# Off-peak City Logistics – A Case Study in Stockholm

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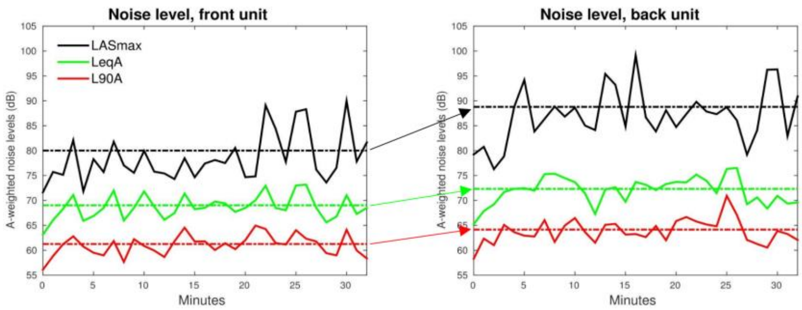


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## Abstract

Two heavy trucks have been operated in Stockholm city center during night time for e period of one and a half years. New technology has been tested: one the trucks was an electric hybrid with zone management and one was a PIEK certified biogas truck. The two trucks have been operated in different delivery schemes: on dedicated and one consolidated. The off-peak trial has been assessed in from four different perspectives: noise, transport efficiency, users and policy, and socioeconomic aspects. In addition, a literature survey has been performed.

Noise produced while travelling with the two trucks tested is not disturbing. The main challenge is noise produced during unloading, and in particular in areas where the background noise is low.

Transportation efficiency is improved from several perspectives compared with daytime deliveries: transport speed increased, fuel consumption decreased and service times decreased. However, one conclusion from the project is that it is challenging to compare daytime deliveries with off-peak deliveries for an individual truck, since the routing will be different depending on the time of the day even if the delivery points are the same. The reason is that the routing during daytime will be optimized to take congestion into account. Therefore, if general conclusions are to be drawn, data from more different trucks in different delivery schemes need to be collected and analyzed.

Stakeholder interviews showed that the most important benefits are increased efficiency, shorter travel and deliver times, higher productivity both for carriers and receivers, less environmental impacts and fuel cost savings, as well as better working conditions when trucks are moved from rush hours to off-peak hours. The most important social costs are increased noise levels and noise disturbances, additional staff, equipment and wage costs as well as higher risks in handling goods deliveries at night times, especially in the case of unassisted deliveries. In general, the benefits exceed the costs.

From the socio-economic analysis it is clear that the dominating type of external cost for daytime deliveries is contribution to congestion. This cost is reduced is nearly eliminated during off-peak deliveries. In addition, off-peak deliveries reduces $CO_2$ emissions, but even more the emissions of air pollutants and can therefore contribute significantly to improving local air quality. The cost of noise is more than twice as big as for daytime deliveries.

From the city's perspective the most important remaining challenges are related to 1) Noise measurements and surveillance, 2) general requirements and surveillance, for example concerning vehicles, fuels, and emission levels that are to be allowed, 3) The responsibility for potential additional costs related to infrastructural changes needed.

The overall conclusion from the project is that the benefits from off-peak deliveries exceed the costs. The results from the project suggest that the concept of off-peak deliveries is beneficiary in the Stockholm region, and the off-peak delivery program is suggested to continue and be scaled up to involve more vehicles and other types of goods. During the upscaling it is relevant to continue to study effects on transport efficiency, noise levels, and potential business barriers that may arise.


## Acknowledgement


The project has been funded by the Vinnova program "Fordonsstrategisk Forskning och Innovation", FFI (project no 2014-05598 and 2015-02338) and ended in December 2016. It has been coordinated by ITRL Integrated Transport Research Lab at KTH Royal Institute of Technology, and has been a collaboration with the City of Stockholm, Svebol Logistics AB, Lidl Sverige KB, Martin&Servera AB, K.Hartwall Oy AB, Scania CV AB, AB Volvo and Chalmers.

# Contents

# 1 Introduction

Goods transports is a significant part of the traffic in cities during day time. Congestion makes effectivity is low. One internationally tested improvement is goods deliveries during off-peak hours: evenings, nights and early mornings, so called Off-peak hours distribution (OPHD). OPHD can make distribution transports more efficient and increase profitability since congestion is avoided and vehicles can be used for an additional shift. OPHD also contributes to better usage of the street room. During 2014 Stockholm City took the initiative to start pilot tests with OPHD in a limited test in the city center. The two projects "Off-peak city logistics, research phase 1" and "Off-peak city logistics, additional project" were started to test new technology that can improve the OPHD and to assess the pilot and create knowledge about transport efficiency, noise, socio-economic effects and stakeholders experiences. In this report we present the results from these two projects.

# 2 Review & State of the Art

In this review of selected previous pilots peer-reviewed literature as well as reports are included, and has been complemented with a set of interviews to participants of previous pilots (i.e., New York City, Paris, London and Denmark) to gain a clear idea of the state of the art in off-peak hours (OPH) distribution. This review shows that shifting freight traffic to the OPH has been a popular initiative considered throughout the years by both the private and the public sector, and there seems to be a consensus on the benefits that these programs could bring about. A key aspect when implementing Off-Peak Hour Deliveries (OPHD) is understanding the decision process leading to delivery-time. Although there are multiple delivery arrangements, the literature shows that receivers' and the public sector's constraints prevail when defining the time-windows for deliveries (often overlapping with peak-hours), while carriers' operational decisions dominate the specific delivery-time within those time-windows. Accordingly, OPHD implementation approaches targeting a relaxation of receivers and the public sectors' constraints have showed better results, than the ones exclusively targeting carriers.

Another aspect that facilitates successful OPHD program is the type of schemes. Past experience revealed that the high cost of staffed OPHD led to unsustainable programs that were usually not pursued, while unassisted deliveries aided by technology and trust links between carriers and receivers led to successful programs. The case of OPHD at large traffic generators is interesting because despite its big potential and suitability, a limited amount of literature was found describing this practice.

As part of this review, representatives from previous OPHD pilots in different cities were interviewed. A summary is presented in

.

The review undertaken in this project shows that OPHD are suitable to tackle common urban challenges and bring about positive outcomes, such as travel time savings, fuel savings, environmental savings, and stakeholders' satisfaction. However, there are a number of challenges to be considered and addressed to ensure the success of OPHD, such as decreasing noise impacts, relaxing access and loading/unloading restrictions, and ensuring stakeholder engagement. The experience in different cities suggest elements to address these issues, such as:

*(i)* Introducing low noise technology, guides and standards, train the drivers on low noise practices, and create a noise measurement program to address noise issues

*(ii)* Discuss with local authorities and communities, initiate pilots, gain high levels officials support, identify and create awareness of existing and non-existing access restrictions, and coordinate restrictions across municipalities.

*(iii)* Develop the OPHD business case and market the program, design incentives program, foster unassisted and large traffic generators OPHD, and target the right industry sectors to encourage receivers' voluntary participation.

*(iv)* Initiate pilots and assess benefits, obtain funds to subsidize changes in technology, provide public recognition, and market the program to encourage carriers' participation

*(v)* Design an articulated stakeholder engagement program that includes the different stakeholders, such as receivers, shippers, carriers, local boroughs, residents, local store managers, business improvement districts, real state owners, local authorities and communities, and high level officials.

In essence, a significant progress has been made in this domain in the last decade. There is a handful of cities that have identified key factors to overcome the challenges of OPHD, and are considering this initiative as part of their Strategic Development Plans. In these cities, the body of research and the pilots have been successful to convince the transportation community, the key stakeholders and the decision makers that OPHD programs can assist in the quest of reaching more sustainable and efficient transportation systems. For the full review refer to (Sanchez-Diaz, Georen, & Brolinsson, 2016).

| City | | NYC | London | Denmark | Paris | **Stockholm** |
|---|---|---|---|---|---|---|
| Origin | | Research project | Olympic Games | Operators' interest | Public sectors' interest | **Research project** |
| motivation | Congestion | ✓ | ✓ | | ✓ | ✓ |
| | Economy | ✓ | | | ✓ | ✓ |
| | Safety | | ✓ | | | |
| | CO2 reduction | | ✓ | ✓ | ✓ | |
| Main challenges | Convincing parties to try | ✓ | ✓ | ✓ | ✓ | |
| | Engage municipalities | | | | ✓ | |
| | Engage carriers: invest on low noise | | | ✓ | ✓ | |
| | Coordinate receivers and carriers | ✓ | | | ✓ | ✓ |
| | Make business case | ✓ | | | | |
| | Control noise | | | ✓ | | ✓ |
| | Residents expectations | | ✓ | | | |
| | Ensure resources | | ✓ | | | ✓ |
| Main lessons and recommendation | | **Strong Industry Advisory Group** | **Need of a set of approved standards** | **Engage residents** | **Need of a set of approved standards** | **Need of a set of approved standards** |
| | | **Business associations support** | **OPHD not possible** | **Incentives for equipment** | **Collaboration (city and also site-by-site)** | **Collaboration (city and also site-by-site)** |
| | | **High level officials support** | **Collaboration (city and also site-by-site)** | **OPHD-electrification go together** | **Incentives for equipment** | **Engage carriers, receivers, local community and enforcement authority** |
| | | **Market the program** | **Neutral party to facilitate stakeholders meetings** | **Be willing to handle complaints** | **Engage carriers, receivers, local community and enforcement authority** | **Document and share good practices** |
| | | **Iconic business support** | **Pilots for multiple industries** | | **Document and share good practices** | **Invest on low noise technology research** |
| | | **Make business case** | **Make business case** | | **Invest on low noise technology research** | |
| Pilot success (1: low, 10: high) | | 9 | 9 | 3 | **9** | **pending** |
| Is OPHD part of City's plan? | | Yes | Yes | No | Yes | **Yes** |

*Table 1: Summary of learning points from previous OPHD pilots. (Sanchez-Diaz, Georen, & Brolinsson, 2016)*

## 3 The Stockholm Pilot

### 3.1 Motivation of the Pilot

Stockholm is a rapidly expanding city with strong economic growth. As the population of the city increases, so does the need for more freight deliveries. Despite a degree of infrastructure expansion, road congestion is expected to increase. For this reason, changes are needed to enable more efficient solutions in the existing transport system. By trialling evening and night deliveries when urban mobility is easier, more hours of the day can be utilised for freight distribution. A condition for this is that city residents are not disturbed and stringent noise restrictions are imposed on distributors and freight vehicles to prevent this. The aim is to reduce the number of deliveries to specific businesses that currently receive large numbers of deliveries during the daytime. The City of Stockholm also hopes that off-peak delivery will enable better urban mobility and efficiency during the daytime and better vehicle utilisation that will support the shift to clean vehicles. The City of Stockholm is enabling this specific pilot by giving one transport company a night delivery permit. In return the data collected will give crucial information on *if* and *how* a night ban potentially could be lifted in the future.

### 3.2 Description of the Pilot

In Stockholm there are regulations prohibiting deliveries with heavy vehicles in the city center between 22:00 and 06:00, to avoid night time noise. In 2014 the Stockholm Freight Plan 2014 – 2017 (Stad, 2014), an initiative for safe, clean and efficient freight deliveries, was released. With goals to improve accessibility and improve efficiency for urban freight transport, one of the activities was to conduct an OPHD pilot giving permissions for night time deliveries to two vehicles during 2015 and 2016. In parallel with the pilot a research project was started to assess the potential efficiency gains from OPHD for the private sector, evaluate the socio-economic benefits for society and to develop low-noise freight distribution solutions.

The OPHD pilot in Stockholm involved two different delivery schemes, one "dedicated" and one "consolidated" case. In the dedicated case one heavy truck delivering big volumes from a warehouse located 30 km outside of the city to three different grocery stores (Lidl stores) in the city center, resulting in three routes back and forth between the city and the warehouse each night. In the consolidated case, one truck delivered small volumes from a warehouse to hotels and restaurants, resulting in one or two routes per night in a multi stop delivering scheme. The two routes are shown in Figure 1. The trucks used in the pilot were specially designed to reduce noise and pollution.

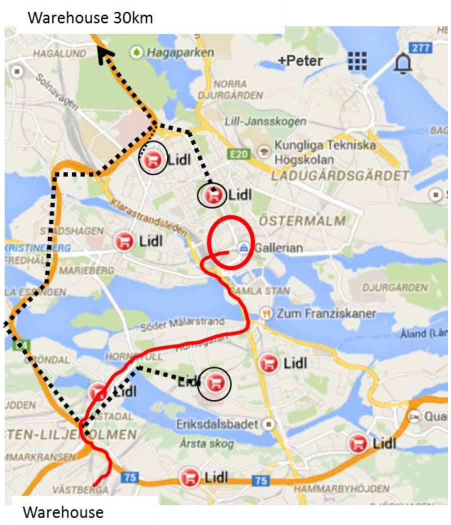



*Figure 1 The two delivery schemes in the Stockholm pilot. The "dedicated" case (black) and the "consolidated case (red)*

To have data from the normal case (without OPHD deliveries), the same delivery tasks were also performed during daytime for one week. One main challenge here is that the delivery routes are completely different during daytime delivery. Especially in the dedicated delivery case, since long delivery times due to congestion makes it necessary to use two trucks to perform the same delivery.

GPS data, fleet management data and noise measurements has been continuously collected from the trucks.

# 4 Technology Solutions

## 4.1 Electric Hybrid with Zone Mgmt

The night deliveries the three Lidl stores in the dedicated delivery scheme were performed with a Volvo FE Hybrid (Euro5). This truck is a three axle rigid 26 ton with a hybrid driveline with brake recuberation, which means that the electric motor can be charged during propulsion both from the internal combustion engine but also by recovering brake energy. Maximum braking power is 90 kW and maximum propulsion power is 120 kW.

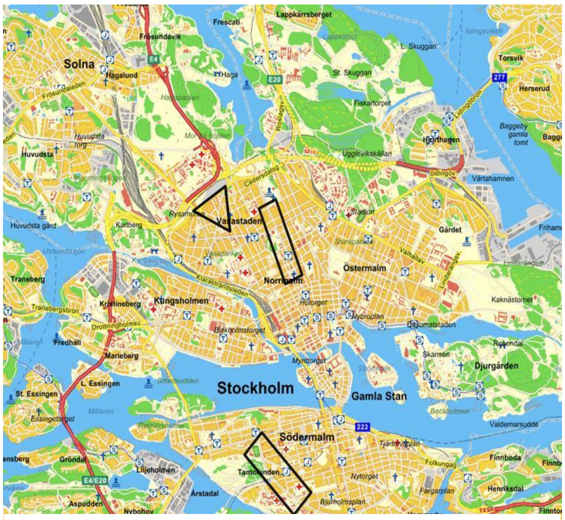



*Figure 2 The three "quiet zones"*

Three different “quiet zones” were arranged in the near vicinity of the stores according to Figure 2 below. Once inside this zone, the driveline automatically switched over to electric drive. The zones were governed by the trucks own GPS-position. Delivering groceries at night in areas of the city where it is normally very quiet at night is much more challenging than close to boulevards with dense traffic.

The challenge with night deliveries is not only to minimize engine noise levels but also to mitigate noise from fork lifts, pavements and thresholds in the streets as well as noise from rolling cages.

Electric drivelines can be beneficial for delivering at nights in quiet areas of the city but does not necessarily have much effect close to busy streets (like Sveavägen). The biggest advantage is the environmental effect on particles and NOx.

## 4.2 Biogas Truck

Scania prepared a gas driven truck to fulfil the PIEK standard. Long time recording in Stockholm traffic has been performed with the truck both with and without the PIEK measures.

## 4.3 Unloading noise

Besides the vehicles the unloading is a source of noise during goods deliveries. In the project several ways to mitigate this noise was tested. First, pavement was equipped with a special asphalt to reduce noise. Second, silent roller cages were used. Third, a special tool, the Silence Advisor, was developed and tested. The silence advisor consists of a microphone and a display with diodes that should be placed so that the user can see them. The microphone collects sounds, and when preset thresholds are passed the diodes lights up to give feedback to the user.

# 5 Evaluation of OPHD – methods & application to Stockholm Pilot

## 5.1 Noise

### Methodology

There are three main configurations where the noise emissions need to be evaluated in the context of off-peak hours deliveries and their potential nuisance for the citizens: noise emissions outside of the city center, i.e. approaching the city via some type of limited-access road, noise emissions while driving in the city, and noise emissions while the vehicle is stationed, upon delivery (loading and/or unloading).

For the purpose of assessing all three areas, it was decided to equip the vehicle with noise monitoring systems which would then place the focus at the source rather than the receiving end of the noise disturbances. For practical reasons mostly due to time constraints for this pilot study, a commercial off-the-shelf technical solution was implemented using noise monitoring systems from Sonitus Systems (http://www.sonitussystems.com). These monitoring devices can measure sound pressure levels as equivalent level LEQ; statistical noise levels L05, L10, L50, L95, and peak sound pressure level LMAX. Both slow and fast time averaging are available, as well as A- and C- filters for the weighted dB scales. These devices are however not providing information in terms of the frequency content of the measurements (e.g. in the form of spectrograms), and are limited to minute-averaged data as the lowest time-averaging period. The methodology adopted intends to offer an alternative to the stationary approach used for example in the construction of noise maps in the form of heatmaps, by shifting the emphasis to the source. The impact at the receiver end can then be obtained after post-processing the source-related data.

In order to be able to adapt the noise monitoring to two essentially different configurations, i.e. driving or delivering conditions, the two trucks taking part in the pilot study are equipped with two such monitoring devices each, as illustrated in Figure 3 for the Volvo truck.


*Figure 3: Noise monitoring setup illustrated on the Volvo truck: back and front*

One such unit is mounted at the front, in between the cabin and the cargo space, on the driver's side, and the other unit is mounted at the top rear of the cargo space, on the roof, on the opposite side to the driver. Beside the obvious benefits of having a Sonitus unit at the front (related to engine noise) and another Sonitus unit at the back (related to delivery noise), the location of these units is assumed to provide further insight into the noise emission by the combination of their respective measurements. In particular, the separation of the two units is assumed to allow for an evaluation of the background noise, or at least provide a reference noise level further away from the source.

This idea and original assumption is schematically presented in Figure 4.

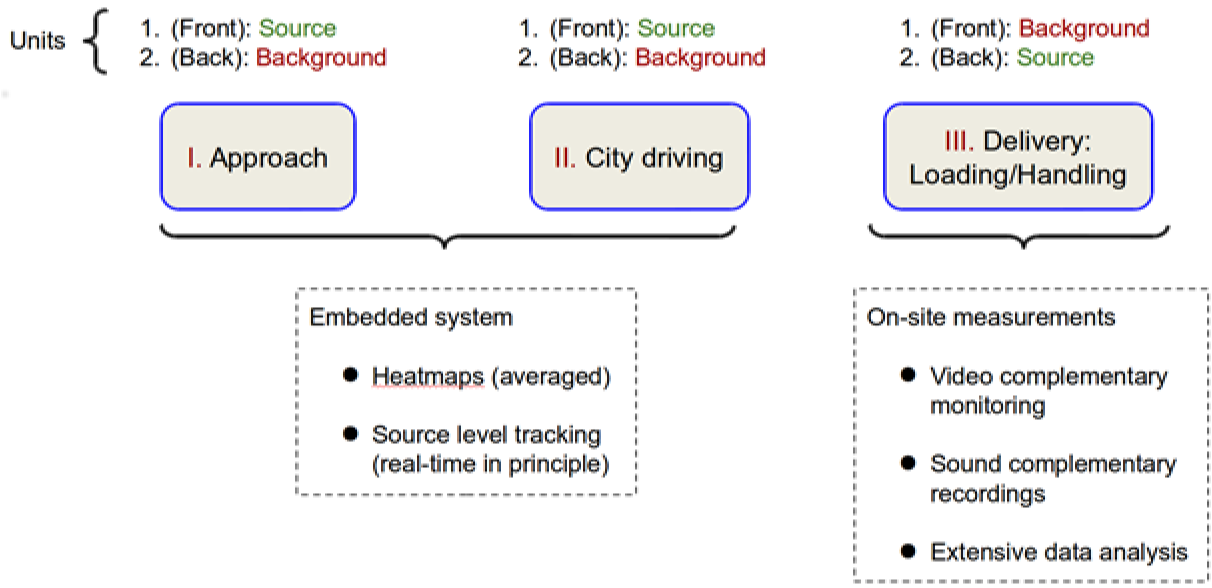



*Figure 4 The idea behind the noise measurement setup*

For example, regarding delivery noise, which is anticipated to be of specific concern in this pilot study, the back Sonitus unit, close to the source of delivery noise, may reflect the delivery noise emissions, while the front Sonitus unit may provide an information of the surrounding noise conditions at the time of delivery. The post-processing of these two information may thus provide an indication of the actual impact of the delivery noise on the environment. A similar assumption may be formulated for the driving condition by exchanging the purpose of the front and back Sonitus units as source and reference respectively.

The following set of measurements, analyses and simulations are conducted:

- Noise emission measurements at Scania: these involve some directivity patterns of noise radiation around a diesel truck, including both measurements with a controlled source (dodecahedral loudspeaker) and measurements of the engine noise.

- Analysis of the methodological assumptions founded on the use of two Sonitus units, and validation of the levels measured by these units against the experimental data produced at Scania.

- Monitoring of the engine noise emission by the Sonitus units, post-processing in the form of noise emission heatmaps.

- Monitoring and analysis of the delivery noise emissions, including deriving a qualitative criterion for noise annoyance potential, a dominating-frequency analysis, and the associated conclusions.

- A range of simulations to support the experimental results.

Results

Vehicle noise emission measurements at Scania Technical Center, Södertälje

Among the wide range of measurements conducted at the Scania Technical Center (more details can be found in the full acoustic report), Figures 6-8 present the directivity patterns for three different configurations of engine noise, idling or running 50% loaded.

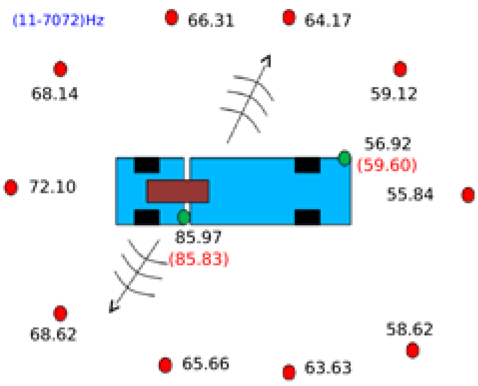



*Figure 6: Directivity pattern from engine noise, SPL, A-weighted, engine idling.*

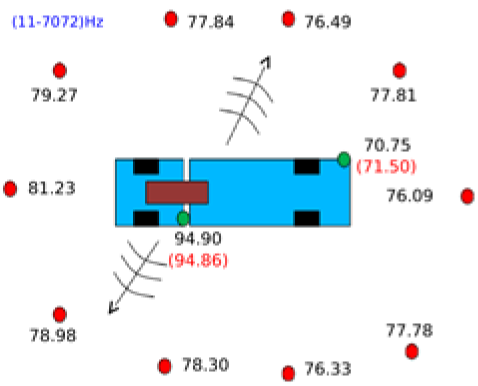



*Figure 7: Directivity pattern from engine noise, SPL, A-weighted, Gear 9 at 1200 RPM (38 km/h), 50% load.*

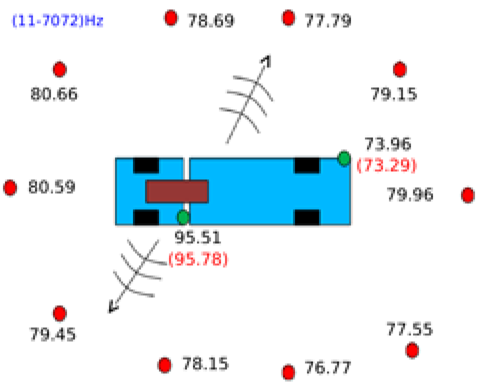



*Figure 8: Directivity pattern from engine noise, SPL, A-weighted, Gear 9 at 1500 RPM (48 km/h), 50% load.*

The values in red correspond to the values measured by the Sonitus monitoring devices, thus validating their calibration in a controlled environment. While the back unit slightly underestimates the noise level perceived 3-4.5 m away from the truck at 1.5 m above the ground (i.e. positions of the microphones), the front microphone may be used for the modelling of an equivalent source, or for comparative noise emission analyses. Note that the back Sonitus unit will not be able to pick-up much of the surrounding noise below around 20dB lower than the front microphone level in driving conditions.

Vehicle noise monitoring, noise maps for inter-day comparison

Figure 9 illustrates a typical evening route of the Volvo truck, approaching the city, driving in the city (switching to hybrid), visiting two delivery locations (a noisy area and a quiet neighbourhood), and departing the city.

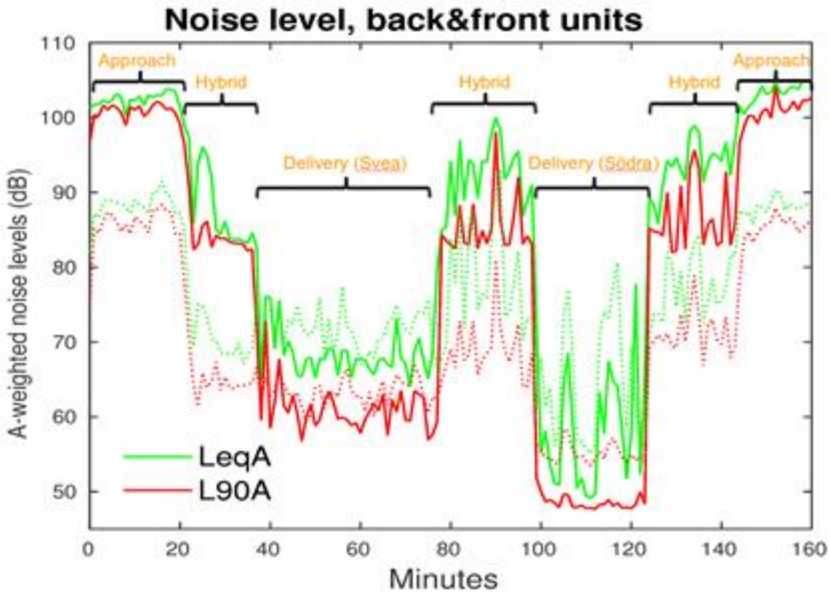



*Figure 9: Illustration of the noise level for the back (solid lines) and front (dotted lines) Sonitus units: approaching*

The impact of the Hybrid Technology for noise reduction purposes, even though not optimally functioning during this specific journey (this highlights the monitoring capability of the proposed approach), is manifest: between 10 and almost 20 dB noise reduction for the front and back units both capturing vehicle noise emissions.

For qualitative inter-day monitoring of vehicle noise emissions, a tool has been developed which allows to create noise maps on Google Maps such as those presented in Figures 10-11, corresponding to ¾ of the journey presented in Figure 9.

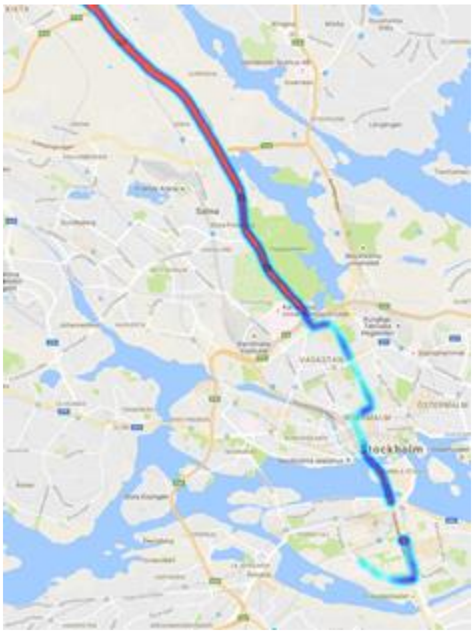


*Figure 10: Visualization of vehicle noise emissions, approaching and inner city, sample day 1.*

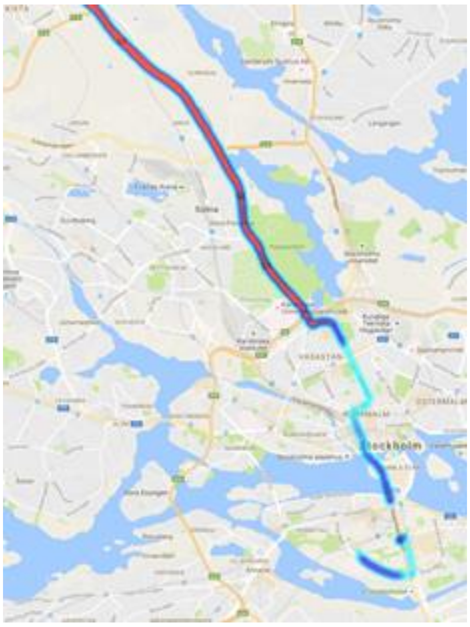


*Figure 11: Visualization of vehicle noise emissions, approaching and inner city, sample day 2.*

The benefit of switching to hybrid mode in the city is immediately noticeable with such visualizations, which may be combined with existing noise mapping of the city in order to specifically address the local impact of OPHDs.

Delivery noise monitoring: indicator derivation for delivery noise impact

The delivery noise impact is assessed by a differential estimate between the back and front Sonitus units, the rationale being that if both units measure approximately the same levels, these correspond to surrounding noise (or background noise) rather than the impact of delivery noise. Figure 12 illustrates such a situation where the delivery noise is masked by the surrounding noise, and may therefore not present an annoyance in itself for the neighbour residents.

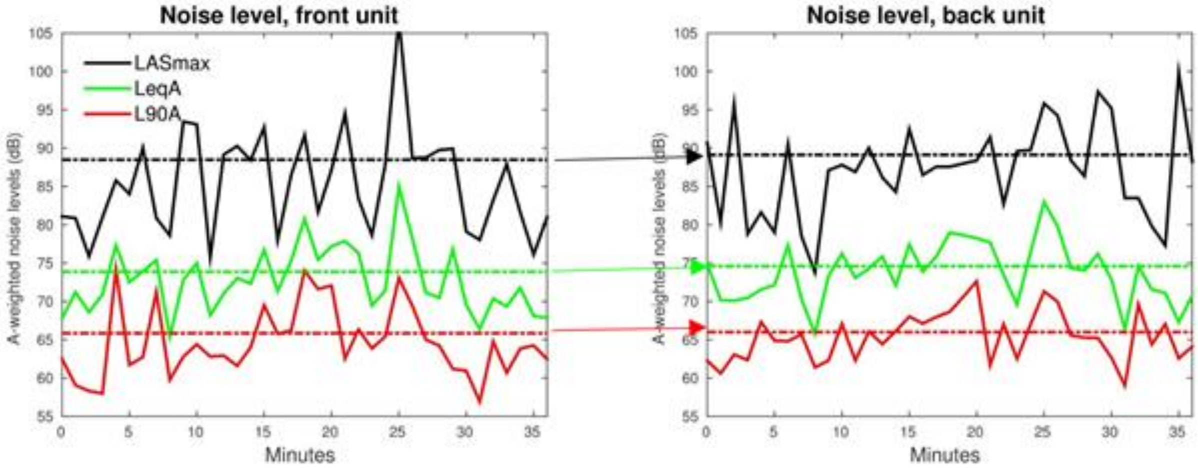



*Figure 12: Illustration of a situation where the delivery noise is masked. The dot-*

The left plot corresponds to the back unit, close to the source of delivery noise. The figure on the right, corresponding to the front unit, is then used for reference levels taking into consideration the noise level without the presence of the delivery. Averaging the measurements over the duration of the delivery and comparing these average levels gives an indication of the overall noise impact of the delivery. Figure 13 illustrates a case, at the same location for another delivery day, where even though the levels recorded by the back unit are similar, the front unit levels are generally lower (i.e. reference noise levels), thus suggesting more annoyance linked to the delivery for the neighbour residents.

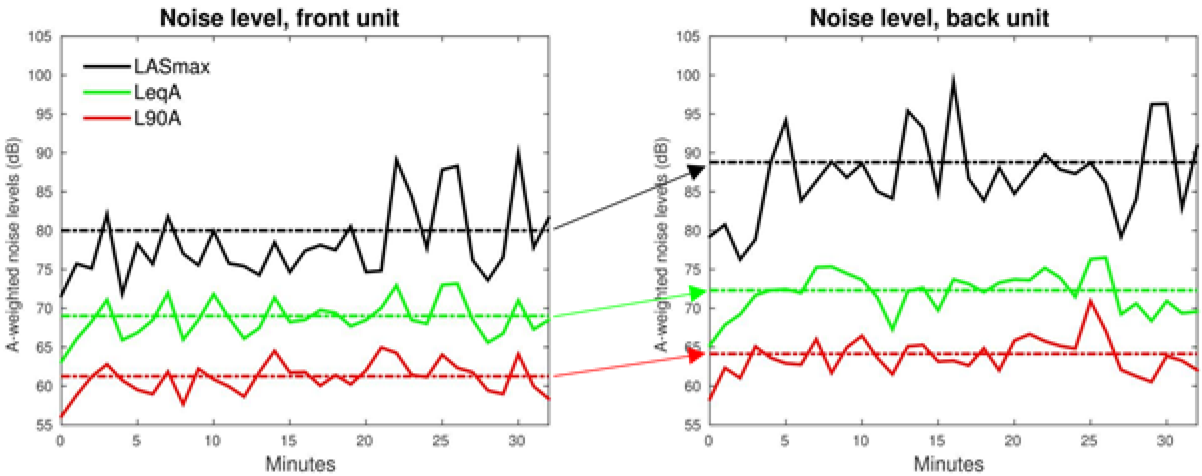



*Figure 13: Illustration of a situation where the delivery noise may present an annoyance. The dot-dashed lines correspond to level averages. (Delivery at Lidl*

This differential approach may be expressed in the form of an indicator reflecting the annoyance potential of a given delivery, e.g. as a summation of the back-to-front difference of average levels for the L90, Leq, and LMAX A-weighted levels. Taking this approach over a full month for the noisy location at Sveavägen and the quiet location at Vanadisplan, provides a striking contrast as to their suitability for night-time deliveries. Figures 14-15 present those results, where the indicator (cumulated back-to-front difference of average levels for the L90, Leq, and LMAX A-weighted levels) is plotted as a function of the delivery ID, i.e. the indexed day of delivery (about the same time every day of delivery).

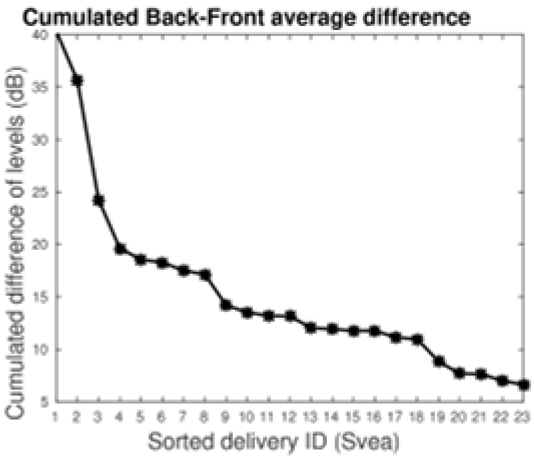



*Figure 14: Delivery noise impact indicator, deliveries at Sveavägen for the month of April 2016.*

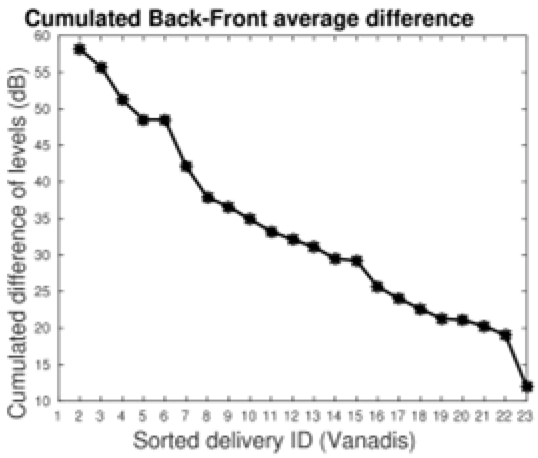



*Figure 15: Delivery noise impact indicator, deliveries at Vanadisplan for the month of April 2016.*

Note that the level in Figures 11-12 is nothing physical but a scaling indicator which allows to compare the noise impact of the different deliveries. They are sorted by most annoying to least annoying. Setting an arbitrary threshold of noise level acceptance for these deliveries between 20-25 for the indicator would imply that 2-3 deliveries (8-13%) at Sveavägen would be unacceptable while 16-20 deliveries (69-87%) would be unacceptable at Vanadisplan. This highlights the prime importance of the choice of location for night-time deliveries, especially when considering that the deliveries at Vanadisplan are much quieter (technological solutions and configuration of the delivery location) than the ones at Sveavägen.

### 5.2 Transport Efficiency

Methodology

We propose a general methodological framework for evaluating the transport efficiency impacts of transferring goods deliveries from daytime to off-peak hours in urban areas. Four aspects of transport efficiency are considered in this study:

- Driving Efficiency

  Driving efficiency considers the efficiency with which goods can be delivered from warehouses to delivery points. Average speed is the most straightforward indicator for driving efficiency. In a congested urban network, delivery vehicles are forced to travel at low speeds and in stop-and-go conditions that significantly increase the time spent driving to each customer and reduce the number of customers that can be served during a shift.

- Delivery Reliability

  Delivery reliability concerns the variability of travel times and arrival times to the delivery points. High reliability indicates good network performance, and carriers need to allocate less buffer time in order to arrive to the customers on time. Further, the customers do not need to keep larger stock in case the expected deliveries do not arrive on time.

- Energy Efficiency

Energy efficiency is measured by fuel consumption per driven kilometer. This indicator not only describes the effects of congestion (unnecessary stop-and-go), but also disturbances such as traffic lights and pedestrians. Energy efficiency is not only critical from carriers' perspective, but it is also an important societal and environmental aspect as it is closely tied to emissions of $CO_2$ and other pollutants.

- Service Efficiency

  Service efficiency is examined using the indicators of service time per delivery stop, service speed, and number of service stops versus driving time.

Different data sources are employed to evaluate the four aspects of transport efficiency:

- Fleet Management System Data
- GPS Data
- Logistics Data

The three different data sources provide all necessary information for computing the above-mentioned indicators of transport efficiency. The methodology for assessing the transport efficiency of off-peak deliveries is shown in Figure 16.

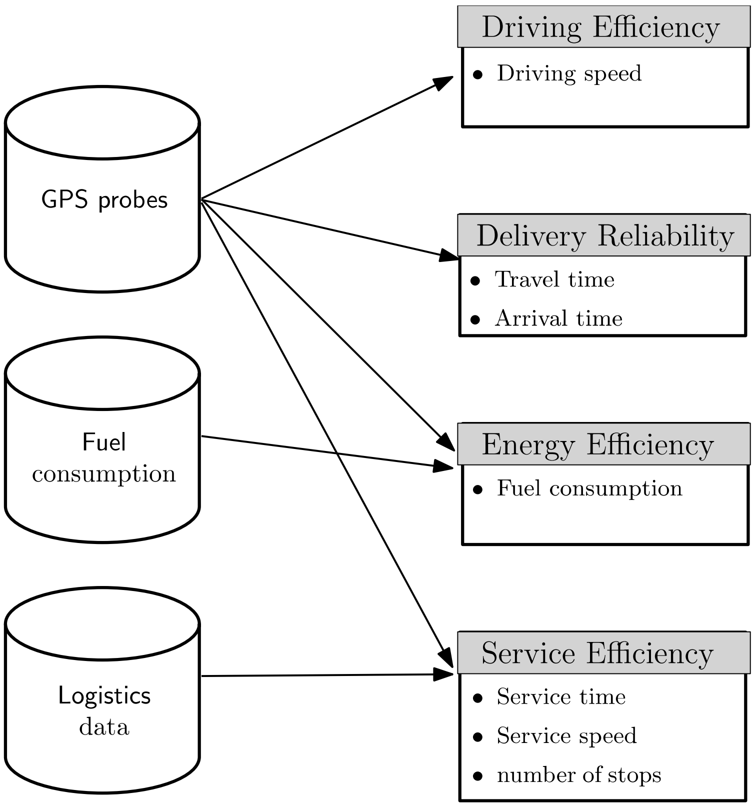



*Figure 16 Flow chart of transport efficiency evaluation using different data sources.*

Evaluation Design

The two trucks made delivery tours with different schemes.

<u>Truck A (Dedicated Delivery to a Single Customer)</u>

Truck A made dedicated deliveries of big volumes to specific receiver in every trip; the delivery route is shown in Figure 17 (a). During the pilot study, three grocery stores in Stockholm inner city changed their delivery routines from daytime to off-peak hours on weekdays. The three stores are located at

Sveavägen (Store 1), Sankt Eriksgatan (Store 2), and Södra Station (Store 3), and are displayed at the lower right corner in Figure 17 (a) as a red circle, a green star and a pink cross, respectively.

In order to generate the comparison data for daytime deliveries, artificial daytime delivery trips were carried out with truck A during a data collection period between May 9$^{th}$, 2016 and May 22$^{nd}$, 2016. During this period, truck A traversed exactly the same delivery routes to the three stores as during the off-peak hours. In total, five delivery trips were made to each of Store 1, 2 and 3 during daytime, and 10, 10 and 9 trips in off-peak hours were made to each store during the measurement period, respectively. Data from these trips are used in the analysis in order to evaluate the transport efficiency indicators.

Truck B (Consolidated Delivery to Various Customers)

Truck B made consolidated deliveries of small volumes to several customers in the city in one tour both during daytime and off-peak hours (Figure 17(b)). The warehouse is located in the south of Stockholm and shown as a red diamond in Figure 17 (b), and the customers are different restaurants and hotels that are spread out in the entire Stockholm region. Due to the business characteristics of the customers, the delivery points of truck B were different from day to day.

The delivery routes of truck B varied from day to day, which means it is not possible to compare the transport efficiency indicators along the same delivery routes as with truck A. On the other hand, the delivery routes cover the entire Stockholm region. The FMS data provided by the truck manufacturer were available on a continuous basis and give an overall picture of the traffic conditions at different times of the day. The FMS data include timestamp, odometer, fuel level, instantaneous speed, GPS coordinates, ignition status, and driver change. The data were recorded at the frequency of one record per minute. Thus, the FMS data of truck B are used to study the general transport efficiency between daytime and off-peak hours in the Stockholm region. The daytime period is further divided into four intervals: 6:00 – 10:00, 10:00 – 15:00, 15:00 – 18:00, and 18:00 – 22:00. FMS data from a 10-month period (in total 244 days) between September 24$^{th}$, 2015 and July 24$^{th}$, 2016 are used in the transport efficiency evaluation.

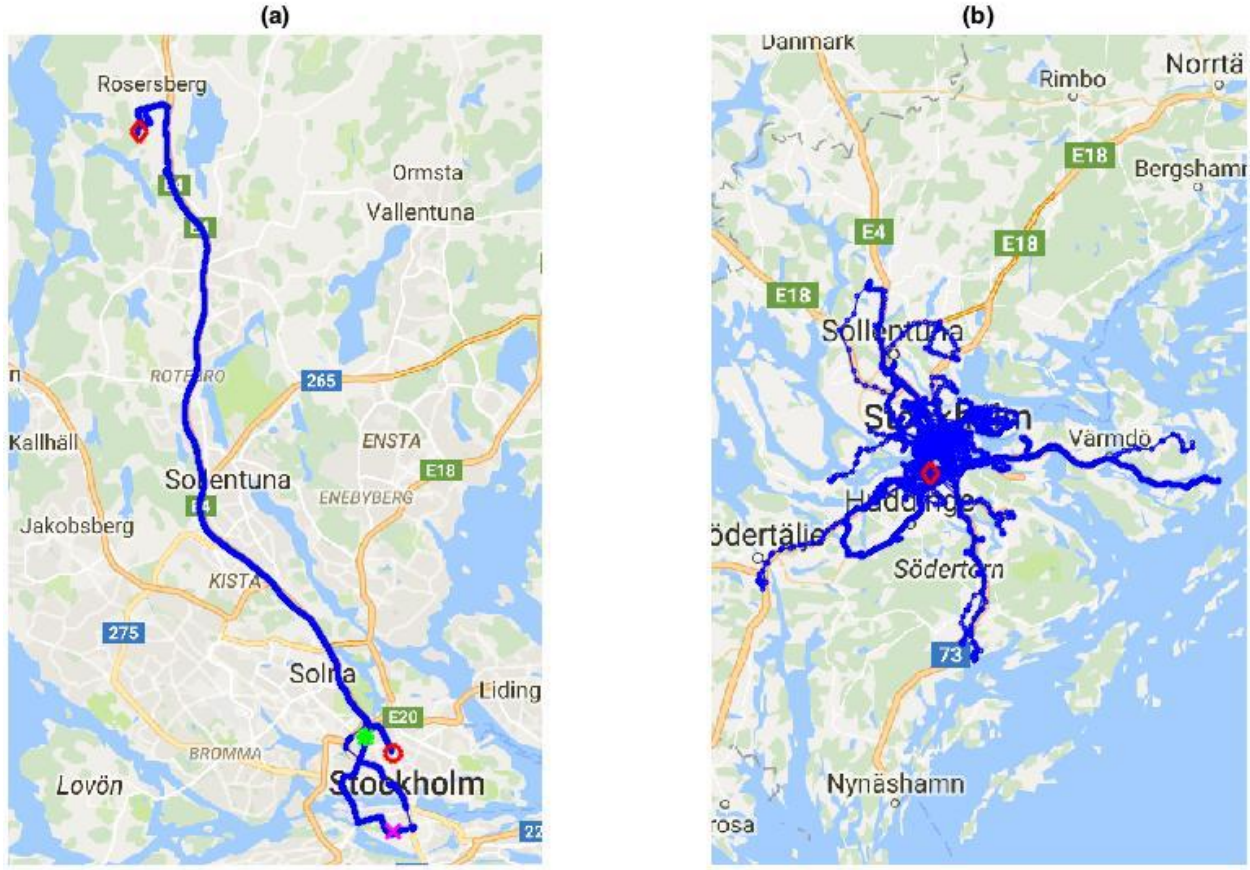



*Figure 17 Delivery routes of the two off-peak trucks. (a) Truck A making dedicated deliveries. (b) Truck B making consolidated deliveries.*

## Results

Table 2 summarizes the evaluation of the four aspects of transport efficiency for both truck A (dedicated deliveries) and truck B (consolidated deliveries) in the Stockholm pilot. The distribution of driving speeds, arrival time, fuel consumption and service efficiency of both trucks are depicted as box-and-whisker plots in Figure 3, 4 and 5.

**TABLE 2 Transport efficiency indicators.**

| Truck A (dedicated delivery) | | | | | | |
|---|---|---|---|---|---|---|
| | Off-peak Delivery (10PM-6AM) | | | Daytime Delivery (6AM-10PM) | | |
| | Store 1 | Store 2 | Store 3 | Store 1 | Store 2 | Store 3 |
| **Driving Efficiency** | | | | | | |
| Average speed (km/h) | 62.08 | 64.71 | 58.95 | 46.00 | 64.37 | 50.74 |
| **Delivery Reliability** | | | | | | |
| Travel time (minutes) | 31.23 | 29.02 | 41.21 | 44.17 | 29.55 | 44.67 |
| Standard deviation of travel time (minutes) | 2.28 | 1.80 | 5.29 | 12.00 | 3.05 | 2.37 |
| **Energy Efficiency** | | | | | | |
| Fuel consumption (liter/100 km) | 28.92 | 28.22 | 28.90 | | | |
| **Service Efficiency** | | | | | | |
| Service time (minutes) | 46.44 | 46.17 | 51.66 | | | |
| Service speed (TPE/h) | 27.63 | 20.90 | 21.39 | | | |
| Truck B | | | | | | |

| (consolidated delivery) | | | | | |
|---|---|---|---|---|---|
| | Off-peak Delivery 22:00 - 6:00 | Daytime Delivery 6:00 - 10:00 | Daytime Delivery 10:00 - 15:00 | Daytime Delivery 15:00 - 18:00 | Daytime Delivery 18:00 - 22:00 |
| **Driving Efficiency** | | | | | |
| Average speed (km/h) | 22.16 | 21.17 | 21.73 | 13.96 | 23.22 |
| **Energy Efficiency** | | | | | |
| Fuel consumption (liter/100 km) | 26.16 | 28.64 | 27.00 | 30.96 | 24.57 |
| **Service Efficiency** | | | | | |
| Service time (minutes) | 14.35 | 18.45 | 14.36 | 11.30 | 11.97 |
| Number of service stops per driving hour | 3.73 | 3.54 | 3.73 | 7.11 | 2.07 |

The evaluation of the pilot study showed that off-peak deliveries in general have better performance regarding driving efficiency, delivery reliability and energy efficiency. The driving speed on the same delivery route in off-peak is approximately 31% higher than in the morning peak using the data from the truck making dedicated deliveries, and the driving speed in the entire urban network in off-peak is ca. 59% higher than in the afternoon peak based on data from the consolidated deliveries. However, no definitive conclusion can be drawn regarding service efficiency aspect using the dataset from the pilot project.

Moreover, the evaluation highlighted that the delivery route of the truck making consolidated deliveries is already adjusted in order to meet customers' demand and at the same time avoid congestion. The comparison conducted in the case study is between a regular delivery route in off-peak and an adjusted route during daytime. Thus, better performance in transport efficiency for off-peak delivery is expected while using the same delivery route.

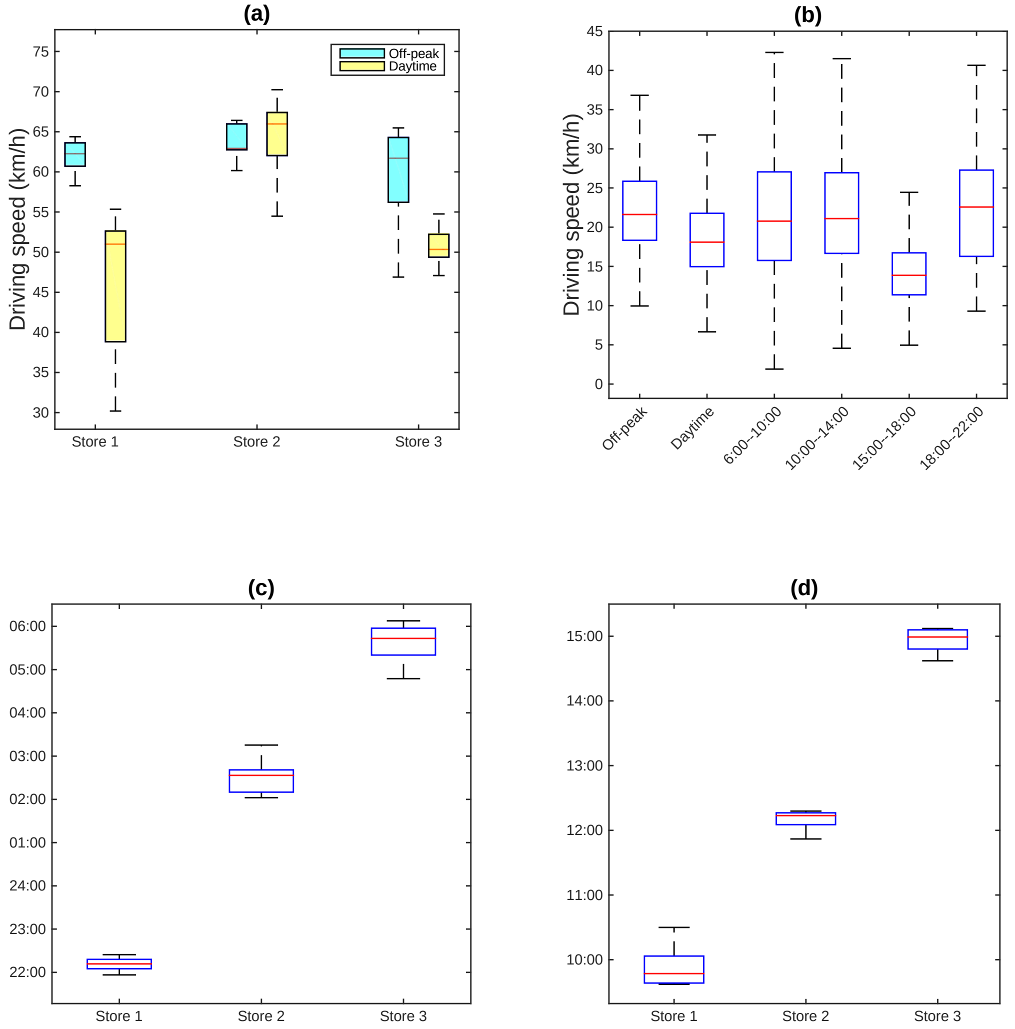



*Figure 18 Driving speeds of truck A (a) and truck B (b), and arrival time at the stores during off-peak hours (c) and daytime (d).*

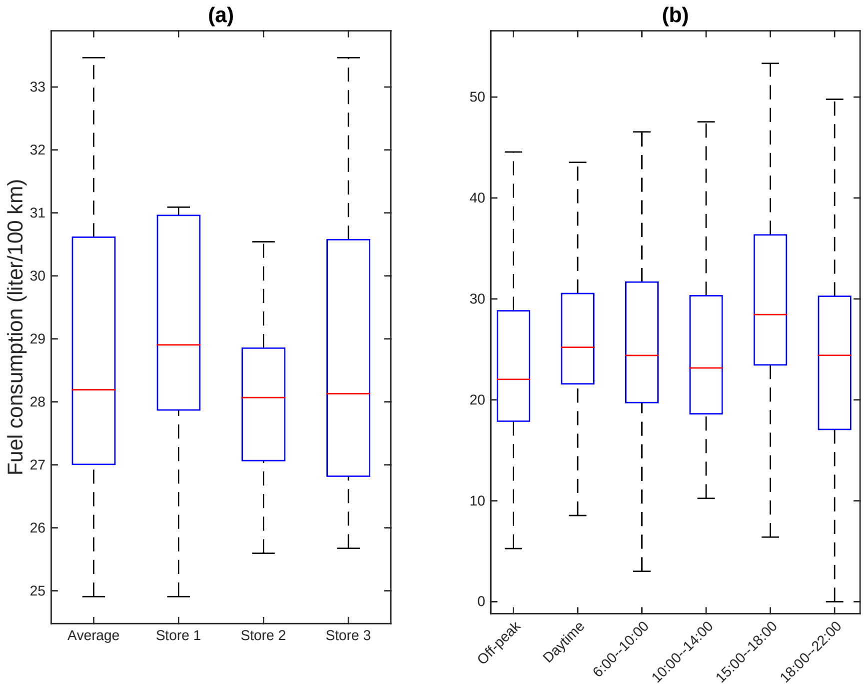
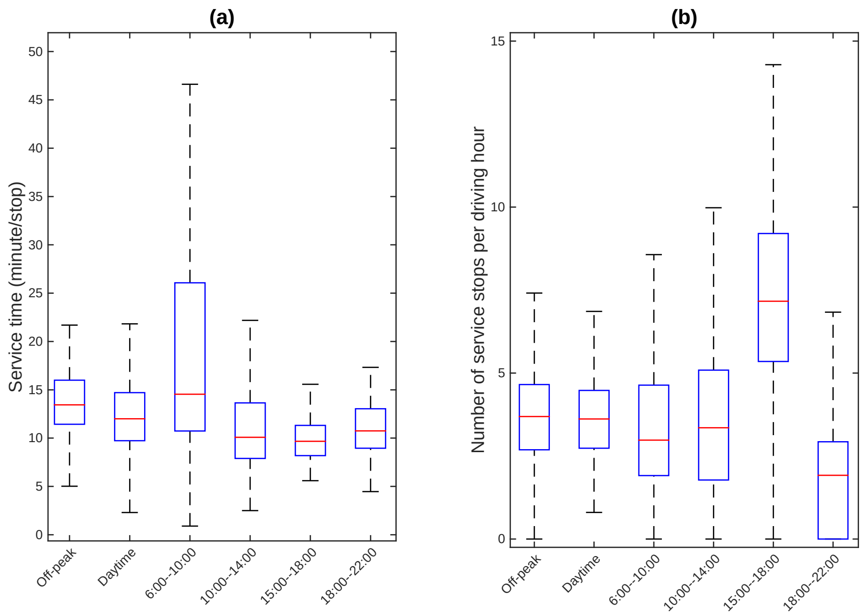



*Figure 19 Fuel consumption of truck A (electric-diesel hybrid) (a) and truck B (gas).*



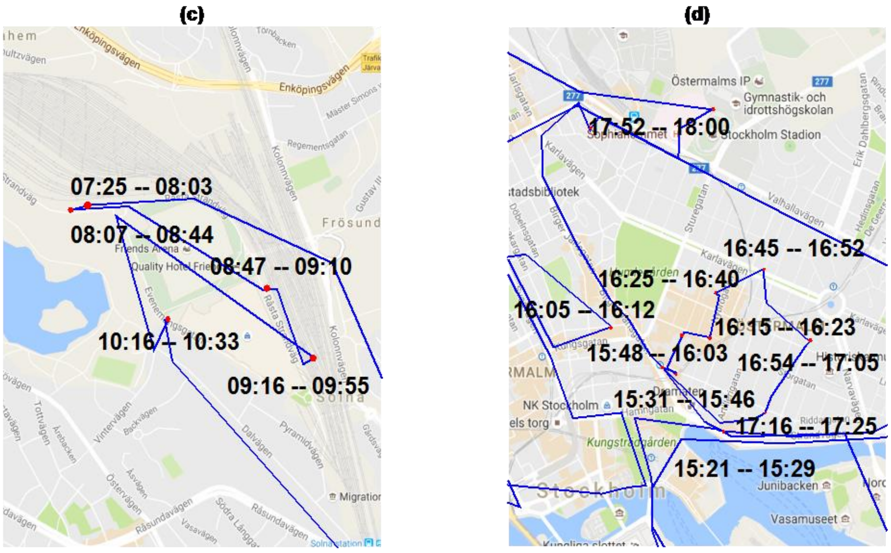



*Figure 20Service efficiency of truck B. (a) Service time at the stops. (b) number of service stops per driving hour. (c) Delivery stops (in red dots) and stop time in the morning peak hours. (d) Delivery stops and stop time in the afternoon peak hours.*

### 5.3 Policy & Users

The policy of shifting freight deliveries from daytime to off-peak hours generates a wide range of different effects that could be analyzed from several angles. One of them is the stakeholders' perspective that was also included in the off-peak city logistics project in Stockholm.

"In-depth interviews" is the method selected for the collection of data in this research. The semi-structured format that enables interviewees to feel more relaxed and comfortable, discussing on more detailed information about complex ideas and issues sets in-depth interviewing a widely used qualitative research technique, especially in the case that there is a distinct individual set of different opinions, as it is in off-peak deliveries.

The interviews were conducted during the period February-March 2016, with the participation of all stakeholders involved in the night time deliveries pilot case in Stockholm. For the conduct of research there was formulated an interview scheme consisting of two sections. The first part was a set of an open-ended questions focusing on the role of each stakeholder and their involvement in each stage, the background of participating organizations in off-peak deliveries, their views on the opportunities, challenges, obstacles or limitations of the expansion of night deliveries in Stockholm, and how are they interconnected in the night time distribution operations. In the second part the stakeholders were asked to quantify the main costs and benefits of delivering goods in night hours in the inner city of Stockholm. Specifically, interviewees had to check from a list which parameters actually affect their operations, in which way, positive or negative, and finally rate the importance of each parameter on a scale ranging from not at all important to very important. The parameters included in the list were selected according to a literature review on the effects of shifting deliveries from day to night time.

For the facilitation of the analysis and presentation of the key findings of the data collected through the interviews, the stakeholders were divided in two main categories, namely:

- Public, comprising of the strategic freight program manager of the city of Stockholm and the former vice-mayor for transportation and environment who initiated the off-peak pilot project.

- Private, including all of the stakeholders participating from industry and divided into two main subcategories:

✓ Carriers/Receivers, comprising of transport managers and initiators of many innovative ideas in two logistics companies and the head of logistics and responsible for warehouses, transports, recycling and waste management of a big retailer in Sweden;

✓ Vehicle/Equipment providers, including the product managers that are working in research in urban transport solution in the biggest two truck manufacturers in Sweden and the sales manager of Nordic countries of an equipment provider company.

As far as the key findings concerns, the social benefits mainly consist of increased efficiency, shorter travel and deliver times, higher productivity both for carriers and receivers, less environmental impacts and fuel cost savings, as well as better working conditions when trucks are moved from rush hours to off-peak hours. On the other hand, social costs may include increased noise levels and noise disturbances, additional staff, equipment and wage costs as well as higher risks in handling goods deliveries at night times, especially in the case of unassisted deliveries.

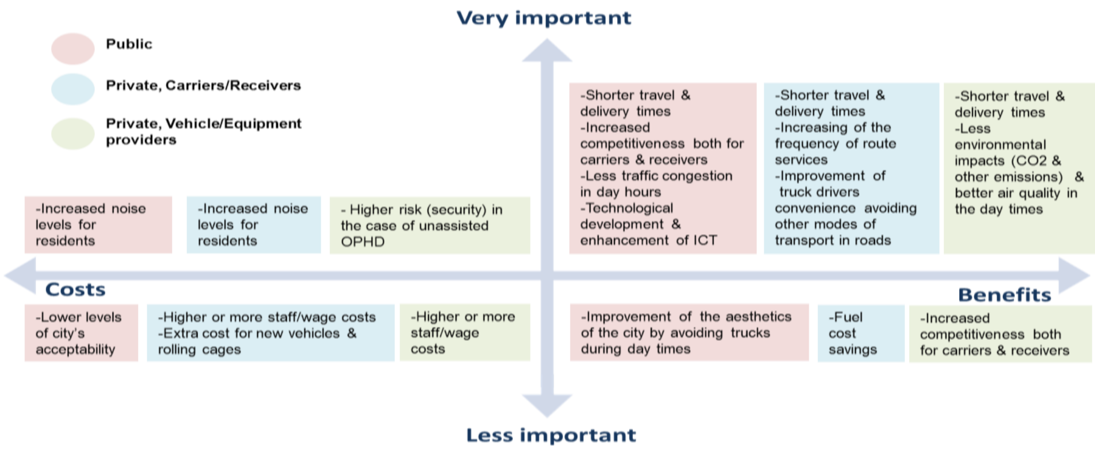



*Figure 21 Summary of costs and benefits of stakeholders involved in off-peak deliveries.*

The experience with the pilot case in Stockholm draws quite similar conclusions to other cities that tested off-peak deliveries in the past. The wide range of different stakeholders from both private and public sector interact in a complex and dynamic way, necessitating the need for closer cooperation and communication between them. Based on what interviewees claimed through the in-depth interviews, although there are some drawbacks mainly having to do with noise and additional costs and risks, off-peak deliveries are beneficial for almost all of the stakeholders participating in the process, ensuring reduction in travel time, increased efficiency, higher productivity and lower emissions. Benefits exceed the costs and since there will be an allowance for operating in off-peak hours they are willing to shift part or all of their business from daytime to nighttime.

The expansion of such a policy is not a simple decision but a quite complex procedure since it imposes a modification of business models for companies. In order to stimulate business involvement, there is a need for incentives and motivations, making participating stakeholders especially from public sector feel more confident. These incentives should focus on the positive aspects of shifting operations to off-peak hours e.g. increase of transport efficiency rather than restrictions, fines or penalties. Subsidies are not an option since companies should be encouraged to participate getting the benefit of efficiency by operating in off-peak hours.

Certification and standardization of the operations and the vehicles/equipment used for night time deliveries not only in national but also in international level is another challenge. In Sweden there is a definition for environmental trucks but it is vague and needs to be further specified. Additionally issues related to infrastructure such as the road load limit or crossing points of distribution of goods with other users of other modes of transport e.g. cycling lanes or pavements should be taken into consideration for promotion of night-time operations over time.

But before the expansion of off-peak deliveries additional research and testing is needed in terms of new technologies in vehicles and equipment, increase of participation and commitment of stakeholders especially in private sector and wider testing area, covering all the centre of the city of Stockholm in order to fully understand the steps required, the benefits, the costs and the challenges.

The city of Stockholm is growing rapidly urging the need for such policies. Although congestion and problems in the distribution of goods in the city centre were identified many years before, there was no policy or action to remedy the situation before the establishment of off-peak logistics project in 2014. According to the former vice-mayor for transportation in Stockholm, although urban logistics is an integral part of everyday life, policies related to freight transport are not part of the political discussion so in most case they are not promoted by politicians. Even they are highly accepted by industry, the fact that they affect indirectly citizens make them not to be priority in policy makers agenda.

### 5.4 Socio-economic analysis

Introduction

This section reviews the socio-economic benefits of off-peak deliveries. This is achieved by comparing the external costs of business-as-usual daytime distribution trips and compare them with the distribution trips at night-time. Two cases are analysed, representing the two pilots in the project as described in the section ‘ **Error! Reference source not found.**’ (p.**Error! Bookmark not defined.**). The first case is a *dedicated delivery to a single customer* (full truckload, FTL). The second is a *consolidated delivery to Various customers* (less-than-truckload transport, LTL). The main design of the cases is displayed in (Figure 22).

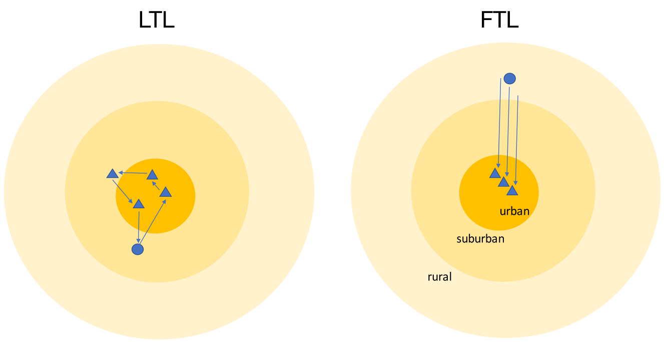



*Figure 22: Typical transport chain. (a) Less-than-truckload, (b) Full truck load*

Method

Figure 23 shows the research approach. The external costs are calculated with the CUTS-Assessment model (see (Behrends, 2016) for model description). The following input data is used:

- Transport chains: GPS data from the project. Traffic data on congestion levels based on GoogleMaps.
- Vehicle data: Size, Diesel E-IV, i.e. the state-of-the art Diesel engine.
- Emission data: based on Handbook of Emission Factors for Road Transport (HBEFA) (INFRAS, 2014). Emission parameters included are 1) The greenhouse gas carbon dioxide contributing to climate change; and 2) the air pollutants particles, nitrogen oxides, hydrocarbons, sulfer oxides and methane. The analysis is limited to ‘wheel-to-tank’, i.e. only emissions from operating the vehicle are included. Neither emissions from fuel production and distribution (‘well-to-tank’) nor from vehicle and infrastructure production, etc. are included

in the analysis. The reason for this limitation is that these issues are not affected by shifting transport times, i.e. their impact is the same in both scenarios.

- External cost values: (AEA, 2014). The following categories are included in the analysis: Climate change, impact of air pollutants on public health and ecosystems, accident risks, noise and congestion.

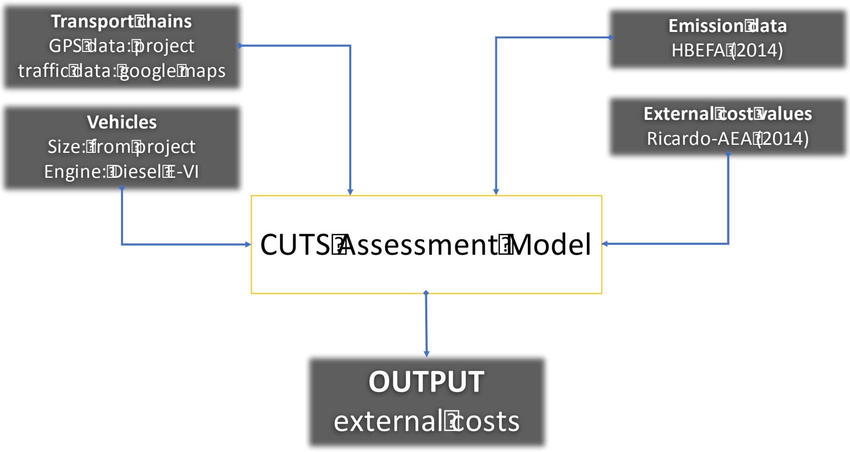



*Figure 23: Research approach for the socio-economic analysis*

Results

Figure 22 shows the relative contribution of the different impact types to the total external costs of daytime deliveries, which form the baseline for this analysis. Though the trips differ in type of delivery pattern (LTL vs FTL), transport distances (approx. 40 km vs. 280 km), dominating road types (urban roads vs. motorways), there are strong similarities. The by far dominating impact type is contribution to congestion which account for roughly 90% of the total externalities. Noise is responsible for about 4% in both cases. The noise impacts are also in the same order of magnitude (2 and 4%). A small difference can be observed for contribution to climate change, which is significantly higher for FTL (9%) than for LTL (3%). This can be explained by the longer transport distances which mainly take place on motorways in less sensitive rural areas, where congestion, air pollution and noise impacts are neglictable. Accident risks are more or less non-existing compared to the other categories.

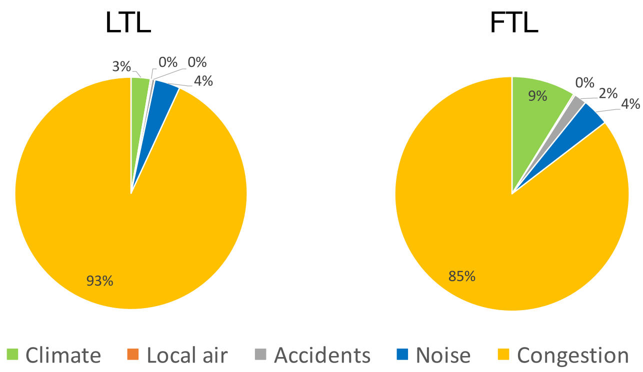



*Figure 24: Distribution of external costs of daytime delivery trips*

In order to identify the improvement potential of OPHD, these daytime trips are shifted to night time. All other parameters are kept constant, e.g. distances, number of stops etc. Obviously congestion levels during daytime play an important role. Hence, a sensitivity analysis is conducted, calculating the impacts of daytime deliveries for lower as well as for higher congestion levels than in the baseline case. The results of this analysis show again similar results for the two different transport chains (Figure 25). Hence, the following conclusions can be drawn:

Congestion cost dominate externalities of urban distribution. Hence, shifting distribution to off-peak hours entails significant benefits. This is not only the case in extreme congestion levels (such as in Manhattan), but are even significant at moderate levels (reduction of 60% in externalities in the low congestion scenario).

- Naturally, OPHD reduces CO2 emissoins, but even more the emissions of air pollutants. OPHD can therefore contribute significantly to improving local air quality.
- There is no signicant effect on safety. This may be due to the methodology used, as according to Ricardo EAE (2014) accident risk costs are independent of congestion levels and time of day.
- The congestion and air pollution benefits are achieved at the cost of higher noise impacts, which are more than 2 times as big as for daytime deliveries.

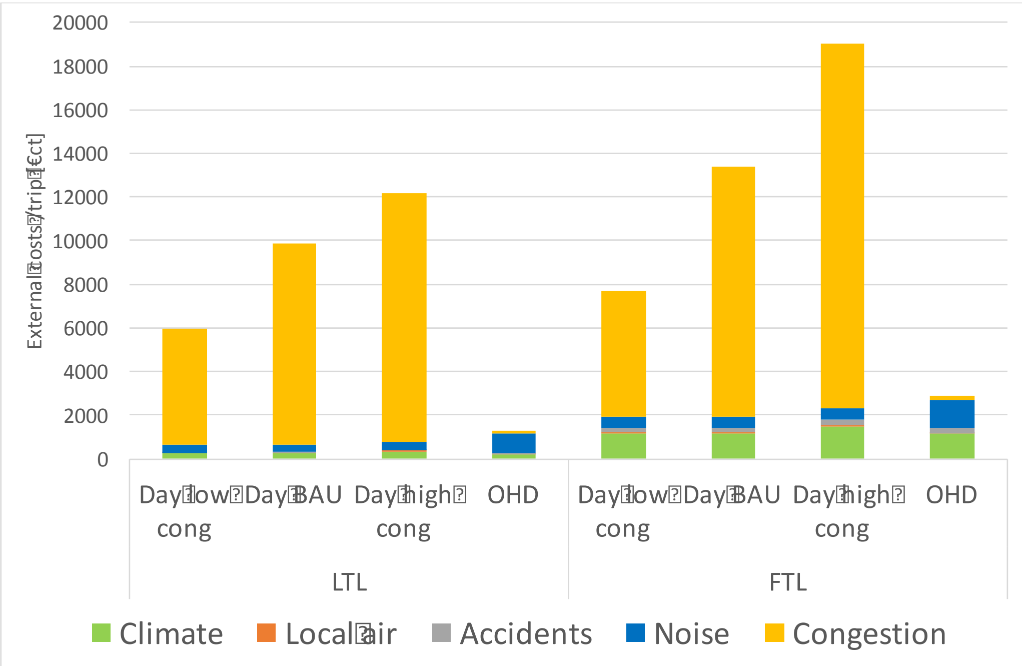



*Figure 25: External cost of daytime and off-hour deliveries*

## 6 Conclusions

Two heavy trucks have been operated in Stockholm city centre during night time for e period of one and a half years. New technology has been tested: one the trucks was an electric hybrid with zone management and one was a PIEK certified biogas truck. The two trucks have been operated in different delivery schemes: on dedicated and one consolidated.

To assess noise generated from the transportation, a new method has been developed and tested. The method uses two microphones mounted on the vehicles, and can thereby distinguish the noise from the truck and the loading procedure from the background noise both during the travelling and the unloading phases. The conclusions from the noise measurements are that the noise produced while travelling with the two trucks tested is not disturbing. The main challenge is noise produced during unloading, and in particular in areas where the background noise is low.

Transportation efficiency is improved from several perspectives compared with daytime deliveries. The speed of the consolidated truck was on the average driving 31% faster during off-peak hours than morning peak hours. The average network speed is almost 60% higher during off-peak hours than during afternoon peak hours. The measurements also showed a decrease in fuel consumption during off-peak operation compared to daytime operation, as well as longer service times during daytime. However, one conclusion from the project is that it is challenging to compare daytime deliveries with off-peak deliveries for an individual truck, since the routing will be different depending on the time of the day even if the delivery points are the same. The reason is that the routing during daytime will be optimized to take congestion into account. Therefore the numbers presented in this report should be seen as examples for those cases rather than general conclusions. If general conclusions are to be drawn, data from more different trucks in different delivery schemes need to be collected and analysed.

Stakeholders from private and public sectors have been interviewed, to get the stake holders perspectives. The most important benefits are increased efficiency, shorter travel and deliver times, higher productivity both for carriers and receivers, less environmental impacts and fuel cost savings, as well as better working conditions when trucks are moved from rush hours to off-peak hours. The most important social costs are increased noise levels and noise disturbances, additional staff, equipment and wage costs as well as higher risks in handling goods deliveries at night times, especially in the case of unassisted deliveries. In general, the benefits exceed the costs.

The expansion of such a policy is not a simple decision but a quite complex procedure since it imposes a modification of business models for companies. Also, the literature study shows that although there are a lot of benefits with off-peak deliveries, often a special program to foster a change from daytime to off-peak deliveries is needed.

From the socio-economic analysis it is clear that the dominating type of external cost for daytime deliveries is contribution to congestion, which account for roughly 90% of the total externalities. This cost is reduced is nearly eliminated during off-peak deliveries. In addition, off-peak deliveries reduces $CO_2$ emissions, but even more the emissions of air pollutants and can therefore contribute significantly to improving local air quality. The cost of higher noise I more than twice as big as for daytime deliveries.

Still there are a few but from the city's perspective very important challenges:

- Levels of background noise in the city should be investigated, and acceptable noise levels need to be established. In addition, methods for measurements and surveillance need to be established.

- General requirements and surveilance methods for performing off-peak deliveries need to be established, for exemple concerning vehicles, fuels, and emission levels that are allowed.

- There may be additional costs related to changes needed to assure safe and silent off-peak deliveries, for example paving, and other infrastructural changes. Who should be responsible and who should fund it.

The overall conclusion from the project is that the benefits from off-peak deliveries exceed the costs. The results from the project suggest that the concept of off-peak deliveries is beneficiary in the Stockholm region, and that the off-peak delivery program continues and is scaled up to involve more vehicles and other types of goods. During the upscaling it is relevant to continue to study effects on transport efficiency, noise levels, and potential business barriers that may arise.

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