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OPTI-UP

# OPTI-UP

## D.1.2.1 Comprehensive Report of Transport Models and Modelling Actions in the Project Area

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# Abbreviations

| | |
|---|---|
| BRT | Bus Rapid Transit |
| CATS | Chicago Area Transportation Study |
| CLD | Causal Loop Diagram |
| DRT | Demand-responsive transport |
| GIS | Geographic Information System |
| GTFS | General Transit Feed Specification |
| GUI | Graphical User Interface |
| LUTI | Land-use transport interaction |
| MARS | Metropolitan Activity Relocation Simulator |
| KPI | Key performance indicator |
| OD | Origin-destination |
| PP | Project partner |
| PT | Public transport |
| SD | System Dynamics |
| SUMP | Sustainable urban mobility plan |

# Executive Summary

Despite its demonstrated value, transport modelling remains underutilized and unevenly adopted across many small- and medium-sized cities in Central Europe. High implementation costs, limited awareness, and a shortage of local expertise continue to pose major barriers. Even in cities with prior experience, the depth of integration into planning and policy-making processes remains ad-hoc, particularly when it comes to selecting appropriate model types and applying them effectively to support strategic decision-making.

The OPTI-UP project's second activity (A1.2) aims to introduce and promote the use of transport models among six participating territorial partners. The primary focus is on the proven and established transport models, particularly the widely adopted four-step model. Where appropriate, the more advanced Land-Use and Transport Interaction (LUTI) models are also introduced. While less commonly used, LUTI models offer valuable insights into long-term policy impacts by capturing the feedback loops between land use patterns and transport behaviours.

This report documents the key activities and findings of A1.2 and is outlined below.

- **Section 1** outlines the objectives and scope of the activity.
- **Section 2** presents an overview of modelling frameworks, including various model types and selection criteria relevant to transport and public transport (PT) planning.
- **Section 3** details the selected modelling methodologies and tools: the four-step models with PTV VISUM, simplified transit assignment using PTV Lines, and the LUTI model MARS. The capabilities and limitations of each methodology and tool are also described in this part.
- **Section 4** provides a status review and gap analysis of the current modelling practices across the six case study areas, along with efforts to improve data readiness.
- **Section 5** presents the implementation progress and results for the base scenario analysis. This includes four-step transport models developed for five case study cities, a simplified PT model implemented for one city, and LUTI models adopted in three cities with adequate scale and data.
- **Section 6** In addition to model development, capacity-building activities are conducted, including two webinars on modelling principles and the creation of a self-assessment checklist for engagement tracking for A1.2 and upcoming activities.
- **Section 7** concludes with key recommendations and future directions.

The outcomes of A1.2 provide a solid foundation for cities to integrate transport modelling into their local planning. The activity delivers a structured analysis of current capacities, identifies practical pathways forward, and produces runnable, calibrated models that will support more tailored local plans (A1.3) and pilot actions (A2.1). The methodology and insights are also transferable to other cities and stakeholders interested in adopting similar approaches.

Looking ahead, the cities involved are equipped with tailored, runnable models and more importantly, with the strategic insights to apply them effectively. The next phase should

capitalize on this momentum: actively integrating modelling outputs into real-world planning decisions, using scenario analysis to guide policy, and continuously refining models based on new data and stakeholder feedback. Case study cities will be assisted to engage in cross-learning, benchmarking their progress against one another, and to establish modelling as a core element of evidence-based urban transit strategies. By doing so, these cities and others following this example can move from experimentation to long-term institutionalization of modelling practices, creating more resilient, adaptive, and future-ready transport systems.

# 1 Introduction

## 1.1 Context and Relevance

Transport models provide scientific evidence on the projected impact of policy interventions on key performance indicators (KPIs). However, their full potential is often underutilized by urban planners and public transport (PT) operators due to high costs and lengthy development timelines. In response to the many challenges faced by small and medium-sized cities in Central Europe regarding PT planning and usage, the OPTI-UP project aims to harness data analytics and modelling techniques to design more efficient and sustainable PT systems.

Work Package 1 (WP1) comprises three key activities focused on theoretical foundations and modelling. The three enclosed activities are summarised below and illustrated in Figure 1.

- Activity 1.1 involves the collection and analysis of foundational data from the case study cities, including their planning processes and the current PT operation status. This data forms the basis for overall case study design and supports the modelling efforts in Activities 1.2 and 1.3. The deliverables of Activity 1.1 can be found on the OPTI-UP website (OPTI-UP, 2025).
- Activity 1.2 (the focus of this report) centres on the review and development of two transport modelling approaches applied to six case study areas. These models are assessed under three thematic policy interventions: PT network optimisation, demand-responsive transport (DRT), and the adoption of alternative fuel vehicles for PT. The modelling work involves two complementary tools: the *four-step-based* **PTV VISUM**, which captures short-term transport dynamics in response to policy changes, simplified public transport model in the PTV Lines, and the *land-use transport interaction (LUTI)-based* **MARS (Metropolitan Activity Relocation Simulator) model,** which analyses the long-term interactions between land use development and transport systems. The primary outcome of Activity 1.2 is the creation of calibrated base scenario models for each case study city, which will serve as a foundation for the scenario-based analyses in Activity 1.3.
- Activity 1.3 will build upon A1.2 (this report) by developing and analysing specific modelling scenarios based on the established base models. These alternative scenarios will not only demonstrate the sensitivity and capability of each model in capturing diverse interventions but also serve as a basis for the pilot strategy actions in WP2.

The results from WP1, including data collection, model development, and scenario results analytics, will directly inform the subsequent phases of the project: WP2 (pilot implementations) and WP3 (development of user-friendly tools).

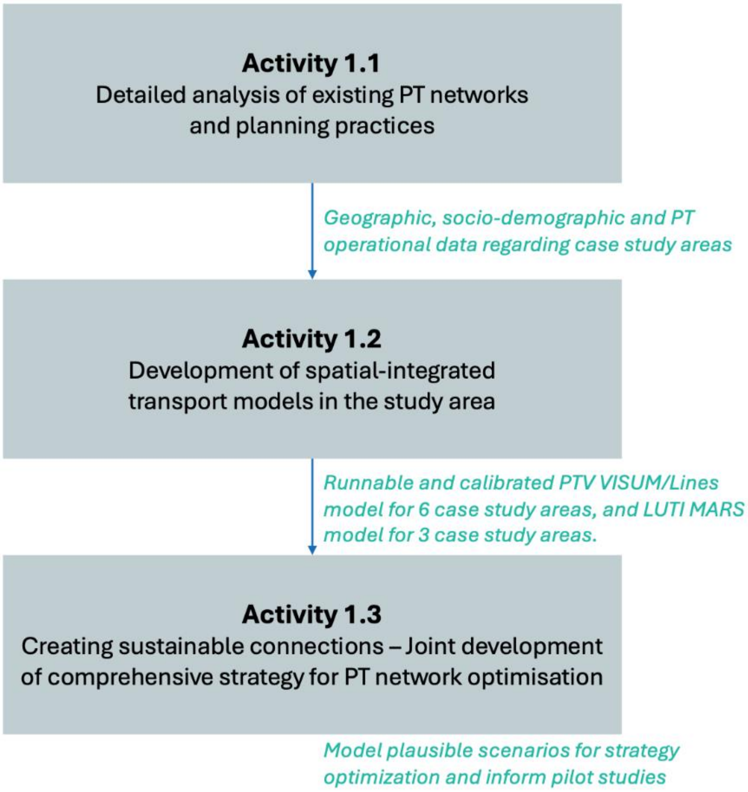



Figure 1. WP1 structure

As already published in the report of Activity 1.1 (OPTI-UP, Oct 2024), the six case study areas in OPTI-UP have diverse geographic, socio-demographic, and transport operational status. In addition, as summarised in Section 1.2 of this report, the six case studies also have diverse levels of familiarity and expertise regarding the use of transport models to support PT planning. The objective of Activity 1.2 is thus to survey the current modelling status among the case study areas, identify gaps of data or model components, and improve the knowledge and capacity for using suitable models for the OPTI-UP project and beyond.

**Activity 1.2 consists of 11 interconnected tasks**, each contributing to the development and refinement of the transport models. A brief overview of these tasks and their relevance to the modelling process is provided below:

1. **Development of joint guidelines and templates for transport modelling engagement.** As the initial step, a spreadsheet-based engagement tool is created to track and document each partner's understanding and involvement in the modelling activities. This tool is filled approximately two to three times during the duration of A1.2 to reflect progress in modelling knowledge across the partnership. This tool will continue to be used in Activity 1.3 and a brief overview of it is given in Section 6.2.
2. **Delivery, familiarization, and preparation of the transport models.** Project partners (PPs) either share their existing PTV VISUM transport models or engage third-party experts to develop or enhance model components. This task involves the evaluation of model readiness and monitoring of development status and is summarised in Section 4.1.

3. **Data gap analysis for an update of the transport models in the pilot areas.** Technical partners review the existing VISUM models to assess their suitability for modelling the planned thematic interventions in each case study area. This includes, for example, evaluating whether the models reflect the most recent PT network and services, and whether they can be adapted for modelling DRT scenarios. In parallel, data requirements for the development of the MARS LUTI model are also identified. The results of this task are summarised in Section 4.2. The insights gained from this analysis directly inform the targeted data collection activities in Task 4.
4. **Collection of new data.** New data are gathered by each project partner, tailored to their respective case study areas and planned thematic interventions. This data collection, together with Task 6, enables the development of LUTI models for three cities, updates to VISUM models in three cities, and the creation of a new PTV Lines model in one city (see Table 1 for details).
5. **Internal seminars for modelling capacity building.** Two webinars focused on the theories and applications of VISUM and MARS are delivered to enhance PPs' understanding of the modelling frameworks. Ongoing support and feedback further strengthen the PPs' technical capabilities. A review of the seminars is provided in Section 6.1.
6. **Importing new data, upgrading and calibrating the transport model.** In cases where existing VISUM models are insufficient to meet the project's needs, PPs perform additional data integration, upgrades, and calibrations to improve model quality and usability. Key facts of the updated models are presented in Section 5.1.
7. **LUTI model formulation.** Although the LUTI model MARS has been applied in various national and regional contexts, this task involves adapting the model to suit the needs of small and medium-sized cities for OPTI-UP, some of which only have limited modes of transport. This step lays the groundwork for LUTI model development in Task 8.
8. **Development LUTI model for 3 project areas.** For three relatively large case study areas, the MARS models are developed and calibrated (see Table 1 for details). Due to its macroscopic and aggregated nature, MARS is better suited for larger regions, while smaller areas may require more detailed, spatially disaggregated approaches. Results of the baseline MARS scenario and calibration steps are given in Sections 5.2 and 5.3.
9. **Upgrade of the database (D.1.1.2) with the four-step and LUTI model data.** Key modelling data, including inputs from both the four-step transport models and the LUTI model, are incorporated into the updated project database alongside city-specific and PT operational data.
10. **Development of comprehensive modelling report.** This task involves compiling and summarising the work undertaken in model development across all pilot areas (the current report). It excludes scenario development, which is the focus of Activity 1.3.
11. **Public events and social media outreach.** Various communication efforts including public lectures, website updates, and social media posts will be carried

out once the report is finalised to disseminate the progress and findings of the modelling work to a broader audience.

## 1.2 Scope and Objectives

In line with the OPTI-UP project's overarching goal of strengthening model familiarity and promoting evidence-based PT planning in small- and medium-sized cities in Central Europe, two types of transport models have been identified as both suitable and valuable for further exploration. These include models that assess the **short-term impacts of policy interventions**, such as PTV VISUM for multimodal transport networks and PTV Lines for PT systems only; as well as models that capture **long-term interactions between urban development and transport systems**, specifically through the use of LUTI models like MARS. An overview of the modelling development status for each case study area is presented in Table 1.

Given that the four-step model represents the state-of-the-art in transport planning involving PT, the initial plan was to either collect or establish PTV VISUM models for all six case study areas. Four PPs already had access to existing VISUM models. In some cases, these models were developed specifically for the study areas (e.g., Modena and Osijek), while in others, they were derived from larger national or regional models (e.g., Grosuplje and Paks). For Český Krumlov, a new VISUM model is commissioned as part of the OPTI-UP project. In contrast, the city of Pécs does not have access to an existing PTV VISUM model. This has further emphasized the misunderstanding of traffic modeling as an important segment in traffic planning, as the existing model of Pécs is no longer operational due to its age and the loss of file structure, a situation that is not uncommon especially in smaller cities. After assessing the technical complexity and maintenance requirements of VISUM or other four-step modeling tool, it is concluded that the tool may not be the most appropriate starting point for the local partner in Pécs. Instead, a more accessible and manageable alternative, PTV Lines, which focuses solely on PT, is proposed as a more suitable modelling approach for Pécs.

Regarding the LUTI model, the MARS model is better suited to larger urban areas due to its aggregated and strategic nature. Accordingly, MARS models are planned for Modena, Osijek, and Pécs, the three largest municipalities among the six case study areas. A detailed overview of the LUTI model and the MARS software will be provided in Section 3. The development of the MARS models relies heavily on data from multiple sources, including VISUM outputs, social demographic information available through the geographic information systems (GIS), and modelling parameters supplied by local partners. Calibration is conducted using recent mobility survey data, particularly the modal split information, to ensure that the models accurately reflect the existing conditions in each city.

Table 1. Model development overview in six case study areas.

| Policy intervention | DRT | | Network optimisation | | Alternative fuel vehicles | |
|---|---|---|---|---|---|---|
| **Cities** | **Modena** | **Grosuplje** | **Osijek** | **Paks** | **Pécs** | **Český Krumlov** |
| **PTV VISUM** | ✓ (updated 2025) | ✓ (updated 2021) | ✓ (updated 2025) | ✓ (2024 model used) | | ✓ (newly developed) |
| **PTV Lines** | | | | | ✓ (newly developed) | |
| **MARS** | ✓ (newly developed) | | ✓ (newly developed) | | ✓ (newly developed) | |

# 2 Overall Framework and Transport Model Review

This section presents the overall methodological framework for Activity A1.2, encompassing both the core modelling tasks and a range of supporting components: including capacity-building efforts, stakeholder engagement, and reporting activities. Additionally, Section 2.2 provides a concise overview of the different types of transport models available, helping to contextualize the OPTI-UP modelling approach within the broader transport modelling landscape.

## 2.1 Overall Framework

The overall framework of OPTI-UP Activity 1.2 is shown in Figure 2. These activities correspond to the 11 tasks introduced in Section 1.1 and can roughly be divided into three types.

(A) Model capacity building

**Capacity building** in the OPTI-UP project focuses on enhancing the understanding of various transport modelling approaches among local municipalities, facilitated through their respective PPs. This is carried out in two main steps:

- Development and distribution of a model engagement guideline: This document outlines monthly milestones, includes a questionnaire using a 0–10 numerical scale to assess each PP's familiarity with modelling theories and implementation, and provides a workbook to record significant modelling activities throughout the project.
- Delivery of two structured webinars: Conducted during the first month of Activity 1.2, these sessions focused respectively on VISUM and MARS models, offering participants a comprehensive overview of the underlying theories and practical applications of each modelling approach.

Further details on the outcomes of these capacity-building activities are provided in Section 6.

(B) Modelling and calibration

**Model development and validation** are the core tasks of both Activity 1.2 and this report. As outlined in Section 1, the OPTI-UP project involves two types of transport models: PTV VISUM/Lines and the LUTI model MARS. The PTV VISUM and Lines models are developed or updated by the PPs and external consultants, with most case study areas already possessing operational VISUM models. In contrast, the MARS models are newly developed for three relatively large cities within the six case study areas through collaboration between the PPs and knowledge providers.

Despite the differences in model type, the development steps for both follow a similar structure:

- Gap Analysis: Building on the existing VISUM models (where available) and the data collected in Activity 1.1, this step focuses on identifying whether sufficient data is available to support model refinement and upgrades in line with the OPTI-UP project goals.

- **Data Collection:** Where necessary, additional data is gathered from census records and various other sources to address gaps identified in the previous step.
- **Modelling Process:** Some models are developed from scratch: for example, the LUTI models for Modena, Osijek and Pécs; the VISUM model for Český Krumlov; and the PTV Lines model for Pécs. Some models are developed by updating existing base models, such as the VISUM model for Modena and Osijek, where additional and updated data from 2024 or 2025 are supplied.
- **Validation:** Model outputs are validated against official data sources, such as mode split statistics from recent mobility surveys, to assess how accurately each model reflects real-world conditions in its base scenario and calibrated according to differences if necessary.

Further details regarding the current model status, modelling activities, and results are given in Sections 3 to 5.

### (C) Reporting and engagement

Since the primary objective of model development in Activity 1.2 is to produce operational models, stakeholder engagement is included but is less frequent than in the scenario development phase of Activity 1.3. The activities in establishing the baseline model are summarised in this report (D.1.2.1). The main format of engagement is to gather supplementary data and validate whether the modelling outputs are reasonable and aligned with local knowledge.

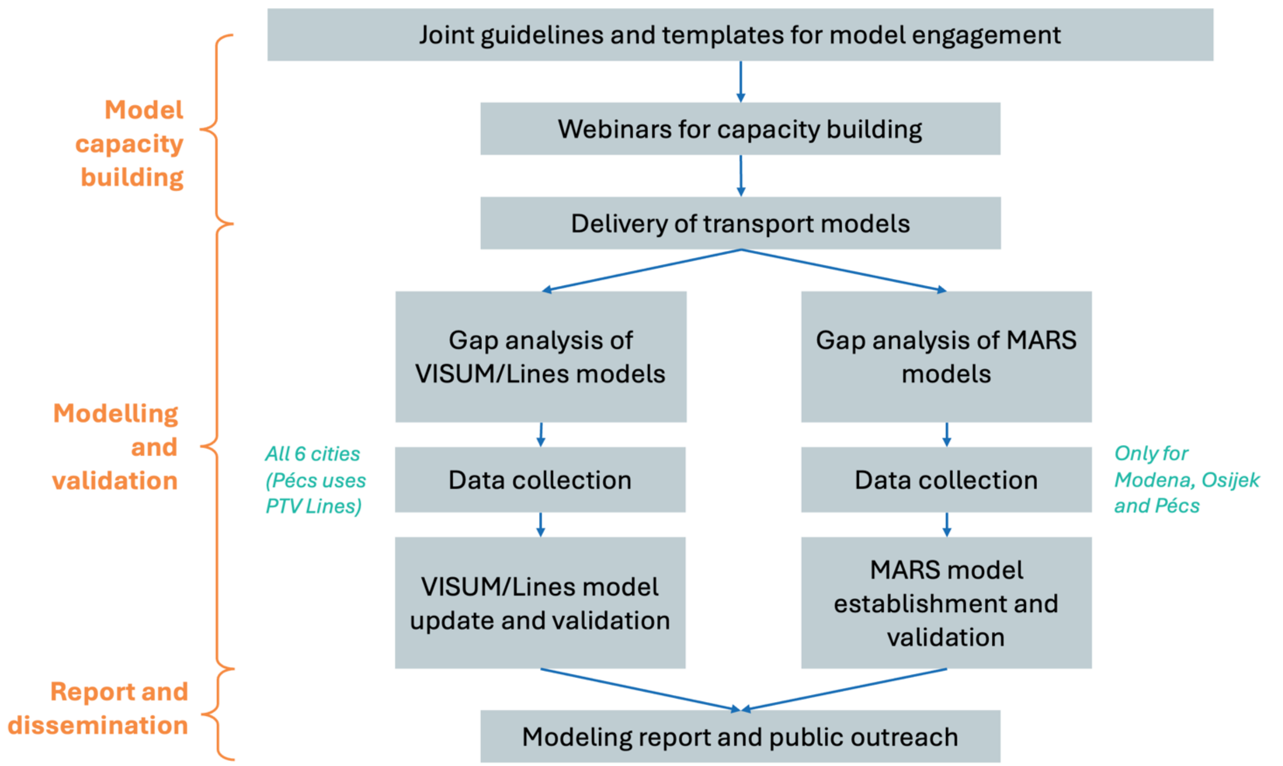



Figure 2. Workflow of Activity 1.2.

## 2.2 Transport models

Over the course of past several decades, various types of transport models have been developed in academia or real-world practices to assist various types of decision making. The Chicago Area Transportation Study (CATS) during the late 1950s and early 1960s is widely regarded as one of the impactful pioneering cases of computer-based modelling, and first comprehensive application of the four-step model approach that is still used today (McNally, 2000). As the planning goals and objectives continue to evolve, transport models, as a decision-support tool, also see a diverse direction of development, through the inclusion of sustainability indicators (Ahn and Rakha, 2013; Zhou et al., 2015; Fontes et al., 2015; Zhao et al., 2024), multi-modal capabilities (Elbery et al., 2018; Balac and Hörl, 2021), and also growth in the level of detailedness to capture the behaviours and responses at a finer spatial, temporal or demographic scales (Horni et al., 2016; Ziemke et al., 2019; Müller et al., 2021).

Due to the high intrusiveness and complexity of conducting real-world transport experiments, modelling is often used as an effective tool to evaluate and compare different policy scenarios before implementing actual changes to the network or operations. The availability of transport models and standardised modelling software significantly enhances evidence-based decision-making in PT planning by providing insights into the potential impacts of proposed policies.

Table 2 outlines different classifications of transport models. Based on spatio-temporal resolution, models can be classified as macroscopic, mesoscopic, or microscopic. In terms of temporal resolution, they can be categorised as static, quasi-/semi-static, or dynamic. Models may also differ by the modes of transport they cover: single-mode models (e.g., car-only or PT-only) versus those designed for multi-modal networks. Additionally, based on the way supply and demand interactions are modelled, there are four-step models, which remain widely used, and increasingly popular activity-based models, which offer greater behavioural realism.

*Table 2. Classification of transport models.*

| Type | Explanation | Application cases or typical software |
|---|---|---|
| ***Based on spatial resolution*** | | |
| Macroscopic model | Treat transport entities (vehicles, cyclists, pedestrians) as aggregated flows across zonal networks. Spatial units are typically large, from city blocks to entire districts. | Used for high-level planning (e.g., new infrastructure, service changes), with congestion estimated via volume-to-capacity ratios. Common tools include **AIMSUN Next, PTV VISUM, EMME, CUBE, SATURN, etc.** |
| Mesoscopic model | May model individual vehicles/users but with simplified behaviour. Spatial resolution ranges from zones to specific links or segments. | Used for more efficient operational analysis (e.g., highway controls) or when detailed microscopic data is unavailable. Less common than macro or microscopic models. Based on models like the **Cell Transmission Model** or **spatial-queue model**. **MATSim** is often considered mesoscopic. However, most macroscopic traffic models also have the option for modeling at the mesoscopic level, and some tools even offer the capability for microscopic modeling within strategic (macroscopic) models. |

| | | |
|---|---|---|
| Microscopic model | Simulate individual entities (vehicles, pedestrians) with high spatial precision, often at sub-meter level. | Used for detailed design (e.g., intersections, signal control). Based on car-following and lane-changing models. Common tools include **SUMO, AIMSUN Next, PTV VISSIM, LEGION, PHEM, etc.** |
| ***Based on temporal resolution*** | | |
| Static model | Use no or coarse time steps (e.g., peak periods), averaging traffic over time. Congestion is simplified and not modelled dynamically. | Used in regional planning with broad time slices and equilibrium-based assignment. Most macroscopic simulation tools support this form of simulation. |
| Quasi- and semi-dynamic model | Some dynamic effects are considered or simulated, but not at vehicle level. | |
| Dynamic model | Simulate system changes over time using progressive time steps, ranging from sub-seconds (e.g., 0.1s in microsimulation) to years (e.g., in land-use transport models). | Used in both detailed traffic simulations and long-term planning. Examples include **PTV VISSIM**, **MATSim**, **SUMO**, and dynamic LUTI models like **MARS**. Additionally, most macroscopic simulation tools have advanced capabilities for dynamic traffic assignment. |
| ***Based on temporal range*** | | |
| Short-term model | Focus on the immediate impacts of traffic interventions, typically within hours, days, or months. | Used for evaluating short-term changes like signal adjustments, new road or PT pricing, or temporary roadworks. |
| Long-term model | Account for long-term effects, including feedback loops like rebound effects and land-use interactions. | Used for strategic planning and policy evaluation over years or decades. Example: **LUTI models** such as **MARS**. |
| ***Based on transport modes considered*** | | |
| Single mode model | Simulate entities within one mode of transport only (e.g., cars or PT), with limited or no interaction across modes. In such models, demand is often viewed in a simplified manner and is based solely on input data - without more complex mathematical processing of that data. | Used for mode-specific analysis. **SUMO** is largely car-focused, while for example **PTV Lines** focuses on public transit. |
| Multi-modal model | Simulate interactions between multiple transport modes (e.g., car, transit, bike, walk). Different modes are usually formulated as an interchangeable network, and users select the desired mode combinations according to, e.g., random utility models. | Used to assess policies affecting mode choice or shifts. Most macroscopic simulation tools have advanced capabilities for multi-modal traffic modeling. |
| ***Based on supply-demand interaction mechanism*** | | |
| Four-step model (trip-based) | Considers the travel decision making process as a sequence of discrete, independent trips, consisting of origins, destinations, modes and paths. More details on four-step modelling are given in Section 3.23.2. | Widely used due to compatibility with census data. Common tools include almost every macroscopic transport modeling software. |
| Activity-based model | Models travel as a sequence of linked trips (trip chains) based on daily activities and individual decision-making. | Used when focusing on traveller behaviour and schedule optimization. Common tool: **MATSim, PTV Visum, AIMSUN, etc.** |

The selection of appropriate transport models depends on several factors, primarily the nature of the problem being studied, but also the availability of data and modelling tools.

For example, if the objective is to examine detailed road geometry or signalised intersection design, a **dynamic, microscopic model** is most suitable. Such models require high-resolution data, including existing road layouts, signal timing plans, directional traffic flows, lane configurations, and modal distributions.

Conversely, if the focus is on the interaction between multiple modes of transport, such as evaluating pricing strategies to encourage sustainable mobility, a **multi-modal model** is necessary. This approach typically requires data on existing modal demand and behavioural characteristics, such as user sensitivity to time and cost.

As a practical-oriented project, in the OPTI-UP project, the model selection process is mainly guided by the spatio-temporal scale of the analysis, multi-modal requirement, data availability and software maturity. Detailed discussions of the model selection process for the case study areas are given in Section 3.1.

# 3 Modelling Approach

## 3.1 Suitability of the transport models

In the OPTI-UP project, all six case study areas will pilot and test city- or district-level interventions aligned with three thematic priorities: **network optimisation**, **DRT**, and **alternative fuel PT vehicles**. These interventions span large geographic areas but do not require the level of detail offered by microscopic or highly dynamic models.

Furthermore, to ensure the long-term usability of the models by PPs, emphasis is placed on widely used tools and standard modelling practices. As a result, two types of models are selected for application across the six case study areas, also summarised in Table 1:

- For five of the six case study areas (all except Pécs), **macroscopic four-step transport models** will be utilised. This approach is selected based on several key considerations:
  - Scale of analysis: The thematic focus areas — PT network optimisation, the introduction of DRT services, and the deployment of electric buses — are expected to affect PT supply at a city-wide or corridor level. At this early planning stage, there is no need to capture fine-grained spatial detail (e.g., roadway geometry) or simulate the dynamic movement of individual PT passengers or vehicles. Therefore, a macroscopic modelling approach is more appropriate and efficient for the purpose of the project.
  - Multi-modal requirements: The planned interventions aim to shift demand between competing transport modes. For example, introducing DRT services is expected to increase PT ridership and reduce private car use in lower-density neighbourhoods. This necessitates a modelling framework that incorporates explicit mode choice modelling, as found in four-step models based on utility functions.
  - Data availability: In small- and medium-sized cities, the availability of detailed, high-resolution data is often limited. However, key inputs such as GIS-based road networks and traffic analysis zones are typically accessible through existing planning documents. As such, a model with moderate data requirements like the aggregated four-step model is better suited to the context.
  - Software availability: PTV VISUM is the chosen platform for modelling, as four of the five participating partners already have existing VISUM models. This offers a valuable foundation for updating and refining the models to align with the OPTI-UP thematic objectives. Although Český Krumlov does not have an existing VISUM model, the city's small scale (22 km$^2$, population of 12,278, and only three PT lines) makes it feasible to develop a new model within the scope and timeframe of the OPTI-UP project.
- For the case study area of Pécs, a **macroscopic, transit-only assignment model** using PTV Lines is applied. Although Pécs falls under the same thematic focus as other case studies (the introduction of **alternative fuel vehicles**) and shares a similar scale of analysis (i.e., line- or city-level), several key factors set it apart:

  - Multi-modal considerations: While the adoption of electric buses is expected to offer indirect benefits such as increased ridership, especially when combined with awareness campaigns, its primary and most immediate impact lies in reducing the consumption of fossil fuels (gasoline and diesel) during PT operations. Unlike interventions such as network optimisation or DRT, which directly influence modal shift and travel behaviour, the demand-side effects of introducing electric buses are more modest. Consequently, complex multi-modal modelling is not essential for this case.
  - Data and software availability: Similar to Český Krumlov, the project partners in Pécs do not have access to an up-to-date PTV VISUM model. However, unlike Český Krumlov, Pécs is significantly larger in both geographic area (162.6 km²) and population (139,330), and it operates a more complex PT system with 85 bus lines. Developing a full four-step model under these conditions would require substantial time and data collection efforts. Given these constraints, a simplified **PTV Lines model**, which focuses solely on PT assignment, is deemed a more practical and efficient solution for conducting the necessary analyses within the project scope.

- For three case study areas (**Modena, Osijek, and Pécs**) a **macroscopic, long-term strategic LUTI model** is chosen to be further developed to assess the extended impacts of policy interventions. The decision to use LUTI modelling in these cities is based on several key factors:
  - Temporal scope of analysis: Unlike short-term outcomes, such as immediate changes in PT ridership following the introduction of DRT services, some impacts unfold over a longer time horizon and are closely tied to broader urban development trends. For example, enhanced accessibility through improved PT infrastructure can drive new residential or commercial developments, supporting transit-oriented growth. These long-term, system-level feedback effects are best captured using LUTI models, which are specifically designed to reflect the dynamic interplay between transport systems and land use.
  - Spatial scale of application: Given the highly aggregated nature of LUTI models, they are most appropriate for larger geographic areas where high-level spatial patterns can be meaningfully analysed. Accordingly, only the three largest case study areas, each covering more than 160 km² and with populations around or exceeding 100,000, are selected for LUTI modelling.
  - Data and software availability: The LUTI analysis is carried out using the MARS model. Much of the required input data can be derived from existing PTV VISUM models or standard planning documents, making implementation feasible within the scope of the OPTI-UP project.

## 3.2 Four-step model and the VISUM software

### Principle

At its core, PTV VISUM implements the well-established **four-step modelling framework** (illustrated in Figure 3), which is widely used in strategic transport planning. The four steps are as follows:

- Trip generation: This step estimates the total number of trips originating from and destined for each zone. These estimates are typically based on land use and demographic characteristics. Common methods include **category models** and **regression models.**
- Trip distribution: In this step, the generated trips are linked into origin-destination (OD) or production-attraction pairs. This is essentially a destination choice process, with the **gravity model** being the most frequently applied methodology.
- Mode choice: This step determines the proportion of trips between each OD pair that are made using different transport modes. Mode choice is typically modelled using **random utility models**, which account for travellers' preferences based on factors such as cost, time, and convenience.
- Route assignment: The final step involves assigning trips to specific routes in the transport network. A key challenge in this step is the interdependence between traffic volumes and travel times: higher volumes can lead to congestion, which in turn influences route choices. To address this, VISUM employs a range of **optimisation and approximation algorithms** to achieve equilibrium between trip assignment and network congestion.

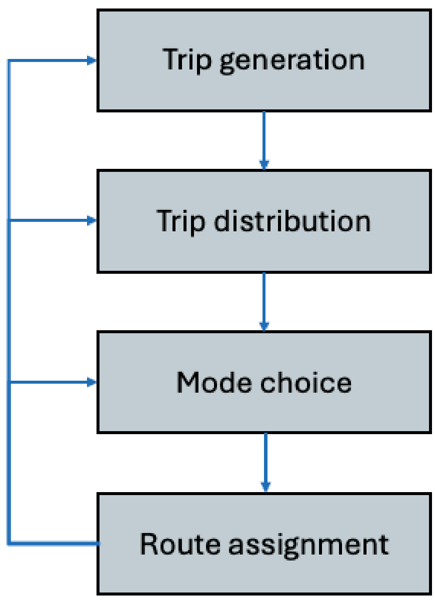



*Figure 3. Four-step model.*

It is important to note that the methodological approach to modelling within the defined framework can be significantly adapted to the specific needs of the project, the model area, and its final purpose and objectives. Accordingly, the aim of this report is not to promote a specific modelling methodology, but rather to provide an overview of the fundamental steps involved in the development of transport models.

### Data inputs

The typical inputs for a four-step model can be broadly categorised into **supply-side** and **demand-side** components:

- Supply-side inputs primarily consist of a **graph-based, multi-modal transport network**, which is structured using nodes and links. Nodes represent key locations such as road intersections or PT transfer points, while links represent the road segments between intersections or the segments of PT lines between two stops or stations. This network structure forms the foundation for modelling both private and PT systems.
- Demand-side inputs are defined through **traffic analysis zones (TAZs)**, each containing data on the number of trips originating from or destined for that zone at various times of day (e.g., peak and off-peak periods). The level of zoning detail depends on the purpose of the analysis: finer-grained studies require smaller, more numerous zones, while broader strategic analyses may use larger zones to reduce complexity.

### Past usage

Four step transport models have been widely used for various tasks of transport planning. Across the OPTI-UP case study areas, cities also have varying levels of experience in applying them, primarily to support local and regional planning efforts (Section 4.1). Modena has used its model extensively, from developing its Sustainable Urban Mobility Plan (SUMP) to evaluating Bus Rapid Transit (BRT) and rail alternatives, managing pandemic-era bus capacity, and informing a province-wide transport strategy. Grosuplje uses an extract of Slovenia's national model to simulate multimodal traffic flows and assess infrastructure and policy impacts. Osijek has used its model for city- and county-level planning and for optimizing its tram network. In contrast, Paks introduced four step modelling for the first time in 2024 to evaluate a revised bus network serving key local employers, although implementation is still pending due to required investments. While these applications highlight the versatility of four step models, access and direct use of the models vary, and it is very often the case that cities rely on existing consultants to develop and maintain the models.

### Advantages and limitations

As with all transport models, four step models come with a range of advantages and limitations that must be carefully considered to determine its suitability for specific planning tasks.

One of the key benefits of VISUM software that is used for OPTI-UP project is its comprehensive **capability to model multi-modal transport networks within a single, integrated platform** (Oliver et al., 2024). This integration allows users to conduct demand modelling, assignment, analysis, and visualisation without concerns about the compatibility of different components. As a result, the modelling process becomes more streamlined and accessible, lowering the barrier to entry and supporting a greater inclusion of evidence-based insights in decision-making. Moreover, due to its aggregated and macroscopic structure, VISUM offers **fast computation speeds**. City-scale simulations can often be completed within minutes, enabling quick scenario testing and facilitating timely input into real-world planning processes.

On the other hand, VISUM is subject to several limitations inherent to the four-step modelling framework. These include the **simplification of real-world travel behaviour** into individual trips, which limits the model's ability to capture more complex, activity-based travel patterns. It also **lacks mechanisms to account for long-term feedback effects between transport systems and land use changes**, a feature found in more integrated LUTI models. Additionally, the use of **aggregated spatial zones and time intervals** constrains its capacity to analyse detailed or dynamic aspects of travel behaviour, which are better addressed through microscopic or dynamic models. Practical challenges also exist, such as the high cost of the software and the potential need to hire external experts, which can pose a **financial barrier** for smaller municipalities. Furthermore, the **lack of backward compatibility** between different versions of VISUM can complicate collaboration and model sharing among stakeholders.

It is important to note that this report is not focused on evaluating modelling software tools, but rather on evaluating the transport models and tools that the project partners possess and are using within this project.

## 3.3 PT and Lines model

### Principle

PTV Lines is a software solution specifically designed for **transit service planning**, facilitating the creation of efficient PT services. Owned by PTV Group, this cloud-based platform enables the planning and optimization of bus and rail networks, allowing users to **adjust routes, timetables, and connections with minimal effort**. The software is structured to support both long-term strategies and daily operational needs.

PTV Lines provides a fully digitalized workflow for network design and timetable planning, utilizing an **interactive map** for editing line routes and stops. Users can modify variables such as stop sequences and waiting times, with immediate visualization of the effects on travel times and capacity utilization. This functionality aids in the precise optimization of route networks, contributing to improved punctuality and reduced waiting times.

### Data inputs

Compared to four step model, the inputs to the PTV Lines model are significantly simpler. On the supply side, only the PT service information as the GTFS file (.zip) is needed or there is option to upload supply data with PTV Visum version files (.ver). On the demand side, OD matrix is needed. Also, zones should be introduced as GeoJSON format.

### Past usage

In 2023, PTV Group launched a PTV lines web-based tool for PT service planning. The use of the software in the cities covered by this project has been limited, with Modena being the only city to utilize the PTV Lines model in the OPTI-UP case study areas. Modena uses this tool for various PT planning tasks. Other cities involved in the project do not have experience in planning with PTV Lines.

### Advantages and limitations

PTV Lines model is easy to operate and offers intuitive GUI functionalities to import data, modify the network and services, and visualise the impacts of PT interventions. However, compared to VISUM model, a significant limitation is the lack of multi-modal capability, thus not able to simulate the mode shift effect of transport system interventions (the mode choice step in the four-step framework).

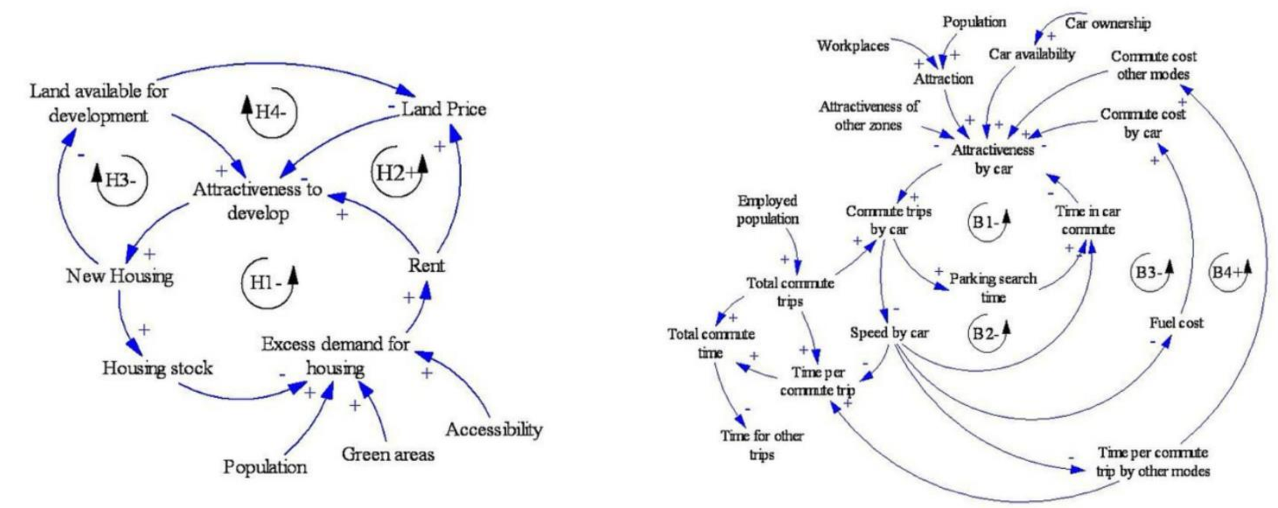
## 3.4 LUTI model and MARS

### Principle

**MARS (Metropolitan Activity Relocation Simulator)** is a **strategic, dynamic LUTI model**. It is based on the hypothesis of a constant travel time budget, which assumes that urban residents allocate a relatively fixed amount of time to daily travel. As transport systems improve and travel times decrease, this can lead to urban expansion, with populations gradually relocating to areas that were previously underdeveloped or less accessible.

Like most LUTI models, MARS comprises two interconnected components: a **land-use sub-model** and a **transport sub-model**. The model is developed using **System Dynamics (SD)** principles, which allow it to simulate long-term feedback loops and behavioural interactions between land use and transport systems. Example **Causal Loop Diagrams (CLDs)** illustrating the structure of both the land-use and transport sub-models are presented in Figure 4.

- The land-use sub model is further divided into residential and commercial land-use development. It simulates new housing and workplace developments by modelling competing markets, land constraints, and accessibility, using LOGIT or gravity-type models to allocate potential across zones. It includes both supply-side (developers, enterprises) and demand-side (population) dynamics. Allocation of residents and workplaces serves as an input for the transport sub-model.
- The transport sub-model simulates passenger travel through trip generation, trip distribution, and mode choice, using a gravity (entropy-maximizing) approach calculating the three steps simultaneously. It considers modes such as walking, cycling, car, bus, and rail, and two different times of day: peak and off-peak. Output of the transport sub-model includes data such as number of trips per mode and purpose, trip length distribution, average travel speed and average costs. Those outputs are again used to calculate accessibility for integration with the land use model, providing dynamic feedback between the sub-models.




(a) Residential land-use development (b) Commuting by private car

*Figure 4. Example CLD in MARS model (FVV, n.d.).*

As a dynamic model designed for long-term scenario analysis, MARS is capable of simulating changes in land use and transport systems over several decades, typically 30 to 50 years, using an annual time step. The model is intended to capture macroscopic transformations, making it suitable for applications ranging from the city scale to the national level. Simulations represent typical workdays and aggregate output data to annual time steps.

The spatial resolution of the model is adapted accordingly. In city-scale applications, each zone typically represents a distinct neighbourhood characterised by relatively homogeneous land use and socio-demographic profiles, such as a city centre, residential area, or industrial district. In national-scale applications, a single zone may represent an entire town or a subregion of a large metropolitan area. For optimal computational efficiency, it is generally recommended to limit the number of zones to fewer than 50.

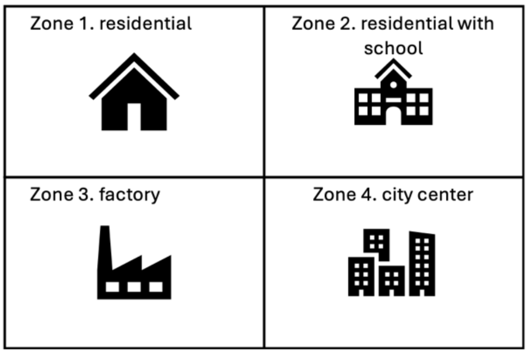
More details about the modelling principles of MARS can be found in Pfaffenbichler et al. (2010).

### Data inputs

MARS model involves three types of inputs. Detailed data types and how they are used in modelling are shown below and illustrated in Figure 5.

- **Scalar:** Scalar inputs are parameters that apply uniformly across the entire simulation area. These typically include:
    - **Model parameters:** For example, the average number of outgoing trips per employed person per workday. A complete list of model parameters and default values (based on the City of Vienna) is provided in Appendix 1.
    - **Calibration parameters**: These behaviour-related parameters are used during model calibration, such as the relative importance of travel time across different transport modes. Initial estimates can be used, but precise values should be adjusted through calibration.

- Vector: Vector inputs vary by zone and are used to capture spatial differences within the study area. Examples include:
    - **Socio-demographic and land-use characteristics**: e.g., base-year population, average monthly rent, number of jobs, car ownership, etc.
    - **Mode-specific attributes**: e.g., access and egress time to the nearest PT stop. Some of these may overlap with matrix inputs if zone-pair-level data are unavailable.
- Matrix: Matrix inputs describe relationships between zone pairs and are mode-specific:
    - **Walking and biking (micromobility)**: Typically include travel distances and speeds. Variations in speed may reflect topographical differences such as hilliness.
    - **PT (bus and rail)**: Include distances, headways, transfer times, speeds, and fares for both peak and off-peak periods.
    - **Private car**: Cover distances, tolls or charges, free-flow speeds, and congested speeds for both peak and off-peak times.




Example scalar inputs

| Parameter | Value |
|---|---|
| Average out trips per employed per working day | 0.9 |

Example vector inputs

| Parameter | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
|---|---|---|---|---|
| Residents base year | 1000 | 500 | 200 | 200 |

Example matrix inputs

| Walking Distance | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
|---|---|---|---|---|
| Zone 1 | 100 | 1000 | 1000 | 1500 |
| Zone 2 | 1000 | 100 | 1500 | 1000 |
| Zone 3 | 1000 | 1500 | 100 | 1000 |
| Zone 4 | 1500 | 1000 | 1000 | 100 |

*Figure 5. Example MARS inputs.*

## Past usage

The MARS model has been applied in numerous case studies worldwide to analyse the interplay between land use and transport systems (TU Wien FVV, 2024). In Austria, MARS has been utilized for national-scale modelling, most recently capturing the effect of national-wide mobility service guarantee on travel behaviours (Laa and Pfaffenbichler, 2022; Laa et al., 2022). The model has also been employed in Vienna to assess the rebound effects of transport efficiency improvements (Fuady et al., 2025). Internationally, MARS has been applied in cities such as Madrid (Wang et al., 2015), where it supported the development of participatory scenario-building methodologies, and in Bangkok, aiding sustainable urban transport planning. Other applications include modelling in Strasbourg and Mulhouse to evaluate electric mobility policies, and in Porto Alegre and Chiang Mai to support sustainable mobility planning. These diverse case studies demonstrate MARS's versatility in addressing complex urban and regional planning challenges across different geographic and socio-economic contexts.

### Advantages and limitations

Although the MARS model is designed to capture the complex interactions between land development and transport systems, the software offers short run times and only requires standard data as inputs. **Most input data can be sourced from existing PTV VISUM models or standard urban planning documents**, making the setup process relatively straightforward. MARS is based on the Vensim software, a commonly used tool for SD modelling that offers many GUI and visualisation features to assist the modelling workflow. Due to its aggregated structure, MARS is capable of running long-term, multi-decade simulations (using annual time steps) in just a few minutes. This **efficiency** makes it easy to test and compare alternative scenarios with relatively low input data requirements. For instance, to simulate the introduction of a new PT line, users can simply adjust the PT travel time matrix by reducing travel times between the relevant zones.

Despite its advantages, MARS has several limitations. One key issue is the model's **sensitivity to certain inputs**, such as distance matrices. This can be addressed through **calibration**, typically by comparing model outputs with observed data, such as modal split figures from recent transport surveys, and adjust parameter values. Another limitation lies in the **land-use component**, which is inherently more uncertain than the transport model. Land-use changes are heavily influenced by political and planning decisions, which are often difficult to predict. To mitigate this, model developers are encouraged to work closely with local stakeholders and refer to official planning documents to ensure external development plans are accurately reflected.

Additionally, due to its **aggregated spatial resolution**, MARS zones are coarser than those used in four step models. The model also lacks a **graph-based transport network**, which limits its ability to perform detailed operational analyses, such as estimating PT ridership at the line or stop level. As such, MARS is best suited for **strategic, high-level planning**, rather than detailed service design or operational modelling.

# 4 Current State of traffic models in the project area

The six PPs involved in OPTI-UP have varying levels of knowledge and familiarity with transport modelling to support PT planning in their respective areas. This variation is representative of the broader situation in many small- and medium-sized cities across Central Europe. While none of the case study possess in-house capabilities to develop transport models, two (Modena and Osijek) already have access to custom-built four step models in PTV VISUM developed by external consultants and experts.

Additionally, Grosuplje and Paks have access to model extracts derived from larger regional or national models. Although these models have been used for broader-scale applications, the local partners lack experience in adapting or applying them specifically for PT planning and operations. The remaining two case study areas do not currently have access to any form of four step model. One of these cities (Český Krumlov) commissions a new four step model in VISUM from scratch as part of the OPTI-UP project, while the other (Pécs) opts for a simplified model (PTV Lines), which is deemed a more practical and manageable entry point.

For modeling long-term impacts of the PT policies, LUTI model is often identified as a suitable tool. However, none of the PPs had prior experience using them before the start of the project.

The following subsections will provide an overview of the existing PTV VISUM models (where applicable) and identify the key gaps that need to be addressed in order to apply them effectively to the PT-focused objectives of the OPTI-UP project.

## 4.1 Existing model characteristics

Table 3 summarizes the existing transport models available in the six OPTI-UP case study areas. As shown, most areas have access to relatively recent four step models. In many cases, the case study areas are subsets of larger municipal, regional, or national models. For instance, Český Krumlov, the smallest case study area, comprises 31 zones in its PTV VISUM model. Grosuplje's model, extracted from the national model, includes 56 zones, while the Polica settlement contains only 7 zones. The largest model is found in Modena, with 208 zones representing the pilot area. A visualisation of zones in the available VISUM model is given in Figure 6.

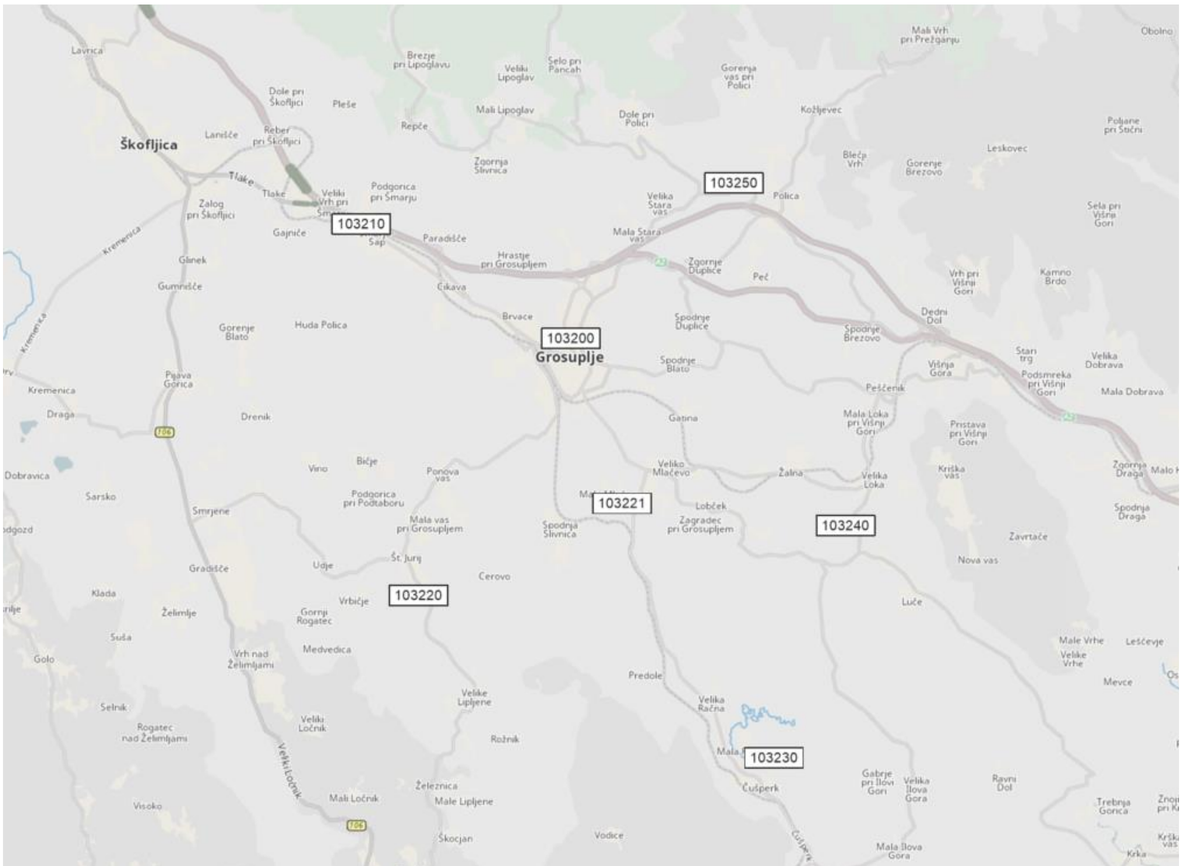
The transport networks are typically modelled using nodes and links. In smaller areas like the Polica settlement in Grosuplje, Paks, and Český Krumlov, the models generally include fewer than 1,000 nodes and 3,000 links. In contrast, larger case study areas such as Modena feature more complex networks, with over 10,000 nodes and 30,000 links.

It is important to note that while VISUM supports four-step modelling, not all modelling steps are currently represented or available to the OPTI-UP project teams. In practice, early model iterations may have included demand generation, distribution, and mode choice steps, but these components were often dropped in subsequent versions used for regular planning tasks. For example, for the VISUM model for Modena, the demand is generated through combining commuting data using private cars from the national statistics office, and the PT ticketing validation data. For the VISUM model for Český Krumlov, the demand for private car traffic is based on the national traffic survey data, and the demand for PT is based on statistics delivered by the municipality. For Osijek, the

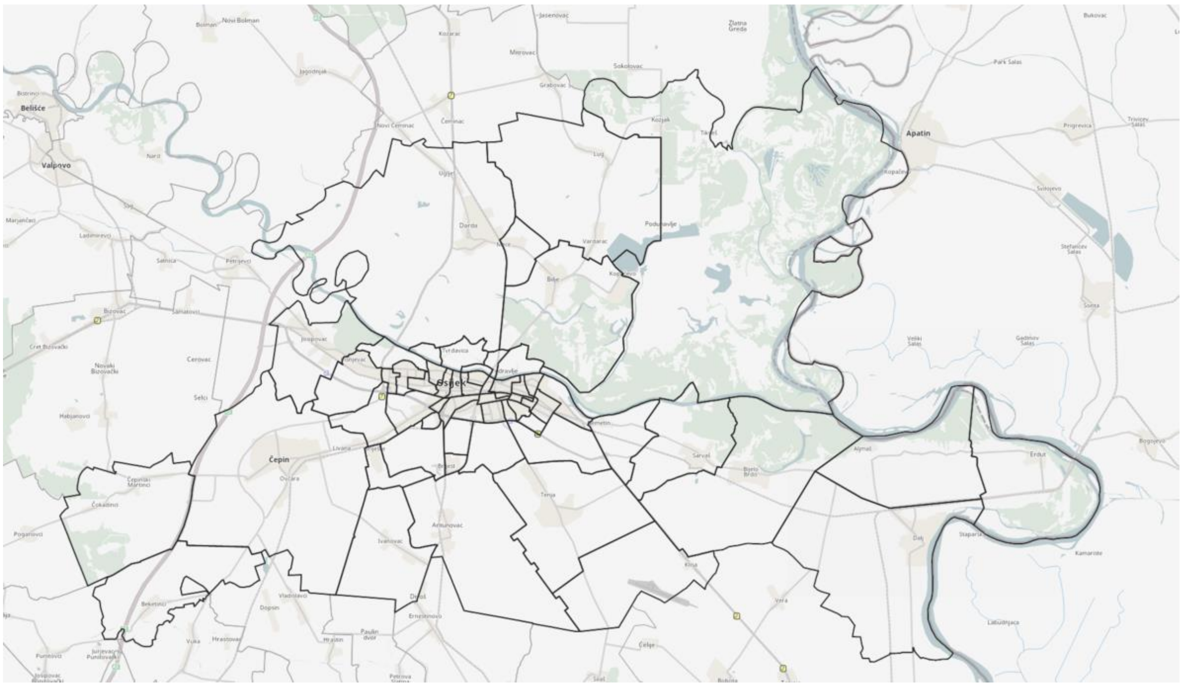
VISUM model was initially developed as part of the city's Master Plan, which includes the complete four steps (traffic generation based on land uses, trip distribution using a gravity model, and verified mode share). The model is updated for the OPTI-UP project, and the first three steps are analysed outside of VISUM, with refinements applied within the software. This is an approach consistent with standard model update practices.

Table 3. Summary of existing transport model characteristics.

| **Policy intervention** | **DRT** | | **Network optimisation** | | **Alternative fuels** | |
|---|---|---|---|---|---|---|
| **Cities** | **Modena** | **Grosuplje** | **Osijek** | **Paks** | **Pécs** | **Český Krumlov** |
| **Software** | PTV VISUM | PTV VISUM | PTV VISUM | PTV VISUM | PTV VISUM | PTV VISUM |
| **Responsible body** | aMo | PIL | City of Osijek | City of Paks | City of Pécs | VSTE |
| **Last update** | 2025 | 2021 | 2025 | 2024 | 2012 | 2025 |
| **# zones** | 208 (399 in total) | 7 (56 in total) | 60 (125 in total) | 13 (1,486 in total) | -- | 31 |
| **# links** | 33,784 (301,290 in total) | 2,042 (8,268 in total) | 7,118 (13,392 in total) | 332 (65,244 in total) | -- | 1,764 |
| **# nodes** | 12,748 (120,143 in total) | 871 (3,934 in total) | 2,964 (5,850 in total) | 120 (26,239 in total) | -- | 743 |
| **Demand model** | No trip generation and trip distribution in current model file | No trip generation, trip distribution and mode choice in current model file | No trip generation, trip distribution and mode choice in current model file | No trip generation, trip distribution and mode choice in current model file | -- | No trip generation, trip distribution and mode choice in current model file |
| **Past usage** | Yes, for BRT lines and interurban railway links. | Yes, national-level planning and real-time management. | Yes, for local and regional master plan and tram modernisation. | Yes, new PT for commuting to the Paks Nuclear Power Plant. | The 2012 model is unavailable. | N.A. The model is developed during OPTI-UP. |

| | Zones |
|---|---|
| **Modena** |  |
| **Grosuplje** |   |

**Osijek**


Osijek
Valpovo
Belišće
Apatin
Čepin

**Paks**


Gyapa
1501
1500
1502
Ordas
1487
1485
1488
1486
1489
1490
Géderlak
1494
Dunaszentbenedek
1503
1505
Uszód
Csámpa

Český Krumlov

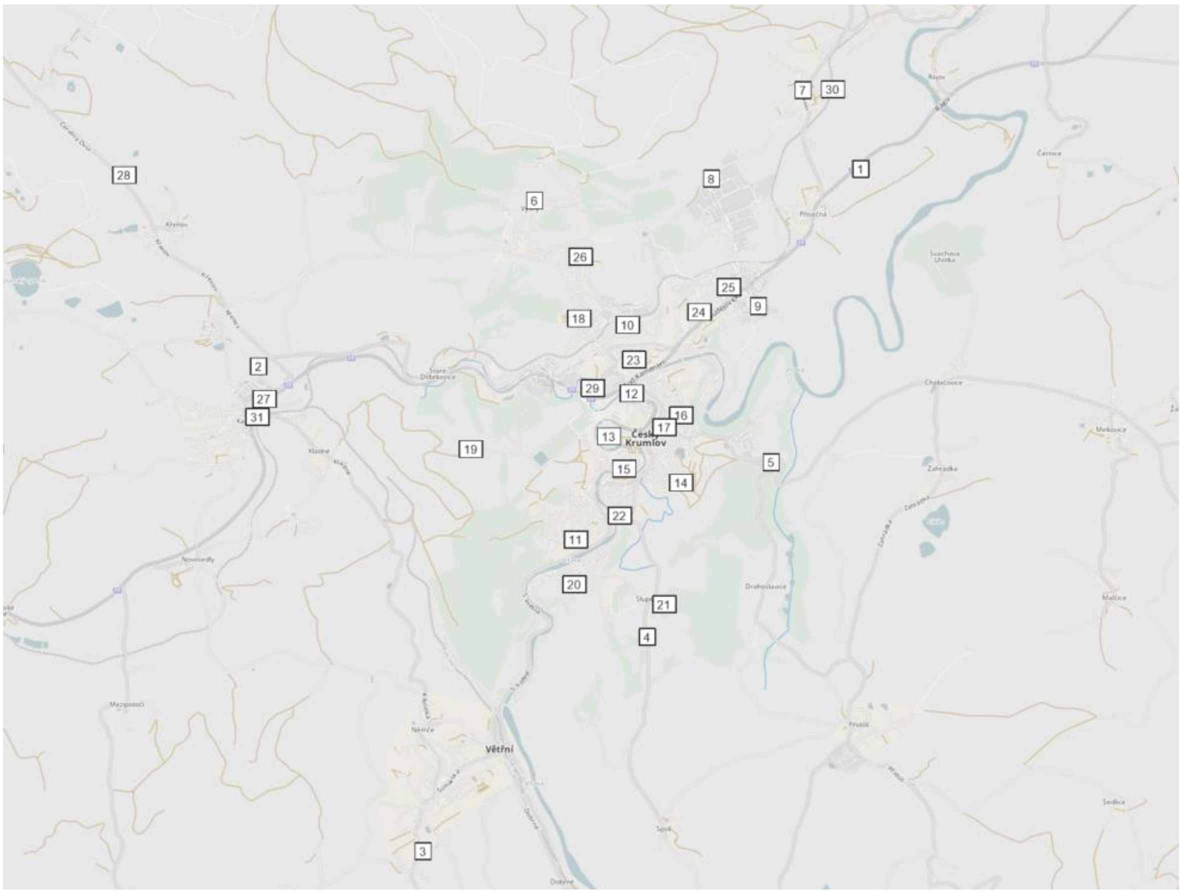



*Figure 6. Transport model zones by city*

For most of the cities with existing PTV VISUM models also have experiences of applying them in past projects, with the specific tasks vary from high-level planning to real-time management. The majority use cases, however, are still on supporting local and regional plans. For the four case study areas where PTV VISUM models have been applied before, their past applications are summarised below.

## Modena

The PTV VISUM model was first applied during the development of the most recent SUMP for the Municipality of Modena. Following the SUMP's approval, two related studies were conducted, both focusing on Modena's urban PT network. One study evaluated various scenarios to define a new network configuration featuring four BRT lines. The other examined the interurban railway corridor between Modena and Sassuolo, a nearby city in the province, by comparing the existing railway with alternative options such as a tram or BRT line, as well as hybrid solutions.

In 2021, during the COVID-19 pandemic, the model was used to identify which bus trips were likely to exceed reduced capacity limits due to physical distancing requirements. This analysis supported operational planning, including the deployment of additional buses to accommodate peak demand.

Later, the model was extended to include interurban services and used to support a broader urban mobility plan for the entire province. This analysis contributed to the development of the *Piano di Bacino*, a strategic document necessary for organizing public procurement processes for PT services in the province.

All modelling work was conducted by external consultants. In several cases, such as the Modena-Sassuolo study, the local project partner received only the final reports and results, not direct access to the model itself.

### Grosuplje

The VISUM model used in Grosuplje is an extraction from Slovenia's national transport model, which is a macroscopic tool developed to analyse and plan transport measures at the national level across all modes. The National Traffic Management Centre (NTMC, originally NCUP) also employs the model for real-time traffic management. It played a central role in preparing the 2016 national transport strategy, during which the model was completely rebuilt using updated travel behaviour data, socioeconomic indicators, and the current transport network.

The Grosuplje model is a four-step based transport model and simulates traffic flows by integrating network characteristics with demographic and mobility data. It supports analysis for various vehicle types (passenger cars, buses, light and heavy goods vehicles) as well as PT modes (bus, train). It has been used to evaluate infrastructure investments, organizational measures, and socio-economic impacts.

### Osijek

The City of Osijek had an operational PTV VISUM model prior to the start of the OPTI-UP project. This model was instrumental in developing the Master Plan for transport in the City of Osijek and Osijek-Baranja County. It provided a framework for analysing current traffic conditions and projecting future mobility needs.

The model also played a key role in the Tram Infrastructure Modernization Project, specifically during the study to determine the optimal tram network configuration. It helped evaluate multiple scenarios and assess their potential impact on mobility, service efficiency, and infrastructure performance.

### Paks

In Paks, VISUM-based PT modelling was introduced for the first time in 2024, when the municipality commissioned a new traffic model to support the design of a revised bus route and line network. The model was developed to evaluate the planned service expansion of the city-owned Paks Transport Company, a project partner in OPTI-UP.

The company currently operates four bus lines within the city. The new model assessed how this local operator could meet transport demands, particularly those of the region's largest employer, the Paks Nuclear Power Plant, whose workforce is currently served by the national bus provider. Data collection methods included on-site counts, video recordings, and both in-person and online surveys. The classic four-step modelling methodology was employed to ensure a robust analysis.

While the model was developed, the modelled strategies or scenarios have not yet been implemented or tested in practice. Full deployment would require significant investment, including the acquisition of eight new buses.

## 4.2 Gap analysis and data collection

An analysis of the existing transport models across the case study areas reveals varying levels of data gaps and corresponding efforts required for additional data collection. In Modena, Osijek, Grosuplje, and Paks, where existing PTV VISUM models are already available, it is relatively straightforward to upgrade these models to support the intended policy interventions. These existing models can be adapted to meet the requirements of both short-term analysis in VISUM and long-term planning using the MARS model.

In contrast, for cities without existing transport models, the data gaps are significantly larger. These cases require more extensive efforts, beginning with fundamental tasks such as defining traffic analysis zones and gathering baseline data, which substantially extends the time needed for model development.

### PTV VISUM/Lines model for short-term policy effect forecasting

Since short-term impact forecasting is required for all case study areas, a comprehensive gap analysis is conducted across all six locations. In Modena, Grosuplje, and Osijek, although existing PTV VISUM models are available, they are not originally developed for the OPTI-UP project but were updated with additional and updated data to better reflect the current transport situation. Therefore, each model required assessment and updates to ensure compatibility with the specific policy interventions to be tested. These necessary updates have since been implemented.

In Paks, the existing VISUM model was commissioned and completed recently (in 2024), and the planned intervention for the Paks case study during OPTI-UP, namely network optimization, falls within the standard capabilities of the software. As such, no major updates are needed.

For the remaining two case study areas, Český Krumlov commissioned the development of a new VISUM model from scratch through external consultants during the duration of the OPTI-UP project. In contrast, Pécs faces more significant challenges, including the absence of even fundamental elements such as defined traffic analysis zones. Due to these substantial data gaps, a simplified approach using the PTV Lines model is recommended. This model focuses solely on PT system assignment and represents a more practical and manageable solution under the circumstances.

A detailed overview of the **data gaps and necessary upgrades for the short-term models (PTV VISUM or Lines)** in each case study area is provided below.

- Modena: In the case of Modena, the municipality already has access to a relatively comprehensive PTV VISUM model. However, several gaps are identified in its suitability for the OPTI-UP project. Most notably, the existing model does not include DRT services, and it lacks detailed components for trip generation and distribution, limiting its analytical capacity.
    - To address these gaps, the local PP, aMo, initiated a series of updates within the OPTI-UP framework. This includes refining both private and public transport demand inputs using open-source data, such as private traffic datasets and PT ticket validation records. The model will also be expanded to include DRT services, enabling scenario-based analysis to support the design of the upcoming pilot interventions.

- To implement these enhancements, an external consultant is selected through a public procurement process. The consultant will use a dedicated model component within VISUM to model the DRT service, incorporating key performance indicators (KPIs) such as total kilometres travelled, passenger numbers, and service reliability. This update also requires adding all DRT bus stops and modifying portions of the road network to accommodate the new service.

- **Grosuplje:** In Grosuplje, the national transport model of Slovenia is extracted and adapted to represent the wider transport context of the area for the purposes of the OPTI-UP project. Within OPTI-UP project, the PT timetables were revised and populated with the updated data. While the model provides a broad and valuable overview, a key limitation identified is its lack of capability to simulate DRT services as planned in the OPTI-UP pilot action. This requires the use of a special DRT transport model component in VISUM for modelling DRT services (as in Modena), rather than changing the operation of the existing regular service as DRT service.
  - Although the Slovenian national model has not previously been used for PT planning at the local level, the local project partner, PIL, is exploring the feasibility of applying the model to simulate other PT optimisation measures within the OPTI-UP framework. As part of this effort, the three municipal lines within Grosuplje will be examined in more detail. This involved checking the number and configuration of zones and connectors in the relevant area, as well as collecting ridership data for Line 72, a key PT service along the proposed route.
  - Initial findings indicate that, to fully utilise the hourly demand matrix data (i.e., passenger boarding data), each PT stop would need to be represented with a corresponding connector. However, the current version of the VISUM model still aggregates this area into a limited number of zones (only two zones along Line 72), which may constrain the model's accuracy. As a result, further investigation is required to determine appropriate modelling trade-offs and assess the feasibility of refining the zoning structure for effective simulation of PT efficiency.

- **Osijek:** The City of Osijek has access to a relatively comprehensive PTV VISUM model developed in 2016 as part of the Master Plan for transport development for the City of Osijek and Osijek-Baranja County; however, it requires updates to accurately reflect current transport conditions and recent changes in urban structure. Within the framework of the OPTI-UP project, the model has been systematically updated to represent the situation as of 2024.
  - The updates focus on both transport supply and demand to ensure alignment with real-world conditions. Key enhancements include the reconstruction of PT lines and timetables, as well as the revision of bus stop locations. A refined zoning system is being introduced to better reflect urban structure and travel behaviour. This includes the subdivision of some existing zones, which necessitates corresponding adjustments to demand matrices. Centroids and connectors are also being updated to improve the spatial accuracy of the network.

  - On the private transport side, the model is being expanded to incorporate newly built roads and a more detailed representation of the road network. Particular attention is being given to updating vehicle access restrictions, such as permissions for different vehicle types, and ensuring correct modelling of one-way street segments. Turn restrictions are also being reviewed and updated across large portions of the network. Additionally, both public and private transport demand figures are being revised based on the most recent available data, further strengthening the reliability and relevance of the updated model.

- Český Krumlov: The City of Český Krumlov is the smallest case study area in the OPTI-UP project. The PT planning has not been done before using VISUM models. Given its smaller size and simpler PT network (3 bus lines), it is deemed possible for a new VISUM model to be created from the scratch. The traffic model is built to reflect the city districts of Český Krumlov.
  - On the supply side, three modes are identified, including private cars, freight transport, and PT. The PT component of the model is built considering the status of line service for the year 2024. The new public tender in 2025 may result in changes in the model of operation. In the future, when data become available, there is a possibility to extend the model to include regional networks and train transport.
  - On the demand side, 31 zones have been identified. Zonal data are updated in cooperation with the municipality and the PT operator. The traffic data are calibrated based on data from the previous national traffic survey.

- Pécs: The City of Pécs had previously commissioned PTV VISUM models around 2012; however, the model files are no longer available. In contrast to Český Krumlov, Pécs is significantly larger, nearly ten times greater in both geographic area and population and operates a complex PT system with 85 bus lines. One of the main challenges identified is the inadequacy of the existing zonal system, which is based on electoral districts. These zones do not accurately reflect homogeneous land use patterns or socio-demographic characteristics, both of which are essential for effective traffic analysis and model development.
  - Given the absence of suitable traffic analysis zones and the scale of the study area, the local PP, STRIA, commissions external experts to develop a new zoning system. These newly defined zones, supplemented by socio-demographic data from the national census, will provide a foundation for estimating transport demand in both the PTV Lines model and the LUTI model MARS.
  - Additionally, the local bus operator in Pécs regularly publishes service schedule updates in General Transit Feed Specification (GTFS) format. This data offers a reliable source of supply-side information needed for building a PT model using PTV Lines.

### LUTI MARS model for modelling long-term interaction of land development and transport systems

Due to the aggregated nature of the LUTI model MARS, only the three relatively larger case study areas (Modena, Osijek, and Pécs) are selected for further MARS modelling. Although the MARS model has been applied in various case studies across Europe and internationally (see Section 3.4 for past applications), it has not yet been used in any of the OPTI-UP case study city or in their respective countries. Consequently, each city is required to collect the necessary input data to support the formulation of individual MARS models.

Key inputs for the MARS model include zone definitions, basic model parameters (e.g., available transport modes), and scalar, vector, and matrix datasets. The latter three are described in more detail in Section 3.4. Modena, Osijek, and Pécs contributed the required inputs to support the development of their respective models.

For Modena and Osijek, the process is relatively straightforward, as both already have established zone-based VISUM models. These zones are aggregated to fewer than 40, as required for efficient MARS operation. Additional data are collected through GIS analysis, exports from VISUM, and local estimates based on land use and population characteristics.

The development of the model for the Pécs case study area is more challenging due to the lack of existing VISUM models, or even predefined zoning system suitable for transport and land-use modelling at the start of the project. Therefore, as part of Activity 1.2 of the OPTI-UP project, a bespoke zoning framework was developed, and the data were populated based on the zones.

- Modena: The Modena case study benefits from relatively good data availability for MARS model development.
    - **Zoning**: The existing PTV VISUM model includes 208 zones, which is too detailed for efficient MARS operation. To improve performance and maintain model efficiency, the zones are aggregated into 27, based on similarities in land use and socio-demographic characteristics. Figure 7 illustrates the zoning structure before and after aggregation.
    - **Transport modes**: The model considers only four modes of transport: walking, cycling, bus and trolleybus (without dedicated lanes), as well as private cars.
    - **Time frame**: The analysis period spans from 2024 to 2040, with a one-year time step. MARS parameter values related to the peak period (e.g. bus headway, changing time, speed of cars in traffic for the peak period) are taken based on the bus operations and traffic status from 7:00 to 9:00 in Modena, while the off-peak period is considered from 9:00 to 11:00.
    - **Scalar inputs**: Most scalar parameters follow the reference MARS settings (see Appendix 1) based on a Viennese model, where MARS was originally developed. They are open for further updates if needed. One parameter is adjusted explicitly for Modena: the car survival rate is extended to 12.5 years, up from the 10 years given in the Viennese model.
    - **Vector inputs**: These are estimated primarily based on the socio-demographic characteristics of each zone. This step involves estimations, as

some zonal inputs (e.g., the ratio of living space and built-up space) are not available directly from any official data.

  - **Matrix inputs**: These are derived through a combination of GIS-based analysis (to calculate inter-zonal distances by different transport modes) and data exports from VISUM matrix outputs.

- Osijek: Similar to the Modena case study, Osijek also has relatively good availability of data for MARS model development.
  - **Zoning**: The existing PTV VISUM model has 60 zones, which are aggregated to 40 zones for the MARS model (Figure 7). The zones are denser in the city centre, reflecting the population density distribution characteristics of Osijek, which is more concentrated in the central areas.
  - **Transport modes**: The mode of transport in Osijek is similar to that of Modena, also consisting of walking, cycling, bus and tram (without dedicated lanes), as well as private cars.
  - **Time frame**: The analysis period spans from 2024 to 2040, with a one-year time step. MARS parameter values related to the peak period are taken based on the PT operation and traffic status from 6:00 to 8:00 (or 15:00 to 17:00) in Osijek, while the parameter values related to the off-peak period is considered from 10:00 to 12:00 (or 19:00 to 05:00). This difference in the selection of timing for defining peak and off-peak parameter values between Modena and Osijek reflect the distinct traffic characteristics in each city.
  - **Scalar inputs**: Most scalar parameters are the same or close to the reference inputs given in Appendix 1. Some changes include: the average daily travel time budget is set to 54 minutes (instead of 73 minutes). The car occupancy rates in the peak hours (1.48) and off-peak hours (1.58) are both slightly higher than the reference values. The share of people with a driving license is larger than the reference values, with 85% of employed people and 77.5% of all persons owning driving license. This is subsequently corrected with a cap value through the vector data.
  - **Vector and matrix inputs**: these inputs are collected using a similar procedure as in the Modena case. Data that is not available directly from official sources are estimated based on local knowledge. Input data suggest the rate of driving license ownership will continue to grow, which may deviate from reality. To correct this parameter, a cap of 80% is applied to the share of people, as well as the employed people, owning driving license.
- Pécs: The MARS data are specially developed during the OPTI-UP Activity 1.2.
  - **Zoning**: With the support of an external expert, 27 zones are delineated, based largely on homogeneous land use types and socio-demographic characteristics (Figure 8).
  - **Transport modes**: The mode of transport in Pécs include walking, cycling, bus, as well as private cars.
  - **Time frame**: The analysis period spans from 2024 to 2040, with a one-year time step. MARS parameter values related to the peak period are taken based

on the PT operation and traffic status from 6:30 to 8:30, while the parameter values related to the off-peak period is considered from 8:30 to 10:00. The timing of peak and off-peak hours is again different from Modena and Osijek, reflecting the distinct traffic patterns of each case study area.

- **Scalar inputs**: Most scalar parameters modified based on the reference inputs given in Appendix 1. Some changes include: the average daily travel time budget is set to 70 minutes (instead of 73 minutes). The households are assumed to move every 24 years, and the vehicle retirement age is assumed to be at 16 years, both higher than the reference value.
- **Vector and matrix inputs**: due to the lack of existing VISUM models, these inputs are collected mainly through external calculations involving socio-demographic statistics and GIS analysis. Data that is not available directly from official sources are estimated based on local knowledge.

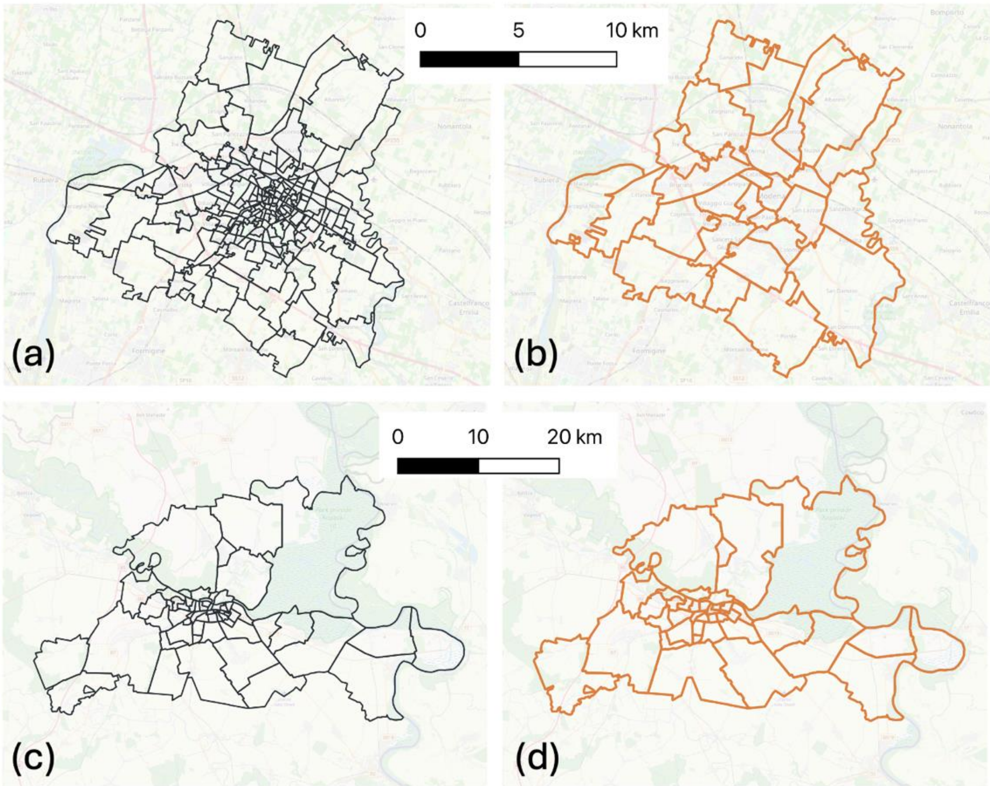



*Figure 7. Comparisons of zones used in VISUM and MARS. (a) VISUM zones for Modena. (b) MARS zones for Modena. (c) VISUM zones for Osijek. (d) MARS zones for Osijek.*

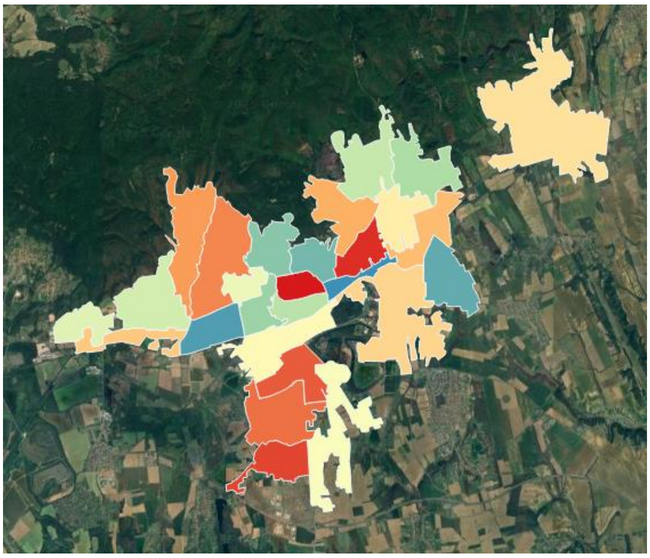


*Figure 8. Zones for transport models in Pécs.*

## 4.3 Challenges

The gap analysis and data collection process revealed several key challenges related to the integration of transport models for PT planning. These include:

- **Inconsistencies in data definitions and availability across countries:** Even for seemingly standard indicators, such as the distribution of jobs by sector, definitions and classifications vary significantly by countries. For example, in Vienna (from which the reference values for the MARS model are taken), employment data is categorized by production and service sectors. In contrast, Modena reports employment figures by public, private, and non-profit sectors, making direct comparison or data standardization difficult.
- **Limited internal capacity for data collection and analysis:** Some aspects of data preparation, particularly those involving geospatial analysis (e.g., extracting census data based on specific zonal boundaries), require technical expertise that may not be available within smaller municipal administrations. This lack of internal capacity can become a barrier to effective model development and integration.
- **Existing transport planning zones can greatly facilitate the modelling tasks:** For cities without an existing transport model, developing a base model requires substantial time and expertise, beginning with the definition of transport planning zones. While this is a necessary first step, it is also a time-consuming one that increases the complexity of subsequent data collection. Establishing consistent and reliable zonal data is critical, as it forms the foundation for modelling activities and provides the basis for generating demand inputs for both the PTV Lines transport model and the LUTI model MARS.

Given these conditions, the modelling process in some cities progressed more slowly than others or than initially anticipated. One key lesson from the gap analysis of the modelling status in the case study cities is the importance of early awareness regarding data prerequisites and institutional readiness. Greater awareness of such foundational gaps at the outset could help anticipate challenges and allocate time and resources more effectively, thereby reducing delays in future modelling efforts.

# 5 Transport Modelling Results

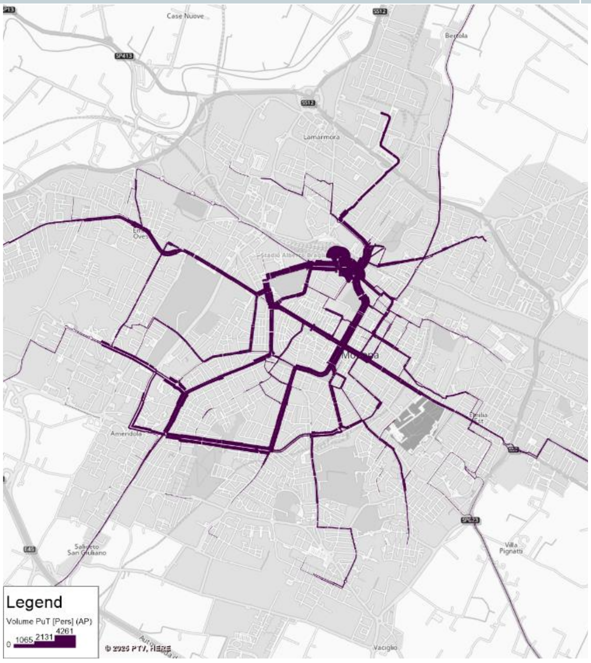
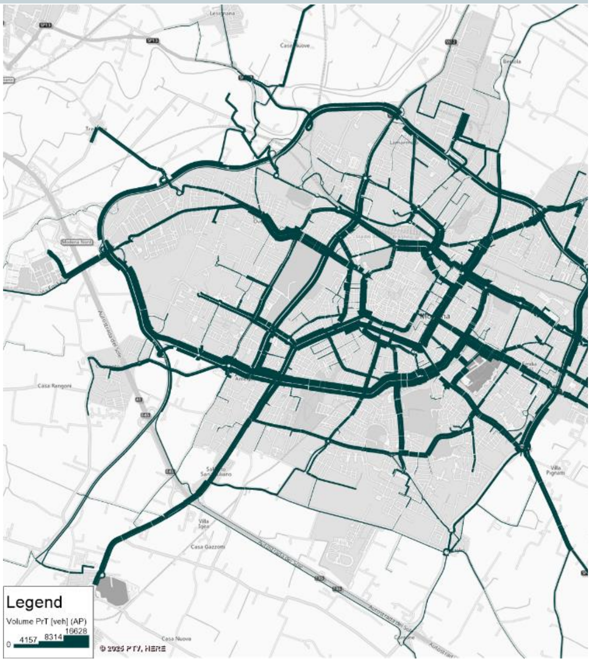
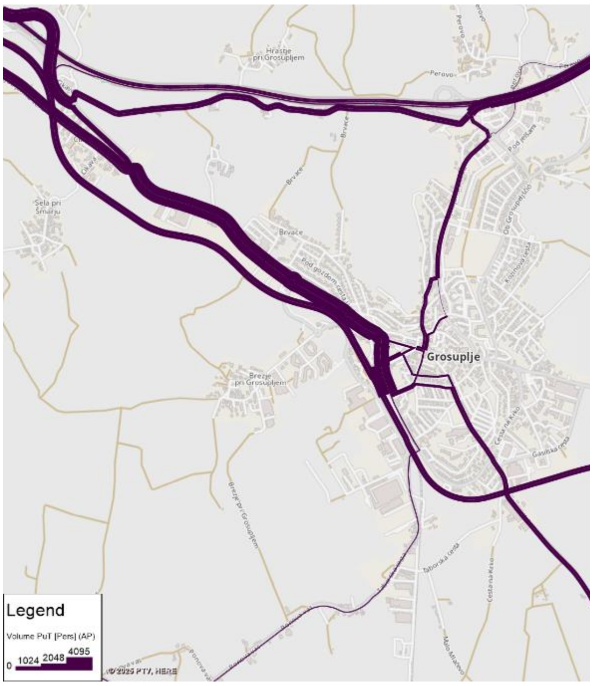
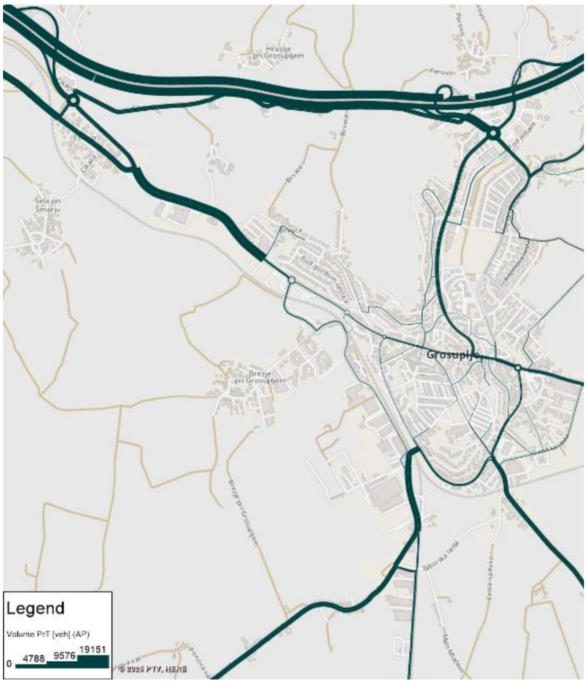
In this section, results from the baseline scenarios are reported for each case study area. Section 5.1 focuses on introducing the results of the four-step model (PTV VISUM), transit simulation (PTV Lines), Section 5.2 focuses on the LUTI model (MARS) results. In addition, validation procedures and results are given in Section 5.3.

## 5.1 PTV Visum/Lines baseline scenarios

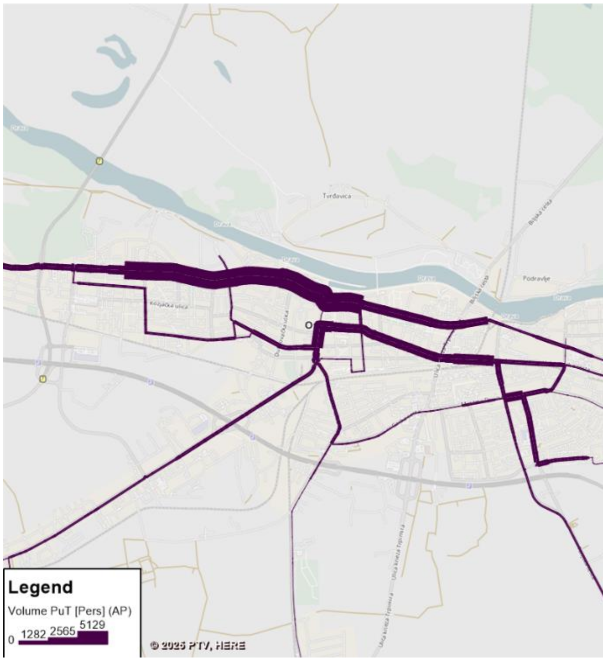
The PTV Visum and Lines software provides a comprehensive framework for modelling and analysing transport networks, allowing for the evaluation of various scenarios and their impacts on traffic flow. This section focuses on the baseline scenarios derived from the OPTI-UP case study area, which encompasses several cities with distinct transport characteristics.

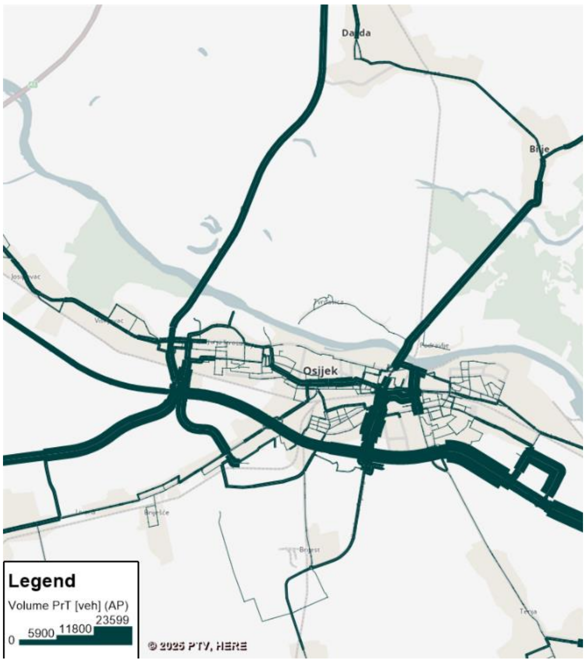
Figure 9 below presents the traffic load on the network for private and public transport for each city that is a part of the OPTI-UP case study area. Each city has specific data depending on the level of detail modelled, as well as demand and supply factors influencing transport patterns.

Using this data, various analyses can be conducted depending on the needs of each city. As there is a focus on PT, there is an opportunity to analyse the efficiency and reliability of PT services, including factors such as frequency, punctuality, and others.

| | PT volume [Pers] | Private transport volume [veh] |
| --- | --- | --- |
| **Modena** |   |   |
| **Grosuplje** |   |   |

**Osijek**


Legend
Volume PuT [Pers] (AP)
0 1282 2565 5129
© 2025 PTV, HERE


Legend
Volume PrT [veh] (AP)
0 5900 11800 23599
© 2025 PTV, HERE

**Paks**


Legend
Volume PuT [Pers] (AP)
0 314 628 1255


Legend
Volume PrT [veh] (AP)
0 15296 30591 61182

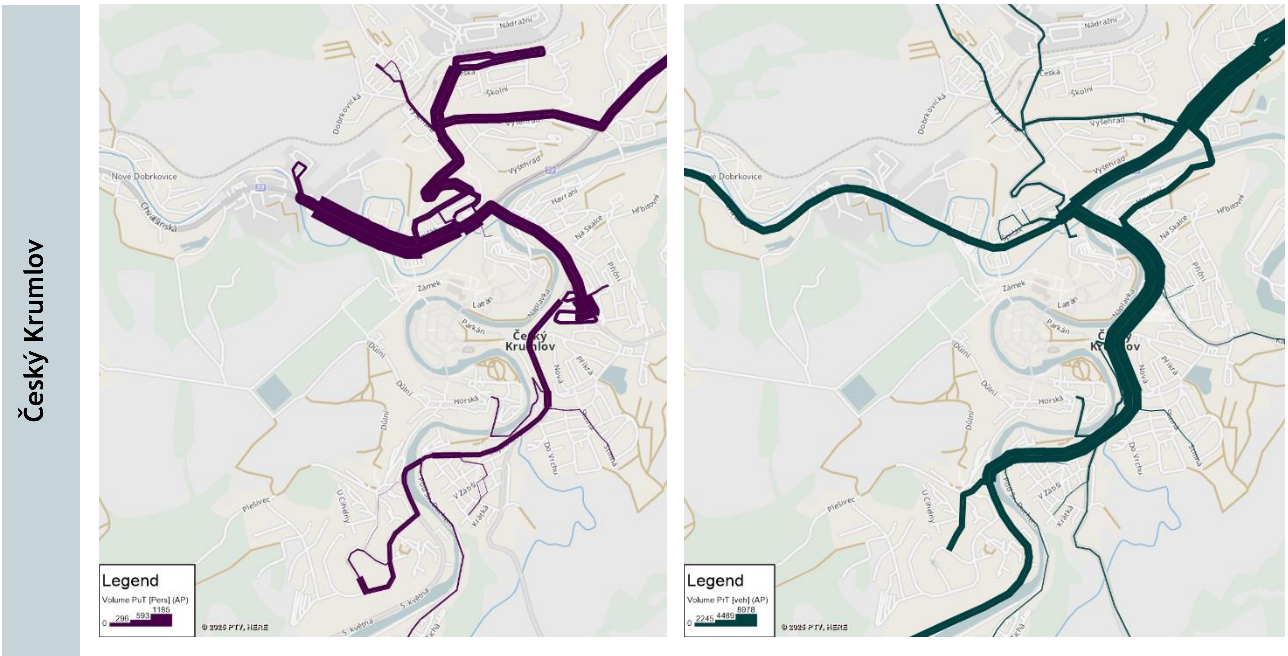



*Figure 9. Volumes in public transport (number of trips) and volumes in private transport (number of vehicles) on the transport network for each of five cities*

Figure 10 illustrates the PT offerings in Pécs, showcasing the bus lines based on GTFS data provided by the local transport operator, Tüke Busz. Due to the lack of data on demand and zoning for Pécs, the demand analysis will be conducted using the PTV Lines software after the necessary data is collected.

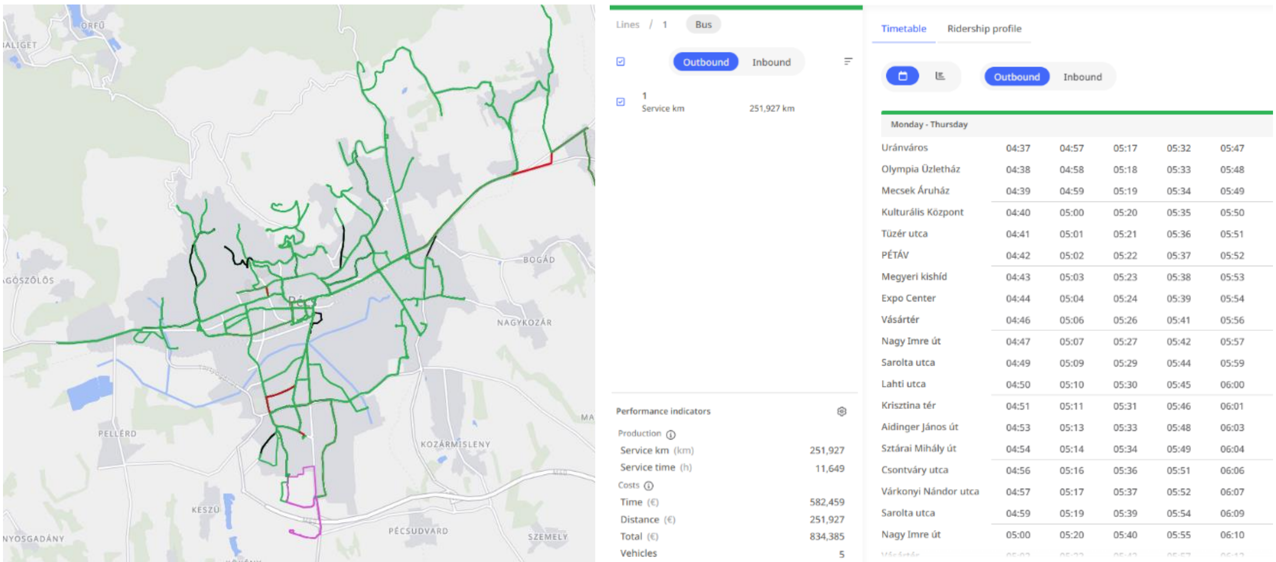



*Figure 10. Public transport lines with timetable example in Pécs*

Figure 11 presents an accessibility map derived from the central area of Pécs, focusing on departure times and acceptable transfer durations based on the existing PT network. The accessibility map serves as an instrument for assessing the efficiency and effectiveness of the PT system. By analysing the travel times and transfer options available to residents, it is possible to identify potential gaps in service and areas for improvement.

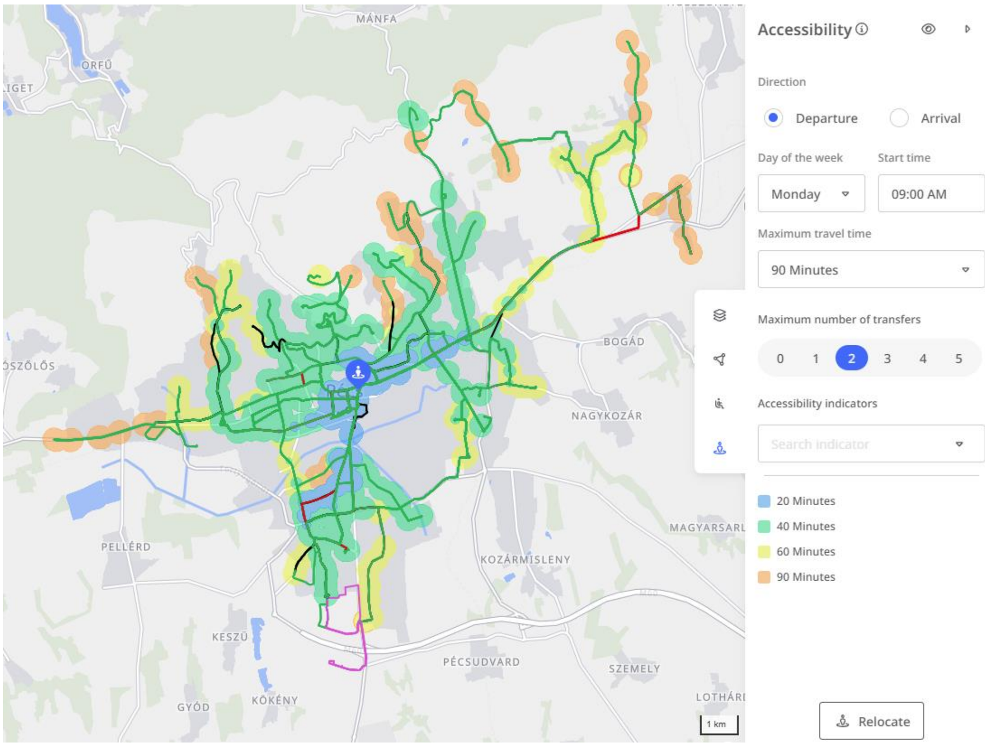



*Figure 11. Accessibility with public transport supply in Pécs*

## 5.2 MARS baseline scenarios

The MARS modelling results for the baseline scenarios in Modena, Osijek and Pécs are presented below. These baseline models are developed using current data and projected future trends as inputs. They are calibrated using mode split data obtained from recent transport surveys in each city. To illustrate the key outputs of the MARS model, results are shown for mode split ratio by number of trips and passenger-kilometres, as well as total passenger- and car-kilometres. Additionally, growth rates are compared across population figures and the various transport parameters mentioned above.

### Modena

The data collection process for establishing the MARS model for Modena is an integral part of the overall modelling activity, as detailed in Section 4.2. While much of the data is derived from existing geospatial sources (e.g., population census) and the VISUM model (e.g., travel distances and speeds between zones), additional approximations were required for data not readily available.

For the base case scenario, several assumptions and approximations are made:

- **Growth Rates:** Several growth rate variables are required, but for the base case, only projections for the number of residents are available. Growth rates for the number of workplaces, employment rate, and household income are set to zero, leaving them open for future scenario adjustments. The number of driving license holders is assumed to remain constant, reflecting the saturation level already reached in Central Europe.

- **Vector Data Estimates:** Some scalar data are either partially available or missing entirely. In such cases, estimations are made using local expert input. This includes average monthly rent (available only for selected zones), the ratio of living to built-up areas, the number of vacant flats, and land-use related variables. The share of employment by sector is also approximated due to a mismatch between Modena's sector definitions and those required by the model. For other missing variables, national averages are applied uniformly across all zones, for example, for the average space and number of workplaces per premise.
- **Calibration Benchmark:** The model is calibrated using the mode split ratios observed in 2017 as part of the Sustainable Urban Mobility Plan (SUMP) prepared in 2020.

The MARS simulation results for Modena are presented in Figure 12. As shown in Figure 12(a), car-based trips account for the highest trip share initially, exceeding 60%, while walking, cycling, and bus transport each contribute approximately 10–13%. When assessed by passenger-kilometres, the dominance of car travel becomes even more pronounced, reaching 77% in the first year and staying above 70% till the end of the simulated period (Figure 12(b)). The mode share based on distance declines progressively from bus to cycling and then walking, reflecting differences in speed and typical trip lengths across these transport modes.

A similar pattern emerges in total passenger-kilometres, where car travel remains the highest (Figure 12(c)). Vehicle-kilometres are available only for private cars and are lower than car passenger-kilometres, due to shared trips involving multiple passengers (Figure 12(d)).

Regarding growth trends, passenger-kilometres increase at a faster rate than population growth across all transport modes except cars. The sharpest increases are seen in cycling, which is predicted to increase by 47% till the end of 2040. This on the one hand comes from the growth of population and attractiveness of cycling, but on the other hand is due to the low absolute value of the passenger-kilometres associated with cycling (only 10% of car trips). The growth trend is also seen for PT and walking trips, while car travel shows the slowest growth till around 2033 and start to decline (Figure 12(e)). The differences in passenger-kilometre growth across transport modes can be attributed to the fact that friction factors for active modes and buses remain constant, while those for cars increase slightly due to congestion. Additionally, it's possible that more residents are located in areas with better conditions for active modes and bus use, which may also contribute to the trend.

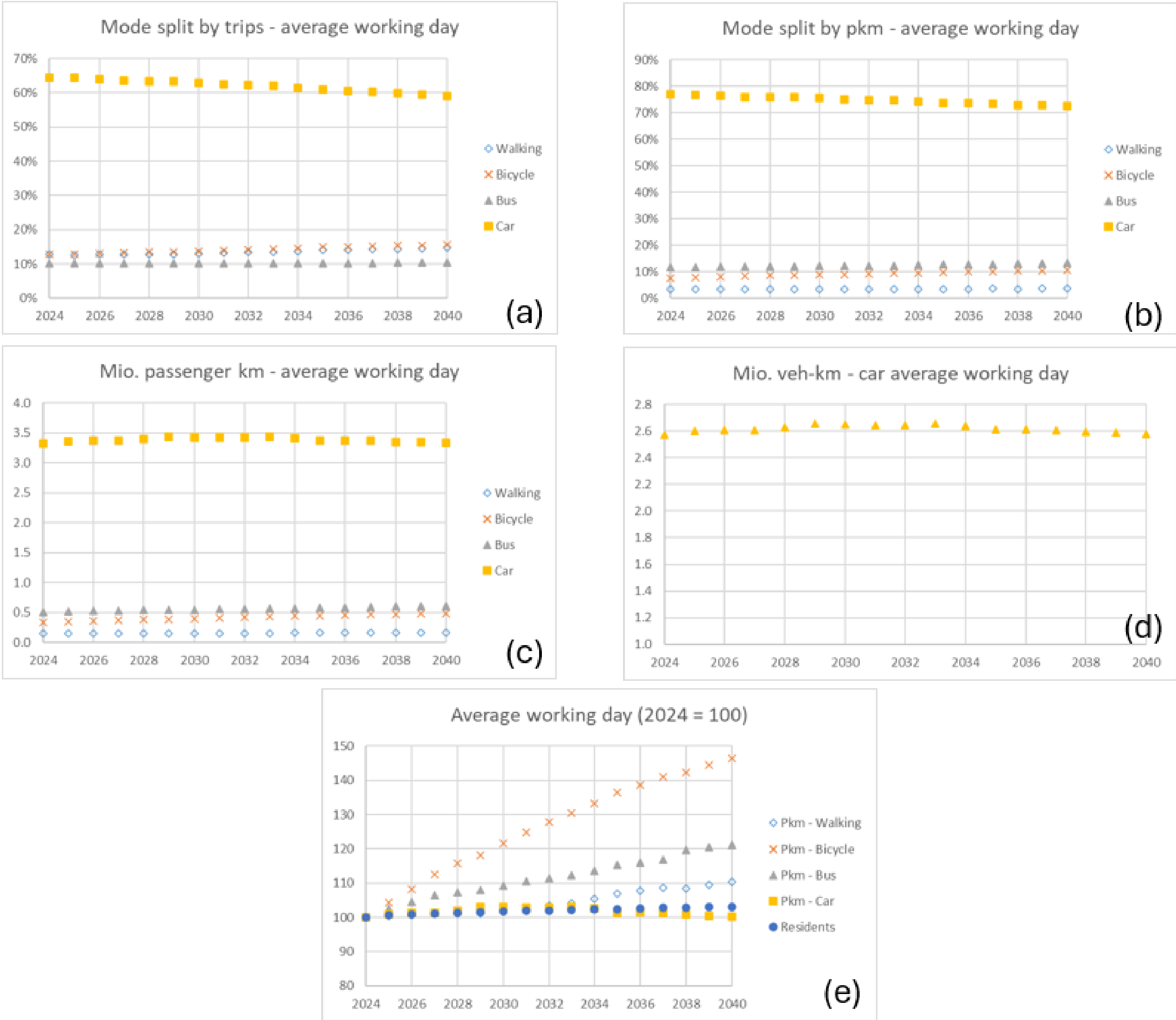



*Figure 12. MARS baseline simulation results for Modena. (a) mode split by number of trips; (b) mode split by passenger-kilometres; (3) Passenger-kilometres (in million); (4) Vehicle-kilometres (in million, private car only); (5) growth rates.*

### Osijek

The data collection process for establishing the MARS model for Osijek is similar to that for Modena, including vector data from geospatial sources, GIS calculations, VISUM models, and additional approximations.

Apart from the data collection detailed in Section 4.2, other key assumptions used for the baseline scenario include:

- Growth Rates: unlike Modena, the number of residents is expected to shrink in all zones. This aligns with the demographic change in Osijek in the past three decades. Comparatively, the number of workplaces and employment rate, household income are all expected to grow.
- Vector Data Estimates: There are several vector inputs that are estimated due to missing official information, or a different definition with the MARS inputs. This includes the ratio of living space to built-up space, areas available for residential and economic development, etc. In addition, the number of rental flats is zero in

some zones as they are not attractive for residential living, and no online advertisements are found regarding rental properties there.

- **Matrix Data Inputs**: while most of the matrix data inputs are available from reliable sources such as ORS tools in QGIS and VISUM. In Osijek, there are zones that are not accessible by PT. Since MARS does not accept empty values as inputs, the corresponding matrix values are replaced by large numbers (e.g., 999 for distance- or duration-related variables).
- **Validation Benchmark:** The model is compared against the mode split data collected during December 5, 2019 to January 31, 2020.

The MARS simulation results for Osijek are presented in Figure 13. As shown in Figure 13(a-b), car-based trips account for the highest share, approximately 52-55% of total trips and around 80% in terms of passenger-kilometres. This closely matches the observed values (as will be further discussed in Section 5.3 on Validation), reflecting Osijek's current car dependency (see Figure 13(c-d)). This level of car dependency could potentially be addressed through network optimization measures in future scenario modelling in Activity 1.3.

A key observation is the non-monotonic trend of car usage, which increases till around 2033 and decreases. This may be due to the relatively fast declination of population in the study area (blue series in Figure 13(e)), combined with increasing rate of employment (0.81% annually), household income (3.27% annually), and high driver license ownership rate (quickly reaches 80%). These trends fuel the increase of the car usage for some time, until the population decline effect dominates, where the overall usage of cars reduces. The impact of declining number of residents is also visible in the passenger-kilometres for all modes, both in terms of the absolute values (Figure 13(c)) and the relative ratio compared to the first year (Figure 13(e)). In one long-term scenario that will be explored in Activity 1.3, the impact of land development in certain zones of Osijek will be modelled.

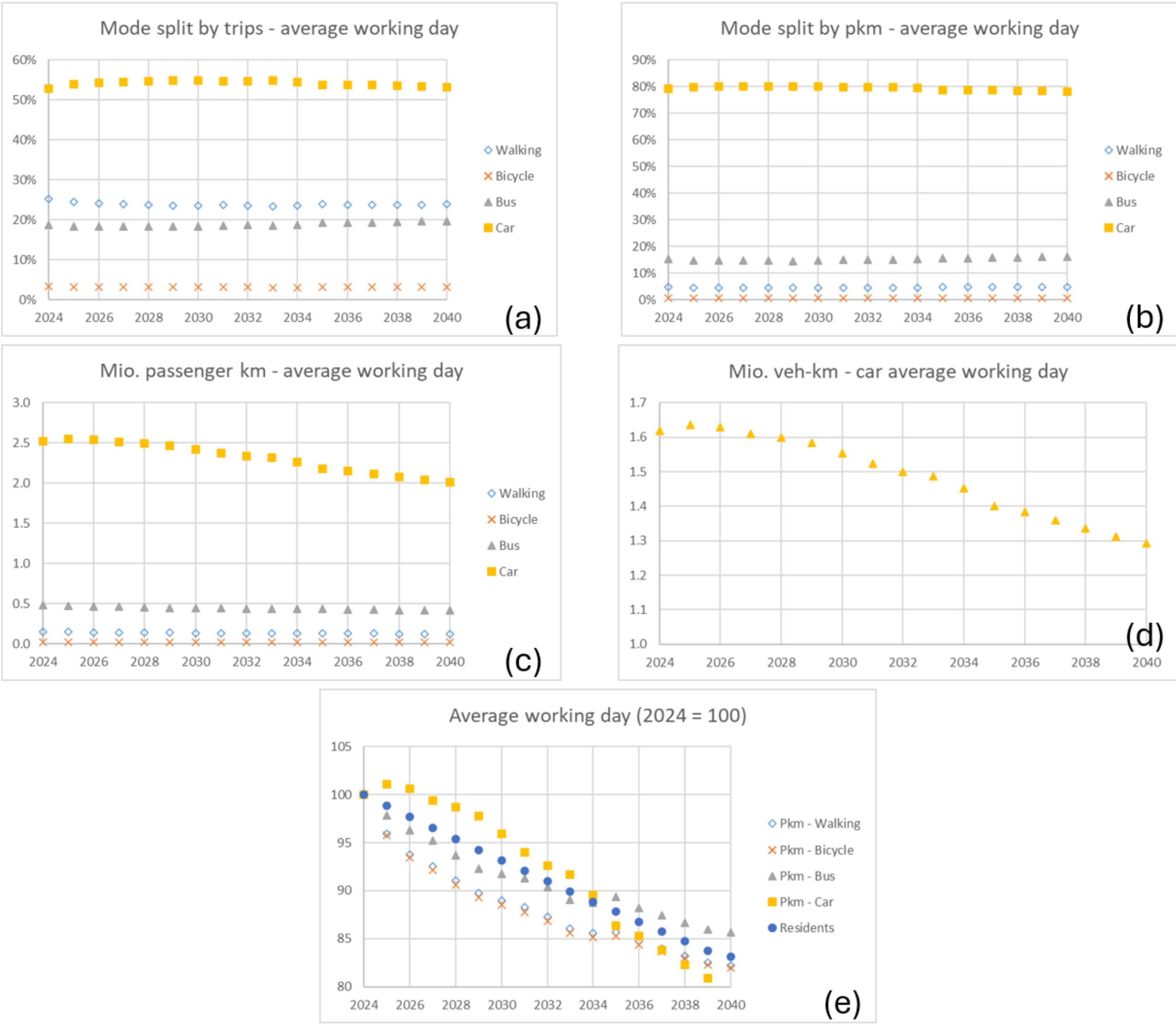



*Figure 13. MARS baseline simulation results for Osijek. (a) mode split by number of trips; (b) mode split by passenger-kilometres; (3) Passenger-kilometres (in million); (4) Vehicle-kilometres (in million, private car only); (5) growth rates.*

## Pécs

The data collection process for establishing the MARS model for Pécs faces unique challenge due to the lack of existing VISUM models. As a result, external consultants are commissioned to generate the inputs directly for MARS based on various types of existing statistics from national or regional level (particularly related to socioeconomics). GIS calculations are used to establish some matrix values, such as the estimated distances between zone pairs.

Apart from the data collection detailed in Section 4.2, other key assumptions used for the baseline scenario include:

- Growth Rates: similar to Osijek, the number of residents is expected to shrink in all zones for Pécs, but at a slower rate of -0.5% annually. The number of workplaces, employment rate, household income, and driving license ownership rates are all expected to remain comparable to the current levels.

- Scalar data: most of the scalar data inputs are assumed to be comparable to the default value as listed in Appendix 1. There are a few modifications, including a slightly lower average daily travel budget (70 minutes), a longer household dwell time at the existing home before moving (24 years), and longer service life of cars (16 years).
- Vector Data Estimates: The vector data inputs are supplied by external consultants based on existing statistics about the socioeconomic and land use of the study area.
- Matrix Data Inputs: The matrix data are either calculated using GIS tools (e.g., those related to the distances and travel times of walking, cycling and car trips), or supplied by external consultant based on the transport system of the local area. A limitation is related to the identification of zones, where nearby settlement areas are not included, thus missing in the matrix inputs.
- Validation Benchmark: The model is compared against the mode split data from the 2017 SUMP data. The share of public transport is noted to be 38%, which might be overestimated when referred to other case study areas (10% in Modena, and 17-19% in Osijek).

The MARS simulation results for Pécs are presented in Figure 14. The share of car trips and bus trips are comparably high (both around 40% in Figure 14(a)), due to the calibration against the empirical data as mentioned previously. This is followed by the mode share of walking (at around 15%), and by cycling (less than 5%). If comparing different modes by the passenger-kilometres (Figure 14(b)), the share of PT is the highest at above 50%, followed by cars at 40-45%. This reflects that although there are higher number of car trips, the average distance travelled by bus is still longer than that of car trips. When weighted by travel distances, the shares of walking and bicycle trips reduce compared to the mode split presented in in Figure 14(a), both below 2%.

Similar to Osijek, Pécs also face a declining population (blue series in Figure 14(e)). This drives the overall declining transport activities. Unlike Osijek, the decline of passenger-kilometres across all modes is more modest in Pécs, which could attribute to the slower rate of population decline in Pécs (-0.5% per year) than Osijek (-1.18% per year).

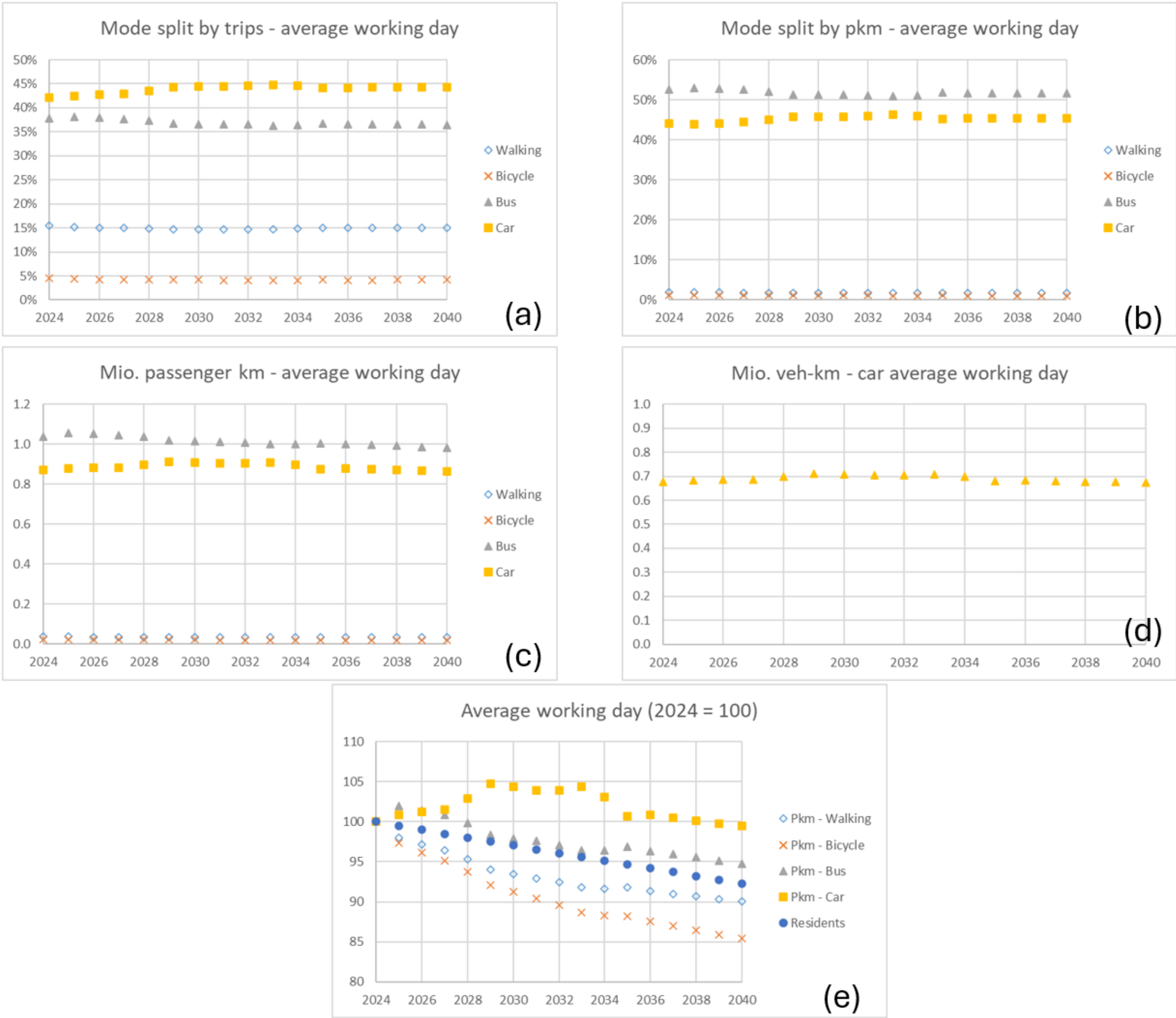



*Figure 14. MARS baseline simulation results for Pécs. (a) mode split by number of trips; (b) mode split by passenger-kilometres; (3) Passenger-kilometres (in million); (4) Vehicle-kilometres (in million, private car only); (5) growth rates.*

## 5.3 Model Validation

### VISUM validation

Validation is a process in transport modelling that ensures the model accurately represents real conditions and reliably predicts the usage PT and other transport services. It involves comparing the model's outputs with observed data to identify discrepancies and areas for improvement. This process helps assess the model's performance, increase its reliability, and ensures that it meets the standards needed for effective decision-making in transport planning.

Table 4 indicates whether comprehensive validation steps are conducted during the development of the model. These steps represent standard practices in the validation process to ensure the accuracy and reliability of the model's outputs. It can be seen that the procedures of calibration and validation vary considerably among different case study areas, with bigger cities (Modena, Osijek, Paks) and newer models (Paks and Český Krumlov) demonstrating a more comprehensive validation process.

*Table 4. VISUM validation steps*

| Calibration/Validation step | Modena | Grosuplje | Osijek | Paks | Český Krumlov |
|---|---|---|---|---|---|
| Network accuracy check | × | × | × | × | × |
| Public transport supply check | × | × | × | × | × |
| Trip distribution check | × | | × | × | |
| Mode choice check | × | × | × | × | |
| OD matrices check | × | × | × | × | × |
| Volume data check after assignment | × | × | × | × | × |
| Iterative adjustments | × | | × | × | |
| Statistical evaluation (GEH statistic or $R^2$ coefficient of determination) | | | × | | |
| Validation with independent data (not used for calibration) | | | × | × | |

The validation of the VISUM model is conducted by comparing the PT demand derived from the D.1.1.1. dataset (OPTI-UP, Oct 2024) with the results generated by the VISUM software. The annual PT transport passenger demand data in D.1.1.1 are divided by the number of working days in 2023 (250 days) to obtain the average daily demand.

Subsequently, the total number of trips from the demand matrix within the study area can be verified. By comparing the total trips generated by the VISUM model with the calculated average daily demand from the D.1.1.1 dataset, the model's performance and its alignment with real-world PT usage can be assessed. Any identified discrepancies will be further investigated to enhance the accuracy and reliability of the model in representing PT demand and usage in the area.

*Table 5. VISUM validation results.*

| Policy intervention | DRT | | Network optimisation | | Alternative fuel vehicles | |
|---|---|---|---|---|---|---|
| **Cities** | **Modena** | **Grosuplje** | **Osijek** | **Paks** | **Pécs** | **Český Krumlov** |
| **VISUM daily PT demand** | 19,738 | 598 | 25,424 | 6,317 | NA | 2,007 |
| **Statistics of daily PT demand** | 34,069 | 1,138 | 24,471 | 4,445 | 137,008 | 2,040 |

There are several differences in the comparison shown in Table 5 due to various reasons. For instance, the discrepancies between the VISUM daily PT usage and the statistical daily demand can be attributed to different areas of data collection and varying supply situations. While cities like Český Krumlov and Osijek show acceptable differences in data comparison, other cities exhibit more significant variations.

Given that areas for improvement have been identified, it is expected that the models will be further updated to the project's needs during the development of local plans and scenario development.

**LUTI validation**

The MARS model results are validated against the mode split (number of trips ratio) from recent mobility surveys as the benchmark data in the case study cities. For all three case study cities, it can be seen that after model calibration, the differences in mode split between the simulated results and the benchmark data is less than 1% for all modes. For Osijek, empirical data exist regarding peak and off-peak (OP) period of the day, which are displayed in Table 6 as well. In addition, as mentioned in the baseline MARS model results for Pécs in Section 5.2, the share of PT trips in the survey data for Pécs (38%) is quite high. Given this is the best empirical data available, the MARS model is still calibrated to reflect the indicated high share of PT trips in Pécs.

It is worth mentioning that the calibration is based on the result of the first year (2024, as indicated in Table 6). The simulated trends (till 2040 for all three cities) cannot be calibrated since data are not available for the future years. Nevertheless, the good match between the MARS model output and the empirical data in the base year indicate that the model is suitable to proceed to further scenario analysis that will be carried out in Activity 1.3.

*Table 6. MARS validation outcomes.*

| Cities | Modena | | Osijek | | Pécs | |
|---|---|---|---|---|---|---|
| **Mode** | **Survey (2017)** | **MARS (2024)** | **Survey (2019-2020)** | **MARS (2024)** | **Survey (2017)** | **MARS (2024)** |
| **Pedestrian** | 12.9% | 12.7% | Peak: 18.4%<br>OP: 26.2% | Peak: 18.5%<br>OP: 26.5% | 16% | 15.5% |
| **Bicycle + micromobility** | 12.4% | 12.8% | Peak: 2.9%<br>OP: 3.4% | Peak: 3.0%<br>OP: 3.4% | 4% | 4.5% |
| **Bus + tram** | 10.1% | 10.2% | Peak: 17.5%<br>OP: 18.9% | Peak: 17.1%<br>OP: 19.0% | 38% | 37.8% |
| **Car** | 64.6% | 64.3% | Peak: 61.3%<br>OP: 51.5% | Peak: 61.4%<br>OP: 51.1% | 42% | 42.2% |
| **Total** | 100% | 100% | Peak: 100%<br>OP: 100% | Peak: 100%<br>OP: 100% | 100% | 100% |

# 6 Model Capacity Building

## 6.1 Capacity building seminars

Within the first six weeks of Activity 1.2, two webinars were conducted to strengthen the knowledge and capacity of PPs in using the PTV VISUM transport model and the LUTI model MARS. Each webinar lasted one hour, comprising a 40-minute presentation followed by a 20-minute Q&A session. Participants also had the opportunity to submit additional questions after the webinar.

### PTV VISUM webinar

The PTV VISUM webinar was held on December 5, 2024, and attracted a total of 19 participants, including at least one representative from each project partner (PP). The session was delivered by the lead partner, EY Croatia, and covered the following topics:

- Definitions and purpose of transport modelling
- Overview of transport modelling software and their characteristics
- Supply and demand models
- Development of a transport model using the four-step modelling framework

The primary objective of the webinar was to familiarize the PPs with the theoretical framework underlying the PTV VISUM model, as well as to highlight key comparisons with other modelling approaches—such as macroscopic, trip-based, and multi-modal models.

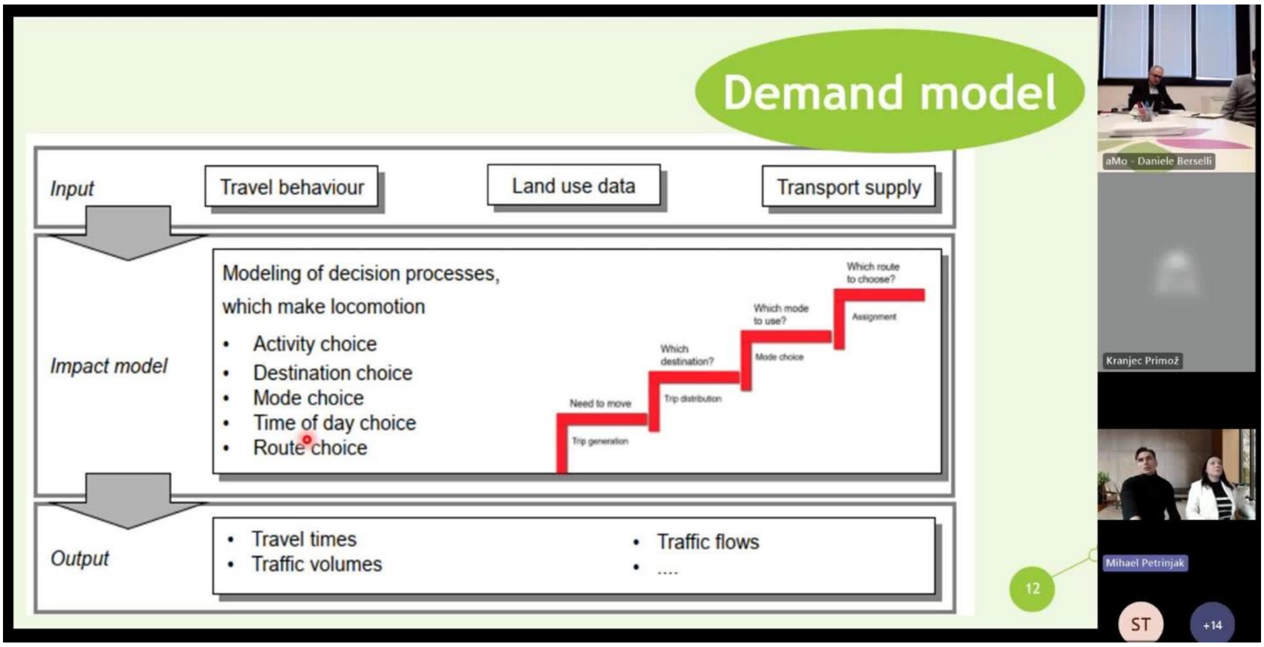



*Figure 15. Screenshot of the PTV VISUM capacity building webinar.*

### LUTI MARS webinar

The LUTI model MARS training webinar was held one week after the VISUM webinar, on December 12, 2024, with a total of 10 participants in attendance. The lower number of attendees is due to the fact that only three pilot areas will be testing the MARS model

(Modena, Osijek and Pécs). The webinar included at least one representative from each of these three pilot areas, as well as all relevant technical partners. The session was delivered by TU Wien, the technical partner responsible for supporting the development of the MARS model and co-lead of Activity 1.

The webinar covered the following topics:

- Theoretical foundations of MARS: System Dynamics, Causal Loop Diagrams (qualitative modelling), and Stock-Flow Diagrams (quantitative modelling)
- Key components of the MARS model: parameters, assumptions, as well as the transport and land-use sub-models
- Software environment and setup
- A case study on the impact of autonomous vehicles

The primary objective of the webinar was to introduce participants to the theoretical foundations of LUTI modelling and the system-dynamics-based MARS model — both of which are new areas for most project partners. The session also emphasized that, in contrast to the PTV VISUM model, the MARS model is dynamic, operates at a more macroscopic level, and requires the use of larger aggregated zones.

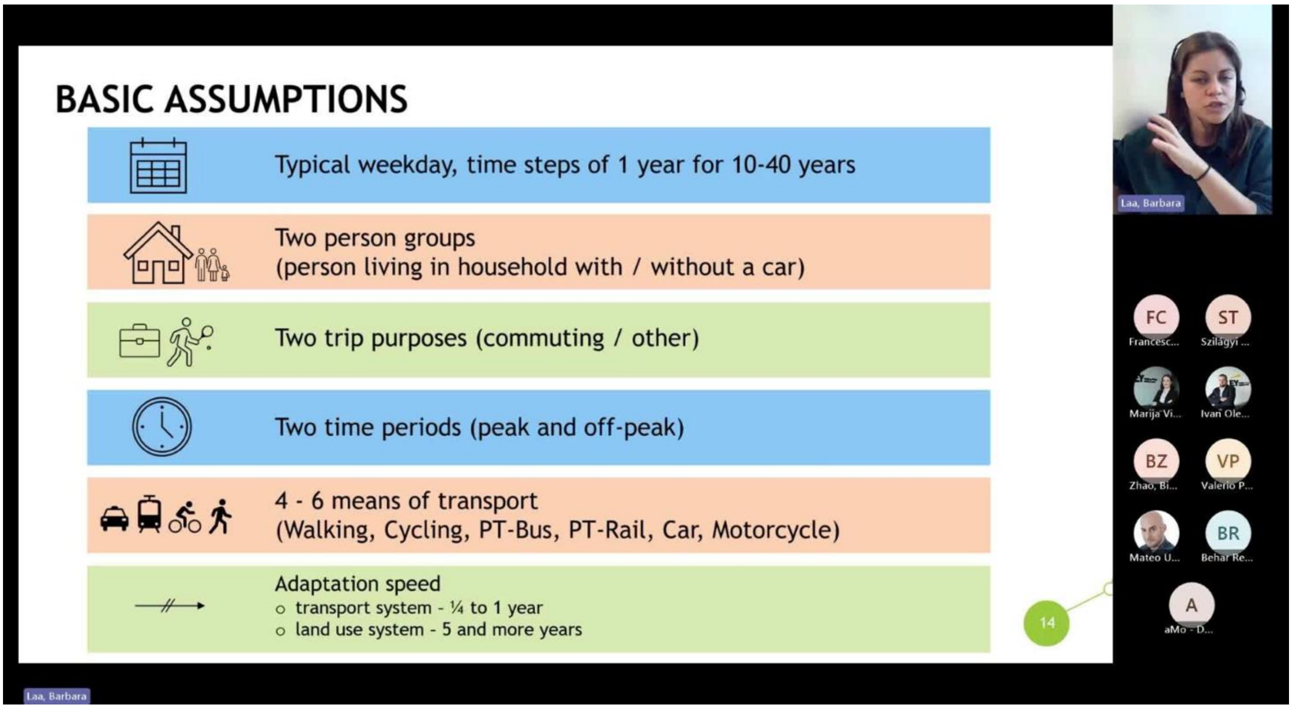



*Figure 16. Screenshot of the MARS capacity building webinar.*

## 6.2 Model engagement logbook

In addition to the webinars, a more interactive Excel-based logbook has been developed to support the PPs in periodically evaluating their knowledge of the model and tracking activities related to the modelling work. The logbook template is given in Appendix 2. The logbook consists of three key components:

A. **Recommended timeline:** A 10-month timeline has been established, outlining key milestones that the PPs are expected to achieve throughout the modelling process.

These milestones are linked to performance scores outlined in Section B of the logbook. For example, by the end of the first five months following webinars and several regular meetings PPs are expected to have a high-level understanding of the transport planning models. By the end of Activity 1.2 (around month 7 of modelling-related activities), all partners should be able to carry out a high-level interpretation of the modelling results.

B. **Self-checking questions**: This section includes a mix of general and model-specific questions. The general questions require short written responses, focusing on foundational knowledge such as the objectives of modelling in the case study area. The model-specific questions use a 0–10 confidence scale, where 0 indicates no knowledge and 10 indicates strong understanding. All PPs are required to respond to questions related to the four-step transport model. For case study areas that include LUTI modelling, additional LUTI-specific questions are provided.

C. **Detailed logbook**: The logbook serves as a structured record of the modelling activities. It allows PPs to document dates, activities, challenges encountered, and new skills acquired throughout the process.

Table 7 summarizes changes in the self-assessment scores submitted by project partners (PPs) at two key points in Activity A1.2: before the model capacity-building webinars and towards the end of the activity (or after the final major model engagement sessions). Overall, the results show increased familiarity and understanding of both the PTV VISUM and LUTI MARS models across most PPs. Initial familiarity levels varied widely, for example, Modena demonstrated strong prior knowledge of PTV VISUM, whereas Osijek started with a much lower baseline. Post-engagement improvements are especially notable in general model understanding. However, progress in more advanced areas, such as scenario adaptation for the MARS model, is less evident, as these aspects are scheduled for deeper exploration in Activity A1.3. Some limitations remain: for instance, Pécs reported relatively high self-assessed scores by the end of A1.2, which may reflect a degree of subjectivity or overestimation. As stakeholder engagement deepens, these perceptions are expected to become more accurate. The self-checking tool will continue to be used in future activities to monitor progress and guide support.

*Table 7. Summary of self-checking question scores.*

| Policy intervention | | DRT | | Network optimisation | | Alternative fuel vehicles | |
|---|---|---|---|---|---|---|---|
| Cities | | Modena | Grosuplje | Osijek | Paks | Pécs | Český Krumlov |
| *Prior to A1.2* | | | | | | | |
| PTV VISUM | General | 7.5 | 3.25 | 1.25 | 2.25 | 4.5 | 6.25 |
| | Input/output | 6 | 1.5 | 1.5 | 2.5 | 5 | 6.5 |
| | Calibration and validation | 7 | 0 | 0 | 1 | 4 | 8 |
| LUTI MARS | Theory | 2.3 | -- | 0 | -- | 3 | -- |
| | Implementation | 0 | -- | 0.75 | -- | 4 | -- |
| | Scenario adaptation | 0 | -- | 1.25 | -- | 3 | -- |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *After webinars/modelling tasks* | | | | | | | |
| **PTV VISUM** | **General** | 7.5 | 4.75 (↑) | 4.25 (↑) | 4.5 (↑) | 8 (↑) | 6.75 (↑) |
| | **Input/output** | 6.5 (↑) | 1.5 | 4.5 (↑) | 6 (↑) | 9 (↑) | 7 (↑) |
| | **Calibration and validation** | 7 | 1 (↑) | 4 (↑) | 3 (↑) | 8 (↑) | 8 |
| **LUTI MARS** | **Theory** | 4.3 (↑) | -- | 3.7 (↑) | -- | 8 (↑) | -- |
| | **Implementation** | 5.5 (↑) | -- | 5 (↑) | -- | 8 (↑) | -- |
| | **Scenario adaptation** | 0 | -- | 2.5 (↑) | -- | 8 (↑) | -- |

# 7 Conclusion and Next Steps

In Activity A1.2 of the OPTI-UP project, all partners collaborated to develop transport models, collect new data, and establish baseline scenarios. Specifically, transport models have been developed for all six case study areas. This includes four-step models using PTV VISUM for five of the areas, and a simplified transit supply model using PTV Lines for the sixth. Additionally, LUTI models based on the MARS software have been created for three of the larger case study areas.

Throughout A1.2, partners engaged in a variety of model capacity-building activities, ranging from webinars to self-assessment tools to track progress and prepare the knowledge base for upcoming scenario modelling in A1.3.

A key finding from the modelling activities is the **uneven level of modelling knowledge and capacity** among project partners. While most transit operators in small- and medium-sized cities lack in-house modelling capabilities, their awareness and prior experience vary significantly. This underlines a common dilemma in using models as evidence-based decision-making tools: their value is widely recognized yet developing models and incorporating them for decision making remain to be perceived as complex and resource-intensive to various degrees by many stakeholders.

Another central theme of the modelling activities is the knowledge transfer. By experimenting with different types of models based on the characteristics and resources of each case study area, the project team aims to **enhance understanding of model suitability and selection criteria given specific local contexts**. For instance, the four-step model serves as a general-purpose tool for short-term impact forecasting, whereas the LUTI model, though more aggregated, allows for dynamic simulation of feedback loops by encompassing not just transport systems but also land use elements like settlements and workplaces. In cases where modelling capacity is limited, simpler tools based on standard data can still provide valuable insights and serve as a tangible step towards more comprehensive modelling analysis tasks.

Furthermore, to overcome existing challenges, the project team emphasises the importance of **maintaining a basic inventory of tools and data that even small- and medium-sized cities should consider**. Such an inventory greatly facilitates modelling efforts when resources become available. This includes a clear understanding of local zones, their activity centres, travel demand characteristics, and potential future developments, which are core elements used across most transport models for both short- and long-term forecasting.

Looking ahead, a key next step is to identify specific scenarios that will support both the local plan (A1.3) and the pilot implementation (A2.1). Thanks to the flexibility of the models, a wider range of scenarios can be tested than those that can be actually implemented. This broader testing will help optimise the pilot plans for OPTI-UP and may also inform future implementations in the project areas. Model engagement will continue, and by collaborating on defining and refining scenarios, the small- and medium-sized cities involved in OPTI-UP are expected to gain a deeper understanding of the models' benefits and limitations. This process could also help pave the way for incorporating model insights into future planning and decision-making.

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# Appendix 1. Default Scalar Parameter Values in MARS

*Table 8. Default Scalar Parameter Values in MARS*

| Variable | Unit | Reference value |
|---|---|---|
| Average number of outgoing trips home - workplace per employed and workday | trips/day | 0.90 |
| Average daily travel time budget | min | 73 |
| Av. household moves every xx years | years | 18 |
| Housing units planned per thousand inhabitants in base year | units/1000 people | |
| Walking speed pedestrian peak | km/h | 4.50 |
| Walking speed pedestrian off peak | km/h | 3.60 |
| Threshold for road capacity development - Percentage of development is higher than ... | percentage | 5% |
| Speed drops below ... | km/h | 30.00 |
| Car Occupancy rate - peak | -- | 1.25 |
| Car Occupancy rate - off peak | -- | 1.30 |
| Car Drivers Licence -employed persons | percentage | 70% |
| Car Drivers Licence - all persons | percentage | 50% |
| Others costs - Car | Euro/km | 0.26 |
| Share of car costs perceived | percentage | 10% |
| Survival rate cars | years | 10 |

# Appendix 2. Model Engagement Logbook

## A. Recommended timeline

### Recommended timeline

Since different PPs have different starting point, the schedule below is based on relative timeline

| Test score | Time & Mile | Description | Actions needed to reach the next level |
|---|---|---|---|
| 0~1 | M0 | no or low familiarity of the model | |
| 1~5 | M1 | High-level overview of transport planning models<br>- basic modelling concepts<br>- different types of models<br>- role and benefits in supporting planning decision making | Attend model capacity building webinars |
| 5~7 | M2 | High-level interpretation of modelling results<br>- understand input requirements (what new data need to be collected?)<br>- able to interpret basic outputs for VISUM (e.g., congestion, mode share)<br>- Modena, Osijke & Pécs: able to interpret basic outputs for MARS | 1-2-1 consultation<br>Supplementary material |
| 7~9 | M3 | Critical assessment of scenario results<br>- understand model and scenario assumptions<br>- able to compare results from different scenarios<br>- able to critically assess the validity and implication of the results | 1-2-1 consultation |
| 9~10 | M5 | confidence in using transport models for planning decision making | peer exchange and 1-2-1 consultation |

<-- Goal: all PPs reach 5 after the model capacity building seminar (Task 1.2.5)

## B. Self-checking questions

### Modena -- Self-cheking questions

#### B.1 Initial questions

*Instructions > please answer the following open-ended questions in 1-2 sentences.*
*you may want to provide new answers as time goes by.*

| | | Dec, 2024 (before webinar) | Dec, 2024 (after webinar) | Jan, 2024 | Feb, 2024 | Mar, 2024 |
|---|---|---|---|---|---|---|
| B.1.1 | What is the specific aim of conducting VISUM modelling for your city? | Text later | Text later | Text later | Text later | Text later |
| B.1.2 | What is the specific aim of conducting MARS modelling for your city (if applicable)? | Text later | Text later | Text later | Text later | Text later |
| B.1.3 | What specific indicators are you interested in obtaining from the models? | Text later | Text later | Text later | Text later | Text later |

#### B.2 Self-checking questions (Transport modelling)

*Instructions > please answer the following questions with a score of 0 (I have no idea) to 10 (I know it very well).*
*you may want to provide new answers as time goes by.*

| | | Dec, 2024 (before webinar) | Dec, 2024 (after webinar) | Jan, 2024 | Feb, 2024 | Mar, 2024 |
|---|---|---|---|---|---|---|
| ***B.2.1*** | ***General*** | | | | | |
| B.2.1.1 | How familiar are you with the general concept of transport modeling and its purpose in transport planning? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.2.1.2 | How well do you understand the role and benefits of modeling in improving transportation systems and supporting sustainable urban mobility? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.2.1.3 | How familiar are you with the different types of transport models (e.g., demand models, network models, macroscopic models)? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.2.1.4 | How familiar are you with the theoretical concepts of creating transport model (e.g. 4-step transport modeling) | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| ***B.2.2*** | ***Input/output*** | | | | | |
| B.2.2.1 | How familiar are you with the input and output data of transport models such as VISUM? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.2.2.2 | How confident are you in interpreting high-level results from transport models, such as changes in travel times, congestion, or mode shares? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| ***B.2.3*** | ***Calibration and validation*** | | | | | |
| B.2.3.1 | How falimiar are you with the terms like calibration and validation in context of transport modeling? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |

#### B.3 Self-checking questions (LUTI modelling)

*Instructions > Modena, Osijek and Pécs: please answer the following questions with a score of 0 (I have no idea) to 10 (I know it very well).*
*you may want to provide new answers as time goes by.*

| | | Dec, 2024 (before webinar) | Dec, 2024 (after webinar) | Jan, 2024 | Feb, 2024 | Mar, 2024 |
|---|---|---|---|---|---|---|
| ***B.3.1*** | ***LUTI -- theory*** | | | | | |
| B.3.1.1 | How familiar are you with the concept of Causal Loop Diagram (CLD)? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.1.2 | How familiar are you with the concept of stock-flow model? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.1.3 | How familiar are you with the concept of generalised cost and utility-based mode choice? | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| ***B.3.2*** | ***LUTI -- implementation*** | | | | | |
| B.3.2.1 | Inputs: I understand the difference between scalar, vector and matrix inputs in MARS. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.2.2 | Simulation: I know how many time periods per day are considered in MARS simulation. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.2.3 | Outputs: I understand what are the basic types of outputs avaialble in MARS. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.2.4 | Outputs: I know MARS only calculates the total numbers of PT passengers from one zone to another zone, not the numbers of passengers for a specific PT line. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| ***B.3.3*** | ***LUTI -- scenario adaptation*** | | | | | |
| B.3.3.1 | I know how to model an added bus line in MARS. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.3.2 | I know how to model the increase or decrease of bus frequency in MARS. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.3.3 | I know how to model an added DRT service in MARS. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |
| B.3.3.4 | I know what needs to be changed if an existing line served by diesel bus is now served by electric bus. | 0-10 later | 0-10 later | 0-10 later | 0-10 later | 0-10 later |

## C. Detailed logbook

### Modena -- Model engagement logbook

| Date | Activity | Issues encountered | New kowledge/skill learnt | What is still missing | Further comments |
|---|---|---|---|---|---|
| *Example* | | | | | |
| 05.12.2024 | VISUM: Attended VISUM training webinar | How VISUM models are suppose to support transport planning? | 4-step transport model, demand models, macroscopic model. | How do we know the validity of the model output? | |
| 09.12.2024 | LUTI: Read the introduction slides of MARS. | Does MARS provide results on the predicted traffic volume of a new line? | System Dynamics modelling | How to use MARS and VISUM results simultaneously for planning? | |
| 15.01.2025 | VISUM: Contracted external expert for model development | NA | NA | NA | |
| 03.02.2025 | VISUM:Attended 1-2-1 feedback session with EY | Scenario definition: what scenarios should we consider? | Model the DRT line in VISUM | Obtaining and interpreting VISUM results under different scenarios | |

*Your answers*