Masters Program in Geospatial Technologies

ECO-FRIENDLY 3D-ROUTING

A GIS based 3D-Routing-Model to estimate and reduce CO_2-Emissions of distribution transports.

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Dissertation submitted in partial fulfilment of the requirements for the Degree of *Master of Science in Geospatial Technologies*

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DISCLAIMER

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ABSTRACT

Road Freight Transportation accounts for a significant share of the worldwide CO_2-Emissions, indicating that respective operations are not sustainable. Regarding the forecasted increase in CO_2-Emissions from Road Freight Transportation, this sector needs to undertake responsibilities for its environmental impact. Although technical and strategic solutions to reduce emissions have been introduced or are in development, such solutions rarely yield instant emission reduction potentials. A strategic approach to reduce them instantly, based on the given infrastructure and existing vehicle fleet, is represented through route optimization. Route optimization is a well-researched topic in the transportation domain. However, it is mainly used to reduce transportation times and expenses. Rising expectation towards sustainability through stakeholders such as authorities and consumers, let to an increased interest in route optimization where environmental externalities as fuel consumption and CO_2-Emissions are minimized. This paper introduces a Geographic Information System (GIS) based 3D-Routing-Model, which incorporates models to estimate vehicle fuel consumption while taking effects as road inclination and varying velocities into account. The proposed model utilizes a Digital Elevation Model to enrich a Road Network with elevation data – An approach which is applicable to any area where respective data is available. To evaluate the effects of road inclination on a vehicles fuel consumption and its proportional CO_2-Emissions, the 3D-Routing-Model is applied in different distribution scenarios within the framework of an artificial company in the Lisbon Metropolitan Area. The obtained results indicate that eco-friendly routes can yield significant fuel and emission saving potentials of up to 20 % in the tested scenarios. However, the results also indicate that eco-friendly routes are characterized through longer distances as well as operation times, which eventually leads to increased expenses. It remains the question if companies within the transportation sector are more interested in maximizing their profits, or to invest in a sustainable future.

KEYWORDS

3D-Road-Network

ArcGIS

CO_2-Emissions

Digital Elevation Model

GIS

GIS Applications

Green Logistics

Green Routing

Heavy-Duty-Vehicles

Route Optimization

Vehicle Routing

Vehicle Routing Problem

ACRONYMS

CF – Correction Factor

CO$_2$ – Carbon dioxide

DEM – Digital Elevation Model

EEM – Emission Estimation Model

FC – Fuel Consumption

GIS – Geographic Information System

HDV – Heavy-Duty-Vehicles

LMA – Lisbon Metropolitan Area

NA – Network Analyst

RFT – Road Freight Transportation

RN – Road Network

SA – Study Area

VRP – Vehicle Routing Problem

INDEX OF THE TEXT

INDEX OF TABLES

INDEX OF FIGURES

1. Introduction

In 2010 road freight transportation (RFT) emitted 1118 million tons of Carbon dioxide (CO_2) which accounts for around 3.5 % of the worldwide total CO_2-Emissions (Statista, 2018-a, 2018-b). Whereas the worldwide CO_2-Emissions increase could be reduced over the past years, as sectors as the manufacturing industry or electricity and heat generation decreased their emissions (International Energy Agency, 2017), CO_2-Emissions from the transportation sector are still rising. The CO_2-Emissions from road freight transportation are expected to increase by 305 % until 2050, if there are no major changes (DVZ, 2015) which is similar to the expected increase in CO_2-Emissions in the whole logistics sector (International Transport Forum, 2015)

With a market volume of more than half a trillion euros in Europe, logistics is a key driver of economic growth, occupation and wealth creation (Grotemeier, 2017). But being one of the main emitters of greenhouse gases, the whole logistics sector needs to undertake responsibilities for their environmental impact, implicating a reduction of 80 % to reach climate goals (Bretzke, 2014). However, CO_2-Emission by logistics are expected to keep increasing, reasoned through demographic growth, changes in geographic patterns of trade structures, growth of emerging nations and their growing consumer behavior as well as free trade agreements (Deutsche Post, 2010). As concerns for environmental impacts, namely climate change and air pollution through the society, the economy as well as through governments rise, activities framed under the term Green Logistics aroused in the last decades. This term refers to all activities and attempts aiming to measure and reduce the environmental impact of all logistics activities (Bretzke, 2014).

In terms of Green Logistics, a variety of approaches to decrease fuel consumption (FC) and its proportional CO_2-Emissions by RFT have been introduced, which can be distinguished in technical and strategic solutions. Being a sub-sector of logistics, RFT refers to the transportation of goods on road-networks (RN), utilizing heavy-duty-vehicles (HDV), trucks, vans or other appropriate vehicles. Therefore, technical solutions as gas and electrical powered vehicles, electronic highways with overhead lines or autonomous vehicles which can reduce emissions as a convoy are in development. Although these approaches yield significant fuel and CO_2-Emission saving potentials, they are not yet ready to be implemented due to various reasons such as expenses and regulations (UBA, 2015). Although strategic improvements in logistics

are primarily aligned to decrease operating times and expenses (Psaraftis, 2016), respective solutions as logistics center allocation, modal shift and a shift from global to regional sourcing, can yield general emission saving potentials as well (Lochmar, 2016). However, such approaches and strategic adaptions require a rather long-running development and implementation time.

A strategic approach yielding instant FC and emission savings based on the given infrastructure and a company's vehicle fleet is represented by route optimization. Respective basics and influencing factors in a Green Logistics context, as well as emission estimation models (EEM) are elaborated by Demir et al. (2014). Whereas recently companies optimize their routes to reduce operation times and expenses to execute as many customer orders as possible, the shortest or fastest routes rarely represent the eco-friendliest routes (Psaraftis, 2016; Toro O. et al., 2015). Routing, what refers to finding a path under a certain optimization criterion as time, distance or any other quantitative measure between points in a network, is a well examined research domain, based on the work by Dijkstra and its well know shortest path algorithm (Dijkstra, 1959). Originated in the domain of operations research and graph-theory, routing optimization has been adapted and continuously extended into the domain of logistics where it represents one of its essential tasks. Respective extensions are known as the Vehicle Routing Problem (VRP). In a VRP not only a single route between two points is optimized, but rather sets of routes between several points of demands (e.g. supermarkets, customers, facilities), which are served by a fleet of vehicles under different optimization criterions and further restrictions. A comprehensive review, description and methodology of the different variations of the VRP is given in Braekers et al. (2016). Whereas the majority of VRP aims to optimize routes for costs or time, an increasing number of works related to the VRP in a Green Logistics context arise where routes are optimized for FC and emissions, which are reviewed by Toro et al. (2015). Eglese and Bektas (2014), as well as Demir et al. (2014) further elaborate respective VRP, as well as the implementation of FC and EEMs in green VRP.

As VRP are complex models, which can only be optimized with linear programming or heuristics, their solution relies on computational power to obtain feasible results in a reasonable computing time. Therefore, routing applications are implemented in various information systems, which is further elaborated by Bräysy and Hasle (2014).

To facilitate the approach of reducing FC and CO_2-Emissions by route optimization based on information systems, GIS enable respective approaches with their implemented functionalities to capture, store, manipulate, analyze, manage and represent spatial data. GIS are widely used in the domain of logistics and transportation. Such systems offer various functionalities to analyze and manipulate spatial data, whereas routing and facility allocation can be named as the most common applications (Rodrigue et al., 2017). Such are for instance implemented in dedicated extensions as the Network Analyst (NA) in Esri's ArcGIS environment. Based on the given GIS functionalities, routes or entire VRP can be optimized for environmental externalities as FC and CO_2-Emissions with implemented EEM.

Andersen et al. (2013) introduced a GIS based system where eco-weights are assigned to road-segments based on collected GPS and FC data. The assigned weights are used to optimize routes for the eco-friendliest alternative based on Dijkstra's algorithm and OpenStreetMap data, whereas the shortest and fastest route between two points can be determined simultaneously. However, the system works only for road-segments with collected data, does not distinguish between vehicle types and neglects effects from road inclination. Implemented in Esri's ArcGIS environment, Zsigraiova et al (2013) proposed a methodology to reduce operation costs and emissions in the collection and transportation routes of waste, where influencing factors such as varying vehicle speeds and weights are considered by applying a EEM. Nevertheless, instead of optimizing routes for minimized FC and emissions, the authors merely compared the results in terms of emitted pollutants for the obtained results of routes for the optimization criterions of travelled time (i.e. fastest route) and distance (i.e. shortest route). The effects of road inclination on FC are neglected in this approach as well. Pamucar et al. (2016) applied a multi-criteria method of Weighted Linear Combination for different influencing aspects as noise, different pollutants, land use, slope and average speed to generate a benefit map for a transport spatial decision support system. Based on a generated benefit map whose values are assigned to a road network (RN), green routes for city logistics are defined in a GIS. However, this approach is not able to estimate FC and CO_2-Emissions for the determined routes. Whereas the presented GIS based publications include EEM or other approaches to determine eco-friendly routes, the effects of road inclination are considered insufficiently, although EEM as COPERT III (Ntziachristos & Samaras, 2000) can take them into account. Being not implemented in a GIS environment, Scott et al. (2010) examined the effects of road

inclination and vehicle weight on optimized routes for the distribution of goods. Based on the COPERT III model, they indicate that further investigation for the optimization of routes in hilly areas is needed. Scora et al. (2015) specifically examine the routing of HDV, emphasizing the effects of road inclination in hilly areas and other factors by introducing a Microscale Fuel and Emissions Model for a specific HDV, which is implemented in the Eco-Routing Navigation System EFNav and was introduced by Boriboonsomsin et al. (2012). EFNav provides a framework, which consists of a RN database which incorporates real-time and static road related data from several authorial and commercial sources, an EEM based on collected data like COPERT III, a routing engine based on Dijkstra's algorithm to determine routes between two points only and a user interface. EFNav is limited to freeways in California though, relies on commercial data and provides eco-routes between two points only. Whereas EFNav only uses on a GIS for data pre-processing purposes, Tavares et al. (2009) introduced an approached for eco-friendly routing in the domain of waste collection, which is entirely implemented in a GIS. By generating a 3D-RN based on contour lines to incorporate effects from road inclination in combination with COPERT III, the authors optimize simple collection routes, utilizing the route solving functionalities of a GIS. However, the route optimization is based on average speeds for entire routes. Therefore, more accurate estimations can be obtained by accounting for varying speeds for different road-segments.

The presented publications represent a variety of approaches to optimize routes for environmental externalities as FC and CO_2-Emissions. Nevertheless, they are either neglecting the effects of road inclination and varying velocities, are limited to specific vehicles or geographical areas, as well as optimization functionalities. Furthermore, they rely on commercial data and external modules and are not necessarily able to estimate FC and CO_2-Emission totals. Besides that, a 3D-Visualisations which represents the routes path, elevation and gradient was not presented by any research paper.

This paper describes an entirely GIS and open source data-based 3D-Routing-Model, which accounts for road inclination by utilizing a Digital Elevation Model (DEM). Furthermore, it implements a EEM for different vehicles which considers varying velocities for different road-segments along a route, optimizes not only routes between two points but also complex VRP and which is applicable to any Study Area (SA) where RN and elevation data is available. Moreover, a 3D-Road-Profile-

4

Visualisation approach is introduced. The developed model is applied on artificial case studies, aiming to reduce a company's carbon foot print in a specific SA in the domain of the distribution of goods. The eco-friendliest route results, where FC and CO_2-Emissions are minimized, are compared to its shortest and fastest alternatives in terms of FC, CO_2-Emissions, distance, time and costs to elaborate the trade-offs between the different routing solutions.

2. Framework

Study Area

The Lisbon Metropolitan Area (LMA) is located around the river outfall of the Tejo on Portugal's west Atlantic coats, as shown in Figure 1. Split by the river, the SA is separated into the district of Lisbon in the north-west and the district of Setubal south of the river, which are both connected by two motorway bridges. With a size of 3015 km^2, a north-south extent of around 75 km and a west-east extent of around 90 km, the LMA accounts for 3,3 % of Portugal's total size. Being home to around 3 million inhabitants, the LMA has the largest population concentration in Portugal as more than one third of Portugal's total population is sedentary in this area. Whereas most people live in highly dense areas in the south of the district of Lisbon, especially in the country's capital Lisbon (~20 %) and along the southern coast line of the district, the remaining areas can be described as rather rural.
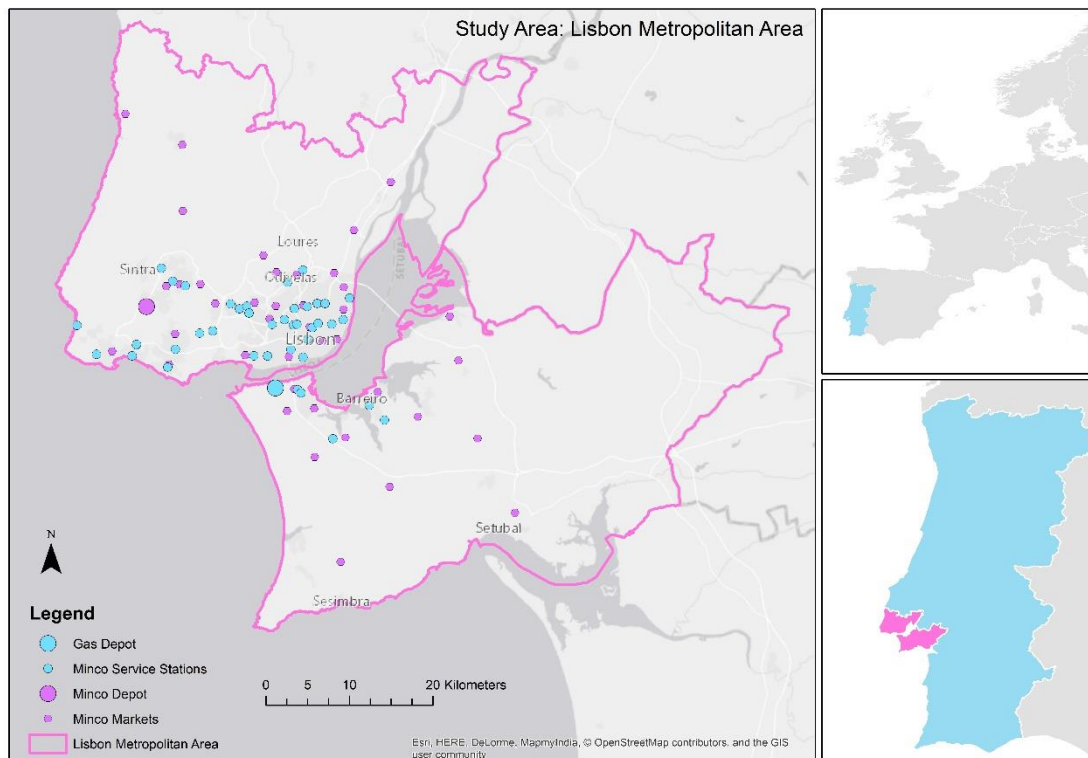

Figure 1: Study Area - The Lisbon Metropolitan Area including the MINCO Framework

Both districts elevations vary between below sea-level and up to around 500 m, as displayed in Figure 2. Well known as "The City of Seven Hills", Lisbon and its eponymous district, are throughout characterized as hilly with many topographic changes reaching its highest point of elevation in the western hills close to the city of Sintra. Whereas the district of Setubal is generally described as regular, it reaches its highest point of elevation in a line of hills close to the city of Sesimbra in the south.

Spanning a total of almost 20.000 km, the Road-Network within the SA can be distinguished in several classes as motorways, trunks, residential, primary or secondary roads and others. The RN of the LMA is highly affected by its topographic changes, resulting in various steep ascents as well as descents even on well enlarged motorways. With an average absolute road inclination of almost 4 %, it can be expected that road inclination has a significant effect on FC and its proportional CO_2-Emissions.
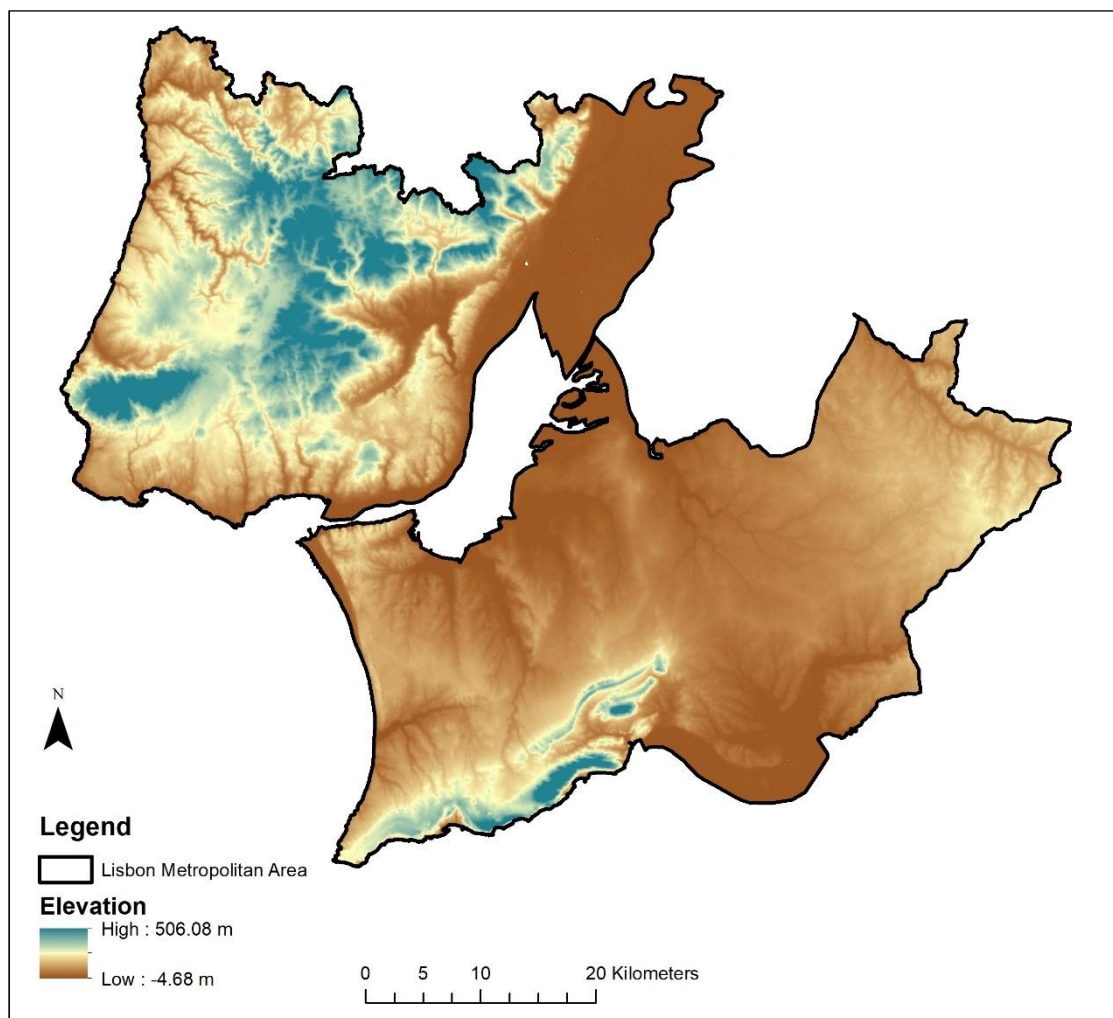

Figure 2: Elevation in the LMA

Framework

The artificial company MINCO operates 40 supermarkets within the LMA with a similar range of goods as well-known supermarkets as Lidl or Pinco-Doce. Furthermore, MINCO operates 45 service stations (i.e. gas stations), which are clustered around the city of Lisbon like the supermarkets as displayed in Figure 1. Whereas the supermarkets are supplied from a grocery depot, which is located close to the city of Sintra, the service stations are supplied with different kinds of fuel from a fuel depot, which is located on the south-bank of the river. Both, supermarket and service station, as well as their respective depot locations are based on real locations of respective facilities within the SA to simulate a realistic allocation.

By agglomerating deliveries of dry goods, each supermarket is directly distributed via Full-Truck-Load (i.e. complete Load) deliveries from the grocery depot on a demand-based schedule. For the delivery of these goods, HDV with a maximum permissible weight of 16 tons (e.g. MAN TGS, Mercedes-Benz Atego and DAF LF series) are utilized. Similar trucks with cooling systems are further utilized to supply the supermarkets with fresh goods on daily basis, where one HDV supplies a set of supermarkets with less than a truck load. The service stations are supplied with fuel from their respective depot by tanker trucks powered by Volvo FH 500 trucks, which are heavier than 32 tons in total. For an economical supply of fuel, the HDV operate as Full-Truck-Loads.

To reduce the company's carbon footprint, the distribution routes, which are optimized for the least operation time so far, are reevaluated with the objective to compare the FC and CO_2-Emissions from the Eco-friendliest, shortest and fastest route alternatives.

3. Methodology

This work presents a GIS based 3D-Routing-Model to determine most eco-friendly routes in the domain of transportation and the distribution of goods. Routes are optimized by minimizing vehicle FC and respective CO_2-Emissions in a RN, while taking topography (i.e. road inclination) and other influencing factors into account. The model is utilizable to determine FC minimizing routes, to estimate the total FC of routes under further optimization objectives as total travel time and total travel distance, as

well as to visualize routes with detailed 3D-Profiles.

The model's implementation is distinguished in four phases: (1) generation of a 3D-RN by connecting a 2D-RN and a DEM; (2) vehicle and case specific FC calculation of each direction for each edge within the 3D-RN by implementing a EEM; (3) route optimization for minimum FC and its alternatives for different scenarios simulated in case studies and (4) a 3D-visualisation of specific routes.

Being entirely implemented in Esri's ArcGIS 10.5.1 environment, the 3D-RN is created in ArcMap using the 3D-Analyst extension and routes are optimized in the NA extension. Determined routes are further processed in ArcScene to generate 3D height and gradient profiles for specific cases. Calculations and attribute manipulations are implemented using the field calculator for calculations by utilizing VB-Scripts.

A general methodology overview is given in Figure 3, which illustrates the connection between the used data and the interconnection between the different phases of the 3D-Routing-Model.
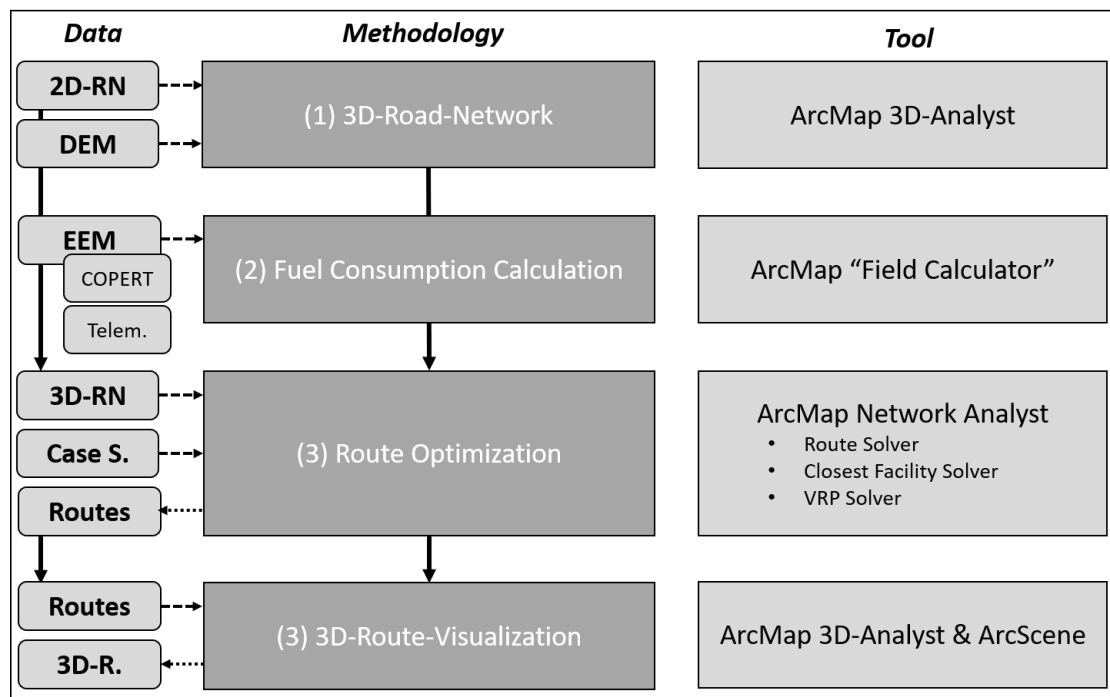

Figure 3: Methodology Overview

(1) 3D-Road-Network

In this work open source data is used to setup a 3D-RN which is created by enriching a 2D-RN Dataset with height related attributes through a DEM. The 2D-RN of the SA is provided by Geofabrik (2017) as routable OpenStreetMap Data-based shapefile, comprising of road-segments that are split at junctions. The shapefile consists of 176.995 polyline records with specific 'road class' (e.g. motorway, trunk, etc.), 'speed' [km/h] and 'length' [m] attribute values. The 2D-RN is pre-processed for later calculations in terms of adding a new field 'velocity' [km/h], where the speed attribute of each corresponding road class is manipulated to fit the SAs speed limits (i.e. Urban = 50; Rural = 80; Motorway = 90) for HDV.

To enrich the 2D-RN with elevation data, a DEM is used in combination with tools of the ArcMap 3D-Analyst extension. The DEM is obtained via the European Environment Agency (2013), which provides a DEM over Europe as Digital Surface Model, representing the first surface as illuminated by sensors. Captured at 1 arc seconds postings (i.e. resolution of about 30 meters). The DEM is a 3D raster dataset available as TIF-File of whole Europe, which is manually accommodated to the extent of the SA.

To transfer a 2D-RN into a 3D-RN, the 3D-Analyst Extension offers several suitable tools. By adding surface information to the RN polylines, an average slope attribute is obtained. However, this attribute provides only absolute values for the road-segments inclination and does not distinguish between the polylines uphill or downhill direction. Furthermore, average slope values are calculated for road-segment lengths of over ten kilometers, which eventually leads to inaccuracies in later calculations. Therefore, a more sophisticated approach is necessary to determine the slopes direction and more accurate values on a higher resolution.

To obtain more granular results, the 2D-RN polylines are interpolated (i.e. Interpolate Shape) with the DEM to create a 3D feature. Following the RN is split at each height and direction change additionally to its junctions, into straight road-segments of around 15 m for higher resolution and a total of 1.408.581 edges. More precise absolute slope values [%] and 3D-Lengths [m] of each edge are added by using the Add Surface Information tool. To determine the slopes direction (i.e. positive values - uphill & negative values - downhill), start points of each edge are extracted (i.e. Feature Vertices to Points) and enriched with their interpolated height (i.e. Extract

Values to Points). In combination with the added surface information results (i.e. max & min height of each straight edge) the height of the edges end points is calculated, and the slopes direction derived as positive or negative value, according to the edges start and end elevation. The presented Methodology and its ArcMap implementations is illustrated in Annex A.

Although the SA is characterized as irregular with many hills and cliffs, the low resolution of the DEM leads to unrealistic slope values for certain RN segments. As e.g. in motorway segments with slopes higher than 15 % or bridge segments with slopes higher than 50 %, which eventually lead to inaccurate FC values of respective edges. Therefore, edges with absolute values higher than 15 % are scaled to a value of 15 %, as this is often stated as maximum restriction for road slopes (Bartlett, 2015).

To account for the terrains elevation changes and respective road inclination in the determination of most eco-friendly routes and FC estimations, the obtained slope and 3D-Length values are used in later calculations. Figure 4 shows a snippet of the 3D-RN within the SA facing a South-Western direction with the city of Cascais in the background, which represents the terrain irregularities of the LMA.
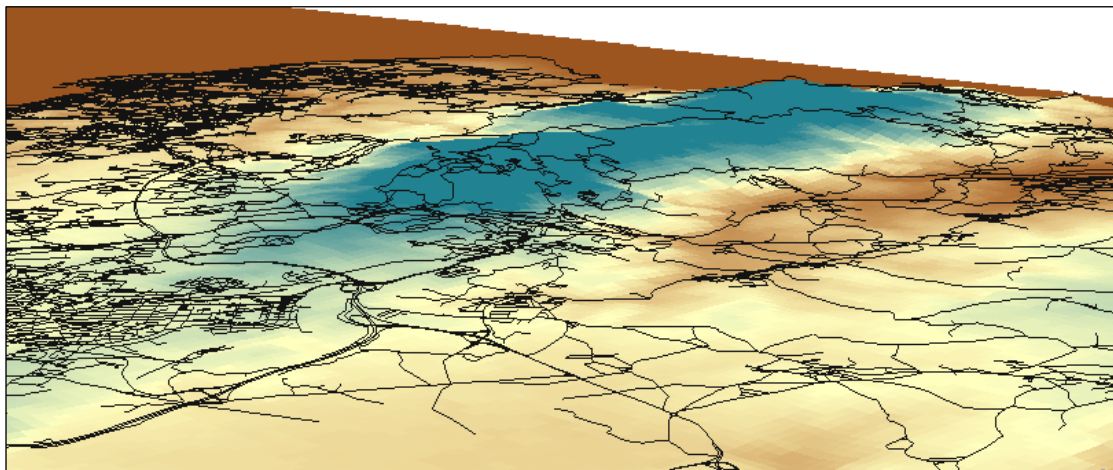

Figure 4: 3D-Road-Network in the LMA

(2) Fuel consumption estimation

A vehicles FC is affected by several factors such as vehicle related specifications as engine power, weight and speed. Likewise, external factors as traffic and weather conditions, as well as driving style affect the FC. Furthermore, FC and associated

11

emissions are influenced by road inclination, leading to altering results compared to simple factor FC estimations, where only the travelled distance in combination with average FC records of a specific vehicle is considered as in factor models (Demir et al., 2014). FC estimation models can be further distinguished in macroscopic and microscopic models. Macroscopic models obtain average aggregated network parameters to assess emissions on different scales, whereas microscopic models estimate vehicle specific FC instantaneous, relying on real-time vehicle parameters as e.g. current speed, acceleration and the used gear. Although microscopic models can obtain more accurate results, macroscopic models are more suitable for planning and optimization models (Bektas et al., 2014). An extensive summary on various FC models is published by Demir et al. (2014), where functionalities and usability are exemplified throughout.

In this 3D-Routing-Model, two approaches for the estimation of FC per RN segment are implemented. Both approaches are based on the macroscopic method proposed via COPERT III (Ntziachristos & Samaras, 2000). The European Economic Area founded emission model COPERT III is based on a database of parameters for the calculation of emissions of a broad range of vehicles and engine technologies. These parameters and emission factors are obtained by sampling a range of vehicles of a specific category (e.g. HDV > 3,5 t) in predefined test conditions (Kousoulidou et al., 2010). Therefore, external factors as traffic conditions, weather and driving behavior are eventually implemented as well. Additionally, the COPERT III method can incorporate effects of road inclination and vehicle weight by applying correction factors to estimate more accurate FC and emission estimates (Kouridiset al., 2010). Although COPERT III was designed to estimate traffic emission on a high aggregation level, it can also be applied at a higher resolution with a sufficient degree of certainty (Ntziachristos & Samaras, 2000). Although microscopic models can estimate vehicle FC and emissions very precise, they rely on extensive data input. Therefore, a model as COPERT III which estimates FC and CO_2-Emissions based on explanatory variables is more applicable in this approach.

In the first approach (A) the COPERT III methodology with stated adjustments for diesel HDV from 7,5 to 16 tons is implemented in the GIS environment. FC estimates that are later used as impedance for route optimization in the following case studies one to three, for each direction of each RN edge are calculated according to the following functions and implemented as new attribute. The second approach (B) is

based on the COPERT III methodology for diesel HDV larger than 32 tons, whereas certain equations (Eq.) are replaced by own functions, which are based on telematics data provided by MzB GmbH for a specific vehicle. The used notation is introduced in Table 1.

Parameter	Unit	Equation	Approach	Description	Impedance
fc_V	[g/km]	1 A	A	Speed depending FC	
	[L/km]	1 B	B		-
fc	[g/km]	2 A	A	Corrected FC	
	[L/km]	2 B	B		-
CF_{Load}	[-]	3	A	Correction Factor for Vehicle Weight	-
CF_{RG}	[-]	4 A & 4 B	A & B	Correction Factor for Road Gradient	-
FC_j	[g]	5	A	FC per Edge	
	[L]	5	B		-
L_j	[km]	5	A & B	3D-Length of Edge	Shortest-Route
FC_{jLiter}	[L]	6	A	FC per Edge to Liter conversion	Eco-Route
T_j	[h]	7	A & B	Time per Edge	Fastest-Route

Table 1: Methodology Notation

Approach A:

The basic formula to estimate vehicle type specific FC based on speed, fc_V [g/km], is expressed as in Eq. (1A). The formulas distinction for different speed ranges incorporates different FC estimates for variations of driving conditions, as in urban or rural RN environments.

$$fc_V = \tag{1A}$$

for $V < 59$ $1068.4 * V^{-0.4905}$

for $V >= 60$ $0.0126 * V^2 - 0.6589 * V + 141.18$

To account for the factors of vehicle weight and road inclination, different correction factors (CF) are applied. Whereas such effects are marginal for passenger vehicles, they have significant consequences for HDV. The dimensionless CF for

vehicle weight CF_{Load} and road gradient CF_{RG} are applied as expressed in Eq. (2A) to calculate a corrected FC value fc [g/km].

$$fc = fc_V * CF_{Load} * CF_{RG} \tag{2A}$$

The vehicle weight CF is based on a reference value accounting for loads of 50 %, i.e. a partially loaded vehicle. For similar road patterns the vehicles engine operates under varying loads depending on the vehicles weight, resulting in a higher FC and emission rate for complete loads and vice versa. The following equation Eq. (3) is derived from the given formula in COPERT III, where LO expresses the actual vehicle load as percentage.

$$CF_{Load} = 0.36 * LO + 0.82 \tag{3}$$

Road inclination has a strong effect on a vehicles FC as an essential amount of more energy is required to climb elevations, whereas less energy is required on descents compared to driving on even surfaces. The COPERT III methodology provides a formula to calculate a road gradient CF, which increases the FC on positive gradients and vice versa. The given polynomial function is based on various parameters for different vehicle types and speed ranges, whereas it is valid for road gradients from -6 % to 6 %. As in this study road gradients vary from -15 % to 15 %, the formula is adjusted for the extended gradient range. Based on the COPERT III formula CF values for different gradient and mean values of corresponding speed ranges are calculated. To incorporate the broader gradient range, the results are fitted to an exponential function. This function is presented in Eq. (4A), where RG expresses the road gradient (i.e. positive or negative slope value).

$$CF_{RG} = 1.0536 * e^{\,0.1655 * RG} \tag{4A}$$

FC values per RN edge, FC_j (g), are calculated according to Eq. (5), which is valid for both approaches. For each road-segment (i.e. edge) FC values are assigned

through multiplication with the segments 3D-Length, L_j [km]. To account for the road gradients direction (i.e. positive or negative), one attribute in the GIS environment is added for the real slopes direction (i.e. Start to End), and attribute for the reverse direction (i.e. End to Start) with its corresponding slope value reciprocal.

$$FC_j = fc * L_j \tag{5}$$

As FC values in gram are not common and of less meaningfulness, the calculated FC_j values are converted to Liters [L] according to Eq. (6). This equation, where ρ_{Diesel} expresses the density of Diesel, is valid for both approaches.

$$FC_{jLiter} = FC_j / \rho_{Diesel} \tag{6}$$
$$\text{with } \rho_{Diesel} = 840 \text{ [kg/m}^3\text{]}$$

As CO_2-Emissions are proportional to the FC, CO_2-Emission estimates are calculated based on the total FC per route, as expressed in Eq. (7). The emission factor for CO_2-Emissions from Diesel, EF_{Diesel} [g/g], is applicable for all Diesel fueled vehicles and states how much gram of CO2 is emitted per grams of Diesel.

$$E_{Route} = FC_{Route} * EF_{Diesel} \tag{7}$$
$$\text{with } EF_{Diesel} = 3.14 \text{ (gram CO2 per gram Diesel)}$$

The calculated FC for each edge and each direction is used as impedance for the route optimization, as well as for FC and emission estimates of a route. To compare different routes as eco-friendliest, fastest and shortest route, the RN is completed by time estimations, T_j [h], for each edge based on its 3D-Length L_j [km] and allowed velocity V_j [km/h] as expressed in Eq. (8). Therefore, it is assumed that drivers tend to drive as fast as possible, while satisfying speed limits.

$$T_j = L_j / V_j \tag{8}$$

Figure 5 displays extrapolated characteristic lines for different speed-based FC results from approach A. Next to the standard COPERT III equation (i.e. *COPERT*) without any corrections for road inclination and vehicle weight, the graphical results for a road gradient of 4 % and complete load (i.e. *COPERT Max*), as well as a road gradient of -4 % and empty load (i.e. *COPERT Min*) are displayed. The graph clearly indicates the effects of road inclination on a vehicles FC.
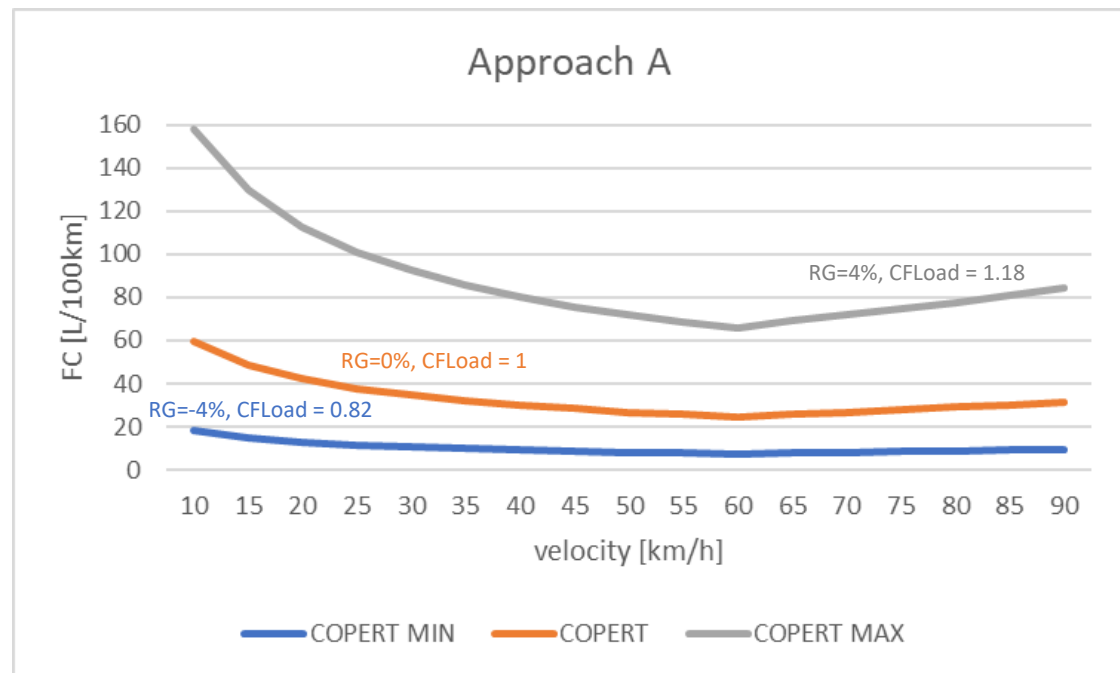

Figure 5: Characteristic Lines for Approach A

Approach B:

To obtain more accurate FC and emission estimates for a particular vehicle type, certain formulas of Approach A are changed or adjusted. Approach B is based on telematics data of a specific vehicle type (i.e. Volvo FH 500; HDV > 32 tons), which is provided by MzB GmbH. The telematics system saves route related data as the average FC along a route, the routes distance and the routes average speed amongst others.

To generate a speed-based FC equation like Eq. (1A), a total of 7655 routes are extracted for eleven vehicles of the stated type over a time frame of 30 days. After removing outliers (e.g. speed > 90 km/h), the extracted data is split into complete load and empty load routes according to the company's vehicle occupancy rate of 75 %, as the company only operates empty or complete loads (i.e. Threshold: empty load < 24 L/100km < complete load).

Furthermore, the extracted data is corrected for its respective road inclination in the data collection area. Therefore, the average FC values are corrected by the later used CF_{RG}, Eq. (4B). The data collection areas RN is characterized by an average absolute slope of 1.94 %, resulting in a CF_{RG} (uphill) of 1.55 and a CF_{RG} (downhill) of 0.75. The mean of this CF values (i.e. 1.15) is applied to reduce the extracted average FC data to exclude road inclination, which is later implemented through its respective CF. For each complete and empty load data set, an exponential function is fitted, resulting in an adjusted speed-based FC equation (1B), fc_V [L/km].

$$fc_V = \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (1B)$$

for *Empty Load*	$0.1547 * e^{0.002 * V}$
for *Complete Load*	$0.4527 * e^{-0.007 * V}$

Like in Approach A, the speed-based FC needs to be corrected to account for the vehicles weight and road inclination. Since the vehicles weight is already integrated through Eq. (1B), CF_{Load} is neglected in this approach. The corrected fc [L/km] is therefore calculated according to Eq. (2A).

$$fc = fc_V * CF_{RG} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (2B)$$

The CF accounting for road inclination is derived from the COPERT III methodology, parameters and adjustments as in approach A. Therefore, CF_{RG} is expressed as in Eq. (4B).

$$CF_{RG} = 1.0798 * e^{0.1872 * RG} \qquad\qquad\qquad\qquad\qquad\qquad (4B)$$

The FC per edge is calculated as in Eq. (5), whereas a conversion to Liter is not necessary and CO_2-Emissions are estimated through Eq. (7) as well. However, FC estimates are implemented in ArcMap for each edges direction as in approach A. As in each approach FC estimates for each edges direction are stored as attribute, these attributes are used as impedance for the route optimization.

Figure 6 displays extrapolated characteristic lines for different speed-based FC estimations based on the proposed EEM. It further compares it to results obtained by the respective COPERT III methodology for HDV heavier than 32 tons. The graph implicates that the developed EEM results in less FC for different vehicle weight and road gradient combinations compared to its respective COPERT III results (cf. Figure 5), where *COPERT Min* represents a combination of -4 % road gradient and empty vehicle, and *COPERT Max* a combination of 4 % road gradient and completely loaded vehicle.
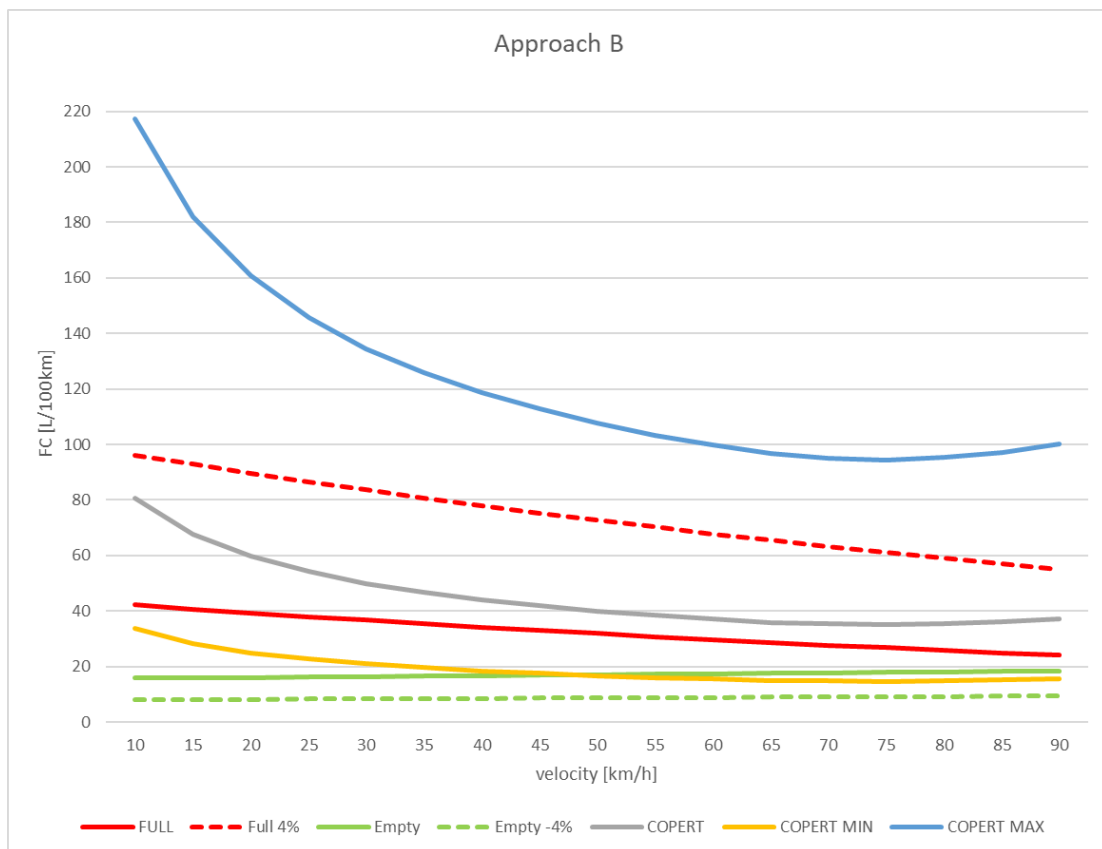

Figure 6: Characteristic Lines for Approach B

(3) Route Optimization

The route optimization is realized with ArcMaps NA, which offers different functions for different route optimization settings and parameters. Each route optimization is based on different algorithms, aiming to minimize the total impedance (e.g. FC, time or distance).

The route optimization primarily aims to minimize the total FC to determine the eco-friendliest route that connects a set of points (e.g. Depot and Market/s). Whereas

the FC is generally set as impedance, the remaining parameters of 3D-Length and time per edge are accumulated for comparison. Furthermore, in each case study routes are optimized for the impedances of 3D-Length and time, to compare the eco-friendliest routes results to these of the shortest and fastest route.

For each Case Study a separate NA network is set up, incorporating the FC_j values for each edges direction as cost attribute without a specific unit, i.e. From Edge-Start to Edge-End (i.e. From-To) and vice versa (i.e. To-From), with its respective slope direction and case specific vehicle weight CFs. The impedances for distance and time are implemented according to their units, whereas for Case Study 3 further adjustments are made. The cases 1, 2 and 4 are solved with the New Route and the Closest Facility tool, which can optimize routes for any given impedance. However, in Case Study 3 routes are optimized to serve subsets of demand points with a specific number of vehicles, a so-called VRP. The NA VRP solver determines the most efficient route based on time impedance. To optimize a VRP in the NA for other impedances, these need to be implemented as time impedance. Furthermore, to obtain accumulated FC, time and distance values, each impedance needs to be further implemented unit likewise (i.e. FC, time and distance each as time and distance impedance), and the tool needs to be solved multiple times for sets of specific route results.

The determined routes for each Case Study are represented by a set of polylines and the related parameters of total FC, total distance and total time. Based on these parameters the eco-friendliest routes are compared to the respective shortest and fastest route alternatives. Detailed Case Study descriptions and their results are presented in the results chapter.

(4) 3D-Route-Visualization

Beside the 2D visualization of the Map based on simple polylines, a 3D visualization as 3D-Height-Profiles provides a more detailed view on the routes inclination and elevation characteristics. A 3D-Height-Profile indicates the elevation, as well as the actual slope and direction of each route segment.

To generate a 3D-Height-Profile, a determined route is extracted as shapefile and interpolated with the original DEM. Similar to the creation of the 3D-RN, the route is further split at each direction and elevation change (i.e. its vertices) to obtain straight

road-segments. After adding surface information for each route segment, the slopes direction (i.e. positive or negative) for each edge is determined by extracting the start point of each segment as well as their respective elevations and by comparing these values with the minimum and maximum height of each straight road-segment.

The generated data is then imported to ArcScene, where the interpolated route can be displayed as floating on the DEM. To generate the 3D profile the route is extruded to the value zero and the symbology is fitted to the slope direction value range. The presented Methodology and its ArcMap implementations is illustrated in Annex B. As ArcScene does not support Basemaps, an ArcMap Basemap can be added by exporting it as global JPEG-File. A 3D-Height-Profile for the results of Case Study 1 is exemplarily presented in the results section.

4. Results

As described the following case studies are situated in the artificial framework of the company *MINCO*. The company operates a set of supermarkets and service stations in the SA, which are supplied by two respective depots. Within the stated framework, the previously presented 3D-Routing-Model is applied to optimize and analyze the companies' distribution routes in four scenarios. For each Case Study the eco-friendliest, fastest and shortest set of routes is determined and compared in terms of total FC, total distance and total time. These parameters are considered along the route only, whereas loading and unloading processes are not considered. Furthermore, the results are monetarily quantified to examine economic repercussions, based on a guideline by Haase (2013). The purpose of the case studies is to illustrate the FC and CO_2-Emission saving potentials, which are enabled through the utilization of the 3D-Routing-Model. The model is implemented in the following Case Studies, which setups are summarized in Table 2 and whose results are shown in Table 3. Whereas the Case Studies 1-3 are based on the methodology Approach A, Case Study 4 is based on Approach B to determine the eco-friendliest route and to estimate the remaining parameters. The following case studies are implemented:

(1) *Simple Routing:* Complete Load from Depot to one specific Market

(2) *Full Distribution A:* Complete Loads from Depot to each Market and Empty Loads back to Depot

(3) *VRP*: From Depot to set of Markets with certain demand back to Depot by set of eight vehicles

(4) *Full Distribution B*: Complete Loads from Gas-Depot to each Service Station and Empty Loads back to Gas-Depot

Case	Description	HDV	Approach	NA Solver	CF_{Load}
1	Depot to one Supermarket	< 16	A	New Route	1.18/-
2	Depot to each Supermarket and back	< 16	A	CF	1.18/0.82
3	Depot to Set of Supermarket and back	< 16	A	VRP	1
4	Gas-Depot to each SS and back	> 32	B	CF	1.18/0.82

Table 2: Case Study Description (CF = Closest Facility Solver, VRP = VRP Solver, CF_{Load} (Outward/Return))

For each Case Study, the eco-friendliest route yields significant fuel and emission saving potentials compared to its alternatives (i.e. fastest and shortest routes), whose FC and Emission estimates result are in similar dimensions.

However, the accumulated distance and time attributes of each eco-friendly route are significantly higher compared to its alternatives, which reach their respective minimum according to their optimized impedance. In general, eco-friendly routes consume less fuel while covering a greater distance and taking more time as the shortest or fastest routes.

Case	FC [L]	Avg. FC [L/100km]	CO2 [kg]	Distance [km]	Time [h]	Costs [€]
Case Study 1						
ECO	*7.35*	*27.8*	*19.39*	26.46	0.50	32.23
FAST	8.51	*33.2*	22.45	25.63	*0.37*	28.40
SHORT	8.31	*35.5*	21.92	*23.39*	0.40	29.20
Case Study 2*						
ECO	*645*	*25.8*	*1701.25*	2500	43.46	2824.30
FAST	809	*32.8*	2133.82	2469	*34.88*	2690.13
SHORT	798	*34.1*	2104.80	*2338*	40.26	2886.40
Case Study 3*						
ECO	*185*	*25.6*	*487.96*	723	12.90	828.31
FAST	207	*28.8*	545.98	719	*10.65*	765.29
SHORT	206	*28.7*	543.35	*717*	12.80	851.90
Case Study 4*						
ECO	*715*	*40.3*	*1885.88*	1775	31.90	2392.20
FAST	793	*46.5*	2091.62	1707	*25.00*	2209.03
SHORT	784	*46.6*	2067.88	*1683*	26.78	2268.19

Table 3: Case Study Results (*accumulated)

Case Study 1:

This scenario simulates the supply of a single supermarket with a completely loaded (CF_{Load} = 1.18) HDV up to 16 tons, which are utilized by MINCO. Complete loads are utilized by MINCO to supply the supermarkets with dry goods (e.g. drinks, packed food) on a demand-based schedule. Therefore, only partially loaded trucks, which do not utilize the complete capacity, are avoided. Based on the generated 3D-RN, the objective of this case is to determine the eco-friendliest route between the Depot and a single supermarket, as well as to compare the route to its shortest and fastest alternative. The NAs Route Solver is thus set up separately for the impedances of FC, 3D-Length and time per Edge.
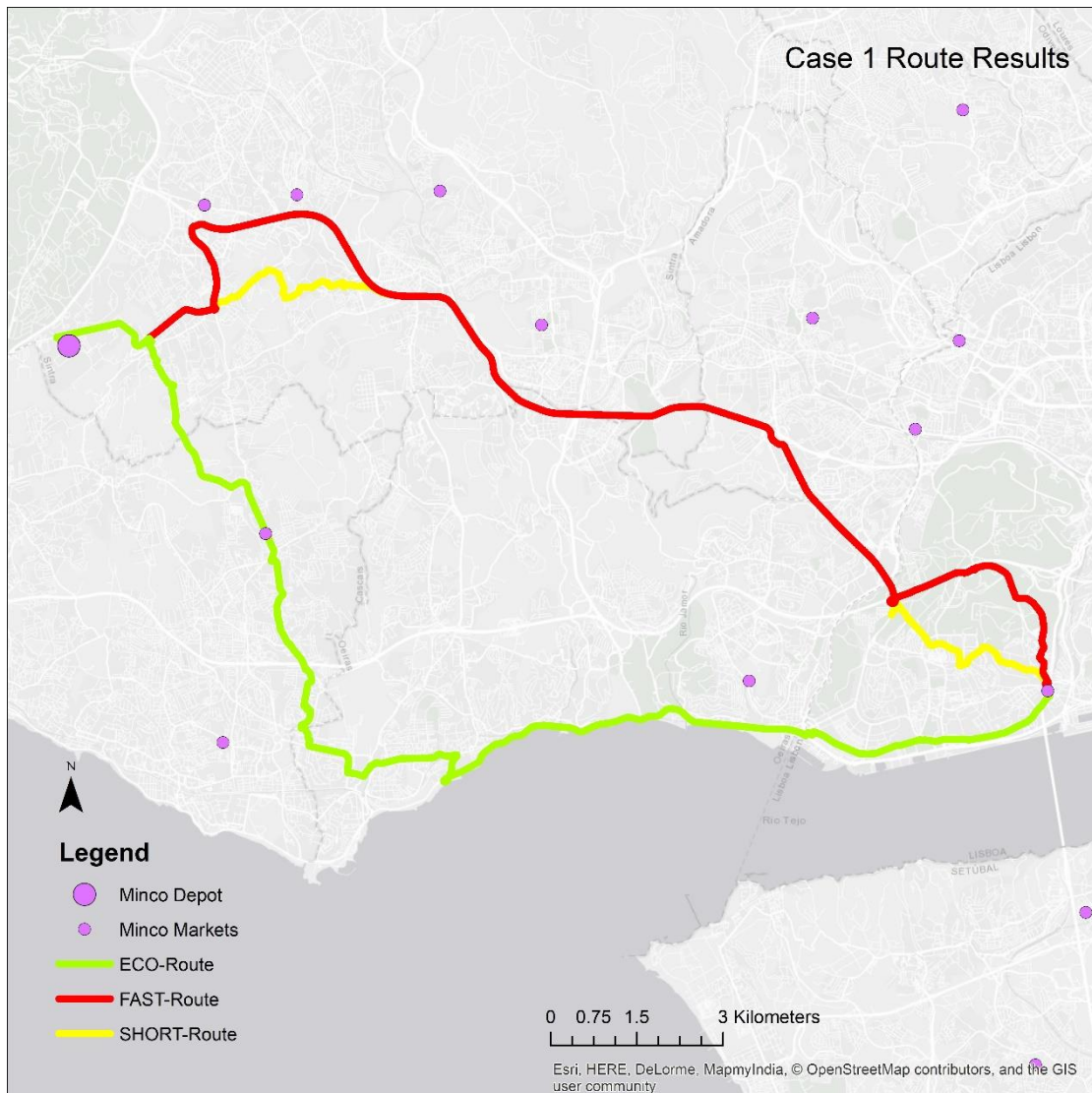
Figure 7: Case Study 1 Routes

The three generated routes from the depot to the supermarket are displayed in Figure 7. Comparing the three routes it can be observed that the shortest and fastest routes, which are not optimized for FC, are partially overlapping as they are mainly utilizing motorways. Both routes are characterized through ascending and descending segments, whereas they can be distinguished as the fastest route maximizes the distance on the motorway. The shortest route by contrast minimizes the distance towards the motorway and from the motorway to the supermarket. On contrary, the eco-friendliest route is characterized through preferring descending road-segments, where the FC is minimized. Therefore, it utilizes mainly descending rural and urban roads, which is also represented in the 3D-Height-Profile displayed in Figure 8, where the elevation values for each road-segmented are factorized for visual purposes. In the 3D-Height-Profile,

23

the slopes direction and gradient are indicated via a color scheme, where green generally indicates descending, and red ascending road-segments.
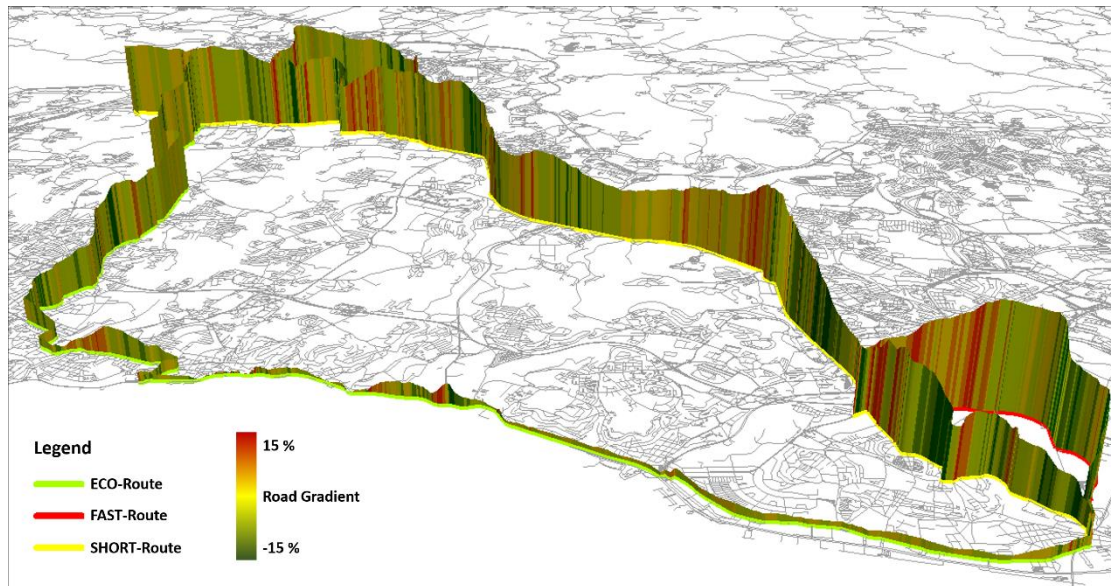

Figure 8: 3D-Height-Profile for Case Study 1

Comparing the total FC and CO_2-Emissions, the absolute difference between the shortest and fastest route are marginal, whereas the eco-friendliest route enables significant fuel and emission savings of 13.6 % compared to the fastest and 11.5 % to the shortest route. However, the eco-routes distance and time are considerably higher than its alternatives. This has significant effects on the routes costs, where monetary savings through fewer FC are counterbalanced by increasing costs of the operation time. The fastest route is therefore 11.8 % less expensive than the eco-friendliest, being around one kilometer shorter and almost eight minutes faster. Figure 9 illustrates the results for different parameters of Case Study 1.
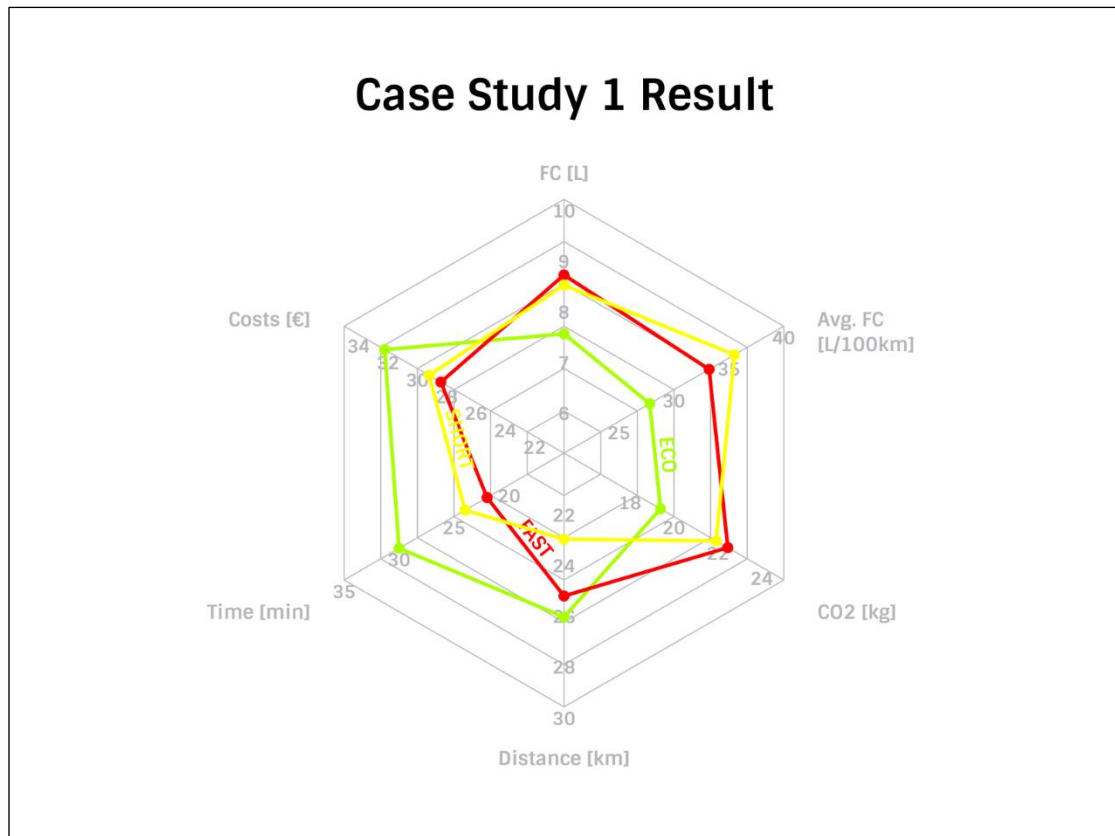
Figure 9: Case Study 1 Parameter Results

Case Study 2:

In the second scenario the transportation of dry goods to each MINCO supermarket is simulated and extended by the return of the HDV to the depot, whereas each supermarket is supplied by a single truck. Like the first scenario the goods are transported as complete loads (CF_{Load} = 1.18) to the markets. However, for the backhaul a CF_{Load} of 0.82 is implemented to account for empty returning trucks. For each supermarket, the eco-friendliest route and its alternatives are determined for its outward and return journeys, with its respective vehicle weight CF. Accordingly, the NA Closest Facility solver is set up for the impedances under consideration, as well as for the travelling direction (i.e. Depot to Facility & vice versa). The resulting routes are displayed in Figure 10, where for each route optimization impedance (i.e. eco, short and fast), the routes towards the markets and back to the depot are displayed.

Resulting in a total of 240 routes, a characterization of each single route would extend this papers objective. For the eco- and fast-routes, the return routes towards the depot alter in specific cases, whereas for the short-routes the return routes don't differ

from their routes towards the market. However, similar to *Case Study 1* the shortest and fastest routes can be described as mixture of ascending and descending road-segments, as they aim to optimize their respective impedances, without taking FC impacts due to road inclination into consideration.
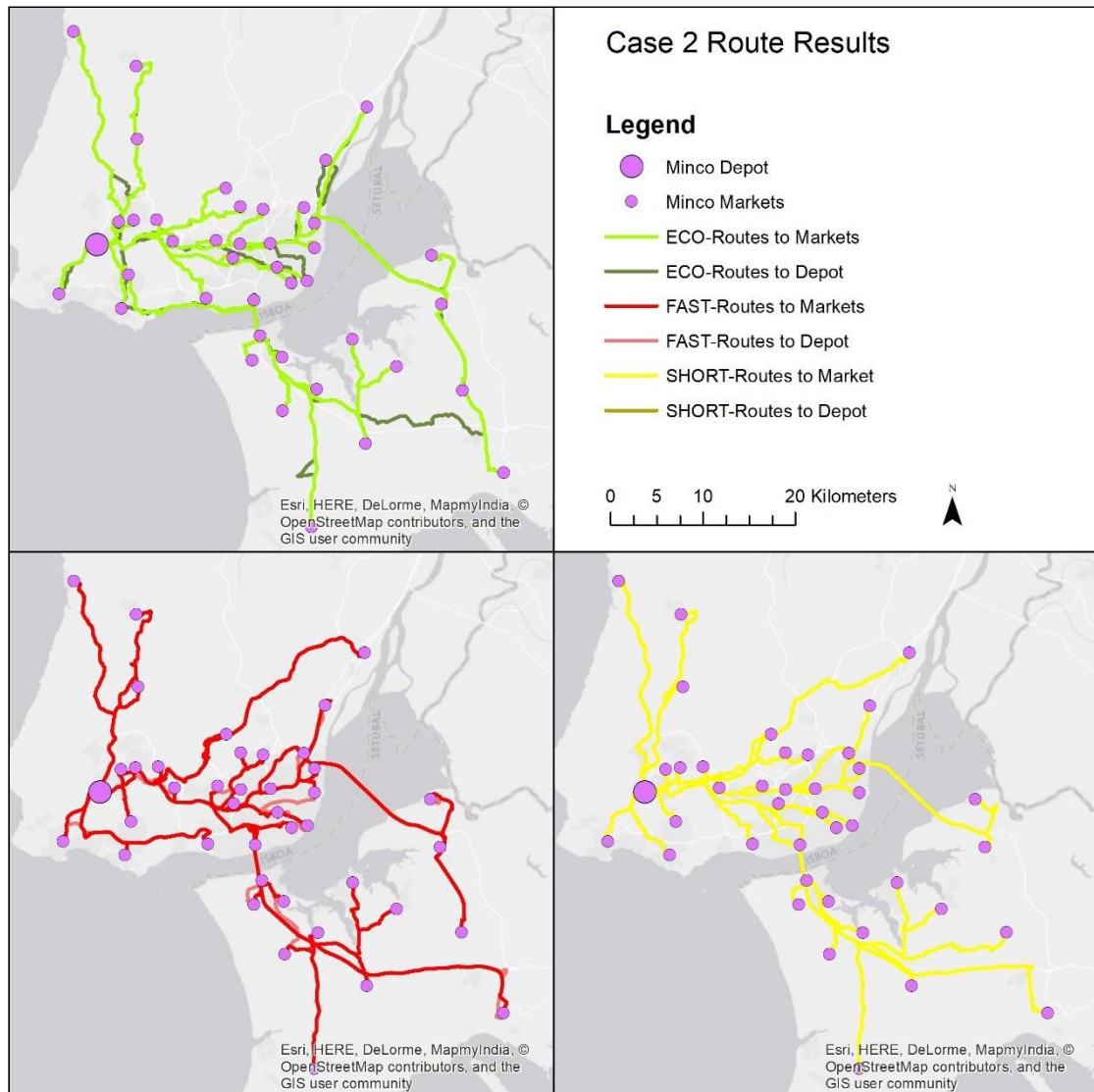

Figure 10: Case Study 2 Routes

As this is considered by the eco-routes optimization, such routes prefer descending road-segments, leading to significant FC savings of 20.3 % compared to the fastest and 19.2 % compared to the shortest route. However, the travelled eco-routes distance is again higher than the shortest routes distance, as is operation time compared

to the fastest route. Despite the absolute differences, the fastest routes are merely 4.8 % less expensive than the eco-friendliest routes, which is even cheaper than the shortest routes. Figure 11 illustrates the results for different parameters of Case Study 2.
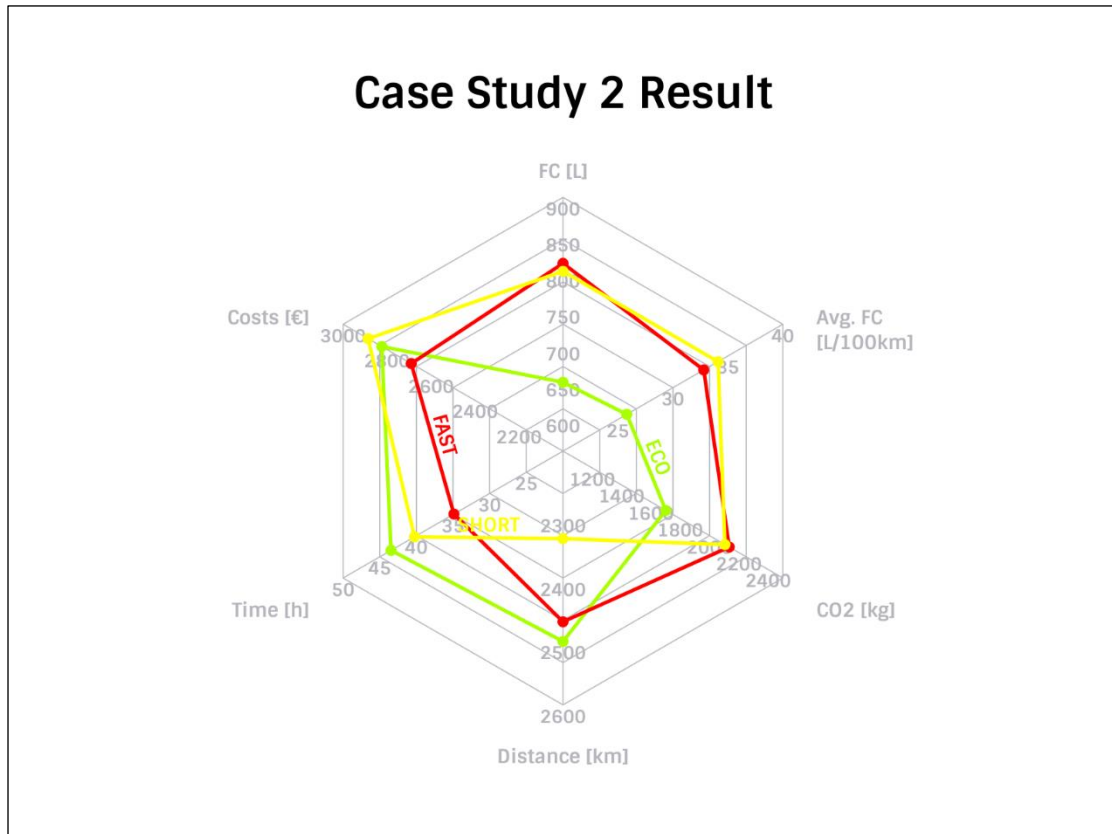

Figure 11: Case Study 2 Parameter Results

Case Study 3:

The third scenario simulates the daily supply of deep frozen goods to each MINCO supermarket as a VRP. Therefore, eight HDV trucks with a capacity of 100 units each individually supply a subset of the 40 Supermarkets and return to the depot. Each Supermarket has a randomly assigned demand between ten and 25 units, thus each truck can supply between ten and four supermarkets per route. As the vehicles weight decreases after supplying a supermarket, the weight CF should change for each route segment, which eventually would alter optimized routes. However, as these changes are not implementable in the VRP solver, a fixed CF_{Load} of 1 is utilized.

To optimize the VRP for the eco-friendliest, shortest and fastest route, which

serves the demands of each supermarket, the stated parameters are set up in the VRP solver properties, as well as the impedances and their variations as stated in the methodology section. According to the optimization criteria, a set of routes (i.e. one route for each HDV) is generated by the VRP solver for each impedance, which are displayed in Figure 12 and are characterized as in the previous scenario.
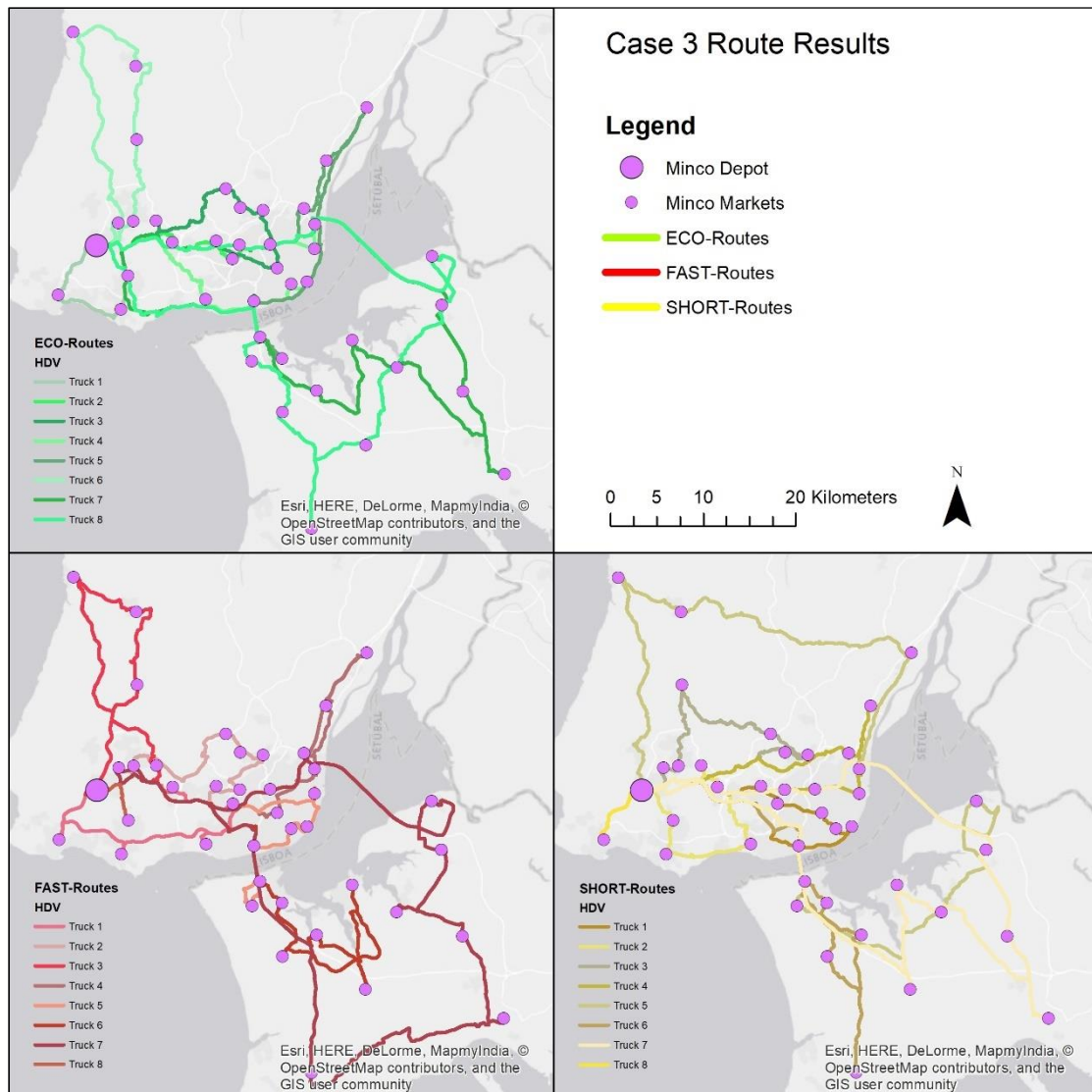

Figure 12: Case Study 3 Routes

The eco-friendliest route yields fuel and emission savings of about 11 % compared to its alternatives, whereas the total travelled distance is similar for each set of routes. However, the fastest route is more than 2 hours (21 %) faster than the eco-

friendliest route, resulting in around 8 % less costs. Figure 11 illustrates the results for different parameters of Case Study 3.
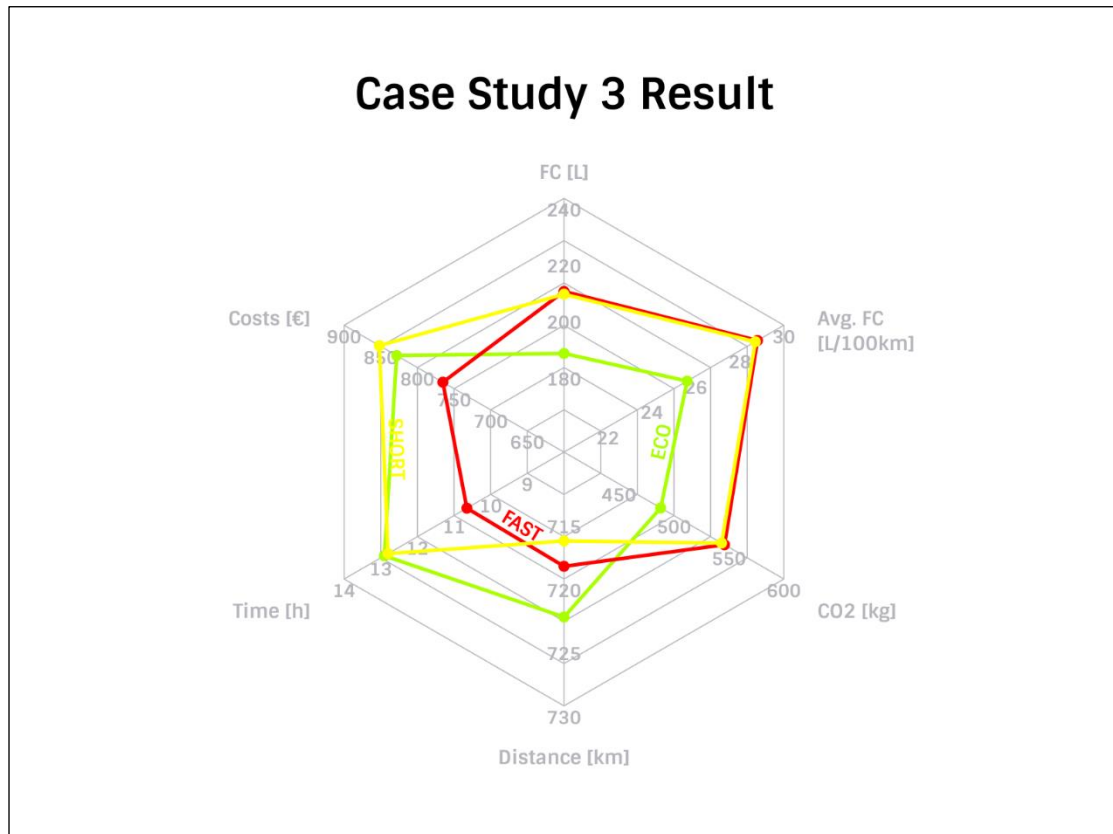

Figure 13: Case Study 3 Parameter Results

Case Study 4:

In the fourth scenario, where Approach B is applied, each service station is supplied with fuel as complete loads (CF_{Load} = 1.18) by HDV (> 32 tons). After supplying the service stations, the trucks return empty (CF_{Load} = 0.82) to the Gas-Depot as in Case Study 2. For each service station, the eco-friendliest route and its alternatives are determined for its outward and return journeys, with its respective vehicle weight CF. Accordingly, the NAs Closest Facility solver is set up for the impedances under consideration, as well as for the travelling direction (i.e. Depot to Facility & vice versa). The resulting routes are displayed in Figure 14, where the different routes are displayed as in Case Study 2. With similar characteristics as in the previous case studies, the eco-friendliest set of routes enables FC and emission savings of 9.8 % compared to the

fastest route and 8.8 % compared to the shortest route. However, the travelled distance and time are significantly higher compared to its alternatives. Therefore, the fastest route is 7.7 % less expensive. This is reasoned as in the previous cases, through the counterbalance of monetary savings through less FC and additional costs for the operating time. Figure 15 illustrates the results for each impedance of Case Study 4, where the altering outward and return journeys are displayed.
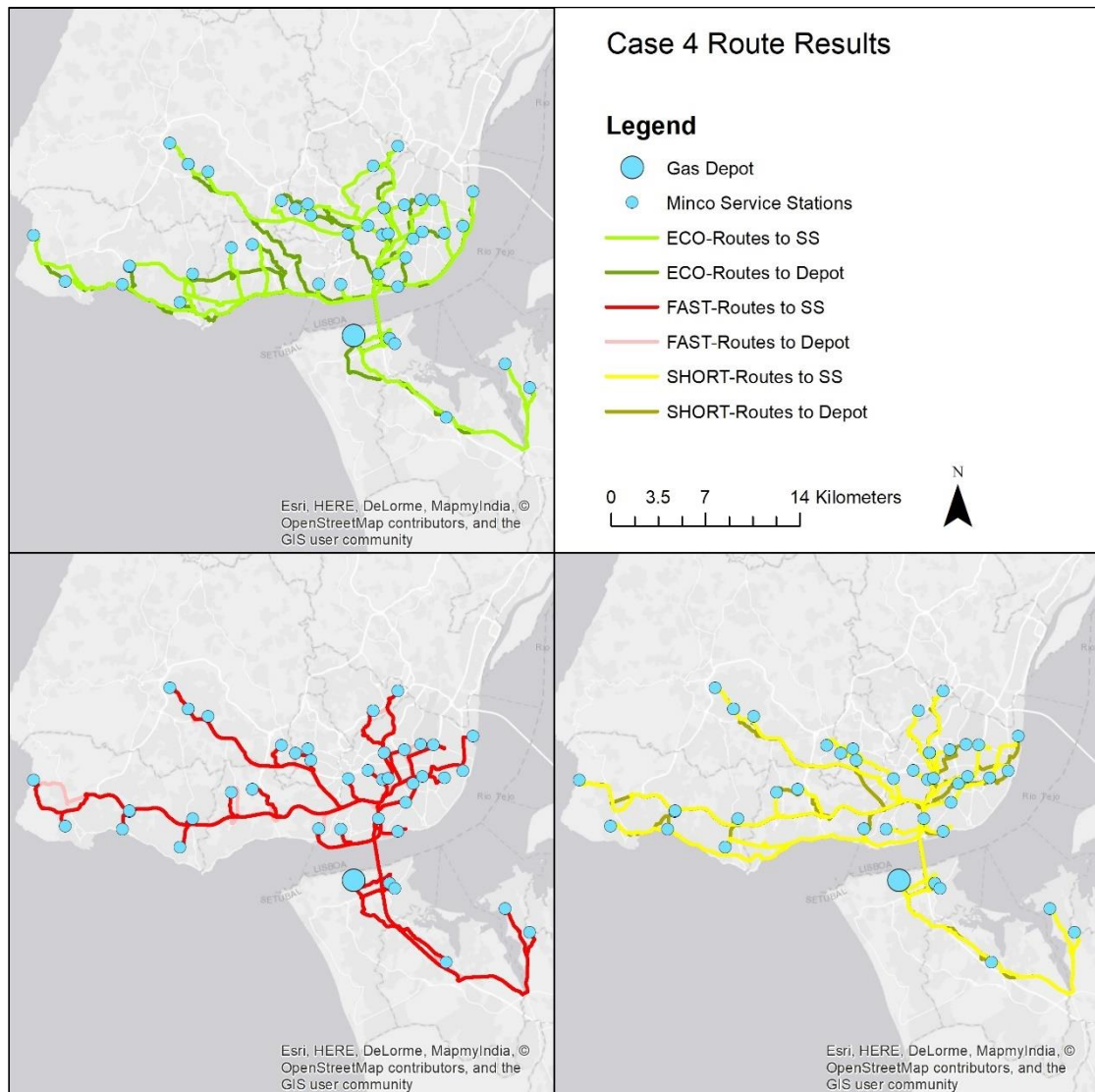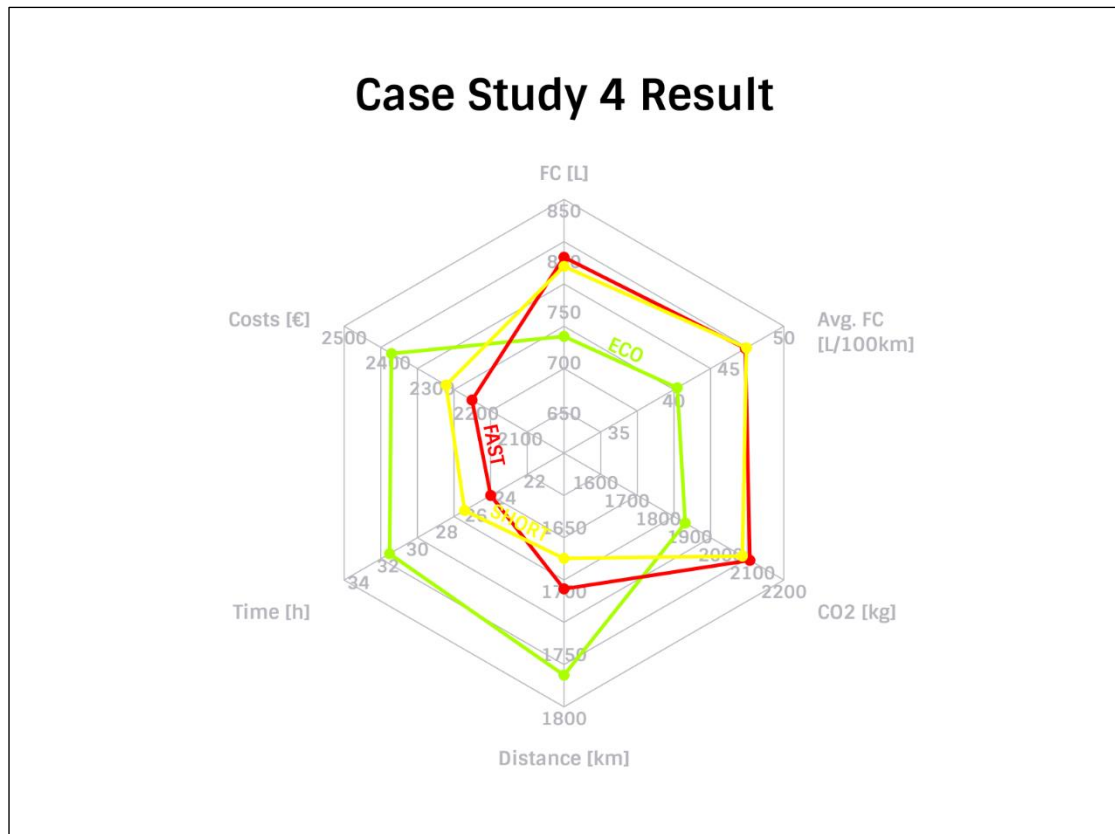

Figure 14: Case Study 4 Routes

Figure 15: Case Study 4 Parameter Results

The obtained results show that the fastest and shortest route often coincide for both delivery directions as the allowed velocity and distance for both directions of a road-segment are the same. Different routes therefore result in such cases where the given RN has one-way sections or other altering paths as in motorway-links. The eco-friendly routes differ for both directions as the optimization criterion minimizes FC, which is significantly higher on ascending road-segments.

Although the consideration of road inclination effects in the route optimization clearly represent fuel and emission saving potentials, the cost estimation results indicate that this comes at a higher price. Although average FC estimates [L/100km] can be reduced, costs through greater distance and longer driving times counterbalance the costs savings through decreased FC.

5. Discussion

As presented in the previous chapters, the developed 3D-Routing-Model shows how significant fuel and emission saving potentials can be obtained in the domain of the distribution of goods. Such potentials are enabled by taking road inclination as an additional degree of freedom into account. The topographic characteristics of a SA have a significant impact on the path of different routes under specific optimization criteria, which is clearly indicated by the obtained results.

The 3D-Routing-Model contributes to the evolving study of technical and strategic approaches to reduce emissions in logistics and especially in RFT, describing a GIS based approach to reduce FC and CO_2-Emissions. According to the works objective, the developed model does not claim to calculate exact FC and emission values. Rather, the model aims to show how topographic characteristics influence the FC and emission rates of different routes in the distribution of goods and how these effects can be incorporated in the optimization of routes. The proposed model, which can be distinguished in the four previously described methodology parts, extends the work of other publications in various ways. The 3D-RN is generated by using a detailed methodology to obtain only straight road-segments from the 2D-RN, which are enriched with height related attributes. Following this methodology, more accurate emission estimates can be obtained based on further adjusted FC formulas. Whereas in Tavares et al. (2009), a slope of 0 % would lead to a reduction of the speed-based FC, the adjusted slope CF equals one for a slope of 0 %, while it increases the FC for uphill directions and vice versa. Furthermore, the proposed methodology can calculate FC estimates for road-segment specific velocities on contraire to Tavares et al. (2009), who calculate FC estimations based on an average velocity for whole routes. Whereas, other models sorely rely on the formulas given by COPERT III, the presented Approach B introduces a methodology to generate a FC estimation formula based on telematics data. Several works implemented their models in the domain of waste collection, whereas this model is applied to case studies in the domain of the distribution of goods.

The proposed GIS based model is applicable to any SA, if a respective DEM and digital RN are available, eventually resulting in FC and emission rates according to the areas topographic characteristics. Whereas the data collection areas RN of Approach B is characterized by an average absolute slope of around 2 %, the Lisbon Metropolitan Areas RN absolute average slope amounts to around 4 %. Therefore, the average FC of

HDV with more than 32 tons results in an increased FC and emission rate of around 33 %. The models FC and emission calculation can be further extended or adjusted by explicit algorithms to obtain results for specific vehicles, or for various vehicle types based on adjusted formulas given by COPERT III.

Theoretically, the model can be also implemented for simple eco-friendly route optimization without FC and emission estimates. Therefore, a fixed FC value for each flat road-segment of e.g. 1 [L/km] can be implemented and corrected by CF_{RG} for each direction, next to the segments length and time. Following this approach, the NA still can determine the eco-friendliest, shortest or fastest route. However, different FC values of specific vehicle types for different velocities are neglected in such an approach.

Although fuel and emission savings can be realized by taking the topography of a RN into account to optimize for eco-friendliest routes, the model estimates FC and emission based on a speed-based formula, which originates from data collected almost 20 years ago. Therefore, absolute FC estimates are averagely around 30 % higher than the estimated FC values for recent HDV up to 16 tons as in Case 1-3. This drawback can be addressed by developing detailed formulas for a specific vehicle type as in Approach B, by implementing more recent formulas which have been developed eventually or reducing Eq. (1A) respectively. As the manufacturers of HDV increase their efforts in the development of hybrid and electric trucks (e.g. Tesla), the development and implementation of respective formulas to estimate the energy consumption for different routes depicts the expandability of the model in the future.

Besides the implementation of more accurate and contemporary formulas as in Approach B, the presented model can be further optimized in its early stages. As the 3D-RN depicts inaccuracies in slopes values for certain cases as in bridges and cliffs, the utilized DEM can only represent the real world up to a certain degree. Therefore, DEM with higher resolutions can be utilized to obtain more accurate slope values. However, respective DEM for specific SAs are rarely available free of charge.

The implementation of varying weight CF for decreasing loads as in Case 3 and varying goods in general, is a matter to be addressed in future advancements of the model. However, therefore it is necessary to manipulate the NAs VRP solver or to manually implement an adjusted VRP, which extends this works objectives. Furthermore, the model can be extended by implementing real time traffic data as the traffic flow and traffic lights, to avoid traffic congestion and stops, which significantly increase FC and emissions. Also, specific restrictions and parameters, according to any

given scenario can be implemented via the NA, as restrictions for certain roads, for delivery schedules and others. The implementation of the entire model in a web application like EFNav, but for a bigger area is a matter which could be addressed in the future as well.

Fuel and emission savings come at the price of increased travelled distances as well as operation times, which has negative impacts on the total costs per route. The cost calculation is based on various parameters as the vehicles acquisition costs, taxes, fuel costs and other factors. Although the eco-friendliest route in all presented cases resulted in not being the most economical route, being up to 13.5 % more expensive than its least expensive alternative, different sets of parameters and FC estimations for other SAs or use cases can generate different outcomes for FC and emission rates, distances and time, as well as for total costs. However, in the highly competitive environment of road freight transportation, predominantly the fastest and cheapest routes are utilized to maximize margins, as more transports per day can be realized. A shift to eco-friendliest routes is therefore only realistic, if companies are forced to reduce their ecological foot print through increasing pressure on behalf of the population, or politic arbitrations as increased emission related taxes.

6. Conclusion

The objective of this work was to develop a GIS based 3D-Routing-Model to illustrate the effects of road inclination on FC and CO_2-Emissions, as well as to optimize routes for the minimization of FC and CO_2-Emissions in the domain of road freight transportation.

The Model was implemented in Esri's ArcMap environment making use of its 3D-Analyst and NA extensions, accompanied by ArcScene for visualization purposes. To illustrate the effects of road inclination the model was applied in four case studies, simulating different scenarios in the domain of the study and its framework of the artificial company MINCO. The case study results illustrate the effects of road inclination on FC and CO_2-Emissions. Whereas significant fuel and emission saving potentials of up to around 20 % can be exhausted by utilizing eco-friendly routes, making them the most ecological solution, such routes come at a price. The results within this framework show that eco-friendly routes are longer and take more time,

compared to its alternatives (i.e. shortest & fastest routes). Although the total FC per route and its respective fuel costs can be minimized utilizing the model, the longer distance and longer travelling time have negative aspects on the total costs per route, resulting in the least economical route.

Demonstrating the effects of road inclination on FC and CO_2-Emissions in road freight transportation, the model also illustrates the relevance of such factors in route optimization efforts. However, as eco-friendly routes result in more costs for companies it remains the question, if companies are more interested in increasing their profits, or to invest in a more sustainable future.
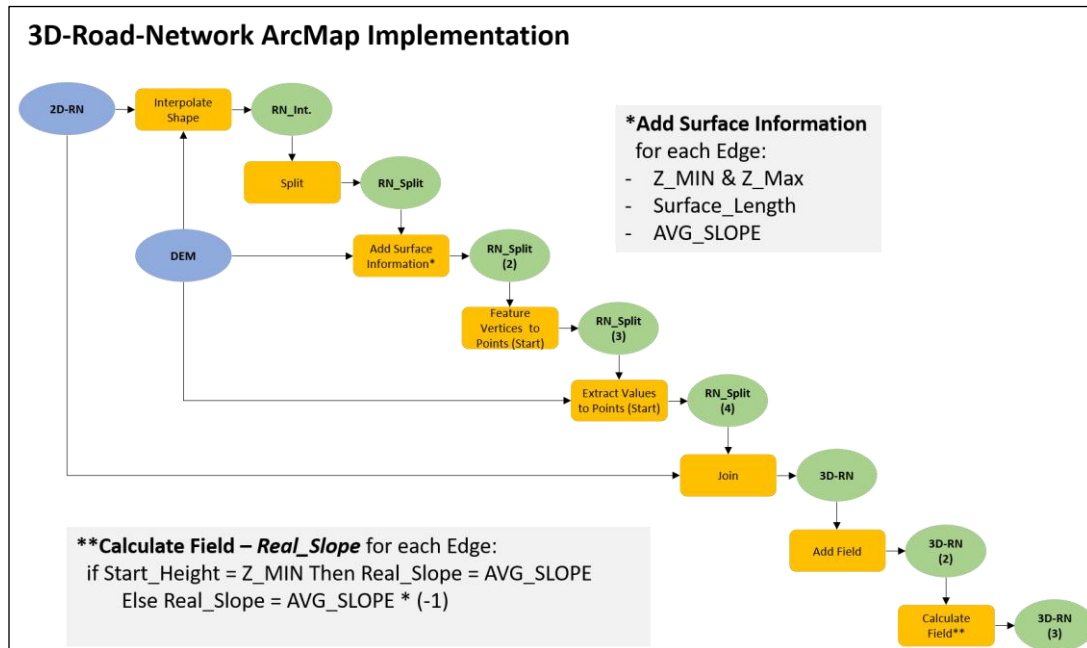
Annex A:

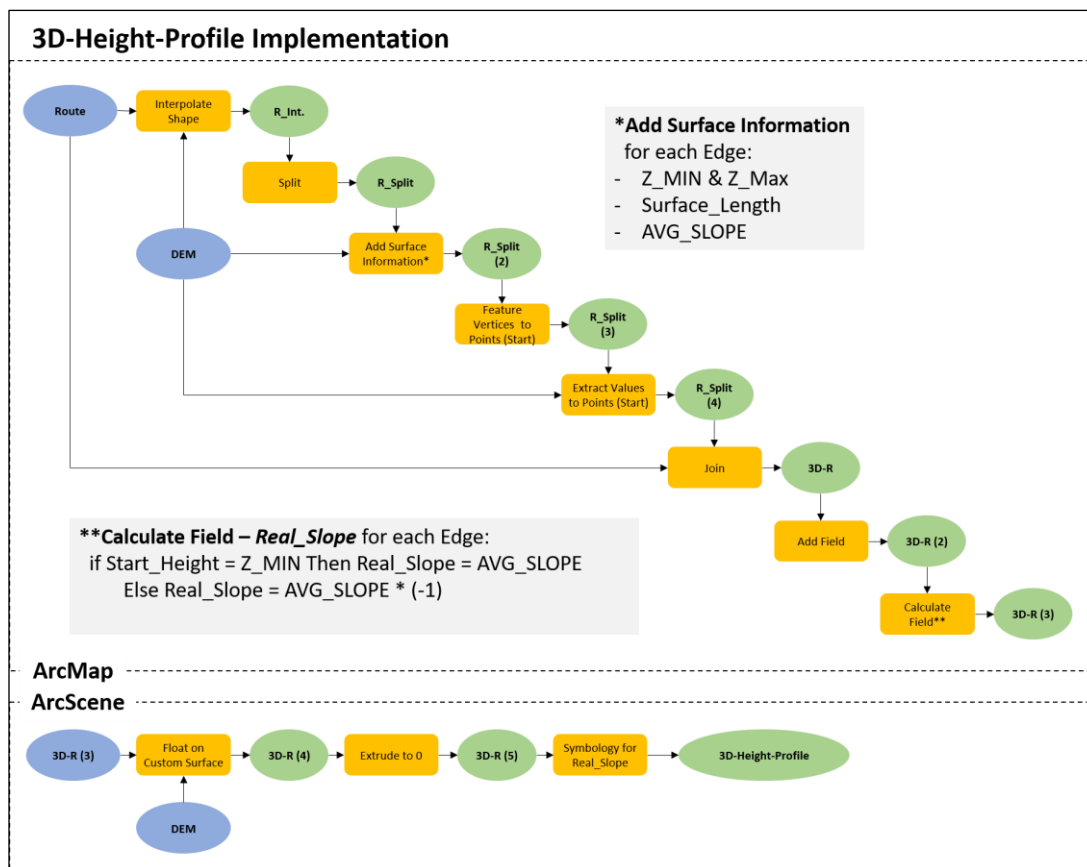*Figure 16: Annex A - 3D-Road-Network Implementation*

Annex B:

Figure 17: Annex B - 3D-Height-Profile Implementation

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