MIT Analytics Lab: Leuven's Sustainable Modal Shift
Final Report

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Executive Summary

This report presents a comprehensive analysis and solution framework for Leuven's ambition to become a climate-neutral city. It focuses on enhancing the urban transportation system and reducing traffic congestion through the implementation of multi-modal mobility hubs. The project employs a mixed-integer multi-objective network flow optimization model to determine optimal locations for these hubs. The model aims to balance CO_2 emissions reduction with travel time efficiency, considering various factors such as willingness to accept higher travel times for lower CO_2 emissions, maximum hubs to be installed, parking availability, and bike-sharing options.

The solutions proposed by the model differ mainly due to variations in two parameters: maximum number of hubs (MH) and the willingness to trade-off travel time and emissions (γ). The different solutions can be explored using an interactive dashboard: [https://mit-akkodis-alab.streamlit.app/.](https://mit-akkodis-alab.streamlit.app/)

To illustrate our main result, consider a baseline where all trips are made solely by car. With a realistically high willingness to accept higher commute times for lower emissions ($\gamma = 0.86$), the model reduces the CO2 emissions by 12% while increasing travel times by 17%. From a more tangible perspective, this means that a typical 30-minute commute would increase by 5 minutes, while the decrease in CO2 emissions is comparable to removing the daily impact of 6300 average car journeys in Leuven. Even assuming a very low trade-off willingness, the model can reduce emissions by 2.59% while leaving travel times practically unchanged (+0.26%). This reduction in CO_2 emissions is equivalent to saving 1050 car trips within the city of Leuven per day.

This report recommends the deployment of 20 strategically located mobility hubs, which will realize the first CO_2-time trade-off outlined above. Additionally, the report advises establishing a bike-sharing network by installing stations at each hub to bolster low-emission travel and expanding parking space near mobility hubs to encourage multi-modal transport. To further promote the adoption of environmentally friendly transport options, the report suggests implementing social engineering techniques, such as travel incentives for travel through mobility hubs or advertising campaigns, aimed at increasing the public's willingness to favor low-emission transportation even at the expense of shorter travel times.

Future efforts to improve the model can be aimed at tailoring each hub to the unique demands of different city areas. Also, expanding data analysis to encompass entire days and varied seasonal travel trends is an avenue for future work. Eventually, enriching the dataset on public transport, parking, and bike docks would provide more accurate insights, allowing for better validation and adjustment of the model's foundational assumptions.

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1 Problem Description

1.1 Objectives of the City of Leuven

Leuven's journey towards a sustainable and climate-neutral future is underpinned by three pivotal sustainability objectives that aim to reshape the city and its infrastructure:

1. **Becoming a Climate-Neutral Municipality:** Leuven is committed to reducing its carbon footprint and becoming a climate-neutral municipality. This aspiration is aligned with global efforts to combat climate change and mitigate its impacts.
2. **Transforming Public Transport:** A key element of Leuven's sustainability goals is to revolutionize the way both residents and visitors interact with the city's public transport system. Leuven seeks to create an integrated and multi-modal public transportation network that encourages the use of sustainable modes of transport reducing the dependency on private cars.
3. **Alleviating Traffic Congestion:** One of the most pressing challenges faced by Leuven is the traffic congestion in its city center, primarily caused by private cars. To address this issue, Leuven is determined to reduce the number of private vehicles clogging the streets.

A significant step towards achieving these sustainability goals is the establishment of multi-modal mobility hubs. These hubs serve as critical pivot points in Leuven's transportation network, facilitating seamless transitions between different modes of transportation, such as buses, trams, and shared bikes. To determine the optimal locations for these hubs, a variety of factors will be considered, including accessibility to various modes of transportation, availability of parking facilities, and existing travel patterns.

1.2 Scope of the Project

The objectives within the project scope are focused and well-defined. The first objective is to provide a clear overview of the available data, which is essential for accurate analysis and informed decision-making. Following this, the project aims to develop an optimization model capable of identifying the most effective network configuration. This model will be designed with the capability to be parameterized, thus enabling differentiated analyses to cater to varying scenarios. Additionally, the development of a user-friendly interface for the model is a key objective, ensuring accessibility and ease of use for individuals with varying levels of technical expertise. It is important to note, however, that certain aspects fall outside the scope of this project. Specifically, the project does not include considerations related to travel costs. Moreover, the communication of the findings and implications of this work to stakeholders from the municipality is not encompassed within the project objectives. This clear demarcation ensures a concentrated and effective approach to achieving the core goals of the project.

2 Data

2.1 Data Provided by the Municipality of Leuven Through the MobiDataLab

For the project, an assortment of data packages was received, each offering valuable insights into different aspects of urban mobility. The Origin-Destination (OD) matrix is the most crucial component, measuring transportation demand **by car** across several key times (7AM-8AM and 4PM-5PM) during the day, which helps in understanding traffic flow and peak travel periods. For this purpose, the municipality of Leuven is divided into 240 zones. The OD matrix shows the transportation demand between two given zones.

Additionally, parking data was obtained that provides comprehensive details on the location and availability of parking spots within the city. The data packages also include information on the cycling and public transportation networks, specifically highlighting the cycling paths, which are instrumental in assessing and enhancing non-motorized transport infrastructure. Furthermore, the socio-economic and demographic data for various city zones offer a deeper understanding of the population dynamics and economic factors influencing transportation patterns.

2.2 Complementary Data Sources

Complementary data sources were crucial for enhancing our analysis, particularly through the use of the Navitia API. Navitia is an open-source platform that provides access to a wide range of multi-modal transportation data. We obtained detailed data on travel times and CO_2 emissions for different modes of transportation within the city of Leuven. For bicycle travel, data was collected for routes from zones to hub candidates and vice versa. In the case of public transportation, similar data was gathered, covering the travel between zones and hub candidates in both directions. Additionally, car travel data was extensively collected, encompassing both zone-to-zone and zone-to-hub travel times and emissions. This information is pivotal in determining whether cars have a significant time advantage over sustainable modes of transport so that it is worth it to trade-off higher CO2 emissions for lower travel times.

3 Methodology

3.1 Overview

The methodology adopted in this project is designed to select the most effective mobility hubs within the urban network out of a set of candidates. Thus, the process begins with the systematic identification of potential candidates for optimal mobility hubs, utilizing a strategic selection criterion that ensures comprehensive coverage and accessibility (see following section). Subsequently, a subset of these candidates is activated through a mixed-integer multi-objective network flow optimization model, which balances the conflicting objectives of reducing CO_2 emissions and travel time providing a nuanced analysis of the network's dynamics. The model takes into consideration a variety of parameters (e.g., maximum number of hubs, availability of parking spots/shared bikes, willingness to trade-off CO_2 emissions and travel time) to identify the most efficacious locations. The evaluation phase involves simulating different choices of input parameters and comparing the output against a baseline scenario which assumes that all journeys in the OD matrix are made exclusively via car.

3.2 Selection of Candidate Hubs

The process for selecting potential candidates for mobility hubs focuses on optimizing the integration between parking availability and public transportation access. The selection criteria are precise: (1) candidates are chosen based on the proximity of parking spots to bus stops, ensuring seamless transitions for commuters. (2) Hub candidates are places so that the total distance from city zone centroids to the respective parking areas is minimized, thereby enhancing the overall efficiency of the transport network. The distance measure used is the squared Euclidean distance adjusted for the curvature of the Earth. In total, 103 candidate hubs were identified.

3.3 Optimization Model

3.3.1 Definitions

The model uses the following **indices** to differentiate between origin/destination zones and hubs.

$$
\begin{aligned}
&i : \text{set of origin zones with } i = 1, \ldots, Z \\
&j : \text{set of destination zones with } j = 1, \ldots, Z \\
&k : \text{set of hubs with } k = 1, \ldots, K
\end{aligned}
$$

The **primary decision variable** indicates whether a candidate hub is activated or not.

$$
\alpha_k : \text{indicator if hub } k \text{ is activated} \begin{cases} 1, & \text{if hub } k \text{ is activated} \\ 0, & \text{otherwise} \end{cases}
$$

Next to the primary decision variable, some **secondary decision variables** were used to model the flow on different routes using different modes of transport. Also, total CO_2 emissions and total travel time are modeled as secondary decision variables.

CD_{ij} : flow from origin zone i to destination zone j by **car (direct)**

CH_{ikj} : flow from origin zone i to hub k with destination zone j by **car**

PH_{ikj} : flow from origin zone i to hub k with destination zone j by **public transport**

BH_{ikj} : flow from origin zone i to hub k with destination zone j by **bike**

PZ_{ikj} : flow from hub k to destination zone j with origin zone i by **public transport**

BZ_{ikj} : flow from hub k to destination zone j with origin zone i by **bike**

E_{Total} : total CO2 emissions

T_{Total} : total travel time

The various data sources listed before provide the model with the following **input variables**.

d_{ij} : transportation demand from other zones to destination zone j

$E_{ij(Car)}$: CO2 emissions for journeys from origin zone i to destination zone j by **car**

$E_{ik(Car)}$: CO2 emissions for journeys from origin zone i to hub k by **car**

$E_{ik(Public)}$: CO2 emissions for journeys from origin zone i to hub k by **public transport**

$E_{kj(Public)}$: CO2 emissions for journeys from hub k to destination zone j by **public transport**

B_k : number of people who can get a shared bike at hub k throughout the day

P_k : number of people who can get a parking spot at hub k throughout the day

$CN_{ik(BH)}$: connections (binary) between origin zone i and hub k by **bike**

$CN_{kj(BZ)}$: connections (binary) between hub k and destination zone j by **bike**

$CN_{ik(PH)}$: connections (binary) between origin zone i and hub k by **public transport**

$CN_{kj(PZ)}$: connections (binary) between hub k and destination zone j by **public transport**

$T_{ij(Car)}$: time from origin zone i to destination zone j by **car**

$T_{ik(Car)}$: time from origin zone i to hub k by **car**

$T_{ik(Bike)}$: time from origin zone i to hub k by **bike**

$T_{kj(Bike)}$: time from hub k to destination zone j by **bike**

$T_{ik(Public)}$: time from origin zone i to hub k by **public transport**

$T_{kj(Public)}$: time from hub k to destination zone j by **public transport**

A couple of **parameters** enable users to run nuanced analyses with the model.

M : maximum flow on one given connection

MH : maximum number of hubs the model can activate

γ : parameter capturing the tradeoff between emissions and total travel time

3.3.2 Model Formulation

$$
\begin{aligned}
\min_{a_k} \quad & E_{Total} + \gamma T_{Total} \\
\text{where} \quad & E_{Total} = \sum_{i=1}^{Z}\sum_{j=1}^{Z} CD_{ij}E_{ij(Car)} + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} CH_{ikj}E_{ik(Car)} + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} PH_{ikj}E_{ik(Public)} \\
& + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} PZ_{ikj}E_{kj(Public)} \\
& T_{Total} = \sum_{i=1}^{Z}\sum_{j=1}^{Z} CD_{ij}T_{ij(Car)} + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} CH_{ikj}T_{ik(Car)} + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} BH_{ikj}T_{ik(Bike)} \\
& + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} BZ_{ikj}T_{kj(Bike)} + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} PH_{ikj}T_{ik(Public)} + \sum_{i=1}^{Z}\sum_{k=1}^{K}\sum_{j=1}^{Z} PZ_{ikj}T_{kj(Public)} \\
\text{s.t.} \quad & CH_{ikj} + BH_{ikj} + PH_{ikj} = BZ_{ikj} + PZ_{ikj} && \forall i,j \in [Z], \forall k \in [K] \\
& CD_{ij} + \sum_{k=1}^{K}(CH_{ikj} + BH_{ikj} + PH_{ikj}) = d_{ij} && \forall i,j \in [Z] \\
& BH_{ikj} \le M * CN_{ik(BH)} * \alpha_k && \forall i,j \in [Z], \forall k \in [K] \\
& PH_{ikj} \le M * CN_{ik(PH)} * \alpha_k && \forall i,j \in [Z], \forall k \in [K] \\
& PZ_{ikj} \le M * CN_{ij(PZ)} * \alpha_k && \forall i,j \in [Z], \forall k \in [K] \\
& BZ_{ikj} \le M * CN_{ij(BZ)} * \alpha_k && \forall i,j \in [Z], \forall k \in [K] \\
& CH_{ikj} \le M * \alpha_k && \forall i,j \in [Z], \forall k \in [K] \\
& \sum_{i=1}^{Z}\sum_{j=1}^{Z} BZ_{ikj} \le B_k && \forall k \in [K] \\
& \sum_{i=1}^{Z}\sum_{j=1}^{Z} PZ_{ikj} \le P_k && \forall k \in [K] \\
& \sum_{k=1}^{K} \alpha_k \le MH \\
& \alpha_k \in \{0,1\} && \forall k \in [K] \\
& CD_{ij}, CH_{ikj}, PH_{ikj}, BH_{ikj}, PZ_{ikj}, BZ_{ikj}, E_{Total}, T_{Total} \ge 0 && \forall i,j \in [Z], \forall k \in [K]
\end{aligned}
$$

3.3.3 Explanation of Objective and Constraints

The main decision made by the model presented above is which of the *K* candidate hubs to activate. Based on the resulting transportation flows, it minimizes both the total CO_2 emissions and total travel time. The **objective function** assumes that **total CO_2 emissions** result from four journey types: (1) direct car, (2) zone-to-hub by car, (3) zone-to-hub by public transport, and (4) hub-to-zone by public transport. In a similar manner, **total travel time** consists of the same four journey types plus zone-to-hub and hub-to-zone journeys by bike. The preference trade-off between lower CO_2 emissions and higher travel times is captured by the parameter γ which was estimated from the input data. The objective function is subject to constraints which are described below.

The **first constraint** ensures that there is a **balanced flow** at every hub. More specifically, a person who arrives at hub *k* from origin zone i by car, bike or public transport and wants to travel to destination zone j, needs to leave the hub to destination zone j by public transport or bike.

The **second constraint** mandates that the **transportation demand** of people wanting to travel from origin zone i to destination zone j must be met exactly. For every origin-destination pair (i,j), the demand is satisfied through direct car transport and the sum of hub transport options.

The **constraints three to seven** are big-M constraints which define the **capacity of a given transportation route**. If the hub included in the route is not activated, the capacity will be forced to be zero. If the respective hub is activated and the given connection matrix deems the connection as "feasible" (i.e., not overly time consuming), the route capacity is essentially unconstrained. This is the case as M is a sufficiently large parameter.

The **eighth and ninth constraints** consider the **availability of shared bikes and parking spots at hubs**. For travelers to changeover to a shared bike, there must be available bikes at the respective hub. Thus, the number of arriving travelers at hub *k* who changeover to a bike throughout the day must be smaller or equal to the capacity of the hub throughout the day. The same is true for travelers who arrive by car at hub *k* and need a free parking spot.

The **tenth constraint** mandates that the **number of activated hubs** may not exceed the prespecified maximum number of hubs (representing the investment budget). The **eleventh constraint** forces the **primary decision variable to be binary** while the **last constraint** ensures that all **secondary decision variables are non-negative quantities**.

4 Results

4.1 Optimization Results

The optimization results are mainly driven by two parameters, the maximal number of hubs to be installed (MH) and the trade-off between CO_2 emissions and travel time (γ). For the MH-parameter, we considered the values 10, 15, 20, and 25 to reflect different values of investment by the municipality. For the trade-off parameter γ, we used the values 0.86, 1.71, and 2.57 which characterize the different levels of accepting higher travel times for lower CO_2 emissions.

γ = 2.57: **low** willingness to accept higher travel times for lower CO_2 emissions

γ = 1.71: **moderately low** willingness to accept higher travel times for lower CO_2 emissions

γ = 0.86: **realistically high** willingness to accept higher travel times for lower CO_2 emissions

Different values for γ were obtained by using the data at hand and by consulting literature on the willingness to tradeoff CO2 and travel time. Further information on our approach can be found in the appendix section 7.2.

As an overall result, a reduction in emissions always comes with an increase in travel time in our model. The following two graphics detail how different values of MH and γ influence the reduction of emissions and increase of travel time.

The first graphic (Figure 1) shows three plots, one for each value of γ. The y-axis shows the four parameter values for MH. The red bars stand for the reduction in emissions against the baseline whereas the grey bars show the corresponding increase in travel times against the baseline. One can see that the emission reduction varies between 7.5% and 12.0% in the realistic scenario. The corresponding time increases lie between 11.3% and 17.2%. Even when considering more conservative scenarios, the model can still achieve a reduction in emissions which lies between 1.9% and 5.4%. The corresponding travel time increases are between 0.3% and 2.8%.

The second graphic (Figure 2) shows a more nuanced view of the same numbers as it also includes the absolute CO_2 values (in grams) and the corresponding travel times (in seconds). The reductions/increases against the baseline are shown as black percentages above the respective data point. One can also find the baseline value represented as a dotted line in the graphics.

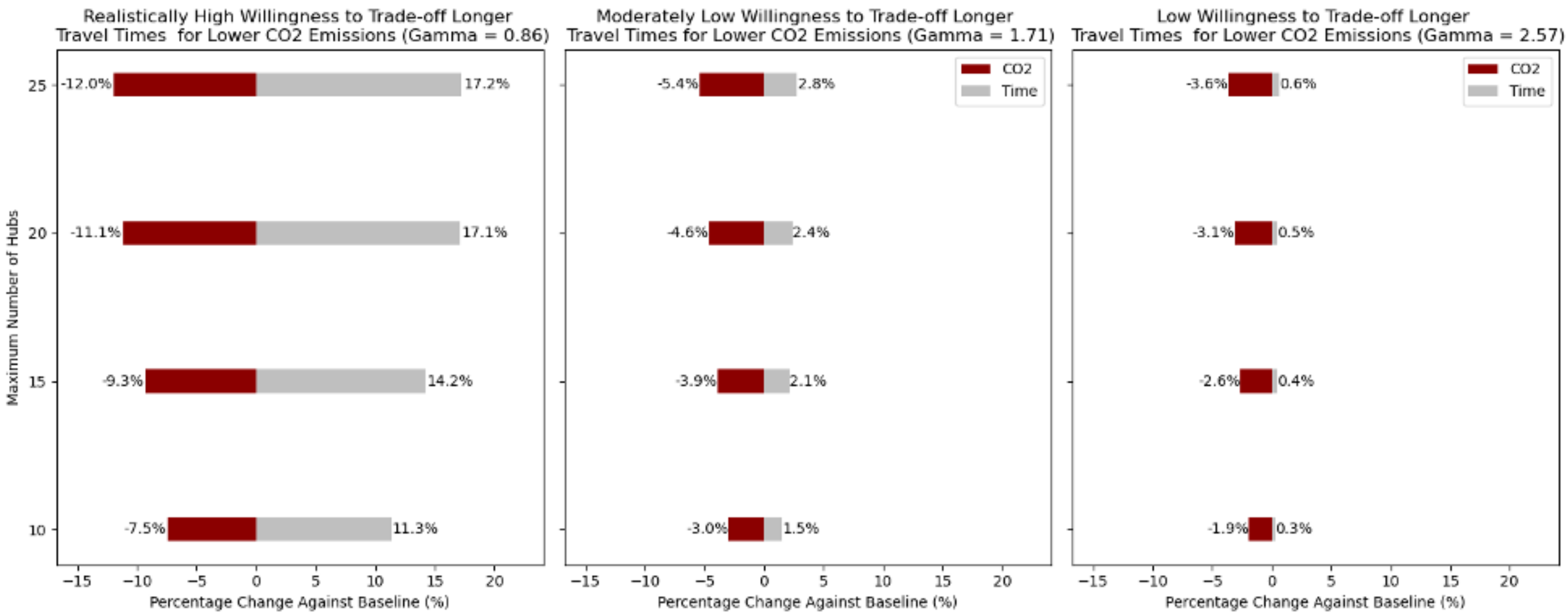

Figure 1 - C02 decreases and travel time increases depending on the number of hubs and trade-off parameter

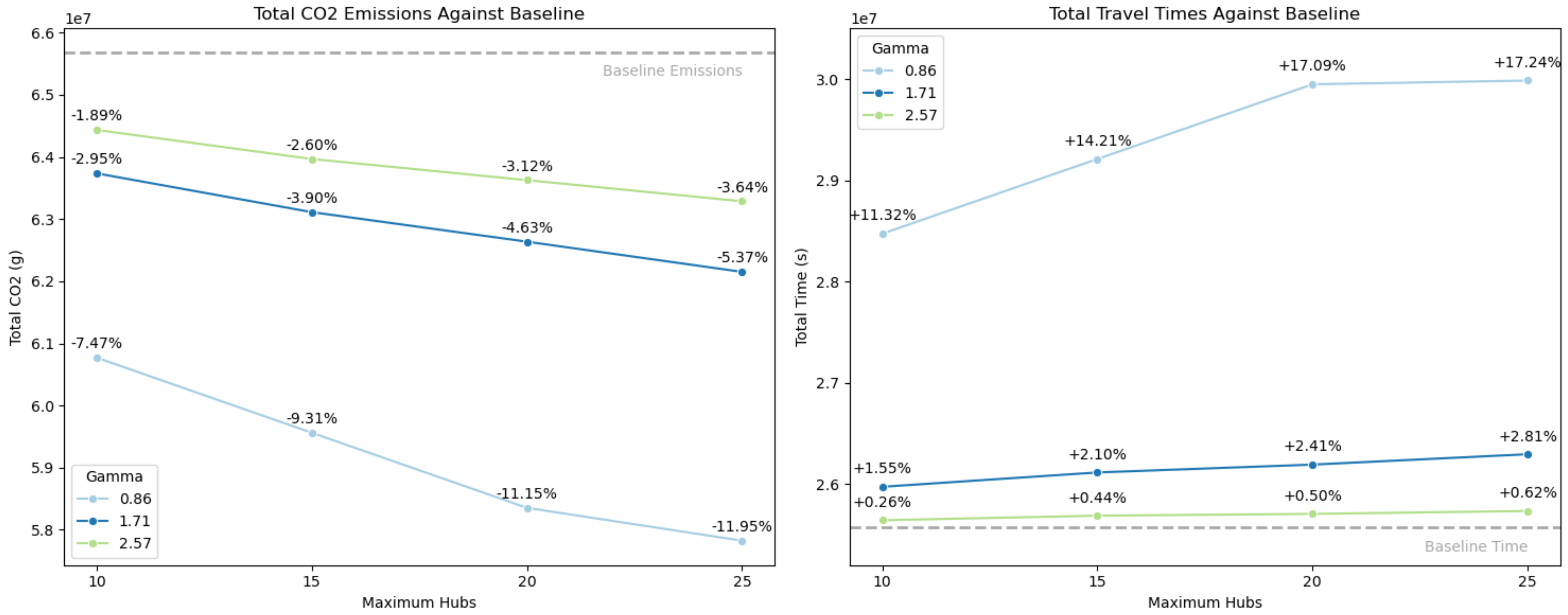

Figure 2 - Model results against the baseline

4.2 Presentation of Results in an Interactive Dashboard

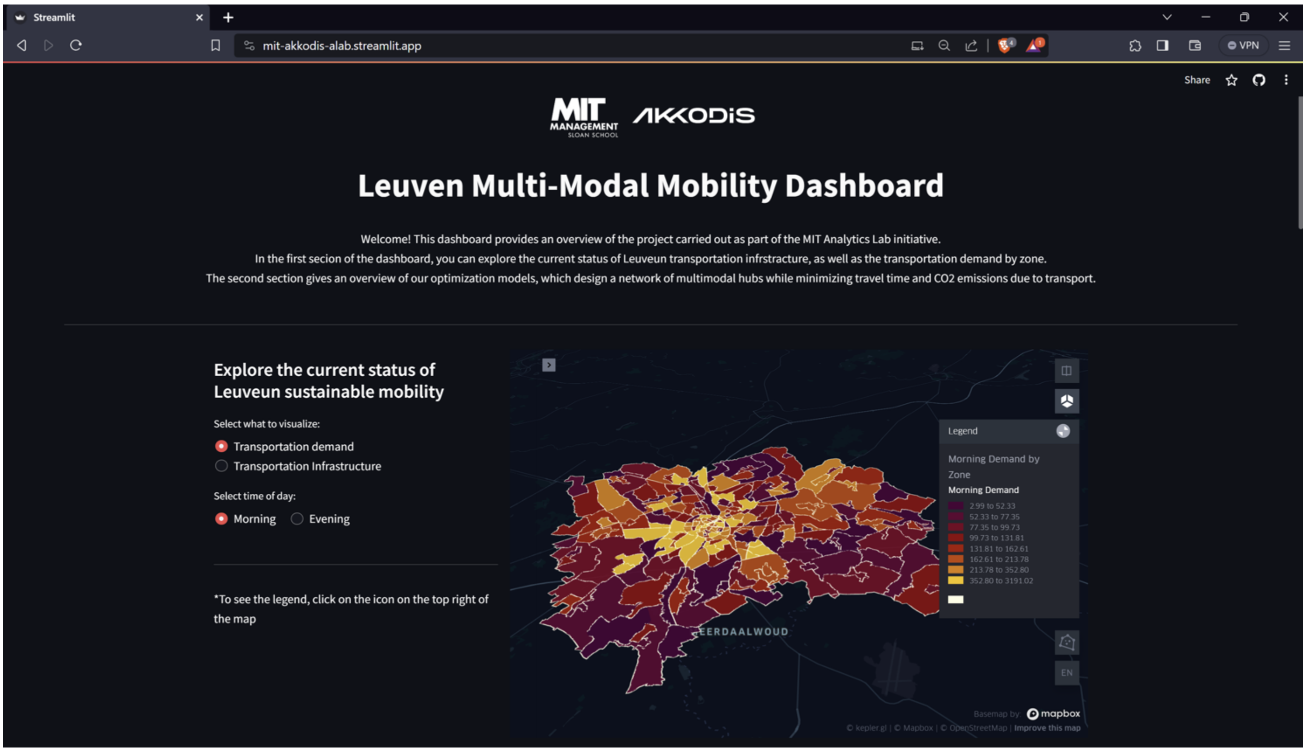

Figure 3 - Screenshot of the top of the dashboard

Our team has developed an interactive, web-based dashboard tailored for both technical and non-technical users, enhancing engagement with our model.

The dashboard's initial section presents a comprehensive overview of Leuven's multi-modal transportation infrastructure. This includes a detailed display of parking spaces, bike and bus networks, current multi-modal hubs, and the transportation demand across different zones.

A central feature of the dashboard is its dynamic model output analysis section. Here, users have the flexibility to tailor their views by adjusting critical parameters, specifically the "number of hubs" and the "willingness to trade-off CO2 emissions for travel time". This functionality enables users to simulate different scenarios, observing how different configurations impact KPIs and the selection of optimal hubs. This level of interactivity fosters a deeper understanding of our model and aids in data-driven decision-making.

Additionally, a detailed map illustrates all transit flows and established hubs. Interactive elements like tooltips and filters enable users to focus on specific data segments, delving into traffic flow patterns and transportation modalities used. Alongside, a detailed guide aids in navigating this complex data landscape. Further, the dashboard offers an in-depth examination of individual selected hubs. Users can access a detailed list of these hubs, including their location and addresses.

Selecting a hub from this list opens a secondary map, providing insights into the traffic type and volume specific to that hub.

The application was developed from scratch, leveraging Streamlit for its development and hosting, coupled with Amazon Web Services for efficient data storage and extraction. One of the primary benefits of this web-based platform is its ease of sharing. Being accessible with a simple hyperlink, it can be quickly accessed from everywhere, fostering collaboration and broadening its reach.

The dashboard is available at: https://mit-akkodis-alab.streamlit.app/

5 Discussion of Results

5.1 Managerial Implications and Recommendations

Pursuant to the analysis of the impact of the activation of mobility hubs at various locations in the city of Leuven, and assuming a realistically high willingness to sacrifice travel time for a decrease in emissions, we recommend as follows:

Deploying 20 mobility hubs in the prescribed locations to achieve an 11.1% reduction in CO2 emissions and a 17.1% increase in total travel time.
A significant consideration in deciding the number of mobility hubs to install in the city of Leuven is the resources available to update existing hubs and construct new ones. In absence of budgetary constraints and estimated costs of construction, we provide recommendations on the optimal locations for the mobility hubs under different scenarios, depending on the number of deployments the municipality of Leuven is able to sustain.

Establishing a bike sharing network, with bike docks stationed at every hub
Bike travel is the lowest-emission method of transport, and increasing the supply of bikes through a bike-sharing scheme on top of the existing cycling network will extend the capacity of low emission transport.

Extending parking space near mobility hubs
Increased parking availability around mobility hubs will facilitate the transition between different modes of transport, thus reducing the portion of a trip that is conducted via car. The model assumes that the current parking capacity is limited, thus restricting the number of modal shifts that can be executed at each hub; an extension in the number of spots available would alleviate some of these constraints, leading to a decrease in emissions.

Implementing social engineering techniques to increase willingness to encourage the use of low-emission modes of transportation

Our results show that a higher level of willingness to trade off short travel time cleaner modes of transport, denoted by the hyperparameter γ leads to a greater decrease in carbon emissions. Campaigns such as reduced cost of travel via mobility hubs and other incentives are important towards ensuring the citizens' propensity to prioritize environmental consciousness over travel time is attained.

5.2 Limitations

The modes of public transport under review are not comprehensive
Given data limitations, the model only considers travel by car, public transport, and bike, while other means of transportation (e.g., shared cars, shared scooters, taxi, ride-hailing apps) are not factored into the recommendations.

Intermodal transfer time is not taken into account
The model is unable to account for the time it takes to switch between modes of transport due to logistical reasons, such as finding parking, waiting for a bus, retrieving, and parking a bike. As travel time is one of the two objectives the model optimizes over, these hidden delays could have a significant aggregate effect on total travel time, which could produce different recommendations.

The model does not propose any adjustments to the public transport network
The model aims to build on top of the existing public transport network, but no analysis of its efficacy is performed when optimizing the mobility hubs' location.

The cost of travel is not considered
The model assumes that the average citizen of Leuven aims to optimize over two objectives: reducing emissions and travel time; however, the cost of travel is equally important when making decisions. Due to unavailability of data, the costs could not be taken into account at this time.

Capacity constraints on public transport and bikes are estimated
Due to unavailability of data on factors such as the capacity of public transport and availability of space for additional bike docks, the model makes flat assumptions on these quantities across the network, which may not necessarily be realistic considering that all areas of Leuven are not uniform in their makeup.

5.3 Avenues for Future Work

Providing more granularity on the size and parameters of each of the hubs
Given that different areas in Leuven have diverse needs in terms of capacity, the model could be extended to make more granular recommendations on the specific number of parking spaces and bike docks that need to be installed at each location to optimize the use of resources, as opposed to constructing uniform hubs throughout the city.

Considering a wide range of timeslots

Currently, our data captures 4 hour-long timeslots of movement throughout the day. To perfectly optimize the location of the hubs to accurately serve the people of Leuven, the model could be extended to build upon travel data measured throughout the full day, at different points in the calendar year.

Gathering more data to validate or adjust our core assumptions

Due to limited data, our model is based on assumptions on the capacity of public transport, parking spaces and bike docks. In efforts to estimate the behavior of the citizens of Leuven more realistically, it would be reasonable to consider enriching our data set to include more granularity on these factors.

6 Literature

Andersson, H., Ahonen-Jonnarth, U., Holmgren, M., Marsh, J., Wallhagen, M., & Bökman, F. (2021). *What Influences People's Tradeoff Decisions Between CO2 Emissions and Travel Time? An Experiment With Anchors and Normative Messages.* Retrieved November 22, 2023, from Frontiers in psychology: https://doi.org/10.3389/fpsyg.2021.702398

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Blad, K., Homem de Almeida Correia, G., van Nes, R., & Annema, J. (September 2022). A methodology to determine suitable locations for regional shared mobility hubs. *Case Studies on Transport Policy, 10*(3), S. 1904-1916. Von Case Studies on Transport Policy. abgerufen

7 Appendix

7.1 Assumptions

Below is a list of assumptions which are made by the model.

1. Bike travel does not emit CO_2.
2. Citizens of Leuven only take a bike if the ride would take 30 minutes or less.
3. Public transport is practically not limited in its capacity or could be managed accordingly by public transport authorities.
4. Citizens of Leuven only take public transport if the ride would take 60 minutes or less.
5. Due to parking spot availability constraints at hub k, the parking spot availability is limited proportional to the available parking spots at hub k.
6. Due to shared bike availability at hub k, at most 70 people per day can changeover to a shared bike at hub k throughout the day.
7. Existing mobility hubs do not fall under our definition of a mobility hub as they do not have a bike station. However, they are considered as candidates in the model.

7.2 Estimation of the Trade-off Parameter Gamma

In the model, the trade-off parameter gamma answers the following question: *"If travel time increases by one unit due to different transport mode choices, how much do the CO_2 emissions need to decrease to even out the effect of higher travel times?"*

$$\gamma = \frac{CO_2\ emissions}{Travel\ time}$$

Therefore, it reflects how important people consider travel times in relation to CO_2 emissions. As estimating this parameter is crucial, we employed different approaches to do so.

7.2.1 Upper Bound for Gamma: Estimation from OD-Matrix Data

Estimating the parameter from the OD-matrix provides an upper bound as the OD-matrix only reflects the trade-off preferences of people who have chosen to go by car. The estimate assumes that the people considered in the OD-matrix would even choose their car even if they were presented with alternatives. Naturally, gamma will be comparatively high since short travel times come with high CO2 emissions in the case of car travel. The data from the OD-matrix provides us with the following gamma parameter.

$$\gamma_{OD} = \frac{\sum \mathrm{CO_2\ emissions}}{\sum \mathrm{travel\ times}} = \frac{65{,}676{,}025.34\ g}{25{,}576{,}671.20\ s} \approx 2.57$$

7.2.2 Realistic Gamma: Estimation from Literature

For a more complete picture, we also consulted academic papers on the topic. In particular, we found the UK study *"What Influences People's Tradeoff Decisions Between CO_2 Emissions and Travel Time? An Experiment With Anchors and Normative Messages"* (Andersson, et al., 2021) very helpful. The study confronts participants with the following situation:

Assume that you have rented a petrol car to journey from Brighton to Manchester. The drive is estimated to take 5 hours and emit 61 kg of carbon dioxide (CO2). [potential anchors and/or normative messages] How much time would you be willing to let the journey take, at most, to reduce the emissions from 61 kg of CO2 to 20 kg CO2? Answer in hours and minutes.

The outcomes of the question depending on the environmental concernedness level of the respondents and the anchoring they received, is shown in the graphic below.

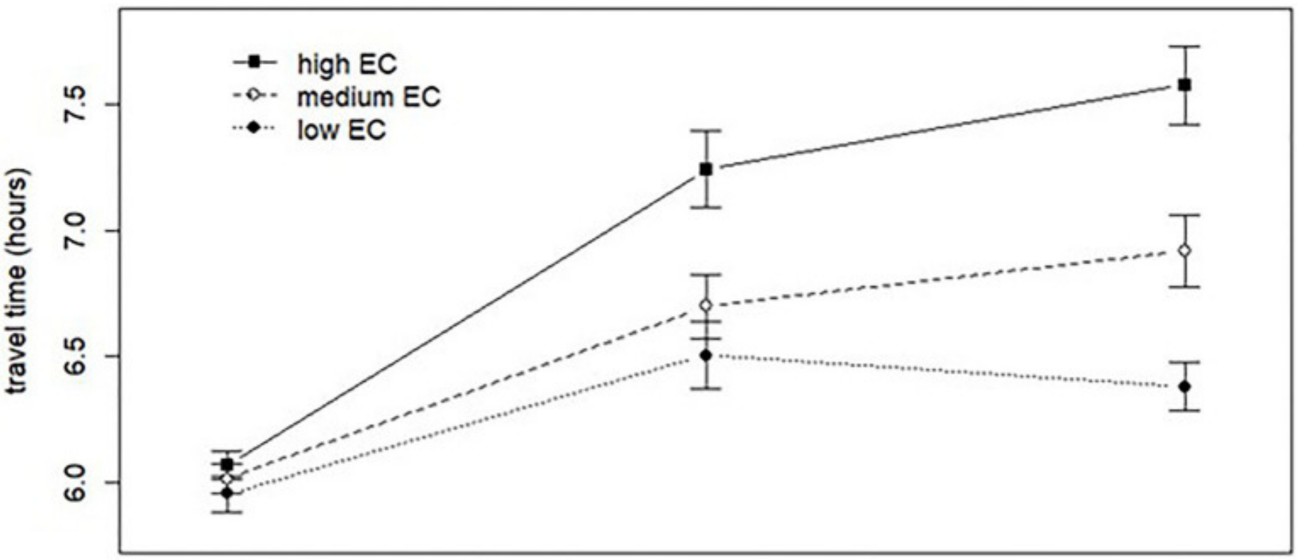

Figure 4 - Responses depending on anchor and environmental concern of respondents (Andersson, et al., 2021)

When adjusting the units from kg to g and from hours to seconds, one yields the following values for the mean travel time (in seconds) and trade-off parameter gamma.

ENVIRONMENTAL CONCERN	LOW ANCHOR	NO ANCHOR	HIGH ANCHOR	AVERAGE
HIGH	21,960	25,920	27,000	24,960
MEDIUM	21,600	23,760	24,480	23,280
LOW	21,240	23,040	22,680	22,320

ENVIRONMENTAL CONCERN	LOW ANCHOR	NO ANCHOR	HIGH ANCHOR	AVERAGE
HIGH	0.91	0.77	0.74	0.81
MEDIUM	0.93	0.84	0.82	0.86
LOW	0.94	0.87	0.88	0.90

The overall value average for gamma is equal to 0.86. Given that the study considers medium-distance travel in the UK and not commuting in the UK, we will use this value as a realistic value for gamma. As a third point, we will also consider the midpoint between this and the upper bound which is 1.71 in this case.