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Greenhouse gas emissions from road works

Case study for Amsterdam region to analyze different planning approaches

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Abstract

Over the previous century, the transportation sector has been identified as one of the largest carbon footprint contributors. Emissions from the transportation industry originate from a range of sources, including vehicle operating as well as road construction and maintenance. With an increase in road users and an aging infrastructure, new road infrastructure is being established and existing infrastructure is being managed with due caution. Rijkswaterstaat has initiated a bridge maintenance program entitled ”Replacements and Renovations Program” to enhance roadways so that they will always withstand increased traffic and improve safety. Rijkswaterstaat strives for thorough maintenance planning that minimizes road closures, environmental damage, and traffic congestion.

There are several stages in a road maintenance project that might affect greenhouse gas emissions, including pre-construction, construction, maintenance, and rehabilitation. Some of these stages have been the subject of previous studies. The majority of researchers concentrate on the emissions connected with road construction from the materials utilized. But an effective way to reduce emission from the road works is to analyze different planning approaches and selecting the approach that minimize the disruption to the traffic. Simulation is used to calculate the emissions from various approaches and to predict these emissions. To begin, a traffic simulation is run using the macroscopic traffic flow model OmniTRANS to generate the traffic indicators needed to calculate emissions, and then the macroscopic emission model MOVES is used to estimate emissions for various scenarios.

The A10 Amsterdam network is chosen for the as the research area and the road works are simulated along the A10 west motorway. The research region is the A10 Amsterdam network, and the roadworks are reproduced along the A10 west freeway. OmniTRANS is used for network preparation and project setup. Rijkswaterstaat has already provided information on the OD matrix and data on different link types. However additional data were required for the simulation is collected from NDW Dexter. For the road work, four scenarios were chosen: complete road closure on weekdays, complete road closure on weekends, partial road closure on weekdays, and partial road closure on weekends. The traffic simulation shows that the city routes passing through the A10 west motorways are most affected by the road closure. A framework for integrating the transportation and emission models was developed to calculate the emissions. The main outputs from OmniTRANS that are utilized as inputs to MOVES are Link source data, Link drive schedule, and Link source type hour. Other project-level input parameters are collected in parallel to these.

The findings provide an assessment of the emissions resulting from various approaches. According to the analysis, the partial road closure emits around 10 MT CO2e more greenhouse gas than the full road closure. The analysis demonstrates that it is possible to minimize project-related GHG emissions during roadwork by by performing a full road closure during the weekdays which has the highest emission savings.

Preface

My master's journey comes to an end with this thesis. Many people have supported me in this endeavor, and I am grateful to them all. I'd like to take this opportunity to express my gratitude to those who have supported me on this incredible experience.

This thesis wouldn't be complete without the support of my daily supervisors, Meng Wang and Henk Taale. Thank you so much for helping me shape this thesis into better form. The weekly meetings provided a better insight into my progress. The starting stages of my thesis were very difficult for me, with learning about the workings of Omnitrans and writing codes. Thank you both so much for your patience in guiding me to a better solution every time I am faced with a challenge. I am so grateful for your encouraging words after each meeting. I'd also like to express my gratitude to Prof. Hans van Lint for his meeting with me at the start of my thesis, during which you shared your insights into the thesis's objective, and Prof. Jan Anne Annema for your informative comments during our last meeting, which helped me structure my report.

I am very grateful for the friends from Delft with whom I shared some great moments. To Sharnish, who loves and supports me unconditionally. Especially my parents, who never fail to inspire me and believe in me. I am blessed to be a part of our family and you are the wind beneath my wings.

Priya Ramakrishnan
Delft, October 2021

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List of Abbreviations

GHG	Greenhouse gas
FHWA	Federal Highway Administration
TSS	Transport Simulation Systems
AON	All or Nothing
DUE	Deterministic user equilibrium
SUE	Stochastic user equilibrium
DTA	Dynamic Traffic Assignment
PMTURI	Purpose, Mode, Time, User, Result, Iteration
NDW	Nationaal Dataportaal Wegverkeer
PDM	Project Data Manager
AVFT	Alternative fuel and vehicle technology
I/M	Inspection/Maintenance
MADAM	Macroscopic Dynamic Assignment Model
GWP	Global-warming potential

1. Introduction

1.1. Research background

During a large-scale infrastructure project, there is two main causes of emission. Firstly, emission from materials of construction, maintenance, repair, and rehabilitation of the highway infrastructure. Secondly, due to the traffic congestion caused by the road works. Road works result in an increased number of road trips, mainly due to the route change in urban areas which leads to a heightened level of emissions in urban transportation networks which has damaging influences on environment. According to the statistics, one of the major sources of the occurrence of congestion is prompted due to road works. Such an immense congestion effect affects the traffic performance of the road network which in its turn influences the emission of greenhouse gases. . And as we know this is one of the causes of the global warming phenomenon which leads to climate change, air pollution, and others. Consequently, the ministry of Infrastructure and Water Management has been taking a lot of effort to reduce the occurrence of these types of congestion by assessing the execution of road works projects associated with greenhouse gas emissions. An example of a policy measure is the use of methods like free public transport. In the Netherlands, one of the prominent examples was in 2008 when the municipality of Utrecht introduced a mobility pass that allowed free travel on all forms of transportation. Their main impulse was to diminish the rush-hour traffic during the road works which indeed reduced the resulting emission **(Lizeke de, 2015)**. Likewise, an effective policy measure should be formulated to calculate the emission and plan the road works accordingly.

Based on the statistics from **(CBS, 2019)** in the Netherlands since 2002, there has been a increase in the total annual mileage by road users which amounts to 147.6 billion kilometers by the end of 2017.They are chiefly attributable to passenger cars and heavy goods. So, diminishing the adverse effects of emission from transportation networks has gained augmented importance over the years. As a densely populated and mobile country, Netherlands has an inclusive network length of about 5800 *km*. The country has been continually taking measures to promote a high level of mobility to its users as the traffic is anticipated to grow to a height of 35 percent at the end of 2020 **(Beck et al., 2017)**. This certainly demands new infrastructure development to accommodate this growing traffic. Across the world, infrastructure aging and its management has been given increasing attention as it's considered to affect the environment and countries economy **(van Breugel, 2017)**. In the Netherlands the vast majority of bridges are built in the 1960s-80s and are now near the end of life and facing a potential problem of fatigue cracks due to the increasing traffic **(Gaal, 2004)**. Extensive road maintenance is done every 15 years to prevent wear and tear. To overcome the failure of the bridges, the Dutch road authority Rijkswaterstaat has introduced a bridge maintenance program called ”Replacements and Renovations Program” to upgrade the roads to handle heavier traffic conditions and to increase the safety. Rijkswaterstaat aims for careful planning of the maintenance program with minimized road closures and congestion issues. This enormous increase in road works and its usage lead to increased emissions which contributes to carbon dioxide, nitrogen oxide, and particulate matter which in turn affects climate change, ecosystem, and wildlife **(Meijer et al., 2018)**.

Not only transport operators but also the policymakers must take into consideration this effect of the emission before plotting the construction work. **Yigitcanlar and Kamruzzaman (2015)** discusses that policymakers should investigate these factors linked to the emissions to draw up strategies for achieving sustainable transportation. With the growing frequency of road works and the severity of congestion, this research into calculating the emission using different methods before planning the construction work, is important. There is a range of strategies employed to calculate these emissions, one of the methods is using simulation to anticipate these emissions.

1.2. Research objectives

The main objective of this research is to investigate the effects of congestion on emission in relation to road construction and maintenance. The main goal of this research is to develop methods that will facilitate Rijkswaterstaat to support decision making using traffic and construction data related to highway infrastructure.

1.3. Research question

To answer the research objective the following research questions will be answered which are categorized into main and sub-research question.

Main Research question

How can the planning of road works be scheduled while taking into account greenhouse gas emission values from road works?

Sub Research questions

(a) What is a suitable method to calculate the spatio-temporal traffic flow variables and why?
(b) What is the suitable method to calculate greenhouse gas emission and why?
(c) What are the type of scenarios considered for planning road works?
(d) What are the spatio temporal traffic flow variables under different scenarios using the selected method from sub-question (a)?
(e) What are the greenhouse gas emissions under different scenarios using the selected method from sub-question (b)?

1.4. Research Scope

There are six main greenhouse gases namely Carbon dioxide (CO2), Methane (CH4), Nitous oxide (N2O) and Flourinated gases like Hydrofluorocarbons (HFCs), perfluorocarbons (PHCs), sulphur hexaflouride (SF6) and Ozone depleting substances **(EPA, 2020)**. In this study we focus only on CO2, CH4 and NO2 as they contribute to 97 % of the total emissions.

According to **Tarja and Kari (1996)** environmental impact caused by road works is divided into three categories. First is impact due to the materials during its whole life cycle. Second is impact by land use and finally the impact caused by diverting traffic. In this study we focus on emission from materials during its life cycle and emissions from the traffic as the effect of GHG emission attributed to land use changes are rather in smaller quantities.

1.5. Research approach

This section explains how the different sub-questions can be answered and how to derive the answer to the main research question. Each subsection below corresponds to each of the sub-questions. For this purpose first emission related to construction materials is addressed followed by the background information on various traffic congestion and vehicle emission models. The results and discussion manifest the estimated capacity, speed, acceleration, and predicted vehicle emission rates under different scenarios like closure timing (n hours weekday vs n hours weekend vs nighttime closure), the number of lanes closed (full closure vs half) and duration of each closure (example four weekday closure vs three-weekday closure) simulation models. The conclusion summarizes the results and proposes the best-case scenario.

Figure 2 gives the overview of the research plan. First step is to select the suitable traffic simulation model through literature study. Second step is to calculate the traffic flow variables like travel delay, queue length due to the road works under different scenarios using the selected simulation model and the results are discussed. Third step is to define the model used for calculating the Greenhouse gas emissions through literature study. Fourth step is to calculate the emissions under different scenarios using the traffic flow variables calculated from step 2 and the results are analyzed and compared. In the fifth step the emissions from construction materials are calculated using life cycle analysis method. Finally total emissions under each scenario is calculated and results are discussed.

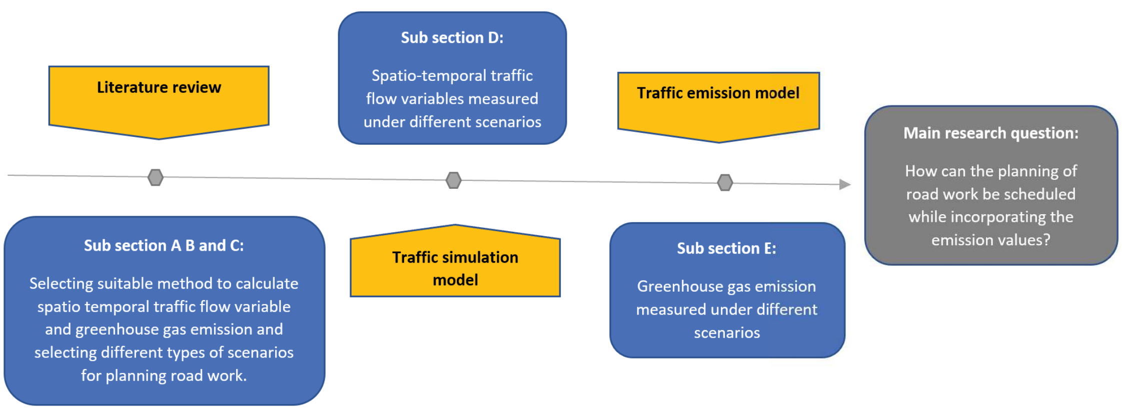


Figure 1: Methodological steps to answer research question

1.6. Thesis layout

1.6.1. Literature review

To answer the sub-questions (a), (b) and (c) a comprehensive literature review is performed. There have been diverse researches held on quantifying the emission factors from the road construction. In our research the literature review consists of three parts. The first part will quantify the emission due to the consumption of materials for the road works. Although the emissions can be either from materials or from construction machines, this study has focused on emission from materials. In our research along with the literature reviews, some emission data from Rijkswaterstaat will be used to quantify the emission which is related to sub-question (a). The second part is about analyzing different methods that are available to estimate the capacity of the highway answering the sub-question (b). Finally analyzing different methods available for estimating emission from the highway answering the sub-question (d). The purpose of the literature review is to collect data, analyze and compare different methods and final select the best suitable method.

1.6.2. Simulation study

Sub-questions (d), and (e) can be answered using simulation. Simulation is a process to imitate the real traffic situation utilizing traffic flow theory. It can be applied to solve traffic problems as predicting traffic flows, design network elements like merging, and assessing traffic measures. There are numerous macro, micro, and mesoscopic traffic simulators like SUMO (Simulation of Urban mobility), OpenTrafficSim (OTS), VISSIM, FOSIM, etc, categorized based on their areas of application. Each software is based on different traffic flow theories. The characteristics of the actual system can be reproduced in the simulation including the behavior of the traffic under different situations. In the first phase capacity, speed, dynamics of vehicles under different scenarios are calculated using a simulation model. In the second phase, the emission model is used to calculate the emission factors using the inputs from the first phase.

1.6.3. Analyze Simulation data

Finally to answer the main research question the simulation study data are analyzed and compared to formulate the planning of the road work. Further recommendations are constructed based on the experience from the simulation study.

1.6 Thesis layout

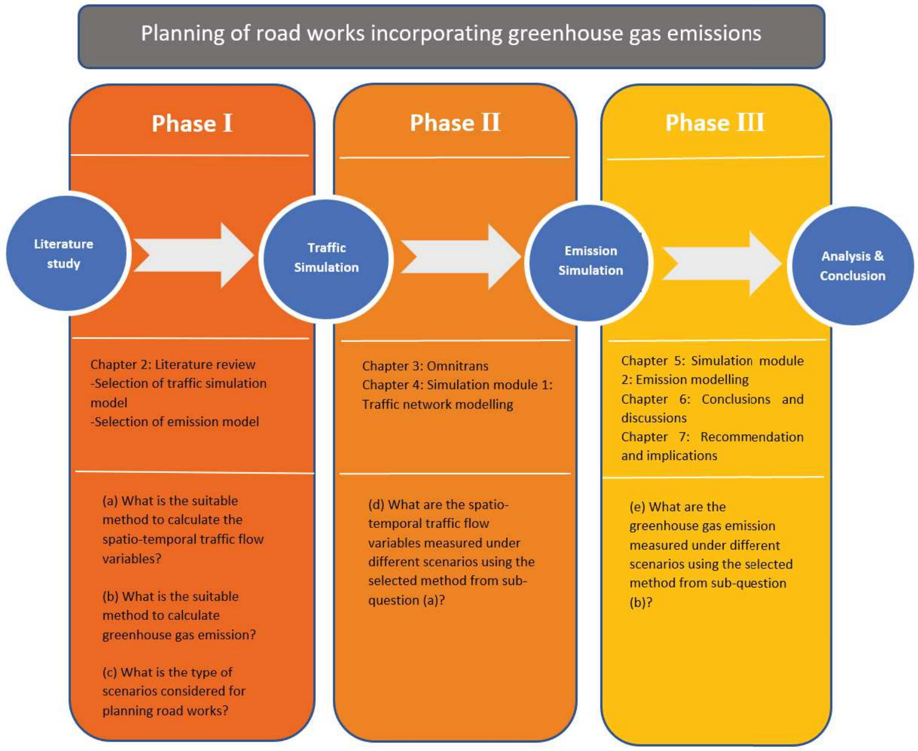


Figure 2: Thesis layout

2. Literature review

2.1. Traffic Simulation Models

Traffic simulation is the extensively used tool for analyzing, designing a model of a real system and conducting experiments with the model for a better understanding of its behavior. It enables the operator to control model input conditions all the time and also permits us to simulate the environment at a faster rate than the experiment conducted in real-life **(Kotusevski's and Hawick, 2009)**. While simulating the traffic systems many different methodological approaches exist and numerous papers reviewed them. **Rao and Rao (2012)** addresses the possible alternatives to recognize and measure metrics for urban arterial congestion. Within most of the literature, two significant distinctions between models were made: macroscopic vs microscopic modeling approaches. The research by **Felipe de et al. (2019)** also distinguishes a third category, mesoscopic models. The main difference between these three classes is the trade-off between optimizing simulation speeds and evaluating the traffic states (or traffic phenomena) as precisely as possible **(Zegeye et al., 2013)**. **Calvert et al. (2015)** has done a detailed analysis on the types of traffic assignment and simulation models including their application and implementation in The Netherlands and internationally. They classify the traffic models into Demand models, Macroscopic models, Mesoscopic models, Microscopic models, Data driven models and Combined or hybrid models. To find a suitable method to calculate the Spatio-temporal traffic flow variables much traffic flow software that falls under these these categories are reviewed in the sections below. An overview of these models including their capabilities to evaluate the traffic flow variables is summarized in Table 2.

2.1.1. Microscopic model

Microscopic models continuously or discretely predict the state of individual vehicles and concentrate on the specific vehicle speed and locations **(Nedal et al., 2009)**. The reason why micro-simulation models are favored over other methods is that micro-simulation models permit us to assemble more knowledge concerning the consequences of one vehicle over the other, for example, speed and also they reproduce the stochastic nature of the traffic, for instance, they incorporate driver behavior data. Also, they assist in estimating the peak hour congestion effects **(MDT, 2004)**. Several microscopic models are developed for modeling traffic congestion, for instance, CORSIM (CORridor SIMulation) developed by U.S Federal Highway Administration (FHWA), VISSIM developed by Planung Transport Verkehr (PTV) in Germany, SimTraffic developed by Synchro, Aimsun developed by Transport Simulation Systems in Spain, Freeway Operations Simulation (FOSIM) developed by Delft University of Technology.

Models like car following, longitudinal motion, gap acceptance, and lane change model are employed in most microscopic models to imitate the movement of the vehicle within the traffic with high accuracy like the behavior of vehicles collectively with lane changes, dynamics, gap acceptance and so on **(Middleton and Cooner, 1999)**. According to **Byungkyu Park and Griffin (2010)** the microscopic model is preferred when the research demands densely detailed analysis of real-world traffic behavior. With the strength comes the weakness, the level detailing in the microscopic model can also be seen as a disadvantage as it entails much data concerning the traffic, road geometry, driver behavior, and so on. When the model is large then the time taken to run the simulation can be quite long which is a shortcoming if the network modeled is small.

2.1.2. Mesoscopic model

The mesoscopic model fulfills the gap between the macroscopic models and microscopic model by the level of detailing, it has the perspective of both of the models illustrating the traffic flow variables at a medium level **(Nedal et al., 2009)**. These models simulate the platoon of vehicles and consolidate equations that indicate how these groups of vehicles cooperate **(Middleton and Cooner, 1999)**. The major difference between the macro and mesoscopic models is that the mesoscopic model can reproduce a large network incorporating many details than a macroscopic model. The mesoscopic analysis also supports the analysis of road segments, multiple routes within a network, basic signalized intersections, freeways, and ramps **(Byungkyu Park and Griffin, 2010)**.

Some of the commonly used mesoscopic models are DYNAMIT (Dynamic Network Assignment for the Management of Information to Travelers), it is a generally used simulation and assignment model developed by Massachusetts Institute of Technology (MIT). VISTA (Visual Interactive System for Transport Algorithm) and CONTRAM (Continous Traffic Assignment Model) are some activity-based dynamic transport model.

Research by **Byungkyu Park and Griffin (2010)** points out that weather impacts on the transportation system can be incorporated into mesoscopic models. Given the strengths of this model, one of the weaknesses is its inadequacy to model detailed operational strategies like coordinated traffic network and complicated traffic signals. This can be done in a microscopic model as it uses many comprehensive data. In the mesoscopic model, the behavior is defined at the individual level.

2.1.3. Macroscopic model

Macroscopic models have a great level of aggregation with the representation of traffic flow, speed, and density **(Nedal et al., 2009)**. This model is based on the deterministic relationships developed through research on highway capacity and traffic flow for freeway sections. The macroscopic simulation takes place on a section-by-section basis rather than simulating individual vehicles **(Middleton and Cooner, 1999)** so it is suitable for reproducing larger regions. This model considers that all the vehicles on the road have identical characteristics so this method is not suitable for analyzing the traffic at the vehicular level. Due to these facts, the modeling set up can be carried out faster and the simulation time is less compared to other models. The only disadvantage of the macroscopic model is its failure to model detailed behavior of traffic in the network **(Byungkyu Park and Griffin, 2010)**.

Some of the macroscopic models are OmniTRANS, PTV Visum developed by PTV Planung Transport Verkehr AG , CUBE a transportation and land use modeling software developed by Citilabs. In the Netherlands, OmniTRANS is the popular macroscopic model practiced for regional modeling as it can model both static and dynamic assignments. Most of the macroscopic models use the Cell transmission model determining the density and flow at each step. Cell transmission model is computationally very effective when compared to other micro and mesoscopic models, it is well suited for modeling traffic interactions like queue spill back **(Szeto et al., 2009)**.

2.1.4. Travel demand model

Travel demand models are mathematical models that forecast the travel demand between an origin-destination pair utilizing the current conditions and future projections in a specific area for a specific mode **(Calvert et al., 2015)**. They are mainly used to determine the positive effects and challenges of taking over highway projects. They follow the four-step modeling process briefly explained in section 2.3. Some models also include the time of the day or departure time choice model in their modeling process. **Chu et al. (2012)** describes two travel demand method approaches, trip-based travel demand model and activity-based travel demand model. The trip-based model follows a traditional four-stage modeling process and uses individual trips as the unit of analysis. Drawbacks of the trip-based model are that this model focuses on individual trips rather than the relationship between all trips, each individual is considered a decision-maker. The alternative approach is an activity-based model where travel demand is based on the need to pursue an activity. **Bifulco et al. (2010)** and **Chu et al. (2012)** define five important features that the activity-based model should have, first, travel demand should be derived from activity participation. Second, an activity-based approach focused on the sequence of activities. Third, the household should be considered as a decision-maker and all the individual activity should be planned and executed in that context. Fourth, Both spatial and temporal constraints are taken into account for example activities should be continuously spread throughout 24 hours. Finally, time and space limitations should be considered when making travel and location choices. The main disadvantage of this model is that it requires much more data than the other models.

2.1.5. Hybrid model

Microscopic model provide a detailed analysis of the traffic process while the macro and mesoscopic models provide a lesser detailed analysis but are faster. Hybrid model makes use of different types of models. Hybrid simulation enables using a microscopic model in selected areas where detail is needed and the macroscopic model in other areas of the selected network. Hybrid model is more advantageous in places where detailed knowledge of the individual vehicles and parameters such as headways are needed as well as wider knowledge about the network such as the speed and flow **(AimsunNext, 2019)**. Many researchers have contributed on developing the framework for integrating different traffic simulation models into one hybrid model. For example **Burghout (2004)** has been developed framework for integrating microscopic and mesoscopic traffic simulation models into one hybrid model. There are many hybrid models developed experimentally, only few hybrid model packages are available to use, one such model is AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks).

AIMSUN was developed by TSS-Transport Simulation Systems. Recent evolution in AIMSUN software package allows modelling simultaneous micro-meso or macro-meso simulation and travel demand modelling which incorporates 4-step modelling process. AIMSUN also incorporates many sub-models such as car-following model, lane-changing model, gap acceptance for lane changing, gap acceptance for give-way, overtaking, on-ramp, off-ramp, and look-ahead **(Anya et al., 2014)**.

2.1.6. Data driven model

Data-driven models focuses on finding patterns in the traffic flow data especially finding connections between the system state variables to make traffic forecasts **(Wei, 2014)**. The main principle of data-driven models as proposed by **Melnikov et al. (2015)** is to calibrate or train the models in order to minimize the model error. Data mining, computational intelligence, machine learning, intelligent data analysis, soft computing and pattern recognition are some of the areas contributing to data-driven models **(Solomatine and Ostfeld, 2008)**. These models follow computational intelligent based approaches to predict the traffic such as neural networks, fuzzy rule-based systems and genetic algorithms **(Solomatine et al., 2008)**.

2.2. Selection of simulation Tool

After analyzing different simulation models based on factors like their capabilities to calculate speed, dynamics, flow, queuing data, routing, lane configuration, vehicle class, model availability, OmniTRANS is chosen for conducting traffic analysis. OmniTRANS follows 4 Stage modeling processes: Trip generation, Trip distribution, Model Split, and Trip assignment. In the assignment process, the route generation model is incorporated, which calculates the shortest path between the Origin-Destination pair using the Dijkstra algorithm. Also, alternative routes are generated using the Monte Carlo algorithm This model is suitable for the research as the main hypothesis is to analyze the traffic flow in the alternative routes. To model the continuous departure pattern, the streamline estimates the route fractions for every origin-destination pair using route costs like travel time, total traveled distance. Finally, the route is selected based on the cost between the initial route and the alternatives from the set of routes.

OmniTRANS allows modeling both static and dynamic assignments. Traffic can be analyzed at an aggregated or dis-aggregated level. For instance, it can be multi-model and multi-temporal. For Dynamic Traffic assignment Streamline model MADAM (Macroscopic Dynamic Assignment Model) developed by OmniTRANS. MADAM is a cell propagation model with cells of equal length on each link. One of the many building blocks of MADAM Streamline is Dynamic traffic management with several controls like Ramp metering, variable speed limits, Outflow limiter, Lane Adapter, etc... some of which will be used for designing the road works of A10 West.

Type	**Model**	**Speed**	**Dynamics**	**Flow**	**Queuing data**	**Routing**	**Lane configu-ration**	**Vehicle class**	**Fuel con-sumption**	**Ranking**
Travel demand model	Cube	✓	✓	✓	✓	✓	✓	✓		7
	OmniTRANS	✓		✓	✓	✓	✓	✓	✓	8
	TRANSIMS	✓		✓	✓	✓	✓			5
	QRS 2	✓		✓	✓	✓		✓		5
	SATURN	✓		✓	✓	✓		✓		5
	TransCAD	✓		✓	✓	✓		✓		5
Macroscopic model	PTV Visum	✓		✓	✓	✓		✓		5
	BTS	✓		✓	✓	✓				4
	KRONOS	✓	✓	✓	✓		✓	✓		6
	METACOR	✓	✓	✓						3
	NETCELL	✓		✓	✓	✓				4
	AIMSUN	✓	✓	✓	✓	✓	✓		✓	7
Mesoscopic model	CONTRAM	✓	✓	✓	✓	✓	✓	✓	✓	8
	DYNAMIT	✓		✓	✓	✓	✓	✓		6
	DYNASMART	✓		✓	✓	✓	✓	✓		6
	VISTA	✓		✓		✓			✓	4
Microscopic model	CORSIM	✓	✓	✓	✓	✓	✓	✓	✓	8
	DRACULA	✓	✓	✓		✓	✓		✓	6
	HUTSIM				✓				✓	2
	MicroSim	✓		✓		✓	✓			4
	MICSTRAN	✓		✓	✓	✓	✓			5
	MIXIC	✓		✓	✓	✓	✓	✓	✓	6
	TRANSIMS	✓		✓	✓	✓	✓	✓	✓	6
	VISSIM	✓		✓	✓	✓	✓	✓	✓	6

Table 1: Types of Traffic Simulation model

2.3. Types of Emission model

Research shows that the emission associated with the road construction and maintenance activities is often from the congestion caused due to the road closure and the emission from the materials used. To mitigate the emission of greenhouse gases various measures have been taken by the government and transportation agencies. One way to reduce these construction/maintenance related emissions is to quantify the emission values before executing the project. These emission values are determined by multiplying the emission factors per mode with the traffic data obtained. There are a variety of pollutants and particulate matter emitted from the vehicles among which methane, nitrogen oxide, and carbon dioxide are the most dangerous and prevalent greenhouse gases and different vehicle characteristics influence the level of emissions. Emission models aids in calculating the pollutant level and the fuel consumption of the vehicles from traffic flow characteristics like average speed, traffic volume, dynamics. There are a variety of emission models depending on the level of detail, level of the resolution, and models that incorporate driver behavior. Similar to the traffic flow model distinctions in Chapter 2, emission models can also be macroscopic, microscopic, and mesoscopic based on their modeling approaches **(Samaras et al., 2019)**. **Smit (2007)** further classifies the emission model into queuing emission model - Matzoros model, Reconstructed speed-time profile emission model - TEE model, Traffic situation emission models, Area-wide emission models and Fuel-based emission models based on the manner in which the emissions are predicted. These emission models vary in the different factors, one of which is driving patterns that connect the effects of congestion to vehicle emissions. Traffic situation models use traffic field data to compute emissions for large inventories, Areawide and fuel-based models are employed at the regional level and other models like Queuing Matzorous model, TEE model, and reconstructed speed time profile models are limited in practical application.

Knez (2013) distinguishes the emission models into two categories based on their level of complexity. They are the average speed based model (macroscopic) and modal emission model (microscopic). Depending on the aggregation and level of detail, there are several model categories which are discussed below in detail.

2.4. Macroscopic model

2.4.1. Average speed based model

Average speed based models or macroscopic emission models estimate the emission and fuel consumption of a traffic flow based on the speed-related emission functions measurements over a variety of trips at different speed levels. The input for this model type is the average speed of traffic flow **(Zegeye et al., 2010)**. The main advantages of these models are faster to compute as they do not consider changes in operating condition at a vehicular level but on a network level and easy to use **(Samaras et al., 2019)**. These models are used in the emission inventories to calculate the emission values on a regional or national level. Some of the macroscopic emission models are COPERT (Computer programme to calculate emissions from road transport), EMFAC (Emission factor), NAEI (National Atmospheric Emission Inventory), and MOBILE (Motor Vehicle Emissions Factor Model).

2.4.2. Area-wide models

This is a straightforward, most aggregated macroscopic emission model. The input and output of this model is total vehicle mileage (vehicle kilometers traveled- VKT) derived from national statistics or using a traffic demand model and emission values per mode (usually passenger cars and heavy-duty vehicles) for the investigated area calculated by combining the traffic data for the area and the emission factor per mode **(Kanagaraj and Treiber, 2017)**. The main assumption of this model is that emission occurs at a constant average rate and are used for calculating emission for a larger area like nation or state for a year **(Smit, 2007)**.

2.4.3. Traffic-situation model

The traffic situation model uses distinct emission factors for several driving patterns. Some of the predefined traffic situation considered by this model are traffic flow patterns like free, congested, stop and go depending on the area type, level of service which is the traffic flow quality (from 1 to 10 with 10 being fully congested) and road type for example motorway, rural, urban roads **(Kanagaraj and Treiber, 2017)** The input for traffic situation model is the VKT (vehicle kilometer traveled), traffic situation and the road type. The output is total emission in g/VKT. Researches **Smit (2007), Wang et al. (2018)** defines the traffic flow situations qualitatively (verbal description like road type, level of congestion, area type) or quantitatively (quantitative variables like speed, volume, length). Quantitative traffic situation models are preferred over qualitative methods because the boundary conditions between the traffic situation are not distinctly set or not inconsistently interpreted in the later **(Wang et al., 2018)**. Some of the quantitative traffic situation models in practice are HBEFA (Handbook Emission Factors for Road Transport), ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems), some version of MOBILE.

2.4.4. Traffic-variable models

Reconstructed Speed-Time Profile Emission Model (TEE model) and Queuing Matzorous model belong to this category of modeling. Matzorous emission model uses the stochastic queuing theory to model the emissions at unsignalised intersections. Some of the inputs of this model are speed, road category, length, etc. While TEE model incorporated four different modeling framework such as speed cycle model, reconstructed simplified cycle model, corrected average speed model and average speed model to calculate

2.5. Microscopic model

2.5.1. Modal emission model

The microscopic or dynamic emission models are based on the instantaneous traffic variables of individual vehicles and provide accurate emission values compared to the other model types. They calculate the emission due to the speed and acceleration variation of the traffic and the computational time is usually higher for these categories of models as they are at the higher level of complexity and can provide the emission levels second by second for the individual vehicle in the traffic. On contrary to average speed models, dynamic emission models are typically used with microscopic traffic flow models. They require a large amount of data especially on each vehicle like engine power and other parameter related to vehicle operation. Modal emission models are further distinguished into instantaneous acceleration speed matrix model, instantaneous engine speed load matrix model, instantaneous analytical speed acceleration functions, instantaneous power-based model, and aggregate modal emission model **(Smit, 2007)**. Some of the microscopic emission models are PHEM (Passenger Car and Heavy Duty Emission Model), CMEM (Comprehensive Modal Emissions Model), VT-Micro (Virginia Tech Microscopic Energy and Emission Model), VERSIT +

Model	**Level of Analysis**	**Computation Time**	**Input**	**Vehicle class**	**Unit Emission**
COPERT (Computer program to calculate emission from road transport)	Macroscopic	Less	Average speed, Number of vehicles per category, Mean trip distance, Climatic conditions	Passenger cars, Light Duty Vehicles, Heavy Duty Vehicles, Buses, Power Two Wheeler's	g/veh km
MOBILE5 (Motor Vehicle Emissions Factor Model)	Macroscopic	Less	Speed, vehicle type composition, temperature and humidities	cars, SUVs, light–commercial vehicles, rigid trucks and articulated trucks	g/veh km
CMEM (Comprehensive Modal Emissions Model)	Microscopic	High	Vehicle activity (second-by-second speed trace, velocity, acceleration) and fleet composition	light-duty vehicles and heavy-duty diesel vehicles	g/s or g/driving mode
MOVES (Motor Vehicle Emission Simulator)	Microscopic	High	Acceleration, deceleration, Total vehicle time, meteorology data, traffic composition and fuel information (gasoline, diesel)	passenger cars (light-duty gasoline vehicles, LDGV), passenger trucks (light-duty gasoline trucks, LDGT), and heavy duty trucks	kg

HBEFA (Handbook Emission Factors for Road Transport)	Macroscopic	Less	fleet composition, vehicle kilometres travelled, traffic intensity, road type	passenger cars, light duty vehicle, heavy duty vehicles, buses, motorcycles	g/veh km
PHEM (Passenger Car and Heavy Duty Emission Model)	Microscopic	High	speed trajectories, acceleration and deceleration rates, cruising rates and gradient information of route travelled	cars, LCV, HDV, Busses	g/km
VT-Micro (Virginia Tech Microscopic Energy and Emission Model)	Microscopic	High	second-by-second speed and acceleration of individual vehicle	light duty gasoline vehicles, light duty trucks (LDT), and heavy-duty trucks (HDTs)	kg/s
VERSIT+	Microscopic	High	speed-time profile data, vehicle kilometres travelled (VKT), traffic composition, proportion of vehicles in cold start mode, and information on air-conditioning use	passenger cars, light commercial vehicle	Kg/s

Table 2: Type of emission models ((Zhang et al., 2011),(RobinSmit, 2013),(Ntziachristos et al., 2009))

2.6. Selection of emission model

In general, macroscopic traffic flow models are utilized with macroscopic emission and fuel consumption models. Macroscopic traffic flow model output may readily be integrated into macroscopic emission and fuel consumption models. Based on the literature study in the above section a macroscopic emission model MOVES (MOtor Vehicle Emission Simulator) is selected.

MOVES distinguishes itself from other macroscopic emission model by estimating emissions based on vehicle operating modes specified by a variety of parameters, such as speed, acceleration, and road grade, rather than average speed. The capacity to model alternate vehicle and fuel types, as well as the usage of MySQL database administration, complex GHG estimation algorithms, and overall energy consumption estimation **(Lin et al., 2011)**. MOVES capacity to produce project-level emissions inventory is a crucial characteristic that distinguishes it from other emission models. The most detailed level of analysis in MOVES is project level analysis, which analyzes a single roadway connection, a set of specific roadway links, and an off-network common space like parking spaces. Simulation at a granular level is used to examine more targeted emissions. MOVES can estimate both emission components and total emissions **(Koupal et al., 2013)**. Taking into account the ability to model dynamic emissions MOVES emission model is selected for this study.

3. OmniTRANS

From the above presented literature review, OmniTRANS is selected as the simulation tool for this research. In this chapter, working of OmniTRANS explained in detail which includes Streamline which is a dynamic traffic assignment framework in OmniTRANS. Section 3.1 explains the different types of assignment and mentions the type of assignment used in this research. Section 3.2 gives an overview of the working of traffic assignment in OmniTRANS. Finally section 3.3 describes the operation of StreamLine and gives a overview of the steps Streamline follows during a simulation.

3.1. 4-Stage modeling process

For every Origin-Destination pairs to calculate the link flows 4 stage model is used. The output of each model is used as input for the next model. The first stage of the four-stage modeling process is the trip generation where trip productions (number of trips produced by each zone) and attractions (number of trips attracted to each zone) are determined. These production and attractions are estimated based on zonal data. The next stage is a trip distribution where the destination choice of the travelers is modeled based on the relative attractiveness of the destinations. The third stage of the modeling process is model split which calculates the distribution of different modes that are used in the model **(McNally et al., 2007)**. In this research, only the car mode is modeled. The modal split is calculated along with the trip distribution using a simultaneous distribution/modal split.

Finally in the assignment stage the loads on the network for each mode are calculated. There are four types of assignment: AON (All or nothing) assignment, Stochastic assignment, DUE (Deterministic User equilibrium) assignment, and SUE (Stochastic User equilibrium) assignment. All or Nothing (AON) does not take congestion into account and assumes that all traffic between an OD pair is assigned to just one route which is the shortest route, while Deterministic user equilibrium (DUE) takes congestion effects into account and assigns traffic in such a way that no individual traveler can improve his/her travel time by changing the routes. In DUE equilibrium is reached under the following condition: All used routes have the same travel time which is not greater than the travel time on any unused route. Stochastic assignment like AON does not model congestion effects and where for each OD-pair all travelers take their perceived shortest route. Finally SUE models both congestion and traveller consider a set of alternative routes. In SUE equilibrium is reached when all travellers choose their optimal route, such that no traveller can improve his/her perceived travel time by unilaterally changing routes **(McNally et al., 2007)**. For this research Stochastic user equilibrium assignment is employed as we model both multiple routes and congestion.

3.2. Overview of traffic assignment in OmniTRANS

4-Stage model is divided into two main modeling components: Demand and Supply modeling. Trip generation, distribution, and modal split are part of Demand modeling where people's travel behavior is utilized to predict future travel data utilizing specific modes in specific periods. Assignment or Supply modeling is the last stage of the modeling process where the demand calculated using demand models is assigned to the corresponding network to estimate the flows **(de Dios Ortúzar and Willumsen, 2011)**. In this research, the main focus is on traffic assignment.

Based on the classification of assignments in the above subsection there are two major distinctions: Static and Dynamic assignment. The dynamic traffic assignment model using in OmniTRANS is StreamLine which determines the dynamic user equilibrium and MADAM is a macroscopic traffic propagation model in StreamLine within the DTA (Dynamic Traffic Assignment) framework which simulates route flows. The dynamic traffic assignment consists of dynamic route choice and dynamic network loading, the route choice model determines how the time-dependent traffic demand is allocated among the alternative routes based on the initial costs. The dynamic network loading model uses the traffic flow theory and the outcomes are dynamic link and route flows, dynamic link travel time, and route travel costs **(Kwak, 2011)**.

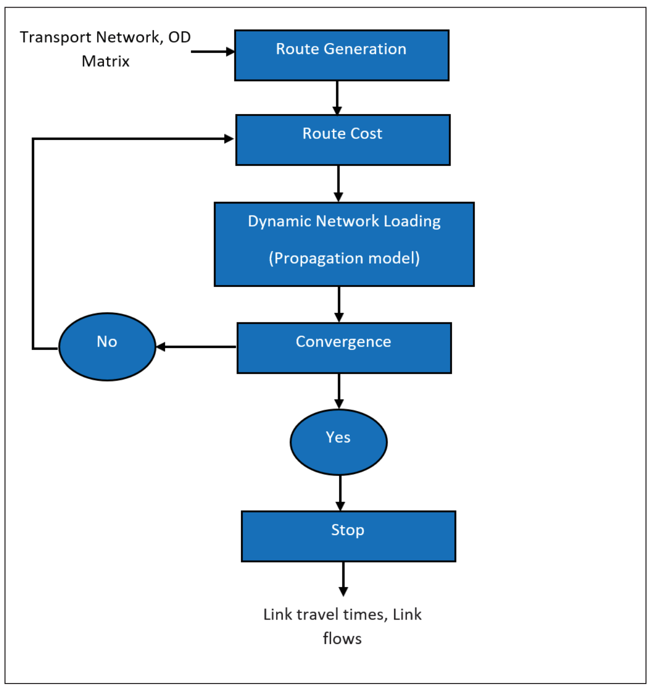


Figure 3: Streamline Framework: Dynamic assignment

3.3. Theoretical Background on Streamline

3.3.1. Route set generation

As discussed in the above section StreamLine is a dynamic traffic assignment framework in OmniTRANS and it follows the following steps to determine the dynamic user equilibrium. The first step is route generation, where Dijkstra Algorithm is used to find the shortest path between the OD pairs. To include the stochasticity and to filter routes for overlap Monte Carlo simulation is used to randomize the cost on all links and to generate a number of alternative routes for each OD pair. The maximum number of iterations and variance is set initially to generate the route set **(Dijkhuis, 2012)**. Finally, route filtering is applied which filters routes based on overlap in the route set and detours. Route generator has four possibilities to control the frequency at which the generated routes are persisted, they are, routes can be generated from one origin to all destination, all origins to one destination, one origin to one destination, all origin to all destination. In this research, routes are generated from one origin to all destination as it has the best compromise between the performance and memory usage when comparing to all to all which uses a lot of memory and one to one which leads to a decrease in the performance.

3.3.2. Route cost

Next is the calculation of route cost for alternative routes. Based on the dynamic link speed, density, and travel time the route costs are calculated during several route choice moments in the simulation where the route fractions of all the alternative routes are calculated for every OD pair. To calculate route cost StreamLine supports both reactive or predictive approaches. The reactive approach uses the instantaneous costs on links in the middle of the route choice period. These instantaneous costs are calculated by MaDAM. While the predictive approach uses the predicted travel time cost of the previous iteration. This predicted travel time is trajectory-based travel time and is more accurate than the instantaneous approach however it is more time-expensive to compute these values **(Dijkhuis, 2012)**. There are two methods available for calculating predictive route costs, first is based on the cumulative vehicles and the second is based on average link speeds **(Rashidy, 2014)**. In research reactive approach is used predictive is used only when the initial route data set is available.

3.3.3. Route Choice

After the route cost is calculated it is compared across the alternative routes and based on this comparison StreamLine calculates the percentage of traffic choosing the specific route at each route choice moments. StreamLine offers different method to distribute the demand among various alternatives routes between an OD-pair like All or Nothing where all route alternatives receive the same proportion of traffic regardless of the calculated cost, Uniform where route alternatives with least cost receives all traffic while other alternatives receive nothing and Multinominal Logit where all the alternative routes receive a proportion of traffic, route alternatives with least cost receives more traffic compared to routes with higher cost.

3.3.4. Propagation model

The Propagation model for StreamLine is MaDAM which is a macroscopic model that handles traffic flow using aggregated variables. It is a cell-based model where the links are split into equal lengthened sections called the cells where the length is equal to the distance traveled by the vehicle in a one-time interval and each cell carries information like speed, density, and traffic flow **(Kant, 2008)**. These properties are equal for all the vehicles in the cell and at each time step traffic state

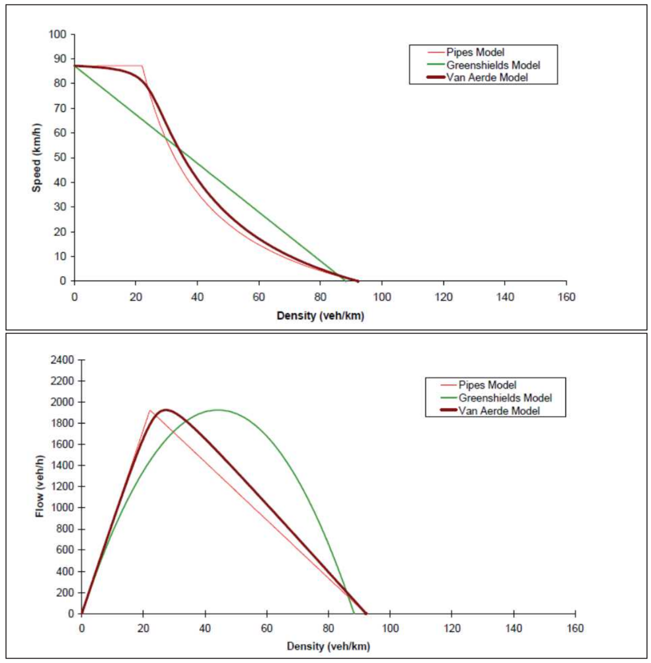


Figure 4: Comparison of three fundamental diagram (Triangular, Greenshield and Van Aerde) showing releation between (a) flow and density (b) speed and density **(Wu and Rakha, 2009)**

is updated as vehicles move from one cell to another based on FIFO (First in First out) Principe **(Jagersma et al., 2015)**.

MaDAM uses the Van Aerde fundamental diagram which defines the relationship between flow and density. They can describe how the queues that are formed at the link propagates upstream to cause spill back to the upstream link. The Figure 4 shows the Van Aerde fundamental diagram, it can be seen that the speed of the vehicle decreased when approaching the road capacity. The model has four input parameters: the speed under road capacity called speedatcap, the maximum flow of a road segment referred to as satflow, jam density and the maximum speed is designated as free speed. These parameters are fixed and are set for every link in the network before the simulation starts.

Jagersma and Brederode (2018) states that the model was later extended by adding car following rule which incorporates three main components. First is the relaxation component where traffic is settled to an equilibrium speed which is the input of the fundamental diagram. Second is the convection component describes the change in speed due to the arrival and departure of the vehicle. Finally, the anticipation component deals with the effect of traffic flow on the concentration conditions downstream of the road. This extended car following model developed by **Payne (1971)** is a second order model describing the conservation of vehicles and velocity dynamics.

4. Simulation module 1: Transport Network Modelling

4.1. Area of research

In this research A10 West is chosen for the major construction and maintenance works and to analyze and quantify the emissions from traffic when diverted to other routes. One reason underpinning this choice is that A10 West attracts majority of the traffic and contributes to frequent traffic jams as it has many on- and off-ramps. A10 ring road have totally 32 Ramp metering systems, A10 west has on and off-ramps every 1.7 km **(CBS, 2019)**. Another reason is that A10 West highway cuts through the residential area which can provide more insights into timing of construction, emission and also the presence of many city routes.

In this subsection the study area within which the transport flows are of interest and the area which is chosen for planning the road works are introduced. In this research the study area is the A10 ring road as Rijkswaterstaat is working on better accessibility of the area. A10 motorway is a ring road around the city of Amsterdam of length 32 km. As Amsterdam is the financial capital of Netherlands it attracts more trips into the area. A10 is recorded as the second busiest highway in Netherlands with an average of 4374 vehicles per hour **(CBS, 2019)** and is divided into 4 sections: A10 North, A10 West, A10 East, A10 West.

A10 has totally 19 S-routes or city routes named from S100 to S118 route leading to the city centre. While A10 West has 7 S-routes, namely S101 which is the short city route in Amsterdam of 4 km, S102 longest city route in Amsterdam of 12 km, S103 running through routes like Bos en Lommer and Sloterdijk, S104 another shortest city route running through Bos en Lommer, Slotermeer and connecting to s103 S105 running through Geuzenveld and Slotermeer, S106 running through Slotervaart and Osdorp, S107 starting from S106 and ends with hamlet of Lijnden on S106. Also A10 West runs over the provincial road N200 but it does not have any physical crossing between these two roads. Two other motorways connected to A10 west are A4 and A5, A4 is in one of the top five busiest motorways in Netherlands with an average of 3200 vehicles per hour. Figure 5 shows the city routes and the provincial road that runs through the study area.

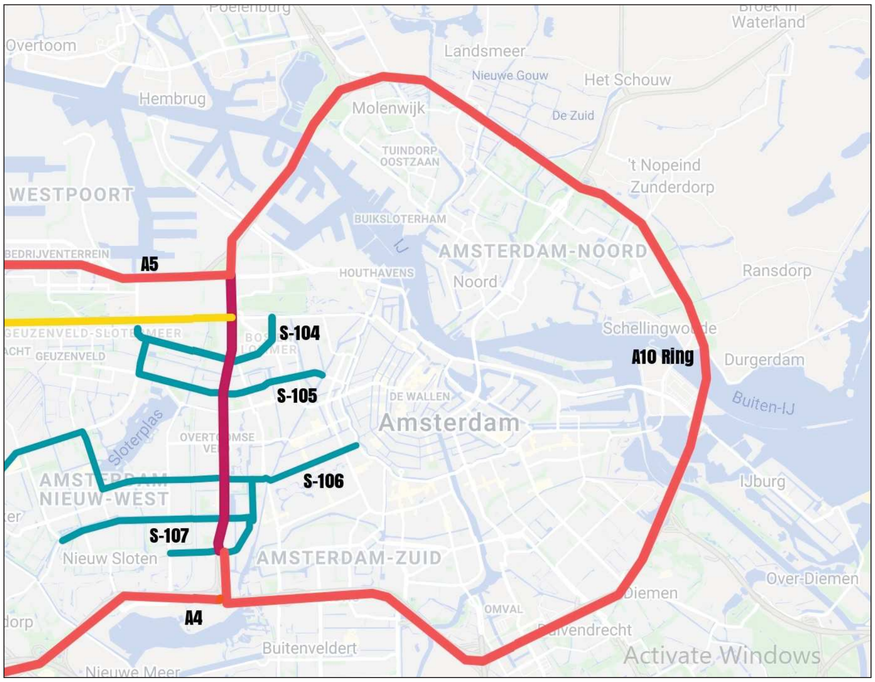


Figure 5: Study Area - A10

4.2. Network preparation and project setup

The first step of traffic simulation is network preparation and data collection and processing. The road networks of the Amsterdam region are already modeled in OmniTRANS. The primary features of the OmniTRANS project are dimensions, network, job, and variants. Dimensions define what kind of traffic modeling data is considered. All the important data and results are stored in the matrix cube under six dimensions PMTURI- Purpose, Mode, Time, User, Result, and Iteration. In this research main vehicle mode with a sub mode car is used and the time dimension is structured according to dynamic time mapping which accommodates 24 hour time period with a 5 minutes time block. And the result dimension is defined to store the assignment results like travel time, lost time, distance. The results for each iteration is stored under the assignment results. The Omnitrans network corresponds to the Amsterdam region. Another feature is the Job Engine, and this is where the calculations and model processing take place. To specify the process, job scripts are written in the job engine. Finally, there are variants and sub-variants for each Omnitrans project to characterize the network. In this research variant describes road construction on the A10 Network, with sub-variants describing different days of the week.

Another important data for the OmniTRANS project is the OD Matrix. The OD matrix contains the value of the number of trips made from each origin to each destination and is stored in the form of a matrix cube under each variant. The OD matrix can be estimated based the traffic counts in the study area. **Savrasovs and Pticina (2017)** describes different methodologies to estimate the OD matrix based on traffic counts. Some of the widely used models are growth factors, gravity model, information minimization (IM) and entropy maximization (EM), OD estimation from license plate surveys, automatic vehicle identification data.

For this research, the OD matrix for period 14:30 to 20:00 with 350 centroids was already available from Rijkswaterstaat. Also, the data on different link types in the network such as capacity, free speed, speed at capacity, saturation flow, road type, directions are included in the network provided by Rijkswaterstaat. The code used for modeling the assignment is given in Appendix A.

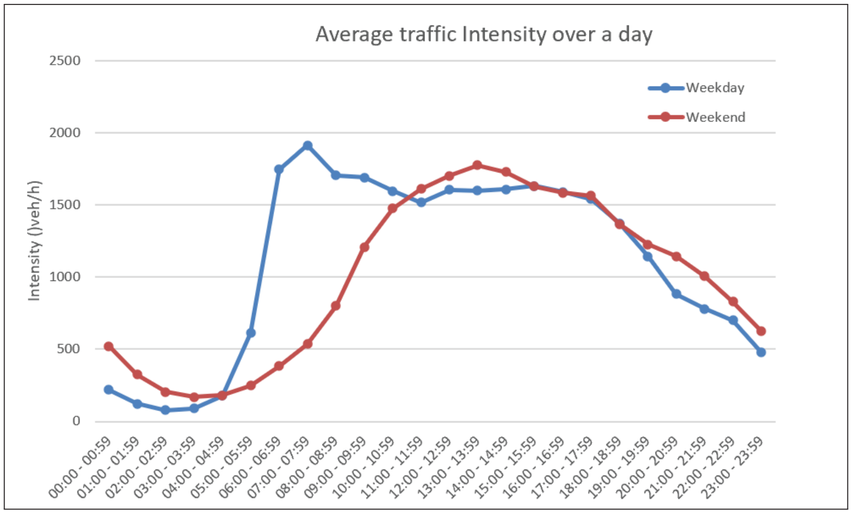


Figure 6: Traffic intensity over a day from 02-2019 to 09-2019

However to analyze the morning time scenarios , the part of the OD matrix for morning time should be calculated. These data on link volume, intensity, speed counts are calculated routinely by road authorities. For this research data are collected from NDW (Nationaal Dataportaal Wegverkeer) which is a national access point for road traffic data in Netherlands. The average vehicle distribution per hour is collected for different sections of A10 motorways and the 24 hour traffic flow pattern was calculated from the data. Totally 10 measurement locations like Coenplein, Watergraafsmeer, Amstel, De Nieuwe Meer, including the exit and access roads along A10 like A2 to northbound in the direction of Zaanstad / Amsterdam-Oost, A1 westbound in the direction of Zaandam, A8 eastbound of zaandam were selected along the A10 motorways . Traffic flow data from February 2019 to November 2019 was used with and exception of weekends, National holidays. After gathering the data it was checked for plausibility and error. All the data was reconstructed for 15 minute travel interval and the pattern of traffic movement was analyzed. This pattern is then applied to the OD Matrix provided by the Rijkswaterstaat and imported to OmniTRANS under a new matrix cube.

To analyse weekend scenarios a separate OD matrix is calculated using the data collected from NDW. For this, the average vehicle distribution per hour is collected for the same measurement locations as above for weekends and the data was constructed for the 15 minutes interval. The pattern of traffic for weekend was compared to the weekdays traffic pattern. The difference is applied to OD matrix for each time interval and stored under a new variant matrix cube.

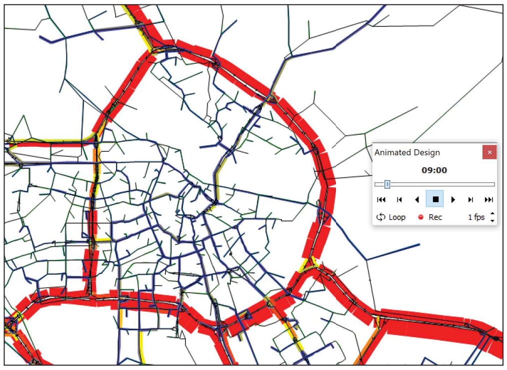
4.3. Verification

4.3.1. Implementation of outflow limiter control

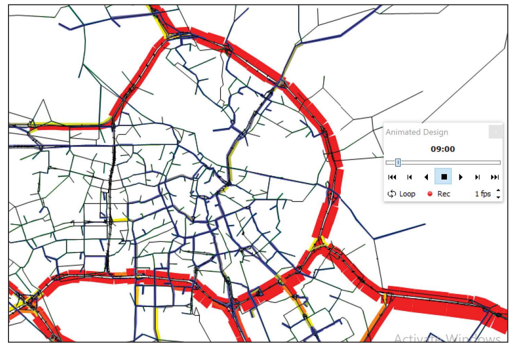
Before calculating the traffic flow variable, the given network is verified to ensure that the network produces accurate results. This is done by implementing the controls to the network and comparing the performance. Six different traffic management controls are available in OmniTRANs such as Ramp metering, Dynamic Variable message sign, Static variable message sign, Lane adaptor, Dynamic Link attribute adaptor, Outflow limiter. In this section Outflow limiter control is applied to the links along A10 West as shown in Figure 7 and a test simulation was conducted. Totally seven controls were implemented and the outflow of 0 veh/h/lane is set to the links from 08:00 to 9:00 and the link flows (average volume of vehicles on the link for the aggregated time step) veh/hour is visualized using animated bandwidth. This is done for both the variants with control and without control. The bandwidth plot for the link flows on the network before and after applying the control is shown in the Figure 8a. The colors in the plot represent the extent of congestion on the link. In the Figure 8b it can be seen that the flow on there is no flow on the A10 west highway and Figure 8c represents the comparison of the flow before (represented by dark blue) and after (represented by green) applying the control.

Figure 7: Implementation of Outflow Limiter

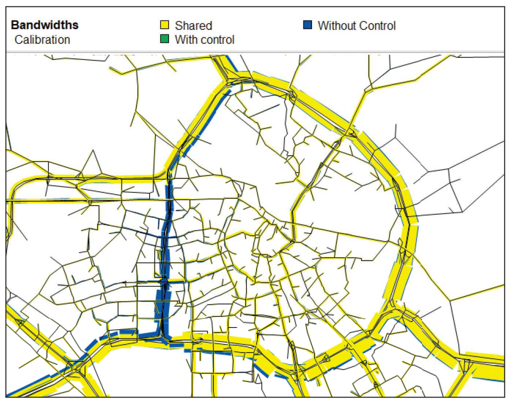
Verification is done by comparing the congestion pattern in the simulation with the traffic data provided. Google maps provide the historical traffic patterns of road network over time, they update both live traffic as well as typical traffic conditions throughout the day. Typical traffic allows to pick the day and time to visualize how the traffic looked like historically but it does not allow to select the date. While TomTom Traffic Index provides detailed insights on live and



(a) Flow at 9:00 without outflow limiter control



(b) Flow at 9:00 with outflow limiter control



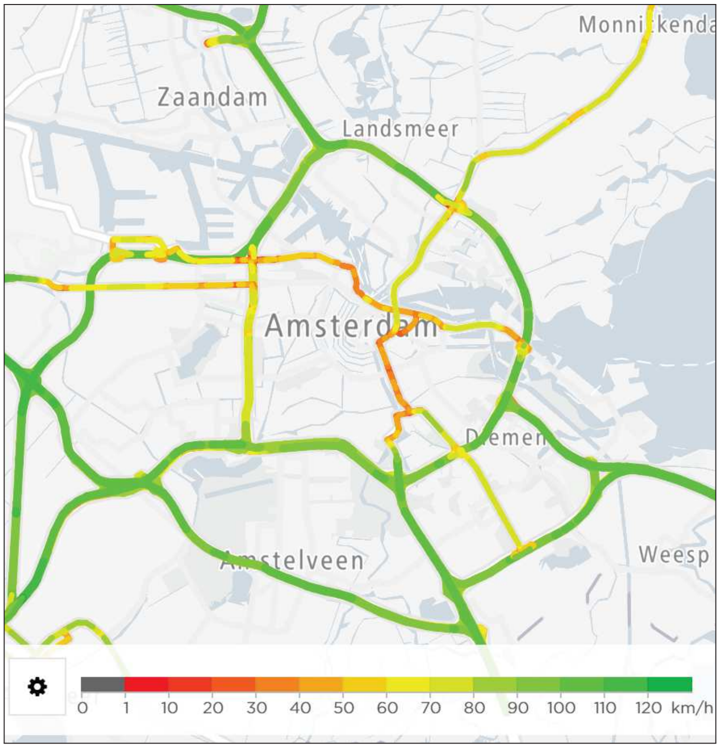
(c) Comparing attributes using bandwidth designer

Figure 8: Comparing the link flows on the network before and after applying the control

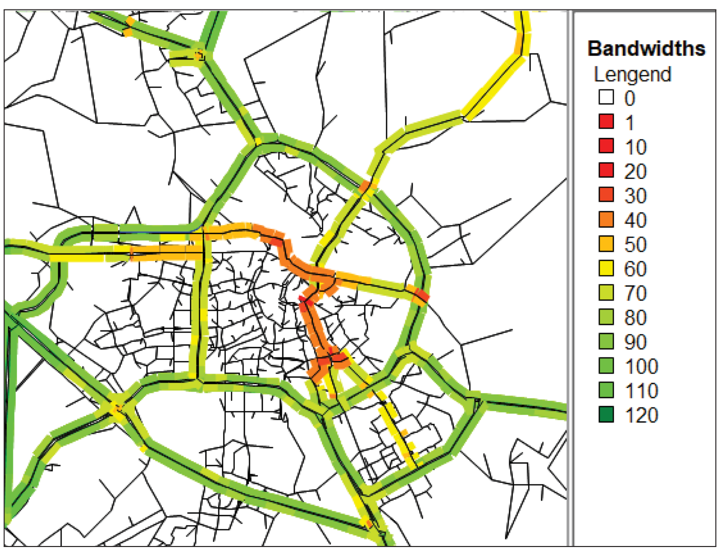
historic road congestion levels on a specific date of the year. The historical traffic data extracted from the TomTom Traffic Stats portal is compared with the traffic condition in the network with the bandwidth plot. Typical traffic condition for Monday during morning rush hour traffic pattern of A10 can be seen in Figure 9a and 9b. It can be noted that the model is consistent with the traffic data, especially along the main highway lines.

4.4. Scenarios Implemented

For one of the busiest motorway network in the Netherlands like A10, planning a road work is demanding as people are continuously in motion. Depending on the type of road work and characteristics of the road like the length, number of lanes, width a road work can be planned for different time of the day. Traffic flow in these work zones can be affected as one or more lanes become unavailable leading to bottlenecks resulting in queues and delay. There are different factors responsible for increased CO2 emissions during the process of road work. Congestion due to the capacity reduction from the road work contributes to this due to increased idling, acceleration and braking . The main trade-off in this case is between the duration of the road work and the capacity



(a) Typical traffic 8.00 AM retrieved from TomTom



(b) Traffic speed plot from OmniTRANS at 8.00 AM

Figure 9: Morning rush hour traffic pattern in the A10 region Amsterdam

of the road. As decreasing the capacity for a longer period of time would directly increase the total emissions from the construction. Short term road work with full closure scenarios gives a lower capacity compared to the long term road work with partial road closures. Therefore a comparison is made between the full closure of the road during construction which has shorter duration of work compared to intermittent or partial road closure.

The time of day and the day of the week are other crucial factors to consider when planning a road project. Because different days of the week have varied usual travel speeds, the amount of emissions generated by the vehicle is also affected by speed. The amount of traffic, the number of trips, the time of travel, and the method of travel are all factors that influence traffic flow variables during road construction. When these factors are analyzed, they differ significantly between weekdays and weekends. Weekend traffic, for example, is relatively low compared to weekday traffic, but the number of kilometers traveled is larger on weekends since commuters take longer excursions on weekends. While the number of trips taken on weekdays is higher because there are far more educational and homework-related trips, there are solely recreational and social outings on weekends. Also, there is a significant difference in the timing of these travels on weekdays versus weekends; weekday peak hours are generally before 9:00 a.m., whereas weekend peak hours are after 9:00 a.m. and into the evening.

In highways the congestion occurs during weekday peak hours when there are more work to home or home to work trips. Planning a highway maintenance project during these times tend to increase the congestion further as there will be more traffic using limited lanes while the other lanes are occupied for road works which in turn leads to a capacity drop and increases the emission. So choosing the time of the day during which the road work should take place has an important role to play as it directly affects the amount of emissions, productivity, quality, safety of workers in the construction site. Weekdays and weekends are the two different scenarios investigated in this research for full and partial closure scenarios. Because the traffic conditions on weekends differ from traffic conditions on weekdays.

Some of the reasons for choosing different day of the week are for construction / maintenance works are while performing a night-time construction work during weekends there is possibility to save time, **Wahid et al. (2014)** describes this in detail. When conducting road works at night combining the off-peak day times during weekdays are considered effective. Also the traffic flow during road works constitutes for movement of machinery's around the construction site. Carrying the works during off-peak hour or weekends can make this transport of machinery's faster without any delays. In this research full and partial road closure for the weekdays and weekends are the two day of the week scenarios considered. And the emissions are calculated for the whole project duration.

Scenario	Strategy	Type	Description
Scenario 1	Full road closure	Full day closure	24-hour closure for 42 days
Scenario 2		Full closure weekends	24-hour closure only on weekends for 42 days
Scenario 3	Partial road closure	Partial closure	24-hour closure for 84 days
Scenario 4		Partial closure weekends	24-hour closure only on weekends for 84 days

Table 3: Scenarios

4.5. Full road Closure

FHWA (2014) defines full road closure as ”the removal or suspension of traffic operations either directionally or bi-bidirectionally from a segment of the roadway for the purpose of construction activities”. The full Road closure is considered one of the potentially efficient ways for road works as it can reduce the project span significantly which have significant impact on the emissions, additionally improve product quality, and incorporates the safety of the road users and workers compared to the partial road closure **(Hourdos, 2010)**. Rijkswaterstaat has used full road closure on different projects such as the renovation of bridges like Tacitus Bridge and many others. The main reason for using the full closure strategy in these projects was to renovate without hindrance. Other reasons for adopting full closure is that it has the potential to accelerate project completion especially when there is pressure on the time limit, narrows the impact of works on road users, increases the availability of work space and flexibility which in turn increases the efficiency, less traffic disturbance increases the productivity diminish overall congestion associated to road works and improve safety for operators as they are not exposed to traffic like in partial closure.

4.5.1. Scenario 1: Full day closure

In this scenario, all the lanes are completely closed for work on a 24-hour basis. Full-day closure enables a longer period of uninterrupted work which can result in increased productivity with a limited amount of time. For this scenario 5 km stretch of A10 west motorways is fully closed for major maintenance work. The roads are closed for the entire day meaning that considerable savings in time required for completion of roadworks achieved faster, despite the number of operational lanes is lower compared to other scenarios.Green-blue-yellow-red plots in the Figure 10 represents the volume of vehicles on the link per hour at 8:30. It can be seen from the plots that maximum flows are along the ring road following the city routes.

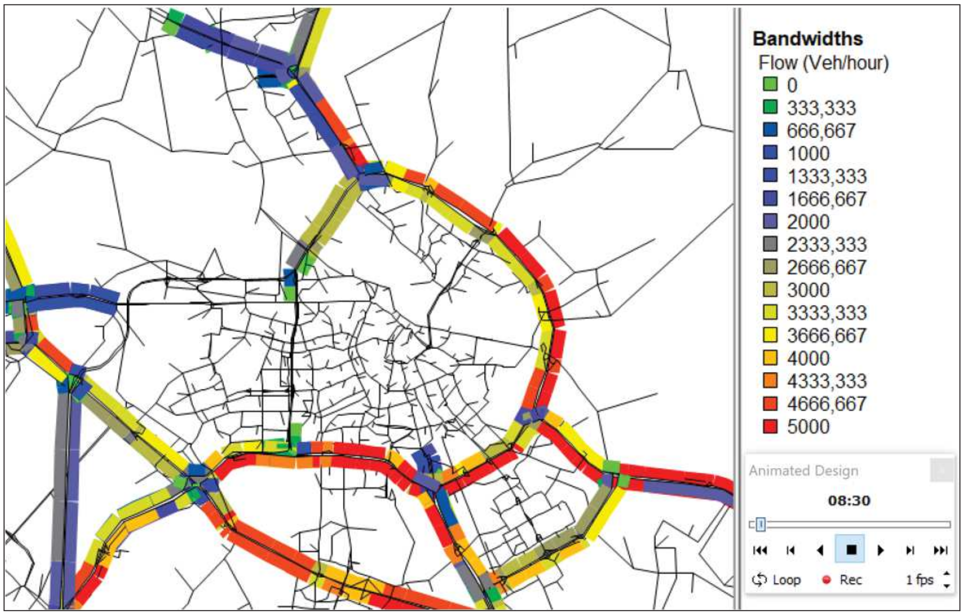


Figure 10: Scenario 1- Flow plot from OmniTRANS at 08:30

The flow curves for different parts of the A10 Network like A10 North, South, East and city routes like S105, S106 and S107 passing through the A10 West motorway network is generated using the reports from Omnitrans. For each location the flow for each scenario is calculated throughout the day and is compared with the base scenario without any controls as presented in the Figures 11, 54, 55, 56, 12, 57. Scenario 1 represents the full road closure for A10 west motorway throughout the day only during weekdays. As observed from the figures there is a major increase in the flow for the other parts of the A10 motorway network specifically in A10 north and A10 east after implementing the controls for road works compared to A10 South. This is because traffic from the A1, A2, and perhaps other provincial roads like N247, N516, N522 heading for the A5 must take the A10 east and north.

The city routes via A10 west has overall less flow as compared to the main network particularly the upper parts of the A10 west motorways like S105, this could be due to the shutdown of certain parts of these city routes that cross the A10 west network, which is blocked for maintenance work, whereas other routes of the network like S106 and S107 experience increased flow. This increased flow causes congestion in that location, as evidenced by the speed contour plots in the Figure 25, which indicate a larger area of congestion when compared to the corresponding baseline scenario in Figure 26. Also, among all other city routes, S106 has the largest overall flow. This may be attributed to the route's length, as well as the fact that it is one of the major interconnecting routes for the Amsterdam nieuw west with the main network.

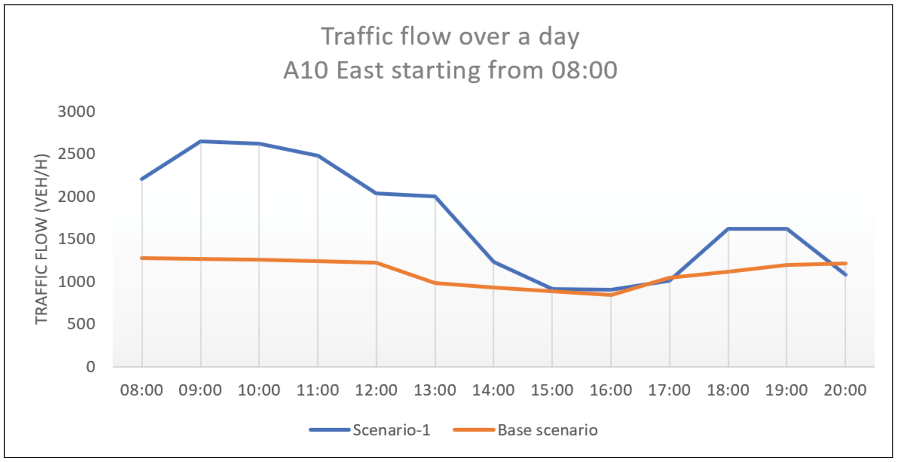


Figure 11: Traffic flow changes over a day for Scenario 1-A10 East

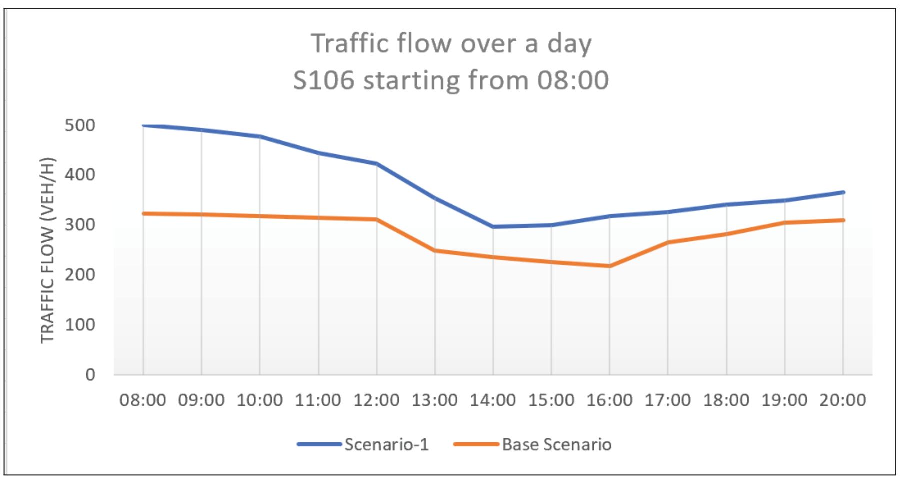


Figure 12: Traffic flow changes over a day for Scenario 1-City Route S106

In terms of the time of the flow effects on the main network, it can be seen that there is a significant increase in the flow from 8:00 to 12:00 in the morning peak, and the flow stabilizes from 13:00. Between 15:00 to 17:00, the flow is remarkably similar to the flow in the base scenario without any intervention. At the evening peak, the flow rises again, from 17:00 to 20:00. While on city roads, the flow increases steadily throughout the day with no unexpected peaks, with the exception of s106, which has a higher flow in the morning comparison to the majority of the day.
Figure 26 depicts the speed contours for the full closure scenario for the main network, whereas Figure 25 depicts the speed contours for the city routes. From 07:00 to 08:30, the A10 west was completely closed, resulting in a 3-kilometer long congestion in the A10 south zone. While locations such as the east and north have huge queues throughout the day. This is supported by the flow numbers, which show that, in comparison to the other networks, A10 south has the

lowest total increased flow owing to the shutdown of A10 west. Without any intervention, there is virtually any congestion when comparing the contour plots for city roads. However, since the roadworks began, S107 has experienced minor congestion in the morning hours.

4.5.2. Scenario 2: Full closure weekends

Weekend closure starts from Friday after evening hour until Monday morning before peak hour. Research shows that many contractors would prefer a weekend closure for road works as it would enable them to work on all lanes for a long period with minimum interference. Research by **Dunston et al. (2000)** shows that average shift production rates for the weekend closure were higher than other closure types such as nighttime employing similar equipment. **Herbsman and Glagola (1998)** interprets that the quality for the weekend closure was good concerning smoothness, density, gradation, and cyclic segregation. These are some of the facts that support the success of the weekend closure strategy.

This scenario also represent the full closure of 5 km stretch except for this scenario weekend OD matrix cube is used. Figure 13 represents the volume of vehicles on the link per hour at 8:30, it can be seen that comparing scenario 1 there is high load on the ring road and A5. During weekends traffic loads increase gradually, compared to other scenarios in week days. According to research **Agarwal (2004)** by weekend is traffic is peeked between 10:00 to 17:00 while weekday volumes is considerably high due to work commutes.

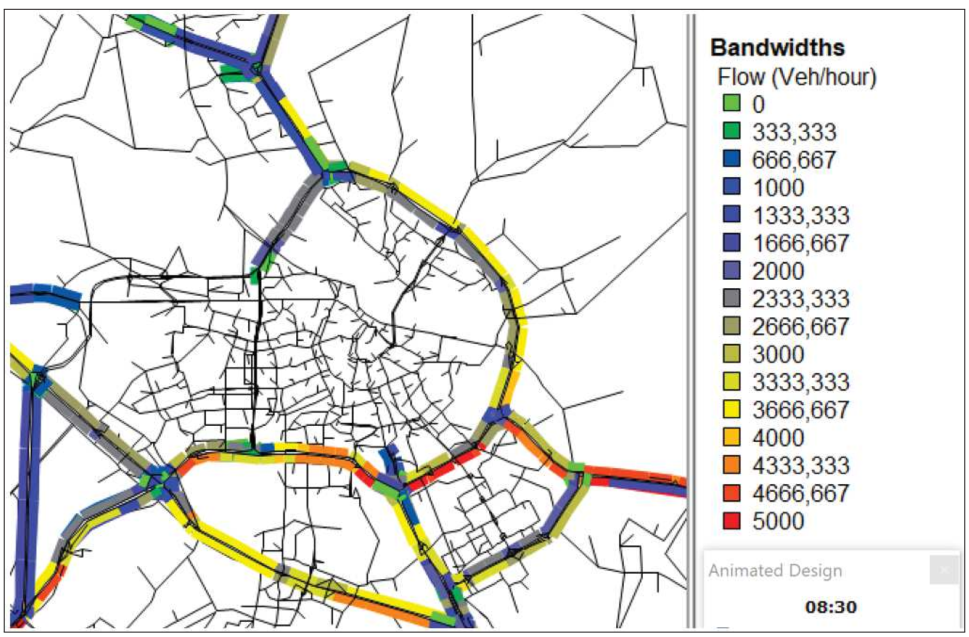


Figure 13: Scenario 2- Flow plot from OmniTRANS at 8:30 (Weekend)

The figures 14, 58, 59, 60, 15, 61 represents the flow curves for each location for scenario 2 where the road works are carried out only during the weekends. These are the flow curves for weekend full closure scenario. These flow curves are compared to the base case scenario which is which is weekend traffic flow without any controls. When analyzing the flow curves for scenarios 1 and 2, the A10 east and north has more traffic during the weekdays, with morning and evening rush hours, but traffic increases gradually during the morning and stays stable throughout the day on weekends, with no major peaks. Similar to the weekday scenario, s106 has the highest reported traffic for city routes, owing to its placement close to Amsterdam neiuw west region and also being the longest city route.

When looking at the speed contour plots (Figure 26), the A10 south has the longest queue length, with just two big congestion events throughout the day, owing to the lower traffic in that area, but the A10 east has heavy congestion for the whole day. Remarkably, the A10 north does not experience considerable congestion throughout the day, as it does on weekdays. This is due to the fact that traffic flow on weekends is much lower in that region than on weekdays, which could be related to the proximity to recreational areas to the A10 east and south. While for the city routes, s105 has the occurrence of congestion at 10:00 and 19:00.

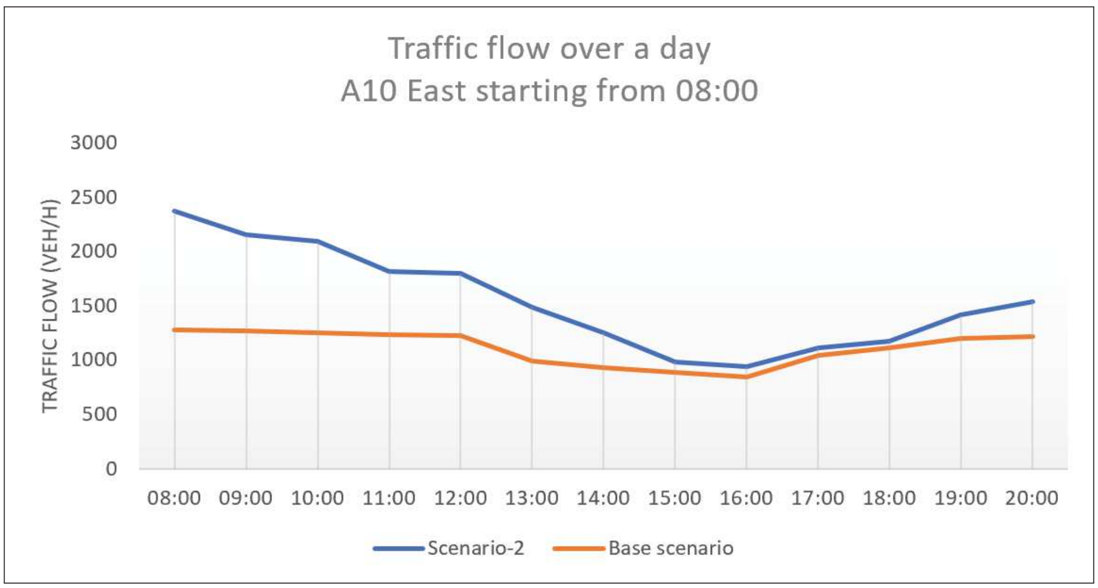


Figure 14: Traffic flow changes over a day for Scenario 2-A10 East

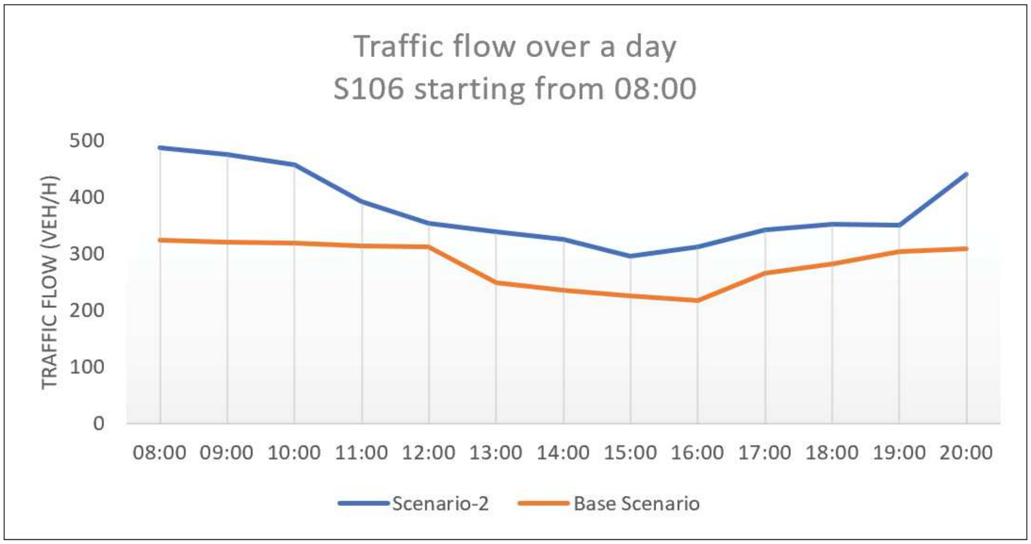


Figure 15: Traffic flow changes over a day for Scenario 2-City Route S106

Shown in the Figure 16 are the impact of the full road closure on the A10 West motorway. In this figure the region marked in red represent change in the flow values from the base case scenarios without the road work for the full closure during the weekdays (scenario 1) and the blue region represent the full closure during the weekend (scenario 2). This figure shows that the city routes near the A10 West highway are most affected from the road works when compared to the motorway network.

Similar to scenario 1 the flow curves for each location are compared with the base scenario which is weekend traffic flow without any controls. Based on the flow figures, it is observed that the city routes passing through A10 west motorways like S105 and S106 have increased flows when compared to main A10 motorways like A10 East and A10 North. While city routes at the lower part of the A10 west like S107 motorway have very less flow unlike scenario 1. This can be proved from Figure 16, flows for scenario 1 is higher than scenario 2. For example during scenario 1 A10 North has 31.4 % increase in total flow comparing to scenario 2, while other motorway networks does not have significant increase. A10 south has a decrease of 0.5 % of traffic while the east has a increase of 7.2 % of traffic flow during scenario 1 comparing to scenario 2. This shows that during scenario 1 most of the traffic are diverted towards A10 North. Upper parts of A10 West has 4.1 % increase in the flow during scenario 2 while other city routes S107 has increased traffic during scenario 1 compared to scenario 2.

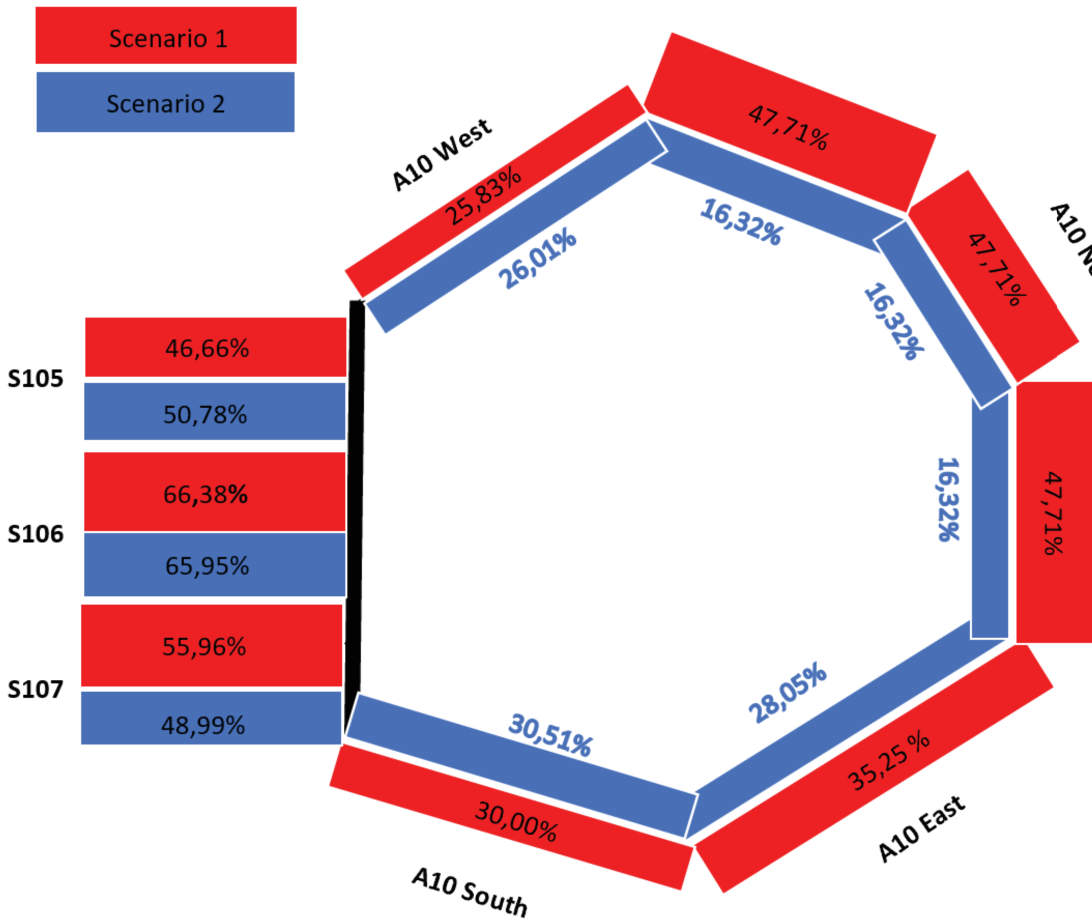


Figure 16: Flow map of Amsterdam network (percentage increase in the traffic flow both the directions during road work)

4.6. Intermittent road closure

The partial closure where the road is closed along one direction giving way for the traffic rather than detouring the traffic like full closure scenarios. The main difference between these two approaches is that whether they are done simultaneously or sequentially along with access roads. Intermittent road closures are performed to reduce the impact of road works to the road users and local community **(Dunston et al., 2000)**. This is one of the least disturbing strategies to the public as it allows it to obstructs traffic in one direction only. There is a high influence on the residents like congestion in alternative routes in full closure alternative which is mostly scheduled for full-day 24-hour basis and this can be reduced by partial closure. For the length of the A10 west, a full day closure of the road in one direction is preferred to intermittent lane closures or only nighttime road closures for maintenance work because a full day closure saves more time for the entire project than conducting maintenance work only at night or with limited lane closures. The longer the project persists, the more construction/maintenance impacts are exposed to travelers and residents residing close to the construction site.

4.6.1. Scenario 3: Partial road closure

For this scenario 5 km stretch of the A10-West motorway is partially closed for work and traffic is open in one direction from south to north. Figure 17 represents the volume of vehicles on the link per hour at 8:30 when the traffic is partially open from north to south. Due the the reduction in the number of the lanes there is a significant reduction in the capacity which can lead to bottlenecks.

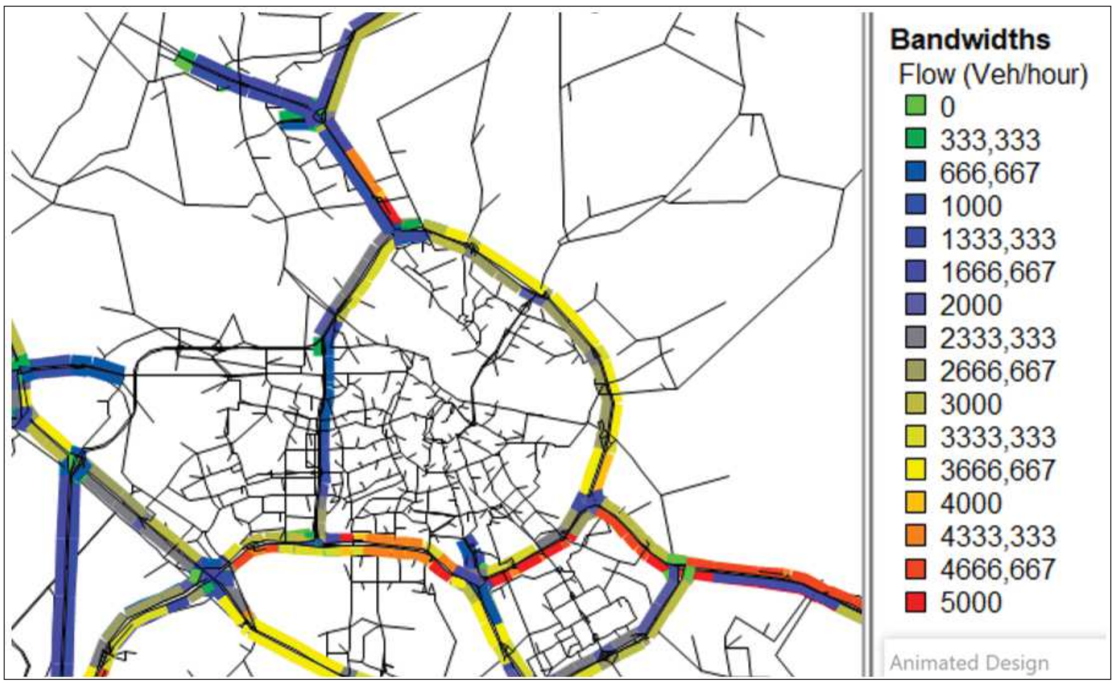


Figure 17: Scenario 3- Flow plot from OmniTRANS at 8:30

The figures 18, 62, 63, 64, 19, 65 are the traffic flow curves for different parts of the A10 Motorway network and city routes around the A10 west motorway. During the partial closure of the A10 west region, A10 east is the most significantly affected area, with about double the real flow and mild congestion throughout the day. The north and south adjacent zones to the A10 west operate normally without interruption; as seen in the flow figures, their flow is almost identical to the flow prior to the road work intervention. They're also experiencing congested throughout the morning and evening rush hours.There will be a considerable traffic flow in the south and eastern ring roads with traffic entering and exiting the A2 and A1 highways with the A10 west only functional 50% of the time where traffic is open in a clockwise orientation from west into the southern area or from A10 towards A4 and A2. For the city routes the traffic flow is almost similar to the the full road closure scenario.

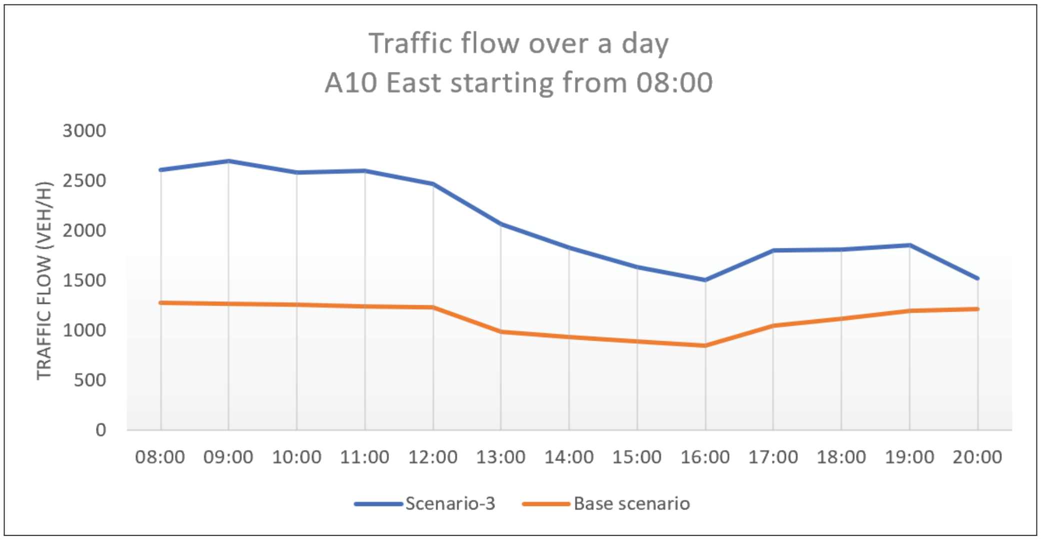


Figure 18: Traffic flow changes over a day for Scenario 3-A10 East

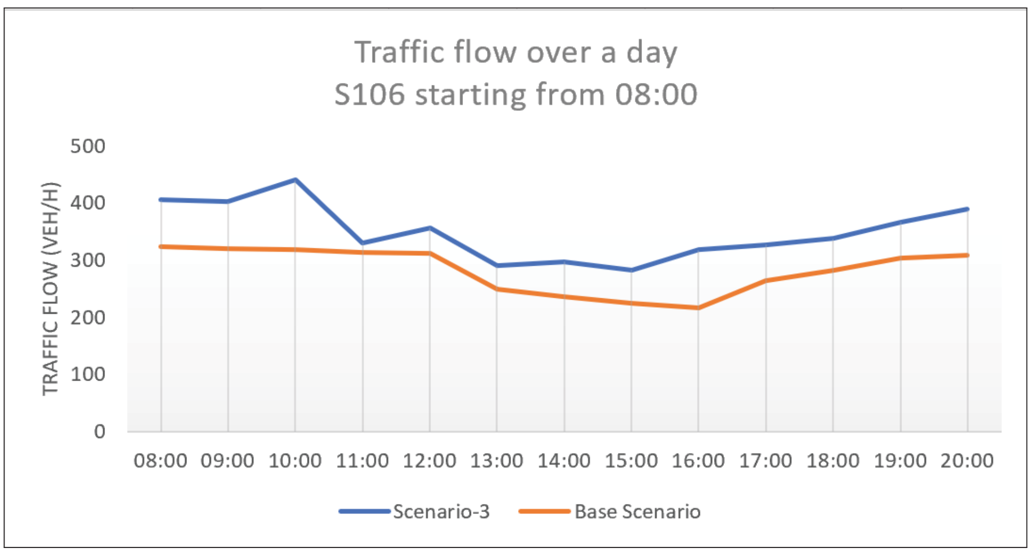


Figure 19: Traffic flow changes over a day for Scenario 3-City route S106

4.6.2. Scenario 4: Partial road closure Weekends

This is similar to scenario represented above, partial closure of 5 km stretch where the traffic is open from north to south on weekends. Figure 20 represents the volume of vehicles on the link per hour at 8:30 on a weekend when the traffic is partially closed from south to north.

The figures 21, 66, 67, 68, 22, 69 represents the flow curves for each location for scenario 4 where the road works are carried out only during the weekends with partial closure. These flow curves are compared to the base case scenario which is which is weekend traffic flow without any controls. Shown in the Figure 23 are the impact of the intermittent road closure on the A10 West motorway. In this figure the region marked in yellow represent change in the flow values from the base case scenarios without the road work for the intermittent closure during the weekdays (scenario 3) and the green region represent the intermittent closure during the weekend (scenario 4).

Based on the flow figures, it is observed that the A10 East has very less or close to the flows of base case without any controls while A10 North and South has a modest increase in traffic flow when compared to the base case. Similar to scenario 3 S106 has increased traffic flow compared to the other city routes S105 and S107. This can been seen from figure 23, S106 has a 63.2 % and 64.2 % increase in the total traffic flow for scenarios 3 and 4. While the other city routes have 50.9 % and 49 % increase for scenario 3 and 41.6 % and 50.5 % increase for scenario 4. The main motorway network has a very less increase in traffic flow comparing to the city routes. Scenario 3 has an increased traffic flow compared to scenario 4. For instance, in A10 North there is 4.1% increase in traffic flow for scenario 3 compared to scenario 4. For A10 East there is 23.6% increase in traffic flow for scenario 3 compared to scenario 4. Figure 25 and 26 also show that S106 has less occurrence of congestion while comparing to S105 and S107. In the motorway section A10 South, North and East scenario 4 has more congestion compared to scenario 3.

Figure 20: Scenario 4- Flow plot from OmniTRANS at 8:30 (Weekend)

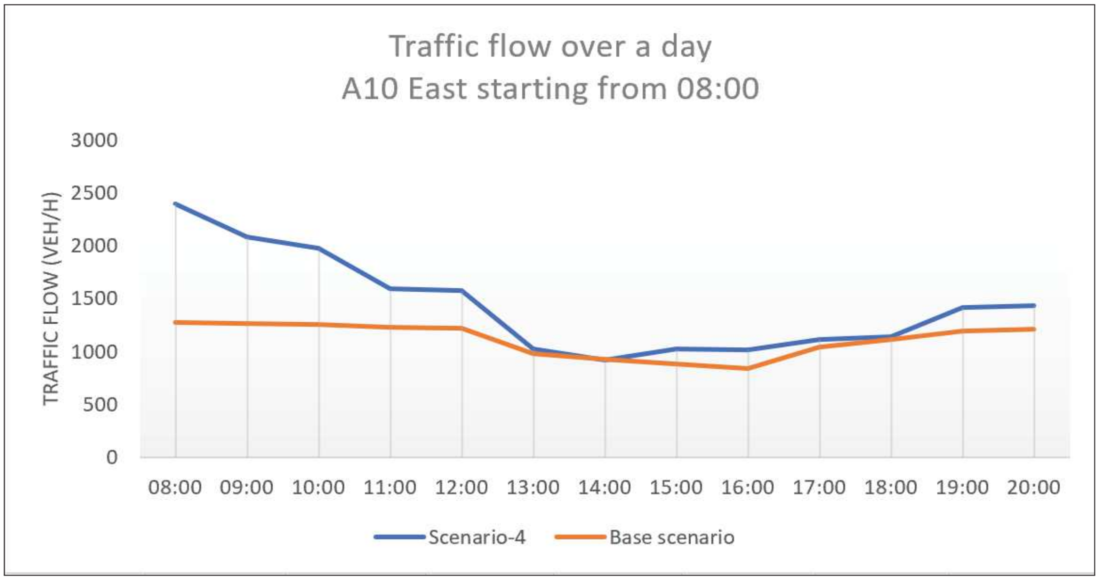


Figure 21: Traffic flow changes over a day for Scenario 4-A10 East

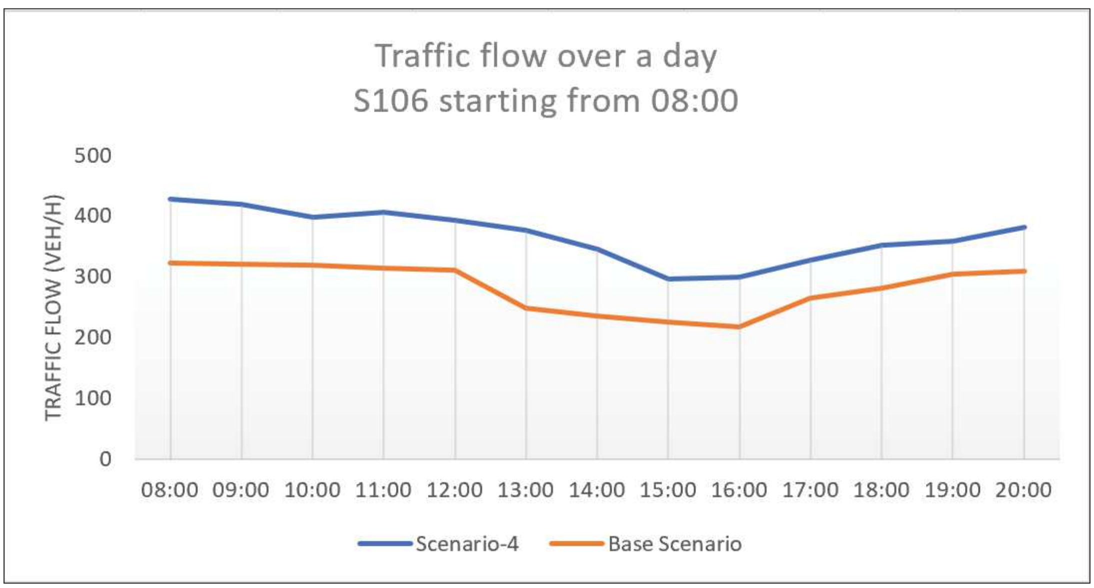


Figure 22: Traffic flow changes over a day for Scenario 4-City route S106

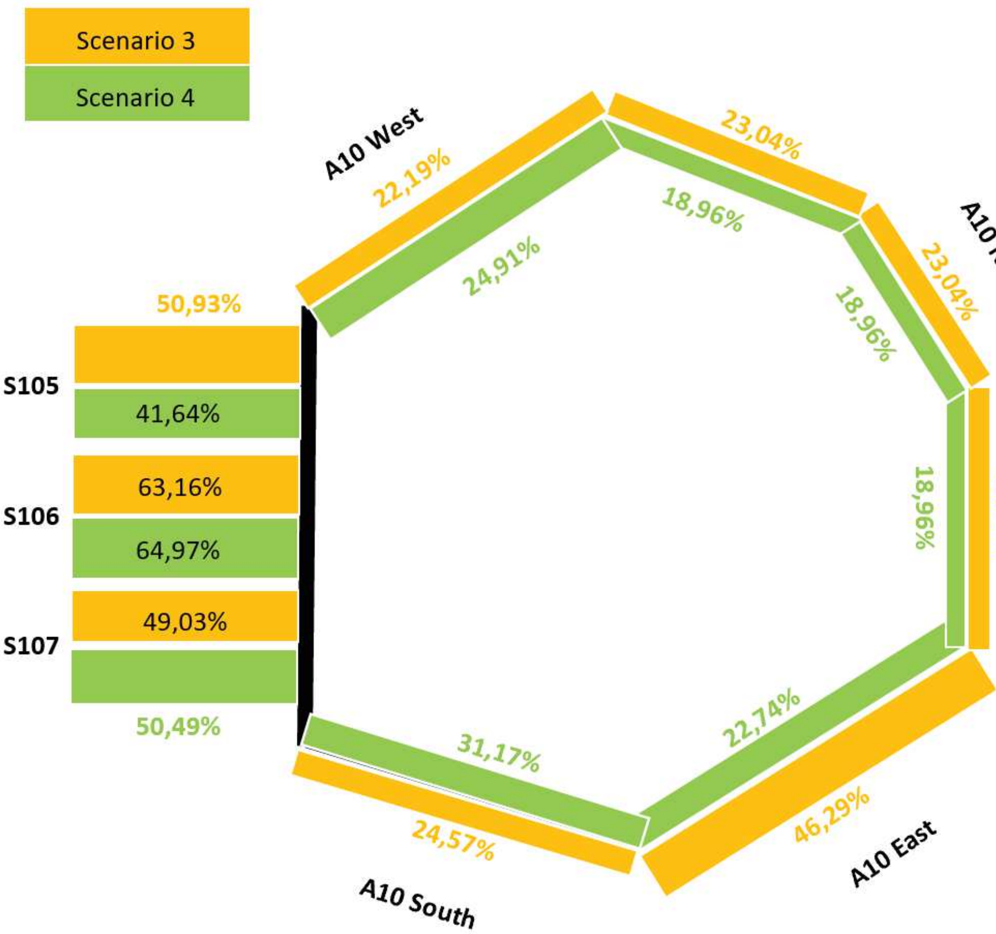


Figure 23: Flow map of Amsterdam network (percentage increase in the traffic flow in both the directions during road work when A10 west is closed from south to west)

This effect map shows that the city routes near the A10 West highway are most affected from the road works when compared to the motorway network, where the total vehicle flow is almost doubled at S105, S106 and S107 compared to the network without control. This may be due the rerouting traffic from A10 network moving toward the highways A4 and A5.

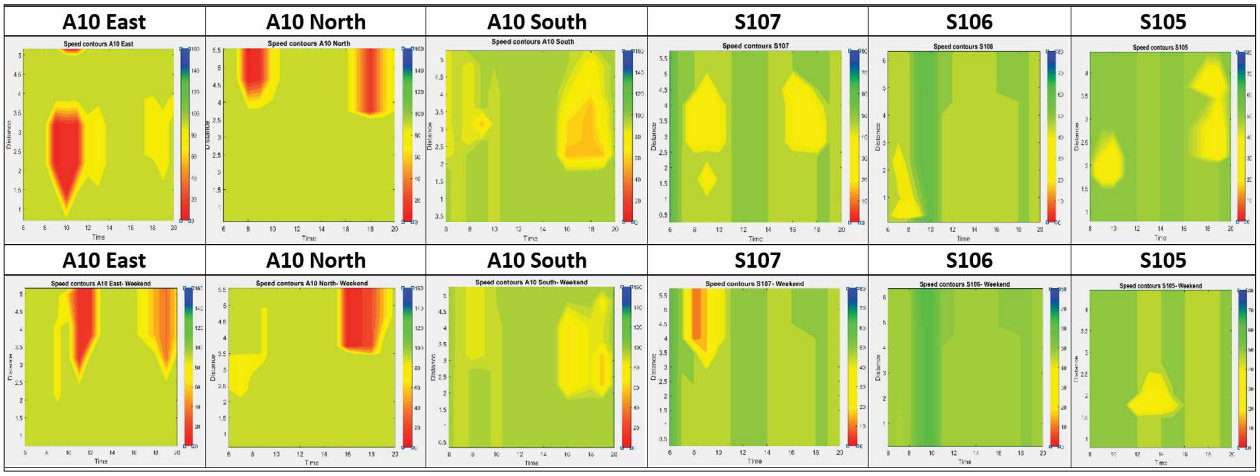


Figure 24: List of speed contour plots for different locations in the A10 network for weekdays and weekends

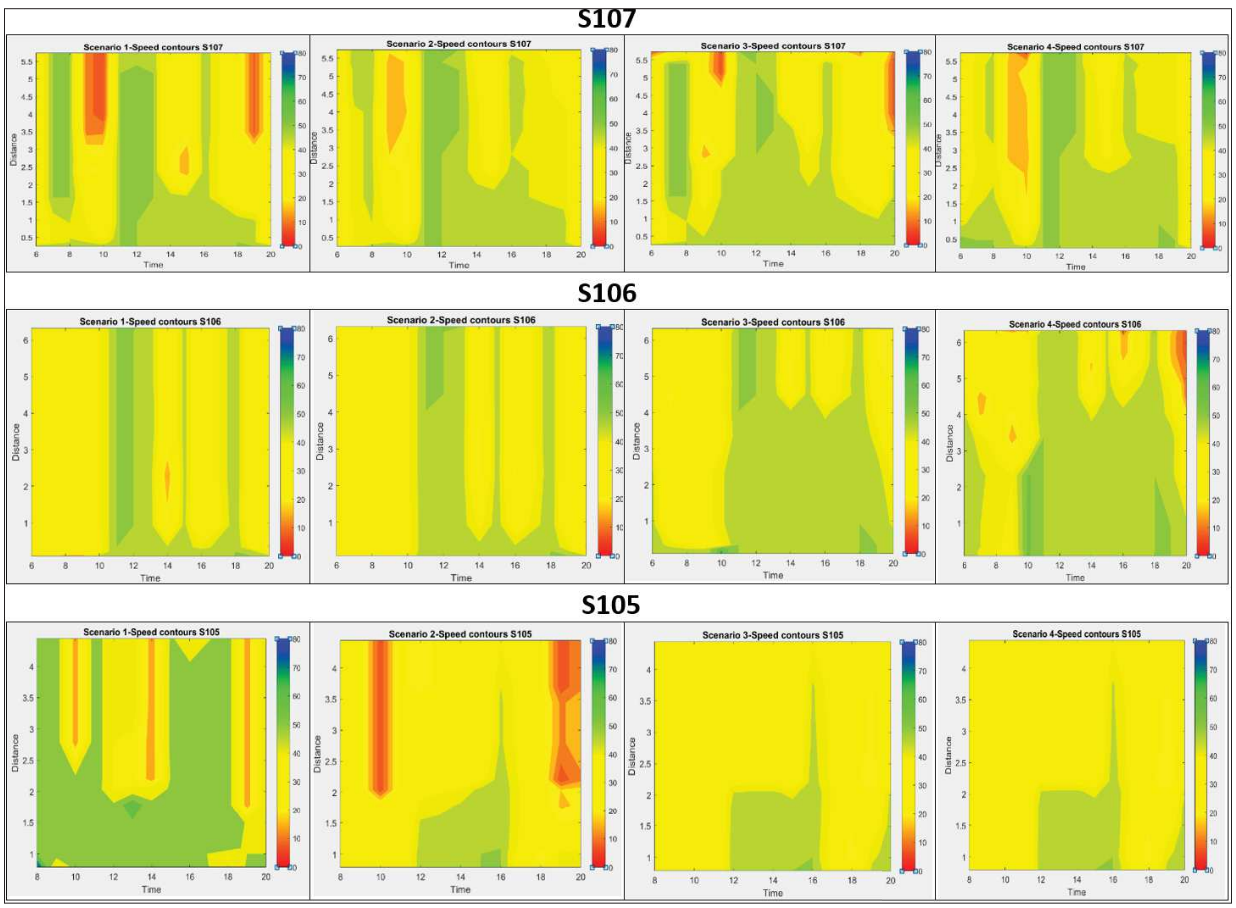


Figure 25: List of speed contour plots for city route S107, S106 and S105 under each scenario

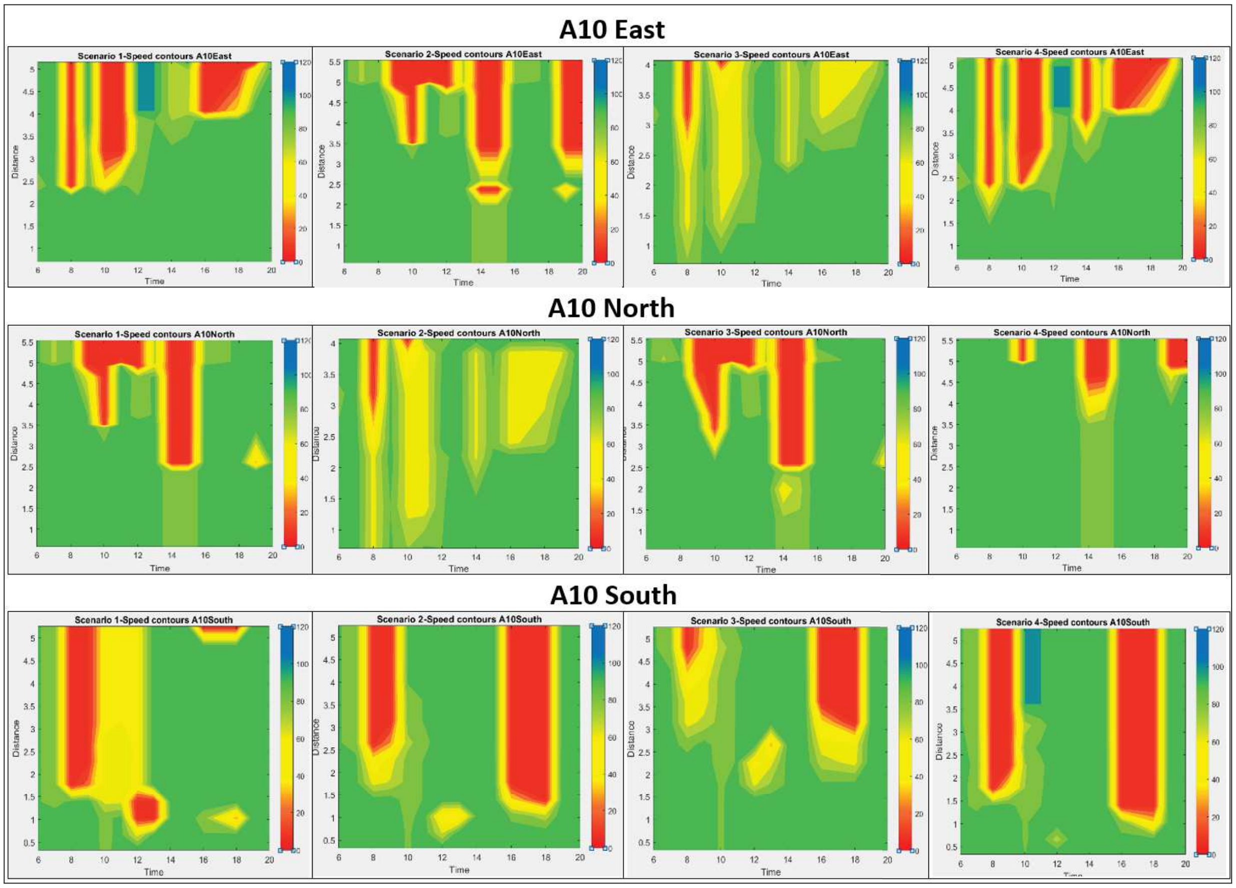


Figure 26: List of speed contour plots for A10 East, South and North under each scenario

The contour plots for the routes S107, S106 and S105 are given with every two hour increment. The red-yellow-green-blue area in the speed plots represents the propagation of jams in that simulation period. The contour plots for this city routes shows not much congestion. For S105 most congestion occurs during the full closure scenario and it can be seen that the maximum queue length is 2km at 10:00 and 20:00. The contour plots for A10 North, South and East regions can be seen from the Figure 25 and Figure 26. There are multiple queue formed in these regions at different time for each scenarios.

5. Simulation module 2: Emission modelling

5.1. Emission model

MOBILE for highway vehicles and NONROAD for off-road mobile source pollution are two of the EPA's (Environmental Protection Agency) emission and emission factor estimating techniques for mobile sources. EPA enhances and improves these tools by developing a all-encompassing modeling system: the MOtor Vehicle Emission Simulator (MOVES) which allows multiple scale analysis including national, county and project scale of analysis which allows detailed link level analysis. MOVES models fuel consumption, CO2, N2O, CH4, PM, NH3 and air toxins. MOVES is adaptable enough to calculate emissions from a variety of sources like on-road and off-road and it is built in a scalable way so that the user may easily update and add specific data **(Koupal et al., 2013)**.

Vehicle operations can be "binned" into categories in MOVES based on many criteria that affect emissions **(Lin et al., 2011)**. Total activity is distributed into two types of bins, source and operating mode bins. Source bins are the bins that categorize activities based on vehicle parameters such as fuel type, model per engine type,engine size and loaded weight while the operating mode bins contain vehicle activity parameters like average speed and vehicle specific power. MOVES estimates an emission rate to each perfect configuration of source and operating mode bin after categorizing activities into respective bins. After this step total emissions are calculated by aggregating the emission rates from source and operating mode bin. Finally, to account for the impacts of temperature, air conditioning, and fuel, a few correction factors are added to the emission rates.

$$Total emissions_{emission\ process} = \left(\sum Emission\ rate_{emission\ process,bin} * Activity_{bin}\right) * Adjustments_{process}$$

To define the vehicle activity for each link MOVES offers three options (1) Defining the link speed, road type and grade through the "Links" input (2) a Link specific drive cycle through the "Link Drive Schedule" input which is second by second speed/grade profile (3) Directly enter a link specific Operating Mode distribution through the "Operating Mode Distribution" input which is the percentage of time the vehicle spends on the link in a given mode **(Zhao and W.Sadek, 2013)**. To link MOVES to macroscopic traffic flow simulator Omnitrans, the first option is used where the speed profile for each time step can be obtained from Omnitrans and based on the speed profile the vehicle drive cycles are utilized.

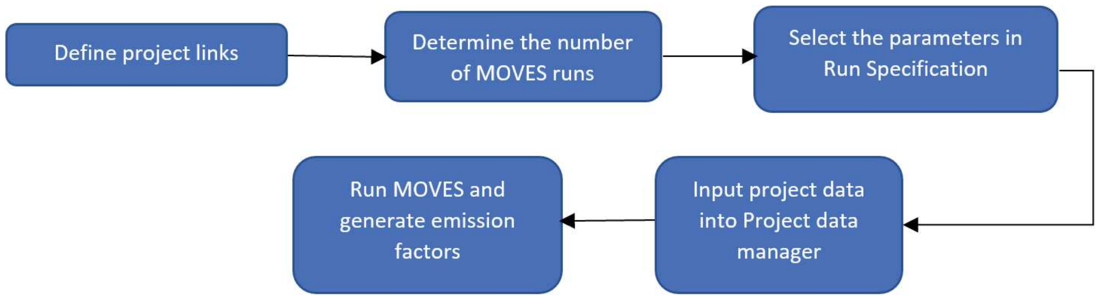


Figure 27: Steps for running MOVES at project scale

First step is defining the link which includes defining the link length, speed, volume and grade. Second step is to determine the number of runs which is important because the emission values are calculated based on the temperature, speed, volume and fleet mix. The necessity to capture emissions fluctuation throughout the day is reflected in the number of runs. Third step is to select the parameters in Run Specification, users must provide or develop a run specification and an input database to run MOVES at the project scale. This includes setting up pollutants, road type, scale, time spans, manage input data sets and create output database aggregated by time. Next step is PDM (Project Data Manager) is a built-in function for entering data into a project database. In PDM all the input files are uploaded and finally MOVES generate emissions **(Senna et al., 2013)**.

5.2. Development of an integrated model

To develop an integration framework between the emission and the transportation model all the data requirements are studied, which included the input and output data for both the models. MOVES, when used in combination with traffic models, estimates emissions for all vehicles in the traffic network specified by the traffic model. The required fuel and engine data is taken from the MOVES database. MOVES categorises all types of on road vehicles like motorcycles, Light duty vehicles, single unit trucks, combination trucks and buses.The traffic model classifies the vehicle categories into cars and light and heavy duty trucks these results are imported into the emission model. The classification of fuel data into fuel supply, formation and usage data, age distribution and retrofit data are automatically chosen by MOVES for each individual vehicle based on the fleet composition. The fleet mix is determined using data from the OmniTRANS model. MOVES utilizes the speed, flow and other input data produced by OmniTRANS in plain text and excel files. These files delivered to MOVES contain time, month, weekday/weekend, link traffic speed, link traffic volume, road grade, roadway type along with other information defining temperature and humidity.

In figure 28 the time period of the study, as well as the vehicle kinds, road types, fuel types, pollutants that will be included in the analysis, are all defined in the Run Specification. And the input database includes the data set from the Omnitrans like the vehicle activity data. These data files are imported into the MOVES model by importing the template and altering it with a spreadsheet application to include relevant specific information, and then importing each data file into an input repository for the run. Both run specification and input data set are run through the graphical user interface of the MOVES model.

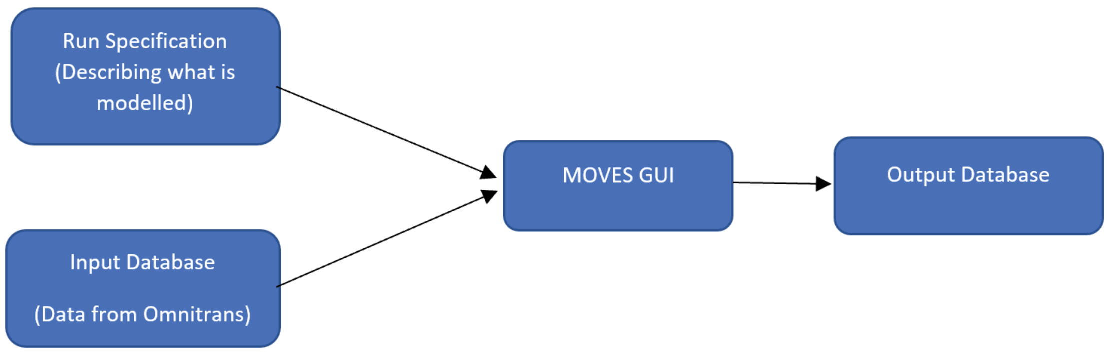


Figure 28: Schematic flow chart of the MOVES

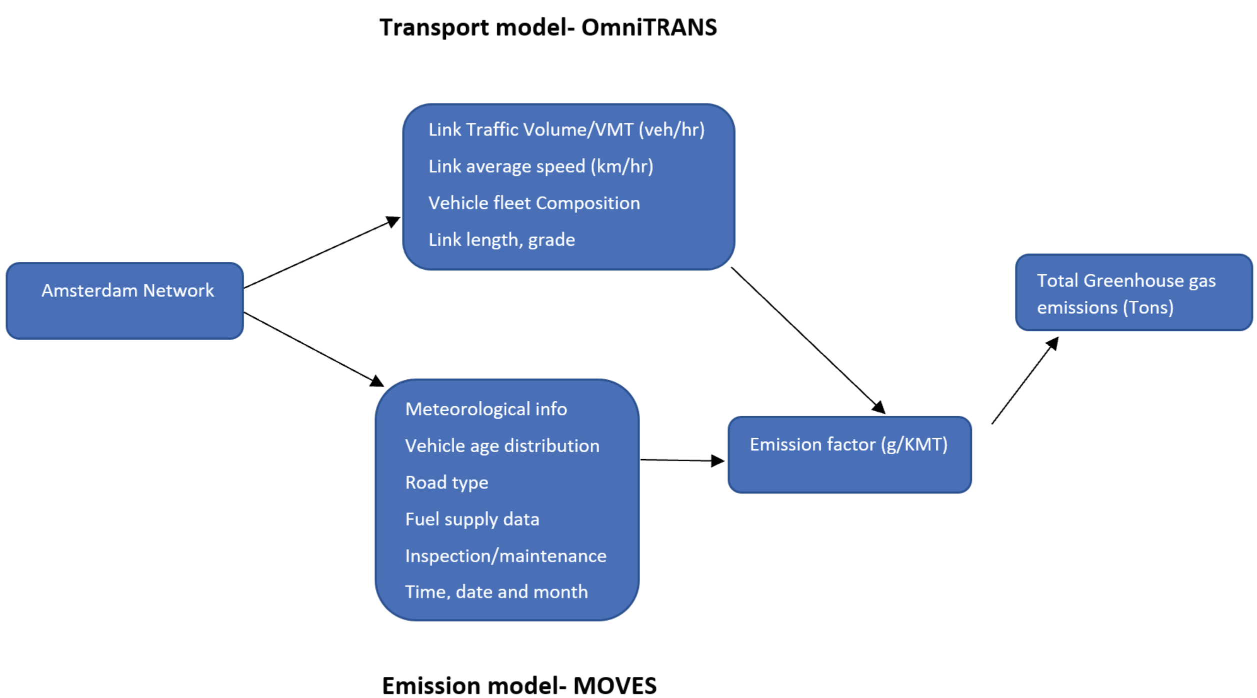


Figure 29: Integrated framework

Category	Inputs
Link source data	Road type, Road length, Link ID, Link speed, Link volume, Link grade and Link description
Link drive schedule	Speed for each time step
Link source type hour	Link ID, Vehicle fleet mix

Figure 30: Data input from OmniTRANS to MOVES

5.3. Data collection

In project scale analysis MOVES calculates emission from the vehicle activity including the vehicle type, number and their activity on a specific link on a particular time of the month of the year, each time period in MOVES requires a separate run. MOVES categorises all types of on road vehicles like motorcycles, Light duty vehicles, single unit trucks, combination trucks and buses. MOVES accounts for project scale, time spans, road type, pollutants, temperatures, humidity, age distribution, fuel, link level data, retrofit data and emission control activities such as inspection and maintenance (I/M) programs. Some of these data are set to default like fuel data including fuel supply, fuel formulation, fuel usage, AVFT (Alternative fuel and vehicle technology) and I/M (Inspection/Maintenance) programs. Other data like meteorological inputs are gathered from **(CBS, 2019)** which includes the temperature and humidity data for each specific month. The minimum and maximum temperature for each time period is collected from **(CBS, 2019)** and the average temperature within that period is used. Link inputs like Link ID, link length in kilometers, link Volume in vehicles per hour and link speed in kilometer per hour, link Description and link Grade in percentage grade are collected from the traffic flow model for each link in the Amsterdam network.

Input Parameter	Values
Year	2018
Month	October
Time	8:00 to 8:15 (15 mins)
Weekday/Weekend	Weekday
Minimum Temperature	3 (°C)
Maximum Temperature	26 (°C)
Humidity	81%
Roadway type	Urban unrestricted access
Type of vehicles	Passenger cars, Light duty trucks and Heavy-duty trucks
Type of fuel	Gasoline for passenger cars and Light duty trucks, diesel for Heavy-duty trucks
Link Length	1.39 kilometers
Link volume	4500 vehicles per hour
Link speed	100 kilometer per hour
Road grade	0%
Output	CO_2, CH_4, NO_x

Figure 31: Project level input parameters

5.4. Verification

To perform the simulation close to the reality the MOVES model is verified. The factors like vehicle age distribution, flow, vehicle miles travelled, speed distribution and road type are used in the calculation of total emission. According to the research by **Koupal et al. (2014)** the importance of each input varies depending on the pollutant. For example, vehicle age distribution is influential particularly for pollutant HC. As this research aims in calculating the greenhouse gases the CO2 is considered for verification, according to this research for a project level emission calculation the CO2 is most influential on speed. The speed data of A10 motorway section for the verification process is collected from NDW Dexter (National Database Road Traffic Data). Figure 32 are the traffic speed data from 7:00 to 21:00 at a section of A10 Motorway. With the collected data emission model is set up. The road type, length, link grade and meteorological data for the 24-hour period are also collected from NDW Dexter. The flow, fuel supply, fuel fraction, retrofit data and fuel formation data are collected as explained in section 5.3.

Figure 33 is the calculated CO2 emission values from 7:00 to 21:00. For the emissions values gives a increase in emission at 12:00, this corresponds to the drop in the vehicle speed at 12:00, similarly CO2 emissions at 19:00 increases which corresponds to the formation of congestion at the same period as shown in the figure 32.The results of the CO2 emissions shows good agreement with the speed patterns.

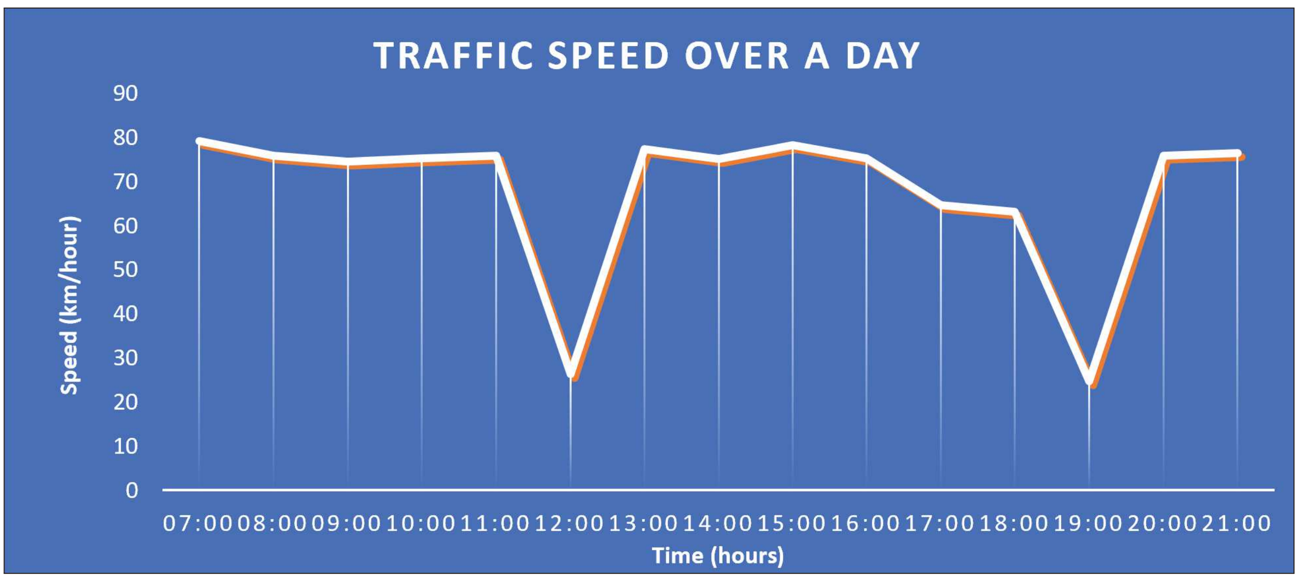


Figure 32: MOVES emission model verification- Speed plot

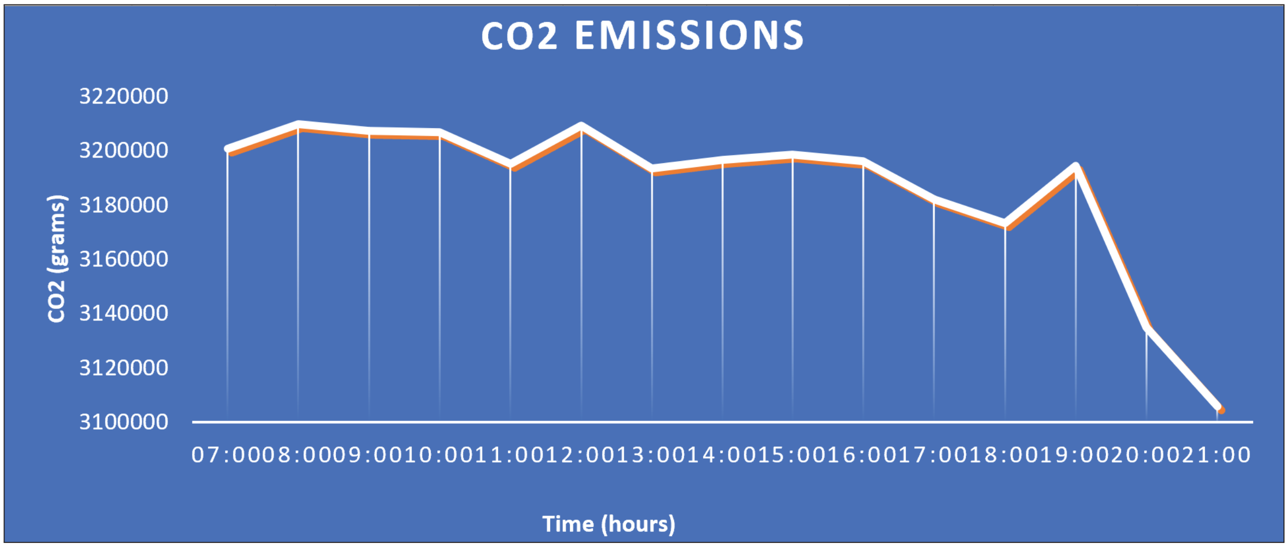


Figure 33: MOVES emission model verification-CO2 emissions over a day

6. Emission calculation

6.1. GHG emissions for weekdays for full closure and intermittent closure of A10 Ring road

For each scenario, the construction work is carried out under different time zones. When comparing the results for each scenario, the results are based on the time of construction (weekday/weekend) and the area of analysis. This subsection consists of the results for the scenarios for weekdays for A10 Ring road. Figures 70, 71, 72 are CH4 emissions, figures 34, 35, 36 are CO2 emissions and figures 73, 74, 75 are N2O emissions for the scenarios of full closure (scenario 1) and intermittent closure (scenario 3) for the weekdays for A10 ring road.

Considering the full closure scenario for weekdays, many parts of the ring road including Northern and Southern parts of the A10 ring road have increased emissions for full closure scenarios especially during the morning peak from 08:00 to 12:00 compared to evening peak. While other parts of the A10 Ring road including the Eastern side have higher emissions from intermittent closure compared to the full closure. This is due to the very high increase up to 46.29% in the traffic flow in the A10 East region when A10 West is partially closed. When fully closed, all the traffic towards A4 and A5 will be diverted through different routes via A10 South and North compared to partial closure where only half of the traffic needs to be diverted. This can be seen from the flow diagram in the figure shows that when fully closed there is an increase in traffic flow up to 47.71% compared to partial closure where the increased traffic flow is 23.04%. Also when comparing the speed plots for these scenarios, there is increased congestion size for morning peaks in full closure scenarios.

In both scenarios, C02 accounts for the majority of the greenhouse gas emissions compared to CH4 and N2O. Each emission type follows a different pattern for each scenario for the same location. When it comes to the A10 East region, it follows diverse patterns for different sorts of emissions. For example for CH4 emissions at A10 East at 8:00, there is a significant variation in emissions between the two scenarios. While for CO2 there is a significant increase of emission for intermittent closure during the evening hours from 14:00. When considering overall emission for A10 South there is almost no increase in the emission especially for intermittent closure from 11:00 to 17:00 for full closure from 13:00 to 16:00. This is due to similar traffic characteristics for both scenarios.

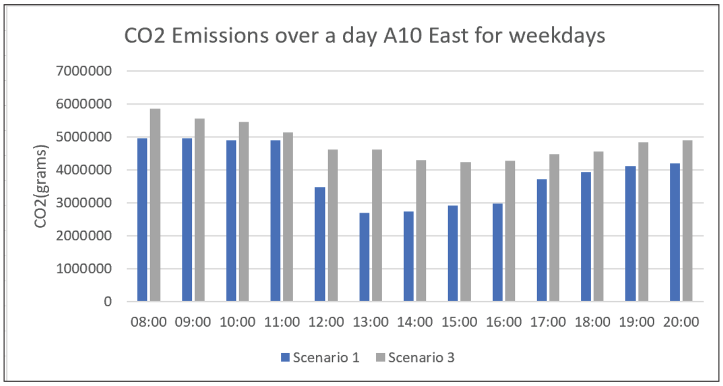


Figure 34: C02 emissions over a day for A10 East Motorway

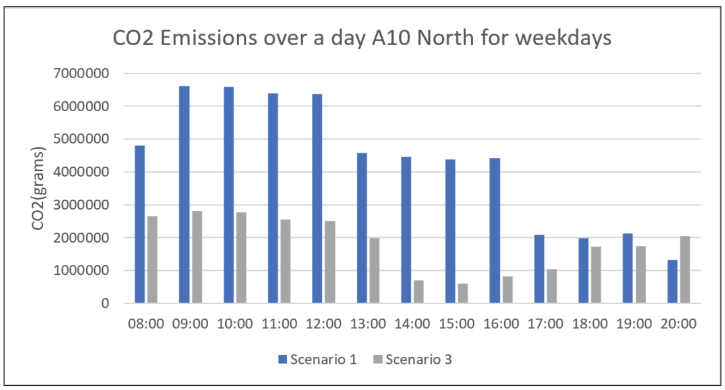


Figure 35: CO2 emissions over a day for A10 North Motorway

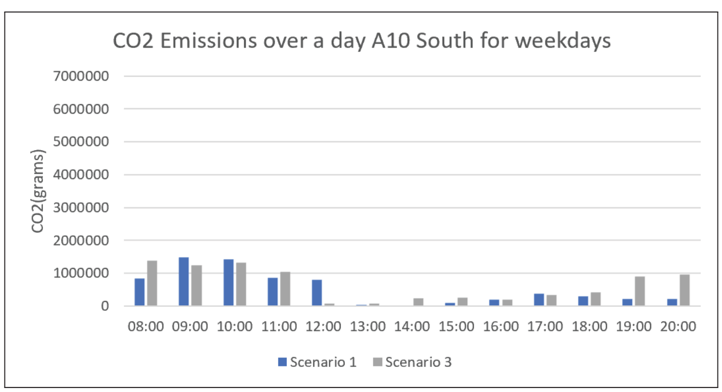


Figure 36: Co2 emissions over a day for A10 South Motorway

6.2. GHG emissions for weekdays for full closure and intermittent closure of city routes

This subsection consists of the results for the scenarios for weekdays for city routes. Figures 76, 77, 78 are CH4 emissions, figures 37, 38, 39 are CO2 emissions and figures 79, 80, 81 are CO2 emissions for the scenarios of full closure (scenario 1) and intermittent closure (scenario 3) for the weekdays for City routes. These figures shows the difference in emission values when comparing the base case scenarios without any controls.

For the city routes there is a huge increase in the emission values as the flow towards the city routes is high. This is because, during the closure of A10 West, most of the traffic is diverted towards the city routes. For example, when the A10 west is closed the traffic between the A10 and connecting networks like A4 and A5 are facilitated by the city routes. For the city routes, the emissions are less compared to the main network as their flows are limited. From the impact map (Figure 16 and Figure 23) it is evident that the flow towards the city routes is almost doubled under both full and intermittent closure scenarios. When comparing their flows to the between the full closure and intermittent closure, there is nearly a 2 % increase in the average flow between the scenarios. Therefore the emission values between the two scenarios do not vary much. Also, the speed plots do not show much queuing. This can be justified by looking into figures 40 and 42, the maximum queue length for the full closure scenario is 2.5km and for the intermittent closure it is up to 2km.

When comparing different greenhouse gases, the N2O value is higher for S106 and S107. This may depend on the vehicle fleet composition, for example, the diesel engine emits very little CO2 but emits more N2O compare to the petrol vehicles which emit more CO2.

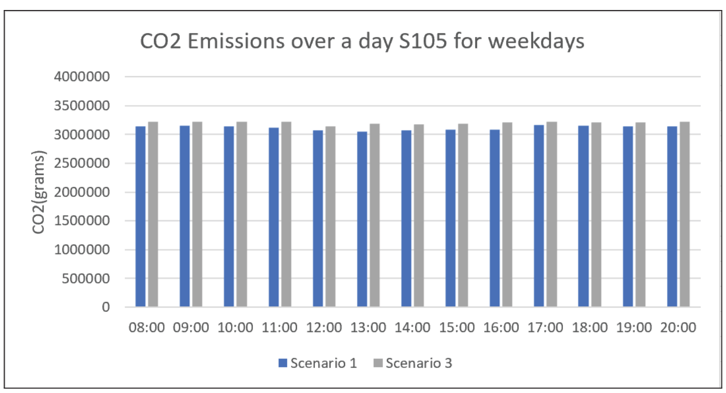


Figure 37: CO2 emissions over a day for S105

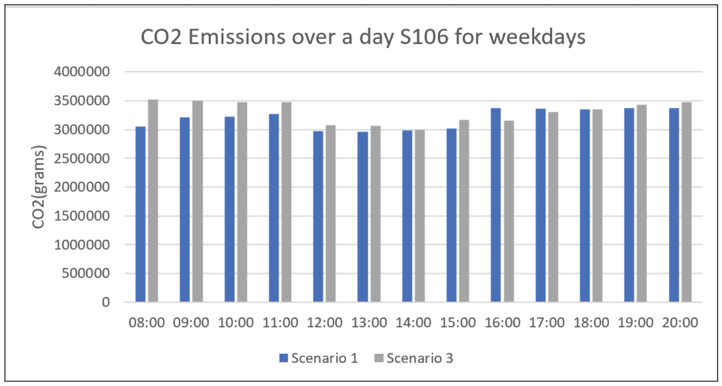


Figure 38: CO2 emissions over a day for S106

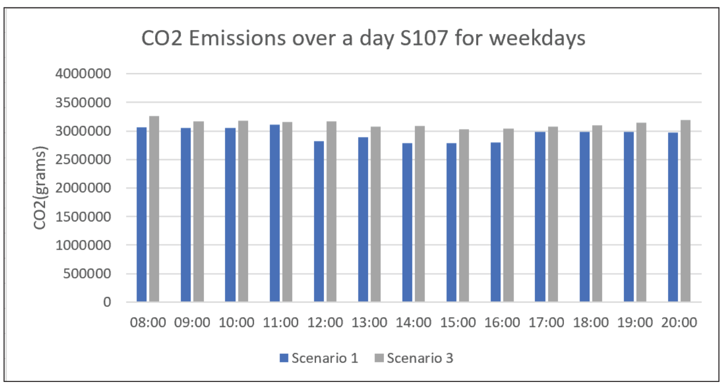


Figure 39: CO2 emissions over a day for S107

6.3. GHG emissions for weekends for full closure and intermittent closure of A10 Ring road

This subsection consists of the results for the scenarios for weekends for A10 Ring road. Figures 82, 83, 84 are CH4 emissions, figures 40, 41, 42 are CO2 emissions and figures 85, 86, 87 are CO2 emissions for the scenarios of full closure (scenario 1) and intermittent closure (scenario 3) for the weekends for A10 ring road.

Weekends have lower emissions than weekdays because they are periods of recreational activities, hence traffic flow is reduced, resulting in lower emissions. On weekdays, a typical traffic flow figure is displayed, with two peak periods in the morning and evening.Weekends, on the other hand, have various peak periods and patterns throughout the day. In addition, the evening traffic flow patterns alter between weekdays and weekends. On weekdays, traffic flows are lower, while on weekends, they are higher.

The results of the traffic simulation demonstrate significant differences in flow and speed activity patterns between weekdays and weekends. As a result of their combined impacts, significant reductions in emissions are achieved. For example, in a full closure scenario, traffic volume on A10 North is up 31.39 % on weekdays compared to weekends. The traffic flow on A10 West varies by 7.2 % between weekdays and weekends, while the southern half of the network has nearly identical traffic flow in both circumstances. This explains why GHG emissions are less in the motorway network. The flow and emission estimates are remarkably similar for both weekdays and weekends in the intermittent closures scenarios.

The speed charts in Figure 26 also show that for both scenarios, there is much less or similar queuing, with a maximum queue length of 2.5 kilometers. For example, during weekends, the A10 north has considerably less congestion than on weekdays, but other areas of the A10, like that of the A10 south, have comparable patterns.

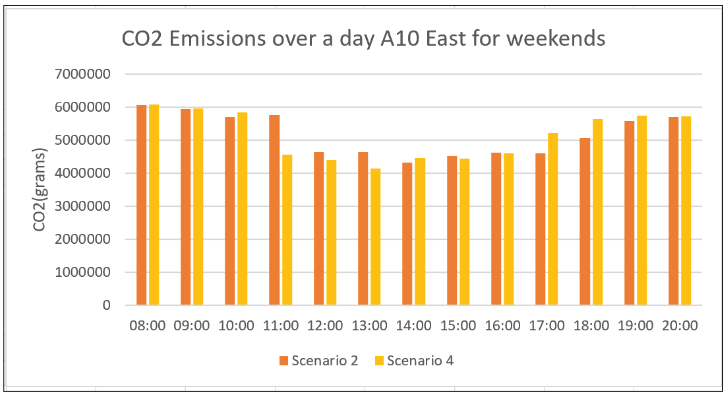


Figure 40: C02 emissions over a day for A10 East Motorway

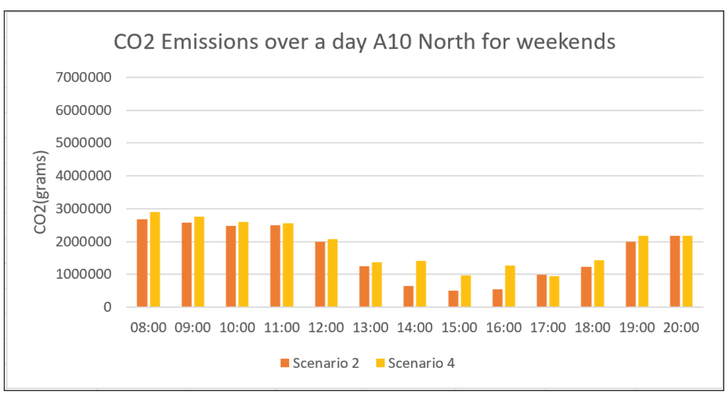


Figure 41: CO2 emissions over a day for A10 North Motorway

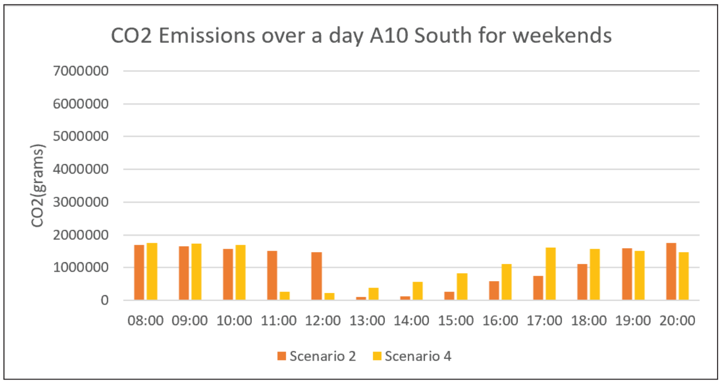


Figure 42: Co2 emissions over a day for A10 South Motorway

6.4. GHG emissions for weekends for full closure and intermittent closure of city routes

This subsection consists of the results for the scenarios for weekends for city routes. Figures 88, 89, 90 are CH4 emissions, figures 43, 44, 45 are CO2 emissions and figures 91, 92, 93 are CO2 emissions for the scenarios of full closure (scenario 1) and intermittent closure (scenario 3) for the weekends for City routes.

Due to increased traffic volume, emissions levels for city routes are quite high on weekends, just as they are on weekdays. However, as compared to the main network, emission values are lower; this is due to the main network's high flow. According to the effect map, there is a nearly 6.97 % rise in traffic flow between full closure weekdays and weekends and a 11.46 % increase in traffic flow between intermittent closure weekdays and weekends. There is a nearly 2.84 % decrease in average traffic flow when comparing the full and intermittent closures. The reduction in traffic flow is the primary source of the reduced greenhouse gas emissions on weekends. Also, unlike weekdays, the speed charts do not show considerable congestion.

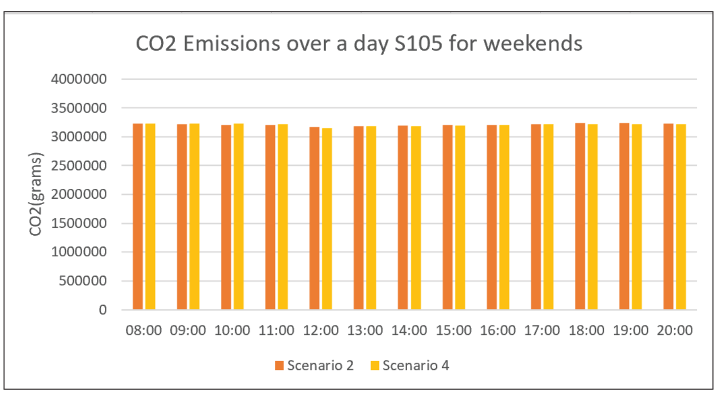


Figure 43: CO2 emissions over a day for S105

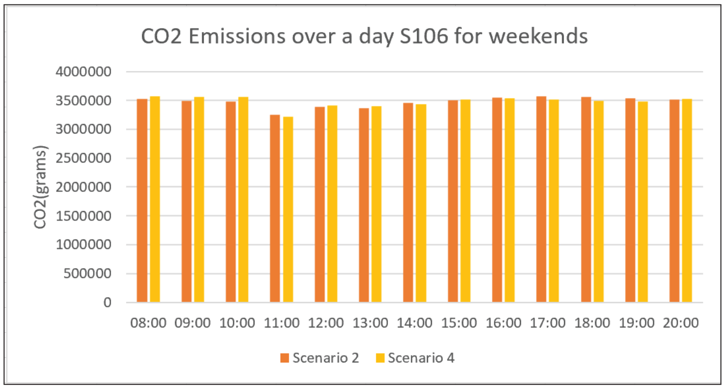


Figure 44: CO2 emissions over a day for S106

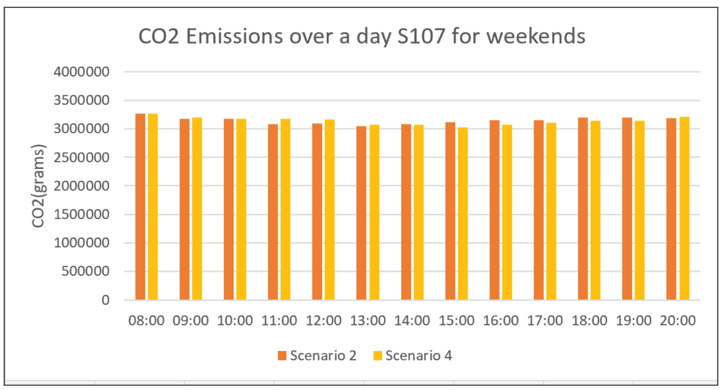


Figure 45: CO2 emissions over a day for S107

6.5. Total emission

The results of the emission calculations for each road work scenario are examined in this chapter at various aggregated levels. This chapter also covers network performance indicators like as volume, delay, and speed, which are utilized to calculate the emission values.

The delay curves are generated based on the flow and speed values for the Amsterdam network. For each of the road closure situations, including full and partial road closures during weekdays and weekends, delay curves are generated at the sub-network level, including A10 west, A10 east, A10 north, A10 south, and S-routes. Figure 46, Figure 47, Figure 48 and Figure 49 demonstrate the delay curves for these four scenarios for each sub-network level, The A10 West is not included in the emissions calculations because city roads bordering the A10 West cover the majority of the redirected traffic and there is no actual flow, resulting in longer delays on city routes.

Figure 46 clearly demonstrates that during full road closures on weekdays, the most delays occur in the A10 east and A10 north regions, compared to the other A10 and city routes. This is to be anticipated since the volume is relatively quiet high in these two regions, and the speed plots show that there are instances of congestion. For scenario 1, the delay is highest between 10:00 and 11:00 in the mornings. The delay for the full road closure on weekends is lower than on weekdays, attributable to lower traffic flow and thus no peak periods. The delay is consistent throughout the day, peaking between 8:00 and 9:00 a.m. Unlike scenario 1, all of the highway networks in scenario 2 have a similar pattern of delay, with s107 having the first and most delay in scenario 2 and S106 encountering the most delay in scenario 1. The full road closure of the A10 west is causing significant delays since it influences traveler route choices, with several people opting for the A10 east and A10 north alternatives.

Figure 48 depicts the vehicle lost hours for a partial road closure during the weekdays; it can be seen that the total delay for this scenario is highest for A10 east, and even more so from 10:00 to 14:00, whereas for the weekend partial closure, the a10 east and a10 north have approximately equivalent delays throughout the day. While all of the city routes have similar delays on weekdays, s106 has the longest delay at 19:00 on weekends, corroborating the congestion in the speed contour plots, where s106 has the worst congestion area for scenario 4 from 19:00 to 20:00.

The total vehicle loss hours for the whole Amsterdam network are shown in Figure 50 for each scenario. As can be seen in figure 51, scenario 1 and 2 have the highest overall delay, which adds up to 800 and 922 respectively. The longer the delay, the higher the emissions for that scenario. Scenarios 1 and 2 have a significant delay since they are full road closure scenarios with much more traffic congestion and rerouting than partial closure scenarios, which leave 50% of the road open for incoming traffic. As a result, the delays for scenarios 3 and 4 add up to 515 and 705 respectively, as illustrated in figure 51, resulting in overall lower emissions for the partial closure scenario.Scenario 2, which involves a complete road closure on weekends, has the highest delay of all the scenarios, accounting for up to 31% of the overall delay, while scenario 3, which involves a partial closure on weekdays, accounts for up to 18%. figure 52 shows that the total delay for the entire project is larger for the weekend partial closure, contributing 34 percent, which is the same percentage as the emissions for that scenario. This demonstrates that as the delay gets longer, so does the amount of emissions produced by road work.

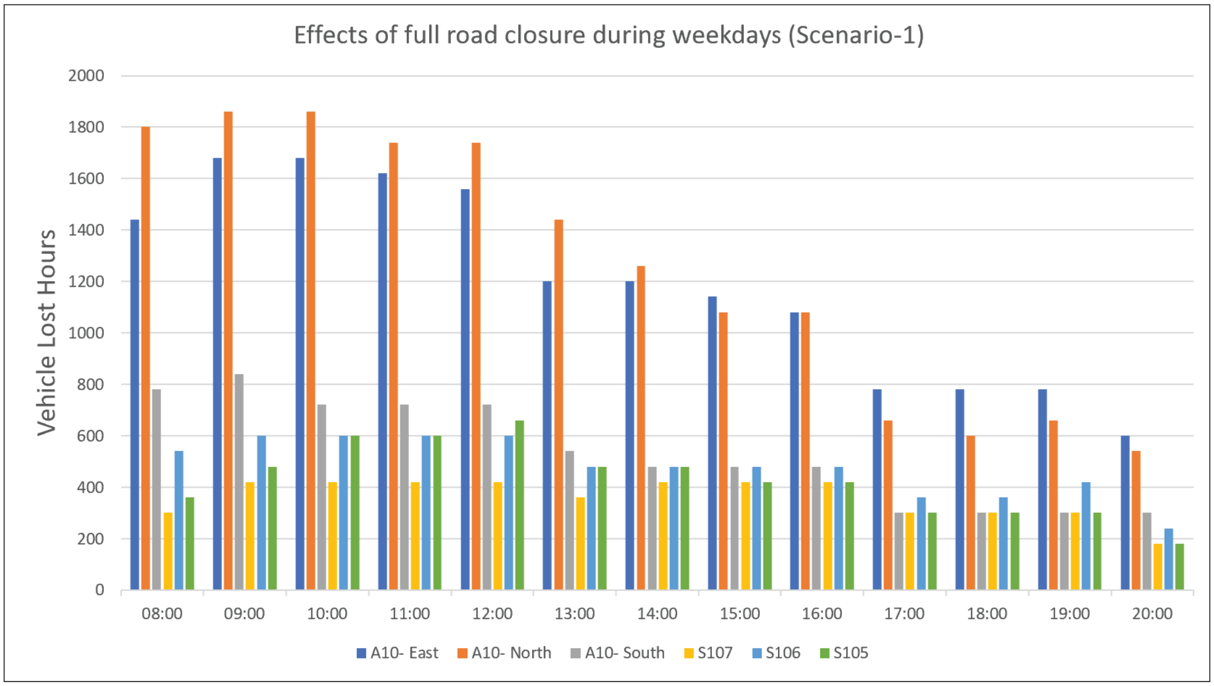


Figure 46: Vehicle lost hours effects of full road closure on weekdays

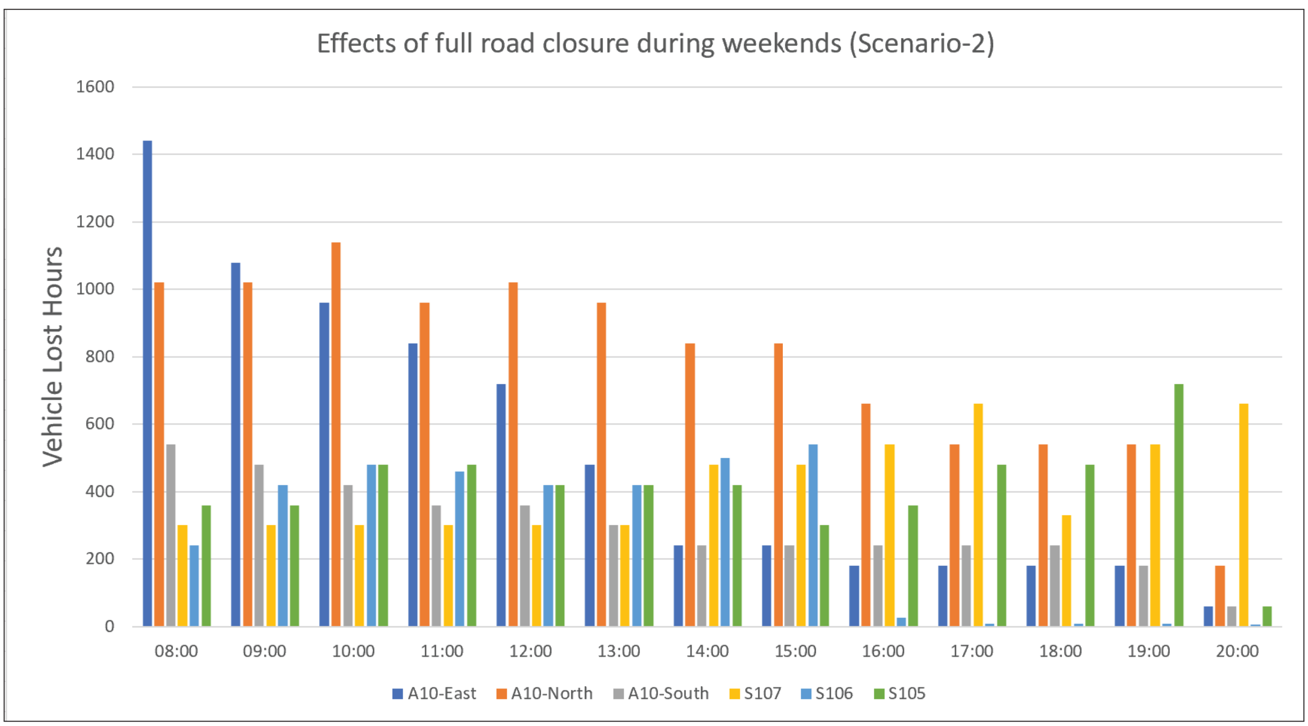


Figure 47: Vehicle lost hours effects of full road closure on weekends

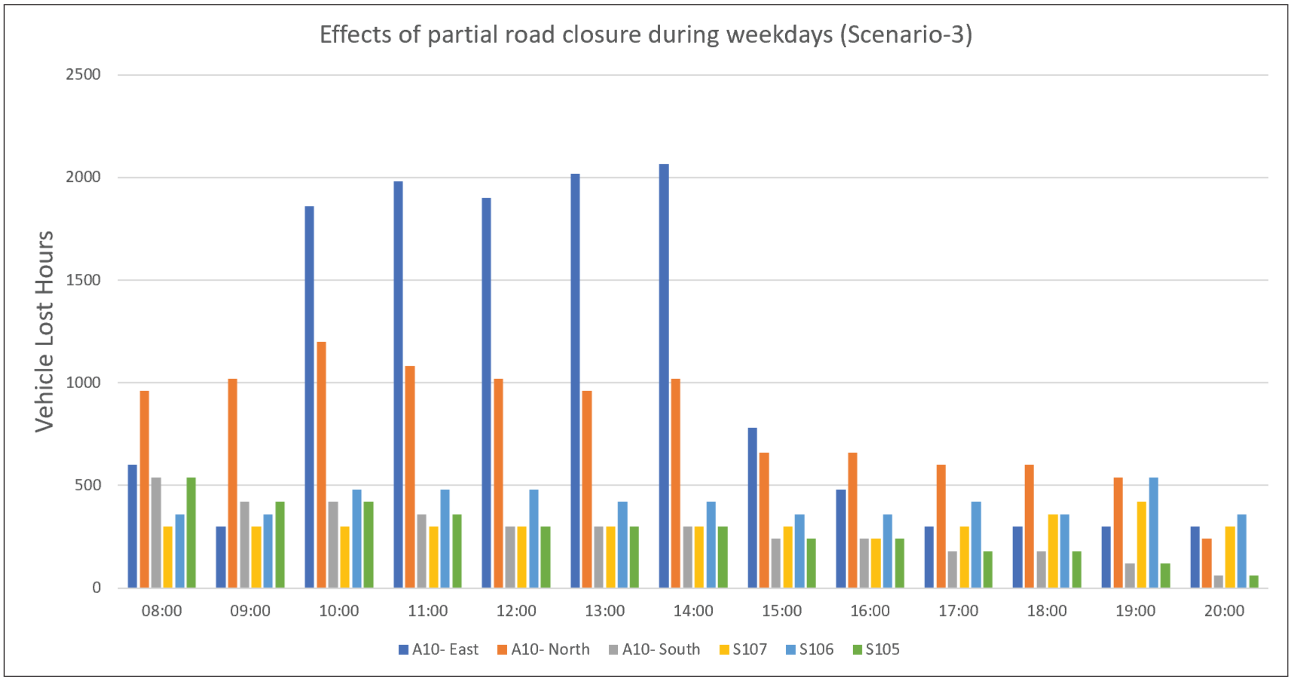


Figure 48: Vehicle lost hours effects of partial road closure on weekdays

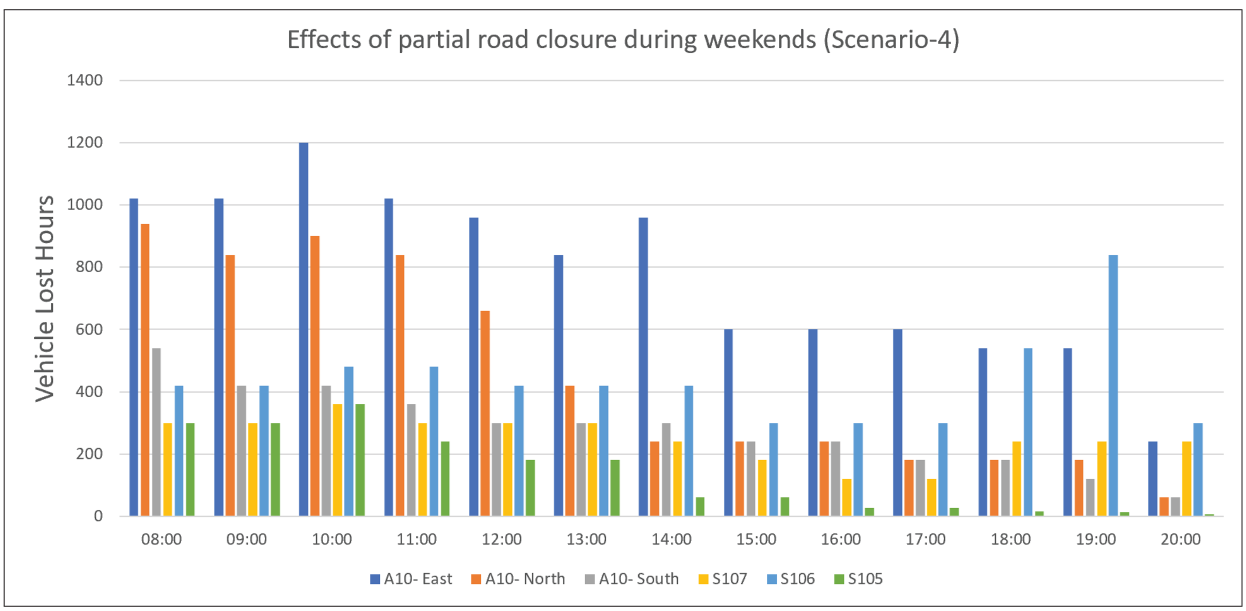


Figure 49: Vehicle lost hours effects of partial road closure on weekends

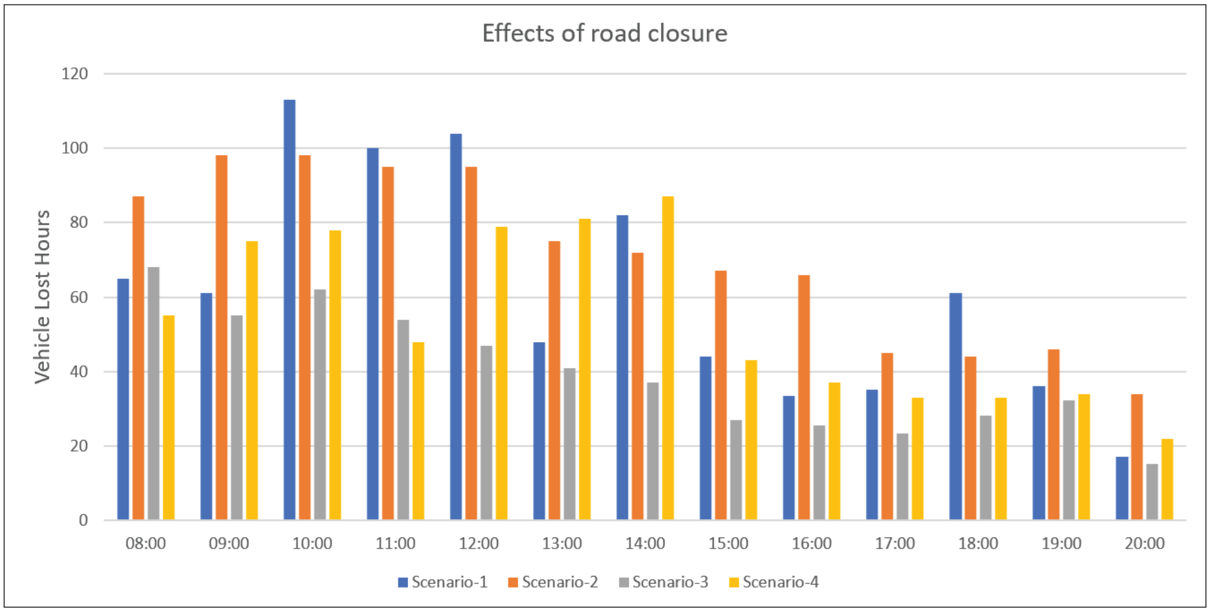


Figure 50: Vehicle lost hours during road closure

		CO2	N2O	CH4	CO2e	Delay
Scenario 1	Full closure- Weekdays	233885	21	3	240346	800
Scenario 2	Full closure- Weekends	235896	21	3	242213	922
Scenario 3	Intermittent closure- Weekdays	220693	20	3	226751	515
Scenario 4	Intermittent closure- Weekends	233670	21	3	240095	705

Figure 51: Δ GHG emissions from full closure and partial closure for a single day

For every sub-network level, the total emission results for each scenario are totaled, and the overall emission for the Amsterdam network is displayed in Figure 51. As the results are the difference from the base case scenario without roadworks, the emission figures are in Δ. This process is performed for each emission category. The overall emissions are estimated by converting each Delta Greenhouse Gas into carbon dioxide equivalents in tons, which is then compared to the lost time due to road work. Figure 51 shows that with longer delays, the emission increases higher. For example scenario 2 has the highest delay which corresponds to more emissions in scenario 2 this correlates to higher traffic congestion and higher total emissions.

The total emission for the project is then estimated by multiplying the current daily emission by the number of days scheduled for road work. According to Rijkswaterstaat, road construction on the entire length of the A10 west might take up to 42 days when fully closed, and up to 84 days when partially closed. Figure 52 illustrates the Δ greenhouse gas emissions from the full and partial closures over the project's lifetime.

6.5 Total emission

		CO2		N2O		CH4		Delay	
Scenario 1	Full closure- Weekdays	9823166	17%	899	17%	137	17%	33600	19%
Scenario 2	Full closure- Weekends	9907641	17%	879	17%	135	17%	38724	22%
Scenario 3	Intermittent closure- Weekdays	18538213	32%	1686	32%	257	32%	43260	25%
Scenario 4	Intermittent closure- Weekends	19628301	34%	1788	34%	273	34%	59220	34%
Total		57897321		5252		802		174804	

Figure 52: Δ GHG emissions from full closure and partial closure for the total project duration

All of the results are converted into carbon dioxide equivalents so that the emission numbers can be added. By converting levels of other gases to the comparable amount of carbon dioxide with the same global warming potential, this metric can be used to compare the emissions of different greenhouse gases based on their GWP. The comparison is made in tons. The global warming potential of CH4 and N2O is 25 and 298 units, respectively, when multiplied by the metric tonnes of gas **(EPA, 2016)**.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
CO2	9823166	97%	9907641	97%	18538213	97%	19628301	97%
N2O	267930	3%	261935	3%	502467	3%	532881	3%
CH4	3431	0,03%	3363	0,03%	6432	0,03%	6829	0,03%
Total	10094528		10172939		19047112		20168012	

Figure 53: Δ CO2 equivalents of GHG emissions from the road works of A10 Network for the total project duration

Figure 53 shows that full road closures on weekdays have the highest greenhouse gas emission value per day, but partial road closures, particularly on weekends, have the highest overall emission when the project is assessed throughout its whole lifetime. This is due to an increase in the amount of days worked on the road due to intentionally closing selected lanes for work while the others continue to operate. It's also important to note that the second largest emission comes from a partial closure for road construction on weekdays, while the lowest emission comes from a full day closure on weekdays. With so many tourist destinations, the Amsterdam region is always busier on weekends, and the closure of the A10 west makes it even congested on other parts of the highway, such as the north and south, resulting in higher emissions in these locations.

As illustrated in Figure 53, a partial weekend road closure produces around 11 MT CO2e higher emissions than a complete weekend road closure which is the difference in total Δ emissions between scenario 4 and 2. While a partial road closure during the week generates approximately 9 MT CO2e higher emissions than a complete road closure during the week which is the difference in total Δ emissions between scenario 3 and scenario 1. The difference in emission values between scenarios 1 and 2 is smaller because they share the same base case scenario, which is a full closure scenario with no road work, and the value shown in Figure 53 is the Δ, which is the difference between scenario 1 and 2 from the base case, implying additional emissions from road work. The same is done for scenarios 3 and 4. The base case scenario is a partial closure scenario without road construction, and the Δ value in Figure 53 is the difference between scenario 3 and 4 and the base case. When looking at the delay curves in Figure 50, it can be observed that the overall delay for a day for the Amsterdam network is greater for scenario 1, which is a full road closure on weekdays, and the next largest delay is a full road closure on weekends. The partial closure scenarios, on the other hand, have relatively short delays per day.When comparing the delay and emission findings, the emission results in Figure 53 show the same pattern, with total emissions being higher for full closure scenarios than partial closure scenarios.

7. Conclusions and Recommendations

7.1. Conclusion

The current study's conclusions and recommendations are discussed in this chapter. The chapter is subdivided into two sub-chapters; the first sub-chapter addresses the answers to the research questions, while the second sub-chapter demonstrates the limitations of this research as well as recommendations for further research.

The main research question (*How can the planning of road works be scheduled while taking into account greenhouse gas emission values from road works?*). This review investigated towards how Rijkswaterstaat might be able to reduce greenhouse gas emissions from road construction and maintenance projects. So for this research roadworks were simulated for A10 west network and the greenhouse gas emissions from the traffic during the roadworks was assessed. For the road works, two major scenarios were considered which are full road closure and intermittent road closure. Rijkswaterstaat provided all of the information on the actual roadworks utilized in this study, enabling the analysis to demonstrate the prospective greenhouse gas reductions.

As previous shown from the impact figures from the results, the partial road closure has about 10 MT CO2e more greenhouse gas emissions than the emissions from the full road closure. Since the partial road closure has less capacity constraint than the full road closure leading to longer period of work which leads to relatively large share of emissions. Table 53 compares the total emissions from all the scenarios. Between the full road closure, there is sub-scenario for weekdays and weekends, from the table 53 it can be seen that full road closure during the weekday has the highest emission savings. From the traffic impact figures it can be seen that for full road closure leads to maximum of 47 % traffic disruption, with partial closure the contribution is about 23% for a single day. So in conclusion the full road closure during the weekdays is considered the best scenario for emission saving as it reduces the overall emission for the project.

The structured research sub-questions are addressed relying on the research conducted prior to the main research question. The first sub-question (*SQ1. What is a suitable method to calculate the spatio-temporal traffic flow variables and why?*) is answered by the means of literature review. The overview of all the traffic flow models presented in Table 2. The models were chosen for their capacity to determine dynamics, speed, flow, lane layout, and routing, among other things. Due to the size of the motorway network in the Amsterdam region, microscopic simulation models become costly and impracticable when considering network configuration and processing performance. In light of the available data, a macroscopic model emerges as the most credible alternative for achieving the research objectives. The macroscopic traffic flow model Omnitrans was selected after the model was analyzed for all the above characteristics. Omnnitrans allows to calculate flow, speed, total travel time, total travel distance, delays per time period. The roadworks in Amsterdam network are simulated by using the controls present in the Omnitrans like Outflow limiter, lane adapter controls. Omnitrans has reportedly been used by the Rijkswaterstat, road operators, and policymakers in the Netherlands to simulate roadworks, allowing for the modeling of the road network in the Amsterdam region already available.

The second sub-question (*SQ2. What is the suitable method to calculate greenhouse gas emission and why?*) is also answered by means of literature review. The macroscopic traffic flow model and the microscopic emission model cannot be integrated since the macroscopic traffic model addresses aggregated traffic patterns while the microscopic model examines the interactions of individual vehicles. As an outcome, a macroscopic emission model is chosen for the research. The MOVES model was selected for the study because it differentiates from several other macroscopic models because of how it allows for individual link level analysis, that are being used to investigate more directed emission. MOVES' multi-scale capabilities to compute both project and network level emissions is one of its most distinguishing characteristics. In addition, MOVES-derived emission factors provide a more precise characterisation of the number of onroad emissions than emission factors provided by conventional average speed-based macroscopic models.

The third sub-question (*SQ3. What are the type of scenarios considered for planning road works?*) is also answered using literature review. The different scenarios for a road work project can be analyzed depending on the overall period of the project and the traffic intensity. Demand, the number of lanes present, the number of lanes closed for road maintenance, and the frequency of road work, including peak and off-peak schedules, are all elements that must be considered in each scenario.The major objective of this thesis is to effectively reduce emissions from roadwork. There are a variety of factors that contribute to increased emissions during road construction, including traffic congestion induced by capacity reductions and the duration of the project. The road work duration can be longer or shorter depending on the capacity reduction (full or partial closure), from this two main scenarios were formulated, which is full road closure and partial road closure. Another important consideration is the day of the week; traffic flow patterns fluctuate between weekdays and weekends. For example, weekday traffic is mainly comprised of educational and working commuters, with traffic being heavier at some times of the day than at other moments of the day, whereas weekend traffic is exclusively made up of recreational and social activities, where there is a shift in the peak period. As a result, sub-scenarios with full and partial road closures during weekdays and weekends were formulated.

Traffic flow simulation is carried out to answer the fourth sub-question (*SQ4. What are the spatio temporal traffic flow variables under different scenarios using the selected method from SQ1*). The traffic flow characteristics for every one of the aforementioned scenarios are estimated by Omnitrans utilizing data from Rijkswaterstaat and NDW Dexter. The important Omnitrans output required for the emission calculation in MOVES are link speed, link length and link volume. When comparing the weekday and weekend scenarios for the full road closure, the weekday scenario has increased traffic volume, resulting in heavier congestion, particularly in city routes passing through A10 west motorways like S105 and S106, which has also increased flows compared to flow rate without any controls when particularly in comparison to main A10 motorways like A10 East and A10 North. Between the two scenarios, A10 North has the maximum traffic volume during scenario 1, which is approximately 30% larger, and city roads have heavier traffic throughout weekend scenarios. This surge in traffic in Amsterdam's inner rings on weekends must be due to tourists and locals travelling on social and recreational trips. When comparing the weekday and weekend scenarios for partial closure scenarios, the weekday scenario has somewhat higher traffic volume, causing congestion on motorways like that of the A10 East. When compared to the motorway network, where total vehicle traffic is nearly doubled at S105, S106, and S107 especially in comparison to the network without control, the actual impact map for the partial closure situation demonstrates that city routes near the A10 West highway are the most affected by the roadworks. This could be attributed to traffic from the A10 network being rerouted to the A4 and A5 motorways.When analyzing the full and partial closure scenarios, the full closure scenarios had more traffic volume and congestion from the speed plots. The delay graphs reveal comparable results, with full road closure causing significant delays in both city routes and the main network than partial road closure scenarios.

Emission modelling was done to answer the fifth sub-question (*SQ5. What are the greenhouse gas emissions under different scenarios using the selected method from SQ2*).MOVES uses Omnitrans measurements to compute the emission results for each scenario per day. The emission for a full road closure is higher than that of the emission for a partial road closure, as indicated in Table 90. Tables 91 and 92 show the overall emissions for the project's whole lifespan, as well as the conversion of each emission value into carbon dioxide equivalents, allowing for comparison of different greenhouse gas emissions. As indicated in Table 92, the project with partial road closure on weekends generates approximately 10 MT CO2e more than the project with full road closure. Because the partial closure has a longer duration of road work and a smaller restriction in capacity than the full closure scenarios, it accounts for a significant proportion of emissions. In addition, the intermittent closure on weekdays generates 9 metric tons additional CO2e than that of the full closure. The outcomes of traffic simulations, such as flow and delay, are compared to these results. Intermittent closures have lower daily delays and congestion than full road closure scenarios, comparable to the emission estimates.

7.2. Recommendations

Only emissions from on-road traffic are computed and compared across different scenarios in this research. To obtain more accurate emissions, the emissions from the construction process and materials should be included, to achieve this the road work should be meticulously recorded by collecting the details of the construction process, analyzing technical documentation, and questioning contractors. One disadvantage of this procedure is that the results can only be utilised after the project has been completed, and it does not provide information on choosing the best scenario to consider before the project is implemented.

The scenarios selected for this study are dependent on the Rijkswaterstaat's prior projects' literature reviews and methodologies. Other types of experiments can be conducted out beforehand, with policymakers selecting on a list of scenarios to investigate. For instance, decision-making approaches such as multi-criteria analysis can be used to weigh the trade-offs between alternatives and select the optimal alternatives for the investigation. Various scenarios are being developed as part of this process, such as executing roadwork exclusively at night and only allowing the road to certain modes of traffic, such as trucks or high-priority vehicles.

The roadworks were analyzed for A10 West for this study, however future research can quantify emissions for different sites because greenhouse gas emissions are highly variable for each location. Furthermore, the similarities and differences in emissions caused by traffic disturbances between different places may be thoroughly investigated.

CO2, CH4, and N2O are the only primary emission types considered in this study. Other emission categories should be examined for a more thorough assessment of emission levels for each scenario, even though they constitute very little to total emissions.

Apart from planning roadworks depending on calculated emission values, capacity-based techniques for road construction/maintenance work can be employed to reduce greenhouse gas emissions from projects. These strategies include capacity based strategies like increasing roadway throughput capacity for certain popular routes, vehicle-based strategies such as specifically targeting emissions through lower carbon emitting vehicles and fuels and demand-based strategies such as road pricing, which reduce emissions by reducing overall volume whilst still reducing traffic congestion.

Other modes of transportation, such as public transportation buses, should be examined for future studies because they have the highest priority at traffic lights. Also, technologies such as automated vehicles should be included in the research which have a greater potential to reduce emissions.

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8. Appendix

8.1. Appendix A: Academic paper

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Greenhouse gas emissions from road works: Case study for Amsterdam region to analyze different planning approaches

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Rijkswaterstaat strives for thorough maintenance planning that minimizes road closures, environmental damage, and traffic congestion. The majority of researchers concentrate on the emissions connected with road construction from the materials utilized. But an effective way to reduce emission from the road works is to analyze different planning approaches. The A10 Amsterdam network is chosen as the research area and the road works are simulated along the A10 west motorway. OmniTRANS is used for network preparation and ad project setup. The analysis shows that the partial road closure emits around 10 MT CO2e more greenhouse gas than the full road closure which demonstrates that it is possible to minimize project-related GHG emissions during roadwork by by performing a full road closure during the weekdays which has the highest emission savings.

Additional Key Words and Phrases: Greenhousegas emissions, road closure, simulation

1 INTRODUCTION

During a large-scale infrastructure project, there is two main causes of emission. Firstly, emission from materials of construction, maintenance, repair, and rehabilitation of the highway infrastructure. Secondly, due to the traffic congestion caused by the road works. Road works result in an increased number of road trips, mainly due to the route change in urban areas which leads to a heightened level of emissions in urban transportation networks which has damaging influences on environment. According to the statistics, one of the major sources of the occurrence of congestion is prompted due to road works. Such an immense congestion effect affects the traffic performance of the road network which in its turn influences the emission of greenhouse gases. . And as we know this is one of the causes of the global warming phenomenon which leads to climate change, air pollution, and others. Consequently, the ministry of Infrastructure and Water Management has been taking a lot of effort to reduce the occurrence of these types of congestion by assessing the execution of road works projects associated with greenhouse gas emissions. An example of a policy measure is the use of methods like free public transport. In the Netherlands, one of the prominent examples was in 2008 when the municipality of Utrecht introduced a mobility pass that allowed free travel on all forms of transportation. Their main impulse was to diminish the rush-hour traffic during the road works which indeed reduced the resulting emission **[17]**. Likewise, an effective policy measure should be formulated to calculate the emission and plan the road works accordingly.

Based on the statistics from [7] in the Netherlands since 2002, there has been a increase in the total annual mileage by road users which amounts to 147.6 billion kilometers by the end of 2017.They are chiefly attributable to passenger cars and heavy goods. So, diminishing the adverse effects of emission from transportation networks has gained augmented importance over the years. As a densely populated and mobile country, Netherlands has an inclusive network length of about 5800 *km*. The country has been continually taking measures to promote a high level of mobility to its users as the traffic is anticipated to grow to a height of 35 percent at the end of 2020 [2]. This certainly demands new infrastructure development to accommodate this growing traffic. Across the world, infrastructure aging and its management has been given increasing attention as it's considered to affect the environment and countries economy [29]. In the Netherlands the vast majority of bridges are built in the 1960s-80s and are now near the end of life and facing a potential problem of fatigue cracks due to the increasing traffic [11]. Extensive road maintenance is done every 15 years to prevent wear and tear. To overcome the failure of the bridges, the Dutch road authority Rijkswaterstaat has introduced a bridge maintenance program called "Replacements and Renovations Program" to upgrade the roads to handle heavier traffic conditions and to increase the safety. Rijkswaterstaat aims for careful planning of the maintenance program with minimized road closures and congestion issues. This enormous increase in road works and its usage lead to increased emissions which contributes to carbon dioxide, nitrogen oxide, and particulate matter which in turn affects climate change, ecosystem, and wildlife [19].

Not only transport operators but also the policymakers must take into consideration this effect of the emission before plotting the construction work. [32] discusses that policymakers should investigate these factors linked to the emissions to draw up strategies for achieving sustainable transportation. With the growing frequency of road works and the severity of congestion, this research into calculating the emission using different methods before planning the construction work, is important. There is a range of strategies employed to calculate these emissions, one of the methods is using simulation to anticipate these emissions.

The main objective of this research is to investigate the effects of congestion on emission in relation to road construction and maintenance. The main goal of this research is to develop methods that will facilitate Rijkswaterstaat to support decision making using traffic and construction data related to highway infrastructure.

To answer the research objective the following research questions will be answered which are categorized into main and sub-research question.

Main Research question
How can the planning of road works be scheduled while taking into account greenhouse gas emission values from road works?
Sub Research questions

(1) What is a suitable method to calculate the spatio-temporal traffic flow variables and why?
(2) What is the suitable method to calculate greenhouse gas emission and why?
(3) What are the type of scenarios considered for planning road works?

(4) What are the spatio temporal traffic flow variables under different scenarios using the selected method from sub-question (1)?
(5) What are the greenhouse gas emissions under different scenarios using the selected method from sub-question (2)?

2 LITERATURE REVIEW

Traffic simulation is the extensively used tool for analyzing, designing a model of a real system and conducting experiments with the model for a better understanding of its behavior. It enables the operator to control model input conditions all the time and also permits us to simulate the environment at a faster rate than the experiment conducted in real-life [14]. While simulating the traffic systems many different methodological approaches exist and numerous papers reviewed them. [23] addresses the possible alternatives to recognize and measure metrics for urban arterial congestion. Within most of the literature, two significant distinctions between models were made: macroscopic vs microscopic modeling approaches. The research by [10] also distinguishes a third category, mesoscopic models. The main difference between these three classes is the trade-off between optimizing simulation speeds and evaluating the traffic states (or traffic phenomena) as precisely as possible [33]. [6] has done a detailed analysis on the types of traffic assignment and simulation models including their application and implementation in The Netherlands and internationally. They classify the traffic models into Demand models, Macroscopic models, Mesoscopic models, Microscopic models, Data driven models and Combined or hybrid models. To find a suitable method to calculate the Spatio-temporal traffic flow variables much traffic flow software that falls under these these categories are reviewed in the sections below.

Microscopic models continuously or discretely predict the state of individual vehicles and concentrate on the specific vehicle speed and locations [22]. The reason why micro-simulation models are favored over other methods is that micro-simulation models permit us to assemble more knowledge concerning the consequences of one vehicle over the other, for example, speed and also they reproduce the stochastic nature of the traffic, for instance, they incorporate driver behavior data. Also, they assist in estimating the peak hour congestion effects [18]. Several microscopic models are developed for modeling traffic congestion, for instance, CORSIM (CORridor SIMulation) developed by U.S Federal Highway Administration (FHWA), VISSIM developed by Planung Transport Verkehr (PTV) in Germany, SimTraffic developed by Synchro, Aimsun developed by Transport Simulation Systems in Spain, Freeway Operations Simulation (FOSIM) developed by Delft University of Technology.

Models like car following, longitudinal motion, gap acceptance, and lane change model are employed in most microscopic models to imitate the movement of the vehicle within the traffic with high accuracy like the behavior of vehicles collectively with lane changes, dynamics, gap acceptance and so on [21]. According to [5] the microscopic model is preferred when the research demands densely detailed analysis of real-world traffic behavior. With the strength comes the weakness, the level detailing in the microscopic model can also be seen as a disadvantage as it entails much data concerning the traffic, road geometry, driver behavior, and so on. When the model is large then the time taken to run the simulation can be quite long which is a shortcoming if the network modeled is small.

The mesoscopic model fulfills the gap between the macroscopic models and microscopic model by the level of detailing, it has the perspective of both of the models illustrating the traffic flow variables at a medium level [22]. These models simulate the platoon of vehicles and consolidate equations that indicate how these groups of vehicles cooperate [21]. The major difference between the macro and mesoscopic models is that the mesoscopic model can reproduce a large network incorporating many details than a macroscopic model. The mesoscopic analysis also supports the analysis of road segments, multiple routes within a network, basic signalized intersections, freeways, and ramps [5].

Research by [5] points out that weather impacts on the transportation system can be incorporated into mesoscopic models. Given the strengths of this model, one of the weaknesses is its inadequacy to model detailed operational strategies like coordinated traffic network and complicated traffic signals. This can be done in a microscopic model as it uses many comprehensive data. In the mesoscopic model, the behavior is defined at the individual level.

Macroscopic models have a great level of aggregation with the representation of traffic flow, speed, and density [22]. This model is based on the deterministic relationships developed through research on highway capacity and traffic flow for freeway sections. The macroscopic simulation takes place on a section-by-section basis rather than simulating individual vehicles [21] so it is suitable for reproducing larger regions. This model considers that all the vehicles on the road have identical characteristics so this method is not suitable for analyzing the traffic at the vehicular level. Due to these facts, the modeling set up can be carried out faster and the simulation time is less compared to other models. The only disadvantage of the macroscopic model is its failure to model detailed behavior of traffic in the network [5].

Some of the macroscopic models are OmniTRANS, PTV Visum developed by PTV Planung Transport Verkehr AG , CUBE a transportation and land use modeling software developed by Citilabs. In the Netherlands, OmniTRANS is the popular macroscopic model practiced for regional modeling as it can model both static and dynamic assignments. Most of the macroscopic models use the Cell transmission model determining the density and flow at each step. Cell transmission model is computationally very effective when compared to other micro and mesoscopic models, it is well suited for modeling traffic interactions like queue spill back [28].

Travel demand models are mathematical models that forecast the travel demand between an origin-destination pair utilizing the current conditions and future projections in a specific area for a specific mode [6]. They are mainly used to determine the positive effects and challenges of taking over highway projects. They follow the four-step modeling process briefly explained in section 2.3. Some models also include the time of the day or departure time choice model in their modeling process. [8] describes two travel demand method approaches, trip-based travel demand model and activity-based travel demand model. The trip-based model follows a traditional four-stage modeling process and uses individual trips as the unit of analysis. Drawbacks of the trip-based model are that this model focuses on individual trips rather than the relationship between all trips, each individual is considered a decision-maker. The alternative approach is an activity-based model where travel demand is based on the need to pursue an activity. [3] and [8] define five important features that the activity-based model should have, first, travel demand should be derived from activity participation. Second, an activity-based approach focused on the sequence of activities. Third, the household should be considered as a decision-maker and all the individual activity should be planned and executed in that context. Fourth, Both spatial and temporal constraints are taken into account for example activities should be continuously spread throughout 24 hours. Finally, time and space limitations should be considered when making travel and location choices. The main disadvantage of this model is that it requires much more data than the other models.

Microscopic model provide a detailed analysis of the traffic process while the macro and mesoscopic models provide a lesser detailed analysis but are faster. Hybrid model makes use of different types of models. Hybrid simulation enables using a microscopic model in selected areas where detail is needed and the macroscopic model in other areas of the selected network. Hybrid model is more advantageous in places where detailed knowledge of the individual vehicles and parameters such as headways are needed as well as wider knowledge about the network such as the speed and flow [1]. Many researchers have contributed on developing the framework for integrating different traffic simulation models into one hybrid model. For example [4] has been developed framework for integrating microscopic and mesoscopic traffic simulation models into one hybrid model. There are many hybrid models developed experimentally, only few hybrid model packages are available to use, one such model is AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks).

Data-driven models focuses on finding patterns in the traffic flow data especially finding connections between the system state variables to make traffic forecasts [31]. The main principle of data-driven models as proposed by [20] is to calibrate or train the models in order to minimize the model error. Data mining, computational intelligence, machine learning, intelligent data analysis, soft computing and pattern recognition are some of the areas contributing to data-driven models [27]. These models follow computational intelligent based approaches to predict the traffic such as neural networks, fuzzy rule-based systems and genetic algorithms [26].

2.1 Selection of simulation Tool

After analyzing different simulation models based on factors like their capabilities to calculate speed, dynamics, flow, queuing data, routing, lane configuration, vehicle class, model availability, OmniTRANS is chosen for conducting traffic analysis. OmniTRANS follows 4 Stage modeling processes: Trip generation, Trip distribution, Model Split, and Trip assignment. In the assignment process, the route generation model is incorporated, which calculates the shortest path between the Origin-Destination pair using the Dijkstra algorithm. Also, alternative routes are generated using the Monte Carlo algorithm This model is suitable for the research as the main hypothesis is to analyze the traffic flow in the alternative routes. To model the continuous departure pattern, the streamline estimates the route fractions for every origin-destination pair using route costs like travel time, total traveled distance. Finally, the route is selected based on the cost between the initial route and the alternatives from the set of routes.

OmniTRANS allows modeling both static and dynamic assignments. Traffic can be analyzed at an aggregated or dis-aggregated level. For instance, it can be multi-model and multi-temporal. For Dynamic Traffic assignment Streamline model MADAM (Macroscopic Dynamic Assignment Model) developed by OmniTRANS. MADAM is a cell propagation model with cells of equal length on each link. One of the many building blocks of MADAM Streamline is Dynamic traffic management with several controls like Ramp metering, variable speed limits, Outflow limiter, Lane Adapter, etc... some of which will be used for designing the road works of A10 West.

2.2 Types of Emission model

Research shows that the emission associated with the road construction and maintenance activities is often from the congestion caused due to the road closure and the emission from the materials used. To mitigate the emission of greenhouse gases various measures have been taken by the government and transportation agencies. One way to reduce these construction/maintenance related emissions is to quantify the emission values before executing the project. These emission values are determined by multiplying the emission factors per mode with the traffic data obtained. There are a variety of pollutants and particulate matter emitted from the vehicles among which methane, nitrogen oxide, and carbon dioxide are the most dangerous and prevalent greenhouse gases and different vehicle characteristics influence the level of emissions.

Emission models aids in calculating the pollutant level and the fuel consumption of the vehicles from traffic flow characteristics like average speed, traffic volume, dynamics. There are a variety of emission models depending on the level of detail, level of the resolution, and models that incorporate driver behavior. Similar to the traffic flow model distinctions in Chapter 2, emission models can also be macroscopic, microscopic, and mesoscopic based on their modeling approaches [24]. [25] further classifies the emission model into queuing emission model - Matzoros model, Reconstructed speed-time profile emission model - TEE model, Traffic situation emission models, Area-wide emission models and Fuel-based emission models based on the manner in which the emissions are predicted. These emission models vary in the different factors, one of which is driving patterns that connect the effects of congestion to vehicle emissions. Traffic situation models use traffic field data to compute emissions for large inventories, Areawide and fuel-based models are employed at the regional level and other models like Queuing Matzorous model, TEE model, and reconstructed speed time profile models are limited in practical application.

[13] distinguishes the emission models into two categories based on their level of complexity. They are the average speed based model

(macroscopic) and modal emission model (microscopic). Depending on the aggregation and level of detail, there are several model categories which are discussed below in detail.

Average speed based models or macroscopic emission models estimate the emission and fuel consumption of a traffic flow based on the speed-related emission functions measurements over a variety of trips at different speed levels. The input for this model type is the average speed of traffic flow [34]. The main advantages of these models are faster to compute as they do not consider changes in operating condition at a vehicular level but on a network level and easy to use [24]. These models are used in the emission inventories to calculate the emission values on a regional or national level. Some of the macroscopic emission models are COPERT (Computer programme to calculate emissions from road transport), EMFAC (Emission factor), NAEI (National Atmospheric Emission Inventory), and MOBILE (Motor Vehicle Emissions Factor Model).

Area-wide model is a straightforward, most aggregated macroscopic emission model. The input and output of this model is total vehicle mileage (vehicle kilometers traveled- VKT) derived from national statistics or using a traffic demand model and emission values per mode (usually passenger cars and heavy-duty vehicles) for the investigated area calculated by combining the traffic data for the area and the emission factor per mode [12]. The main assumption of this model is that emission occurs at a constant average rate and are used for calculating emission for a larger area like nation or state for a year [25].

The traffic situation model uses distinct emission factors for several driving patterns. Some of the predefined traffic situation considered by this model are traffic flow patterns like free, congested, stop and go depending on the area type, level of service which is the traffic flow quality (from 1 to 10 with 10 being fully congested) and road type for example motorway, rural, urban roads [12] The input for traffic situation model is the VKT (vehicle kilometer traveled), traffic situation and the road type. The output is total emission in g/VKT. Researches [25], [30] defines the traffic flow situations qualitatively (verbal description like road type, level of congestion, area type) or quantitatively (quantitative variables like speed, volume, length). Quantitative traffic situation models are preferred over qualitative methods because the boundary conditions between the traffic situation are not distinctly set or not inconsistently interpreted in the later [30]. Some of the quantitative traffic situation models in practice are HBEFA (Handbook Emission Factors for Road Transport), ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems), some version of MOBILE.

Reconstructed Speed-Time Profile Emission Model (TEE model) and Queuing Matzorous model belong to Traffic-variable models category of modeling. Matzorous emission model uses the stochastic queuing theory to model the emissions at unsignalised intersections. Some of the inputs of this model are speed, road category, length, etc. While TEE model incorporated four different modeling framework such as speed cycle model, reconstructed simplified cycle model, corrected average speed model and average speed model to calculate

The microscopic or dynamic emission models are based on the instantaneous traffic variables of individual vehicles and provide accurate emission values compared to the other model types. They calculate the emission due to the speed and acceleration variation of the traffic and the computational time is usually higher for these categories of models as they are at the higher level of complexity and can provide the emission levels second by second for the individual vehicle in the traffic. On contrary to average speed models, dynamic emission models are typically used with microscopic traffic flow models. They require a large amount of data especially on each vehicle like engine power and other parameter related to vehicle operation. Modal emission models are further distinguished into instantaneous acceleration speed matrix model, instantaneous engine speed load matrix model, instantaneous analytical speed acceleration functions, instantaneous power-based model, and aggregate modal emission model **[25]**. Some of the microscopic emission models are PHEM (Passenger Car and Heavy Duty Emission Model), CMEM (Comprehensive Modal Emissions Model), VT-Micro (Virginia Tech Microscopic Energy and Emission Model), VERSIT +

2.3 Selection of emission model

In general, macroscopic traffic flow models are utilized with macroscopic emission and fuel consumption models. Macroscopic traffic flow model output may readily be integrated into macroscopic emission and fuel consumption models. Based on the literature study in the above section a macroscopic emission model MOVES (MOtor Vehicle Emission Simulator) is selected.

MOVES distinguishes itself from other macroscopic emission model by estimating emissions based on vehicle operating modes specified by a variety of parameters, such as speed, acceleration, and road grade, rather than average speed. The capacity to model alternate vehicle and fuel types, as well as the usage of MySQL database administration, complex GHG estimation algorithms, and overall energy consumption estimation [16]. MOVES capacity to produce project-level emissions inventory is a crucial characteristic that distinguishes it from other emission models. The most detailed level of analysis in MOVES is project level analysis, which analyzes a single roadway connection, a set of specific roadway links, and an off-network common space like parking spaces. Simulation at a granular level is used to examine more targeted emissions. MOVES can estimate both emission components and total emissions [15]. Taking into account the ability to model dynamic emissions MOVES emission model is selected for this study.

3 TRAFFIC SIMULATION

In this research A10 West is chosen for the major construction and maintenance works and to analyze and quantify the emissions from traffic when diverted to other routes. One reason underpinning this choice is that A10 West attracts majority of the traffic and contributes to frequent traffic jams as it has many on- and off-ramps. A10 ring road have totally 32 Ramp metering systems, A10 west has on and off-ramps every 1.7 km **[7]**. Another reason is that A10 West highway cuts through the residential area which can provide more insights into timing of construction, emission and also the presence of many city routes.

For this research, the OD matrix for period 14:30 to 20:00 with 350 centroids was already available from Rijkswaterstaat. Also, the data on different link types in the network such as capacity, free speed, speed at capacity, saturation flow, road type, directions are included in the network provided by Rijkswaterstaat. However to analyze the morning time scenarios , the part of the OD matrix for morning time should be calculated. These data on link volume, intensity, speed counts are calculated routinely by road authorities. For this research data are collected from NDW (Nationaal Dataportaal Wegverkeer) which is a national access point for road traffic data in Netherlands. The average vehicle distribution per hour is collected for different sections of A10 motorways and the 24 hour traffic flow pattern was calculated from the data. Totally 10 measurement locations like Coenplein, Watergraafsmeer, Amstel, De Nieuwe Meer, including the exit and access roads along A10 like A2 to northbound in the direction of Zaanstad / Amsterdam-Oost, A1 westbound in the direction of Zaandam, A8 eastbound of zaandam were selected along the A10 motorways . Traffic flow data from February 2019 to November 2019 was used with and exception of weekends, National holidays. After gathering the data it was checked for plausibility and error. All the data was reconstructed for 15 minute travel interval and the pattern of traffic movement was analyzed. This pattern is then applied to the OD Matrix provided by the Rijkswaterstaat and imported to OmniTRANS under a new matrix cube.

To analyse weekend scenarios a separate OD matrix is calculated using the data collected from NDW. For this, the average vehicle distribution per hour is collected for the same measurement locations as above for weekends and the data was constructed for the 15 minutes interval. The pattern of traffic for weekend was compared to the weekdays traffic pattern. The difference is applied to OD matrix for each time interval and stored under a new variant matrix cube.

For one of the busiest motorway network in the Netherlands like A10, planning a road work is demanding as people are continuously in motion. Depending on the type of road work and characteristics of the road like the length, number of lanes, width a road work can be planned for different time of the day. Traffic flow in these work zones can be affected as one or more lanes become unavailable leading to bottlenecks resulting in queues and delay. There are different factors responsible for increased CO_2 emissions during the process of road work. Congestion due to the capacity reduction from the road work contributes to this due to increased idling, acceleration and braking . The main trade-off in this case is between the duration of the road work and the capacity of the road. As decreasing the capacity for a longer period of time would directly increase the total emissions from the construction. Short term road work with full closure scenarios gives a lower capacity compared to the long term road work with partial road closures. Therefore a comparison is made between the full closure of the road during construction which has shorter duration of work compared to intermittent or partial road closure.

For full road closure during the weekdays, all the lanes are completely closed for work on a 24-hour basis. Full-day closure enables a longer period of uninterrupted work which can result in increased productivity with a limited amount of time. For this scenario 5 km stretch of A10 west motorways is fully closed for major maintenance work. The roads are closed for the entire day meaning that considerable savings in time required for completion of roadworks achieved faster, despite the number of operational lanes is lower compared to other scenarios. As observed from the figures there is a major increase in the flow for the other parts of the A10 motorway network specifically in A10 north and A10 east after implementing the controls for road works compared to A10 South. This is because traffic from the A1, A2, and perhaps other provincial roads like N247, N516, N522 heading for the A5 must take the A10 east and north.

The city routes via A10 west has overall less flow as compared to the main network particularly the upper parts of the A10 west motorways like S105, this could be due to the shutdown of certain parts of these city routes that cross the A10 west network, which is blocked for maintenance work, whereas other routes of the network like S106 and S107 experience increased flow. This increased flow causes congestion in that location, as evidenced by the speed contour plots in the Figure 4, which indicate a larger area of congestion when compared to the corresponding baseline scenario in Figure 5. Also, among all other city routes, S106 has the largest overall flow. This may be attributed to the route's length, as well as the fact that it is one of the major interconnecting routes for the Amsterdam nieuw west with the main network.

Full road closure during weekends also represent the full closure of 5 km stretch except for this scenario weekend OD matrix cube is used. The flow curves for this scenarios are compared to the base case scenario which is which is weekend traffic flow without any controls. When analyzing the flow curves for scenarios 1 and 2, the A10 east and north has more traffic during the weekdays, with morning and evening rush hours, but traffic increases gradually during the morning and stays stable throughout the day on weekends, with no major peaks. Similar to the weekday scenario, s106 has the highest reported traffic for city routes, owing to its placement close to Amsterdam neiuw west region and also being the longest city route.

When looking at the speed contour plots (Figure 5), the A10 south has the longest queue length, with just two big congestion events throughout the day, owing to the lower traffic in that area, but the A10 east has heavy congestion for the whole day. Remarkably, the A10 north does not experience considerable congestion throughout the day, as it does on weekdays. This is due to the fact that traffic flow on weekends is much lower in that region than on weekdays, which could be related to the proximity to recreational areas to the A10 east and south. While for the city routes, s105 has the occurrence of congestion at 10:00 and 19:00.

Similar to scenario 1 the flow curves for each location are compared with the base scenario which is weekend traffic flow without any controls. Based on the flow figures, it is observed that the city routes passing through A10 west motorways like S105 and S106 have increased flows when compared to main A10 motorways like A10 East and A10 North. While city routes at the lower part of the A10 west like S107 motorway have very less flow unlike scenario 1. This can be proved from Figure 1, flows for scenario 1 is higher than scenario 2. For example during scenario 1 A10 North has 31.4 % increase in total flow comparing to scenario 2, while other motorway networks does not have significant increase. A10 south has a decrease of 0.5 % of traffic while the east has a increase of 7.2 % of traffic flow during scenario 1 comparing to scenario 2. This shows that during scenario 1 most of the traffic are diverted towards A10 North. Upper parts of A10 West has 4.1 % increase in the flow during scenario 2 while other city routes S107 has increased traffic during scenario 1 compared to scenario 2.

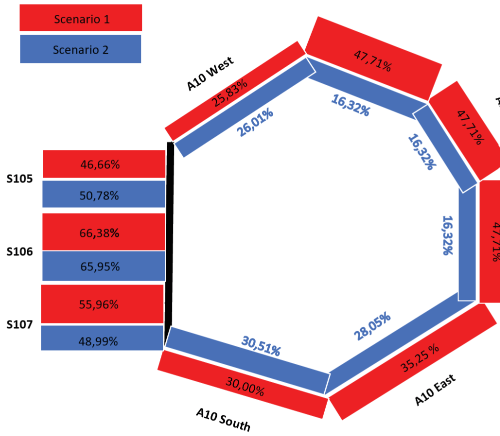

Fig. 1. Flow map of Amsterdam network (percentage increase in the traffic flow both the directions during road work)

For the partial closure during weekday scenario 5 km stretch of the A10-West motorway is partially closed for work and traffic is open in one direction from south to north. During the partial closure of the A10 west region, A10 east is the most significantly affected area, with about double the real flow and mild congestion throughout the day. The north and south adjacent zones to the A10 west operate normally without interruption; as seen in the flow figures, their flow is almost identical to the flow prior to the road work intervention. They're also experiencing congested throughout the morning and evening rush hours.There will be a considerable traffic flow in the south and eastern ring roads with traffic entering and exiting the A2 and A1 highways with the A10 west only functional 50% of the time where traffic is open in a clockwise orientation from west into the southern area or from A10 towards A4 and A2. For the city routes the traffic flow is almost similar to the the full road closure scenario.

Finally partial closure during weekends, this is similar to scenario represented above, partial closure of 5 km stretch where the traffic is open from north to south on weekends. Shown in the Figure 2 are the impact of the intermittent road closure on the A10 West motorway. In this figure the region marked in yellow represent change in the flow values from the base case scenarios without the road work for the intermittent closure during the weekdays (scenario 3) and the green region represent the intermittent closure during the weekend (scenario 4).

Based on the flow figures, it is observed that the A10 East has very less or close to the flows of base case without any controls while A10 North and South has a modest increase in traffic flow when compared to the base case. Similar to scenario 3 S106 has increased traffic flow compared to the other city routes S105 and S107. This can been seen from figure 2, S106 has a 63.2 % and 64.2 % increase in the total traffic flow for scenarios 3 and 4. While the other city routes have 50.9 % and 49 % increase for scenario 3 and 41.6 % and 50.5 % increase for scenario 4. The main motorway network has a very less increase in traffic flow comparing to the city routes. Scenario 3 has an increased traffic flow compared to scenario 4. For instance, in A10 North there is 4.1% increase in traffic flow for scenario 3 compared to scenario 4. For A10 East there is 23.6% increase in traffic flow for scenario 3 compared to scenario 4. Figure 4 and 5 also show that S106 has less occurrence of congestion while comparing to S105 and S107. In the motorway section A10 South, North and East scenario 4 has more congestion compared to scenario 3.

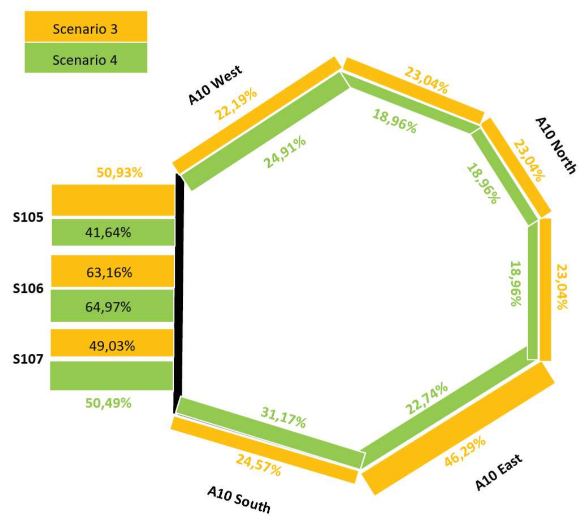

Fig. 2. Flow map of Amsterdam network (percentage increase in the traffic flow in both the directions during road work when A10 west is closed from south to west)

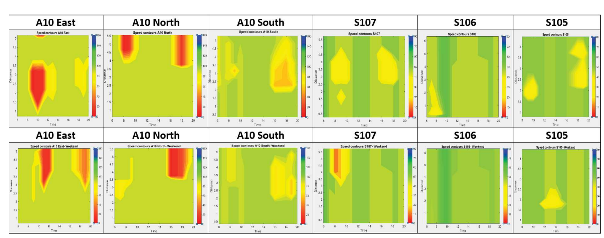

Fig. 3. List of speed contour plots for different locations in the A10 network for weekdays and weekends

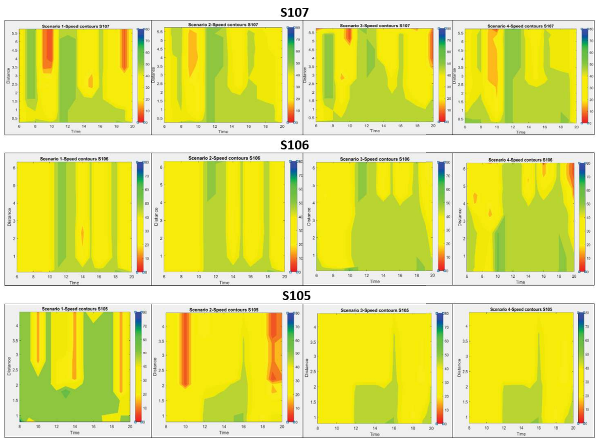

Fig. 4. List of speed contour plots for city route S107, S106 and S105 under each scenario

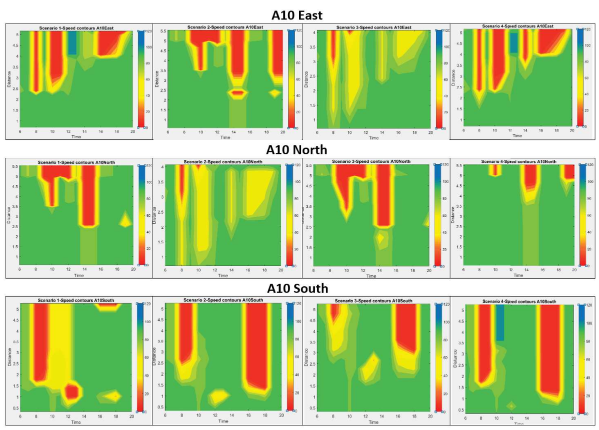

Fig. 5. List of speed contour plots for A10 East, South and North under each scenario

4 EMISSION MODELLING

MOtor Vehicle Emission Simulator (MOVES) is used for emission modelling in this research which allows multiple scale analysis including national, county and project scale of analysis which allows detailed link level analysis. To develop an integration framework between the emission and the transportation model all the data requirements are studied, which included the input and output data for both the models. MOVES, when used in combination with traffic models, estimates emissions for all vehicles in the traffic network specified by the traffic model. The required fuel and engine data is taken from the MOVES database. MOVES categorises all types of on road vehicles like motorcycles, Light duty vehicles, single unit trucks, combination trucks and buses.The traffic model classifies the vehicle categories into cars and light and heavy duty trucks these results are imported into the emission model. The classification of fuel data into fuel supply, formation and usage data, age distribution and retrofit data are automatically chosen by MOVES for each individual vehicle based on the fleet composition. The fleet mix is determined using data from the OmniTRANS model. MOVES utilizes the speed, flow and other input data produced by OmniTRANS in plain text and excel files. These files delivered to MOVES contain time, month, weekday/weekend, link traffic speed, link traffic volume, road grade, roadway type along with other information defining temperature and humidity. The time period of the study, as well as the vehicle kinds, road types, fuel types, pollutants that will be included in the analysis, are all defined in the Run Specification. And the input database includes the data set from the Omnitrans like the vehicle activity data. These data files are imported into the MOVES model by importing the template and altering it with a spreadsheet application to include relevant specific information, and then importing each data file into an input repository for the run. Both run specification and input data set are run through the graphical user interface of the MOVES model.

In project scale analysis MOVES calculates emission from the vehicle activity including the vehicle type, number and their activity on a specific link on a particular time of the month of the year, each time period in MOVES requires a separate run. MOVES categorises all types of on road vehicles like motorcycles, Light duty vehicles, single unit trucks, combination trucks and buses. MOVES accounts for project scale, time spans, road type, pollutants, temperatures, humidity, age distribution, fuel, link level data, retrofit data and emission control activities such as inspection and maintenance (I/M) programs. Some of these data are set to default like fuel data including fuel supply, fuel formulation, fuel usage, AVFT (Alternative fuel and vehicle technology) and I/M (Inspection/Maintenance) programs. Other data like meteorological inputs are gathered from [7] which includes the temperature and humidity data for each specific month. The minimum and maximum temperature for each time period is collected from [7] and the average temperature within that period is used. Link inputs like Link ID, link length in kilometers, link Volume in vehicles per hour and link speed in kilometer per hour, link Description and link Grade in percentage grade are collected from the traffic flow model for each link in the Amsterdam network.

For each scenario, the construction work is carried out under different time zones. When comparing the results for each scenario, the results are based on the time of construction (weekday/weekend) and the area of analysis.

		CO2	N2O	CH4	CO2e	Delay
Scenario 1	Full closure- Weekdays	233885	21	3	240346	800
Scenario 2	Full closure- Weekends	235896	21	3	242213	922
Scenario 3	Intermittent closure- Weekdays	220693	20	3	226751	515
Scenario 4	Intermittent closure- Weekends	233670	21	3	240095	705

Fig. 6. Δ GHG emissions from full closure and partial closure for a single day

For every sub-network level, the total emission results for each scenario are totaled, and the overall emission for the Amsterdam network is displayed in Figure 6. As the results are the difference from the base case scenario without roadworks, the emission figures are in Δ. This process is performed for each emission category. The overall emissions are estimated by converting each Delta Greenhouse Gas into carbon dioxide equivalents in tons, which is then compared to the lost time due to road work. Figure 6 shows that with longer delays, the emission increases higher. For example scenario 2 has the highest delay which corresponds to more emissions in scenario 2 this correlates to higher traffic congestion and higher total emissions.

The total emission for the project is then estimated by multiplying the current daily emission by the number of days scheduled for road work. According to Rijkswaterstaat, road construction on the entire length of the A10 west might take up to 42 days when fully closed, and up to 84 days when partially closed. Figure 7 illustrates the Δ greenhouse gas emissions from the full and partial closures over the project's lifetime.

		CO2		N2O		CH4		Delay	
Scenario 1	Full closure- Weekdays	9823166	17%	899	17%	137	17%	33600	19%
Scenario 2	Full closure- Weekends	9907641	17%	879	17%	135	17%	38724	22%
Scenario 3	Intermittent closure- Weekdays	18538213	32%	1686	32%	257	32%	43260	25%
Scenario 4	Intermittent closure- Weekends	19628301	34%	1788	34%	273	34%	59220	34%
Total		57897321		5252		802		174804	

Fig. 7. Δ GHG emissions from full closure and partial closure for the total project duration

All of the results are converted into carbon dioxide equivalents so that the emission numbers can be added. By converting levels of other gases to the comparable amount of carbon dioxide with the same global warming potential, this metric can be used to compare the emissions of different greenhouse gases based on their GWP. The comparison is made in tons. The global warming potential of CH4 and N2O is 25 and 298 units, respectively, when multiplied by the metric tonnes of gas **[9]**.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
CO2	9823166	97%	9907641	97%	18538213	97%	19628301	97%
N2O	267930	3%	261935	3%	502467	3%	532881	3%
CH4	3431	0,03%	3363	0,03%	6432	0,03%	6829	0,03%
Total	10094528		10172939		19047112		20168012	

Fig. 8. Δ CO2 equivalents of GHG emissions from the road works of A10 Network for the total project duration

Figure 8 shows that full road closures on weekdays have the highest greenhouse gas emission value per day, but partial road closures, particularly on weekends, have the highest overall emission when the project is assessed throughout its whole lifetime. This is due to an increase in the amount of days worked on the road due to intentionally closing selected lanes for work while the others continue to operate. It's also important to note that the second largest emission comes from a partial closure for road construction on weekdays, while the lowest emission comes from a full day closure on weekdays. With so many tourist destinations, the Amsterdam region is always busier on weekends, and the closure of the A10 west makes it even congested on other parts of the highway, such as the north and south, resulting in higher emissions in these locations.

As illustrated in Figure 8, a partial weekend road closure produces around 11 MT CO2e higher emissions than a complete weekend road closure which is the difference in total Δ emissions between scenario 4 and 2. While a partial road closure during the week generates approximately 9 MT CO2e higher emissions than a complete road closure during the week which is the difference in total Δ emissions between scenario 3 and scenario 1. The difference in emission values between scenarios 1 and 2 is smaller because they share the same base case scenario, which is a full closure scenario with no road work, and the value shown in Figure 8 is the Δ, which is the difference between scenario 1 and 2 from the base case, implying additional emissions from road work. The same is done for scenarios 3 and 4. The base case scenario is a partial closure scenario without road construction, and the Δ value in Figure 8 is the difference between scenario 3 and 4 and the base case. From the traffic flow analysis it is also clear that the overall delay for a day for the Amsterdam network is greater for scenario 1, which is a full road closure on weekdays, and the next largest delay is a full road closure on weekends. The partial closure scenarios, on the other hand, have relatively short delays per day.When comparing the delay and emission findings, the emission results in Figure 8 show the same pattern, with total emissions being higher for full closure scenarios than partial closure scenarios.

5 CONCLUSION

The current study's conclusions and recommendations are discussed in this chapter. The chapter is subdivided into two sub-chapters; the first sub-chapter addresses the answers to the research questions, while the second sub-chapter demonstrates the limitations of this research as well as recommendations for further research.

The main research question (*How can the planning of road works be scheduled while taking into account greenhouse gas emission values from road works?*). This review investigated towards how Rijkswaterstaat might be able to reduce greenhouse gas emissions from road construction and maintenance projects. So for this research roadworks were simulated for A10 west network and the greenhouse gas emissions from the traffic during the roadworks was assessed. For the road works, two major scenarios were considered which are full road closure and intermittent road closure. Rijkswaterstaat provided all of the information on the actual roadworks utilized in this study, enabling the analysis to demonstrate the prospective greenhouse gas reductions.

As previous shown from the impact figures from the results, the partial road closure has about 10 MT CO2e more greenhouse gas emissions than the emissions from the full road closure. Since the partial road closure has less capacity constraint than the full road closure leading to longer period of work which leads to relatively large share of emissions. Table 8 compares the total emissions from all the scenarios. Between the full road closure, there is sub-scenario for weekdays and weekends, from the table 8 it can be seen that full road closure during the weekday has the highest emission savings. From the traffic impact figures it can be seen that for full road closure leads to maximum of 47 % traffic disruption, with partial closure the contribution is about 23% for a single day. So in conclusion the full road closure during the weekdays is considered the best scenario for emission saving as it reduces the overall emission for the project.

The structured research sub-questions are addressed relying on the research conducted prior to the main research question. The first sub-question (*SQ1. What is a suitable method to calculate the spatio-temporal traffic flow variables and why?*) is answered by the means of literature review. The models were chosen for their capacity to determine dynamics, speed, flow, lane layout, and routing, among other things. Due to the size of the motorway network in the Amsterdam region, microscopic simulation models become costly and impracticable when considering network configuration and processing performance. In light of the available data, a macroscopic model emerges as the most credible alternative for achieving the research objectives. The macroscopic traffic flow model Omnitrans was selected after the model was analyzed for all the above characteristics. Omnnitrans allows to calculate flow, speed, total travel time, total travel distance, delays per time period. The roadworks in Amsterdam network are simulated by using the controls present in the Omnitrans like Outflow limiter, lane adapter controls. Omnitrans has reportedly been used by the Rijkswaterstat, road operators, and policymakers in the Netherlands to simulate roadworks, allowing for the modeling of the road network in the Amsterdam region already available.

The second sub-question (*SQ2. What is the suitable method to calculate greenhouse gas emission and why?*) is also answered by means of literature review. The macroscopic traffic flow model and the microscopic emission model cannot be integrated since the macroscopic traffic model addresses aggregated traffic patterns while the microscopic model examines the interactions of individual vehicles. As an outcome, a macroscopic emission model is chosen for the research. The MOVES model was selected for the study because it differentiates from several other macroscopic models because of how it allows for individual link level analysis, that are being used to investigate more directed emission. MOVES' multi-scale capabilities to compute both project and network level emissions is one of its most distinguishing characteristics. In addition, MOVES-derived emission factors provide a more precise characterisation of the number of onroad emissions than emission factors provided by conventional average speed-based macroscopic models.

The third sub-question (*SQ3. What are the type of scenarios considered for planning road works?*) is also answered using literature review. The different scenarios for a road work project can be analyzed depending on the overall period of the project and the traffic intensity. Demand, the number of lanes present, the number of lanes closed for road maintenance, and the frequency of road work, including peak and off-peak schedules, are all elements that must be considered in each scenario.The major objective of this thesis is to effectively reduce emissions from roadwork. There are a variety of factors that contribute to increased emissions during road construction, including traffic congestion induced by capacity reductions and the duration of the project. The road work duration can be longer or shorter depending on the capacity reduction (full or partial closure), from this two main scenarios were formulated, which is full road closure and partial road closure. Another important consideration is the day of the week; traffic flow patterns fluctuate between weekdays and weekends. For example, weekday traffic is mainly comprised of educational and working commuters, with traffic being heavier at some times of the day than at other moments of the day, whereas weekend traffic is exclusively made up of recreational and social activities, where there is a shift in the peak period. As a result, sub-scenarios with full and partial road closures during weekdays and weekends were formulated.

Traffic flow simulation is carried out to answer the fourth sub-question (*SQ4. What are the spatio temporal traffic flow variables under different scenarios using the selected method from SQ1*). The traffic flow characteristics for every one of the aforementioned scenarios are estimated by Omnitrans utilizing data from Rijkswaterstaat and NDW Dexter. The important Omnitrans output required for the emission calculation in MOVES are link speed, link length and link volume. When comparing the weekday and weekend scenarios for the full road closure, the weekday scenario has increased traffic volume, resulting in heavier congestion, particularly in city routes passing through A10 west motorways like S105 and S106, which has also increased flows compared to flow rate without any controls when particularly in comparison to main A10 motorways like A10 East and A10 North. Between the two scenarios, A10 North has the maximum traffic volume during scenario 1, which is approximately 30% larger, and city roads have heavier traffic throughout weekend scenarios. This surge in traffic in Amsterdam's inner rings on weekends must be due to tourists and locals travelling on social and recreational trips. When comparing the weekday and weekend scenarios for partial closure scenarios, the weekday scenario has somewhat higher traffic volume, causing congestion on motorways like that of the A10 East. When compared to the motorway network, where total vehicle traffic is nearly doubled at S105, S106, and S107 especially in comparison to the network without control, the actual impact map for the partial closure situation demonstrates that city routes near the A10 West highway are the most affected by the roadworks. This could be attributed to traffic from the A10 network being rerouted to the A4 and A5 motorways.When analyzing the full and partial closure scenarios, the full closure scenarios had more traffic volume and congestion from the speed plots. The delay graphs reveal comparable results, with full road closure causing significant delays in both city routes and the main network than partial road closure scenarios.

Emission modelling was done to answer the fifth sub-question (*SQ5. What are the greenhouse gas emissions under different scenarios using the selected method from SQ2*).MOVES uses Omnitrans measurements to compute the emission results for each scenario per day. The emission for a full road closure is higher than that of the emission for a partial road closure, as indicated in Table 90. Tables 91 and 92 show the overall emissions for the project's whole lifespan, as well as the conversion of each emission value into carbon dioxide equivalents, allowing for comparison of different greenhouse gas emissions. As indicated in Table 92, the project with partial road closure on weekends generates approximately 10 MT CO2e more than the project with full road closure. Because the partial closure has a longer duration of road work and a smaller restriction in capacity than the full closure scenarios, it accounts for a significant proportion of emissions. In addition, the intermittent closure on weekdays generates 9 metric tons additional CO2e than that of the full closure. The outcomes of traffic simulations, such as flow and delay, are compared to these results. Intermittent closures have lower daily delays and congestion than full road closure scenarios, comparable to the emission estimates.

6 RECOMMENDATIONS

Only emissions from on-road traffic are computed and compared across different scenarios in this research. To obtain more accurate emissions, the emissions from the construction process and materials should be included, to achieve this the road work should be meticulously recorded by collecting the details of the construction process, analyzing technical documentation, and questioning contractors. One disadvantage of this procedure is that the results can only be utilised after the project has been completed, and it does not provide information on choosing the best scenario to consider before the project is implemented.

The scenarios selected for this study are dependent on the Rijkswaterstaat's prior projects' literature reviews and methodologies. Other types of experiments can be conducted out beforehand, with policymakers selecting on a list of scenarios to investigate. For instance, decision-making approaches such as multi-criteria analysis can be used to weigh the trade-offs between alternatives and select the optimal alternatives for the investigation. Various scenarios are being developed as part of this process, such as executing roadwork exclusively at night and only allowing the road to certain modes of traffic, such as trucks or high-priority vehicles.

The roadworks were analyzed for A10 West for this study, however future research can quantify emissions for different sites because greenhouse gas emissions are highly variable for each location. Furthermore, the similarities and differences in emissions caused by traffic disturbances between different places may be thoroughly investigated.

CO2, CH4, and N2O are the only primary emission types considered in this study. Other emission categories should be examined for a more thorough assessment of emission levels for each scenario, even though they constitute very little to total emissions.

Apart from planning roadworks depending on calculated emission values, capacity-based techniques for road construction/maintenance work can be employed to reduce greenhouse gas emissions from projects. These strategies include capacity based strategies like increasing roadway throughput capacity for certain popular routes, vehicle-based strategies such as specifically targeting emissions through lower carbon emitting vehicles and fuels and demand-based strategies such as road pricing, which reduce emissions by reducing overall volume whilst still reducing traffic congestion.

Other modes of transportation, such as public transportation buses, should be examined for future studies because they have the highest priority at traffic lights. Also, technologies such as automated vehicles should be included in the research which have a greater potential to reduce emissions.

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8.2. Appendix-B: Streamline Ruby Script

streamLine = OtStreamLine.new
streamLine.input.fractions = [0.10, 0.15, 0.20, 0.15, 0.10, 0.0]
streamLine.input.network = [1,1]
streamLine.input.odMatrix = [1,1,[1871],10]
streamLine.input.defaultApproachLength = 0.1
streamLine.input.impedanceMultiplier = 1.0
streamLine.input.initialCostsMultiplier = 1.0
streamLine.input.controls = true

To set the multiplicity which controls the frequency at which the generated routes are persisted
streamLine.routeGenerator.multiplicity = SL_ONETOALL
streamLine.routeGenerator.alternativeGenerator = SL_MONTECARLO

Choosing the configuration for the generation of alternative routes
streamLine.routeGenerator.alternativeGenerator.minIterations= 2
streamLine.routeGenerator.alternativeGenerator.maxIterations= 50
streamLine.routeGenerator.alternativeGenerator.initialVariance= 0.09
streamLine.routeGenerator.alternativeGenerator.varianceGrowValue= 0.02
streamLine.routeGenerator.alternativeGenerator.maxVariance = 0.3
streamLine.routeGenerator.alternativeGenerator.threshold = 3
streamLine.routeGenerator.alternativeGenerator.consecutiveThreshold = true

Configuring the route filter that chooses viable routes from the generated alternatives. This category of properties is also accessed via the routeGenerator on the streamLine instance
streamLine.routeGenerator.filter.maxTotalDetourFactor = 1.9
streamLine.routeGenerator.filter.minNonCommonDetourFactor = 0.01
streamLine.routeGenerator.filter.maxNonCommonDetourFactor = 2.0
streamLine.routeGenerator.filter.maxOverlapFactor = 0.6
streamLine.routeGenerator.filter.maxNumberOfRoutes = 5

Route Choice Manager for multiple iterations using the Method of Successive Average (MSA)
streamLine.routeChoice = SL_MSA
streamLine.routeChoice.maxIterations = 10
streamLine.routeChoice.lambda = 1
streamLine.routeChoice.dualityGap = 0.01
streamLine.routeChoice.successiveAverageOffset = 0

Configuring the initial route choice object to be used at the start of the first iteration
streamLine.routeChoice.initial = SL_PCL
streamLine.routeChoice.initial.spread = 0.14
streamLine.routeChoice.initial.relativeSpread = true
streamLine.routeChoice.initial.relativeSpreadBasedOnCost = true

Configuring a successive route choice object to be used at the start of all other iterations
streamLine.routeChoice.successive = SL_PCL
streamLine.routeChoice.successive.spread = 0.14
streamLine.routeChoice.successive.relativeSpread = true
streamLine.routeChoice.successive.relativeSpreadBasedOnCost = true

Configuring a pre-trip route choice object to support within simulation route choice
streamLine.routeChoice.preTrip = SL_PCL
streamLine.routeChoice.preTrip.spread = 0.14
streamLine.routeChoice.preTrip.relativeSpread = true
streamLine.routeChoice.preTrip.relativeSpreadBasedOnCost = true
streamLine.routeChoice.periodEndTimes = [1800,3600,5400]
streamLine.routeChoice.preTripPercentageApplied = 1.0

Calculating Route cost
streamLine.routeCost.initialReactive = true
streamLine.routeCost.successiveReactive = true
streamLine.routeCost.valueOfTime = [1]
streamLine.routeCost.valueOfDistance = [0]
streamLine.routeCost.collectionInterval = 300

Collecting the route costs via a Route Dataset object
streamLine.routeCost.routeDataSet = SL_OMNITRANS
streamLine.routeCost.routeDataSet.saveIterations = false

Setting the Propagation model- MADAM
streamLine.propagation = SL_MADAM
streamLine.propagation.duration = 1800+3600+5400
streamLine.propagation.timeStep = 2

Saving route set
streamLine.output.routeSet = SL_OMNITRANS

PMTURI for storing the route results
streamLine.output.routeSet.pmturi = [1,1,1871,10,22,1]

PMTURI for storing the output results
streamLine.output.load = [1,1,1871,10,23,1]

streamLine.execute

8.3. Scenario 1: Full road closure weekdays

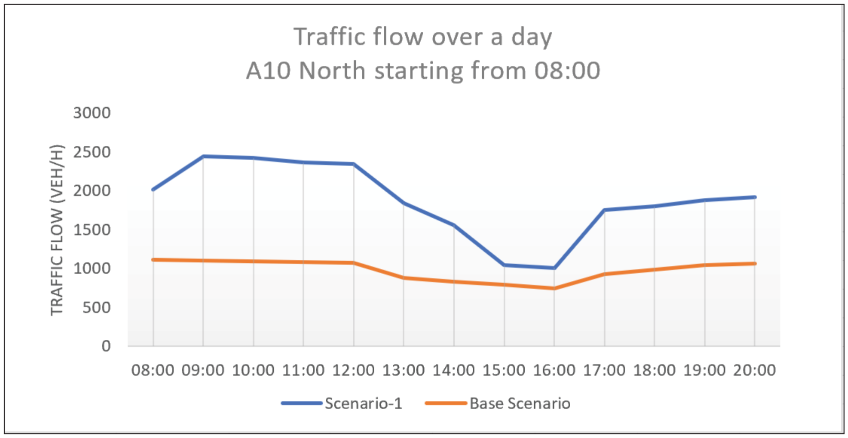

Figure 54: Traffic flow changes over a day for Scenario 1-A10 North

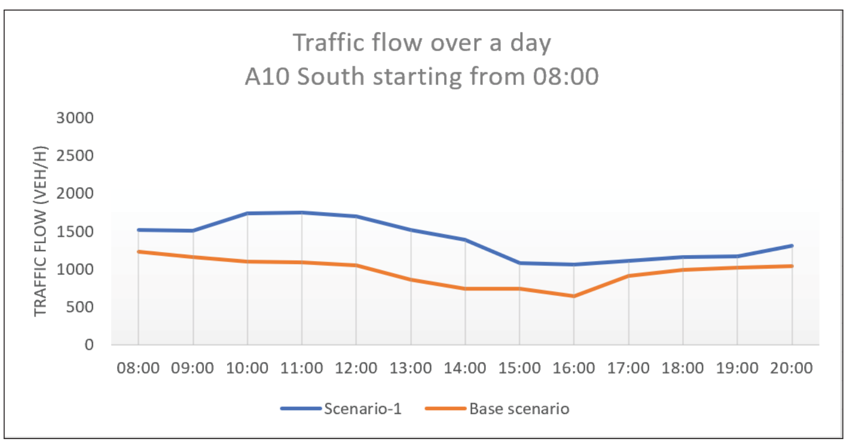

Figure 55: Traffic flow changes over a day for Scenario 1-A10 South

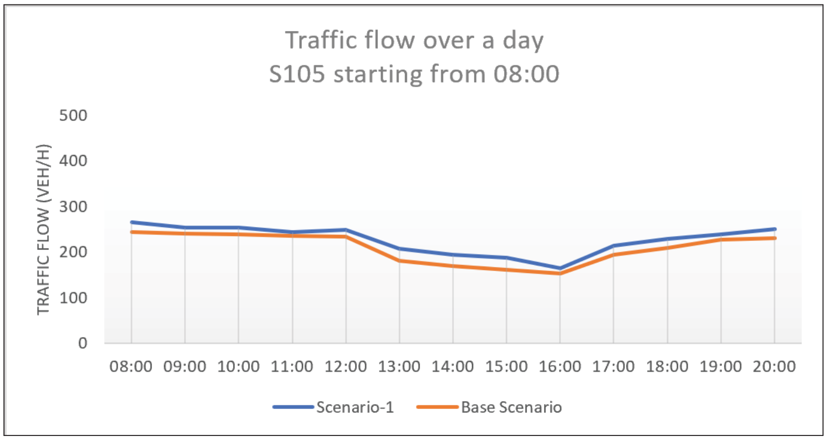

Figure 56: Traffic flow changes over a day for Scenario 1-City Route S105

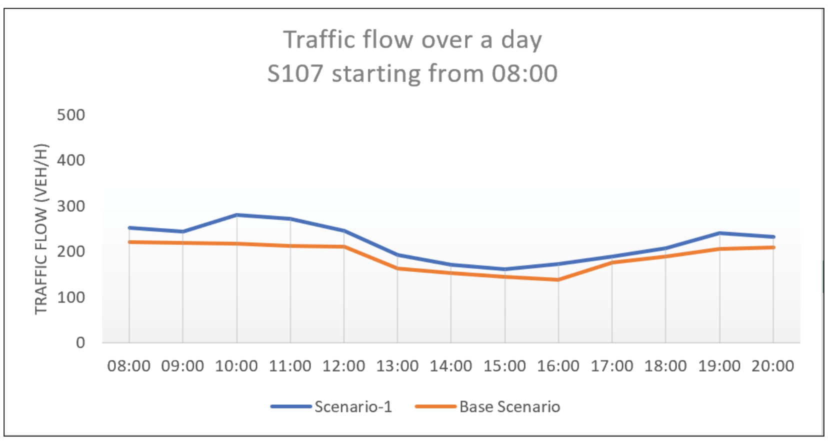

Figure 57: Traffic flow changes over a day for Scenario 1-City Route S107

8.4. Scenario 2: Full road closure weekends

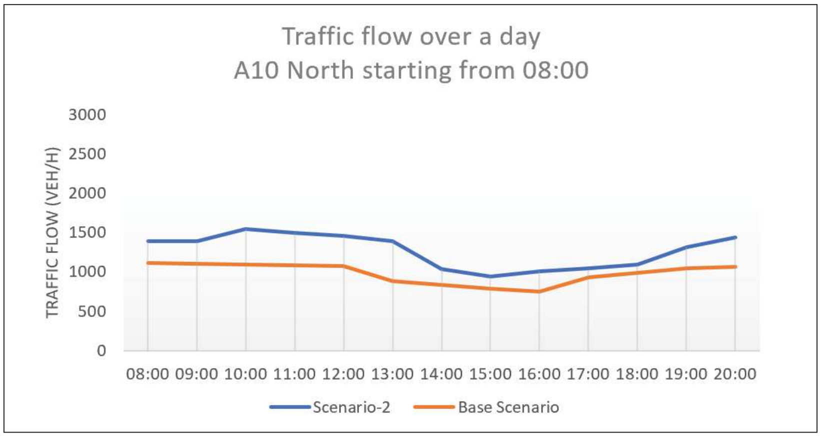

Figure 58: Traffic flow changes over a day for Scenario 2-A10 North

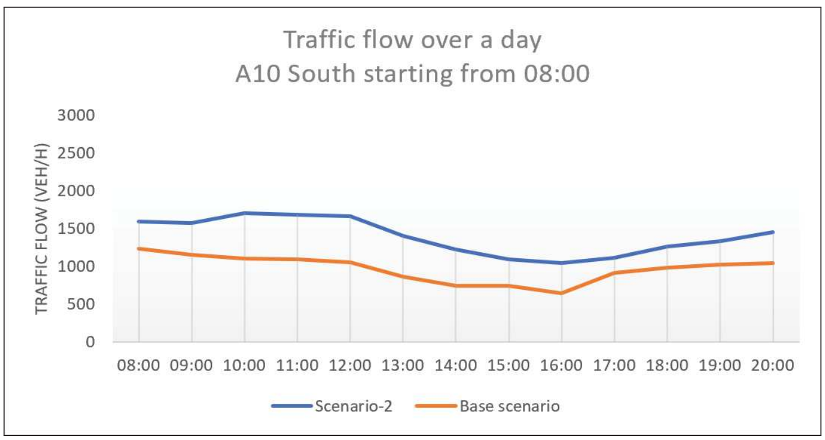

Figure 59: Traffic flow changes over a day for Scenario 2-A10 South

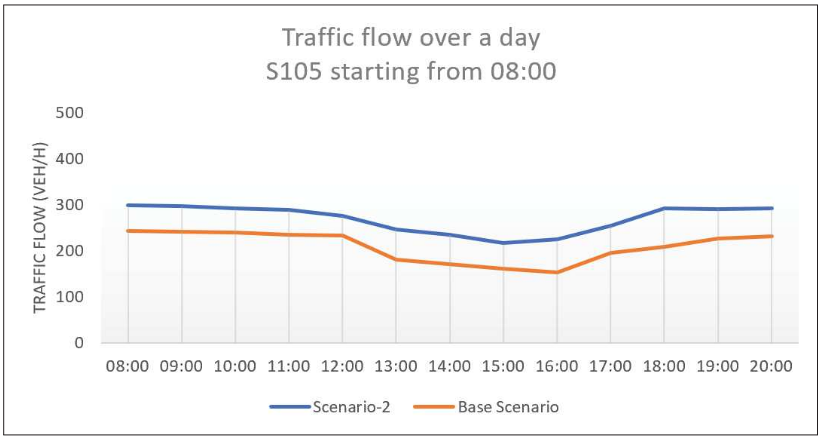

Figure 60: Traffic flow changes over a day for Scenario 2-City Route S105

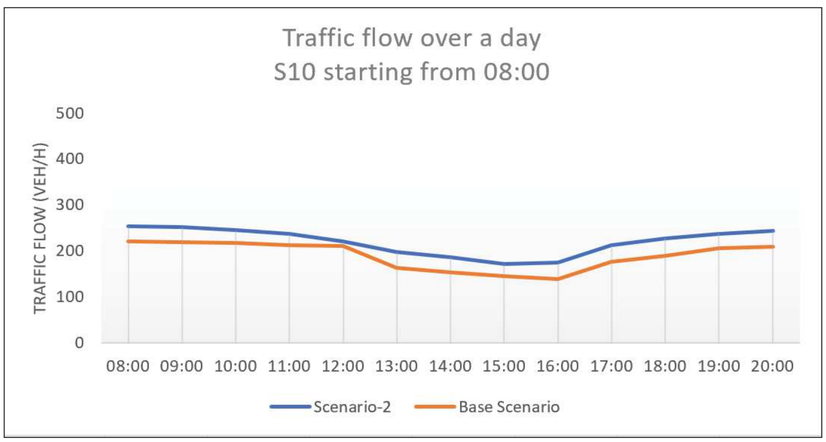

Figure 61: Traffic flow changes over a day for Scenario 2-City Route S107

8.5. Scenario 2: Partial road closure weekdays

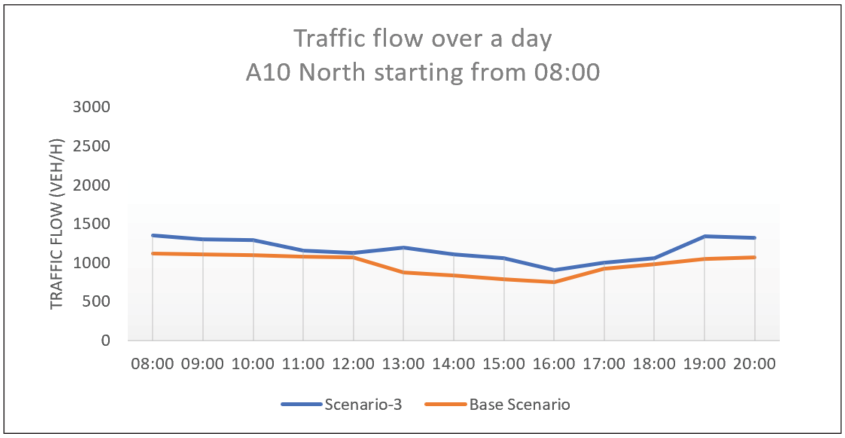

Figure 62: Traffic flow changes over a day for Scenario 3-A10 North

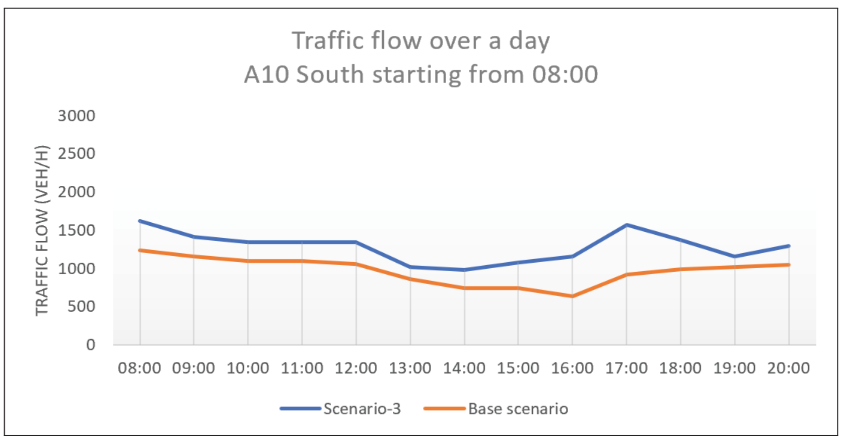

Figure 63: Traffic flow changes over a day for Scenario 3-A10 South

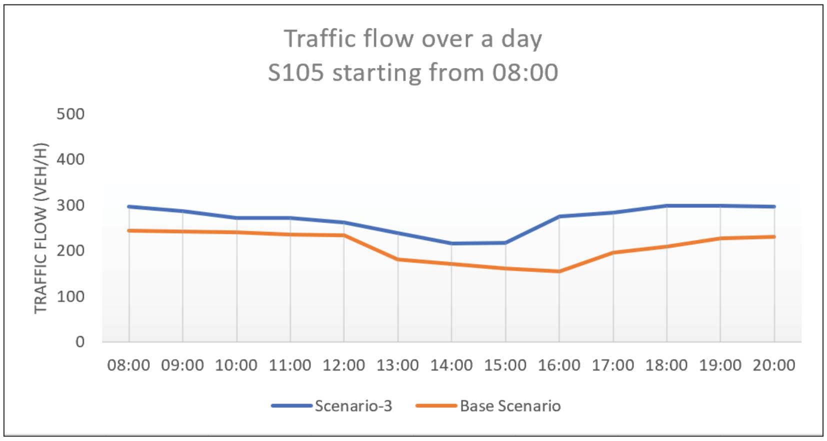

Figure 64: Traffic flow changes over a day for Scenario 3-City route S105

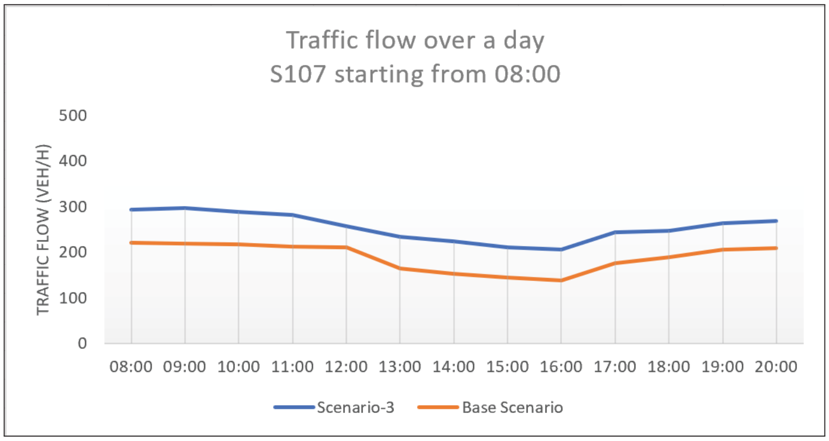

Figure 65: Traffic flow changes over a day for Scenario 3-City route S107

8.6. Scenario 4: Partial road closure weekends

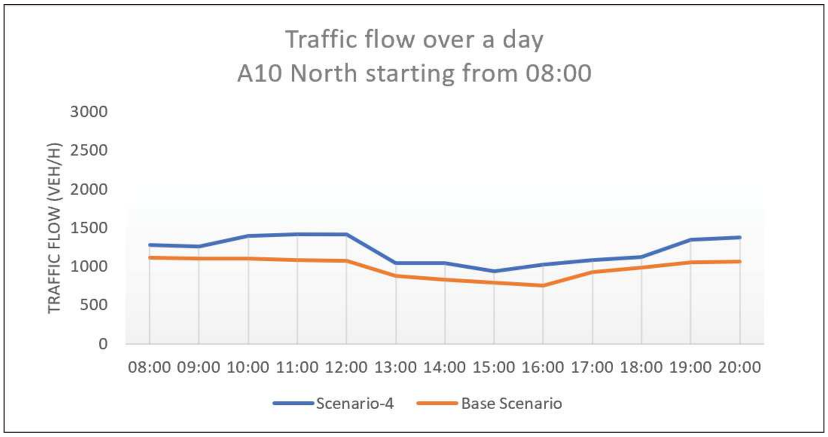

Figure 66: Traffic flow changes over a day for Scenario 4-A10 North

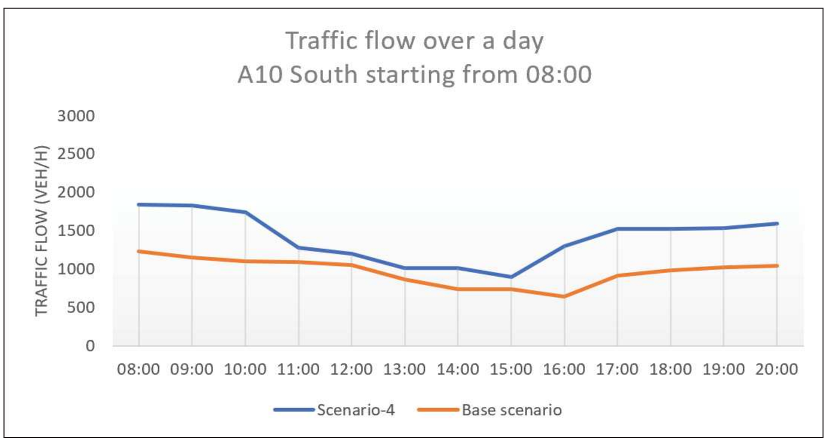

Figure 67: Traffic flow changes over a day for Scenario 4-A10 South

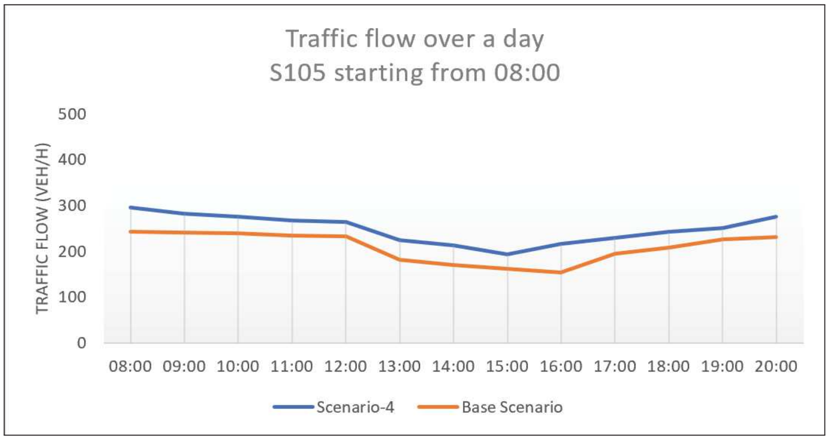

Figure 68: Traffic flow changes over a day for Scenario 4-City route S105

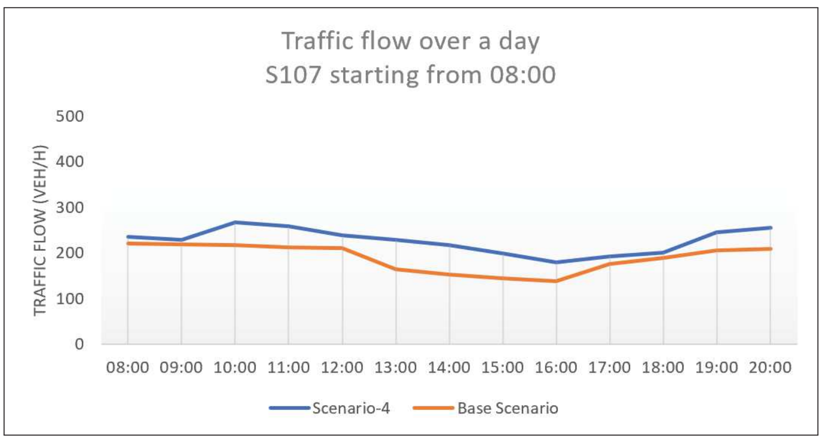

Figure 69: Traffic flow changes over a day for Scenario 4-City route S107

8.7. GHG emissions for weekdays for full closure and intermittent closure of A10 Ring road

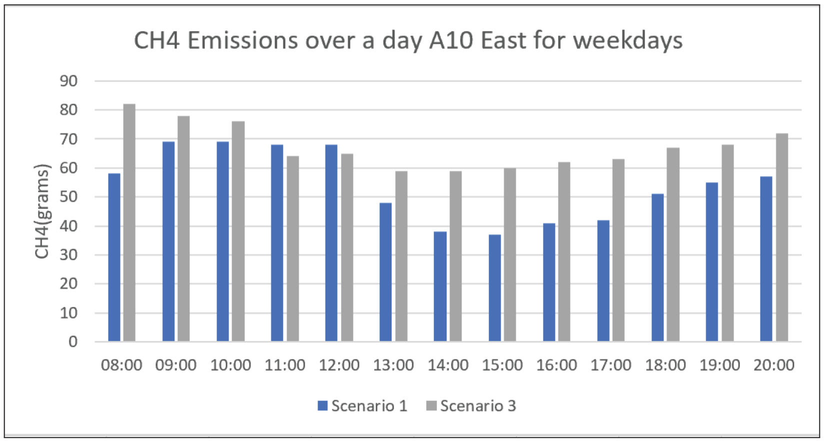

Figure 70: CH4 emissions over a day for A10 East Motorway

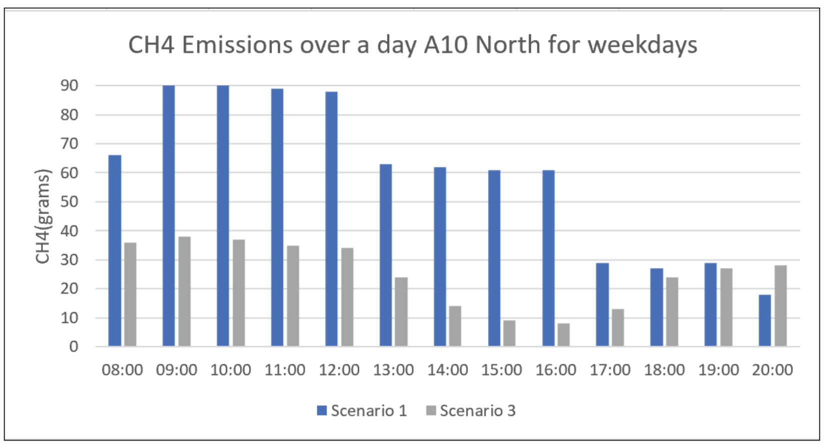

Figure 71: CH4 emissions over a day for A10 North Motorway

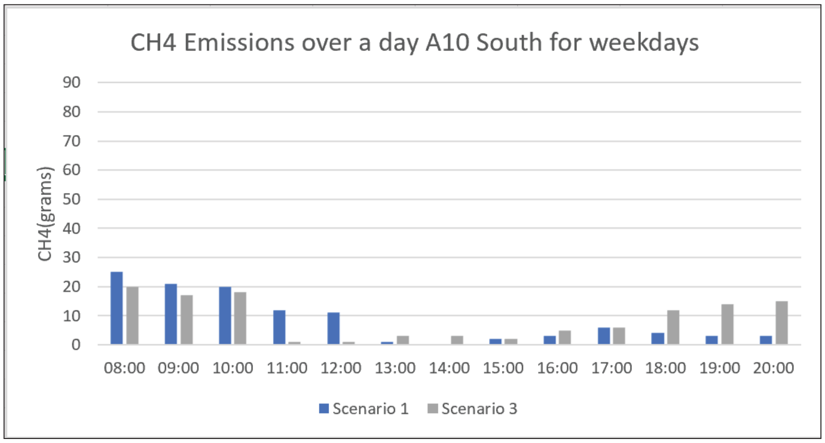

Figure 72: CH4 emissions over a day for A10 South Motorway

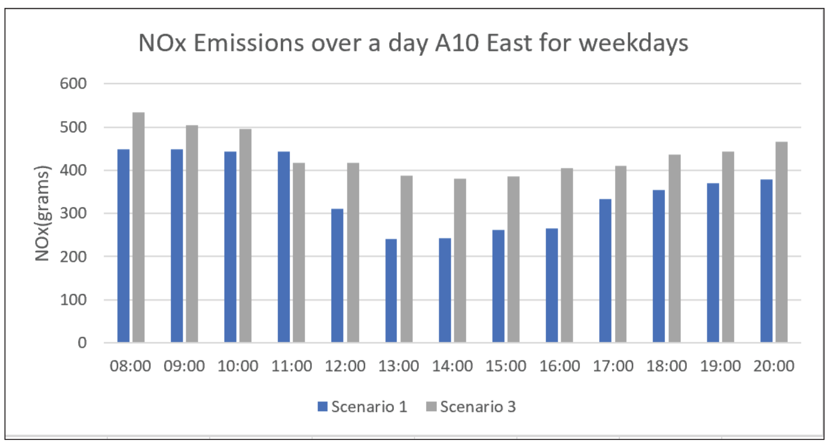

Figure 73: N2O emissions over a day for A10 East Motorway

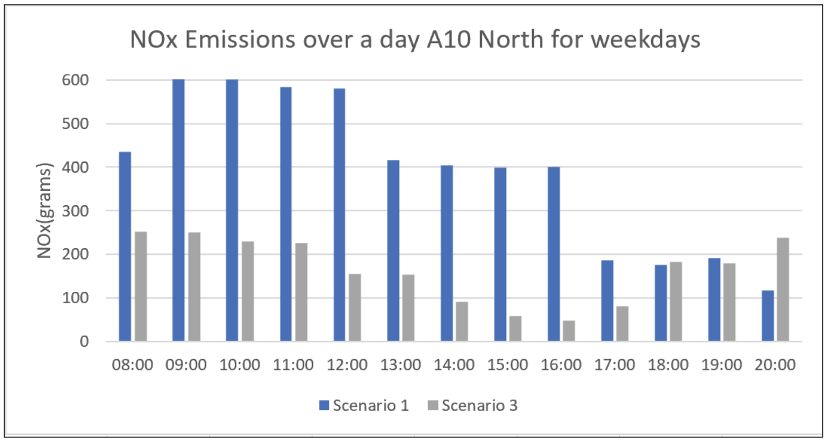

Figure 74: N2O emissions over a day for A10 North Motorway

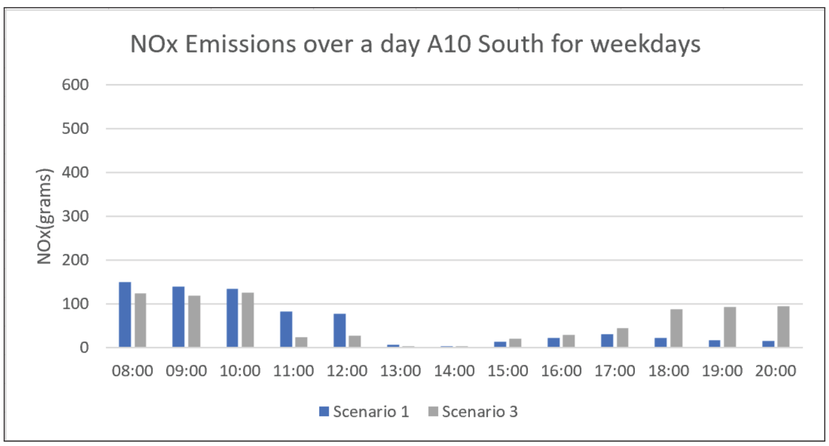

Figure 75: N2O emissions over a day for A10 South Motorway

8.8. GHG emissions for weekdays for full closure and intermittent closure of city routes

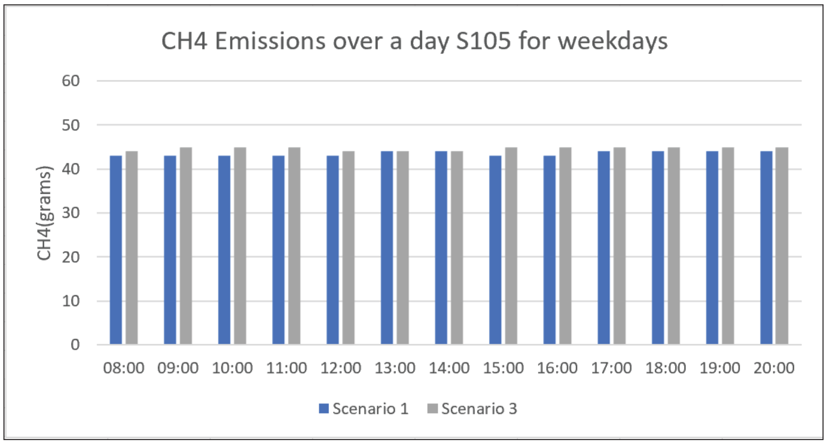

Figure 76: CH4 emissions over a day for S105

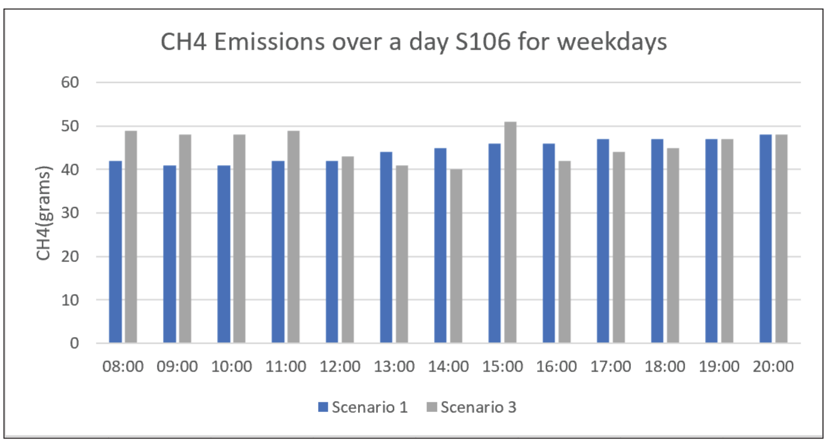

Figure 77: CH4 emissions over a day for S106

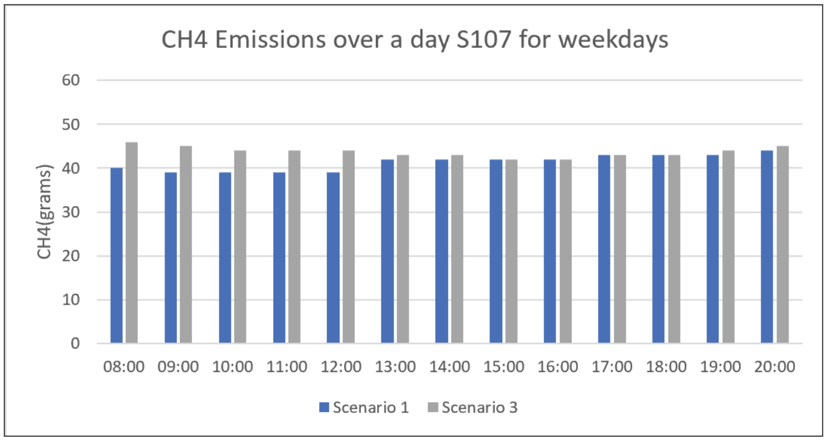

Figure 78: CH4 emissions over a day for S107

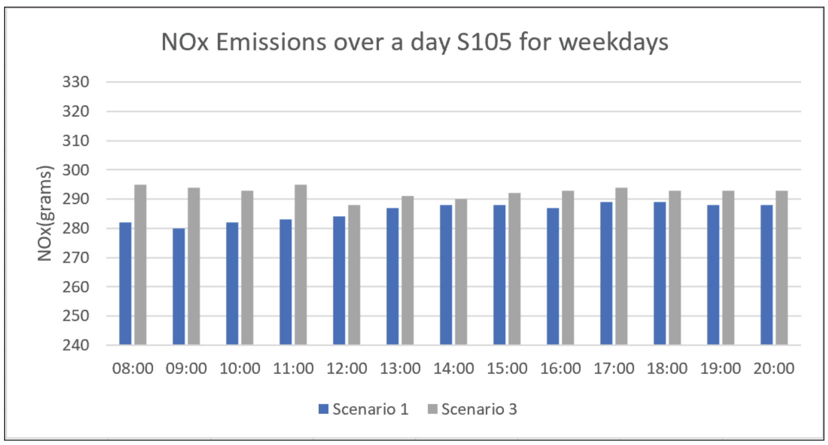

Figure 79: N2O emissions over a day for S105

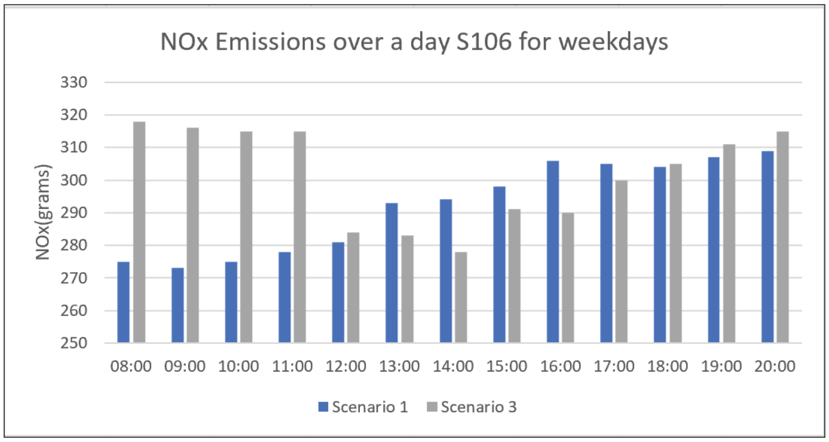

Figure 80: N2O emissions over a day for S106

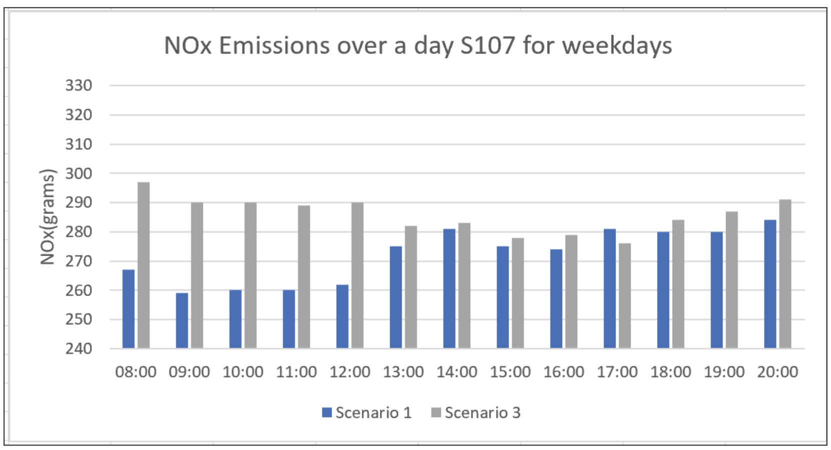

Figure 81: N2O emissions over a day for S107

8.9. GHG emissions for weekends for full closure and intermittent closure of A10 Ring road

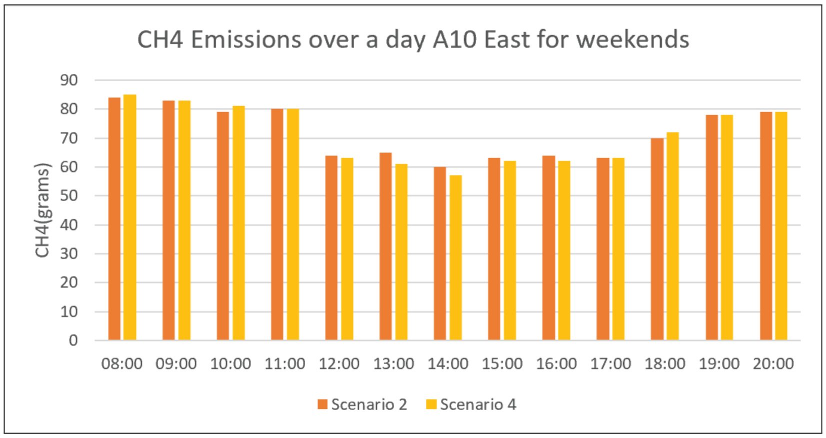

Figure 82: CH4 emissions over a day for A10 East Motorway

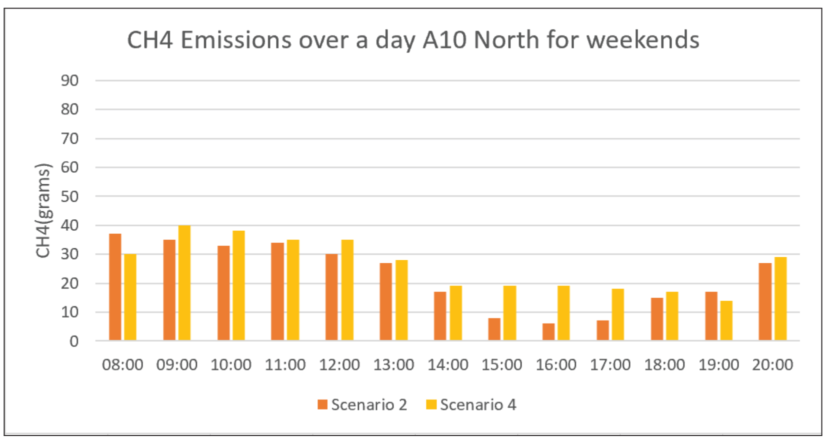

Figure 83: CH4 emissions over a day for A10 North Motorway

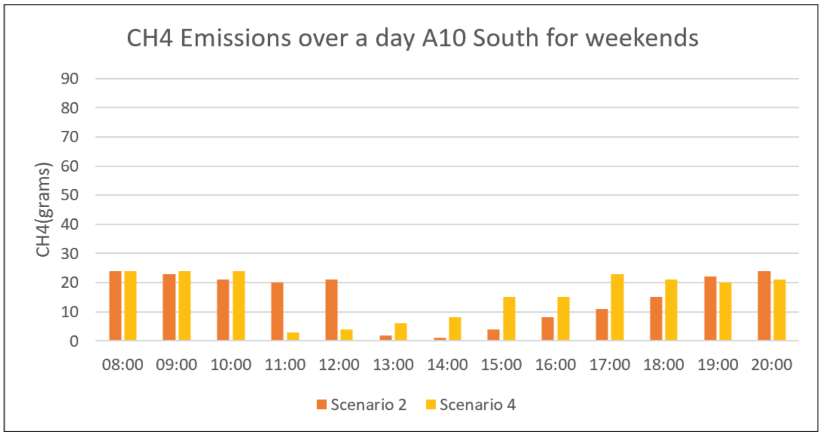

Figure 84: CH4 emissions over a day for A10 South Motorway

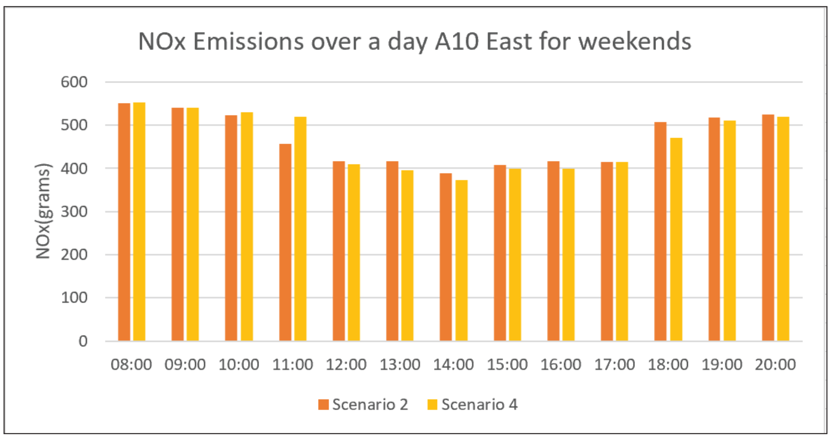

Figure 85: N2O emissions over a day for A10 East Motorway

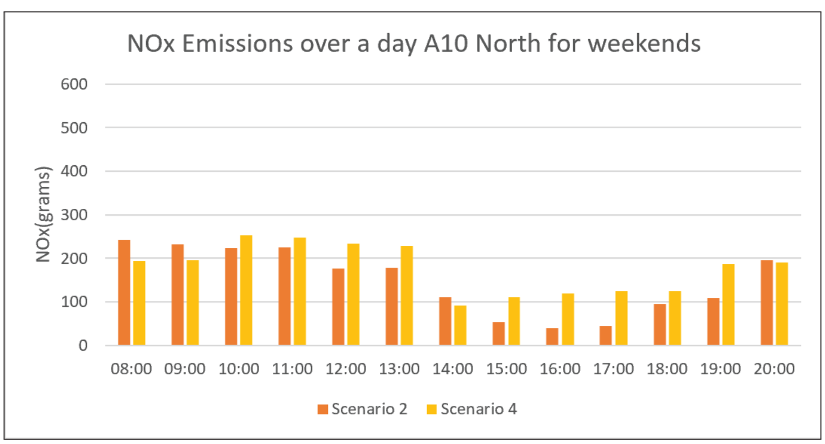

Figure 86: N2O emissions over a day for A10 North Motorway

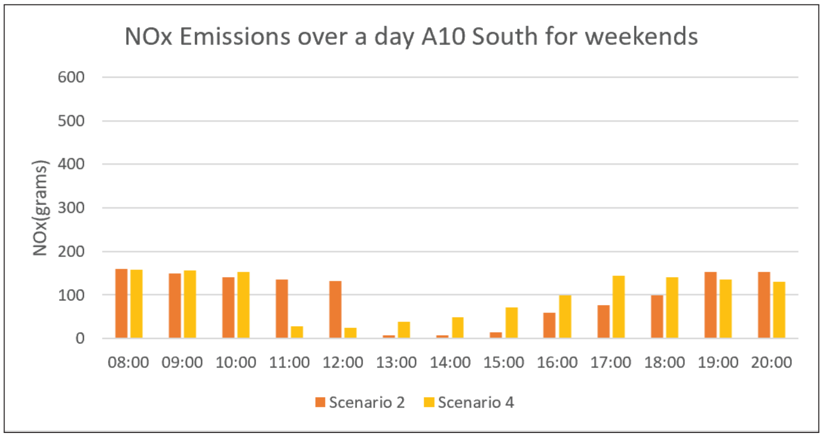

Figure 87: N2O emissions over a day for A10 South Motorway

8.10. GHG emissions for weekends for full closure and intermittent closure of city routes

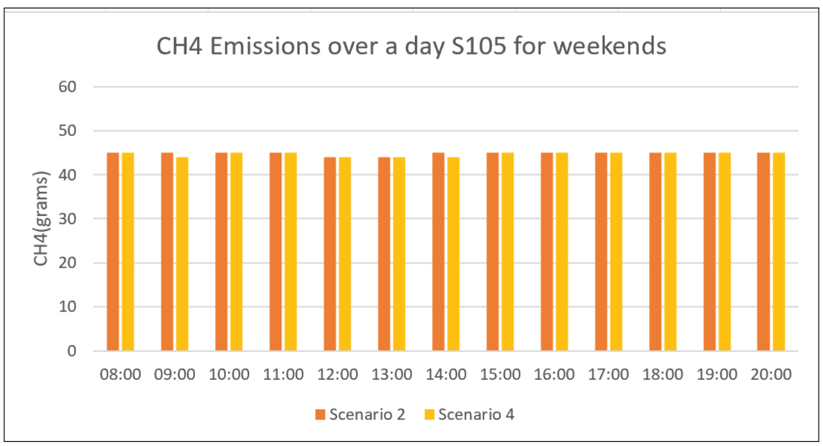

Figure 88: CH4 emissions over a day for S105

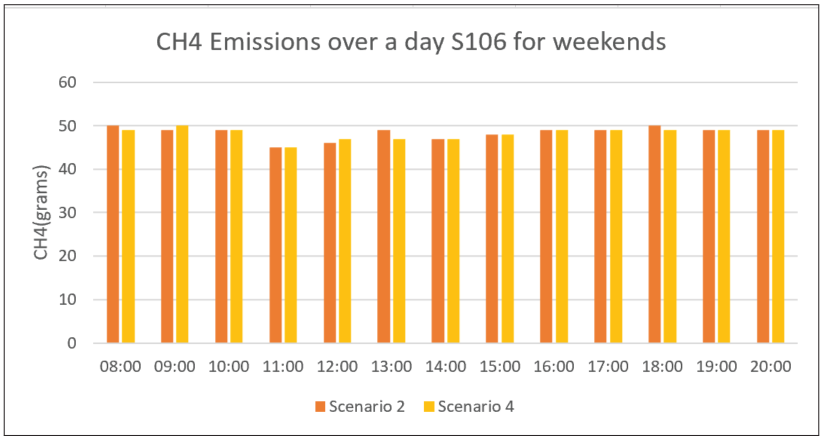

Figure 89: CH4 emissions over a day for S106

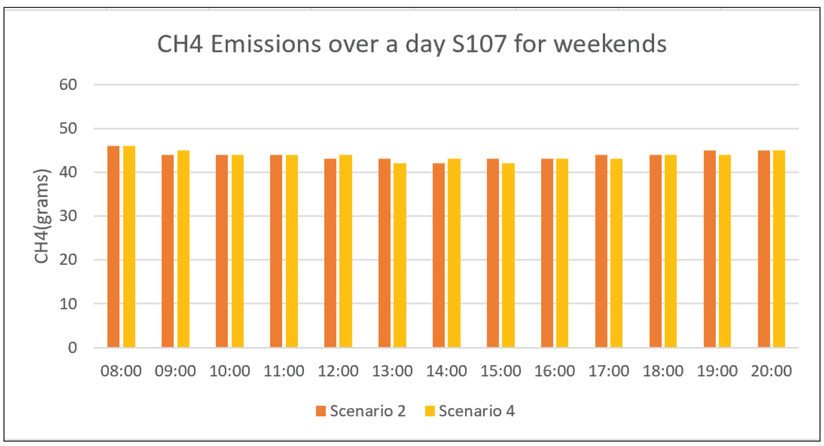

Figure 90: CH4 emissions over a day for S107

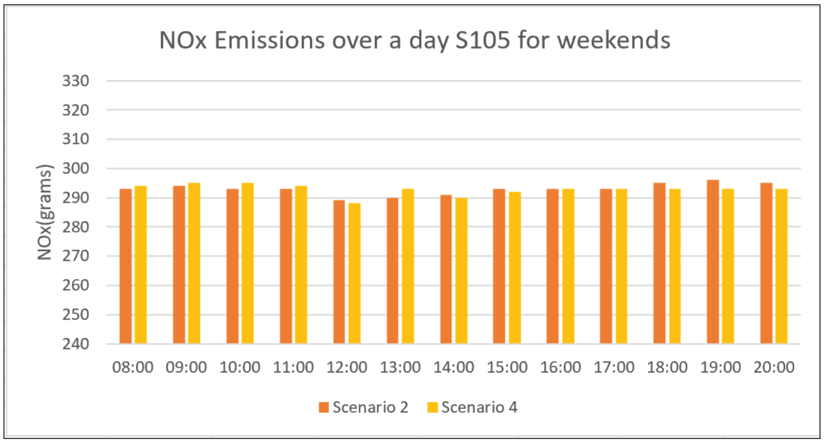

Figure 91: N2O emissions over a day for S105

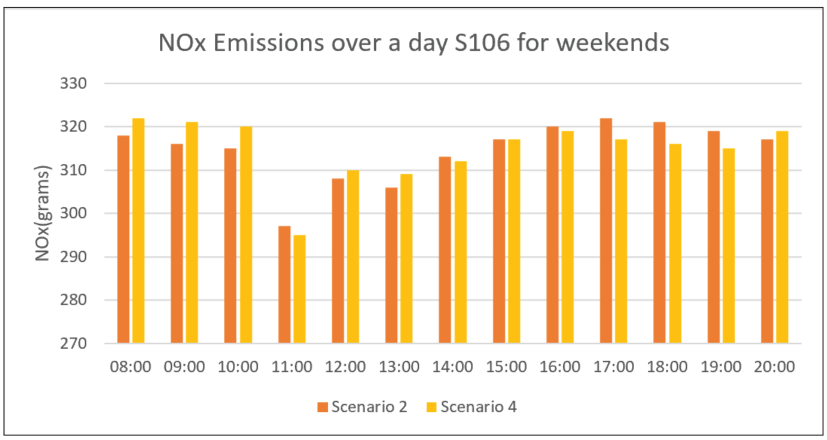

Figure 92: N2O emissions over a day for S106

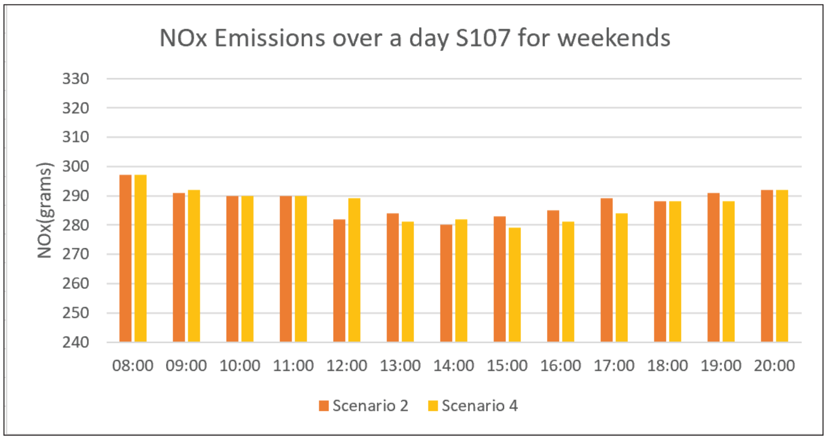

Figure 93: N2O emissions over a day for S107