The Impact of Off-Peak Delivery on Urban Freight Movements during the Pan American Games

by

Graeme L. Pickett

A thesis submitted in conformity with the requirements for the degree of Master of Applied Science
Department of Civil Engineering
University of Toronto

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Abstract

Large scale sporting events provide distinct challenges to urban freight movement. The 2015 Toronto Pan and Parapan American Games introduces high demand for goods and services as well as delivery restrictions in key sections of Toronto. First-hand accounts from members of London, England’s freight community and relevant literature are presented as a case study on best practices, including off-peak delivery, for freight delivery during such sporting events. A second case study of Nestlé Canada examines the benefits of advanced routing and off-peak delivery in mitigating the impact of the Games, as well as the potential for reducing the fleet size. A heuristic model is used to identify and select off-peak customers and to estimates route travel times. The results show that the Games are expected to increase Nestlé travel times by 6.4%, and that off-peak delivery can be used to reduce the travel time impacts by an average 2.9%.
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Chapter 1

1 Introduction

1.1 Large Sporting Events

Large sporting events that are operated on a city-wide scale provide distinct logistic challenges to the freight community. During these events the planning emphasis is usually placed on the transportation of athletes and spectators, with the movement of freight being considered of lower importance to the success of the event. This can result in a number of distinct challenges for the freight community, including but not limited to: longer travel times, longer delivery times, difficulty finding parking, and overall economic losses to logistics companies during these events. However, recently there has been more attention placed on goods movement during event planning. In particular, freight planning for the 2012 London Olympic Games brought the issues and concerns of the freight community to the forefront of the planning process, and while these types of events may still strain a company’s normal day-to-day operations, they also provide the incentive and opportunity for companies to make improvements in operational efficiencies and practices.

In the summer of 2015, Toronto will host the Pan and Parapan American Games. The Pan Am Games are the third largest multi-sport event in the world with over 7,000 athletes from 41 countries, only smaller in size than the Summer Olympics and the Asian Games (Toronto, 2014). The number of Parapan Am athletes has been estimated at 1,608 making it the largest Parapan Am Games ever. The Pan Am Games are held every year before the Summer Olympics, and contain all of the Olympic events plus a number that are not currently classified as Olympic sports. In addition to the athletics, there will also be a series of cultural events around the City of Toronto, titled Panamania, which will put further strain on the transportation network due to spectator movement. The cultural events, featuring concerts, visual arts, dancing, and cultural exhibitions will attract a wider range of spectators to various locations in downtown Toronto and around the Greater Toronto and Hamilton Area (GTHA).
The City of Toronto, and the surrounding municipalities in the GTHA, will face the challenge of transporting the “Pan Am Games family” to and from competition venues on Toronto’s already congested road network. The Games family includes not only the athletes, but coaching staff as well as officials and media personnel. The partnering municipalities of the GTHA will also be responsible for the movement of spectators to and from the competition venues outside of downtown Toronto, as well as to the cultural events in downtown Toronto. In addition to the Games running smoothly it is essential that the day-to-day activities in the GTHA continue operating with as little disturbance from the Games as possible.

From the perspective of freight logistics companies, there are many ways in which the Pan Am Games will impact a company’s normal day-to-day operations. Congested road conditions, worsened by the influx of spectators, will make travelling to and from delivery locations more difficult. Added to this, especially for the food industry, is the potential for increased product demand for the duration of the Games. This will likely result in either increased delivery frequency or delivery size. Finally the introduction of a Games Route Network (GRN) will introduce significant barriers to efficient goods movement as certain key sections of the city will contain restrictions for any traffic other than through traffic.

The City of Toronto and the Ministry of Transportation (MTO) will be employing many strategies to facilitate the movement of both people and goods. Free transit use for spectators, clear and consistent signage, new transit routes, and new parking regulations will all be employed to ensure the smooth movement of spectators (Ontario, Strategic Framework for Transportation - Executive Summary, 2014a). To facilitate goods movement freight operators will be able to employ several strategies for minimizing the impact of the Games, including, but not limited to, off-peak delivery, up-to-the-minute communication with transportation operators, consolidated deliveries, and route planning tools for operators.
1.2 Off-Peak Delivery

One of the strategies being employed by a number of companies to help mitigate some of the impacts of the Pan Am Games on their delivery operations is the use of off-peak delivery. Off-peak deliveries are deliveries made outside of the normal peak commuting hours. In theory this means that the middle of the day could be considered off-peak, where in the concepts being explored in this thesis off-peak refers to the late evening and overnight hours. By delivering to customers late in the evening or during the overnight hours, companies can take advantage of calmer traffic conditions in order to reduce travel time, parking search time, and delivery time, amongst other benefits. Figure 1 illustrates traffic volume by time of day for a typical road network. The AM and PM peaks contain the highest traffic volumes, while the evening and overnight hours contain the lowest.

![Figure 1: Typical vehicle volume by time of day. (U.S Department of Transportation Federal Highways Administration, 2013)](image)

One of the oldest known records of off-peak delivery describes a law imposed by Julius Caesar banning commercial deliveries during the daytime in Rome (Holguin-Veras, et al., 2005). Today, off-peak delivery is used in different parts of the world, but still only represents a minority of the deliveries made on a day-to-day basis. This is likely because the use of off-peak delivery is still a
highly debated issue. Large scale off-peak delivery programs can be successful, as was demonstrated New York City’s restaurant sector (Holguin-Veras et al, 2007c), but there are certain barriers that need to be overcome first. As part of their urban freight initiative, Metrolinx (2011) listed off-peak delivery as one of their 17 actions they wish to improve upon in future work. In their report they identified that the current barriers to off-peak delivery were restricted delivery times due to noise bylaws, as well as the lack of incentive for companies and customers to participate. For off-peak delivery to be accepted by both carriers and receivers, it is essential that there be mutual benefits to both parties (Churchill, 1970).

1.3 Research Objectives

This thesis has two primary research objectives:

1. Identify the challenges and best practices, including off-peak delivery, of urban goods movement during large sporting events.

2. Quantify the travel time impact of the Pan Am Games on Nestlé’s delivery operations, and determine the benefits off-peak delivery can have in minimizing some of these impacts.

The first objective was addressed using a more qualitative analysis, drawing on relevant literature as well as the author’s experience gathering information concerning urban logistics during the London 2012 Olympic Games. A series of interviews were conducted with different members of London’s freight and transportation community in January of 2014 as part of a student exchange grant funded by the Volvo Research and Education Foundation. The interviews provided a unique opportunity to gather information not only on the challenges and benefits of the implemented practices during the Games, but also about continuing legacy effects of the policies implemented. This information is therefore useful not only to policy planners for other large sporting events, but for companies interested in maintaining operations during sporting events as well as looking at longer term policies.

The second objective also draws on relevant literature which provides the foundation for the proposed method of quantifying the travel time impacts of the Pan Am Games and off-peak
delivery. The specific goal was to determine the travel time impacts of the Pan Am Games on normal delivery operations, and whether using off-peak delivery could yield any travel time savings for carriers. A five step heuristic was created to estimate these travel time savings. This heuristic identifies potential off-peak customers, determines if these off-peak customers should be delivered to during the daytime or during off-peak hours, clusters the customers into routes using a capacity constrained k-means clustering algorithm, and finally uses a simple vehicle routing algorithm to determine the optimal routing and total travel time. Customer and delivery data provided by Nestlé Canada and travel time data provided by IBI Group were used as inputs to the heuristic to answer three questions concerning Nestlé delivery operations.

1. What will be the impact of the Pan Am Games on current Nestlé operations?
2. What are the benefits of planning routes one week at a time rather than on a call-and-place basis for normal Nestlé operations outside of the Games?
3. Can off-peak delivery be used to mitigate the impacts from the Games?
4. Can advanced routing and off-peak delivery be used to reduce the total number of trucks used?

The first question examines the impacts to Nestlé’s normal delivery operations should they make no changes to their operations in preparation for the Games. This impact was estimated using travel time estimates for the Pan Am Games travel conditions and compared against estimates as to what the travel times would be without the Pan Am Games. The second question estimates the potential benefits for advanced route planning against Nestlé’s current call-and-place delivery practices. The third question focuses on the use of off-peak delivery in mitigating the impacts from the Games. Different methods for off-peak customer selection were analyzed, and were meant to represent different possibilities for customer participation in the off-peak delivery program. Finally the possibility of reducing the number of total trucks used, and the impact on travel times was examined. Further details concerning these three questions and their analysis can be found later in the thesis.
1.4 Thesis Structure

This thesis is organized into eight chapters. The first chapter provides an introduction and outline of the research goals and contributions. Chapter two introduces the London case study, and outlines the findings of the qualitative analysis, including the list of best practices concerning freight logistics during the London Olympic Games. Chapter three summarizes relevant literature pertaining to goods movement and off-peak delivery, building on the findings of chapter two. Chapter four introduces the Pan Am Games, outlines the expected conditions and challenges specific to freight operation, and introduces the Nestlé case study. Chapter four also details the data used for this project specific to the Nestlé case study. Chapter five reviews relevant literature concerning different vehicle routing and clustering methods, and presents the heuristic methodology used to analyze Nestlé’s operations during the Pan Am Games. Chapter six presents the results of the analysis, and discusses the benefits of off-peak delivery and advanced planning of Nestlé delivery operations. Finally, chapter seven provides a brief conclusion to the thesis questions and touches upon the project limitations and possible future work.
Chapter 2

2 London Case Study

2.1 Purpose

In 2012, the summer Olympic Games were held in London, England. Over 10,000 athletes from 204 countries, as well as millions of spectators, descended on England for the 30th Olympic Games. From a logistic perspective, these Games provided an excellent opportunity to examine the legacy the Olympics had on freight stakeholders in London. Sponsored by the Volvo Research and Education Foundation, and hosted by Michael Browne at the University of Westminster, the author conducted a series of interviews with four organizations with different responsibilities for freight logistics during the London Olympics. These four organizations were: TNT, Tradeteam, the Freight Transport Association (FTA), and Transport for London (TFL). TNT is a global logistics provider operating on a global scale delivery goods using a variety of transportation modes. Tradeteam is a beverage carrier operating on a national scale in England. The FTA is an organization of freight specialists who advise and work with freight operators around the country. Finally, TFL is responsible for all of the public transit in London, as well as the operation of many of the road networks in and around the city. These interviews were conducted to gain the following information:

1. What was the company’s/organizations’ main role during the Olympics?
2. What logistic challenges were faced that were the direct result of the Olympics?
3. What strategies were used to deal with these challenges?
4. What went well? What didn’t go well? Would any changes be made in hindsight?
5. Are there any “legacy effects” that came as a result of policy changes implemented during the Olympics?

As discussed above, the purpose of this case study is to identify a list of “best practices” concerning freight delivery in London during and following the Olympic Games. The information gathered supplements the quantitative analysis presented in later chapters of this thesis.
2.2 Freight and the Olympics

2.2.1 Challenges

As multi-sport sporting events, the Olympics and the Pan/Parapan American Games are comparable in terms of the logistic challenges faced by their respective host cities. The experiences gained during the London Olympics are particularly useful to the Toronto case study as many similarities exist between the two events and cities. The Summer Olympics and Pan Am Games (as well as Paralympics and Parapan Am Games) are roughly two weeks in duration, and contain more than 7,000 athletes in each case. The Summer Olympics are the larger of the two with over 10,000 athletes participating. In terms of population, the GTHA and the Greater London Area are home to 6 and 8 million people respectively. Both cities are the economic hub of their respective regions and experience substantial traffic and freight movements on a daily basis. For the London case, this made the efficient movement of athletes, officials and media, in addition to goods and services a difficult task as the normal day-to-day activities could not be shut down for the duration of the Olympics. A careful balance had to be struck between prioritizing the movement of athletes and officials with the normal day-to-day commuters.

Part of the reason for hosting an event like the Olympics or the Pan Am Games is to showcase the hosting cities to the world in order to promote tourism. Negative press resulting from chaotic traffic conditions would hurt the image presented by the host cities. Employing proper traffic management tools was essential to facilitate the movement of athletes, officials and media, who make up the Olympic family, throughout the city during the Olympics. The principle method used for this purpose was to create an interconnecting road network which restricted normal traffic and allowed preferential access to the Olympic family. This interconnecting road network is known either as the Games Route Network (GRN) or the Olympic Route Network (ORN), and the specific segments of the road network are referred to as Games lanes.

The use of designated Games lanes has been a requirement of hosting the Olympics since after the 1996 Atlanta Olympics (O'Sullivan, 2012) and a requirement for hosting the Pan Am Games since 2011. The reasoning behind their use is to facilitate the movement of the Games family. The 1996 Atlanta Olympics are notorious for the issues caused by transportation problems, with several reports of athletes almost missing their events. The legacy was that by the 2000 Sydney Games a Games Route Network was required for the bid by each host country. However, the
Olympic lanes were designed for moving athletes and other spectators to and from events, and were not specifically designed for moving freight. In particular, turning and parking restrictions along the ORN made delivering to customers in that region difficult. Specifics about the London ORN is presented in the following section.

2.2.2 The London 2012 Olympic Route Network

A major obstacle to freight delivery during the period of the Olympic and Paralympic Games was the ORN. Created in order to facilitate the movement of athletes, officials and media personal between venues, the ORN restricted the movement of vehicles not directly associated with the Olympics along key corridors between venues and the Olympic village. The ORN was in effect from 6 AM to 12 AM, and most segments were used for the duration of the Olympics. Other segments of the ORN, which connected the athlete’s village to venues outside of the city, were only used until the events taking place at those venues were finished.

Figure 2: Olympic Route Network for the London Olympics. (BishopsGate, 2012)
Figure 2 shows the scope of the ORN stretched across London, which occupied many of the major transportation routes into the city. Since the ORN limited the crossing of major arteries, this made it very difficult for delivery trucks to access different parts of the city on the same route. Challenges faced specifically by logistics companies as a result of the ORN are presented in Table 1.

Table 1: Rules and restrictions introduced by the ORN for the London 2012 Olympics

<table>
<thead>
<tr>
<th>ORN Road Restrictions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closing of Side Roads</td>
<td>Restricted traffic on roads branching from the ORN to local traffic only.</td>
</tr>
<tr>
<td>Restricted turns</td>
<td>Restricting turning movement to specific locations on the ORN.</td>
</tr>
<tr>
<td>Traffic Signal Timing</td>
<td>Retiming of traffic signals to prioritize through traffic.</td>
</tr>
<tr>
<td>Parking/Loading Suspensions</td>
<td>Suspended the loading or unloading of vehicles, commercial or otherwise, along the ORN.</td>
</tr>
<tr>
<td>Reduced Pedestrian Crossing</td>
<td>Limited intersections available for pedestrian crossing</td>
</tr>
<tr>
<td>Suspension of Roadwork</td>
<td>Suspension of roadwork on and around the ORN with the exception of emergency situations</td>
</tr>
<tr>
<td>Games Lanes</td>
<td>Designated section of the road network restricted to members of the Olympic family.</td>
</tr>
</tbody>
</table>

Note: Table 1 adapted from (Hirst, 2012)

In particular, turning and parking restrictions around the ORN would restrict a company’s ability to make efficient deliveries to customers located on or around the ORN. The scope of the ORN also played a role in the challenges faced by logistics companies. Specific challenges in addition to those presented in Table 1 are discussed in the next section.
2.3 The Interviews

Four interviews were conducted with individuals associated with freight logistics in London and the UK during the Olympics. These interviews were organized by Michael Brown of Westminster University, who was the hosting member of VREF for the student exchange. The four people interviewed were:

1. Natalie Chapman, Freight Transport Association Head of Policy for London
2. Jaz Chani, Freight Project Manager at Transport for London
3. Martin Schulz, Projects, City Logistics & Public Affairs - Network Operations TNT Express
4. John Crosk, Operations Manager at Tradeteam

The responses below are summaries of the interviews. They are not word-for-word responses from the interviewees.

2.3.1 Interview 1: Natalie Chapman, Freight Transport Association

What is the FTA and who do they represent?

- The Freight Transport Association (FTA) is composed of a group of freight specialists who advise and represent the interests of over a third of England’s delivery vehicles.

What did they do in anticipation of the Olympics?

- FTA’s main role in the lead-up to the Olympics was to act as a channel to voice company concerns to the Olympic policy makers. In direct preparation for the Olympics, the FTA worked very closely with any member companies who would be directly affected by either the heavy traffic or the ORN. A door-to-door campaign along key effected corridors provided information early, while raising awareness among affected parties. They likewise provided packets of information to carriers and receivers about conducting off peak deliveries and the challenges faced due to borough bylaws, particularly noise bylaws.

- The FTA also worked with TFL on their freight forums, which were gatherings of companies and policy makers designed to facilitate the sharing of ideas and issues.
What went well during the Olympics?

- A key aspect that really brought freight forward as a potential serious issue was the involvement of a senior planner in the freight forums. By involving someone who had real influence in the planning process, it demonstrated to the organizations and member companies how important it was to make sure that they were prepared for the Games. It also brought freight forward on the list of critical issues that needed attention during the remaining planning meetings.

What didn’t go well during the Olympics?

- There was an initial viewpoint that freight issues had very minimal importance during the planning process when compared to other issues such as public transportation. As a result of this viewpoint, very little attention was given to freight early on. It wasn’t until the inclusion of senior members of the Olympic planning committee during the freight forums that freight was finally identified as something that needed direct attention before the Games began. The logical reasoning behind this was that if the movement of goods were to be interrupted, than the impact would have been felt at every bar, restaurant and venue.
- Associated with the above point was the lack of consistent information during the early planning stages of the Olympics.

Legacy and message

- In terms of a legacy effect, the freight community is better off post Olympics than pre-Olympics. This is due, not in small part, to the new open channels of communication that exist amongst members of the freight community.

2.3.2 Interview 2: Jaz Chani, Transport for London

What is Transport for London?

- Transport for London (TFL) is responsible for managing public transportation in London. They also maintain and manage around 5% of the capital roads in London and operate a freight team consisting of 16 members.

When did they take over control of freight activities?
- TFL assumed control of all freight related activities roughly 18 months before the start of the Olympics.
- This included organizing freight forums, providing ORN information, door-to-door informative campaigns and running pilot off-peak projects, among others.

What role(s) did they play in freight movement during the Olympics?
- TFL’s key role was to provide information to those affected by the Games and the ORN. This was done by being a central source of information, something that was lacking before they took over. One of their primary goals was to provide accurate information as early as possible, so that proper preparations could be made.
- TFL was also responsible for the creation of the freight forums. Mentioned previously, the freight forums provided a place for companies, with the guidance of the FTA, to voice their questions and issues with TFL. It also allowed for the exchange of ideas between companies, something which had rarely happened because of competition.
- Introduce and promote the four R method for freight delivery; reduce, retime, reroute or revise mode
- TFL also provided email bulletins to the freight community. These bulletins, which were sent out more frequently as the Games approached, provided up-to-the-minute information to companies about road closures, changes in regulation, and any other information that they would need throughout the period of the Games.

What went well?
- The freight forums were seen as a success, as the flow of information between competing companies was something that had never happened before on such a large scale.
- The door-to-door campaign (similar to the FTA’s) helped the spread of information
- Trip planners, mostly used by smaller companies with fewer registered trucks, provided a way for companies to try and optimize their routes around the ORN.

What didn’t go well/could have gone better?
- Off-peak delivery, while an excellent idea in theory, was not continued after the Games by the vast majority of the companies. There were simply too many issues with the different boroughs to contend with.
Legacy and messages

- The main legacy effect was the creation of the freight forums, which are still a twice yearly occurrence.

2.3.3 Interview 3: Martin Schulz, TNT

What is TNT?

- TNT is one of the world’s largest freight logistics companies, operating air, rail and truck fleets.
- TNT owns the largest market share of freight in the United Kingdom.

What were their preparations for the Olympics?

- As with the other organizations, communications with their stakeholders was essential in the success of TNT operations during the Games, such as keeping them informed of changes in delivery patterns resulting from the ORN.
- Normal operations consisted of deliveries made during the normal peak hours. A slight shift to earlier departures was made for a portion of the Olympics. Delivery volumes were increased and extra trucks were put onto the road to help deal with the potentially higher delivery times. However, it was determined that this shift in start time and extra truck traffic was not necessary, as the traffic conditions on the road were not as bad as anticipated.
- Information packets were distributed to all truck drivers. These packets were route specific and contained information about closures or restrictions on each individual route.

TNT had a different reaction to the outcomes than the other companies, as they found that their normal operations were not significantly impacted. There was no legacy effect that was introduced as a result of the Olympic planning.
2.3.4 Interview 4: John Crosk, Tradeteam

What is Tradeteam?
- Tradeteam is a logistics company specializing in beverage delivery to bars and business.

What were their preparations for the Olympics?
- Tradeteam started their Olympic planning two years before the start of the Games. The planning involved an open doors policy which allowed their customers to see what Tradeteam was doing to prepare, and hopefully get some ideas as how best to prepare themselves.
- Tradeteam also worked closely with the different boroughs, specifically about off-peak delivery regulations. In many of the boroughs off-peak delivery wasn’t allowed due to noise restrictions. Steps were made to create a “common sense” approach to night delivery that would allow for fewer complaints during the Games.
- Consolidating alcohol deliveries with other (food etc.) deliveries so that fewer trucks would have to be on the road.
- Off-peak deliveries were conducted along some corridors affected by the daytime ORN.

What didn’t go well/could have gone better
- Planning team neglected to prepare for deliveries that were made to cities other than London. Some Olympic events were held outside of the city and across the country. Some distance deliveries to some of these locations were affected by the Games but not properly prepared for.

Legacy and messages
- Start planning for the Games early, and involve your customers in the discussion from the beginning.
2.4 Common Themes and Best Practices from London

This section will outline some of the key lessons learned from personnel involved in logistics planning for the London Olympic Games. These “best practices” are not specific to the Olympic Games in London, but can be applied for any major sporting events, including the Pan Am Games.

2.4.1 Lesson 1. Plan for freight movement well in advance

Proper transportation planning takes a good deal of time. There will always be new issues that arise and must be dealt with in order for the plan to be a success. In situations such as the Olympics or Pan Am Games, the transportation discussion is usually centered on the movement of people rather than the movement of freight. Stressing to the Games planners about the importance of freight delivery to the success of the eventual success of the Games is essential. This involves proactive organization on the part of local freight authorities, as well as a freight presence during the planning process.

2.4.2 Lesson 2. Involve senior planners in the freight discussion

According to Natalie Chapman and Jaz Chani, of the FTA and TFL respectively, freight was not being recognized as an issue of concern until after a senior Olympic planning official was involved in the planning process. Bringing a senior official to the freight forums accomplished two things. Firstly it sent the message to the contributing companies that freight movement during the Olympics was a serious issue, and that without proper planning the companies would struggle with their deliveries for the duration of the Games. Secondly it demonstrated to the senior official the potential consequences if they were to do nothing. The senior planner’s involvement allowed for the concerns of the freight community to be heard directly by the planning department. This was considered to be an essential step for logistics planning.
2.4.3 Lesson 3. Freight forums are an essential part of planning efforts

The consensus amongst all of the interviewees was that the freight forums were the most useful tool in preparation for the Olympic Games. Freight forums were an organized effort for affected transportation and delivery companies, as well as those receiving freight, to be involved in an ongoing discussion to assist with their planning. This was not only an excellent method for spreading information, but the open discussion concept brought forward ideas and issues that were previously unknown. The forums brought together competing companies and planning officials, and set the groundwork for many of the successful initiatives. These freight forums are still held on a semi-annual basis, and are one of the legacy effects of the freight planning that went into the Olympics.

2.4.4 Lesson 4. One consistent, reliable source of information to the stakeholders

It is essential that all of the stakeholders are receiving information from the same source. Before TFL took over the freight management 18 months prior to the Olympics, information provided to the stakeholders was not distributed consistently, and was not optimal. Aside from the introduction of the freight forums, TFL also provided a consistent stream of information to the freight community. This included weekly bulletins leading up to the Games, daily or twice daily bulletins during the Games, ORN information, route planning assistance and any other support needed. This allowed 91% of businesses surveyed to feel like they were prepared for the Games (Browne et al. 2014).

2.5 Summary and Olympic Freight Legacy

Members of the freight community in England faced many challenges during the Olympics which impacted their ability to make deliveries. The main challenge was the implementation of the ORN, which reduced access to certain key sections of the road network. Careful planning and coordination between members of the freight community allowed for success both in terms of Games time operations as well as legacy impacts. The overarching theme consistent across all four of the lessons presented is the idea of communication. From the perspective of the overall city
planning it is essential to involve freight from the beginning. Having a voice in the early stages allows for the concerns of the freight community to be heard. From the perspective of individual companies it is essential to have an open line of communication with their customers. Starting the conversation with customers far in advance of the event will help insure successful Game time operations. It allows companies time to plan out their operations and procedures for the events, while informing customers of potential changes to operations and allowing them to have a say into their specific preferences. Finally, during the events it is important to have updated information concerning the road network and the Games lanes in order to help companies deal with last minute changes or incidents.

The transportation aspects of the 2012 Olympics were deemed a success by many of the parties involved. The regular traffic experienced a shift in time period, with off-peak hours experiencing a 13% increase in central London, while peak hours experienced a decrease by up to 12% (Browne et al. 2014). As a result of Transport for London and the FTA’s pre-Game initiatives, 91% of businesses and 81% of freight operators were prepared for the Olympics (Browne et al., 2014). Both Browne et al. (2014) and Transport for London (2013b) indicate that over 50% of carriers and receivers made changes to their normal operations in response to TFL and the FTA’s initiatives. Of the four R’s outlined above, reduce was the most popular, with almost 50% of stakeholders participating. This was followed by re-time with 41% and 45% for carriers and receivers respectively, and reroute with 42% of carriers and only 5% of receivers (TFL. 2013b) (Browne et al. 2014). The revise route strategy had very little participation, probably due the lack of alternative options for most deliveries. TFL provided route planners online to aid businesses with rerouting their trucks, while the FTA worked closely with carriers and receivers on off-peak delivery (TFL. 2013b).

The lasting impacts and legacy of the freight management during the Olympic Games were less successful than anticipated. Only 7% of carriers continued with the operational measures used during the Olympics. Two reasons for this was a related lack of support from receivers, and noise bylaws, which in the case of off-peak delivery had been eased during the Olympics to facilitate off-peak delivery (Browne et al. 2014) (TFA. 2012). Positive legacies of the Olympic Game efforts included the freight forums, spearheaded by the FTA, as well as the off-peak delivery projects. However, there needs to be considerable collaboration with local municipalities before off-peak delivery becomes commonplace as a routine consideration (FTA. 2012).
3 Literature Review: Off-Peak Delivery

Off-peak delivery is the delivery of goods during the evening and overnight hours. A successful off-peak delivery program requires cooperation and communication between receivers and carriers, as well as a careful balance between the benefits and challenges associated with delivering during off-peak hours. This literature review will outline in detail the benefits and challenges of off-peak delivery, and will introduce the different methods carriers can use for off-peak delivery and will conclude with a summary of key points.

3.1 Benefits and Challenges of Off-Peak Delivery

There has been extensive work conducted on the benefits and challenges of off-peak delivery in New York City’s restaurant and business sector. Professor Jose Holguin-Veras and his research group at the Rensselaer Polytechnic Institute have been responsible for a large portion of the current research examining the impacts and challenges of off-peak delivery. The scope of their research includes studies on the economic impact of off-peak delivery, studies on the variation of travel times and speeds, pilot projects involving New York City’s restaurant sector, and a particular focus on carrier receiver relationships.

The possible benefits of off-peak delivery can be broken down into benefits incurred while travelling to and from customers, and benefits incurred during the drop-off or pick-up. The lowest traffic levels are generally experienced during the overnight hours. Logically, this should correspond to a range of benefits; including but not limited to: shorter travel time, higher travel speeds, less idle time, and fewer emissions. However, the benefits experienced are likely to be different for each carrier/receiver pair. Carriers whose tours contain only a small number of customers located outside the central business district may experience different benefits and challenges compared to those who usually make many stops in the downtown core on a regular basis. Similarly, the type of customers being delivered to will have an impact.
Holguin-Veras et al. (2014b) organized a pilot off-peak delivery project which moved the delivery schedules of 33 food delivery companies to off-peak hours. The trucks were monitored using GPS technology to determine location and speed on an ongoing basis. Results from this project align with what was expected in terms of the potential benefits of off-peak delivery. A speed increase between the depot and first customer was observed, from 11.8 mph to 20.2 mph, while a smaller increase was found while traveling between subsequent customers. These changes lead to a large economic benefit which, when extrapolated for all freight across the entire city, were estimated at roughly $147 million to $193 million in potential savings per year. In addition to these travel time improvements, it was estimated that the delivery time during the pilot project was on average a half of what would normally be experienced during the morning hours, when the majority of the deliveries would have taken place.

There are further benefits that can be expected in addition to travel time improvements. Making deliveries in urban areas can be difficult due to the lack of proper truck parking. It is estimated that upwards of 96,000 additional vehicle kilometers are travelled every year on an average city block due to the search for parking (Shoup, 2005). For commercial vehicles, the additional parking search time is likely to have a significant impact on their total tour time. In addition, the delivery of many types of goods requires parking nearby to the delivery location, either due to size or weight of the products. As a direct result of this, many commercial vehicles are forced to park illegally closer to their delivery location, resulting in parking tickets. For example, in 2012 Toronto commercial vehicles accumulated $27 million in parking fines (Wenneman, Habib, & Roorda, 2014). In Toronto this issue is further impacted by the recent crackdown on illegal parking during the morning peak hours by the City of Toronto (Moore, 2015). Fines of up to $1000 per month per truck are not uncommon in New York for some companies (Holguin-Veras et al. 2014b). Holguin-Veras et al. (2007c) indicates companies paying more for parking fines would be more likely to switch to off-peak delivery in an attempt to reduce operating costs.

Several studies have shown the potential of off-peak delivery in reducing truck emissions. Yannis, Golias, & Constantinos (2007) used a traffic simulation model to estimate the impact of delivery time restrictions on truck traffic in Athens, Greece. Results of their analysis showed improvements in overall traffic emissions by restricting truck movement during peak hours. While not specifically analyzing the effects of off-peak delivery on emissions, the results show the potential benefits of reducing truck movements during the normal working hours. Campbell (1995)
generated analytical models to estimate emissions from large trucks in the Los Angeles area. Results of the study were more inconclusive in terms of the total emissions reduction. The results indicated that emissions reductions were possible, but only under conditions where the average speed increased. For the case of Los Angeles, where there were nighttime restrictions on truck movement in some areas, the increase in average speed is negated by the extra distance needed to travel to avoid the restricted areas. The Barcelona nighttime delivery project showed the potential for reducing the number of trucks required to make deliveries. The project showed that seven smaller trucks which would normally make the daily deliveries could be replaced by two larger trucks, which would normally not be able to maneuver through downtown peak hour traffic (Chiffi, 2014).

The implementation of an off-peak delivery program requires addressing a number of challenges. The current limited use of off-peak delivery is an indication of the challenges that companies face in implementing an off-peak delivery program. The three concerns that encompass most of the issues faced are: noise restrictions when delivering near residential areas, receiver participation in the off-peak delivery program, and the security issues associated with making deliveries at night.

Considerable research (Holguin-Veras et al. 2007a, 2007b, 2007c) suggests that the largest barrier to off-peak delivery is receiver willingness or ability to accept off-peak delivery. The main reason receivers do not accept off-peak delivery is the associated cost. If the business already operates over off-peak hours then this isn’t an issue, but for many receivers who only operate during daytime hours this presents a major barrier. The cost to receivers to staff their business outweigh the potential benefits of off-peak delivery (Holguin-Veras et al. 2014b). Holguin-Veras et al. (2007c, 2005) surveyed restaurants to determine their likelihood of accepting off-peak deliveries given a financial incentive. The hypothetical incentives, or disincentives, offered were the deduction of one worker’s salary from their taxes, an unspecified Government subsidy, an unspecified tax cut, or an increase in shipping cost during peak hours. Survey findings indicated that the first two options (deduction of one worker salary or Government subsidy) would be the most effective in enticing receivers to switch to off-peak, with 50% of respondents responding positively. The other two options both had lower than 50% positive responses, indicating they would not be sufficient incentives to switch to off-peak delivery. The question left unanswered is the value of the Government subsidies required for the off-peak program to be worthwhile.
A policy restriction to off-peak delivery exists in many municipalities. This surrounds noise regulations and bylaws, which restrict what activities may be done at night. Nighttime noise is likely to generate opposition to off-peak delivery projects from members of the community (Holguín-Veras et al. 2014). Noise can come from a number of different sources during the delivery. Moving products within the vehicle, both with or without a lifting device, loading and unloading the ramp, backup beepers as well as closing doors all add to the noise produced during the delivery (Holguín-Veras et al. 2014). Other possible sources are personnel-related and can include the playing of music and unnecessary slamming of doors. Some types of noise can be reduced or eliminated with driver training and self-discipline, but other types of noise require more innovative solutions. Wang et al. (2014) and Holguín-Veras et al. (2014a) suggest some possible solutions. Hybrid fuel or electric trucks produce less engine noise on average than diesel trucks. Refrigeration units can be further isolated and insulated to reduce noise, and low noise lifts can be purchased which operate at around 60 db. Alternatively ‘quiet’ truck beds or liners can be used which minimize the noise caused by metal making contact with metal. In Barcelona delivery trucks were refurbished to include many of the low noise technologies. This allowed for the success of an off-peak delivery project which saw food being delivered to grocery stores around the city during hours normally restricted by noise restrictions. Results of that study showed noise caused by the delivery differed very little from ambient background noise (Chiffi, 2014).

In Toronto, noise bylaw 591 (City of Toronto, 2010) limits what type of activities may take place during the overnight hours, in particular in residential zones. Toronto has many mixed use zones, and as a result this noise bylaw is in effect for a large portion of the city overnight. A pilot off-peak delivery project organized by Ontario’s Ministry of Transportation (2014) monitored the noise levels of deliveries in downtown Toronto. The conclusions of the pilot project were that “background hum” of the urban environment was able to mask the sounds of the off-peak delivery, and that the noise produced in the residential areas was sufficiently low as to not bother the residents. This last conclusion was reinforced by the fact that no complaints were received during the pilot project from residents.

With nighttime delivery there is an inherent risk involved that is less present during daytime delivery. The risk can be broken down into risk of driver injury due to the dark conditions, and risk to the driver due to other persons (Brom, Holguín-Veras, & Hodge, 2014). Dark conditions make curbside deliveries more dangerous due to the risk from other drivers, as oncoming traffic
may not be expecting deliveries to be taking place at that time of night. This can be overcome through the use of proper reflective safety gear for the driver, or through the use of pylon barriers to warn other drivers of hazards. The risks to drivers due to other people are likely harder to predict and control. Precautions can be made, especially for the delivery of more valuable goods such as the delivery of alcohol, but it is likely impossible to completely eliminate the risks. A survey of carriers in the New York off-peak pilot project indicates that some drivers actually felt more secure delivering during off-peak hours. Their major concern was the dangers from other drivers, which are much more prevalent during the daytime. The quieter conditions at night allowed them more freedom while making deliveries (Brom, Holguin-Veras, & Hodge, 2014).

3.2 Off-Peak Delivery Methods

Assisted delivery is the most common delivery method for daytime deliveries. It involves having a person present in the store to accept deliveries. While obviously not an issue for daytime deliveries, staffing the store during the off-peak hours can be expensive. Receivers that normally staff their stores during the off-peak hours also wouldn’t have this issue, but customers that are not normally open overnight would.

Not all deliveries must be received by an employee of a business or other type of establishment. Different methods for unassisted or unassisted delivery exist, but are dependent on the type of product being delivered and the business setup. Delivery lockers or staging areas are examples of methods that do not require direct access to the store or business (Holguin-Veras et al. 2013). Both methods require a space separate from the interior of the business premises where the delivery can be placed. The downside is that some products, like perishable goods, frozen items or high value goods require extra infrastructure that can be expensive. The upside is that the stores/businesses can operate on normal hours and do not need to staff the store overnight.

Other options for unassisted delivery involve giving the driver access to the store, either through the use of a key or electronic code (Holguin-Veras et al. 2013). The benefits are similar to the staging area, which allow the driver to make the delivery without staff being present; however, these methods are less expensive as they do not require a large amount of additional space for
deliveries to take place. An obvious downside surrounds driver security; whenever a new driver is assigned to a route, the security measures in place would have to be altered.

Lock boxes and separate delivery lockers can be used for non-perishable goods delivery. Lock boxes and lockers are separated, locked area which can be accessed by delivery personnel. They allow for the secure storage of goods without giving the driver access to the store proper. Virtual cages use a series of small sensors to monitor a small area of floor space in the store proper (Holguin-Veras, 2014d). Drivers are allowed access to this small area inside the store proper where they can leave the goods. The sensors are able to detect if the driver leaves the virtual cage and enters into restricted areas of the store. This method is beneficial in that it doesn’t require the construction of any additional lockers or storage locations, but does require the installation of the motion sensing equipment.

The final option is to give the delivery driver complete access to the store proper. This method allows for complete delivery of the products, but does require a certain level of trust by the receivers. Drivers can either be given a copy of the key to the store, the code to the electronic lock, or some combination of those two in order to allow them to make the deliveries independently. Alternatively, if a company is delivering to multiple locations of the same store, for example different locations of the same clothing store, than a company representative can follow the driver around, allowing access to each individual store. This would ensure that the delivery drivers cannot access the stores at any other time while still allowing for, mostly, independent off-peak delivery of the products.
3.3 Summary

Research shows that the principle barrier to the implementation of off-peak delivery programs is receiver participation. Receivers generally dictate when deliveries should arrive at the store. For them to accept a change in delivery schedules it is essential that they perceive some benefits to themselves. For many receivers that operate only during the normal working hours, this benefit may simply not exist. The cost of staffing the store overnight, or the extra security concerns would simply outweigh any benefits of receiving their delivery before the stores open in the morning.

This leaves the carriers with several options: tailor the off-peak routes for customers who would be willing to accept off-peak deliveries; offer incentives to customers who normally would not accept off-peak deliveries to accept them; or in the special case of major sporting events, encourage the use of off-peak deliveries by emphasizing the challenges that stores might face in receiving their goods in a timely manner. This last method was used in London to encourage participation in companies that may have otherwise not chosen to participate. Each of these options have disadvantages associated with them. Tailoring the off-peak routes for customers who are willing to accept off-peak deliveries doesn’t require the cost of incentives, but may result in largely spaced out routes, possible resulting in increased travel times. Offering incentives to certain customers may allow companies to create more efficient off-peak routes, but at the additional cost of providing those incentives. Finally, encouraging the participation of customers during sporting events may increase participation during the sporting events, but does not provide much framework for maintaining off-peak delivery operations after the event is finished.
4 Toronto 2015 Pan Am Games

4.1 Pan Am Games

The Pan American Games are one of the largest multi-sport sporting events in the world. The first official Pan Am Games were held in Buenos Aires, Argentina in 1951, and were attended by around 2500 athletes from 21 nations from North, Central, and South America (Wikipedia, 2015). The most recent Pan Am Games were held in 2011 in Guadalajara, Mexico, and were also the first Games to use a Games Route Network to facilitate the movement of the Games family to and from their events. The Toronto Pan Am Games are set to be the largest ever Pan Am event in terms of the number of competing athletes, with over 7,000 athletes representing 41 countries.

Initial preparations for the Toronto Pan Am Games began in 2009, after the final voting to determine the host country. Toronto beat out Lima, Peru and Bogotá, Colombia for the right to host the Games. The preparations included, amongst others, the construction of new venues, the installation of the Union-Pearson Express rail service, and the creation and modelling of various transportation demand management tools. These tools were used to estimate various travel and road conditions, and to test the impact of these conditions on the movement of people and goods throughout the GTHA. One of the main challenges in planning transportation for an event of this size is the magnitude of the Games in terms of the location of the venues. For example, the rowing event takes place in Saint Catherine’s Ontario, over 120 km from the athlete’s village in downtown Toronto. This creates issues as the transportation policies had to be extended a large distance outside of the City of Toronto, which in turn impacts more people commuting into the city to work. Figure 3 shows the location of the venues across the GTHA.
The City of Toronto contains the highest concentration of venues with the largest continual expected number of spectators. The athlete’s village, the Pan Am Ceremonies venue, and Pan Am Park at Exhibition Place are all located in downtown Toronto. In particular, Pan Am Park is expected to experience high numbers of spectators on a daily basis for the duration of the Games.

4.1.1 Expected Travel Conditions

During the Pan Am and Parapan Am Games there will be an estimated 250,000 spectators coming to the GTHA, along with the 10,000 athletes and officials (Toronto, 2014). This additional demand will have to be absorbed by the current road and transit networks. Estimates for the number of additional travelers to each of the event venues were developed based upon the expected ticket sales at those venues (Ontario, Volume one - Strategic Framework for Transportation, 2014b). This was done for each day of the Games, and the estimated additional demands were added to the
normal expected travel conditions to estimate the total demand on the road network. The venue with the largest expected number of spectators is the Pan Am Park, located at Exhibition Place in downtown Toronto. Figure 4 shows the expected number of total spectators per day at the Pan Am Park. Peaking at around 45,000 spectators for the first two days of competition, and maintaining high levels of expected spectators for the duration of the Pan Am Games. Pan Am Park had no planned events for the Parapan Am Games.

![Expected spectator numbers at the Pan Am Park in downtown Toronto](image)

**Figure 4: Expected spectator numbers at the Pan Am Park in downtown Toronto**

*Source: (Ontario, Volume one - Strategic Framework for Transportation, 2014b)*

Having the knowledge of expected traffic conditions during the Games for different key regions of the city would help companies plan their delivers during those days. Focus was placed during the planning process on certain days that were expected to place the most strain on the transportation network. Two days, July 11 and July 15, which are day one and five in Figure 4, were identified as the two days with the highest expected volumes of traffic. July 11 has the highest expected spectator movements, but falls on a Saturday. July 15 has a number of events expecting large numbers of spectators taking place across the GTHA and falls on a Wednesday, and therefore is expected to be one of, if not the worst day, for traffic during the Games. For this day, an hour by hour impact assessment was conducted to identify key venues and segments of the road network.
which were likely to cause high traffic conditions. It was determined that the most impacted areas were likely to be the major highways leading to the venues, partially due to the additional demand, but mostly due to the Games Route Network being in effect during this time.

4.1.2 2015 Pan Am Games Route Network

The Ministry of Transportation Ontario (MTO) is responsible for organizing and maintaining the transportation network during the 2015 Pan Am Games. A significant portion of their responsibility will be governing the GRN. Similar to the ORN used in London, the GRN consists of key, interconnect road segments that will serve to transport the Games family to and from their events. One lane in each direction will be designated as Games Lanes for every section of the GRN. These lanes will not be exclusively for Games family vehicles, but will also count as high occupancy vehicle (HOV) lanes and will permit vehicles with 3+ occupants during the Pan Am Games and 2+ occupants during the Parapan Am Games, as well as transit vehicles (MTO 2014a). Other vehicles will be restricted to the non-designated lanes, the penalty for illegally using the HOV lanes being a ticket. The MTO will operate the Games lanes for the duration of the Pan and Parapan Am Games.
Figure 5 shows the scope of the GRN, and identifies the four types of Games lanes, which are designated either as core, venue, training, or alternate lanes. In total, 770 km of the road network in the GTHA is being identified as Games lanes. The core GRN will connect the locations which are expected to experience a large and consistent flow of Games family members. Key destinations along the core GRN include the airport, the athlete’s village, and some of the more heavily used event venues. The core network will remain in place throughout both the Pan and Parapan Am Games. The venue GRN lanes will connect the athlete’s village with the venues outside of the downtown Toronto core. Some of these venues will only be used for a short period of time during the Games, and as a result the GRN lanes servicing those venues will only be in effect for the short duration of those events. The training GRN lanes link the athlete’s village and the training venues. While in operation for the full duration of the Games, the training lanes will not be subject to any of the additional traffic management tools being implemented to the core and venue networks. Finally the alternative routes will only be regulated should there be major issues to any of the core or venue Games lanes.
The location of the venues in Figure 5 are identified by the red circles. Venues outside of Toronto are being used to host some of the Games events. This would reduce the capital cost required for Toronto to host the Games, but requires a more extensive GRN. This is similar to the situation in London during the Olympics, which had some events outside of the city proper.

Implementing HOV Games lanes is not the only traffic management tool being implemented for the Games. A list of the tools can be found in Table 2.

Table 2: Additional Traffic Management Tools. Source (MTO 2014b)

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking and loading restrictions</td>
<td>Restricts parking and loading in certain locations, specifically in close proximity to event venues.</td>
</tr>
<tr>
<td>Management of road/lane closures</td>
<td>Construction closures will be rescheduled to avoid the Pan Am Games</td>
</tr>
<tr>
<td>Traffic signal control</td>
<td>Improve vehicle movement along the GRN</td>
</tr>
<tr>
<td>Traffic regulations</td>
<td>Turning restrictions along key GRN sections to improve flow</td>
</tr>
<tr>
<td>Incident response team</td>
<td>Quick response and clearing of traffic accidents</td>
</tr>
</tbody>
</table>

Many of these traffic management tools are used to help move as much traffic as possible through the key sections of the GRN. Restricting parking, especially truck parking, along key GRN segments will help reduce the amount of space occupied by stationary vehicles, which in turns provides more space to move vehicles through the road network. Traffic signal control and turning restrictions are likewise designed to help vehicles move to and from the event venues out to the highways and freeways. These tools are not meant to optimize freight flow and delivery operations. As a result, companies will have difficulty making deliveries to customers located on or around the GRN. In preparation for these challenges the MTO have worked with several major companies who make large numbers of deliveries to the downtown core to prepare them for the challenges they will face.
4.1.3 Freight Planning Initiatives

In preparation for the Games, the MTO have been working with freight operators to ensure that their operations can continue as normal and with as little impact from Games related activities as possible. During the lead up to the Games, the MTO organized an informational campaign directed at businesses concerning their transportation needs. This campaign was designed to inform businesses of the challenges they would likely face during the Games, as well as provide some potential solutions to those problems. The information to businesses was summarized in a document titled ‘Keep Your Business Moving – Creating a Games Travel Plan’ (MTO 2014c). The MTO outlines six steps for companies to follow to create a successful Games travel plan:

1. Understand Games operations and impacts
2. Access your workplace needs and activities
3. Make your commitment
4. Consider options and choose strategies
5. Detail your Games travel plan
6. Implement your Games travel plan

Steps two, three, five, and six require more effort on the part of the companies and less on the part of the MTO. Step one, however, specifically requires the MTO to be able to provide accurate and timely information to the different companies. Information concerning the GRN, event schedules, and the expected congestion around the GTHA were released in February of 2014, more than one year prior to the Games. This information will be supplemented with additional daily traffic updates for the duration of the Games. This allows carriers not only to preplan for the Games, but allows them to have the most up to the date information should any major incidents or changes take place. The MTO has also made available a route planner which allows drivers, or companies, to plan routes that avoid many of the Games lanes and venues (MTO, 2015).

As part of step four, consider options and choose strategies, the MTO encourages the use of the 4 R’s: reduce, retime, reroute, and revise mode which were used in London during the Olympics to great effect. Reduce can mean two things. For office buildings and businesses where a large number of people work, reduce means limiting the number of people that have to come into the office on a daily basis. For example people could work from home and meetings could be held
remotely. For businesses who do attract many truck deliveries reducing means minimizing the number of deliveries to the store through the use of consolidated deliveries. This is a straightforward way for customers to receive the required number of products they need while reducing the number of deliveries made during the Games. It would require a larger number of trucks to be on the road in the period leading up to the Games, but a reduced number during the Games when the conditions will be busier. The downside to this is that for customers in the food industry, such as restaurants, grocery stores, and convenience stores, delivery larger quantities of products further in advance is not possible due to storage issues or problems associated with perishable goods.

Retiming deliveries requires shifting the hours of delivery. This can either be done by having the trucks leave earlier or later from the depot, or by delivery products during the off-peak hours. This would help avoid any of the issues associated with the expected congested conditions as well as the GRN. As part of the retime option, the MTO was involved in organizing and testing the use of off-peak delivery during the Games. The MTO pilot project conducted a customer satisfaction survey post pilot project completion. Survey results showed for the most part a negative response from receivers with respect to the off-peak delivery pilot project, as well as with the prospect of receiving off-peak deliveries in the future. The main issues reported were a lack of communication between managers and store employees, and issues with getting the stores stocked before the morning rush should that customer fall late in the delivery schedule. A further pilot project was planned for the spring of 2015 which hopes to improve upon these aspects. The positive outcomes of the pilot project showed average speed increases and perceived ease of driving when compared to daytime deliveries. One of the companies involved in the off-peak pilot was Nestlé Canada. Nestlé delivers ice cream and other frozen products to a large number of customers in the GTHA.
4.2 Nestlé Case Study

In preparation for the Pan Am Games, Nestlé Canada expressed interest in incorporating off-peak delivery into their normal delivery operations in order to minimize some of the impacts of the Pan Am Games. As a case study, Nestlé’s delivery operations present specific challenges to off-peak delivery as they deliver similar products to a wide range customer types. Different customer types have different requirements on the size and frequency of their deliveries, as well as varying abilities and constraints to accepting off-peak deliveries. This is different from companies who deliver their own products to their own stores, like Tim Hortons or MacDonald’s, and likely have more control over when the products will be delivered. Nestlé delivers their products to over 3000 different customer locations across the GTHA. Due to data restrictions the study area for this project was restricted to the regions of York, Peel, and Toronto. As can be expected, the greatest customer density is located in the city centers, particularly in downtown Toronto as can be seen in Figure 6.

Figure 6: Nestlé customer density by TTS zone.
The focus of this project was on Nestlé’s ice cream and frozen goods delivery in the GTHA. The deliveries originate at Nestlé’s depot, which is located in Brampton Ontario. Nestlé currently employs a call-and-place delivery model for their deliveries. In general, Nestlé’s customers request deliveries at relatively consistent intervals. The most common requests are for one delivery per week or one delivery every two weeks. Less frequently, customers will request two deliveries per week, or one delivery per month. The frequency of deliveries to a specific customer are dependent on the time of the year the deliveries are taking place; people are less likely to buy ice cream in the winter; as well as the customer type and customer location. Larger customers, such as grocery stores and department stores, are more likely to sell larger volumes of products as they experience more traffic than convenience stores, and are therefore likely to require larger deliveries. Delivery routes are generated every two days and only contain customers that have requested a delivery. A benefit of this method is that it provides flexibility to Nestlé’s delivery operations, allowing them make deliveries to customers on short notice. One of the downsides to this method is that it limits the carrier’s ability to create efficient routes. Efficient routes in this case mean routes which have customers relatively close to one another, limiting the total distance traveled.

4.3 Data

The data for the Nestlé case study was provided from three different sources. Travel time tables were provided by IBI Group, a Toronto consulting firm responsible for developing Pan Am Game’s traffic assignment models for the MTO. Information concerning Nestlé’s customers and delivery operations were provided by Nestlé for this project. The information concerning the GRN, particularly the location of the network and the venues, was obtained through documents publically released by the MTO (MTO, 2014a; MTO, 2014b).

4.3.1 Travel Time Tables

Travel time tables were provided for the travel between Toronto, York and Peel regions, and travel times were generated between all the different zones in each region. The zonal system used by IBI Group is the 2011 GTHA Transportation Tomorrow Survey (TTS) zonal system, and the values generated by the Emme model are zonal average travel times (DMG, 2011). The study region contains a total of 1491 different TTS zones. The TTS zones are broken down between the regions
as follows: the Region of Peel contains 377 TTS zones, York contains 483 TTS zones, and Toronto contains with 631 TTS zones. Not all of the travel times were used for this project as Nestlé customers were only located in a little over 60% of the TTS zones. In order to make the travel time tables more manageable from a computational standpoint, travel times from zones which do not contain any Nestlé customers were removed from the tables. This reduced the total size of the travel time matrices from 1491-by-1491 down to 953-by-953. Figure 7 below shows the study area and the zonal boundaries.

Figure 7: Study area and TTS zonal boundaries
Travel time data was provided for the AM peak, midday, PM peak, evening, and free flow conditions. The hourly breakdown of these travel times are as follows:

- AM Peak: 8-9 am
- Midday: 2-3 pm
- PM Peak: 4-5 pm
- Evening: 6-7 pm

The free flow travel times are an estimation of the travel time with no congestion on the road. The off-peak travel time is calculated as the average of the evening travel time and the free flow conditions. This assumption was made because some of the off-peak travel may take place in the evening hours, after the PM peak period. Including the evening travel time reflects this fact. The daytime travel time is taken as the average of the AM peak, the midday travel time and the PM peak travel time. Nestlé trucks historically have delivered goods between the morning and late afternoon, and therefore an average travel time value is used. A single average travel time value was calculated, rather than using multiple different travel times, in order to simplify the vehicle routing portion of the heuristic model. Time dependent vehicle routing problems are very complex in their formulation, and therefore a singular travel time value is used to help simplify the problem.

Travel times were estimated for two different scenarios: the Pan Am Games (Games) Scenario, and the Business-as-Usual (BAU) scenario. The Games scenario incorporates the changes to the road network expected for the Games. This includes not only the introduction of the GRN and all of its relevant road restrictions and Games lanes, but also the increased demand on the system as a result of spectator movements to and from the event venues. Network volumes were also increased to reflect the expected increase in background traffic due to factors such as population increases amongst others. The BAU scenario travel time tables are the expected travel times should the Pan Am Games not be taking place. They still incorporate the same increases in background traffic as a result of population increases, but do not include any of the Pan Am related increases or changes to the road network.

Figure 8 below contains the travel time differences between the daytime and off-peak Games scenarios. It shows an average increase of approximately 11 minutes between the daytime and off-
peak travel times. This shows that while some significant travel time savings can be made during the off-peak hours, half of the trips taken will experience between 0-11 minutes of travel time savings. A similar analysis was performed which showed that the average percentage travel time savings for all trips was around 37%.

![Figure 8: TTS travel time difference between daytime and off-peak Games scenario.](image)

The largest travel time savings in Figure 8 are for trips between zones located large distances apart. The expected travel time differences for shorter trips between adjacent or nearby zones is much smaller. Figure 9 shows the expected average travel time differences between adjacent zones by switching to off-peak hours during the Pan Am Games. The average travel times for adjacent zonal travel was determined for each zone for both the daytime and off-peak hours. The yellow sections of the map show an average travel time decrease of under 30 seconds. Green sections contain average travel time decreases of over 30 seconds, with the maximum being around 11 minutes. Small travel time differences can be expected due to the small size of the TTS zones.
4.3.2 Nestlé Delivery Log and Customer Data

For this project Nestlé provided driver delivery log data containing information on their delivery operations for the months of January-April 2014, as well as detailed customer information. The customer information consists of customer location, customer type, average delivery request frequency, and regional location. The delivery logs contain the route ID, which corresponds to the particular region the customer is located in, the customer name and ID, which relates back to the customer information tables, order size, and arrival time at the customer. From the delivery logs the order in which customers were delivered was determined.

The delivery logs also provided insight as to the minimum and maximum number of customers delivered to on single routes. No fewer than 5 and no more than 22 customers were ever delivered to by one truck during the months that the delivery logs represent. These numbers, 5 and 22,
represent the lower and upper limits of Nestlé’s delivery operations and are considered hard limits for route generation in the methodology. These limits are referred to as the minimum and maximum route size constraint respectively.
Chapter 5

5 Methodology

This chapter presents the methodology used for the quantitative analysis. The five step heuristic is then presented, and each step explained in detail. The first section, 5.1., introduces relevant literature pertaining to the methodology. Two sections of the methodology, 5.5 and 5.6, use clustering methods to group customers in clusters. The reasoning behind the choice of clustering methods is presented in section 5.1.1 and 5.1.4. The final step of the methodology is a vehicle routing algorithm, section 5.7, the relevant literature of which is presented in section 5.1.2 and 5.1.3.

5.1 Literature Review: Clustering and Vehicle Routing

5.1.1 Clustering Methods

Clustering is a method used across many different disciplines to group objects or data together. Clusters are created such that each group created contains data or objects that are more similar to each other than to the data or objects in the other groups. Clustering is used in many different fields, including, but not limited to: biology, medicine, computer science, and transportation. A visualization of a simple clustering algorithm can be seen in Figure 10, where a number of objects are grouped into three clusters.

Figure 10: Simple Clustering Example
In terms of transportation, clustering has been used in vehicle routing problems (Bodin & Golden, 1981), vehicle routing and customer consolidation (Koskosidis & Powell, 1992) and multi-depot vehicle routing problems (Lam & Mittenthal, 2013), among others. There are many types of clustering algorithms available, each with its own advantages and disadvantages, but this literature review will focus on clustering algorithms which are more suited for location based clustering. In particular, centroid based clustering algorithms, hierarchical clustering algorithms, and genetic clustering algorithms.

Hierarchical clustering algorithms join objects together based on their similarity to each other. This similarity could be based on some characteristic attributed to the objects, for example the type of store the customer operates, or it could be based on the distances between sets of customers. Hierarchical clustering is either performed using a bottom up approach, called agglomerative clustering (Davidson & Ravi, 2005), or a top down approach, called divisive clustering (Jain, 2010). Agglomerative clustering starts with each object or customer belonging in its own cluster. Each iteration of the algorithm joins clusters together based on similar attributes or distances between clusters. This process of combining small clusters into larger clusters is repeated until the desired number of clusters is reached. Divisive clustering is the exact opposite of agglomerative clustering. All customers belong to the same cluster at the beginning, and each iteration sees the clusters separated into smaller clusters containing more related objects.

Traditionally, one of the main benefits of using a hierarchical method over a centroid based method is that hierarchical methods do not require the user to know the exact number of clusters beforehand (Manning, Raghavan, & Schutze, 2008). While beneficial in many instances where clustering is required, it is less important in terms of customer clustering and truck allocation. As cost is a primary factor in goods movement, and each truck is restricted in its total capacity and total tour time, the number of trucks is likely going to be known before the customers are clustered. The major disadvantage to clustering customers using a hierarchical method is that the hierarchical method is not an iterative process, meaning once a customer has been assigned to a cluster it cannot be reassigned.

Centroid-based clustering uses a centroid location for each cluster, the distances to which help determine which cluster an object belongs in. The classic example of centroid-based clustering is the k-means clustering algorithm. The k-means clustering algorithm was developed using Lloyd’s
algorithm as its foundation (Lloyd, 1982), although an improvement on the formulation, which is now more commonly used, was developed in the 1970’s (Hartigan & Wong, 1979). The k in the k-means stands for the number of clusters desired for the current data set. The algorithm works by identifying initial starting centroid locations. While not actually centroids during the first iteration, these locations will serve as starting points to which objects or customers will be assigned. Once initial clusters are generated, the location of the centroid for that cluster can be recalculated. The customers are then reassigned to centroids, and this process continues until the location of the centroids does not change. Figure 11 shows an example of the clustering process.
After the first clustering iteration

15th clustering iteration
Figure 11 shows the progression of the k-means clustering algorithm. In this example 235 customers are clustered into 20 different clusters. The primary benefits of the k-means clustering algorithm are the efficiency of the algorithm and the certainty about the number of clusters. The number of trucks, and therefore the number of clusters, is likely going to be known before the routes are generated. With the k-means algorithm the user sets this value, something that cannot be done with hierarchical clustering. The k-means algorithm is also efficient in terms of run time and relatively straightforward to add constraints to (Kim, 2007). A number of additions or alterations to the traditional k-means method have been developed over the years.

One disadvantage of using a k-means clustering algorithm is that the results of the clustering are dependent on the initial starting locations. Different starting locations for the cluster centroids may result in different final clusters, even if everything else is kept constant. When clustering a small number of objects it is possible to find the optimal solution by running the algorithm multiple times for every combination of starting points, but this method quickly becomes too computationally intensive for large numbers of objects or clusters. It is also possible for the k-means algorithm to not converge on a final solution, which happens when certain object assignments and reassignments results in a pattern of repeating object cluster configurations.
A genetic clustering technique was developed which utilizes a genetic algorithm to find optimal clusters (Maulik & Bandyopadhyay, 2000). Genetic algorithms are used commonly for search and optimization problems, and are based on the theories of evolution and natural selection (Mitchell, 1998). The initial conditions of the problem are initialized as what are referred to as chromosomes, which are strings of numbers representing the current conditions of the problem. The fitness of each set of chromosomes is calculated, similar to the initial solution of the problem. Sections of the chromosomes are swapped or mutated with the purpose of trying to maximize the total fitness of the problem. This process is repeated until the maximum fitness is calculated (Mitchell, 1998). According to Maulik & Bandyopadhyay (2000), their genetic clustering algorithm is able to outperform the standard k-means clustering algorithm for every scenario they tested. Genetic algorithms are not restricted by one of the major shortcomings of the k-mean clustering methods, they are more likely to determine the global minimum rather than run the risk of alternating between local minima. The limitations of genetic clustering methods are their complexity, difficulty of adaptation, and CPU time.

5.1.2 Vehicle Routing

The vehicle routing problem is one of the most thoroughly studied problems in transportation. In the simplest form, the vehicle routing problem is equivalent to the travelling salesman problem (TSP). The goal of the TSP is to minimize the total travel time or distance required to make a stop at every location specified on the network while finishing at the starting location. However, real-world examples are rarely as simplified as the TSP, and will often require additional constraints. Common additions include the capacity constraint, time window constraints, and day of the week constraints. Each variation of the vehicle routing problem adds additional complexity to its formulation, increasing the computational requirements. Among the most common variation to the TSP is the capacity constrained vehicle routing problem. This constraint can either limit the number of deliveries each truck can make based on the trucks physical capacity, or the length of the tour based on the number of stops, the total distance travelled, or the total time spent on the road (Augerat et al, 1998). Capacity constraints are common in multiple vehicle TSP (m-TSP) problems, as well as many more complex vehicle routing formulations.
A second common variation to the standard vehicle routing algorithm is the vehicle routing problem with time windows (VRPTW). The reason for this variation is that some customers may be unavailable during certain times of the day to accept deliveries, and this reality must be reflected in the vehicle routing model. Travel times, starting times, and delivery times are used to estimate the time in which a delivery would take place at a certain customer. The VRPTW problem can be separated into two formulations: hard formulations and soft formulations (Kallehauge, Larsen, Madsen, & Solomon, 2005). Hard VRPTW have strict time windows in which the delivery is to take place, and should a solution propose delivery to a customer outside of their requested time window, that solution would be rejected. Soft time windows will allow for deliveries outside of the specific time windows, but will impose a penalty to the system.

The periodic vehicle routing problem extends the regular vehicle routing problem to m days of delivery. For example, instead of performing 50 deliveries using 5 trucks on one day, the company would perform 10 deliveries a day using one truck. This method takes into account a customer’s delivery availability, similar to the time windows constraint but over days instead of hours. The periodic vehicle routing problem can also be formulated to deal with customers who require more than one delivery in a short amount of time. These customers can therefore be included in routes on separate days without having to redo the entire vehicle routing algorithm.

### 5.1.3 Subtour Elimination

In many cases, the optimal conditions resulting in the minimum total travel time and which satisfy all the constraints of a vehicle routing algorithm will not be a complete tour. A complete tour is one in which the vehicle in question will stop at all the customers on its route, and then return back to the depot. It is possible, and likely in many cases, that the generated truck route will contain subtours. A subtour is a group of at least two customers that are not connected to the depot via the generated route. The problem is that the basic constraints of the vehicle routing problem do not account for this issue, and therefore specific subtour constraints have to be formulated in order to generate reasonable results.

The difficulty in eliminating subtours is not in the constraint generation, but in the number of constraints that are required to eliminate all possible subtours. The total number of subtours
consists of all possible combinations of customers from the total list. For example, a group of twenty customers contain over 500,000 possible subtours. The complete list of subtours is actually over one million, but for each set of customer’s each subtour contains an associated subtour made up of the remaining customers. The result is that by eliminating one particular subtour its pairing subtour is also eliminated. For example, a constraint which prohibits a subtour containing customers 1-5 in a 10 customer vehicle routing problem would also eliminate the subtour containing customers 6-10. The sheer number of constraints needed for even small problems makes it so that eliminating all subtours at once is impossible. As a results, several methods were developed to eliminate subtours without having to add all constraints.

The cutting plane method of subtour elimination takes advantage of the fact that the vast majority of possible subtours are not likely to appear in the potential solution for a vehicle routing problem. The cutting plane method starts with no subtour constraints and allows the vehicle routing algorithm to solve for the optimal solution. After the solution is found there is a check to identify any subtours in the solution. For each subtour found, a constraint is formulated and added into the vehicle routing algorithm, and the problem is resolved. This continues until no subtours are found in the solution.

5.1.4 Cluster-First Route Second-Models

An alternative way to route multiple vehicles is by using a cluster-first method. A benefit of using this method is that it can reduce a complicated vehicle routing problem to a series of less complex formulations. Clustering can incorporate the capacity constraint algorithms as well as some of those required for the periodic vehicle routing problem. They can do this by limiting the size of the cluster, either in terms of truck capacity or the number of customers, or by clustering similar customers together, for example customers that can only be serviced on one day of the week. Cluster-first methods are unable, however, to eliminate the time window requirements for VRPTW problems, as the time window constraints are essential to the delivery order of the customers. Common examples of cluster-first route-second vehicle routing models include the Fisher and Jaikumar heuristic, the Petal Algorithm, and the sweep algorithm.
The sweep algorithm is a very simple method of clustering. The concept is to generate clusters by performing a rough ‘sweep’ of the customers, meaning generating an imaginary line from the depot as the starting point, and moving a secondary line from the first in a rotational movement similar to the hands of a clock. The rotation stops when the trucks capacity is met or the target number of customers are contained in the cluster. After the clusters are created, a vehicle routing algorithm can be performed for each cluster. Figure 12 shows a visualization of the sweep algorithm for a simple three cluster example.

![Figure 12: Example sweep algorithm method for customer clustering](image)

The main benefit of the sweep algorithm is its simplicity. It can be performed quickly for large numbers of customers if necessary. The downside is that because of its simplicity, it does not take into account actual travel time or customer distances, and is usually only effective with a central depot location. The sweep algorithm is typically outperformed in terms of overall travel time results by more involved algorithms such as the petal algorithm and the Fisher and Jaikumar
The improved petal algorithm (Renaud, Boctor, & Laporte, 1996) is similar to the sweep algorithm with the exception that it allows for multiple routes within one ‘sweep’ of the customers. The Fisher and Jaikumar heuristic solves a general assignment problem to generate the clusters (Fisher & Jaikumar, 1981). Seed customers are identified as the starting point for the customer assignment to specific trucks and the general assignment problem assigns other customers to these trucks.

Geetha, Poonthalir, & Vanathi (2009) introduced a cluster-first route-second method which incorporates a k-means clustering algorithm specifically designed for the capacitated vehicle routing problem. The benefits of this method were the relative simplicity in which changes or additional constraints could be added to the algorithm. The results showed this method was competitive with other vehicle routing heuristics in terms of travel times and computational times.
5.2 Nestlé Case Study Methodology

There were four specific research objectives identified in section 1.3 of this thesis concerning the Nestlé case study. The first objective analyzed the travel time impacts the Pan Am Games would have on Nestlé’s normal operations. The method used for this objective was straightforward, and involved comparing the Pan Am Games travel times versus the business-as-usual travel times using the driver delivery logs to determine the customer deliver order. The methodology used for objectives 2-4 used the heuristic presented in this chapter. The methods used are a five step process. This chapter will outline this process and provide details into the assumptions and specific methods used to evaluate off-peak delivery potential. The five steps of this process are introduced in Figure 13:

Figure 13: Five step heuristic methodology
The first step of this process is identifying potential off-peak customers. These are customers that have the potential to be serviced in the off-peak hours. Multiple methods of customer identification were tested, with customers either identified by type or by proximity to the GRN. The second step of this process refines the list of potential off-peak customers based on several factors. In this context, refining the list of potential off-peak customers means identifying potential off-peak customers that could be serviced during the off-peak hours, but that should be serviced during daytime hours. The third step involves selecting off-peak customers from the list of potential off-peak customers. The customers are selected either randomly or more strategically from the list of potential off-peak customers. The number of customers selected for delivery during the off-peak hours depends on the number of trucks being used during the off-peak hours and the capacity of those trucks. The fourth step of the heuristic groups the off-peak customers selected in the third step into different clusters. This same process is applied separately to the off-peak customers and the remaining daytime customers. Each cluster generated represents the deliveries made by one truck during either the daytime or off-peak hours, and the number of clusters depends on the number of trucks identified in the third step. The fifth and final step is a simple vehicle routing algorithm, which determines the optimal routing for each cluster generated using the k-means clustering algorithm.

This five step process is a heuristic model for analyzing the potential impacts and benefits of using off-peak delivery. The purpose of this analysis was fourfold: to estimate the impact of the Pan Am Games on normal Nestlé operations, to estimate the benefits of using advanced routing techniques on total travel times, to estimate the impact of using off-peak delivery during the Pan Am Games to mitigate some of the expected operational challenges, and to determine if a reduction in the number of vehicles used is possible. Some assumptions were made during the creation of this heuristic. A single truck size, in terms of capacity, was assumed in order to simplify the clustering and vehicle routing problem. The number of customers assigned to a single route were also limited by the data available in the Nestlé delivery logs, presented in section 4.3.2, which showed the maximum route size to be 22 customers, and the minimum route size to be 5 customers.
5.3 Identifying Potential Off-Peak Customers

This step of the heuristic is used to identify customers that have the potential to accept off-peak deliveries. A total of two identification methods were used to identify potential off-peak customers:

1. Identification of potential off-peak customers based on customer type.
2. Identification of potential off-peak customers based on customer proximity to the GRN.

Off-peak customer identification based on customer type identifies potential off-peak customers based on what type business they operate. This type of customer identification is based on the assumption that some customers are more likely to be able to accept off-peak deliveries than other customers. This is either because they already operate during the off-peak hours, or have the ability to accept unassisted off-peak deliveries. Identifying customers willing to accept off-peak deliveries without incentives would help reduce the cost of Nestlé’s off-peak delivery program, should they choose to use incentives as a tool to attract customers.

Off-peak customer identification based on distance to the GRN identifies customers in close proximity to the GRN. These may not necessarily be customers who would normally accept off-peak deliveries, however, due to their proximity to the GRN they may experience negative impacts from the Games due to the GRN restrictions. This impact, or unreliability of service, is the potential delay in deliveries due to the travel conditions around the GRN as well as the parking and stopping restrictions for delivery trucks. The assumption is that these customers may be willing to accept off-peak deliveries, at least for the duration of the Pan Am Games, as deliveries during off-peak hours would not experience these impacts.
5.3.1 Identification Based on Customer Type

All customers are classified by Nestlé as one of four types: convenience store, grocery store, department store, or drug store. Convenience stores are every type of store that does not fall into one of the other three categories. Figure 14 shows an example customer type distribution for one week’s worth of Nestlé deliveries.

Knowing the customer type becomes important when selecting customers to participate in the off-peak delivery program. Realistically, customer participation in an off-peak delivery program is limited to those customers that operate in some capacity during the off-peak hours. While deliveries to these customers may be possible in some cases, the fact that Nestlé is delivering ice cream limits the use of unassisted off-peak deliveries as the products being delivered have to be stored in a cool environment. The only option available for unassisted delivery would be to give

![Figure 14: Example customer type distributions](image-url)
drivers access to the store freezers or cold storage facilities so the products being delivered do not melt before the store opens in the morning.

The following assumptions were made to simplify the customer selection process.

1. Grocery stores, department stores, and drug stores stock shelves at night, and are therefore able to accept off-peak deliveries.
   a. The first assumption is based upon an internet search for job postings in the GTHA. There were numerous job postings for night crew positions at major grocery stores (Loblaw’s, Sobeys, No-Frills, Metro), as well as for department stores (Walmart) and drug stores (Shoppers Drug Mart).

2. Convenience stores are not open during off-peak hours, and therefore are not able to accept off-peak deliveries, with the following exceptions:
   a. 7-Eleven stores, which are categorized as convenience stores, are all open 24-hrs per day according to their website.
   b. Gas stations, which are categorized as convenience stores, are open overnight and are able to accept off-peak deliveries. This is based on an online survey of the different gas stations in the GTHA reveals that the three major operators, Shell, Esso and Petro-Canada, all operate the majority of their stores 24-hrs per day.
   c. Mac’s convenience stores, also categorized as convenience stores, operate a majority of their locations 24-hrs per day according to their website.
   d. Rabba’s Fine Foods are open 24-hrs according to their website.

There exist a number of other chain stores that Nestlé delivers to, such as International News and Daisy Mart, which may operate some of their locations 24-hrs per day. However, from the information available, the decision to operate during the nighttime hours is often dependent on the owner of the franchise, and not a company requirement. For the simplicity of this project, only chain customers who operate a majority of their locations 24-hrs are considered available for off-peak delivery. Customer types and customer names were provided for each customer in the data tables supplied by Nestlé. The customer type was used to efficiently identify some of the off-peak customers; the grocery stores, department stores, and drug stores. Customer names were used to identify potential off-peak customers that were labeled as convenience stores.
5.3.2 Identification Based on Customer Proximity to the GRN

The second method of customer selection chooses customers based on their proximity to the GRN. This method of customer selection was considered because these are the customers that are likely going to be the most impacted by the Games. The increased congestion as a result of the Games combined with parking and turning restrictions are likely to make deliveries to these customers difficult. Parking restrictions will be enforced in key locations along the GRN, making it difficult for trucks to park and make deliveries on and around the GRN. Turning restrictions will likewise be implemented at key locations, restricting left-turn movements in order to minimize delays. This will likely have a similar impact on a truck driver’s ability to reach their intended delivery destination.

A 500 m buffer around the GRN is used to identify potential off-peak customers. This was done using the buffering tool in ArcGIS. The buffer size was chosen based on the anticipation of spillover traffic from the GRN onto adjacent road segments, and that 500 m is an approximate average distance between major arterials in downtown Toronto. An example of identification by proximity to the GRN is shown in Figure 15.
Selecting based on customer location is likely not as feasible as selection based on customer type. Nestlé would have to convince many of these customers, as many of them are convenience stores which are not open during off-peak hours, to participate in an off-peak delivery program.

5.4 Potential Off-Peak Customer List Refinement

It was determined through preliminary analysis that having more off-peak customers did not necessarily correlate to lower travel times. Since certain potential off-peak customers may be situated in much closer proximity to daytime customers than to other off-peak customers, the resultant travel times if those customers were moved to off-peak hours were higher than if they were left as daytime customers. As a result of the preliminary analysis, two processes were developed to refine the list of potential off-peak customers.

The first process, used only for identification by customer type, determines if a potential off-peak customer is necessary for keeping a daytime route above the minimum route size requirement of
five customers. The second process adapts a clustering outlier algorithm to determine if a potential off-peak customer is an outlier during the off-peak hours, and if there would be an improvement in moving that customer to the daytime. The two processes are referred to as the cluster refinement process and the outlier refinement process respectively. The outlier refinement process was used for both selection by customer type and for selection by customer distance to the GRN. The cluster refinement process was determined to not be a necessary addition for identification by customer type, but was not required for identification by proximity to the GRN.

The algorithm for the cluster refinement process is presented in Figure 16. In broad terms it refines the list of potential off-peak customers by determining if delivering to certain customers during the off-peak hours would result in certain daytime routes falling below the minimum size constraint. More specifically, the cluster refinement process starts by determining the optimal clustering should all the customers be delivered to during the daytime. Then, for each of the clusters generated, the total number of clusters being represented by the variable $k_{\text{max}}$, the number of potential off-peak customers, $n_{\text{op}}$, and the total number of customers, $n_k$, contained in the cluster is determined. If the difference between $n_k$ and $n_{\text{op}}$ is greater than five, the minimum route size constraint, then the cluster in question contains enough daytime customers to create a route. If the difference between $n_k$ and $n_{\text{op}}$ is less than five it must be determined whether there are sufficient nearby clusters which may be joined with the cluster in question, bringing the total number of customers above the minimum size constraint.
Figure 16: Flow chart for potential off-peak customer refinement
This concept is illustrated in Figure 17, which contains all of the customers for one scenario. The square customers are the potential off-peak customers as identified by customer type, and the remaining customers are daytime customers.

Figure 17: Example of the clustering refinement process

The customers, both potential off-peak and daytime, contained within the circle belong to one route should all customers be delivered to during the daytime. If all the potential off-peak customers were to remain as off-peak customers there would only be two daytime customers remaining in that route, both of which are a large distance from any other daytime route.

The outlier refinement process identifies customers that have the potential to be serviced in the off-peak hours, but that are more closely situated to daytime customers. The savings that could potentially be made in the off-peak hours are negated by the longer distances the truck would have
to travel to reach these customers during the off-peak routes. The difference between the outlier refinement process and the cluster refinement process (Figure 16) is that the cluster refinement process identifies customers that are required to stay as daytime customers in order to ensure that the daytime routes meet the minimum route size requirements, while the outlier refinement process identifies customers that fit in better to daytime routes.

This outlier detection process is based on the work of Pamula et al. (2011). For each customer $i$, an outlier number is generated based both on its proximity to other customers, $d_i$, as well as the proximity of those other customers to each other, $D_i$. $N_q$ is the group of the $w$ closest customers, and $q$ is one of the $k$ customers in $N_q$.

\[
\text{Outlier}_i = \frac{d_i}{D_i}
\]

\[
d_i = \frac{1}{w} \sum_{q \in N_q} \text{dist}(i, q)
\]

\[
D_i = \frac{1}{w(1 - w)} \sum_{q \in N_q} \sum_{q' \in N_q, q \neq q'} \text{dist}(q, q')
\]

The larger the outlier number is, the more of an outlier that customer is in relation to nearby customers. This means a customer’s average distance to nearby customers is larger than the average distance of those customers to each other. No changes to the equations were made, but the method in how they were used was altered to adapt it to the off-peak outlier scenario. This involved calculating $\text{Outlier}_i$ twice for each customer, once using potential off-peak customers to generate $N_q$, while the second time using both potential off-peak and daytime customers to generate $N_q$. The number of nearby customers, $w$, was taken to be four. The reason four was chosen for $w$ is that the four closest customers, plus the customer in question, is five total customers, the same size as the minimum route size constraint for a single truck. Using only potential off-peak customers generates an outlier number for that customer for a potential off-peak route, while using daytime customers generates a similar outlier number for potential daytime routes. The difference in these two numbers indicates whether there would be improvement in travel times by keeping customer $i$ as a daytime customer over making it an off-peak customer.
If the difference between the daytime and off-peak outlier number exceeds a certain cutoff number it is determined that the customer is better of left as a daytime customer. For selection by customer type the cutoff number was determined empirically to be 20, and any difference between the daytime and off-peak outlier numbers greater than 20 indicates that that customer should be left as a daytime customer. Various cutoff numbers were tested, with smaller cutoffs resulting in too many potential off-peak customers moved to the daytime, and numbers larger than 20 resulting in too few. For selection by customer distance to the GRN, the cutoff number was determined to be a lot smaller at only 0.5. The reason that these two cutoff numbers are so different reflects the differences in where the off-peak customers are located. Selecting off-peak customers by type results in a moderately even distribution of off-peak customers, whereas selecting by proximity to the GRN will result in off-peak customers in much closer proximity to one another. A cutoff of 20 for selection by distance to the GRN will result in no refinement of the potential off-peak customers. Figure 18 shows the outcome of this algorithm for selection by customer type.

Figure 18: Identifying outlying potential off-peak customers
5.5 Off-Peak Customer Selection

Once the list of potential off-peak customers has been refined, the next step in the heuristic is to select off-peak customers for clustering. Two methods were tested for selecting off-peak customers for different numbers of off-peak routes: random selection and strategic selection. The details of each of these methods is presented in the following sections.

5.5.1 Random Customer Selection

Random customer selection reflects the possibility that Nestlé does not have control over which customers would choose to participate in their off-peak delivery program. Customers would choose to participate because they perceive some benefit to themselves, and not due to any influence from Nestlé. The method randomly selects subsets of customers from the group of potential off-peak customers without any of the refinement processes being applied to that list of customers. The number of customers chosen depends on the number of trucks that are being designated as off-peak trucks. For example, if two off-peak routes are designated, a sufficient number of customers are identified such that their total demand does not exceed the capacity of two trucks. The location of the customers had no influence as to which customers were selected.

The following flowchart, Figure 19, outlines the process of randomly selecting off-peak customers. The inputs required are the demand quantity for each customer, \( q_i \), as well as the total number of customers \( N \). Customers are assigned a randomly generated number, and the order in which these customers are assigned to the trucks depends on the number generated. The number of customers assigned to the truck depends on the total demand the truck is carrying, \( q_{\text{current}} \), and the number of customers being delivered to, \( n_{\text{current}} \). No further customers are assigned to a truck if either \( q_{\text{current}} \) or \( n_{\text{current}} \) are going to be larger than the truck capacity, \( q_{\text{max}} \), or the maximum route size, \( n_{\text{max}} \), respectively.
Inputs
Demand Quantity for each customer = qi
Total number of customers = N

Initialize
qcurrent = 0
qmax = 960
ncurrent = 0
nmax = 22

Assign each customer a random number between 0 - 1

Sort customers based on random number from smallest to largest

Starting with customer i = 1

Is qi + qcurrent < qmax?

Yes

Is ncurrent + 1 < nmax?

Yes

Assign customer i as an off-peak customer
qcurrent = qcurrent + qi
ncurrent = ncurrent + 1

No

i = i + 1

No

Output group of off-peak customers

Does i = N?

Yes

End

Figure 19: Random off-peak customer selection algorithm

Figure 20 and Figure 21 are two examples of the output of the random off-peak customer selection
Figure 20: The output of random off-peak customer selection for one truck

Figure 21: The output of random off-peak customer selection for two trucks
5.5.2 Strategic Customer Selection

Strategic customer selection reflects the possibility that Nestlé does have some influence over which customers participate in their off-peak delivery program, and are therefore able to tailor the off-peak routes in order to maximize their total travel time savings. The customers considered in this step of the process are the off-peak customers that were not identified in the refinement process in step 2 as being better suited to daytime delivery. The method used to strategically select off-peak customers is a 1-means clustering algorithm, which identifies single groups of off-peak customers. The 1-means algorithm is iterated N_{op} times, where N_{op} is the total number of potential off-peak customers. Each iteration of the algorithm uses a different off-peak customer as the starting centroid location. The data inputs required are the demand quantity for each customer, q_{i}, and its geo-coordinates as well as n_{max} and q_{max}. For each model run the sum of the distances between the final cluster of customers and the centroid is calculated. This number, D_{i}, is used to determine which cluster of customers creates the most optimal cluster. This cluster is outputted to be used in the next step of the methodology. The algorithm is presented in Figure 22.
Start

Inputs
Demand Quantity for each customer = q_i or q_j
Customer geo coordinates

i = 1

Initialize
j = 1
N_op = Total number of off-peak customers
n_current = 1
n_max = 22
q_current = q_i
q_max = 960
Iter = 1
D_i = 0

Assign customer i as the centroid

Calculate distance from the centroid, i, to each customer.
Distance to customer j = dist_j

Sort customers by dist_j in ascending order
Set j = 1

Identify customer j

q_current = q_current + q_j
n_current = n_current + 1
D_i = D_i + Dist_j
j = j + 1

Yes

q_current + q_j ≤ q_max?

n_current + 1 ≤ n_max?

No

Calculate new centroid location
The off-peak customer selection algorithm presented in Figure 22 is a variation of a traditional k-means clustering algorithm (Zalik, 2008). The traditional k-means algorithm generates k clusters where k is usually a number greater than one. However, in this case there is only one cluster being generated at a time, so the algorithm becomes a 1-mean clustering algorithm. The single cluster
generated represents one delivery truck which delivers to all the customers contained in that cluster. The size of the cluster is limited by the same set of constraints introduced in the random customer selection algorithm in the previous section of this thesis. The truck capacity constraint limits the total demand of customers so that the sum of the total demand quantity of the customers in the cluster does not exceed the carrying capacity of the truck.

The 1-means clustering problem is a relatively simple computational problem. The algorithm only has to be run once for each customer in the pool of potential off-peak customers in order to find the optimal solution. This is in contrast with a k-means algorithm where k is greater than one. For that type of problem, to test every combination of starting centroid locations quickly becomes very computationally intensive. The reason this was used for off-peak delivery customer selection is that it can find single compact clusters out of the large number of potential clusters. This is beneficial to Nestlé, who may only be able to offer incentives to a small number of customers, which will in turn only generate a small number of off-peak routes. Figure 23 and Figure 24 provide examples of the output of strategic off-peak customer selection.

![Figure 23: The output of strategic off-peak customer selection for k=1.](image)
5.6 Capacity Constrained K-Means Clustering

This section of the methodology involves grouping both the daytime and off-peak customers into clusters. Each cluster of customers can then be serviced by one truck, either entirely in the daytime or entirely in the off-peak hours. The clustering was done using a capacity constrained k-means clustering algorithm. The algorithm groups customers into clusters with the objective of minimizing the total distance between each customer and its associated cluster centroid. The size of a cluster, meaning the number of customers assigned to it, is limited by the capacity of the truck that will serve it, the number of stops one truck can reasonably make in a full 24-hrs, and the minimum number of customers required for a route. These constraints are referred to as the capacity constraint, the maximum route size constraint, and the minimum route size constraint respectively. The formulation of the capacity constrained k-means clustering algorithm, and the specifics of the constraints, are outlined below in Figure 25.
Figure 25: Capacity constrained k-means clustering algorithm
Geetha et al. (2009) incorporates two distinct alterations to a more traditional k-means clustering algorithm (Zalik, 2008). The first alteration added a capacity constraint specifically designed to incorporate truck capacity. This limited the size of the clusters so that the total demand from one cluster would fit on one truck. The second alteration Geetha et al. (2009) made was the inclusion of a priority assignment value. The k-means algorithm is an iterative process, meaning the optimal solution is usually not found with the first customer assignment. Each iteration requires the identification of the new centroid locations, and the process is repeated until these centroid locations do not change between successive iterations. The priority value allows for a more efficient customer assignment order. The priority value is a function of both the customer demand quantity as well as the customers distance to the nearest centroid. The first benefit is that this ensures that customers with large demands are not left until the end of the assignment order. The reason this would be a problem is because it is likely that by the end of the customer assignment process, many of the routes will be very near capacity in terms of total customer demand quantity and the number of customers in that route. Therefore customers with large demands left to the end of the assignment would have difficulty fitting into nearby routes. The priority function also ensures that customers with small orders, but that are situated very close to a centroid, are also assigned earlier. This limits the scenario where a customer that is very close to a cluster centroid cannot join that cluster due to the capacity and route size constraints.

There are several practical improvements on the Geetha et al. (2009) method which are introduced in this project. These improvements are the addition of constraints which limit the size, being the number of customers, in a cluster. The maximum and minimum route size constraints are based upon the delivery limits taken from the Nestlé delivery logs presented in section 4.3.2.

There are some challenges to using a k-means style clustering algorithm. For example, it is possible for the algorithm to get stuck in a loop, alternating between local minima. This occurs when one set of centroid locations is identified in one iteration, and in the next iteration there is a small shift in customer allocation resulting in a slightly different set of centroid locations. The iteration after that can revert back to the previous group of centroid locations, and this process will repeat itself endlessly. If this is the case changing the initial centroid locations can sometimes result in the algorithm converging properly. The process of changing the starting conditions, in this case the initial centroid locations, is an adaptation of work conducted by Bradley and Fayyad (1998) and Bradley et al. (2000). This method is also used to attempt to eliminate clusters with fewer than five
customers. Exchanging the initial centroid which results in a cluster with fewer customers than the minimum required allows the model to re-run, potentially resulting in the elimination of the cluster in question.

If changing the initial centroid locations still results in a cluster with fewer than five customers, a second step must be taken. This step involves assigning customers from nearby clusters to the smallest cluster in order for it to meet the minimum size requirements. This results in a slightly less optimal solution, due to the fact that some customers have to be reassigned, but maintains the number of trucks used and ensures all the trucks have a least the minimum number of customers assigned to them, and no more than the maximum allowed. It is important to note that customers are only reassigned if their reassignment does not in turn result in the violation of the minimum capacity constraint of the cluster they are being assigned from.

### 5.7 Vehicle Routing

The final step in the process is a vehicle routing algorithm. The single vehicle routing problem is formulated as a binary integer linear program. The algorithm is adapted primarily from Laporte (1992) and Winkenbach et al. (2012). Laporte (1992) provides a summary of exact and heuristic solution methods for the vehicle routing problem. The bulk of the formulation for the vehicle routing problem is taken from Laporte (1992) while the detail on integer linear programming is provided by Winkenbach et al. (2012).

The algorithm inputs required are: \( f, t_{ij}, n_i, V, \) and \( S \). The objective function to be minimized, \( f \), is the total travel time for the truck to visit all of the customers, and is a function of \( t_{ij} \) and \( x_{ij} \). The travel time, \( t_{ij} \), is the travel time between customer \( i \) and customer \( j \). The binary decision variable \( x_{ij} \) is a is equal to one if the truck travels from customer \( i \) to customer \( j \), or is equal to zero if the truck does not travel from customer \( i \) to customer \( j \). The variable \( n_i \) is the number of customers, including customer \( i \), that are located in the same zone as customer \( i \). \( V \) is a matrix which is used for the subtour elimination constraint. Each row of the matrix \( V \) contains a different combination of the customers being routed, and as a whole \( V \) contains every possible combination of customers for the given routing problem. Every possible subtour is therefore contained somewhere within the matrix \( V \). \( S \) is a subset of the matrix \( V \), and represents one possible subtour contained within the
matrix V. Also important to the algorithm is the size of variable S, meaning the number of customers contained in each variation of S. The mathematical formulation of the vehicle routing algorithm is as follows:

Optimization Function

\[ f = \sum_i \sum_j t_{ij} x_{ij} \quad \text{Equation 4} \]

Constraints

\[ \sum_j x_{ij} = 1 \quad \forall i \quad \text{Equation 5} \]

\[ \sum_i x_{ij} = 1 \quad \forall j \quad \text{Equation 6} \]

\[ x_{ij} = 0 \quad \text{if } i = j \quad \forall i, j \quad \text{Equation 7} \]

\[ \sum_{i \in S} \sum_{j \in S} x_{ij} \leq |S| - 1 \quad \forall S \subseteq V, |S| \geq 2 \quad \text{Equation 8} \]

\[ \sum_i \sum_j x_{ij} = (n_i - 1) \quad \forall i \quad \text{Equation 9} \]

\[ x_{ij} = [0, 1] \quad \text{Equation 10} \]

\[ x_{ij} \geq 0 \quad \forall i, j \quad \text{Equation 11} \]
The objective function, Equation 4, is the total vehicle routing travel time. The objective is to minimize the function $f$ without violating any of the other constraints. Equation 5 and Equation 6 ensure that the truck only arrives at and only leaves each customer one time. Equation 7 ensures that customer $i$ and customer $j$ are not the same, making sure that every trip made is between different customers. Equation 8 is the subtour elimination constraint, which is discussed in more detail in section 5.7.1. Equation 9 is a constraint that forces all customers located in the same zone to be linked in such a way that the truck delivers to all these customers before leaving the zone. Further details and reasoning are also discussed in section 5.7.1. Equation 10 is the binary constraint, which limits the value of $x_{ij}$ to either zero or one. Finally, Equation 11 is the non-negativity constraint.

The program used to solve the linear program is a simplex-based solver called IBM ILOG CPLEX. A CPLEX plugin created by IBM for Matlab was used for this project. Generation of the objective function and constraints was done in Matlab, which in turn were used as inputs into the CPLEX plugin. This method takes advantage of Matlab’s simple user interface as well as CPLEX’s efficient linear program solver.

5.7.1 Subtour Elimination

The subtour elimination constraint is the most computationally intensive component of the optimization algorithm. The method employed does not create constraints for every possible subtour due to the immense number of subtour combinations possible. For example, there are over 500,000 ways to create different combinations of customers from a 20 customer tour, which means there are over 500,000 different possible subtours that can be created. Generating these matrices is too computationally intensive for Matlab. However, constraints for subtours containing two, three, and four customers are within the capabilities of Matlab and were therefore generated beforehand. Eliminating the smaller subtours (two, three, and four stops) prior to solving the vehicle routing algorithm reduces the computational time required.

After the CPLEX plugin solves the linear program, a check is made to identify any subtours in the solution vector. This is done by examining the solution vector to see if all the customers are visited in one continuous tour before the truck returns to the depot. Returning to the depot before
delivering to every customer indicates that there are at least two subtours present in the solution vector, and that the calculated solution vector is not a viable solution. If this happens, specific constraints are added to the linear program for the next iteration according to Equation 8. These constraints are formulated so that the specific subtours identified do not appear in the solution vector $x$ during the next iteration (Laporte et al., 2006). This process of solving the linear program, identifying subtours in the solution vector, creating specific constraints to eliminate those subtours, and rerunning the algorithm is repeated until the solution vector $x$ contains no subtours.

The long model run time is a result of the problem formulation and the subtour elimination constraints. Travel time data is not available between all customers’ actual locations, so zonal travel times are used as a reasonable approximation. An issue arises when multiple customers are located within the same zone. With multiple customers in the same zone, there now exist multiple subtour possibilities, all of which contain the same travel time. Figure 26 below provides an example of multiple subtours within a group of four zones. The ideal solution for the customers in Figure 26 would be to have one tour which begins and ends at customer one, and that visits every other customer. Instead, the solution presented contains two subtours; smaller tours which do not visit every customer. Both of the two subtours illustrated have the same travel time according to the zonal travel time method. The reason this is such a significant issue in terms of computational time is due to the number of subtour combinations available. For example, there exist 16 different ways to connect one customer from each zone in Figure 26. For more complex problems, the number of subtours gets exponentially larger. The problem is still solvable, but for each time constraint that is added, the longer the CPLEX solver takes to solve the linear program.
Equation 9 is formulated to minimize the number of subtour constraints that need to be added. A small section of code determines for each scenario how many customers are located in the same zone. A constraint is then formulated for those specific customers which forces the vehicle routing algorithm to connect those customers without inserting any other customers in between.

This constraint takes advantage of the fact that intrazonal travel will usually have a smaller travel time than interzonal travel. The travel time tables do not contain intrazonal travel times, and therefore they have to be estimated. The assumption made is that the intrazonal travel time is equal to 50% of the average interzonal travel times to adjacent zones (Martin and McGuckin, 1998). This method for intrazonal travel time estimation is called the nearest neighbor method. For every TTS zone, all the adjacent zones were identified using ArcMap. The TTS zones are not of equal size or shape, and therefore the number of adjacent zones is not necessarily equal. Using the list of adjacent zones and the travel time data, the intrazonal travel time for zone i is calculated according to Equation 12.
\[ t_i = \frac{\sum_{j=1}^{p} t_{i \rightarrow j} \cdot 1}{p} \]

Equation 12

\[ t_i = \text{Intrazonal travel time for zone } i \]

\[ t_{i \rightarrow j} = \text{Travel time from the TTS zone in question, } i, \text{ to the adjacent zone, } j. \]

\[ p = \text{Number of adjacent TTS zones}. \]

An analysis of all the calculated intrazonal travel times reveals that the intrazonal travel time is not always smaller than the travel time to the nearest zone. This is contrary to the assumption of Equation 9, which says that if multiple customers fall within the same zone, that the truck will deliver to all the customers in the zone before exiting the zone. This constraint is meant to greatly reduce the number of subtour constraints that are generated before a solution is found. The decision to keep the assumption of Equation 9, despite the evidence which contradicts it, was made for two reasons. Firstly, the addition of this constraints reduces the total model run time significantly, reducing it in some cases tested by half. Secondly, further analysis showed that for zones whose intrazonal travel time is larger than the travel time to the closest adjacent zone, the average travel time difference is only 15 seconds. Such a small travel time difference is unlikely to have a significant impact on the vehicle routing. For this reason, and for the computational time improvements this constraint produces, the assumption of Equation 9 is maintained.
Chapter 6

6 Results and Discussion

This chapter introduces the scenario analyses used for this project and presents the results of the quantitative analysis for the Nestlé case study. The purpose of the quantitative aspect of this research was to determine the travel time impacts large sporting events like the Pan Am Games can have on a company’s day-to-day operations, as well whether off-peak delivery can be used to mitigate some of these impacts and result in decreased overall travel times. The four research questions examined were:

1. What will be the impact of the Pan Am Games on current Nestlé operations?
2. What are the benefits of planning routes one week at a time rather than on a call-and-place basis for normal Nestlé operations outside of the Games?
3. Can off-peak delivery be used to mitigate the impacts from the Games?
4. Can advanced routing and off-peak delivery be used to reduce the total number of trucks required?

6.1 Scenario Analysis

Nestlé has provided delivery log data for a portion of their deliveries between January and April 2014. The delivery data is separated into nine scenarios for analysis, with each scenario representing a week’s worth of deliveries. The number of customers in each scenario, as well as the number of potential off-peak customers, are presented in Table 3.
### Table 3: Number of customers and summary of the number of potential off-peak customers for all scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Number of Customers</th>
<th>Potential Off-Peak Customers Identified by Customer Type</th>
<th>Potential Off-Peak Customers Identified by Proximity to the GRN</th>
<th>Number of Routes Used by Nestlé to Deliver to All Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>Percentage</td>
<td>Number</td>
</tr>
<tr>
<td>1</td>
<td>235</td>
<td>76</td>
<td>32.3</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>137</td>
<td>28</td>
<td>20.4</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>161</td>
<td>38</td>
<td>23.6</td>
<td>61</td>
</tr>
<tr>
<td>4</td>
<td>192</td>
<td>48</td>
<td>25.0</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>211</td>
<td>70</td>
<td>33.2</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>172</td>
<td>62</td>
<td>36.0</td>
<td>46</td>
</tr>
<tr>
<td>7</td>
<td>249</td>
<td>84</td>
<td>33.7</td>
<td>51</td>
</tr>
<tr>
<td>8</td>
<td>173</td>
<td>50</td>
<td>28.9</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>145</td>
<td>52</td>
<td>35.9</td>
<td>41</td>
</tr>
</tbody>
</table>

The average number of customers for the nine scenarios was 180 customers, with an average of 56.4 potential off-peak customers when identified by customer type, 52.8 potential off-peak customers when identified by proximity to the GRN, and delivered to by Nestlé by an average of 17.5 trucks.
6.2 Impact of the Pan Am Games on Nestlé’s Normal Operations

This section will outline the travel time impacts of the Pan Am Games on Nestlé’s normal operations. This analysis estimates the increase in total travel time that Nestlé vehicles can expect due to the impacts from the Pan Am Games should Nestlé not make any changes to their operations in preparation for the Games. This analysis was performed using the delivery logs provided by Nestlé and the travel time estimates provided by IBI Group. In order to estimate the impact of the Games, two different travel time estimates were made. The Games travel times, which incorporated the additional demand and the changes to the road network, and the BAU travel times, which estimates the travel times without any of the changes due to the Games, were compared in order to determine how much longer each trip would take. This is possible because the delivery logs provided by Nestlé contain the order in which the customers were delivered to. This order of customers was maintained for both the Games and BAU travel time scenarios in order to compare the results. The results of this analysis are presented in Figure 27.

Figure 27: Total travel time comparison between Games and BAU conditions
The results in Figure 27 show higher travel times for the Games conditions compared against the BAU conditions. The average travel time for Games conditions is approximately 6.4% higher than the BAU, which corresponds to an average of 171 minutes of extra time spent on the road for a one week period. This analysis only captures the travel time impacts, which are only one part of the delivery process. Nestlé can expect further impacts from the Games in terms of parking search time, especially around the GRN.

6.3 Impact of Advanced Routing on Travel Times

Current Nestlé delivery operations are organized on a call-and-place delivery model. Customers will request deliveries somewhere between 24 and 48 hours in advance of when the delivery will actually take place. The benefit of this method is that it provides flexibility for customers at the expense of less efficient routes. The argument for more advanced routing is two-fold. Firstly, planning deliveries in advance allows for a more optimal route generation, likely with much shorter distances between stops. Secondly, a successful off-peak delivery program would require advanced knowledge of which customers would be willing to accept off-peak delivery. It is unlikely that a sufficient number of off-peak customers would be identified using the call-and-place method to justify a complete off-peak route.

Table 4 shows the travel times generated for each scenario. For the call-and-place method the same order of deliveries was maintained as was presented in the driver deliver logs. Each scenario, roughly a week’s worth of customers, was then clustered using the capacity constrained k-means clustering algorithm and routed using the vehicle routing algorithm. The travel times used were the BAU travel times with all customers being delivered to during the daytime.
Table 4: Travel time comparison between call-and-place deliveries versus more advanced weekly routing

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Call-and-Place Travel Times (Minutes)</th>
<th>Advanced Routing Travel Times (Minutes)</th>
<th>Travel Time Savings (Minutes)</th>
<th>Travel Time Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2850</td>
<td>2076</td>
<td>774</td>
<td>27.2</td>
</tr>
<tr>
<td>2</td>
<td>2049</td>
<td>1654</td>
<td>395</td>
<td>19.3</td>
</tr>
<tr>
<td>3</td>
<td>2132</td>
<td>1482</td>
<td>650</td>
<td>30.5</td>
</tr>
<tr>
<td>4</td>
<td>2327</td>
<td>1871</td>
<td>456</td>
<td>19.6</td>
</tr>
<tr>
<td>5</td>
<td>2725</td>
<td>2069</td>
<td>656</td>
<td>24.1</td>
</tr>
<tr>
<td>6</td>
<td>2289</td>
<td>1734</td>
<td>555</td>
<td>24.2</td>
</tr>
<tr>
<td>7</td>
<td>3870</td>
<td>2672</td>
<td>1198</td>
<td>31.0</td>
</tr>
<tr>
<td>8</td>
<td>2406</td>
<td>1741</td>
<td>665</td>
<td>27.6</td>
</tr>
<tr>
<td>9</td>
<td>2040</td>
<td>1409</td>
<td>631</td>
<td>30.9</td>
</tr>
</tbody>
</table>

The results in Table 4 show an average potential travel time savings of 25.9% if deliveries are planned on a weekly basis rather than on a call-and-place basis. These numbers were generated for the same number of customers and the same number of trucks. Converting from a call-and-place delivery method to a weekly delivery method would require flexibility on the part of Nestlé’s customers. Only 5.7% of Nestlé’s customers require more than one delivery per week. Several options exist for accounting for these customers in the methodology. The first option would be to consolidate both deliveries into one larger delivery, should the storage space be available. This would reduce the number of total trips required, as well as the delivery cost for the customer. The second option would be to duplicate the customer and add a specific constraint during the clustering process that would eliminate the possibility of both the customer and its duplicate being assigned to the same cluster.
6.4 Impact of Off-Peak Delivery on Travel Times during the Pan Am Games

The third quantitative thesis question analyzed the use of off-peak delivery in reducing travel times during the Pan Am Games. The five step heuristic used for the analysis of this question was presented in section 5.2 to 5.7 of this thesis. The first step identified potential off-peak customers based either on their type or on their proximity to the GRN. The second step refined the list of potential off-peak customers using combinations of two refinement processes referred to as the cluster refinement process or the outlier refinement process. The refinement processes were only used for strategic selection, as the random customer selection selected off-peak customers from the complete list of potential off-peak customers. The third step selected off-peak customers from the refined list either through random or strategic selection. The number of customers chosen for off-peak delivery depended on the number of trucks being routed. A capacity constrained k-means clustering algorithm was then used to separate the customers into different routes, or trucks, and finally a vehicle routing algorithm was used to estimate travel times for each route.

In order to provide a basis for comparison of the results, the upper and lower limits for travel time were determined by assigning all customers to the daytime or off-peak hours respectively. The all daytime travel time analysis represents the total travel time should all customers be serviced in the daytime hours, and provides the base travel time for which improvements can be compared. The all off-peak analysis shows the very lowest travel times possible should all customers be delivered to at night. The travel time tables used were the Pan Am Games scenario daytime tables and the Pan Am Games scenario off-peak table. The results are presented in Table 5.
Table 5: Travel time results for all daytime and all off-peak customers

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of Clusters</th>
<th>Number of Customers</th>
<th>Total Travel Time All Daytime Customers (minutes)</th>
<th>Total Travel Time All Off-Peak Customers (minutes)</th>
<th>Percentage Travel Time Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>235</td>
<td>2242</td>
<td>1653</td>
<td>26.3</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>137</td>
<td>1822</td>
<td>1312</td>
<td>28.0</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>161</td>
<td>1607</td>
<td>1194</td>
<td>25.7</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>192</td>
<td>2028</td>
<td>1489</td>
<td>26.6</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>211</td>
<td>2212</td>
<td>1656</td>
<td>25.1</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>172</td>
<td>1851</td>
<td>1390</td>
<td>24.9</td>
</tr>
<tr>
<td>7</td>
<td>25</td>
<td>249</td>
<td>2858</td>
<td>2112</td>
<td>26.1</td>
</tr>
<tr>
<td>8</td>
<td>17</td>
<td>173</td>
<td>1886</td>
<td>1395</td>
<td>26.0</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>145</td>
<td>1512</td>
<td>1125</td>
<td>25.6</td>
</tr>
</tbody>
</table>

The results in Table 5 show an average decrease in travel time of 26% between the all daytime and all off-peak scenarios. These results represent the possibility for travel time improvements should Nestlé’s entire delivery operations be shifted to off-peak hours. However, the likelihood that all of Nestlé’s customers would participate in an off-peak delivery program is small. The rest of this section (6.4) presents the results for the two potential off-peak identification methods, selection by customer type and selection by customer proximity to the GRN, as well as the two methods of off-peak customer selection, random selection and strategic selection.

Detailed results and figures are presented for scenario 1 in order to provide detail into how the process works, and summarized results are presented for the remaining scenarios. Scenario 1 has 235 total customers, of which 76 are considered as potential off-peak customers according to their customer type, and 60 are considered as potential off-peak customers according to their proximity.
to the GRN. A total of 20 trucks were used to deliver to these customers according to the Nestlé delivery logs. The number of trucks was held constant over every model run. Figure 28 below shows the result of the capacity constrained k-means clustering algorithm for all 235 customers clustered into 20 routes.

Figure 28: Result of clustering for all scenario 1 customers
6.4.1 Random Off-Peak Customer Selection

Random selection represents the possibility that Nestlé does not influence which potential off-peak customers will participate in the off-peak delivery program, and instead participation will be purely on a volunteer basis. The five-step heuristic is used for random selection, with the exception that the second step, the refinement of the list of potential off-peak customers, is excluded. The analysis presented in this section will show the travel time difference for off-peak routes created using randomly selected off-peak customers. Table 6 and Table 7 show the travel time results for randomly selected off-peak customers for identification by customer type and identification by proximity to the GRN respectively for scenario 1. Complete results for the remaining 8 scenarios can be found in the Appendix A.

Table 6: Travel times for randomly selected off-peak routes as identified by customer type

<table>
<thead>
<tr>
<th></th>
<th>Number of Off-Peak Clusters</th>
<th>Number of Peak Clusters</th>
<th>Number of Off-Peak Customers</th>
<th>Number of Peak Customers</th>
<th>% of Off-Peak Customers</th>
<th>Total Travel Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Daytime</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>2242</td>
</tr>
<tr>
<td>All Off-Peak</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>100</td>
<td>1650</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>2</td>
<td>18</td>
<td>21</td>
<td>214</td>
<td>8.9</td>
<td>2224</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>3</td>
<td>17</td>
<td>42</td>
<td>193</td>
<td>17.9</td>
<td>2263</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>4</td>
<td>16</td>
<td>64</td>
<td>171</td>
<td>27.2</td>
<td>2233</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>5</td>
<td>15</td>
<td>76</td>
<td>159</td>
<td>32.3</td>
<td>2183</td>
</tr>
</tbody>
</table>

These results (Table 6) show that the travel times for randomly selecting off-peak customers may result in higher travel times than if all customers were delivered to during the daytime. A travel
time decrease of 2.6% was the largest travel time decrease generated for five off-peak routes, an increase in travel time of 0.9% was generated for three off-peak routes.

The results in Table 7 show the travel times for randomly selected off-peak customers identified by proximity to the GRN.

Table 7: Travel times

<table>
<thead>
<tr>
<th></th>
<th>Number of Off-Peak Clusters</th>
<th>Number of Peak Clusters</th>
<th>Number of Off-Peak Customers</th>
<th>Number of Peak Customers</th>
<th>% of Off-Peak Customers</th>
<th>Total Travel Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Daytime</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>2242</td>
</tr>
<tr>
<td>All Off-Peak</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>100</td>
<td>1650</td>
</tr>
<tr>
<td>Selection by proximity to GRN</td>
<td>2</td>
<td>18</td>
<td>22</td>
<td>213</td>
<td>9.4</td>
<td>2184</td>
</tr>
<tr>
<td>Selection by proximity to GRN</td>
<td>3</td>
<td>17</td>
<td>44</td>
<td>191</td>
<td>18.7</td>
<td>2168</td>
</tr>
<tr>
<td>Selection by proximity to GRN</td>
<td>4</td>
<td>16</td>
<td>60</td>
<td>175</td>
<td>25.5</td>
<td>2156</td>
</tr>
</tbody>
</table>

The results in Table 7 show travel time improvements for off-peak customers identified by proximity to the GRN, up to 3.8%. When selecting off-peak customers based on the proximity to the GRN, the resultant customers identified are all located within close proximity to one another. This is not the case for potential off-peak customers identified by type, as those customers are more evenly distributed across the city. For identification by customer type this means any travel time benefits gained as a result of the off-peak delivery are negated by the extra distances needed to travel between these more spread out customers. The differences between the two identification methods can be seen in Figure 29.
Figure 29: Random selection of single off-peak routes for both off-peak customer identification methods

Figure 29 shows how the random selection for off-peak customers identified by type can result in an off-peak route spread out across downtown, whereas off-peak customers identified by proximity to the GRN result in more localized routes.
6.4.2 Strategic Selection by Customer Type

Strategic selection selects off-peak customers after the refinement processes have been applied to the complete list of potential off-peak customers. Identification by customer type identifies customers that may be more willing to accept off-peak delivery due to the fact that they already operate in some capacity during the off-peak hours. The additional cost to these customers to accept off-peak deliveries would likely be very low, or even zero. The benefit of identifying these customers is that receiver participation is widely recognized as the principle barrier preventing the implementation of off-peak delivery programs. Focusing on those customers that wouldn’t have to incur large additional costs to accept off-peak deliveries would likely allow for more successful off-peak program implementation. The potential off-peak customers for scenario 1 are shown in Figure 30.

Figure 30: Potential off-peak customers for scenario 1 as identified by customer type
Figure 30 shows the distribution of the potential off-peak customers (grocery stores, department stores, drug stores, and other 24-hr stores) are distributed evenly across the downtown core. Table 8 contains the results for total travel times for scenario 1 using different combinations the refinement processes which refine the list of potential off-peak customers. The purpose of this analysis is to show the benefits of using these refinement processes, rather than using all of the potential off-peak customers. The shaded row in the different tables indicates the lowest travel times.

<table>
<thead>
<tr>
<th></th>
<th>Number of Off-Peak Clusters</th>
<th>Number of Peak Clusters</th>
<th>Number of Off-Peak Customers</th>
<th>Number of Peak Customers</th>
<th>% of Off-Peak Customers</th>
<th>Total Travel Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Daytime</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>2242</td>
</tr>
<tr>
<td>All Off-Peak</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>100</td>
<td>1650</td>
</tr>
<tr>
<td>No Refinement to List of Potential Off-Peak Customers</td>
<td>5</td>
<td>15</td>
<td>76</td>
<td>159</td>
<td>32.3</td>
<td>2161</td>
</tr>
<tr>
<td>Clustering Off-Peak Refinement Only</td>
<td>5</td>
<td>15</td>
<td>73</td>
<td>162</td>
<td>31.1</td>
<td>2195</td>
</tr>
<tr>
<td>Outlier Off-Peak Refinement Only</td>
<td>5</td>
<td>15</td>
<td>65</td>
<td>170</td>
<td>27.6</td>
<td>2135</td>
</tr>
<tr>
<td>Both Refinement Processes</td>
<td>5</td>
<td>15</td>
<td>63</td>
<td>172</td>
<td>26.8</td>
<td>2100</td>
</tr>
</tbody>
</table>

The results in Table 8 show the total travel time improvements for delivering to all customers during the off-peak hours, and the possible improvements incorporating the different refinement processes.
processes. The maximum improvement in travel time possible by delivering to all customers during the off-peak hours is 592 minutes. This represents a possible savings of 26.5% from the case where all customers are delivered to during the daytime. The possible improvement made delivering to all potential off-peak customers, without any refinement process is 81 minutes, a 3.6% travel time savings. The travel time after using the clustering refinement process is at 2195 minutes, while the outlier refinement process shows further improvement down to 2135 minutes. When both processes are used, the travel time is reduced to 2100 minutes, a savings of 142 minutes or 6.3%.

Table 9 contains the full set of results using different numbers of off-peak routes. The off-peak customer selection algorithm strategically selected different numbers of off-peak customers depending on the number of routes specified. Both refinement processes were used while generating the results in Table 9.

<table>
<thead>
<tr>
<th>Number of Off-Peak Clusters</th>
<th>Number of Peak Clusters</th>
<th>Number of Off-Peak Customers</th>
<th>Number of Peak Customers</th>
<th>% of Off-Peak Customers</th>
<th>Total Travel Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Daytime</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>2242</td>
</tr>
<tr>
<td>All Off-Peak</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>1650</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>2</td>
<td>18</td>
<td>20</td>
<td>215</td>
<td>8.5</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>3</td>
<td>17</td>
<td>34</td>
<td>201</td>
<td>17.4</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>4</td>
<td>16</td>
<td>56</td>
<td>179</td>
<td>24.7</td>
</tr>
<tr>
<td>Selection by Customer Type</td>
<td>5</td>
<td>15</td>
<td>63</td>
<td>172</td>
<td>26.8</td>
</tr>
</tbody>
</table>
Table 9 shows decreases in travel times for additional off-peak routes, with small expected decreases for a single off-peak route, and larger expected decreases for the maximum number of off-peak routes.

### 6.4.3 Strategic Selection by Proximity to the GRN

The same analysis was performed using off-peak customer identification by proximity to the GRN as the method for identifying potential off-peak customers. There were 60 customers located within the 500 m buffer to the GRN for scenario 1 out of the total 235 customers. Figure 31 shows the location of the potential off-peak customers as identified by proximity to the GRN and Table 10 presents the travel time results using different combinations of the refinement processes.
The customers identified as potential off-peak customers in Figure 31 were not necessarily all delivered to during off-peak hours. The refinement processes were applied to the list of potential off-peak customers and the effectiveness of the different refinement process in reducing travel time are presented in Table 10.

Table 10: Travel time results for strategic selection by customer proximity to the GRN for scenario 1.

<table>
<thead>
<tr>
<th></th>
<th>Number of Off-Peak Clusters</th>
<th>Number of Peak Clusters</th>
<th>Number of Off-Peak Customers</th>
<th>Number of Peak Customers</th>
<th>% of Off-Peak Customers</th>
<th>Total Travel Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Daytime</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>2242</td>
</tr>
<tr>
<td>All Off-Peak</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>100</td>
<td>1650</td>
</tr>
<tr>
<td>No Refinement to list of Potential Off-Peak Customers</td>
<td>4</td>
<td>16</td>
<td>60</td>
<td>175</td>
<td>25.5</td>
<td>2156</td>
</tr>
<tr>
<td>Clustering Off-Peak Refinement Only</td>
<td>3</td>
<td>17</td>
<td>41</td>
<td>194</td>
<td>17.4</td>
<td>2188</td>
</tr>
<tr>
<td>Outlier Off-Peak Refinement Only</td>
<td>4</td>
<td>16</td>
<td>48</td>
<td>187</td>
<td>20.4</td>
<td>2123</td>
</tr>
<tr>
<td>Both Refinement Processes</td>
<td>3</td>
<td>17</td>
<td>30</td>
<td>205</td>
<td>12.8</td>
<td>2160</td>
</tr>
</tbody>
</table>

The results in Table 10 show similar results to those in Table 8, with one key difference. Using only the cluster refinement process resulted in increased travel times, 2188 from the no refinement time of 2156 minutes, while using both processes resulted in a very small increase in travel times. The two refinement processes identify customer configurations, with the cluster refinement process more likely to identify potential off-peak customers in closer proximity to one another.
For the case of selection by proximity to the GRN, the off-peak customers identified are in much closer proximity to one another. This resulted in too many of the potential off-peak customers being re-designated as daytime customers, generating a travel time that is higher than the no refinement travel time. The largest decrease in travel times came as the result of only using the outlier off-peak refinement process, with a decrease down to 2123 minutes. Using the outlier refinement process only, travel times are presented in Table 11 for different numbers of off-peak routes.

Table 11: Comparison of travel times for different number of off-peak routes for scenario 1 selection by proximity to the GRN

<table>
<thead>
<tr>
<th></th>
<th>Number of Off-Peak Clusters</th>
<th>Number of Peak Clusters</th>
<th>Number of Off-Peak Customers</th>
<th>Number of Peak Customers</th>
<th>% of Off-Peak Customers</th>
<th>Total Travel Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Daytime</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>2242</td>
</tr>
<tr>
<td>All Off-Peak</td>
<td>20</td>
<td>0</td>
<td>235</td>
<td>0</td>
<td>100</td>
<td>1650</td>
</tr>
<tr>
<td>Selection by proximity to GRN</td>
<td>2</td>
<td>18</td>
<td>22</td>
<td>213</td>
<td>9.4</td>
<td>2194</td>
</tr>
<tr>
<td>Selection by proximity to GRN</td>
<td>3</td>
<td>17</td>
<td>44</td>
<td>191</td>
<td>18.7</td>
<td>2144</td>
</tr>
<tr>
<td>Selection by proximity to GRN</td>
<td>4</td>
<td>16</td>
<td>48</td>
<td>187</td>
<td>20.4</td>
<td>2123</td>
</tr>
</tbody>
</table>

Table 11 shows a similar trend to the results presented in Table 9. The results show that there can be travel time improvements made by delivering to any number of off-peak customers but decreasing travel times as the number of off-peak routes increases. The results for the remaining scenarios are presented in the Appendix A.
6.4.4 Discussion of Results

Sections 6.4.1-6.4.3 presented in detail how the five step heuristic was applied to different methods of off-peak customer identification and selection using scenario one as the primary example. This section presents the results for all nine scenarios and compares results for the following analysis:

1. The differences in travel time for strategic selection versus random selection for off-peak routes.
2. The differences in identifying potential off-peak customers based on customer type or based on proximity to the GRN.
3. The travel time improvements that can be achieved over the all daytime scenario.

The following three figures (Figure 32, Figure 33, and Figure 34) show the difference between strategic and random selection for off-peak customer identification by type. For each scenario, an additional truck was added for the off-peak hours while one truck was removed from the daytime hours. The additional truck was added because many of the customers being delivered to during off-peak hours have large demands, and an additional truck helped create route lengths more consistent with daytime routes.
Figure 32: Comparison of strategic and random selection based on identification by customer type for scenarios 1-3.
Figure 33: Comparison of strategic and random selection based on identification by customer type for scenarios 4-6
Multiple key trends are apparent when examining the results in Figure 32, Figure 33, and Figure 34. The first is that, for most of the strategic selection scenarios, there is a downward trend showing decreased total travel time for higher numbers of off-peak routes. The results from random off-peak customer selection do not show similar trends, and are much less predictable in whether an increase in off-peak routes will correspond to lower total travel times. The second observation is that for every scenario tested in these three figures, the strategic travel time is lower than the random travel time. On average, the strategic customer selection produces travel times that are 73 minutes smaller overall than the random customer selection.

The same analysis was conducted for identification by proximity to the GRN, and the results for this analysis are presented in Figure 35, Figure 36, and Figure 37.
Figure 35: Comparison of strategic and random selection based on identification by proximity to the GRN for scenarios 1-3
Figure 36: Comparison of strategic and random selection based on identification by proximity to the GRN for scenarios 4-6
Figure 37: Comparison of strategic and random selection based on identification by proximity to the GRN for scenarios 7-9

The results for strategic selection show smaller total travel times as the number of off-peak clusters increases, similar to the results presented for off-peak identification by customer type. However, unlike identification by customer type, the identification by proximity to the GRN shows a smaller difference between the strategic and random selection methods. On average the strategic selection method only produces results that are 25.9 minutes lower than the random selection method, with some results showing better travel time using the random selection method.

The second and third questions presented in this section (6.4.4) asked whether identification by customer type or identification by proximity to the GRN is able to generate lower travel times, and how these travel times compared to the all daytime scenario. The results for both of these questions are presented in Figure 38. The results shown are the all daytime scenario, shown in black, and the
four combinations of off-peak customer identification and selection. The numbers for these four combinations are averaged from the total travel times presented in Figures 32-37.

Figure 38: Comparison of total travel times for all off-peak selection methods

Figure 38 shows improvement over the all daytime scenario for all strategic selection methods, both using identification by customer type and proximity to the GRN, with the exception of scenario 9 identification by customer type. For most scenarios, 7 out of 9, both the random and strategic selection by proximity to the GRN generates lower average travel times compared to identification by customer type, as well as larger maximum travel time decreases. This indicates that there is some benefit to focusing off-peak delivery efforts on customers surrounding the GRN.

The summary of travel time decreases for each scenario from the all daytime scenario is shown in Table 12. The numbers displayed are the average travel time percentage differences and maximum travel time decreases for each customer selection and identification method. For this table, the positive numbers represent travel time decreases from the all daytime scenario, while the negative numbers represent travel time increases when compared to the all daytime scenario.
Table 12: Average and maximum travel time decreases for all combinations of off-peak customer identification and selection.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Strategic Selection by Customer Type</th>
<th>Random Selection by Customer Type</th>
<th>Strategic Selection by Proximity to the GRN</th>
<th>Random Selection by Proximity to the GRN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.8</td>
<td>6.3</td>
<td>0.3</td>
<td>2.6</td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
<td>3.8</td>
<td>1.1</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>3.8</td>
<td>-2.9</td>
<td>-1.0</td>
</tr>
<tr>
<td>4</td>
<td>1.8</td>
<td>3.0</td>
<td>-0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>2.5</td>
<td>-5.7</td>
<td>-3.8</td>
</tr>
<tr>
<td>6</td>
<td>1.7</td>
<td>3.9</td>
<td>-2.8</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>2.0</td>
<td>3.8</td>
<td>-2.1</td>
<td>-1.1</td>
</tr>
<tr>
<td>8</td>
<td>3.4</td>
<td>5.5</td>
<td>0.5</td>
<td>2.0</td>
</tr>
<tr>
<td>9</td>
<td>-1.9</td>
<td>0.3</td>
<td>-4.2</td>
<td>-2.1</td>
</tr>
<tr>
<td>Average</td>
<td>1.5</td>
<td>3.7</td>
<td>-1.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Max</td>
<td>3.4</td>
<td>6.3</td>
<td>1.1</td>
<td>2.6</td>
</tr>
</tbody>
</table>

The key data presented in Table 12 are the last two rows, which contain the overall averages and maximum travel time decreases generated. The maximum average travel time decrease from the all daytime scenario is by strategically selecting off-peak customers identified by proximity to the GRN. The results show an average travel time decrease almost double that of identification by customer type. Random selection of off-peak customers identified by proximity to the GRN also
produces better total travel times than strategic selection based on customer type. For random selection based on customer type, the average total travel time is higher than the all daytime scenario, indicating that there are no travel time benefits to be gained from using that method.

In terms of planning for a large sporting event like the Pan Am Games, these results demonstrate the need for complete information concerning the GRN to be available to companies well in advance of the Games. Customers situated in close proximity to the GRN are the most likely to be impacted during the Games, and the data shows that focusing on these customers can bring the greatest travel time benefits. There are also benefits to be had from parking search time which is generally easier at night, but also would be more difficult during the Games due to parking restrictions on the GRN.
6.5 Impact of Advanced Routing and Off-Peak Delivery on Fleet Size

One of the benefits of advanced vehicle routing and off-peak delivery is it may allow the possibility for the carrier to reduce their truck numbers. Reducing truck numbers without reducing the number of customers being delivered to would reduce operating costs for Nestlé as well as limit the total number of trucks on the road network. For this analysis, all of the potential off-peak customers remaining after the refinement process in section 5.4 were selected to be off-peak customers. The total number of trucks used for daytime and off-peak deliveries was reduced by one for each successive model run. The minimum number of trucks used was determined by the total demand being delivered to, and the minimum number of trucks required to deliver to those customers should the entire truck capacity be used. The analysis was conducted for both identification by customer type and identification by customer proximity to the GRN, as these two identification methods resulted in different numbers of off-peak customers.

The results for the impact of advanced routing and off-peak delivery on truck numbers for each of the nine scenarios is presented in Figure 39, Figure 40, and Figure 41. The results are separated into three figures in order to increase the readability.

Figure 39: Total travel time for different truck numbers for scenarios 1-3
Figure 40: Total travel time for different truck numbers for scenarios 4-6

Figure 41: Total travel time for different truck numbers for scenarios 7-9
The results in Figure 39, Figure 40, and Figure 41 show consistent travel time decreases as a result of reducing truck numbers. The percentage travel time decrease from the highest to the lowest truck number, averaged over all nine scenarios, is 26.6% when potential off-peak customers are identified by type and 28.4% when potential off-peak customers are identified by proximity to the GRN. The average travel time decrease expected by reducing truck numbers by one is 4.8% and 5.2% for potential off-peak customers identified by customer type and proximity to the GRN respectively.

The possibility for reducing truck numbers is more of a function of the advanced routing rather than the off-peak delivery. Section 6.3 shows the benefits advanced routing can have over the call-and-place delivery method without changing the number of trucks being used. The cluster-first route-second method allows for higher utilization of each truck’s total capacity. It has been shown that off-peak delivery can reduce the overall travel time required to make all deliveries.
Chapter 7

7 Conclusion

This thesis first examined the challenges introduced by large sporting events to urban good movements and the best practices used by stakeholders during these events, and then analyzed the possibility of using off-peak delivery to help mitigate some of these impacts, with a specific focus on the travel time impacts. This concluding chapter will summarize the important points and findings from qualitative and each of the quantitative analyses. It will conclude by briefly discussing some limitations of the work presented and some recommendations for future research.

7.1 Best Practices for Goods Movement during Sporting Events

One of the primary research objectives for this project was to examine the impact of large sporting events and to determine best practices for urban freight movement during these events. A series of interviews was conducted with stakeholders in the London freight community who had first-hand experience preparing and participating in freight logistics during the 2012 London Olympics. The questions posed to them were concerned with what did and did not go well for their respective organizations during the Olympics, what they might do differently given a second chance, and finally whether they incorporated some form of off-peak delivery during the Olympics.

The two overarching themes present in the interview responses were the need to introduce freight early on in the planning process, and to have one consistent and reliable source of information for freight stakeholders. Introducing freight early helps ensure that the issues of major concern to freight operators and stakeholders are factored into the decision making process. Maintaining one consistent and reliable source of information allows individual companies and their customers to plan for the Games accordingly with the most up to date knowledge of road conditions and restrictions.
7.2 Impact of the Pan Am Games on Normal Operations

The first research question was concerned with the impact that the Pan Am Games would have on Nestlé’s normal operations should Nestlé not make any changes in preparation of the Games. The results show a travel time difference of 6.4% between the Games and BAU conditions. This 6.4% represents an average travel time increase of 171 minutes per week. This increase in travel times is only one of the expected impacts from the Games. Parking and delivery restrictions in and around the GRN and event venues are also expected to cause further delays and longer tour times for Nestlé’s delivery vehicles.

7.3 Impact of Advanced Routing on Travel Times

The travel time benefits of advanced route planning over call-and-place delivery methods of routing were shown by comparing delivery log travel times for Nestlé deliveries against a capacity constrained k-means clustering algorithm. The results showed an average potential travel time savings of 26% when routing on a weekly basis. The reason behind the large decreases in travel time is that there is a possibility of generating much more compact and localized clusters. This would reduce the in-between customer travel time, and in some cases may also allow for multiple deliveries to be made from the same parking location.

7.4 Potential of Off-Peak Delivery in Minimizing Travel Times

The results for the off-peak delivery analysis show that travel time improvements are possible by incorporating off-peak delivery into normal operations. Four methods for generating off-peak routes were used: strategic selection using off-peak customer identification by type, strategic selection using off-peak customer identification by proximity to the GRN, random selection using off-peak customer identification by type, and finally random selection using off-peak customer identification by proximity to the GRN. The results showed that the greatest travel time benefits could be made by incorporating strategic selection, and by focusing on customers situated in close proximity to the GRN, resulting in an average of 2.9% below the all daytime scenario. Travel time decreases were also generated for strategic selection by customer type and random selection by
proximity to the GRN, at 1.5% and 1.6% respectively. In terms of policy, these results indicate that efforts should be placed on getting customers near the GRN to participate in off-peak delivery programs.

7.5 Potential of Advanced Routing and Off-Peak Delivery in Reducing Fleet Size

A significant benefit of advanced routing over the call-and-place methods is that, in addition to generating more compact and localized clusters, it introduces the possibility of reducing the total number of trucks required to make the deliveries. Routes can be configured that utilize more of a trucks capacity, allowing carriers to reduce the total number of trucks required. The analysis conducted shows fairly consistent total travel time decreases of 4.8% and 5.3% per truck removed depending on whether the off-peak customers were identified based on customer type or by proximity to the GRN, respectively.

7.6 Limitations and Recommendations for Future Research

There are several limitations to this project that need to be mentioned. Some of these limitations were necessary due to the quality and quantity of the data available, while other were practical limitations to simplify the models. Assumptions were made concerning the customer’s likelihood of accepting off-peak delivery. The assumption was made based upon what type of customer was being delivered to, and whether that customer routinely operates in some capacity during the off-peak hours. Ideally a full survey of customers would be required to generate the list of potential off-peak customers. This would give Nestlé the greatest likelihood of maximizing their travel time savings. However, for this project a survey of customers was not practical, and therefore the assumptions had to be made.

An assumption was made concerning the size of the delivery truck used in all of the deliveries. Nestlé uses three different truck sizes to make deliveries, but only one size was chosen to simplify the models. Delivery logs did not contain information about what size of truck was used to make the deliveries.
The travel time tables provided were average travel time values between TTS zones. There is a loss of accuracy in vehicle routing using actual customer locations combined with zonal travel times. This is unavoidable as actual travel times between specific customer locations would be challenging to generate. Another limitation is the lack of intrazonal travel times provided by IBI. An estimate had to be made for travel time between customers in the same zone. This estimate is used whether the customers are right next to one another or on the opposite side of the zone.

The decision as to whether to include a customer in off-peak delivery was based solely on the total travel times. In reality there would be more to consider when making those decisions. Parking time and delivery time are two key components in determining the total time a truck is out making deliveries. Some research has shown that there can be significant improvements in both the parking and delivery time when deliveries are made during the off-peak hours. It is possible that a carrier like Nestlé would be willing to make some sacrifices in travel time in order to make greater benefits in overall tour times. Since parking and delivery time were not estimated, these two factors were ignored.

There are several policy implications for the carriers and their drivers which may impact the possibility of an off-peak delivery program being implemented. The switch from daytime to nighttime deliveries would also require truck driver’s approval, as it is possible that many of them would not be willing to deliver at night. Extra costs may also be required not only for driver pay, but also for potentially higher insurance costs and the cost for adding low noise technology to existing vehicles. A larger study would have to be conducted including the cost analysis in addition to the tour time estimates before a final decision could be made concerning the total costs and benefits of an off-peak delivery program.

There are two key aspects of off-peak delivery for which there are still gaps in the current literature. One of the benefits of off-peak delivery is the reduction in parking search time. Delivering during off-peak hours would not only benefit the carriers in reduced delivery times, but the daytime traffic as well which would benefit from reduced truck numbers during the day. Knowing the benefits for reduced parking search time would allow for a more complete picture of off-peak delivery, and would allow carriers to make more informed decisions concerning their use of off-peak delivery. The second gap in the current literature is related to the environmental impact of off-peak delivery. More specifically, the differences in truck emissions as a result of changes in average speed and
dwell time during the off-peak hours. It is possible that the positive possible externalities associated with off-peak delivery would help to drive policy changes that would allow for reduced restrictions for off-peak delivery implementation.
References


Wenneman, A., Habib, K., & Roorda, M. A Disaggregate Analysis of the Relationship Between Commercial Vehicle Parking Citations, Parking Supply, and Parking Demand: Critical
Understandings and Policy Implications. *Transportation Research Record: Journal of the Transportation Research Board*. (Forthcoming)


## Appendix A

Table A1: Travel time results for random selection by customer type

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Table A2: Travel time results for random selection by proximity to the GRN

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Table A4: Travel time results for strategic selection by proximity to GRN

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