	0.088	0.003	0.006
12	6.14	6	0.4078	-0.014	0.041	-0.075	-0.052	0.055	-0.015
18	9.17	12	0.6885	0.019	0.026	0.001	-0.065	-0.014	0.071
24	15.47	18	0.6296	0.014	0.068	-0.008	0.099	-0.045	0.070
30	24.41	24	0.4383	0.027	0.164	-0.008	-0.002	0.023	-0.042
36	30.91	30	0.4197	0.048	-0.050	-0.063	-0.052	-0.032	-0.093
42	34.64	36	0.5331	0.054	-0.004	-0.081	-0.040	0.002	0.028
48	47.05	42	0.2734	-0.015	0.004	0.066	0.180	0.013	-0.031

C3. Location 142 St. btw. 104A - 105 Ave.

Table 61: Autocorrelation Check of Residuals- Location 142 St. btw. 104A - 105 Ave.- (1-2)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	5.49	4	0.2403	0.021	-0.059	-0.109	-0.072	-0.086	-0.010
12	14.86	10	0.1374	0.184	-0.090	0.008	-0.026	-0.048	0.051
18	16.90	16	0.3922	0.066	0.020	-0.036	0.016	0.045	-0.039
24	21.44	22	0.4937	-0.015	-0.119	-0.025	-0.013	0.072	-0.032
30	25.11	28	0.6220	-0.026	-0.036	-0.058	-0.040	-0.044	0.087
36	28.37	34	0.7397	-0.026	0.007	-0.038	0.011	0.085	-0.067

Table 62: Autocorrelation Check of Residuals- Location 142 St. btw. 104A - 105 Ave.- (2-3)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	2.72	3	0.4367	-0.003	0.027	-0.055	0.024	-0.059	0.020
12	5.30	9	0.8074	0.021	-0.060	-0.025	0.054	-0.002	-0.008
18	17.49	15	0.2903	-0.054	0.036	-0.042	0.005	-0.129	-0.114
24	26.83	21	0.1766	-0.024	0.139	-0.072	0.021	-0.039	-0.008
30	39.56	27	0.0563	0.026	0.146	-0.052	-0.053	-0.065	0.065
36	44.76	33	0.0831	-0.056	-0.013	0.002	0.038	0.058	0.079
42	46.02	39	0.2044	0.031	-0.016	-0.013	0.019	-0.020	0.035
48	51.67	45	0.2295	-0.019	-0.045	0.043	0.048	0.045	-0.079

Table 63: Autocorrelation Check of Residuals- Location 142 St. btw. 104A - 105 Ave.- (4-5)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	2.90	2	0.2341	-0.010	-0.014	-0.003	-0.023	0.074	0.054
12	13.99	8	0.0819	-0.035	-0.082	-0.071	0.088	0.117	0.007
18	17.06	14	0.2529	-0.012	-0.036	-0.053	-0.027	-0.026	0.061
24	23.54	20	0.2629	-0.078	0.011	-0.074	0.081	0.020	0.027
30	27.51	26	0.3832	0.062	-0.043	0.018	-0.015	0.016	-0.071
36	31.26	32	0.5037	-0.041	-0.038	0.002	0.053	-0.033	0.061
42	35.99	38	0.5629	-0.011	0.028	-0.048	-0.086	-0.051	0.005
48	46.55	44	0.3680	0.015	-0.055	0.040	0.041	0.061	0.136

C4. Location Saskatchewan Dr. btw. 107 - 105 St.

Table 64: Autocorrelation Check of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (1-4)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.81	2	0.1489	-0.076	0.041	-0.061	0.005	0.002	0.021
12	12.11	8	0.1466	-0.057	-0.052	0.014	0.011	-0.096	-0.097
18	16.08	14	0.3084	-0.048	0.010	0.036	-0.006	-0.071	0.054
24	19.74	20	0.4740	-0.021	-0.029	0.069	0.021	-0.047	-0.042
30	30.59	26	0.2439	0.107	0.024	0.119	0.009	-0.041	0.054
36	35.61	32	0.3021	-0.030	0.037	-0.058	-0.040	0.055	0.061
42	43.43	38	0.2509	-0.055	-0.095	-0.050	0.012	-0.003	-0.080
48	59.41	44	0.0603	0.023	-0.011	-0.025	0.010	-0.081	0.185

Table 65: Autocorrelation Check of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (4-6)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	0.95	1	0.3295	0.000	-0.011	0.015	0.029	-0.032	-0.004
12	5.23	7	0.6325	0.068	0.022	-0.038	0.041	0.041	-0.011
18	9.08	13	0.7666	-0.018	0.027	0.033	-0.073	-0.021	0.031
24	13.76	19	0.7977	-0.086	-0.001	0.022	0.007	-0.039	-0.035
30	32.68	25	0.1392	0.151	-0.082	-0.047	-0.018	0.022	-0.101
36	37.84	31	0.1852	-0.046	0.036	-0.046	-0.069	-0.006	-0.032
42	45.85	37	0.1509	-0.061	0.050	-0.039	-0.001	-0.079	-0.060
48	57.82	43	0.0650	-0.032	-0.028	0.055	0.096	0.081	0.070

Table 66: Autocorrelation Check of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (6-7)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	2.86	4	0.5815	-0.026	0.039	0.018	0.081	-0.045	-0.088
12	10.86	10	0.3686	0.033	-0.136	-0.072	-0.031	-0.048	-0.151
18	19.71	16	0.2335	-0.047	0.015	0.092	-0.099	-0.095	0.153
24	24.61	22	0.3163	-0.067	-0.038	0.098	0.102	-0.033	0.038

Table 67: Autocorrelation Check of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (7-8)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	0.63	1	0.4281	-0.012	0.027	-0.002	0.017	-0.012	-0.034
12	3.33	7	0.8527	-0.093	-0.033	-0.020	-0.007	0.017	-0.003
18	6.43	13	0.9293	-0.062	-0.037	0.055	-0.032	-0.038	0.030
24	10.63	19	0.9357	-0.075	0.013	0.016	0.079	0.002	-0.055
30	19.10	25	0.7924	0.139	0.042	0.025	-0.086	0.001	-0.036
36	25.58	31	0.7413	-0.117	-0.029	-0.081	0.004	-0.003	0.039
42	30.73	37	0.7567	-0.051	0.008	-0.055	-0.053	-0.042	-0.084
48	51.56	43	0.1738	0.050	-0.121	0.005	0.033	0.202	-0.093

Table 68: Autocorrelation Check of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (8)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	2.84	3	0.4176	-0.012	0.030	0.069	0.065	0.018	-0.029
12	5.26	9	0.8114	-0.041	-0.021	0.074	-0.012	-0.009	-0.039
18	12.21	15	0.6630	-0.119	-0.073	0.008	0.007	-0.079	0.021
24	14.23	21	0.8593	-0.029	0.067	0.007	-0.015	-0.001	-0.042
30	26.09	27	0.5137	0.151	0.087	0.068	-0.034	-0.006	-0.077
36	28.26	33	0.7023	-0.022	-0.037	-0.003	-0.008	0.008	0.074
42	33.59	39	0.7147	-0.007	0.022	-0.076	-0.025	0.070	-0.078
48	52.04	45	0.2188	0.099	-0.020	0.040	0.053	0.192	-0.091

C5. Location 132 Ave. btw. 123 - 121 St.

Table 69: Autocorrelation Check of Residuals- Location 132 Ave. btw. 123 - 121 St.- (1-4)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	.	0	.	-0.015	-0.013	0.073	-0.061	0.016	-0.026
12	8.24	6	0.2212	-0.028	0.031	-0.060	-0.010	0.018	0.017
18	11.97	12	0.4485	0.010	0.030	-0.064	0.011	-0.035	-0.029
24	16.80	18	0.5367	0.030	-0.068	0.008	0.054	-0.016	-0.024
30	27.45	24	0.2840	0.115	-0.049	-0.032	-0.000	0.055	-0.027
36	34.56	30	0.2591	-0.103	-0.005	-0.022	0.013	-0.024	-0.039
42	37.82	36	0.3862	0.003	-0.057	-0.029	-0.003	-0.016	-0.041
48	43.53	42	0.4063	-0.054	0.030	0.017	0.041	0.017	0.066

Table 70: Autocorrelation Check of Residuals- Location 132 Ave. btw. 123 - 121 St.- (4-5)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	2.03	2	0.3620	-0.010	0.040	0.013	-0.040	0.050	-0.009
12	6.49	8	0.5925	-0.035	-0.016	0.026	0.086	0.008	0.058
18	9.48	14	0.7994	0.040	-0.058	-0.002	-0.043	-0.004	-0.042
24	19.50	20	0.4893	0.010	-0.127	0.016	0.040	0.100	-0.017
30	27.24	26	0.3968	0.083	-0.054	-0.050	-0.041	0.034	-0.078
36	36.00	32	0.2868	-0.028	-0.108	-0.097	-0.003	-0.043	-0.005
42	43.27	38	0.2564	-0.018	-0.011	-0.104	-0.033	-0.083	0.000
48	49.69	44	0.2570	-0.013	-0.010	-0.064	0.060	0.075	-0.054

C6. Location 127 St. btw. 137 - 135 Ave.

Table 71: Autocorrelation Check of Residuals- Location 127 St. btw. 137 - 135 Ave.- (1-3)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.61	1	0.10	-0.013	-0.033	0.084	-0.005	0.002	0.021
12	9.63	7	0.2108	-0.036	0.097	-0.006	-0.027	0.007	0.055
18	19.43	13	0.1103	-0.016	-0.044	-0.074	-0.109	-0.060	-0.007
24	26.15	19	0.1261	-0.031	0.005	0.024	0.045	-0.060	-0.092
30	33.25	25	0.1249	0.113	0.016	-0.010	0.029	-0.011	0.050
36	35.08	31	0.2807	-0.017	-0.015	0.016	-0.034	-0.011	0.046
42	39.16	37	0.3733	0.083	-0.010	-0.003	-0.021	-0.010	-0.039

Table 72: Autocorrelation Check of Residuals- Location 127 St. btw. 137 - 135 Ave.- (3-4)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	.	0	.	-0.010	-0.031	0.020	0.036	0.011	-0.085
12	9.58	6	0.1435	-0.070	0.032	-0.032	-0.132	0.032	0.048
18	12.63	12	0.3968	0.010	0.008	0.011	-0.038	-0.058	-0.081
24	18.24	18	0.4400	-0.025	0.068	0.072	-0.008	-0.040	-0.094
30	24.21	24	0.4499	0.080	0.066	0.070	0.052	0.052	0.025
36	27.35	30	0.6051	-0.018	-0.075	0.009	0.057	-0.036	-0.024
42	41.04	36	0.2590	0.051	-0.156	-0.094	0.035	0.081	-0.057

Table 73: Autocorrelation Check of Residuals- Location 127 St. btw. 137 - 135 Ave.- (4-6)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.36	2	0.1864	-0.006	-0.007	0.066	-0.015	-0.007	-0.056
12	8.41	8	0.3949	-0.011	-0.059	-0.011	-0.075	-0.010	0.047
18	11.59	14	0.6391	-0.026	-0.031	-0.035	0.027	-0.009	-0.060
24	21.01	20	0.3968	-0.016	0.028	0.031	0.080	-0.056	-0.098
30	37.58	26	0.0662	0.161	0.020	0.018	0.041	0.061	-0.072
36	39.54	32	0.1687	-0.028	0.000	0.011	0.008	-0.058	0.001
42	45.02	38	0.2017	-0.009	-0.012	-0.036	-0.035	-0.089	-0.035
48	54.13	44	0.1408	-0.021	-0.066	0.111	0.032	0.003	0.033

Table 74: Autocorrelation Check of Residuals- Location 127 St. btw. 137 - 135 Ave.- (6-7)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	4.59	2	0.1009	-0.033	0.089	0.003	0.031	-0.063	-0.009
12	10.88	8	0.2085	0.027	-0.013	-0.106	-0.066	-0.025	0.039
18	16.49	14	0.2841	-0.004	-0.004	-0.005	-0.070	-0.077	-0.074
24	25.48	20	0.1837	0.018	0.028	0.046	0.103	-0.011	-0.107
30	32.33	26	0.1825	0.109	0.055	0.015	0.014	0.041	-0.048
36	35.15	32	0.3212	-0.067	-0.009	0.030	0.021	-0.017	0.040
42	40.12	38	0.3765	-0.018	-0.035	0.003	-0.108	-0.004	0.013
48	54.05	44	0.1425	-0.114	-0.056	0.070	-0.032	-0.030	0.118

Table 75: Autocorrelation Check of Residuals- Location 127 St. btw. 137 - 135 Ave.- (7-8)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	2.11	2	0.3486	0.016	0.017	-0.055	0.048	-0.092	0.007
12	4.46	8	0.8135	0.043	-0.014	0.004	-0.034	-0.084	0.070
18	14.11	14	0.4419	-0.047	-0.016	0.022	-0.205	-0.119	-0.023
24	18.36	20	0.5636	-0.038	-0.038	0.075	0.078	-0.039	-0.094

C7. Location 109 St. btw. 108 - 110 Ave.

Table 76: Autocorrelation Check of Residuals- Location 109 St. btw. 108 - 110 Ave.- (1-5)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	7.84	4	0.0978	-0.067	0.061	0.065	0.110	-0.063	0.038
12	15.90	10	0.1024	-0.097	0.001	-0.056	-0.059	-0.115	-0.028
18	20.70	16	0.1903	0.051	-0.110	0.022	-0.033	-0.000	0.036
24	25.31	22	0.2823	-0.025	0.015	0.026	0.107	0.046	-0.034
30	31.99	28	0.2750	0.142	-0.001	-0.005	-0.001	0.051	0.023
36	37.51	34	0.3112	-0.046	-0.047	0.056	-0.079	-0.061	-0.034
42	45.09	40	0.2675	-0.094	-0.038	-0.030	-0.072	-0.026	-0.089
48	53.80	46	0.2004	-0.054	0.060	0.054	-0.040	0.078	0.102

Table 77: Autocorrelation Check of Residuals- Location 109 St. btw. 108 - 110 Ave.- (5-7)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.31	2	0.1907	0.013	0.044	-0.059	0.011	-0.026	0.026
12	10.95	8	0.2048	-0.036	0.056	-0.028	-0.020	-0.100	-0.022
18	14.40	14	0.4203	-0.047	-0.032	0.032	-0.008	-0.028	-0.045
24	23.93	20	0.2454	0.034	0.058	0.021	0.056	0.107	-0.007
30	27.85	26	0.3659	0.069	0.002	0.054	-0.011	0.001	-0.012
36	35.64	32	0.3010	-0.072	-0.031	-0.095	0.008	-0.012	-0.008
42	46.35	38	0.1658	-0.065	-0.036	-0.087	-0.044	-0.046	0.062
48	52.29	44	0.1831	-0.090	0.002	0.006	-0.006	0.050	-0.030

Table 78: Autocorrelation Check of Residuals- Location 109 St. btw. 108 - 110 Ave.- (7-8)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	2.71	2	0.2579	0.007	0.034	-0.033	-0.073	0.056	0.031
12	6.82	8	0.5560	-0.034	0.080	-0.049	-0.043	-0.056	-0.050
18	13.46	14	0.4906	0.075	-0.093	-0.084	-0.011	-0.076	-0.017
24	18.10	20	0.5805	-0.026	0.074	0.105	-0.004	-0.026	-0.030
30	22.40	26	0.6666	0.085	0.095	0.001	0.015	0.016	-0.014
36	33.05	32	0.4157	-0.047	-0.074	0.039	-0.162	0.069	0.003
42	40.58	38	0.3574	-0.008	-0.023	-0.003	-0.130	0.052	-0.085

C8. Location 144 Ave. btw. 77 - 79 St.

Table 79: Autocorrelation Check of Residuals- Location 144 Ave. btw. 77 - 79 St.- (1-5)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	7.19	3	0.0661	-0.054	0.021	0.071	0.057	0.037	0.026
12	10.85	9	0.2860	0.009	0.051	-0.039	0.007	0.038	0.035
18	13.85	15	0.5366	0.015	0.004	-0.054	-0.018	-0.039	0.023
24	30.68	21	0.0791	-0.052	0.018	-0.022	0.118	0.115	-0.012
30	37.73	27	0.0822	0.077	0.051	0.032	0.054	-0.014	-0.008
36	40.49	33	0.1734	-0.021	-0.034	-0.025	0.047	0.006	-0.022
42	47.53	39	0.1641	0.050	0.033	-0.046	-0.058	-0.037	-0.045
48	58.98	45	0.0789	-0.007	-0.133	0.035	-0.028	-0.018	0.006

Table 80: Autocorrelation Check of Residuals- Location 144 Ave. btw. 77 - 79 St.- (4-7)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.61	2	0.1646	-0.011	0.041	0.049	0.035	0.008	0.014
12	6.74	8	0.5654	0.025	0.011	-0.032	0.050	-0.023	-0.008
18	19.25	14	0.1557	0.045	-0.051	-0.033	-0.055	-0.060	-0.084
24	20.97	20	0.3987	-0.044	-0.024	0.002	0.011	0.005	-0.003
30	28.83	26	0.3187	0.076	0.029	0.027	-0.017	0.059	-0.027
36	30.51	32	0.5419	-0.012	-0.004	-0.010	0.012	0.038	-0.026
42	38.80	38	0.4333	0.083	-0.059	0.005	0.021	-0.027	-0.029
48	44.47	44	0.4520	-0.013	0.029	-0.060	-0.046	0.037	0.015

C9. Location 156 St. btw. 94 - 92 Ave.

Table 81: Autocorrelation Check of Residuals- Location 156 St. btw. 94 - 92 Ave.- (1-3)

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.13	2	0.2088	-0.031	0.056	0.012	-0.047	-0.027	-0.012
12	10.35	8	0.2412	-0.004	0.012	0.093	0.076	0.043	0.001
18	14.52	14	0.4118	-0.070	-0.027	-0.030	0.038	0.000	0.037
24	17.13	20	0.6443	-0.032	-0.015	-0.032	0.044	-0.038	-0.011
30	21.80	26	0.6993	0.078	0.015	0.000	-0.007	-0.051	-0.034
36	29.25	32	0.6066	-0.082	-0.019	-0.043	-0.063	-0.056	0.004
42	34.84	38	0.6162	-0.034	0.053	-0.034	0.011	-0.079	-0.020
48	49.69	44	0.2570	0.016	0.036	-0.116	0.102	0.018	0.072

Appendix D– SAC and SPAC Plots of Residuals at Different Lags for ARIMAX Models Developed at All Locations

D1. Location 142 St. btw. 106 - 104 Ave.

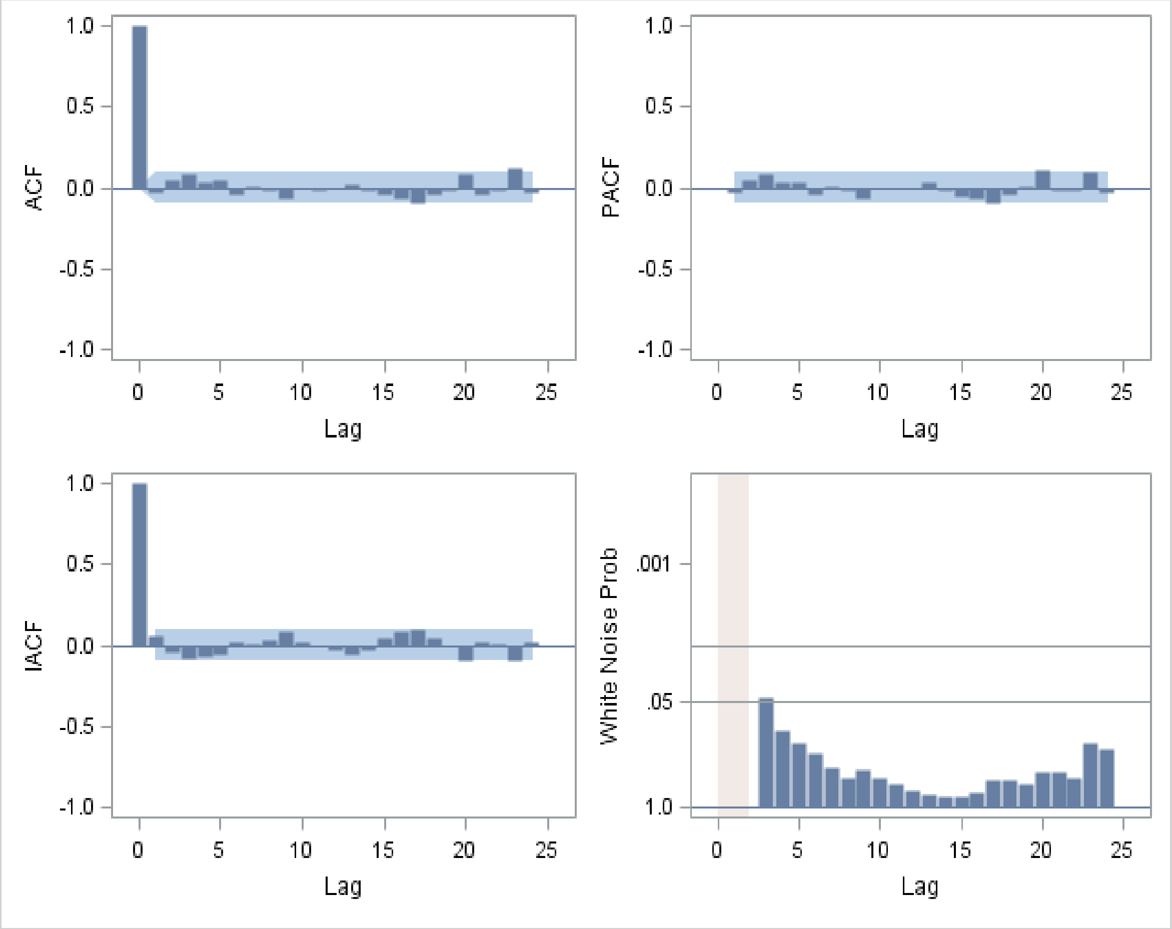

Figure 26: SAC and SPAC Plots of Residuals- Location 142 St. btw. 106 - 104 Ave.- (1-4)

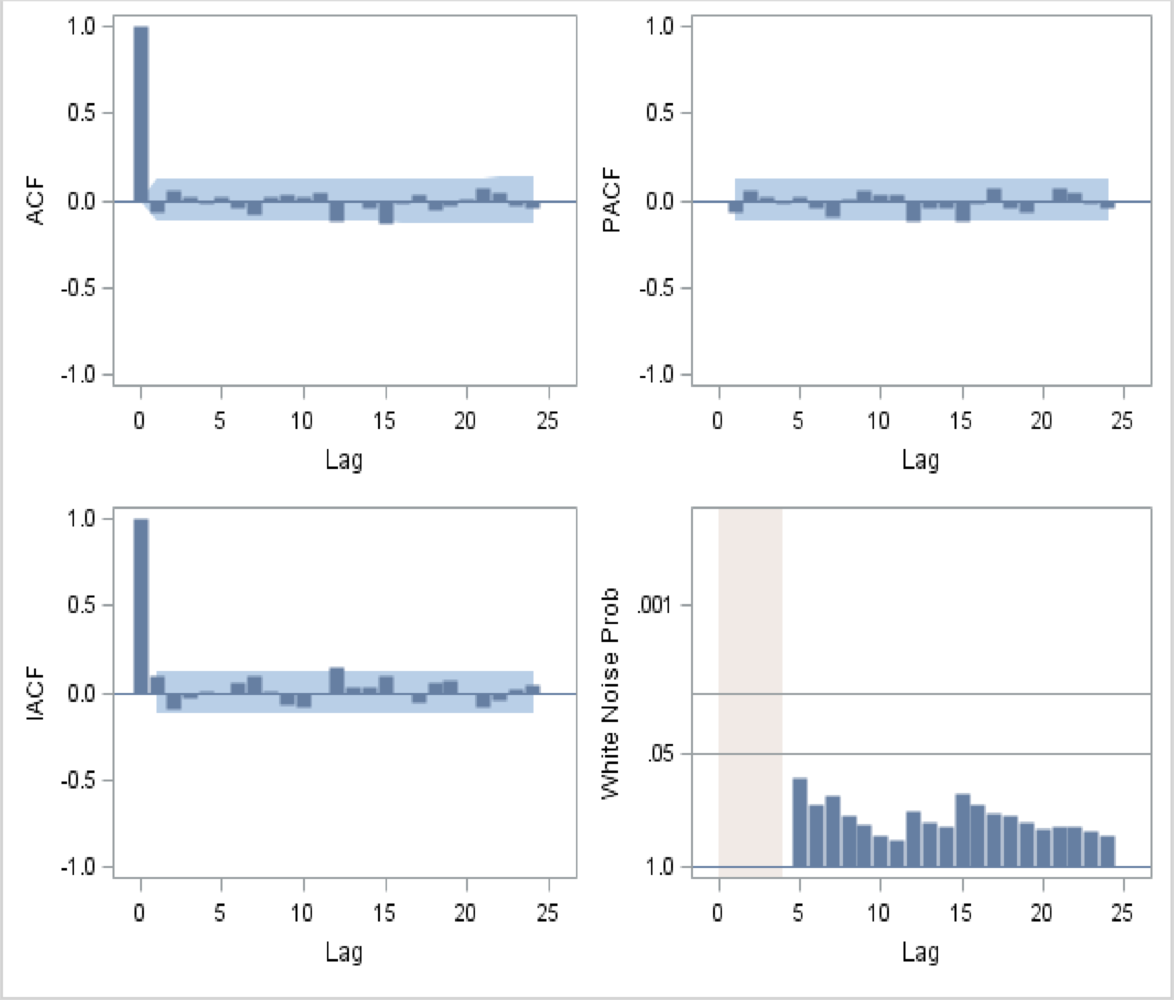

Figure 27: SAC and SPAC Plots of Residuals- Location 142 St. btw. 106 - 104 Ave.- (4-5)

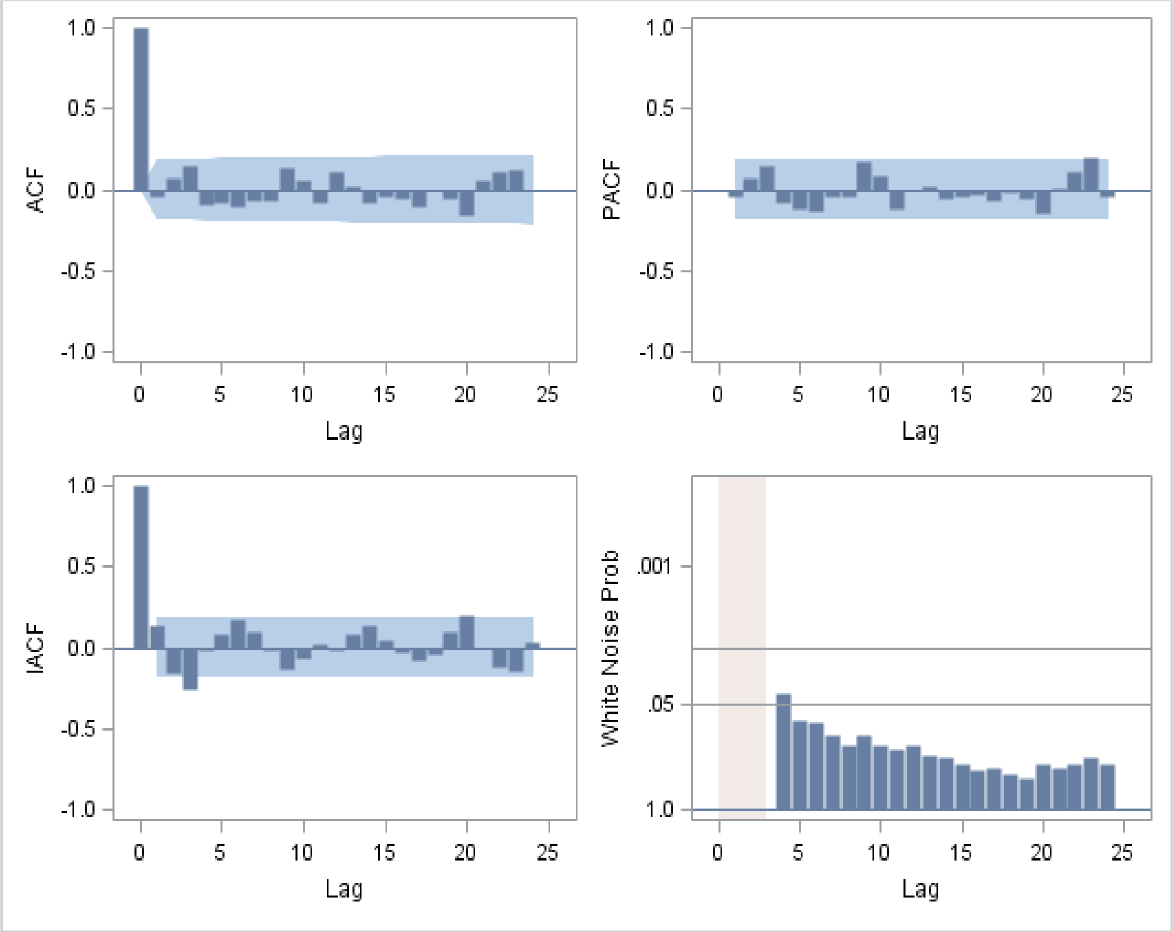

Figure 28: SAC and SPAC Plots of Residuals- Location 142 St. btw. 106 - 104 Ave.- (5-6)

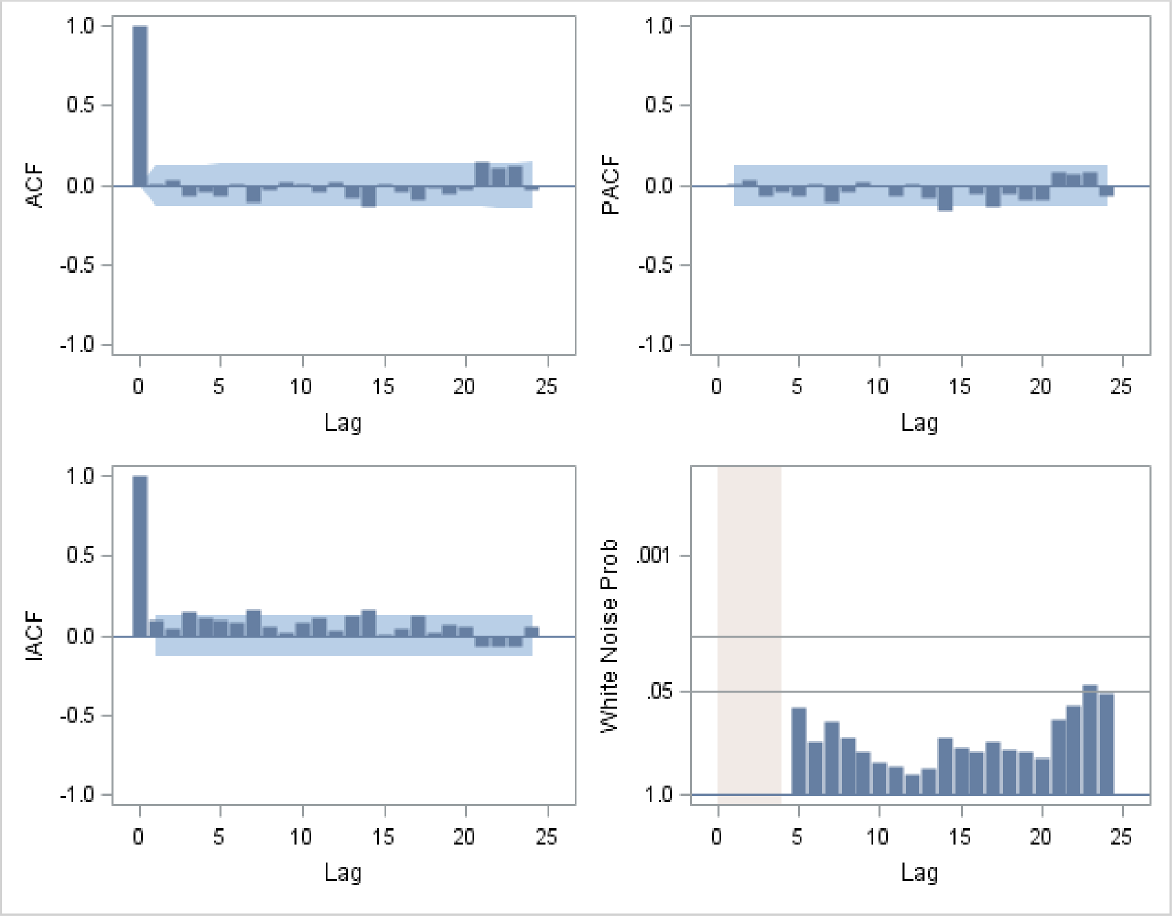

Figure 29: SAC and SPAC Plots of Residuals- Location 142 St. btw. 106 - 104 Ave.- (6-7)

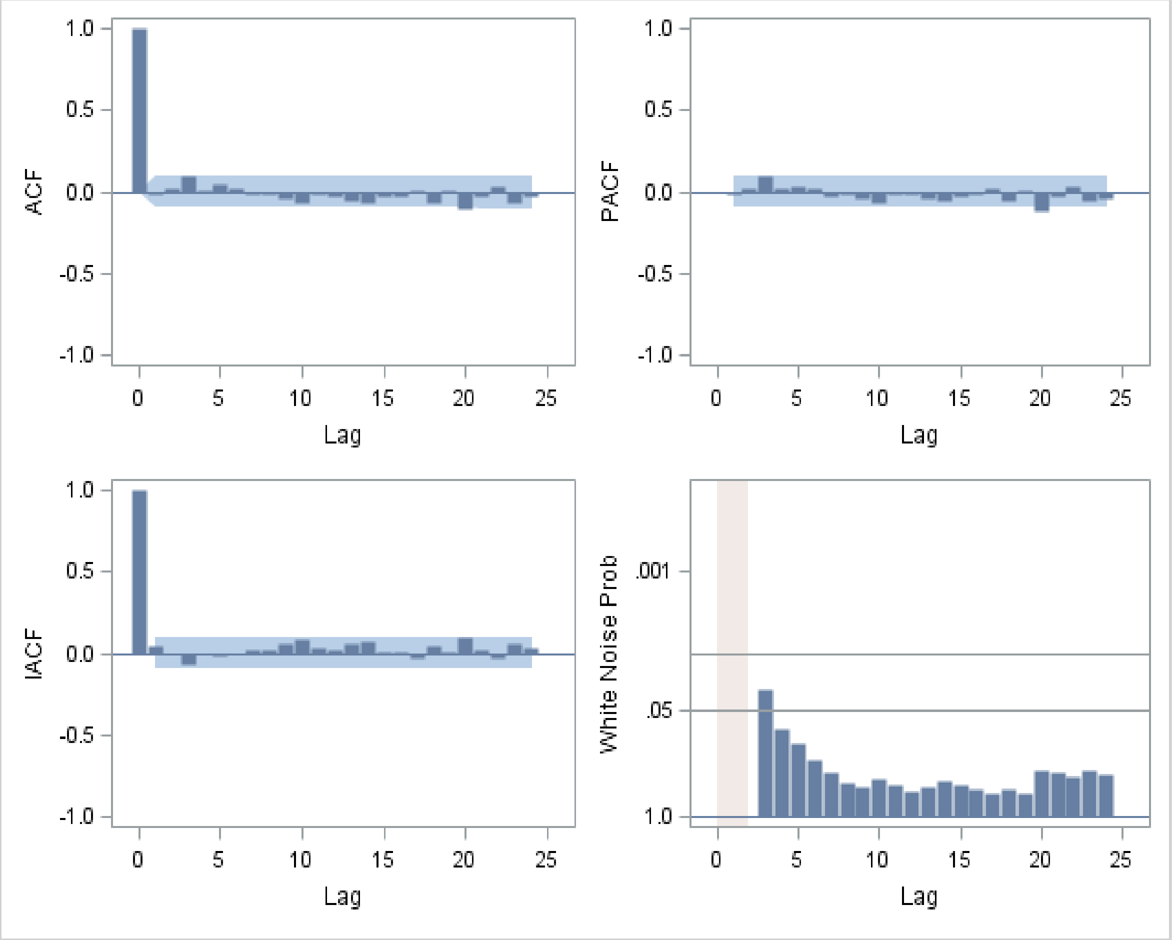

Figure 30: SAC and SPAC Plots of Residuals- Location 142 St. btw. 106 - 104 Ave.- (7-8)

D2. Location 101 Ave. btw. 67 - 70 St.

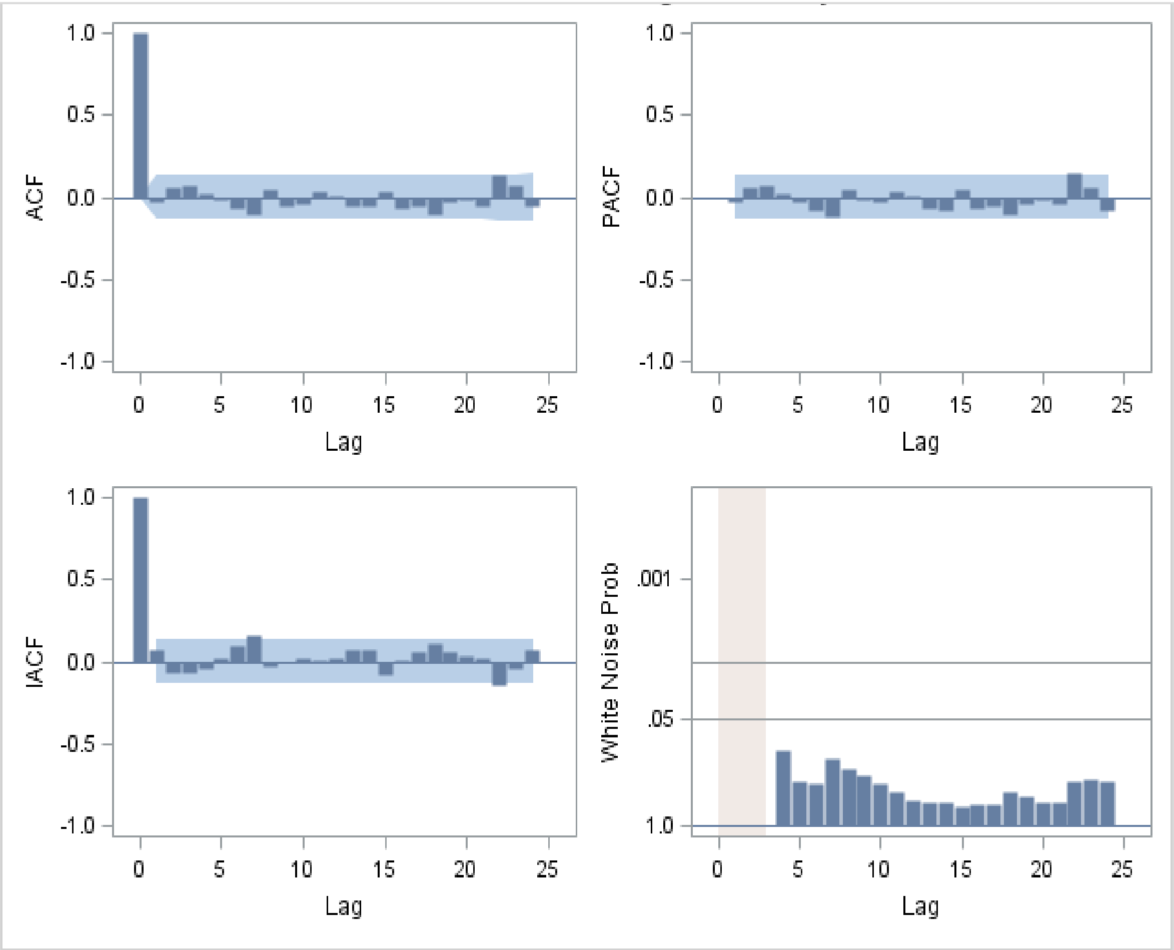

Figure 31: SAC and SPAC Plots of Residuals- Location 101 Ave. btw. 67 - 70 St.- (1-2)

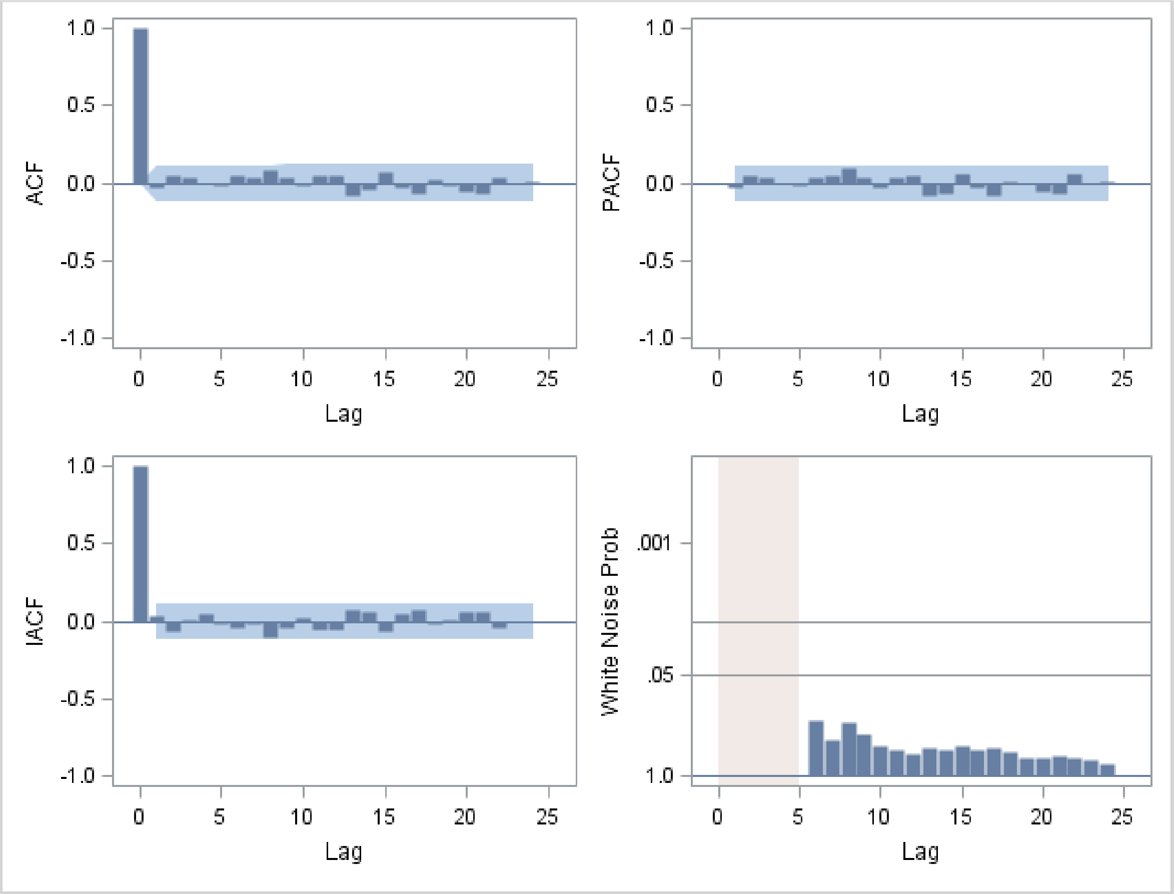

Figure 32: SAC and SPAC Plots of Residuals- Location 101 Ave. btw. 67 - 70 St.- (2-3)

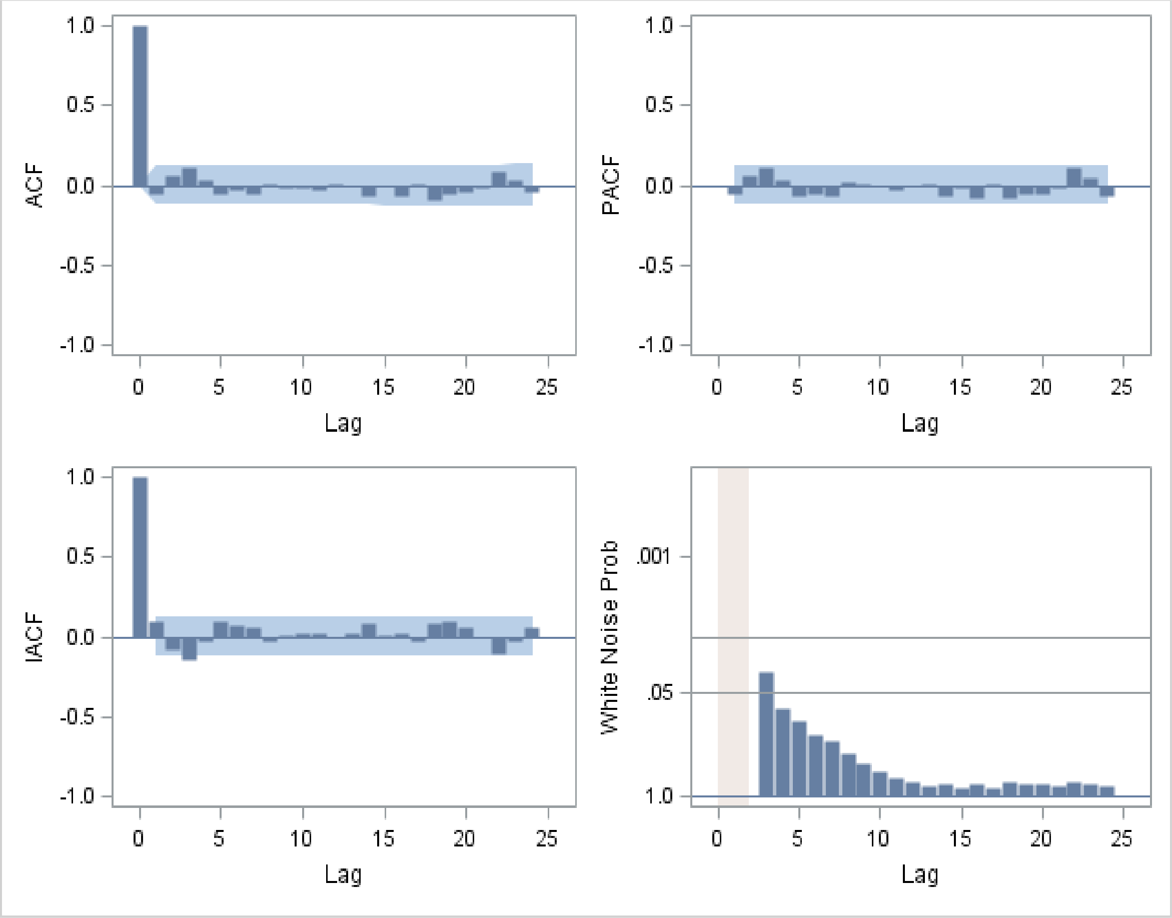

Figure 33: SAC and SPAC Plots of Residuals- Location 101 Ave. btw. 67 - 70 St.- (3-4)

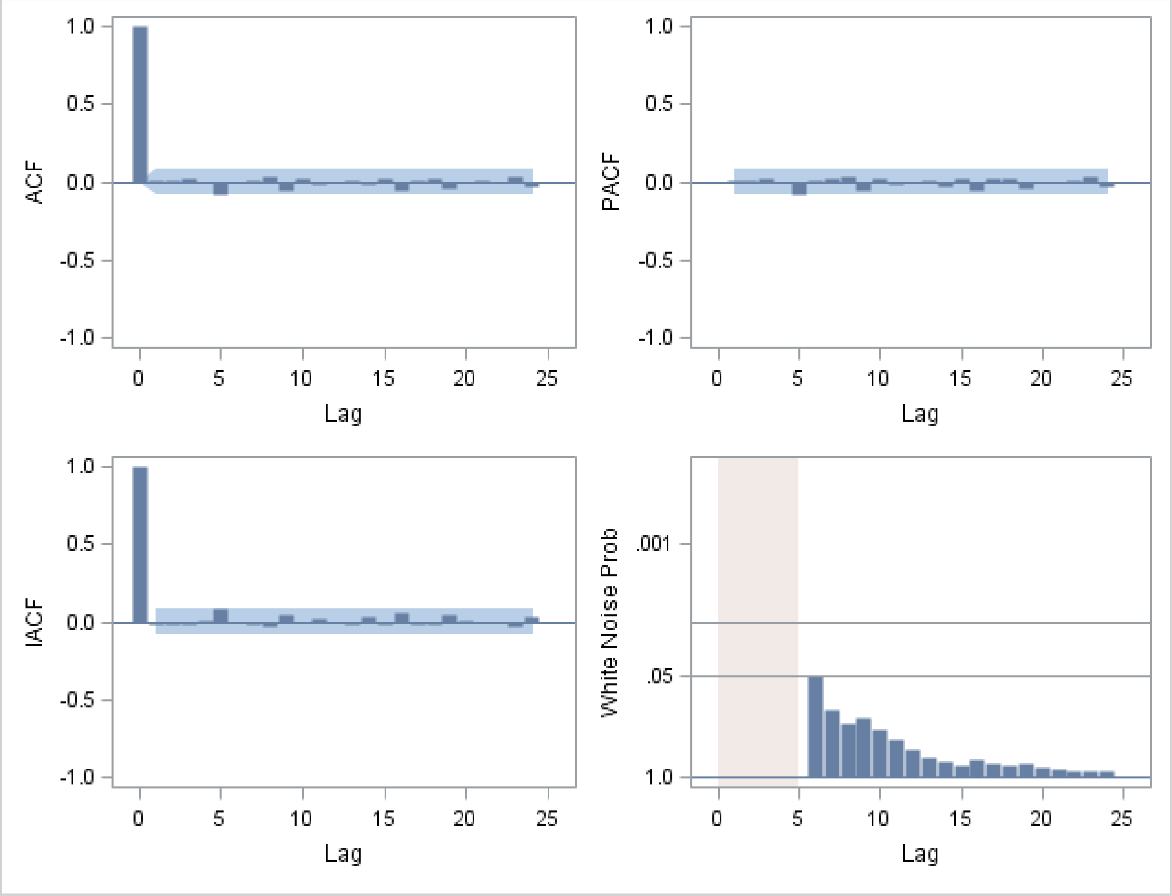

Figure 34: SAC and SPAC Plots of Residuals- Location 101 Ave. btw. 67 - 70 St.- (4-7)

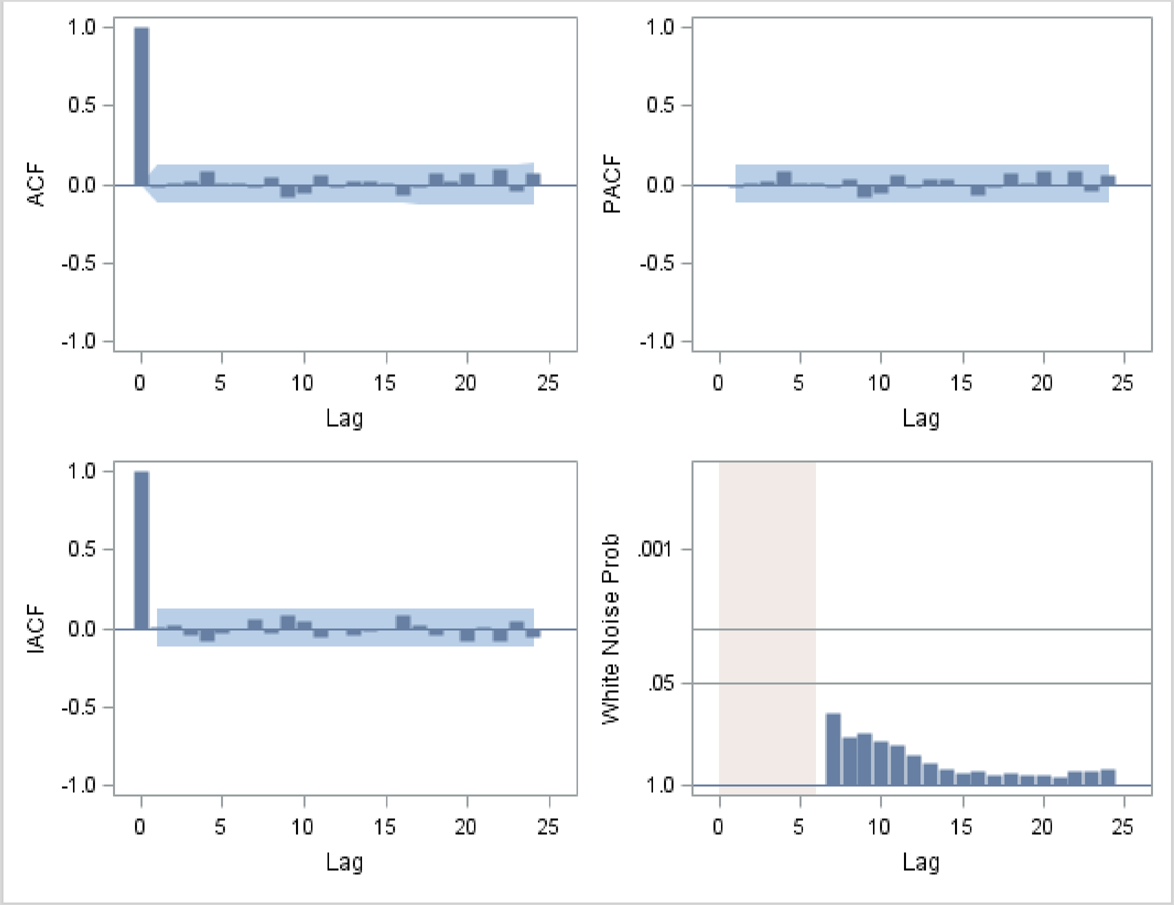

Figure 35: SAC and SPAC Plots of Residuals- Location 101 Ave. btw. 67 - 70 St.- (7-8)

D3. Location 142 St. btw. 104A – 105 Ave.

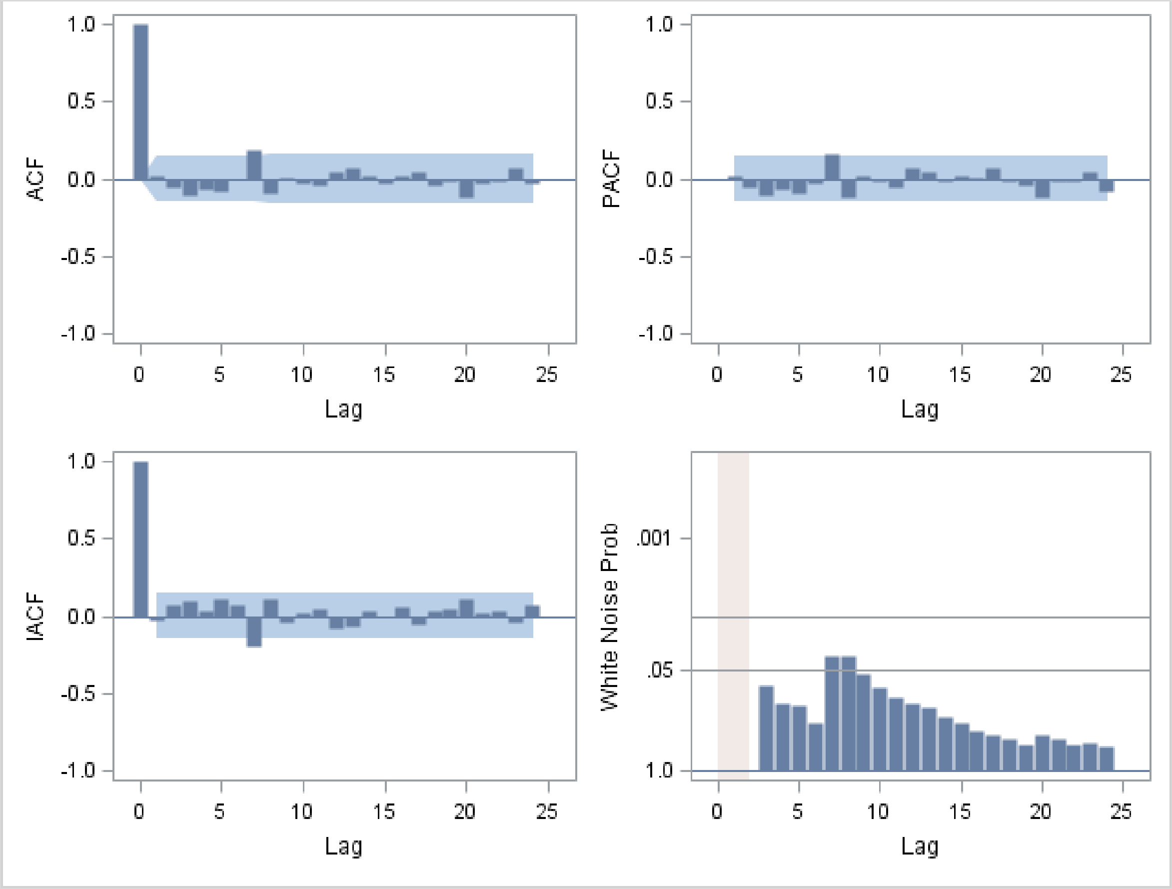

Figure 36: SAC and SPAC Plots of Residuals- Location 142 St. btw. 104A – 105 Ave.- (1-2)

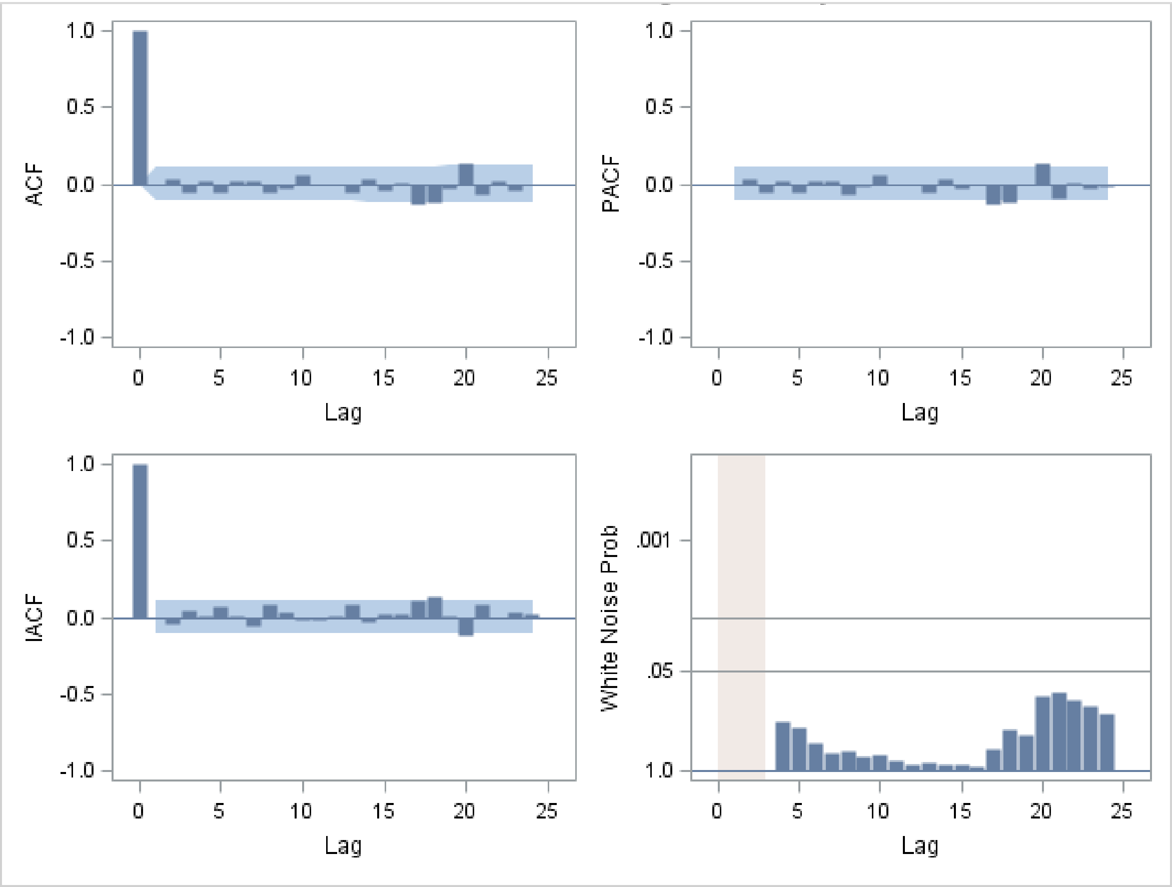

Figure 37: SAC and SPAC Plots of Residuals- Location 142 St. btw. 104A – 105 Ave.- (2-3)

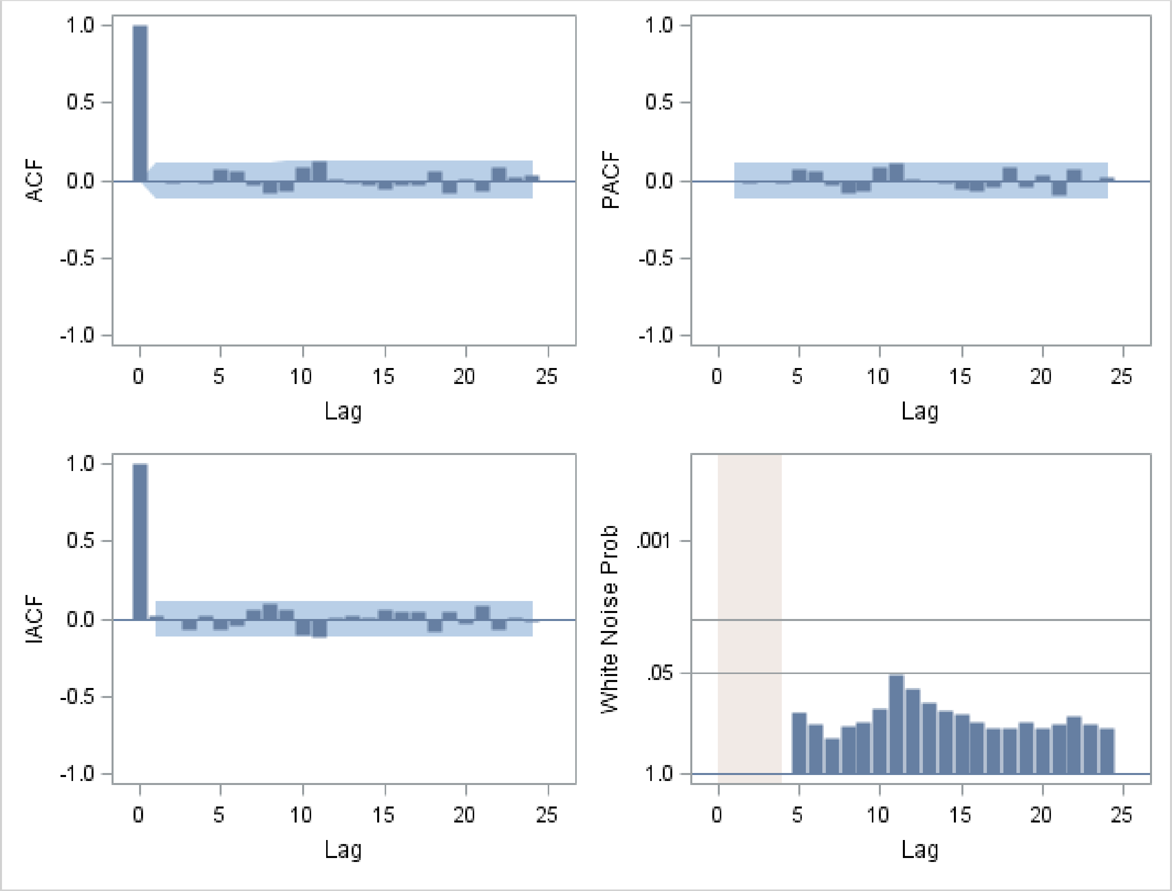

Figure 38: SAC and SPAC Plots of Residuals- Location 142 St. btw. 104A – 105 Ave.- (4-5)

D4. Location Saskatchewan Dr. btw. 107 - 105 St.

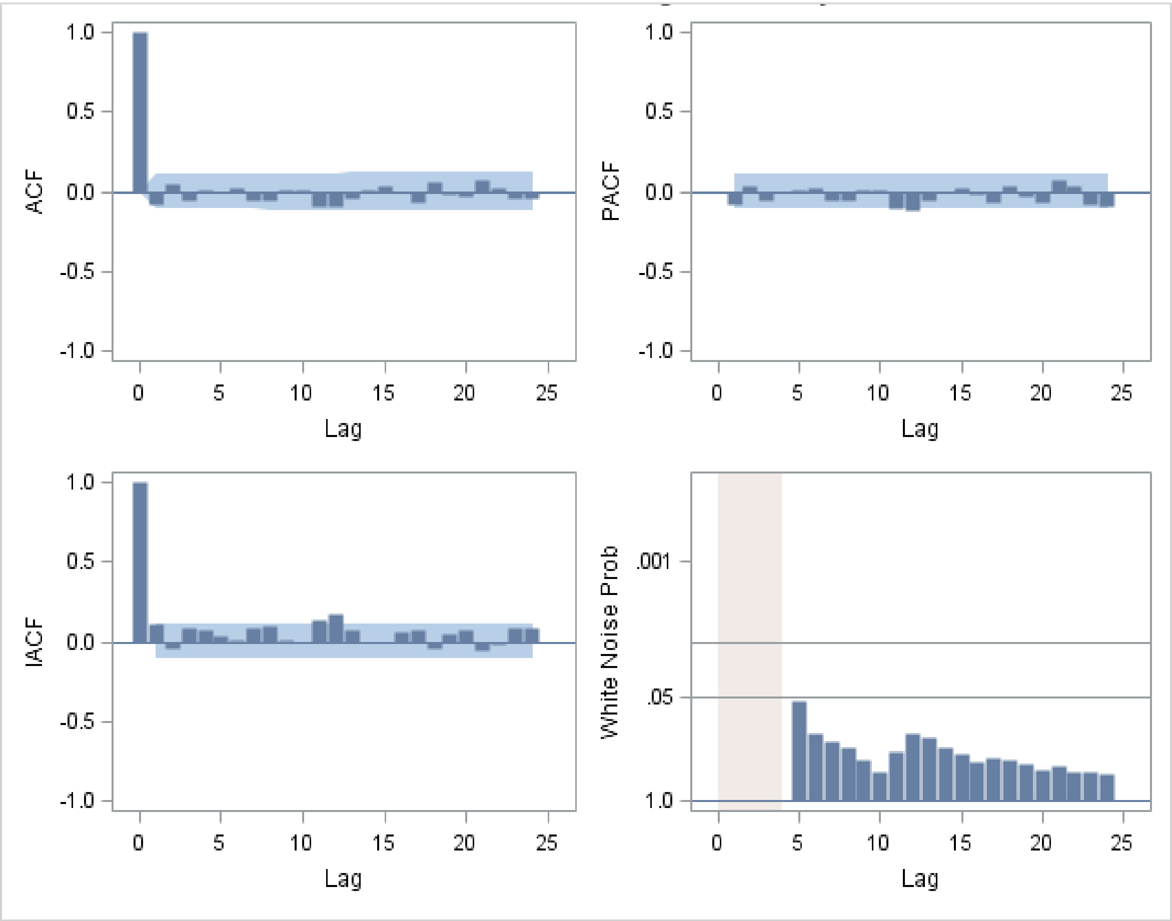

Figure 39: SAC and SPAC Plots of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (1-4)

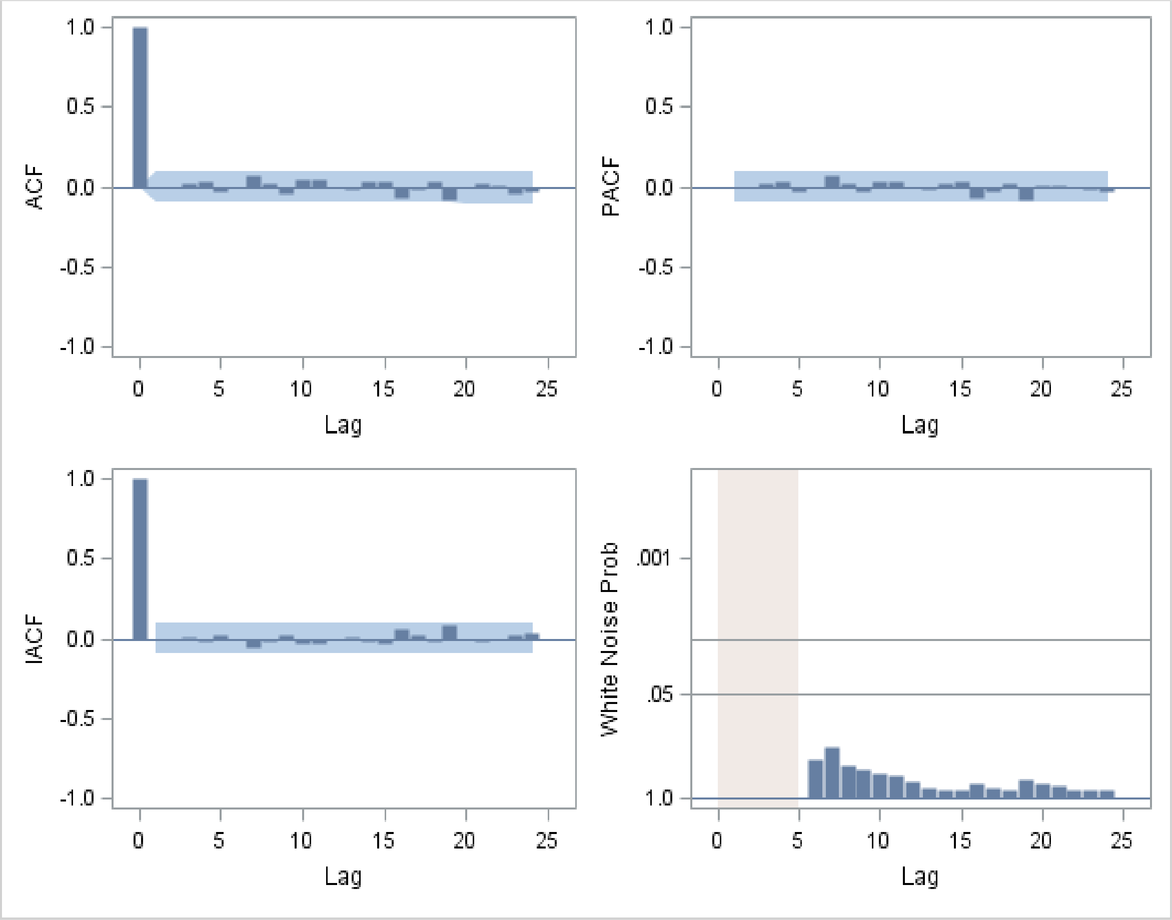

Figure 40: SAC and SPAC Plots of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (4-6)

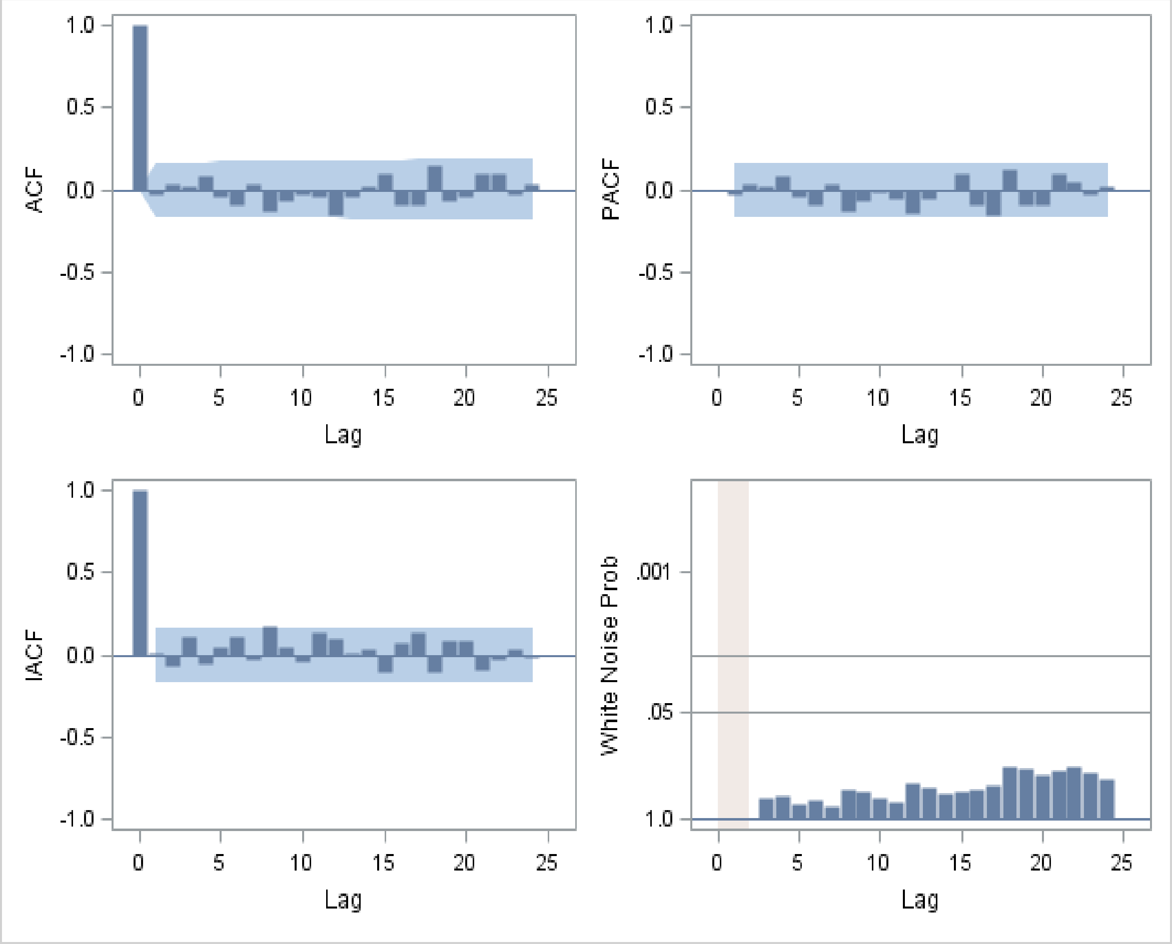

Figure 41: SAC and SPAC Plots of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (6-7)

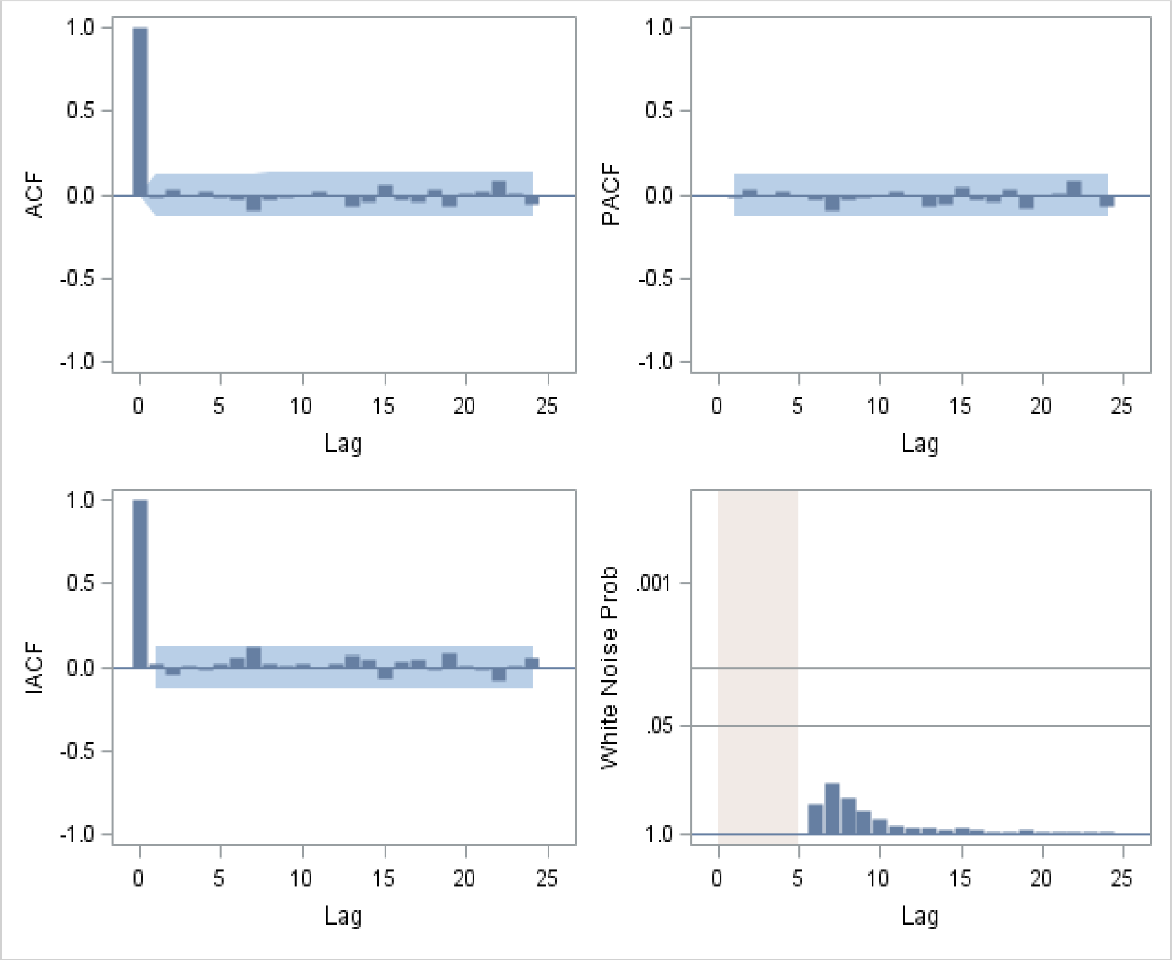

Figure 42: SAC and SPAC Plots of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (7-8)

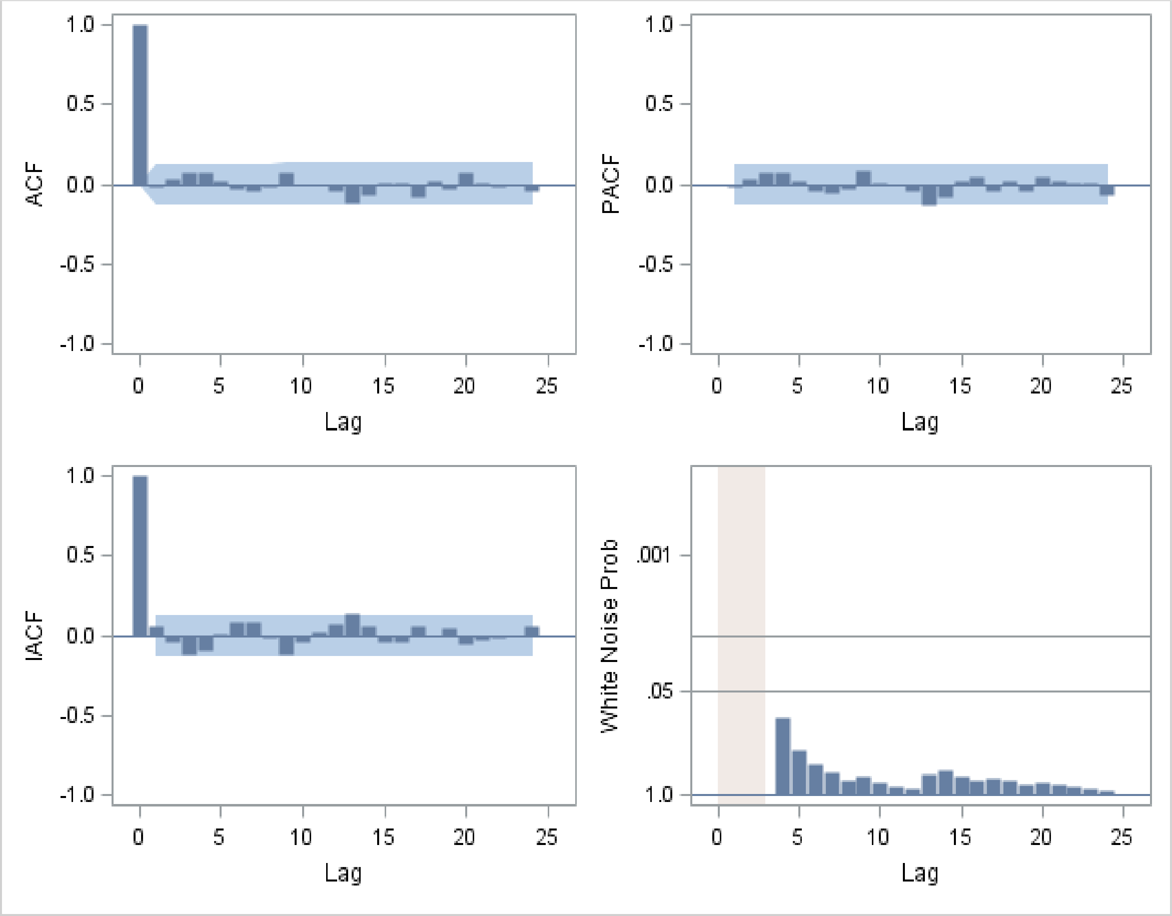

Figure 43: SAC and SPAC Plots of Residuals- Location Saskatchewan Dr. btw. 107 - 105 St.- (8)

D5. Location 132 Ave. btw. 123 - 121 St.

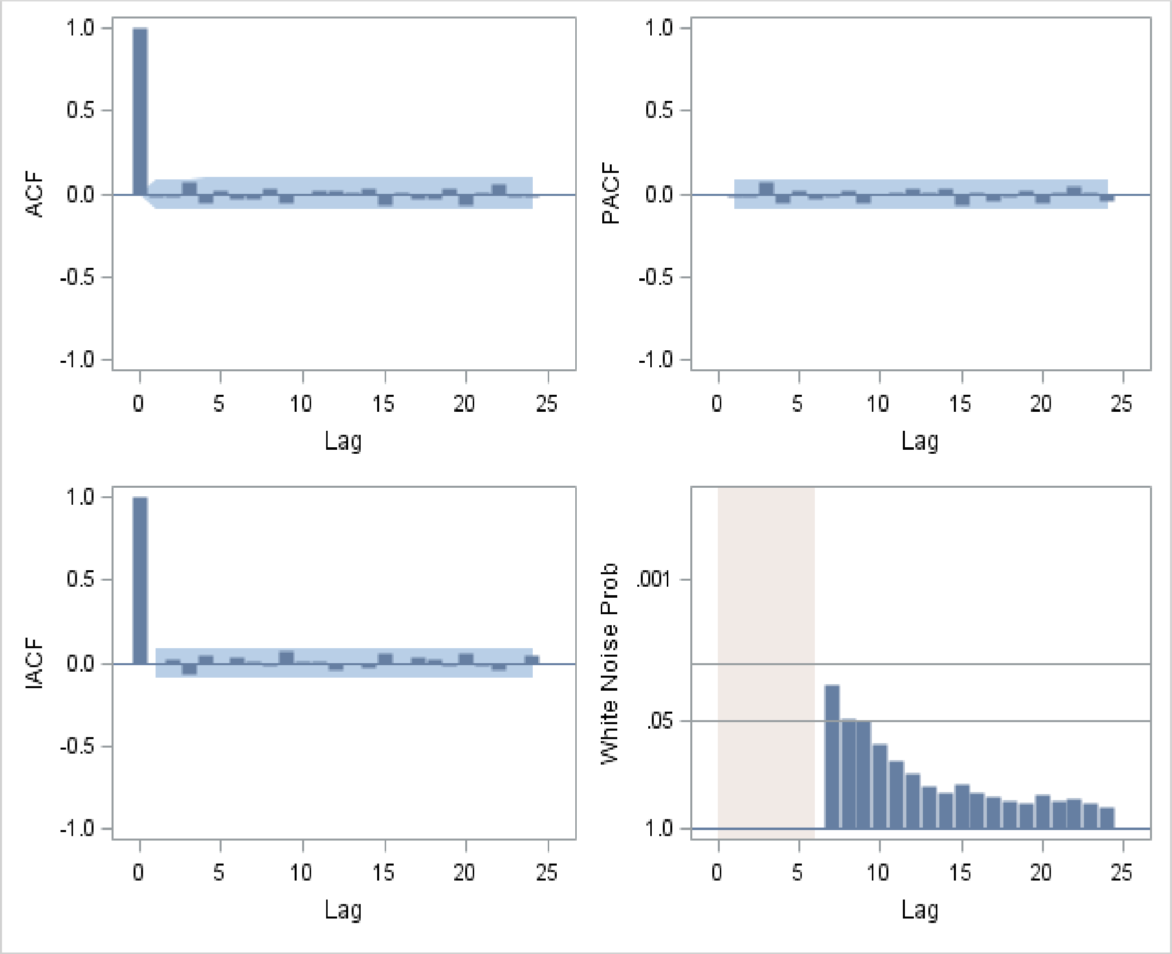

Figure 44: SAC and SPAC Plots of Residuals- Location 132 Ave. btw. 123 - 121 St.- (1-4)

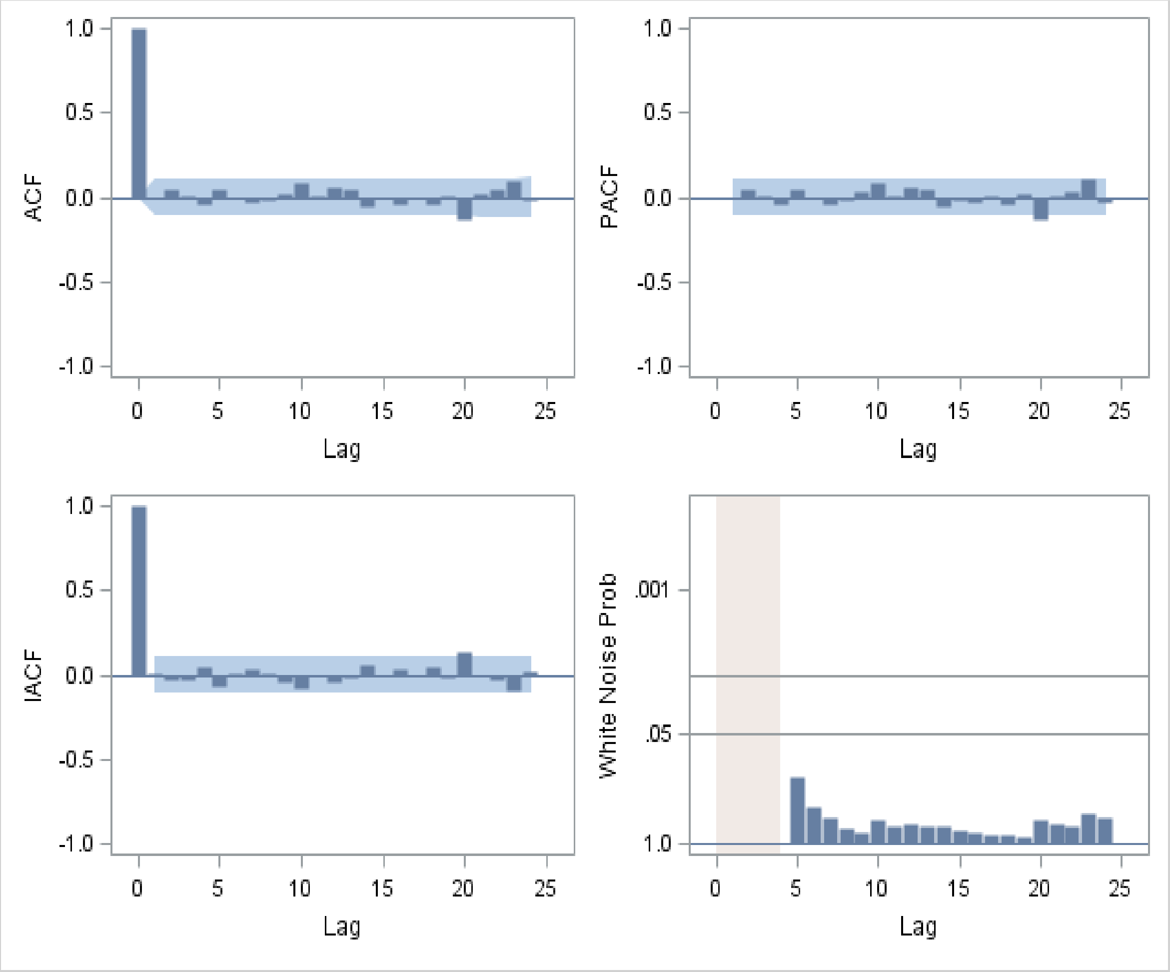

Figure 45: SAC and SPAC Plots of Residuals- Location 132 Ave. btw. 123 - 121 St.- (4-5)

D6. Location 127 St. btw. 137 - 135 Ave.

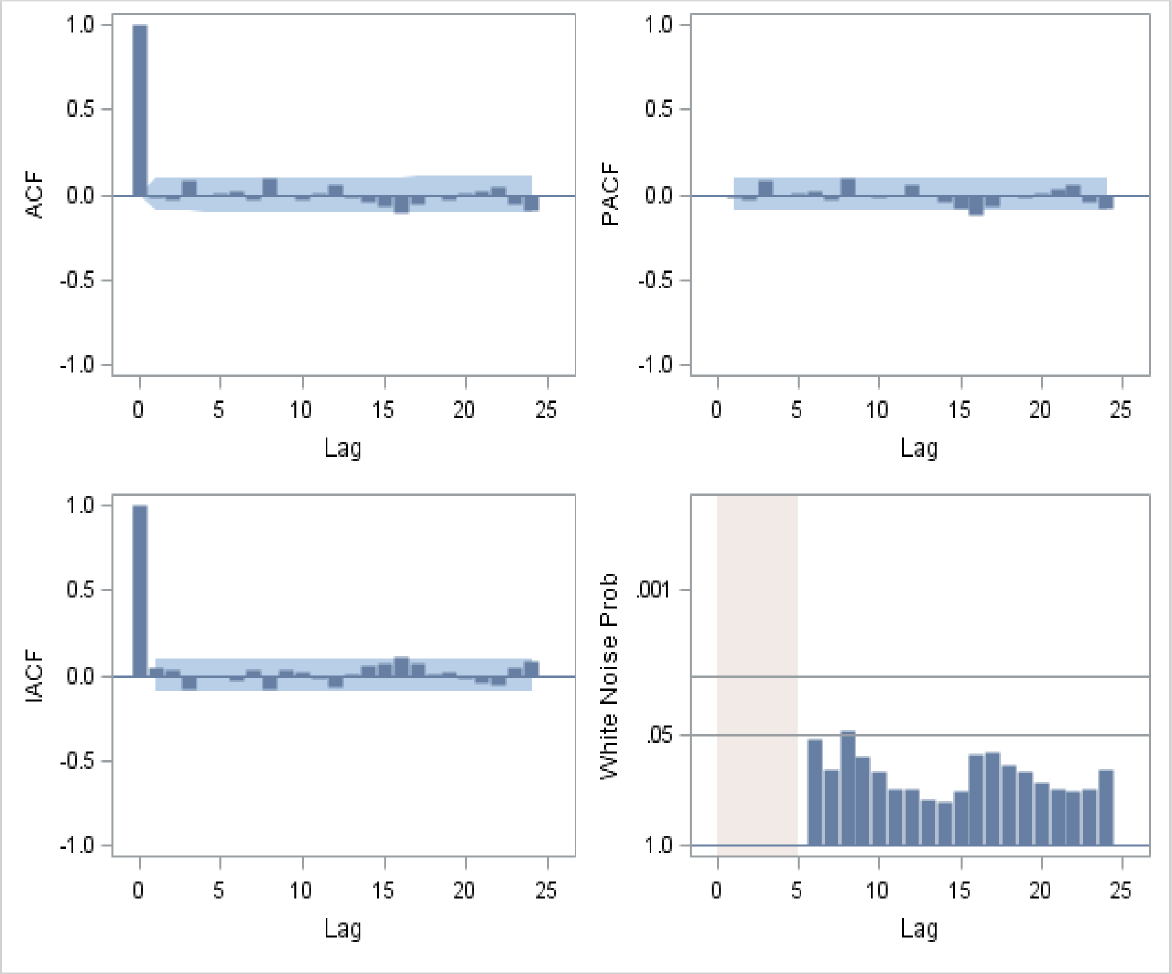

Figure 46: SAC and SPAC Plots of Residuals- Location 127 St. btw. 137 - 135 Ave.- (1-3)

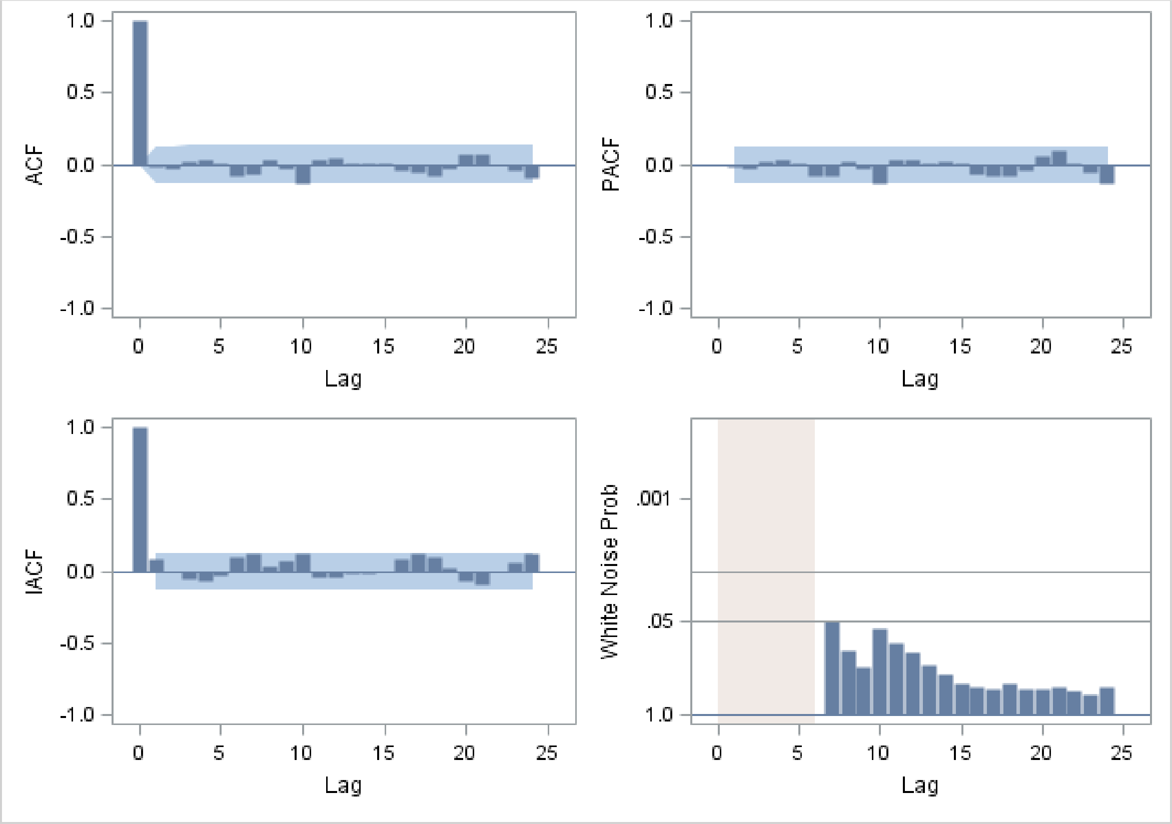

Figure 47: SAC and SPAC Plots of Residuals- Location 127 St. btw. 137 - 135 Ave.- (3-4)

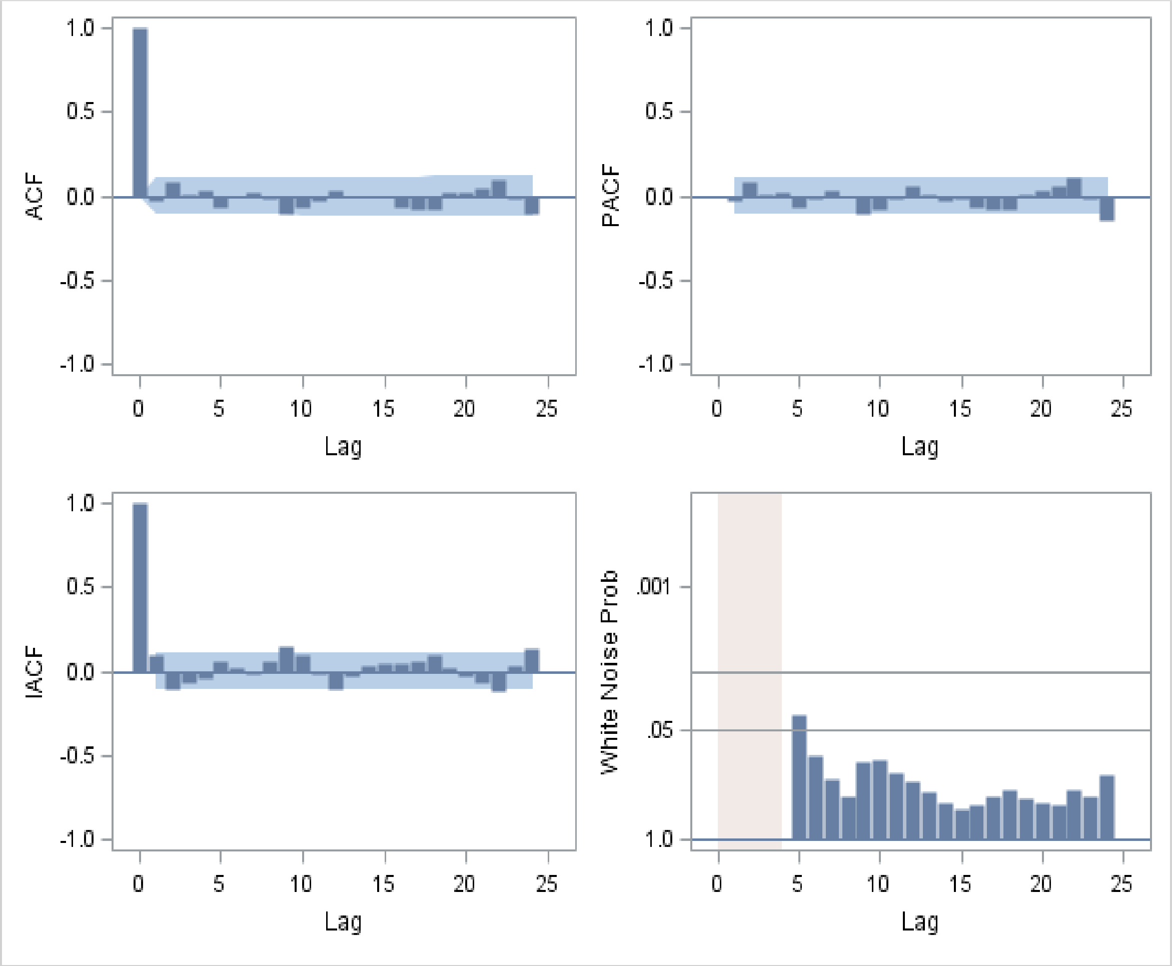

Figure 48: SAC and SPAC Plots of Residuals- Location 127 St. btw. 137 - 135 Ave.- (4-6)

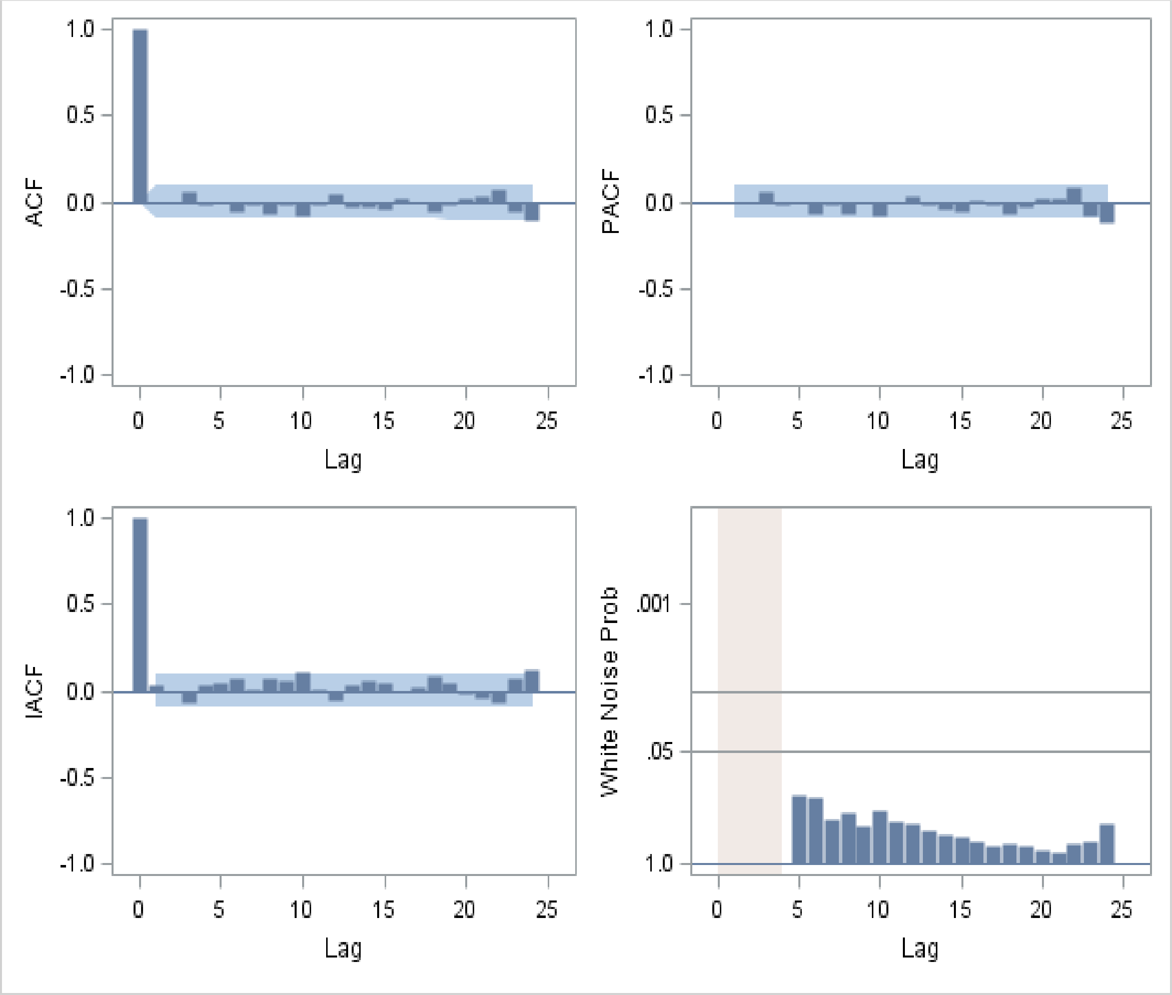

Figure 49: SAC and SPAC Plots of Residuals- Location 127 St. btw. 137 - 135 Ave.- (6-7)

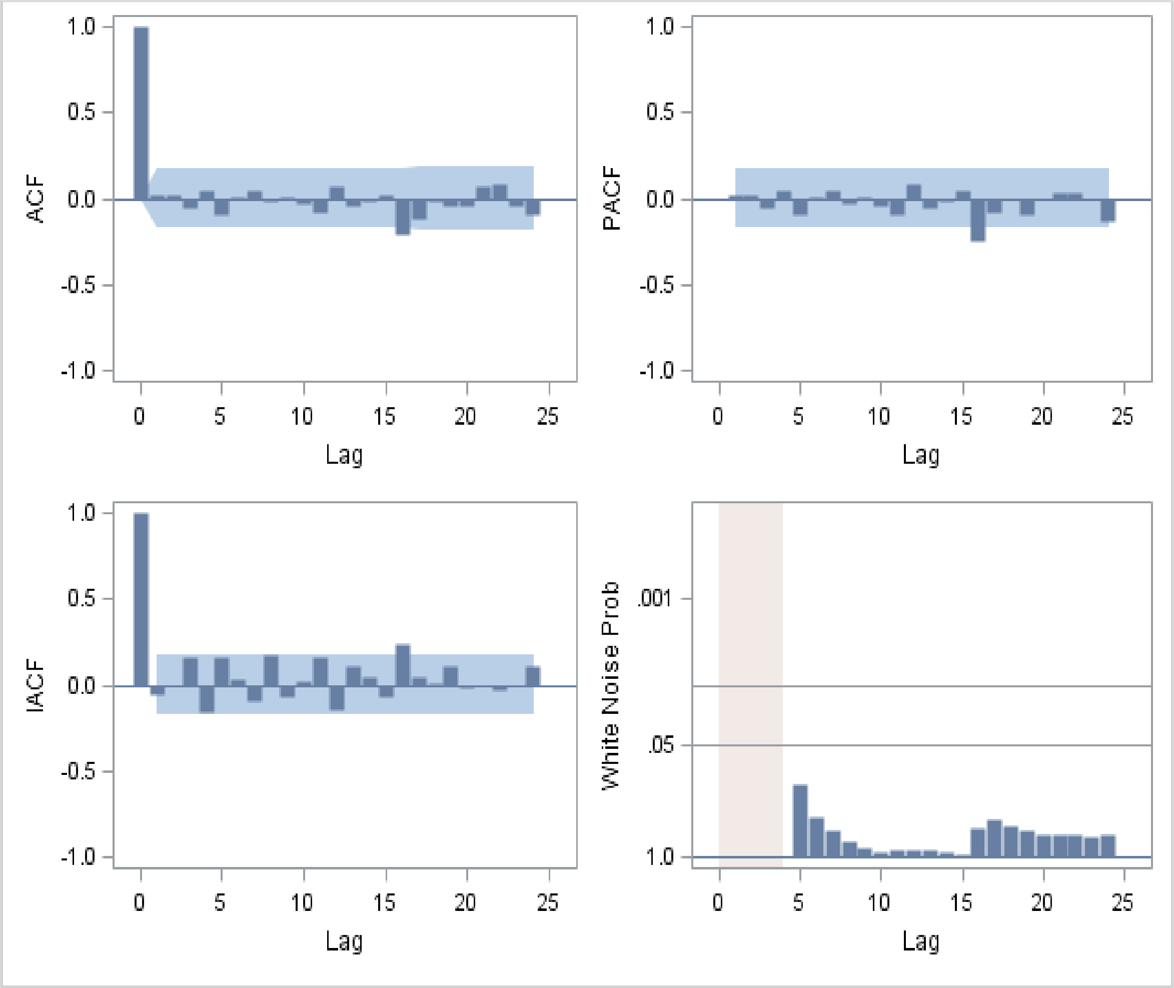

Figure 50: SAC and SPAC Plots of Residuals- Location 127 St. btw. 137 - 135 Ave.- (7-8)

D7. Location 109 St. btw. 108 - 110 Ave.

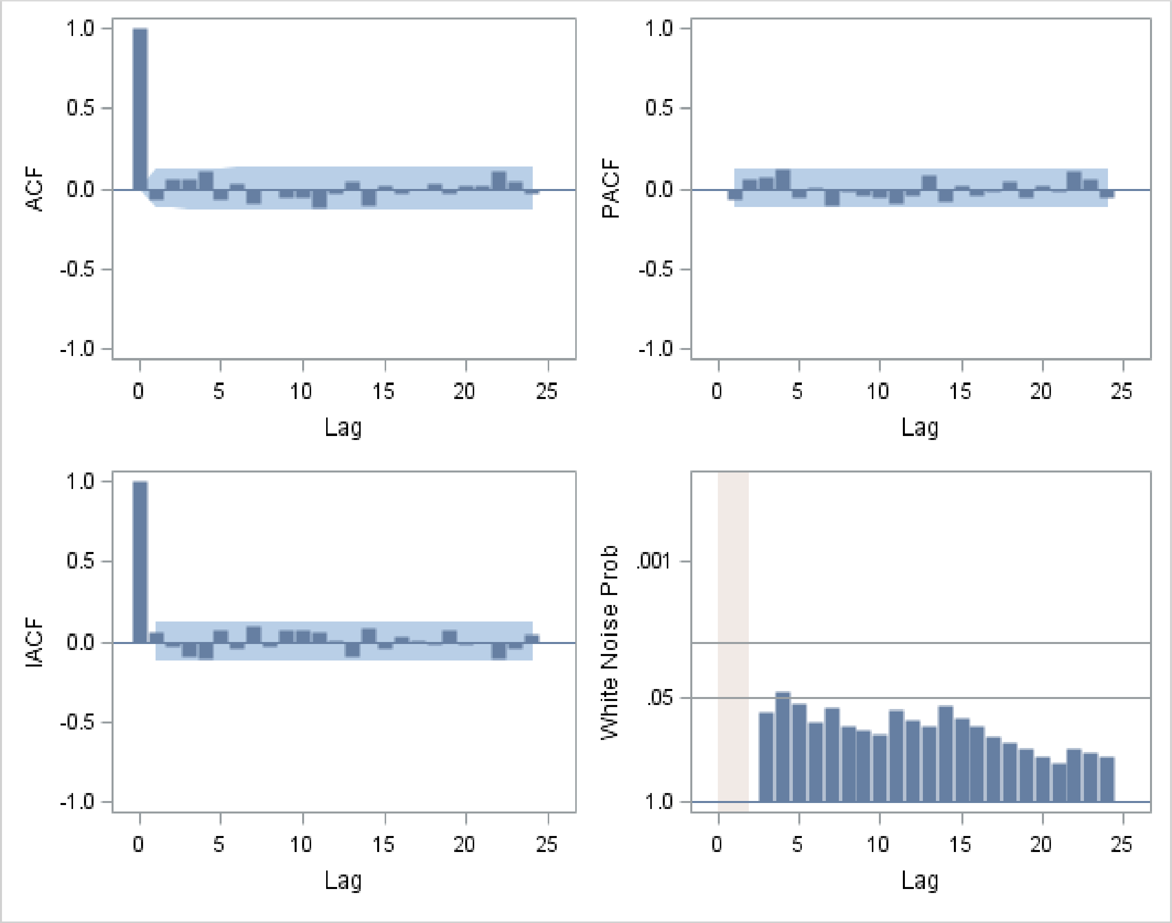

Figure 51: SAC and SPAC Plots of Residuals- Location 109 St. btw. 108 - 110 Ave.- (1-5)

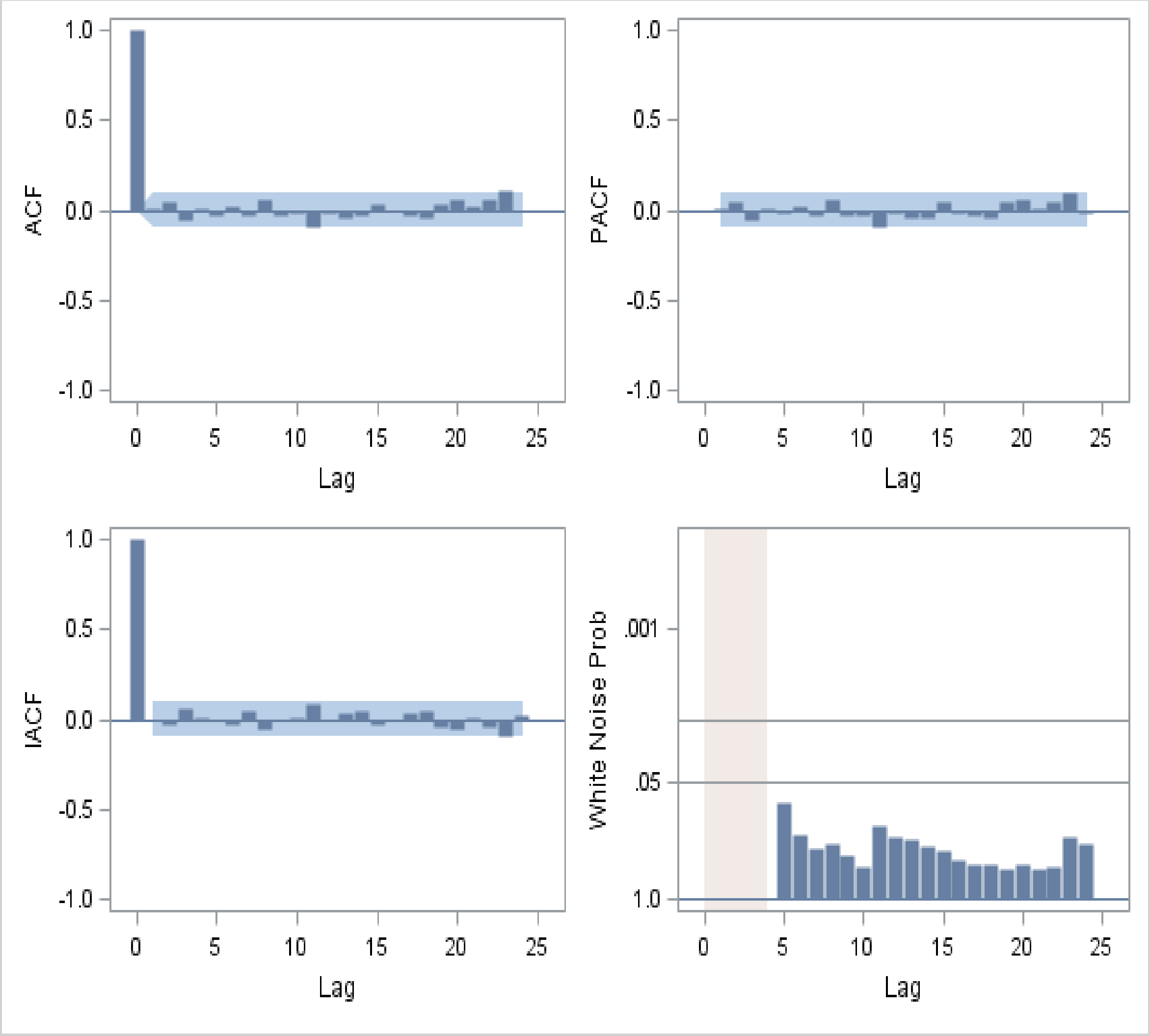

Figure 52: SAC and SPAC Plots of Residuals- Location 109 St. btw. 108 - 110 Ave.- (5-7)

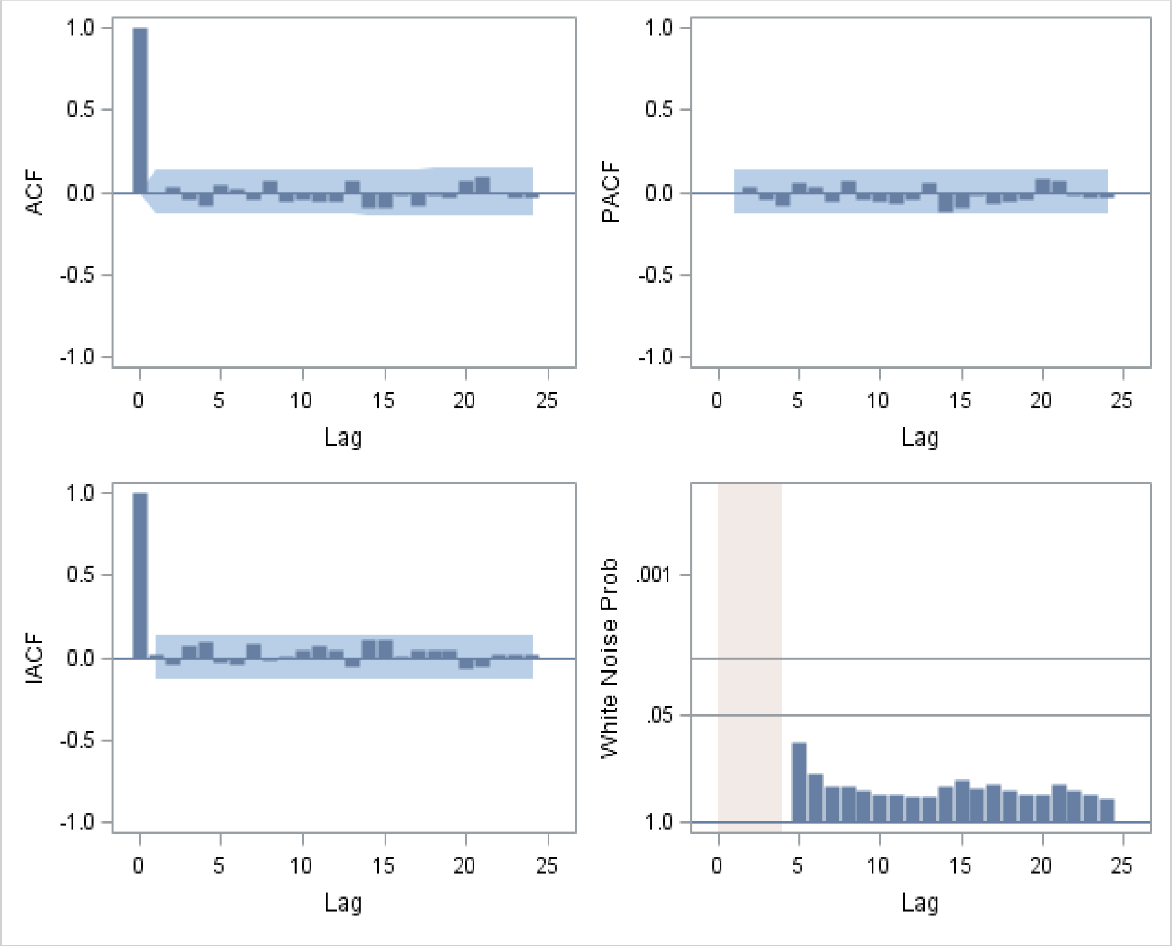

Figure 53: SAC and SPAC Plots of Residuals- Location 109 St. btw. 108 - 110 Ave.- (7-8)

D8. Location 144 Ave. btw. 77 - 79 St.

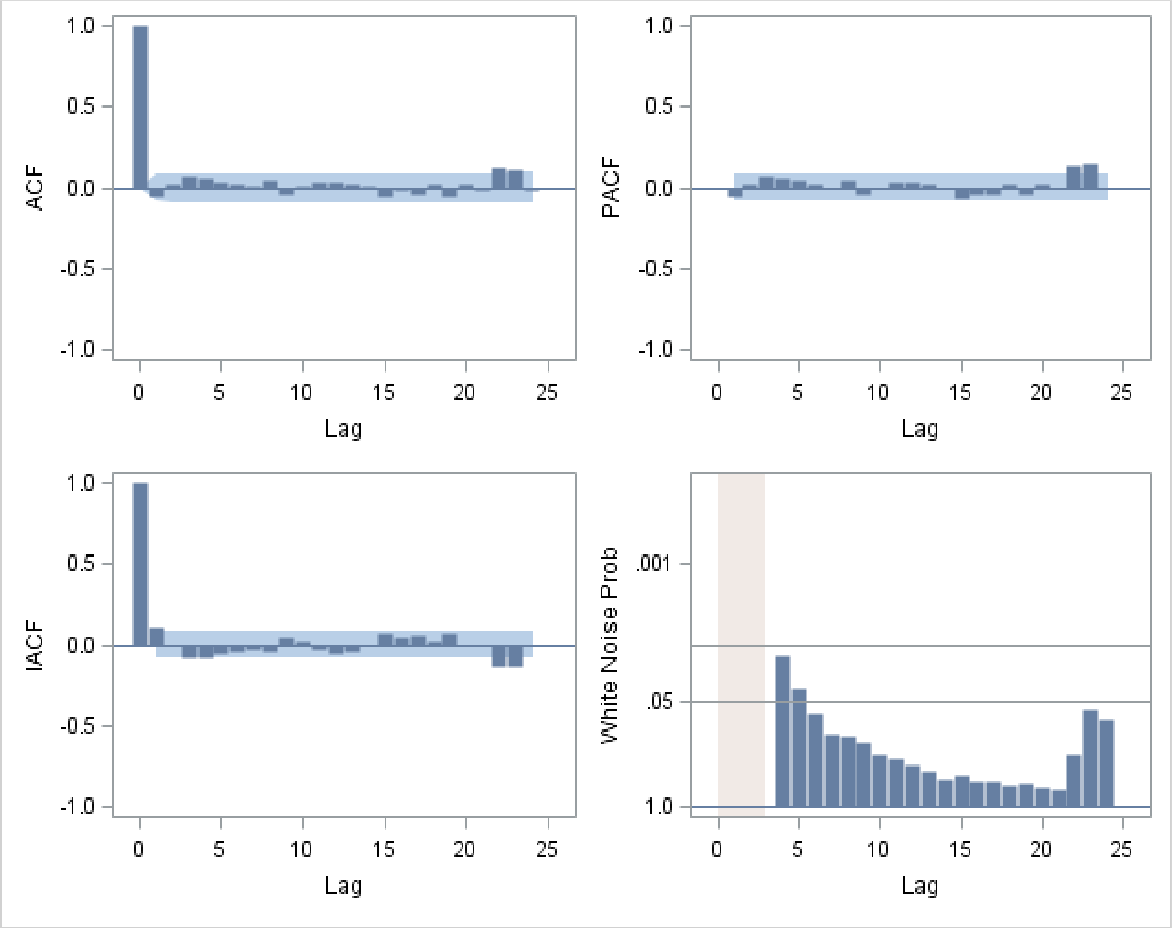

Figure 54: SAC and SPAC Plots of Residuals- Location 144 Ave. btw. 77 - 79 St.- (1-5)

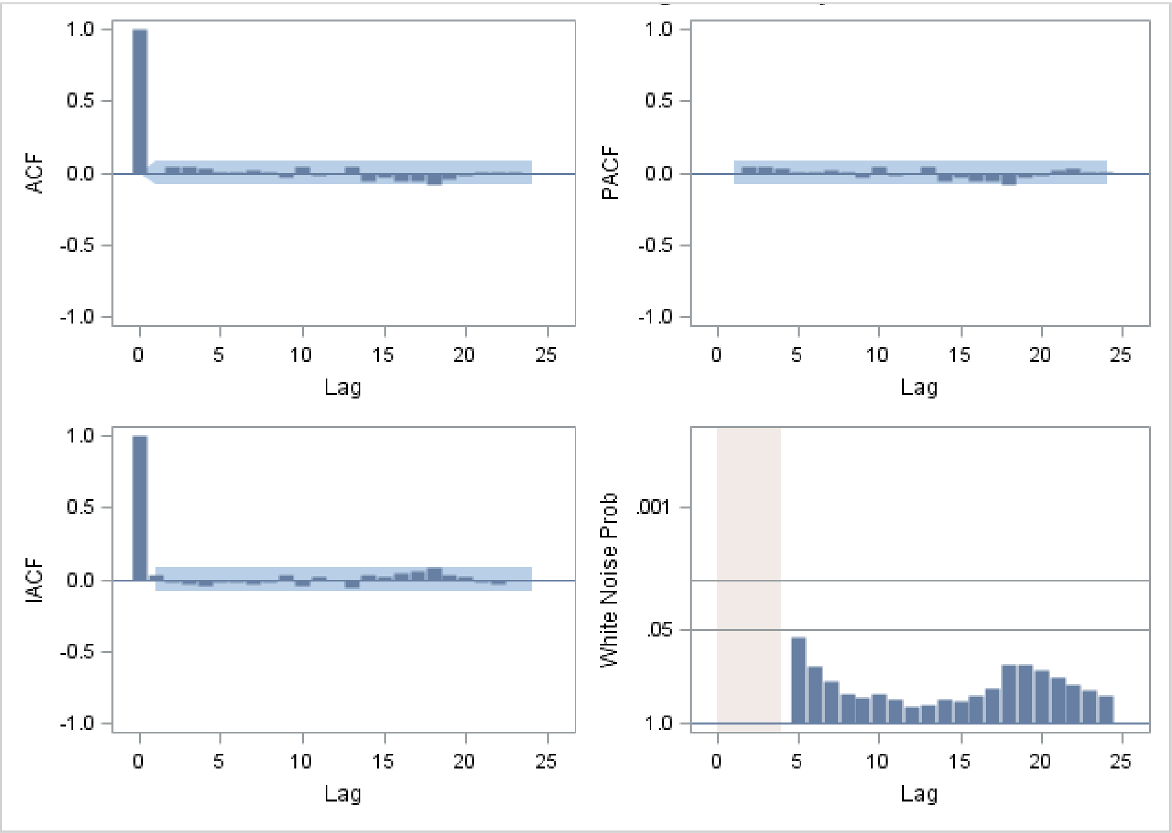

Figure 55: SAC and SPAC Plots of Residuals- Location 144 Ave. btw. 77 - 79 St.- (4-7)

D9. Location 156 St. btw. 94 - 92 Ave.

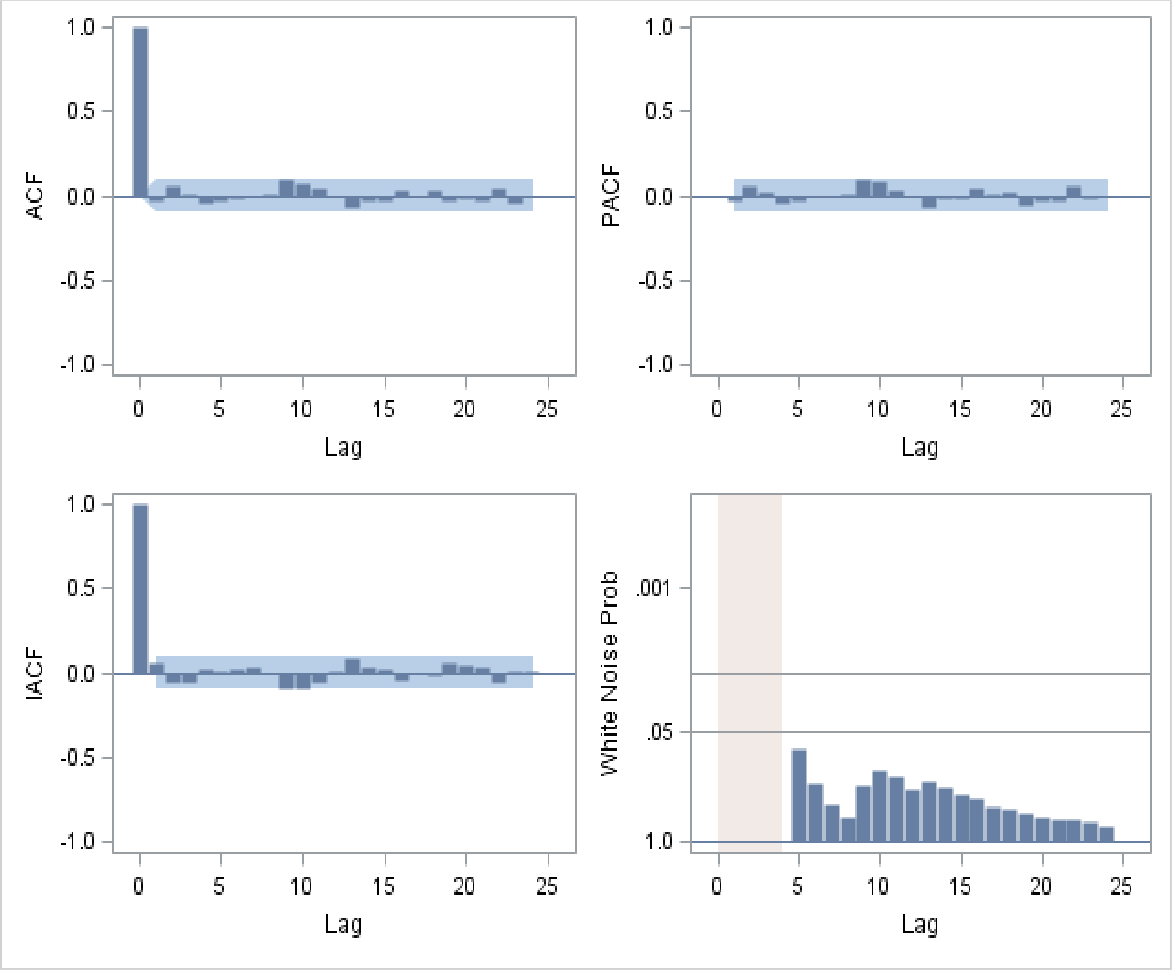

Figure 56: SAC and SPAC Plots of Residuals- Location 156 St. btw. 94 - 92 Ave.- (1-3)