Implementing Off-peak Deliveries in the Greater Toronto Area: Costs, Benefits, Challenges

Jessica McPhee, Ari Paunonen, Taufiq Ramji, and James H. Bookbinder

Abstract
Nestle Canada currently uses 32 routes that serve over 4,500 customers in the Greater Toronto Area (GTA). This study aims to quantify Nestlé’s costs and benefits of modifying their ice cream supply chain to incorporate night-time deliveries, while providing a framework for the regulatory, conceptual, and inertial obstacles to implementation. Employing Nestlé’s customer data set, we created routing software to determine the proportion of customers who must be willing to accept deliveries outside of normal working hours so that the change would be financially feasible. Based upon a literature review we found that, before proceeding, the following qualitative factors should be considered: safety, sustainability, regulatory concerns, truck noise, traffic, and congestion. Reduction of 3–10 percent in the number of routes may result from switching a suitable proportion of deliveries to night-time, achieving the minimum fleet size when 50–60 percent of locations are served on night routes. The operation of both night-time and daytime deliveries would enable an increase in truck utilization, thus decreasing the number of vehicles required. Recommendations for success of night-time deliveries include preparation of a safety plan, procurement of plate trucks, noise-abatement techniques, and the development of a noise-monitoring program.

Keywords
Night delivery, congestion, environment, truck noise, sustainability
Introduction
Toronto is a rapidly growing city and, for two years in a row, was ranked the number one most sustainable city in Canada (Marchington 2011). As a byproduct of urban growth, daytime congestion is increasing as more and more people are commuting into the downtown core. The volume of cars is adversely impacting delivery vehicles by increasing travel times, fuel consumption, and accumulated truck-parking violations. In addition to the nuisance caused by heavy traffic, these vehicles are also a major contributor of smog and pollution.

One mitigation strategy to address this problem is shifting deliveries to off-peak hours. Although hardly novel, it is only recently that this concept has been given serious consideration. Several academic papers and industry initiatives have examined implementing a night-time delivery model, concluding that significant financial and environmental benefits are realizable from adopting this approach. (See the “Literature Review” section below.)

Enticed by these benefits, Nestlé Canada—wholly owned subsidiary of Nestlé S.A., the world’s largest food company—became interested in modifying its ice cream distribution network to incorporate off-peak delivery. Specifically, Nestlé wished to quantify the costs and benefits of switching, as well as a framework for navigating the regulatory, conceptual, and inertial obstacles to implementation. We have analyzed Nestlé’s ice cream direct-store delivery network for the Greater Toronto Area (GTA), the status quo with respect to off-peak deliveries in the GTA, and contemporary academic research on numerous factors affecting successful implementation, including environmental effects (Sathaye, Harley, and Mandanat 2010), noise (City of Toronto By-law No. 111-2003), and safety (Cavar, Kavran, and Jolic 2011). This article summarizes the methodology and results of the investigation, and provides recommendations for eventual adoption of an off-peak delivery schedule.

Literature Review
The concept of delivering goods during the off-peak hours to reduce daytime traffic congestion has been of interest to policymakers throughout history. In fact, the first known record of the implementation of night-time deliveries dates back all the way to ancient Rome, when Julius Caesar banned all commercial deliveries during the day (H. Dessau, Inscriptioás Latinæ selectæ, no. 6085 [1892], cited in Holguín-Veras 2008). It is interesting to note that this move may have been influenced by similar rules in
Greek cities, indicating that traffic congestion required legislation even before the era of Julius Caesar.

Much more recent publications on the topic of night-time deliveries include Churchill (1970), Organization for Economic Growth (1979), and Noel et al. (1980). In fact, most of the research and information on this subject has appeared in the last 15 years. Holguín-Veras et al. (2007, 2008) study the policies of the carrier and consignee. Verlinde et al. (2010) consider these and other stakeholders. Holguín-Veras (2006, 2008) and Vilain and Wolfrom (2007) treat the problem as that of the pricing of urban freight. A survey of restrictions on night-time deliveries has been given by Browne et al. (2006).

Vilain and Wolfrom (2007) conducted a set of interviews with management-level personnel at various trucking companies. The questions pertained to proposed off-peak discounts (or peak-period surcharges) for the New Jersey–Manhattan bridges and tunnels. It was found that “value pricing,” as those authors termed it, would have minimal effect in encouraging night deliveries. Many consignees specify delivery time windows to their carriers; the financial penalty for missing a time window far outweighs any off-hour discount in the bridge tolls. Other findings of the interviews were that union regulations and/or hours of operation at consignees worked against avoiding congestion by trying to deliver in the 6:00 PM–6:00 AM interval.

Several intuitive reasons initially attract organizations to consider implementing night-time deliveries: optimized vehicle utilization, possibly lower truck emissions due to favorable night-time traffic conditions, and fewer disturbances for shop owners receiving deliveries during peak sale times (Forkert and Eichhorn n.d.). Although these factors are typically cited as arguments in favor of switching to night-time deliveries, some elements (such as environmental and traffic congestion) have wider-spanning implications that may be difficult to quantify accurately. The impact to traffic congestion and the environment will be discussed in more detail in subsequent sections.

A significant aspect of successfully implementing off-peak deliveries is stakeholder buy-in. Three key stakeholders have been identified: city administration, transport operators, and shop owners (Forkert and Eichhorn n.d.). The majority of drawbacks associated with night-time deliveries affect receivers (shop owners); they will now require staff trained to accept deliveries that arrive during the off-peak (potentially incurring training costs and wage increases/shift premiums), will probably have
higher heating and lighting costs due to additional operating hours, and may also have increased security and insurance costs (Holguín-Veras et al. 2005). As such, these stakeholders could pose the biggest roadblock to implementation. Hence, it has been suggested that the most likely configuration to successfully implement off-peak deliveries are shippers who handle their own transportation and receivers who are open during extended hours, followed closely by the same shippers who handle their own transportation and receivers who do not currently operate over a lengthened day, but would be willing to (Holguín-Veras et al. 2005).

Among the most important considerations for implementation of night-time deliveries is the general effect on society, mainly increased noise in residential areas during off-peak hours due to delivery activities. Noise abatement techniques have been widely studied, and will be discussed later in this article.

Assuming that potential benefits outweigh the drawbacks discussed above for night-time deliveries, a corporate organization will typically not make such a significant strategic move without a justified reason to expect long-term financial benefit. The major cost savings associated with implementing night-time deliveries are achieved through lowered logistical expenses due to optimized utilization of vehicles and personnel. However, there are also many financial costs associated with the implementation of night-time deliveries, such as the potential expense of purchasing quiet vehicles and equipment, increased customer costs due to receiving deliveries at night, and shift premiums paid to off-shift employees (Forkert and Eichhorn n.d.). This article will provide a thorough analysis of the major benefits and drawbacks of implementing night-time deliveries, both financial and otherwise, to offer a framework for implementation at Nestlé Canada Ice Cream.

Our Approach

From the insights gained through the literature review, this study was refined to encompass two major subject areas: quantitative factors, including the requisite changes to the supply chain and the cost of implementation, and qualitative factors such as environmental and societal impacts.

The initial quantitative concern was to determine whether the implementation would be financially feasible. Customized routing software was created to simulate a heuristic approach that closely approximates Nestlé’s current routing methods. By varying the proportion of customers receiving at night and the relative increase in speed for off-peak travel vis-à-vis daytime travel, the software is able to estimate the number of routes and, ergo, the number of vehicles required to serve the network.
From a qualitative perspective, several conditions must be satisfied before a night-time delivery network can be implemented. Many of these factors are specific to the municipality or region. In this article, the noise, environmental, and societal considerations are explored, particularly with respect to the GTA. Together, this qualitative analysis and the analysis of outputs from the software form the framework for implementing night-time deliveries in the GTA.

A significant element of evaluating the potential impact of night-time deliveries was the consideration of qualitative factors affecting the feasibility of their implementation. The following section details the consequence of night-time deliveries on safety, sustainability, bylaws, truck noise, traffic congestion, and parking.

**Qualitative Factors**

**Safety**

There is not much literature related to safety conditions during night-time deliveries. Cavar, Kavran, and Jolic (2011) discuss the technologies of intelligent transportation systems for the planning of safe deliveries at night. Their context is that of “City Logistics,” the picking up and delivering of goods within urban areas, with the goal that these freight movements be environmentally friendly. Those authors emphasize advanced traveler information systems that would enable delivery personnel to better estimate their travel times, and perhaps reroute, in light of the reduced night-time congestion.

The article by Bjerkan, Sund, and Nordtømme (2014) refers to “Green Urban Distribution,” different words than employed by Cavar, Kavran, and Jolic (2011), but with essentially the same context and goals, in this case for Oslo, Norway. Bjerkan, Sund, and Nordtømme go further in that they focus on the stakeholders: carriers, consignees, and the municipal authorities. Survey results demonstrated that each of the stakeholder groups faced obstacles to successful implementation of night deliveries.

The present authors have identified additional safety concerns associated with implementation of such deliveries. Suggested resolutions are given here because they are not consequences of the routing analyses we performed.

One of the major issues facing implementation is the theft of product or cash. (Many deliveries of ice cream were to smaller, mom-and-pop convenience stores. Their preference for cash payment, a request accepted by
Nestlé, may have been somewhat related to various ethnic backgrounds. Night-time deliveries increase the risk of theft due to darkness and lack of crowds. As a result, implementation of a low-cash policy, or a switch entirely to automated transactions for night-time deliveries, should be instigated. This will minimize the chance of theft and potentially dangerous conflict for the driver. Additionally, procedures for unloading must be developed for the purpose of product safety. Keeping the door of the truck locked and adopting methodologies for delivery analogous to those developed by armored transportation companies will increase both driver and product safety.

Another important concern is associated with driver fatigue. If night-time deliveries are implemented in a company that previously operated only one shift, the firm and its distributors (if applicable) will need to determine how they will schedule the second shift of employees. To lessen fatigue and ensure a smooth transition to overnight work, organizations should try to minimize the frequency with which drivers change between the two shifts. Two common shift schemes that could be adopted are fixed shifts, where some employees work the day shift and some work the off-shift, and a rotating-shift schedule, where employees alternate between the two shifts for a set period of time (i.e., a one- or two-week period). The shift schemes and rotations should be applied to drivers, warehouse personnel, and any other relevant support staff.

Sustainability and Environmental Issues

A significant benefit commonly associated with implementation of night-time deliveries is the potential reduction in truck emissions. By shifting deliveries from the peak periods during the day, when roads are congested, to the off-peak periods, when travel is less interrupted, drivers will experience decreased idling and shorter travel times. Therefore, the amount of emissions produced by the same delivery trucks will be reduced if they switch to night-time operations (Forkert and Eichhorn n.d.). Additionally, some case studies have shown that the number of trucks can be diminished if an organization switches to night deliveries, due to the time savings gained by avoiding traffic (Finlay 2008). Clearly, fewer trucks performing deliveries would also lessen the emissions, although some researchers have found that truck emissions (with the exception of NOx) are likely to noticeably decline only if the number of trucks is decreased sufficiently (Campbell 1995).

Several studies provide estimates for these emission reductions in specific contexts (e.g., Sathaye, Harley, and Mandanat 2010). Piecyk and
McKinnon (2010) conducted research with a focus group and employed a large-scale Delphi survey. Based on those opinions, they developed three possible scenarios concerning freight-related energy consumption and CO₂ emissions. These scenarios were employed in a model to forecast road-freight movements and the corresponding emissions in 2020. Only if the “optimistic” scenario prevailed would the motor freight sector in the United Kingdom be on a trajectory to meeting the 80 percent CO₂-reduction targets set by the government for the overall economy by 2050.

Another area of environmental impact that is frequently overlooked by publications examining night-time deliveries is the effect on 24-hour-average pollution levels. Using atmospheric modeling, research in California demonstrated that the night-time stability of the atmospheric layer is always equal to, or more stable than, daytime stability. The enhanced night-time stability of the atmospheric layer could trap more pollutant particles than during the day (Sathaye, Harley, and Mandanat 2010).

However, there is greater probability of environmental benefit when off-peak policies target a particular time period, for example, the morning rush hour. Benefits are also more likely when traffic speeds in that peak period are relatively low, implying high peak-period emission factors (Sathaye, Harley, and Mandanat 2010). Recommendations for identifying and quantifying environmental issues are offered in our section on “Future Work.”

**Regulatory Concerns and Bylaws**

To address potential regulatory worries, the authors reviewed the current noise bylaws within the City of Toronto to determine their effect on off-peak deliveries. In city-designated “quiet zones,” the act of loading, unloading, delivering, packing, unpacking, or otherwise handling any containers, products, or materials is prohibited from 7:00 PM one day to 7:00 AM the next day, and all day Sunday and statutory holidays. A quiet zone is defined as any property within the municipality used as a hospital, retirement home, nursing home, senior citizens’ residence, or for other similar use (By-law No. 111-2003). In residential areas, loading/unloading noise is prohibited from 11:00 PM one day to 7:00 AM the next day (9:00 AM Sundays and statutory holidays). It is important to note that the City of Toronto By-law No. 111-2003 specifically defines supermarkets as routine unloading points, and as such, a stationary source of sound. Deliveries during the night would, therefore, be acceptable at these locations.
For Nestlé, typical residential areas within the city where the majority of their customers are located are considered “class 1 areas.” These are defined as “areas with an acoustic environment typical of a major population center, where the background noise is dominated by the urban hum” (By-law No. 111-2003). The maximum acceptable noise levels for a class 1 area within the City of Toronto are defined as 45 decibel (dB) during the night, between 11:00 PM and 7:00 AM. Refrigeration units, more commonly known as “reefer” units for half trucks such as those Nestlé uses, have been evaluated at 64 dB at 15 meters (Cvercko and Coulter 2009). That noise is evidently far greater than the acceptable limit during evening hours. However, Nestlé has begun procuring nonreefer trucks utilizing cold plate technology; these operate at sound levels within the acceptable night-time range.

There are, thus, several challenges that an organization will face regarding noise issues and violations when determining the feasibility of implementing night-time deliveries. Simple sound-level testing on the company’s fleet should be completed for more accurate analysis of the impact of noise bylaws within the urban center. Moreover, even if night routes may be implemented legally and fall within acceptable noise limitations, residents might still complain to the city about the continuous disturbance due to evening deliveries. The city could then launch an investigation to protect the best interests of its inhabitants. In all cases, it is imperative to advocate the benefits of this study to the population as a whole.

**Truck Noise**

Although truck noise is an important roadblock to successful implementation of night-time deliveries, the noise caused by a firm’s equipment used for daytime deliveries is not typically of major concern. Current equipment configurations may, thus, make it impossible to comply with noise bylaws at night. While delivery vehicles alone may not violate the noise restrictions, noise caused by delivery events in addition to the truck noise may result in a violation. Therefore, it would be prudent for the organization to consider, where possible, retrofitting the equipment that will be used for night-time deliveries to minimize the amount of noise caused by those deliveries.

Research related to noise emission includes SenterNovem (2002) and Finlay, Byrne, and Grimes (2008). A study on noise-abatement techniques for night-time deliveries (Finlay 2008) determined the delivery events that caused the majority of peak sounds: passage of pallets on the floor of the
trailer, positioning the tail-lift platform, crossing pavement to the delivery point, and stacking empty pallets inside the trailer unit.

As a result, equipment associated with the events above should be targeted to maximize noise reduction. Some examples of suggested equipment retrofits are: dampening material for floor and rollers of trucks, a hush-kit for steel roll-cages, and rubber or polyurethane wheels on pallet trucks (Finlay 2008).

It is recommended that the company examine the noise levels associated with its equipment and processes to determine where the focus of noise-abatement retrofitting could have the most impact, as those efforts may greatly increase their ability to successfully implement this project. Additionally, drivers should receive training that enhances their awareness and provides ways for them to proactively reduce high-noise activities at night. It is interesting to note that increasing the awareness of noise-reduction efforts (e.g., by attaching quality labels, indicating “quiet equipment” is used on trucks with low-noise equipment) can result in a positive impact on the project’s success (Forkert and Eichhorn n.d.).

Traffic Congestion and Parking

For organizations in urban centers, it is of significant concern that parking is scarce for vehicles attempting to deliver. As a result, many trucks are forced to park illegally to make a delivery; the cost of parking tickets is accepted by the firm as a cost of doing business (Han et al. 2005). Nestlé currently estimates their annual expenses for parking fines at several thousand dollars per delivery truck.

A one-month pilot study to test the feasibility of night-time deliveries was conducted in Manhattan in 2010, in which each truck that operated between 7:00 PM and 6:00 AM saved about $1,000 in parking tickets, along with decreases in delivery-route time and improvement in driver working conditions (Smerd 2010). Similar outcomes are expected from implementation in other urban areas due to increased parking availability during off-peak hours.

A final consideration is the aggregate impact of many distribution networks switching to night deliveries. If large numbers of trucks are removed from the road in the daytime, the decrease in congestion is expected to result in increased daytime travel speed, especially in urban centers. These aggregate effects may be significant if off-peak delivery becomes the norm. But it could also happen that, if daytime congestion improves, more people may choose to drive to the city center, tending to negate some of the benefits of fewer trucks.
Routing Simulation and Software

Customized routing software, which applies heuristic methods to achieve a feasible, “good” solution, was created for Nestlé. The intended use of that software was to allow Nestlé to estimate the number of routes needed and, by extension, the cost of operation for night-time delivery for various conditions. The primary focus of development was to provide software that could take as input a list of locations and as output a list of routes by applying various heuristics and iterating. For the purposes of analysis, algorithms were selected to replicate Nestlé’s current manual route-creation methodology. External validity of the model was established by comparing outputs for only daytime routes under standard conditions against empirical data provided by Nestlé. Models were then formulated to vary two parameters: the proportion of night routes and the night-time travel-speed multiplier. These models were run and the outputs analyzed to understand the impacts of those variables on night deliveries.

Nestlé Methodology

Currently, Nestlé uses mapping software to develop route clusters manually. The approach is as follows:

1. Find the outermost store location to first define a route.
2. Add nearby locations to the route until that route reaches a maximum number of locations based on truck capacity.
3. Repeat until all locations have been added to routes.
4. Using expert judgment, manipulate the routes to respect geographical and contractual constraints.
5. For each route, divide the locations into groups that receive on the same day based on customer requirements.

It is important to note that Nestlé does not specify a sequence in which the stores are visited. Rather, drivers are given a list for a particular day, and are free to deliver to these locations in any order. Therefore, routes—in the academic sense of the word—are not truly created. The actual sequence is determined by the driver based on knowledge of the area, traffic congestion, and loading-dock availability.

Software Design

Our software architecture implements a model-view-controller (MVC) architectural style. The MVC design separates the logic of the user interface from the “business logic” of the model itself. Changes to the way data
are manipulated (by the model) are, thus, decoupled from how they are displayed and stored.

The core of the program is a model object that represents the entire network of sites to be serviced using a list of locations and a list of routes. A configuration file defines values of a number of parameters, as well as the heuristics to be employed to reach a solution.

To run a model, the initialization phase reads input data and creates clusters of locations. Each cluster is simply an unordered collection of sites to be served by a single truck on one of six daily trips each week. Next, an iteration method swaps locations between clusters, sequences the locations in each cluster to create that day’s route, and resizes those clusters. The number of sites on a given day is limited by the total trip time. If a cluster cannot route all locations onto the six trips, the cluster is considered “over capacity” and marked for reduction. On the other hand, if all locations are assigned to day trips and the cluster has enough available capacity, the route is marked for growth. Clusters are resized, and the iteration step is repeated until feasibility is established (or a predetermined limit on iterations is reached). The last step finalizes route assignments and computes various metrics.

Traffic, Distance, and Time

To incorporate traffic volumes in the GTA, traffic was monitored over the course of five business days using real-time information from Google Maps (https://www.google.com/maps). The observed area was segregated into zones with each location assigned a traffic intensity factor from 1 to 5, with the value 5 representing severe gridlock, and value 1 denoting free-flowing traffic. (The traffic intensity factor, thus, reflects differences in average speeds achieved relative to the posted speed limit within the given area.) While an intensity factor is as much a qualitative as a quantitative measure, the factor assigned within each zone agreed with information obtained from Google Maps. Where possible, factors were also verified for consistency with traffic counts summarized by GTA civil engineers. The GTA network of Nestlé customers, with their assigned intensity factors, was used in the software model to indicate a preference for a higher-intensity traffic location to be placed on a night route.

In each case, the Euclidean distance in kilometers between any two points is found using the latitude and longitude of each location and a scaled conversion factor from degrees to kilometers for the region. For time calculation, a travel speed is obtained by dividing the base speed of 60km/h by the average traffic intensity of the endpoints.

\[
\text{speed} = \frac{\text{baseSpeed}}{\left(\frac{\text{trafficFactor location 1} + \text{trafficFactor location 2}}{2}\right)}
\]
Thus, between two locations with traffic intensity factors of 1, the average speed of travel is 60 km/h, whereas between two locations with traffic intensity factors of 5, the average speed of travel is 12 km/h. For travel at night, the speed is multiplied by a constant night speed-up factor between 1 and 1.5.

Choice of Heuristics

Drawing from academic literature, four heuristics were selected to emulate Nestlé’s routing procedure and were customized for simple, efficient implementation. We refer to the first heuristic employed in the initialization phase to create clusters as the “far-point” heuristic. It is a variant of that described by He (2011) and closely approximates Nestlé’s manual procedure. The (un-assigned) location farthest from the depot is the basis upon which each new route is created.

Locations are iteratively swapped between clusters using the second heuristic. It minimizes average distance between each location and the centroid of all locations on that location’s assigned cluster. The swap heuristic, referred to as “local max savings,” defines a neighborhood of the k clusters that are closest to the chosen cluster. It considers each pair of locations and swaps locations to maximize distance savings. This heuristic is nearly identical to that of Kanungo et al. (2002), which utilizes squared distance rather than linear distance.

The third heuristic performs the routing between sites. Because Nestlé’s methodology does not prescribe the sequence to visit locations, it was decided not to optimize the routes generated. Instead, the unimproved route distance was used as an approximation of actual distance traveled by Nestlé drivers. Based on trial runs, the sweep algorithm (Gillett and Miller 1974) was employed to obtain conservative distance estimates.

Finally, a resizing heuristic is applied to dynamically change the number of locations in a cluster. That heuristic, also responsible for adding or removing routes, is implemented as follows:

Step 1: If there are both routes with available capacity and routes over capacity, randomly assign a location from each overcapacity route to a route with available capacity.

Step 2: If there are routes with available capacity, no routes over capacity, and the model has not already failed to find a feasible solution with one route less than the current number of routes, randomly select a route and move all locations to the other randomly selected routes.
Step 3: If there are routes over capacity, and no routes with available capacity and the model has not previously found a solution with the current number of routes, create a new route, randomly select one location from each other route and move it to the new route.

Step 4: If there are no routes with available capacity and no routes over capacity, STOP.

This algorithm is actually “pseudorandom,” in the sense that the probability of a location or route being chosen is weighted by an appropriate parameter such as density, distance from centroid, or extraCapacity. This small modification greatly improves performance.

Night-time Routing

The selection of night routes is conceptually simple: The model forces all sites that can receive deliveries at night to do so. Night routes could be chosen via the same clustering algorithms employed in the initialization stage, considering only the feasible night-delivery locations. However, as routes have already been selected, there is an opportunity to locate night routes efficiently to obtain a good starting assignment.

The heuristic implemented attempts to develop densely clustered night routes by creating routes from day routes that have the greatest number of sites capable of receiving night deliveries. Each location that cannot receive night deliveries is swapped to the closest day route. This is repeated until all sites that can receive at night are on a night route.

Validation and Verification

Throughout development, the software and methodology were validated considering adherence to Nestlé’s current routing methodology, conformance with academic best practice, and the satisfaction of stakeholders. Early in the design process, close work with Nestlé route engineers ensured a full understanding of the methodology used to create routes. Extensive research was conducted into contemporary methods used in route creation. The “cluster-first, route-second” methodology (e.g., Laporte and Semet 2002) was selected due to the unordered nature of each day’s drops. Over the course of our study, regular contact was maintained between the authors and Nestlé to ensure the software accurately represented Nestlé’s routing methods.

To verify the software-generated results, values for the model’s number of routes and total distance traveled were compared to the values for Nestlé’s current delivery network. A feasible routing model was
created for all customer locations using 31 routes. In comparison, Nestlé currently serves all customers using 32 routes—a difference of 3.1 percent. The slight inaccuracy may be attributed to several factors (e.g., speed of travel or traffic factors used); however, this variation was considered small enough to lend credibility to the model’s numerical results for routes.

Nevertheless, there was a large difference between Nestlé’s estimate of total annual distance traveled and the software figure. But two major factors satisfactorily explain this discrepancy. Firstly, Nestlé builds daily trips based on the days its customers receive deliveries, whereas the model develops a day’s trips based on a distance-minimizing heuristic, hence underestimating the distance traveled. Second, the software uses Euclidean distance rather than rectilinear distance.

We briefly remark that the use of Euclidean distance was not considered to be problematic because:

- A large component of the distance driven was on a near-Euclidean path; the highway line-haul from a distribution center (DC) to the customer cluster would be close to a straight line.
- Actual distances driven would differ from rectilinear distances because, in many cases, drivers had to circle the block several times to find parking.

Therefore, to interpret the values obtained for distance in sensitivity analysis, it was necessary to consider relative changes from the baseline prediction. The distances were used for comparative purposes. Because we knew our distance figures were not likely to be 100 percent accurate, the most important consideration was that the same methodology be used so that we could compare relative changes.

**Results and Recommendations**

Models were employed to assess the impact of varying off-peak delivery adoption rates and the relative increase in travel speed during those hours. The specific locations that may receive during off-peak hours were randomly chosen. Table 1 summarizes the results of simulations.

In general, results indicate that a reduction of 3–10 percent of total routes may be attained by switching an appropriate proportion of deliveries to off-peak hours. The minimum fleet size is achieved for a 50–60 percent adoption rate, with the exact figure dependent on the relative speed increase. Figure 1 shows the number of routes as a function of the proportion of night deliveries for off-peak travel speeds at 1.25 times the daytime travel speed.
The total number of routes increases for very small adoption rates of off-peak deliveries, then decreases as the proportion becomes relatively equal. The total number of routes then slightly increases again as the balance shifts toward a greater number of off-peak deliveries, and tapers off as the entire network moves to night deliveries. The result is a distinctive W-shaped curve for the total number of routes because when only a small number of sites are either on day routes or night routes the average distance between locations grows significantly. Figure 2 shows a comparison of the total number of routes for different relative night-time travel speeds.

It is important to note that this does not necessarily rule out the possibility of operating off-peak deliveries for low adoption rates. Since

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randomness was incorporated in determining which locations accept night deliveries, those sites are spread out across the network. It may be cost effective to select a subset of these locations that are close together for a night route. Such a decision requires inputs such as a fixed cost of operating trucks, and variable costs per unit distance traveled, as well as an accurate distance calculation.

The most significant effect of implementing off-peak deliveries is the increase in truck utilization, which results in a decrease in the total fleet size. Figure 3 demonstrates the number of trucks needed as a function of the off-peak adoption rate.

There is clearly strong potential for decreasing fleet size by delivering off-peak. The number of trucks is at a minimum when close to an
equal proportion of locations are on day and night routes. Notably, the optimal proportion does shift closer to 60 percent as the relative speed at night increases, since more locations can then be served on a given route. However, this effect is minimal.

Collectively, results of the analysis indicate that there may be potential for cost savings if the decrease in fixed cost of operating trucks is greater than the increase in costs incurred per unit distance travelled. The optimal proportion, therefore, will vary based on the cost structure used. In general, it is necessary to have at least a 25 percent off-peak adoption rate if the number of routes operated is to decrease. Even so, cost savings will not be realized if the variable cost multiplied by the mean incremental distance is greater than the fixed cost per truck multiplied by the average decrease in number of trucks.

Recently, Nestlé surveyed a sample of approximately 180 customers in order to grasp their attitudes toward receiving night-time deliveries. Customers were asked whether they would be willing or able to receive night-time deliveries between the hours of 4 PM–8 PM, 8 PM–12 AM, and 12 AM–4 AM. In total, approximately 40 percent of those surveyed indicated that they would be willing or able to receive deliveries during one of those periods. These preliminary results indicate that the organization is well within its feasible range for implementing off-peak deliveries.

Overall, our findings show some possible cost savings if Nestle decides to implement night-time deliveries. The subsections below provide an overview of suggested measures they (or any organization) should follow.
to implement evening routes, a summary of qualitative advice, and areas for future work.

**Steps for Implementation**

To determine whether off-peak deliveries are a feasible undertaking, the following will be required to prepare the organization for implementation:

1. Complete a survey of a sample of key customers to assess the interest in deliveries at night.
2. Estimate the impact of safety, environment, traffic, and local bylaw regulations on off-peak deliveries.
3. Create a model to simulate evening routes, and do sensitivity analysis to learn the effect of various factors such as traffic speed and percentage of night-time customers.
4. If the above three steps indicate positive results, obtain the network of customers who are willing and able to accept deliveries at night.
5. Specify the day and night shift hours.
6. Renegotiate contracts with distributors (if applicable).
7. Calculate total anticipated cost versus benefits to obtain final figures.
8. Decide whether to proceed with implementation.
9. Define operational strategy for noise management and warehouse requirements.

Table 2 provides recommendations for mitigating the potential negative impacts concerning safety, environment, traffic, and noise.

**Future Work**

Considerations 1–3 below have been identified for potential future work in areas where the study scope has been limited due to lack of expert knowledge.

1. Research the impact of night-time deliveries on driver safety: There is currently limited literature available in this area. A possible future study could examine such areas as driver fatigue, possible traffic accidents, and risk of theft. (The latter will likely emphasize theft of product. Nestlé is now developing a system whereby night-time transactions will be electronic or prepaid.)
2. Study the environmental consequence of evening deliveries on emissions: Although there is fairly extensive literature pertaining to the general environmental effects of night-time deliveries,
there is a gap on how to quantitatively determine the environmental impacts. Sathaye, Harley, and Mandanat (2010) provide a framework for a comprehensive environmental assessment that involves six steps; these anticipate the ways that a given policy may influence traffic congestion, and the resultant emissions and pollutant concentrations.

3. Advocate the advantages to society of evening deliveries: As congestion in urban areas continues to grow at a rapid rate, alternative delivery solutions must be explored. To obtain the maximum benefit from night-time deliveries, awareness must be raised and a significant number of organizations need to implement the policy.

**Summary and Conclusions**

The primary objective of this research was to assess the feasibility of implementing off-peak deliveries in an urban center such as the Greater Toronto Area (GTA). Working with Nestlé Canada, the authors quantified the costs and benefits of modifying its ice cream supply chain to incorporate night-time deliveries, and provided a framework for the regulatory, conceptual, and inertial obstacles to implementation. Using Nestlé’s routing

<table>
<thead>
<tr>
<th>Area of Impact</th>
<th>Recommendations</th>
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<tr>
<td>Safety</td>
<td>1. Operators working at night should minimize the amount of cash that they carry.</td>
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<td>2. The organization should consider implementing a no-cash policy for night-time deliveries by switching all transactions to electronic, credit or prepaid.</td>
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<td>3. To increase product safety, a protocol for delivering product that includes risk identification and locking doors should be developed.</td>
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<tr>
<td>Environment</td>
<td>4. The company should consider investing in delivery vehicles with low-noise using sustainable energy when increasing fleet size.</td>
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<td>5. Impact on the environment from emissions will not be initially significant; however, the large-scale adoption of night-time deliveries will reduce the number of trucks on the road during rush hour periods. If the average vehicle velocity in the downtown core increases, there will be a large-scale positive impact on both society and the environment.</td>
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<tr>
<td>Traffic</td>
<td>6. Traffic volumes within the customer data set should be considered when creating night routes in order to focus concentration in the most congested areas.</td>
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<td>7. Additional analysis into the seasonal nature of traffic should be undertaken by the firm.</td>
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<tr>
<td>Noise</td>
<td>8. The organization should identify and examine the bylaws for its urban center.</td>
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<td>9. The company should do an internal study of the noise levels associated with its equipment and processes to determine whether they are bylaw compliant.</td>
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<td>10. The firm should attempt to retrofit current equipment in order to prevent unnecessarily large capital investments.</td>
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<td>11. Drivers should receive training to increase awareness and provide ways for them to proactively reduce high-noise activities at night.</td>
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methodologies and GTA customer data set as a case study, the authors developed customized routing software to determine the proportion of customers who must be willing to accept deliveries outside of normal working hours for the implementation to become financially feasible for Nestlé.

The routing software created applies heuristic methods to achieve feasible solutions for the Nestlé customer network in the GTA. The software logic was validated against Nestlé route engineering methodology, academic literature, and industry best practice. Analysis of a number of models, with varying proportions of locations assigned to night routes and night-time travel speeds, was completed.

Our major findings are contained in the sensitivity analysis of table 1. Whether the proportion of evening deliveries is small or is close to 100 percent, there is typically a 3–10 percent savings in the number of routes. The percentage saving in the number of trucks is often double that: Operation of a second shift permits a given vehicle to serve that many more customers. Note that the range of these percentage improvements holds for each level of the night speed factor (1.0, 1.25, and 1.5).

The total number of routes (day plus night) for each of the three night speed factors is given in figure 2 in terms of the proportion of night deliveries. These savings are conservative, perhaps slightly underestimated due to the random locations chosen for evening routes. We remark that some of the improvements are achievable not just because routes were moved from day to night, but may also be a consequence of using automated routing tools rather than a manual algorithm.

Figure 3 shows that the minimum fleet size occurs when around 50 percent of locations are served by day and night routes, respectively. (From Nestlé’s perspective, this target is preferable to a much higher percentage of night-time deliveries.) An implementation plan, in terms of safety, environment, traffic and noise, for any firm considering a switch toward evening deliveries, is presented in table 2.

Feasibility for implementing night-time deliveries occurs when the proportion of customers willing to accept such deliveries is approximately 25–80 percent of all customers. When only a small number of locations are either on day routes or night routes, the average distance between those sites grows significantly. Trucks have to travel much further between locations and they spend more time on line-haul as opposed to making deliveries. Therefore, it may be cost effective to select a subset of close-together sites for an evening route. Locations in the central business district or nearby could, thus, form a natural cluster.
The most significant effect of operating both night-time and daytime delivery is the increase in truck utilization, resulting in a decrease in the required number of vehicles. Collectively, results of the analysis indicate that there may be potential for cost savings if the decrease in fixed cost of operating trucks is greater than the increase in costs incurred per unit distance traveled.

Additionally, the authors conducted a thorough literature review in order to analyze the qualitative factors that must be considered prior to implementation. The major concerns addressed in this article include sustainability, regulatory issues, and congestion. GTA-specific recommendations for the factors analyzed are provided to create a general framework for ensuring the most effective implementation of night-time deliveries. These recommendations include the development of a safety plan, procurement of plate trucks, the addition of noise-abatement techniques, and the implementation of a noise-monitoring program.

We mention in closing that, while improved performance and reduced costs accrue to the carrier from night deliveries, the consignees assume an additional cost to accommodate those deliveries. Hopefully, the societal benefits will tip the overall balance in favor of the new schedule.

Note
This article was written as part of a fourth year undergraduate design project in Management Engineering at the University of Waterloo. The project was conducted by the first three authors, under the guidance of the fourth.

References


