SUTLab Framework Guide

Technical Infrastructure and Methodological Implementation

IMPLEMENTATION OF SUSTAINABLE URBAN DEVELOPMENT GOALS IN TRANSPORT BACHELOR DEGREE

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INTRODUCTION

The rapid transformation of urban mobility systems – driven by digitalisation, environmental challenges, and the growing demand for sustainable transport solutions – has significantly increased the importance of data-driven approaches in the fields of transport and logistics. Modern cities face complex problems related to traffic congestion, greenhouse gas emissions, air and noise pollution, inefficient freight management, and increasing pressure on urban infrastructure due to urbanization and the rise of e-commerce. In this context, developing sustainable urban transport systems requires not only the implementation of innovative technological solutions but also the use of advanced methods for the collection, processing, and analysis of transport data.

The purpose of this guide is to present and evaluate the modern technologies, tools, and methodological approaches used for data collection, monitoring, visualisation, and information analysis within sustainable urban transport systems. Particular attention is paid to the role of digital technologies, Intelligent Transport Systems (ITS), environmental monitoring tools, transport modelling platforms, and visualisation instruments that support decision-making in urban mobility and logistics management.

Interest in sustainable urban transport and urban logistics is steadily increasing as cities strive to mitigate the negative impacts of transport activities while ensuring the efficient movement of passengers and goods. Transport systems are a cornerstone of economic development and social interaction; however, they also significantly impact the environment and quality of life through congestion, energy consumption, emissions, accidents, and the inefficient use of urban space. These issues have become especially acute with the rapid growth of "last-mile" delivery and the increasing complexity of urban freight flows. Traditional monitoring methods often fail to fully capture the dynamic and heterogeneous transport processes occurring in modern cities.

A lack of reliable and comprehensive transport data remains a major obstacle to the effective planning and management of sustainable transport systems. Local authorities, transport operators, and urban planners increasingly require accurate, timely, and spatially integrated data to support infrastructure development, traffic management, environmental assessment, and strategic planning. Modern sensor technologies, transport monitoring systems, geographic information systems (GIS), and transport modelling software suites offer new opportunities to research traffic flows and evaluate the effectiveness of sustainable urban mobility measures.

This guide is developed within the context of European practices in sustainable urban transport and the integration of Sustainable Development Goals (SDGs) into the educational process. The methodological foundation of the guide is primarily **SDG 11 – "Sustainable Cities and Communities,"** which emphasizes the need for safe, affordable, inclusive, and environmentally oriented transport systems. The content also aligns with the priorities of the

European Green Deal, "Smart City" concepts, green logistics, and the digital transformation of transport education.

Higher education institutions play a vital role in transforming the transport sector by training specialists capable of solving complex, interdisciplinary tasks in sustainable mobility. Modern transport education requires a combination of technical knowledge and competencies in digital technologies, data analysis, environmental assessment, and systems thinking. Therefore, this guide bridges theoretical principles with practice-oriented learning, allowing students to work with modern laboratory equipment, transport modelling software, environmental monitoring systems, and digital visualisation tools.

The structure of the guide reflects the interdisciplinary and applied nature of the subject matter:

- **Chapter 1** explores European practices and policies in the field of sustainable urban transport and mobility.
- **Chapter 2** is dedicated to the technical specifications of laboratory equipment and software used for traffic flow analysis, environmental monitoring, transport modelling, and digital visualisation.
- **Chapter 3** provides methodological recommendations for laboratory and practical sessions focused on field data collection, traffic flow analysis, transport process modelling, environmental assessment, and the determination of Key Performance Indicators (KPIs) for transport systems.

The use of modern teaching laboratories and digital technologies fosters the practical competencies necessary for a career in modern transport and logistics. The integration of ITS, environmental monitoring tools, GIS technologies, VR/AR platforms, Unmanned Aerial Vehicles (UAVs), and transport modelling software ensures that students gain hands-on experience addressing real-world urban mobility challenges. This approach adheres to the principles of competency-based education and promotes the synergy of academic learning, technological innovation, and sustainable urban development goals.

In conclusion, this guide aims to support the moderniaation of transport education by establishing the methodological and technical foundations for applied learning in sustainable urban transport. By integrating European practices, sustainability principles, and modern digital technologies into the curriculum, we aim to prepare specialists capable of designing, managing, and improving efficient, safe, and resilient urban mobility systems.

CHAPTER 1. EUROPEAN PRACTICES OF SUSTAINABLE URBAN TRANSPORT AND THEIR INTEGRATION INTO THE EDUCATIONAL PROCESS

1.1. EU STRATEGIC OBJECTIVES: THE EUROPEAN GREEN DEAL AND THE URBAN MOBILITY FRAMEWORK

The environmental effects of transportation are not limited to the release of harmful gases into the atmosphere. Soil and water contamination caused by fuel leaks, high levels of noise and vibration, and negative impacts on human health in urban environments are among the multifaceted problems of this sector.

The ecological impact of transportation is:

- Atmospheric impact – CO_2, NOx, CH, and particulate matter (PM2.5, PM10) reduce air quality, leading to an increase in respiratory diseases.

- Noise pollution – Road and air transport generate noise ranging between 70 –95 dB in urban areas, which reaches a critical threshold for human health.

- Soil and water pollution – Fuel and lubricating oil leaks disrupt the biological balance of hydro-ecosystems.

Many European cities are global frontrunners when it comes to transport innovation, sustainable urban mobility planning, and the implementation of ambitious climate targets. Cities are still facing major challenges to further improve their mobility and transport systems. At the same time, they still have to fully tackle the negative consequences of transport for society, health, and environment, namely the creation of greenhouse gas emissions, air, and noise pollution as well as congestion and road fatalities.

Those challenges – as well as the vision on the way forward – have been highlighted in the following documents:

- European Green Deal.
- Sustainable and Smart Mobility Strategy (SSMS).
- Fit for 55 package.
- Zero Pollution Action Plan.

In order to be able to offer the urban population a good quality of life, the problems generated by the transport sector must be assessed, analysed, and solved using the appropriate mechanisms specific to the region from which they come. To solve them, the main objectives of sustainable urban mobility must be taken into account: the quality of life of the inhabitants, accessibility, safety, economic efficiency, and environmental quality.

For each region, metropolis, or city where measures to reduce pollution and CO_2 emissions are needed, the specific elements of these must be determined - the characteristics that make them different from other cities / regions.

Sustainable transport includes vehicles, energy, infrastructure, roads, railways, airlines, shipping, and terminals. The sustainability of transport is measured by the efficiency of the transport system, as well as the impact on the environment. Sustainable mobility is characterised by a range of integrated options, including social and environmentally friendly transport options, such as walking, cycling, green vehicles, and the use of public transport, including sharing.

The European Green Deal

Climate change and environmental degradation are an existential threat to Europe and the world. To overcome these challenges, the **European Green Deal** will transform the EU into a modern, resource-efficient, and competitive economy, ensuring:

- No net emissions of greenhouse gases by 2050.
- Economic growth decoupled from resource use;
- No person and no place left behind.

The European Commission has adopted a set of proposals to make the EU's climate, energy, transport, and taxation policies fit for **reducing net greenhouse gas emissions by at least 55% by 2030**, compared to 1990 levels.

Figure 1. The European Green Deal objectives (Source: https://www.rescoop.eu/toolbox/europes-green-new-deal-whats-in-it-for-energy-citizens)

The document was finalised in 2019 and consists of a package of policy initiatives towards a green transition, with the ultimate goal of achieving climate neutrality by 2050. This is an improvement on the Paris Agreement, which the EU and all its Member States have ratified and which set a target of keeping global warming to a maximum of +1.5°C compared to pre-industrial levels. It stresses the need for all policies to contribute to tackling climate change through action in all economic sectors (energy, transport, industry, agriculture, and sustainable finance).

The key objectives of the Green Deal are to make the EU the world’s first climate-neutral zone by 2050, to reduce pollution and restore a healthy balance in nature and ecosystems.

Objectives:

- Climate neutrality – Drastically reducing greenhouse gas emissions to make the EU the world's first climate-neutral zone.
- Circular economy – A new economic model in which products are reused, repaired and recycled, reducing waste and conserving resources.
- Clean industry – Promoting greener, more sustainable and energy-efficient industries.
- A healthier environment – Carrying out a plan for the regeneration of nature and working towards zero pollution.
- More sustainable agriculture – Greener farming practices to protect the environment while ensuring healthy, affordable food.
- Climate Justice and Equity – Making a plan to make the transition just and inclusive to help those most affected by the transition and leave no one behind.

Reducing pollution in cities as a result of road traffic is one of the objectives pursued by the European Green Deal. In this regard, it envisages proposing more ambitious standards for pollutant emissions (other than CO_2) from internal combustion engine vehicles. At the same time, it is necessary to revise the CO_2 emission standards for passenger cars and light commercial vehicles for the post 2025 period, which draw a clear trajectory towards electromobility. In parallel, the opportunity to include road transport in the EU ETS (EU Emissions Trading System) as a complementary measure to the emission standards will also be explored.

Mobility as a Service (MaaS):

Transport climate policies need to integrate technology-driven measures on standards, fuels used and infrastructure, through pricing, urban mobility planning, and digital services such as Mobility as a Service (MaaS). EU climate and environmental policies address MaaS solutions as part of the 'smart and sustainable choices' pillar, supporting both widespread modal shift and more efficient transport demand management. The predominant role of MaaS should be largely based on its potential to change users’ preferences for individual transport solutions. Optimising multimodal transport networks should thus be the main objective, as an alternative to the use of private vehicles through accessibility benefits, not just through the competitiveness of services.

Involvement of the academic environment in the achievement of the objectives:

For inclusive transport services, collaboration between local authorities, politicians, specialists, academia and civil society is needed. Analysing the current initiatives, several patterns emerge regarding the roles of stakeholders and academic involvement:

- The government's positioning ranges from legislative facilitator (Finland) to direct operator (Vienna) and research funder (Sweden), fundamentally shaping the ecosystem.

- Academic roles cover an important spectrum, from peripheral research contributors (Finland, Germany) to strategic research leaders (Sweden) and evaluation specialists (UK, Australia), but rarely as primary testing platforms, even though the literature emphasizes this potential.

- Private sector involvement predominates in market-oriented models (Finland, Netherlands), while public scrutiny characterises other approaches (Belgium, Austria), influencing innovation dynamics and sustainability pathways.

The importance of sustainable mobility to achieve the goals:

Traditionally, society depends on efficient transport systems, but at the same time, cities are negatively affected by transport due to greenhouse emissions, air pollution, noise pollution, traffic jams, and limited public spaces. Compared to traditional mobility, the objectives of sustainable mobility in metropolitan areas are aimed at reducing risks, reducing the number of journeys, multimodality, and accessibility, as shown in Figure 2.

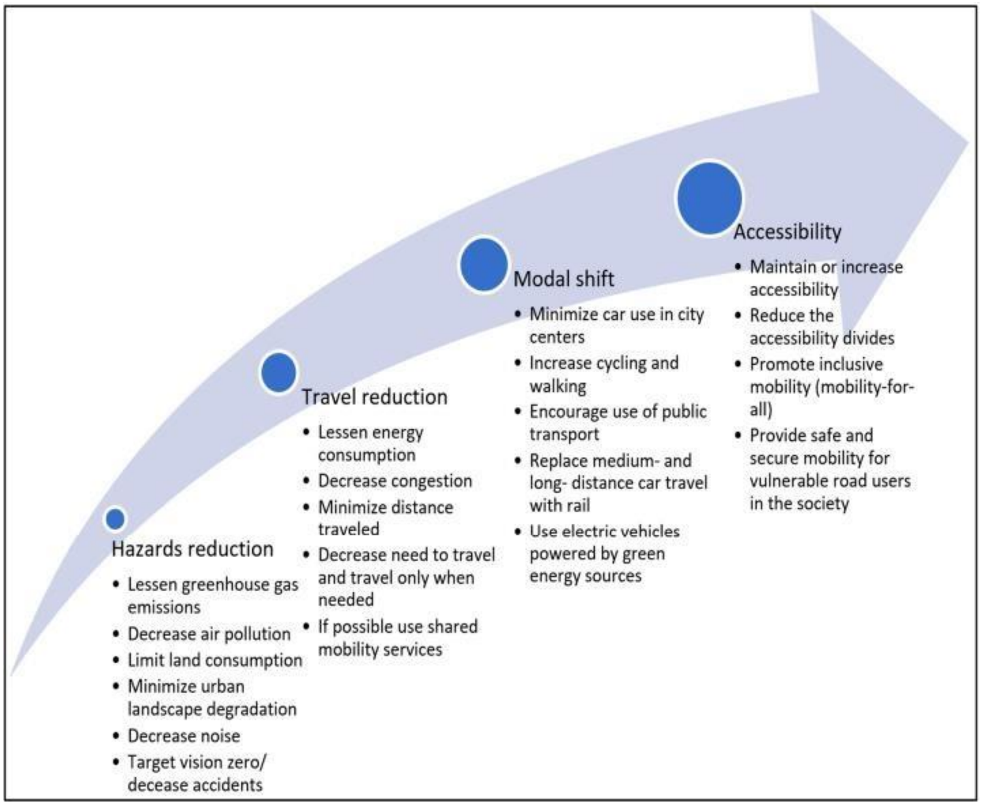

Figure 2. Goals of sustainable mobility in metropolitan areas (Source - Bokolo, A.J. Examining Sustainable Mobility Planning and Design for Smart Urban Development in Metropolitan Areas. Urban Sci. 2025)

The urban mobility framework for Europe

Urban mobility is defined as the movement of individuals within urban areas, influenced by diverse transport modes and urban transformations, which accounts for the complexities of practicing mobility alongside changes in lifestyles and movement practices. Urban mobility is one of the most problematic issues in urban planning. Transportation planning is highly dependent on simulation, and all policies are based on real-time data that could be improved through smart city development. Moreover, as mobility in urban areas is the main source of pollution and CO_2 emissions, it has always been at the core of sustainable development concerns.

Key Trends for Transport Planning and Urban Mobility are:

- Inclusive, Safe and Accessible Mobility.
- Environmental Sustainability.
- Electrification of Transport.
- Autonomous Vehicles.
- Sustainable Urban Planning and Proximity Cities.
- Smart Mobility, Data Analytics.
- Mobility and Logistics Hubs.

In 2020, the European Commission released an Urban Mobility Framework, which delivers on the Sustainable and Smart Mobility Strategy Action Plan. The mobility strategy's main objective was: A fundamental transport transformation - plan for green, smart, and affordable mobility. The Framework comprises four proposals, which collectively will modernise the EU's transport system. The new Urban Mobility Framework focuses on:

- A smart and sustainable TEN-T network.
- Increasing long-distance and cross-border rail traffic.
- Intelligent transport services for drivers.
- Clean, greener, and easier urban mobility.

Furthermore, these objectives were presented by the CIVITAS Initiative, as it focuses on addressing the mobility challenges that stem from economic activity - such as congestion, emissions, and noise. Public transport, walking, and cycling play a starring role in the proposal, as well as e-mobility, last-mile logistics, and the development of multimodal hubs. Moreover, the Framework sets out guidance for cities on how to introduce Sustainable Urban Mobility Plans. Local and regional authorities are also provided with mapped out funding options for the implementation of these priorities.

The European Commission Work Group for Sustainability worked on strengthening cooperation and sharing good practices on facilitating mobility and access to the city, benefiting businesses. Three targeted reports have looked in particular into:

- Mobility service providers for sustainable passenger transport – analysing regulatory and operational frameworks that impact their effectiveness and sustainability. The report identifies good practices demonstrating that such challenges can be effectively addressed through coordinated and forward-looking policies.

- Road freight transport – examining how freight operators access European cities under evolving urban mobility policies. The report discusses access regulations and their interaction with low- and zero-emission fleets. The report includes approaches and good practice examples helping to reconcile efficient freight access with wider societal and environmental objectives.

- Coach access to cities, especially coach tourism – documenting challenges, and identifying practices that support both sustainable urban mobility and the economic vitality of coach travel.

The EU Urban Mobility Framework (https://op.europa.eu/en/publication-detail/-/publication/ad816b47-8451-11ec-8c40-01aa75ed71a1) strives to improve the quality of life of the EU urban population by addressing urban mobility challenges (such as air pollution, congestion, accessibility, urban road safety, growth of e-commerce, etc.) and by increasing the share of sustainable transport modes (in particular public transport and active mobility) as well as zero-emission urban logistics, last mile deliveries and urban fleets (taxis and ride-hailing services).

Figure 3. Goals of EU Urban Mobility Framework (Source: https://transport.ec.europa.eu/transport-themes/urban-transport/sustainable-urban-mobility_en)

The new framework also covers making urban transport resilient, environmentally friendly, and energy-efficient by identifying zero-emission solutions for urban logistics.

Measures to achieve the targets include obligations to deploy recharging and refuelling infrastructure for electric and hydrogen vehicles in cities, dedicated funding for cities under the EU Climate Neutral and Smart Cities Mission, and the integration of sustainable urban logistics plans into sustainable urban mobility plans.

European policies will be complemented by guides for on-demand passenger transport, such as on-demand transport, to ensure that it can become more sustainable and provide efficient services to citizens, while helping the single market to function smoothly and safely. Urban mobility is included in the ongoing legislative work on the provision and processing of commercially sensitive data for multimodal digital mobility (MaaS) services and a common European data space for mobility. The European Commission will also explore what digital solutions are available to enable low-emission zones that are more efficient and user-friendly, as well as other types of regulation of urban vehicle access.

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1.2. SUSTAINABLE URBAN MOBILITY POLICY IN THE EUROPEAN UNION

Urban mobility policy in the European Union has evolved from traditional car-oriented transport planning toward citizen-oriented and sustainability-focused governance frameworks. Contemporary European mobility policy recognises that transport systems should not only provide efficient movement of people and goods, but also contribute to environmental, social and economic sustainability, which includes social inclusion, public health, road safety, accessibility, economic competitiveness, climate resilience, and urban quality of life. This transformation reflects a broader change in European urban development: transport is no longer understood only as a technical infrastructure sector, but as a strategic policy field that shapes how people access opportunities, how cities use public space, and how urban areas respond to climate, energy, social, and technological challenges (Banister, 2008).

From Car-Oriented to Sustainable Urban Mobility Vision

In the decades following the Second World War, urban transport planning in many European countries was strongly influenced by rapid motorisation, economic growth, suburban expansion, and rising private car ownership. During the 1950s–1970s, the private car became a dominant element of urban mobility and was widely associated with economic progress, individual freedom, and modern urban development. As a result, transport planning was mainly oriented toward increasing road capacity, improving vehicle flows, reducing travel time for cars, and adapting urban space to automobile use.

Over time, the limitations of this car-oriented model became increasingly visible. European cities experienced growing congestion, air pollution, greenhouse gas emissions, noise, road safety problems, and the loss of public space to traffic and parking. Dependence on private cars also created social inequalities in access to urban opportunities. People without access to a car, including children, older people, low-income households, persons with disabilities, and residents of peripheral areas, often face reduced access to employment, education, healthcare, and social activities. These challenges gradually shifted the focus of transport planning from the movement of vehicles to the accessibility, safety, environmental quality, and social inclusiveness of urban mobility systems.

The oil crises of the 1970s became an important turning point in this transition. Concerns about energy dependency and fuel shortages encouraged European countries and cities to reconsider the efficiency and resilience of car-dependent transport systems. Public transport, walking, cycling, and more energy-efficient forms of mobility gained stronger political and planning attention. During the 1980s and 1990s, this shift was reinforced by the wider concept of sustainable development, particularly after the publication of the *Brundtland Report Our Common Future* in 1987, which defined sustainable development as "*development that meets* *present needs without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development, 1987).

The European Union (EU) gradually incorporated these sustainability principles into transport planning through strategic documents, directives, funding instruments, and urban mobility initiatives. Initially, EU action was closely linked to environmental regulation, including vehicle emissions and air quality. Later, the policy agenda expanded from reducing the negative impacts of transport toward transforming the organisation of mobility systems. The European Commission's White Paper *European Transport Policy for 2010: Time to Decide* marked an important step in this direction by emphasising the need to reduce excessive dependence on private cars, strengthen public transport, promote intermodality, and support environmentally friendly modes (European Commission, 2001).

This policy direction was reinforced by the 2011 White Paper *Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System*, which introduced the objective of reducing greenhouse gas emissions from transport by 60% by 2050 compared with 1990 levels. The document promoted integrated, multimodal, and low-carbon transport systems and confirmed that urban mobility is a crucial field for achieving European climate and resource-efficiency objectives (European Commission, 2011).

A further stage in EU urban mobility governance was the introduction of *Sustainable Urban Mobility Plans* (SUMP) through the European Commission's Urban Mobility Package in 2013. A SUMP is not only a transport plan, but a strategic governance process that helps cities analyse mobility problems, define long-term objectives, involve stakeholders, select integrated measures, implement actions, and monitor results. This approach encouraged local authorities to move beyond fragmented infrastructure projects and adopt long-term, participatory, and evidence-based planning that connects transport with environmental, social, economic, health, and spatial development objectives (European Commission, 2013; SUMP Guidelines, 2019).

The European Green Deal, introduced in 2019, placed sustainable mobility within the broader objective of making the European Union climate-neutral by 2050. Transport is a key sector in this transition because it remains a major source of greenhouse gas emissions, air pollution, noise, and energy consumption. The European Commission states that transport accounts for around one quarter of EU greenhouse gas emissions, while climate neutrality requires a 90% reduction in transport-related emissions by 2050 (European Green Deal; Transport and the Green Deal). The *Sustainable and Smart Mobility Strategy* of 2020 translated this climate objective into a transport agenda focused on zero-emission mobility, digitalisation, multimodal integration, resilient logistics, public transport, and active mobility (European Commission, 2020).

The *EU Urban Mobility Framework*, adopted in 2021, further strengthened the urban dimension of European transport policy. It reinforced the role of SUMPs and encourages cities to develop integrated, multimodal, zero-emission, inclusive, and safe mobility systems. The framework gives particular attention to public transport, walking, cycling, zero-emission vehicles, urban freight logistics, digital services, accessibility, and road safety (EU Urban Mobility Framework, 2021).

Since the early 2000s, there has been a shift in Europe towards a more comprehensive approach to urban mobility, encompassing not only passenger transport but also freight and logistics. Whereas earlier policies focused primarily on passenger mobility, more recent strategies have adopted an integrated perspective that considers all components of urban transport, including freight and logistics.

Road safety is addressed through the EU Road Safety Policy Framework 2021–2030, which follows the *Vision Zero* approach and aims to move close to zero road deaths and serious injuries by 2050, with an intermediate target of reducing deaths and serious injuries by 50% by 2030 (EU Road Safety Policy Framework, 2021–2030). This is especially relevant in cities, where pedestrians, cyclists, and micromobility users are particularly exposed to traffic risks.

Active mobility has also gained stronger political recognition at EU level. The *European Declaration on Cycling*, formally adopted in 2024, recognises cycling as a sustainable, accessible, inclusive, affordable, and healthy mode of transport. It encourages Member States and cities to develop safe cycling networks, improve cycling infrastructure, support cycling data collection, integrate cycling with public transport, and promote active mobility as part of wider urban mobility strategies (European Declaration on Cycling, 2023/2024).

Implementation is supported through European programmes and platforms that help cities test, finance, and exchange sustainable mobility solutions. For example, the CIVITAS initiative has been supporting research, innovation, and demonstration projects in sustainable urban mobility since 2002 (CIVITAS Initiative). Other programmes, including Horizon Europe, Interreg, EIT Urban Mobility, and the Connecting Europe Facility, provide support for research, innovation, pilot projects, and cooperation between cities, universities, enterprises, and public authorities. Knowledge-sharing platforms such as the Eltis – EU Urban Mobility Observatory provide guidelines, case studies, training materials, and policy recommendations related to SUMP development and sustainable urban mobility practice (Eltis – EU Urban Mobility Observatory).

Sustainable Transport and Sustainable Urban Mobility Planning: from System Performance to Governance

The concepts of sustainable transport and sustainable urban mobility planning are closely related, but they should not be treated as identical. Sustainable transport mainly refers to the characteristics, performance, and impacts of the transport system itself. Sustainable urban mobility planning refers to the governance, policy, regulatory, financial, and institutional processes needed to achieve sustainable mobility outcomes.

Sustainable transport can be understood as a transport system that meets current mobility and accessibility needs while minimising negative environmental, social, and economic impacts for present and future generations. In practical terms, sustainable transport includes public transport, walking, cycling, rail-based mobility, low-emission vehicles, shared mobility, electric mobility, and energy-efficient urban logistics. It is usually evaluated through indicators related to greenhouse gas emissions, air pollution, energy use, road safety, affordability, accessibility, land consumption, modal share, and service quality.

Sustainable urban mobility planning has a broader governance meaning. It concerns how cities and institutions plan, organise, regulate, finance, implement, and evaluate mobility systems. It includes strategic planning, stakeholder cooperation, public participation, regulatory instruments, financial mechanisms, behavioural measures, data management, land-use integration, digitalisation, and monitoring. Therefore, sustainable urban mobility planning does not only ask which transport modes should be promoted. It also asks how institutions should cooperate, how decisions should be made, how citizens should be involved, how mobility measures should be financed, and how policy outcomes should be assessed.

This distinction is important because sustainable transport solutions do not automatically produce sustainable results. For example, cycling infrastructure can support sustainable transport, but its effectiveness depends on network continuity, safety, maintenance, public acceptance, traffic regulation, integration with public transport, and land-use patterns. Similarly, improving public transport requires more than purchasing new vehicles or opening new routes. It also requires stable financing, reliable services, accessible stops, fare integration, digital information, good interchanges, and coordination between operators and public authorities.

The EU increasingly emphasises this governance-oriented perspective. Contemporary EU urban mobility policy promotes integrated planning rather than isolated transport projects. SUMPs are one of the clearest examples of this approach. According to the European Commission’s Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan, a SUMP should integrate transport policy with environmental, economic, social, health, and spatial planning objectives and be based on stakeholder involvement, citizen participation, evidence-based decision-making, and continuous monitoring (European Commission, 2019).

European Case Studies of Sustainable Urban Mobility Implementation

European cities provide important examples of how sustainable urban mobility planning can be translated into practice. These case studies demonstrate that successful implementation depends not only on infrastructure investment, but also on long-term governance, stakeholder cooperation, citizen acceptance, and adaptation to local conditions.

Rome is an important case of sustainable urban mobility implementation because it shows how a large historic and tourism-intensive capital can modernise mobility while protecting its urban heritage. Its Sustainable Urban Mobility Plan, known in Italy as PUMS – Piano Urbano della Mobilità Sostenibile, promotes a shift from fragmented transport measures toward an integrated system based on public transport, walking, cycling, shared mobility, road safety, and better use of urban space. Measures such as Limited Traffic Zones, 30 km/h areas, shared mobility, cycling development, and Mobility as a Service initiative illustrate the Rome' gradual transition toward multimodal and citizen-oriented mobility. At the metropolitan level, the PUMS of the Metropolitan City of Rome Capital extends this approach to Rome and its surrounding municipalities, demonstrating the importance of coordination between local, metropolitan, regional, and national actors.

Vienna demonstrates the importance of institutional coordination, affordability, and social inclusion in sustainable mobility. The city has invested in high-quality public transport, affordable fare policies, walking and cycling improvements, and integrated urban development. Its mobility approach shows that environmental sustainability and social accessibility can be pursued together when transport policy is connected with housing, public space, affordability, and quality of service. Vienna is particularly relevant because it demonstrates that public transport attractiveness depends not only on infrastructure, but also on fare policy, reliability, coverage, and user experience.

The CIVITAS programme provides further examples of partnership-based mobility innovation. Many CIVITAS projects operate as living laboratories, where cities cooperate with universities, transport operators, technology providers, and local communities to test new mobility solutions in real urban conditions. These projects have addressed public transport improvement, cycling, shared mobility, urban logistics, clean vehicles, behavioural change, and digital mobility services. The living-lab approach is important because it allows cities to experiment, learn, evaluate impacts, and adapt measures before wider implementation.

These examples show that sustainable urban mobility cannot be achieved through a single universal solution. However, they share common principles: long-term vision, integrated planning, stakeholder cooperation, evidence-based decisions, citizen orientation, and continuous adaptation. These principles are relevant for cities across Europe and for neighbouring countries seeking to align their mobility systems with EU sustainable mobility policy.

Implementation Barriers and Citizen-Oriented Adaptation

Despite significant progress in European urban mobility policy, implementation remains challenging. Many cities have adopted ambitious strategies, climate targets, and mobility plans, but the translation of these documents into everyday practice is often difficult. The main challenge is not only to design good policies, but to implement them in complex institutional, financial, political, technical, and social environments.

Institutional barriers are among the most common obstacles. Responsibilities for transport, land use, environment, public health, parking, road safety, and public space are often divided between different departments or levels of government. This fragmentation can lead to inconsistent priorities, delays, and weak coordination. For example, a city may promote cycling in its mobility strategy while road design standards, parking policies, or land-use decisions continue to favour car use.

Financial barriers also limit implementation. Sustainable mobility measures require not only initial investment but also long-term funding for operation, maintenance, monitoring, and adaptation. Public transport systems need stable financial support to provide reliable and affordable services. Cycling and walking infrastructure requires maintenance, winter service, safety improvements, and network expansion. Many cities depend on project-based funding, which can support pilot measures but may not guarantee long-term continuity.

Political barriers are particularly important because sustainable mobility policies often involve the redistribution of urban space. Measures such as reducing car lanes, limiting parking, introducing low-emission zones, lowering speed limits, or prioritising cycling and public transport may face resistance from some residents, businesses, or political groups. This does not mean such measures should be avoided. Rather, they require clear communication, evidence, participation, and gradual implementation adapted to local conditions.

Technical barriers also affect policy delivery. Many cities lack reliable data on travel behaviour, accessibility, emissions, road safety, public transport reliability, or user satisfaction. Without good data and analysis methodologies, it is difficult to identify problems, prioritise interventions, monitor outcomes, and justify decisions. Technical capacity is also needed for transport modelling, geographic information system (GIS) analysis, cost-benefit assessment, accessibility evaluation, and scenario planning.

Behavioural and cultural barriers should not be underestimated. Travel habits are shaped by daily routines, perceptions of safety, comfort, social norms, service reliability, and household constraints. Even when sustainable modes are available, people may continue using cars if alternatives are perceived as inconvenient, unsafe, unreliable, or socially unattractive. Therefore, infrastructure investment should be accompanied by behavioural measures, communication campaigns, travel planning support, and improvements in service quality.

Digitalisation creates both opportunities and challenges. Intelligent transport systems, real-time information, mobility-as-a-service platforms, shared mobility services, and digital payment systems can improve efficiency and user convenience. However, they also require careful governance related to data protection, interoperability, cybersecurity, digital exclusion, and public control over essential mobility services. Digital innovation should therefore be evaluated not only by technological performance but also by its contribution to public value.

Climate adaptation and urban resilience are becoming increasingly important implementation concerns. Recent crises, including the COVID-19 pandemic, energy price shocks, extreme weather events, and geopolitical disruptions, have demonstrated the need for flexible and resilient mobility systems. Cities require diversified transport networks that can maintain access during disruptions. Walking, cycling, public transport, shared mobility, and local accessibility can all contribute to resilience when they are planned as complementary parts of an integrated system.

Citizen-oriented adaptation is essential for overcoming these barriers. Policy transfer should not mean simple copying of measures from one city to another. Cities differ in urban form, population density, economic structure, public transport supply, institutional capacity, travel culture, and political priorities. Therefore, sustainable urban mobility measures should be adapted to local needs, tested through pilots where appropriate, monitored carefully, and revised based on evidence and public feedback.

Building Professional Capacity through Higher Education

The complexity of sustainable urban mobility creates a strong need for specialised education and professional training. Universities play a crucial role in preparing future transport planners, engineers, policymakers, researchers, and urban managers who can address mobility as a multidimensional policy field. Without professional capacity, even well-designed policy frameworks may remain difficult to implement.

Traditional transport education has often been dominated by technical and engineering approaches focused on road design, traffic flow, infrastructure capacity, and transport modelling. These skills remain important, but they are no longer sufficient. Contemporary sustainable urban mobility policy requires interdisciplinary knowledge that combines transport engineering, urban planning, environmental policy, economics, governance, behavioural science, public health, digital technologies, and participatory methods.

EU sustainable urban mobility policy should therefore be integrated into university curricula. Students need to understand key EU frameworks such as the European Green Deal, the Sustainable and Smart Mobility Strategy, the EU Urban Mobility Framework, Sustainable Urban Mobility Plans, the Road Safety Policy Framework, and the European Declaration on Cycling. This policy literacy is important because future professionals must be able to connect local transport decisions with European climate, safety, accessibility, and sustainability objectives.

In addition to policy knowledge, students need to develop practical analytical skills. These include GIS, telematics applied to transport systems, accessibility analysis, transport data collection, public transport planning, road safety assessment, emissions analysis, transport modelling, cost-benefit assessment, and monitoring of mobility indicators. Such skills allow future professionals to move beyond general sustainability statements and produce evidence-based mobility plans and interventions.

Governance and participation skills are equally important. Sustainable urban mobility planning requires stakeholder engagement, public consultation, communication, conflict management, institutional coordination, and project management. Future transport professionals must be able to work with local authorities, transport operators, private enterprises, civil society organisations, and citizens. They must also understand how to balance technical evidence with political feasibility and social acceptance.

The European Union supports this educational transition through programmes such as Erasmus+, Horizon Europe, and EIT Urban Mobility. These initiatives encourage universities to integrate European transport policy, sustainability principles, innovation, and practical case studies into academic curricula and professional training. They also support cooperation between universities, municipalities, enterprises, and civil society organisations.

Universities can also act as living laboratories for sustainable mobility. Campus mobility plans, cycling facilities, pedestrian improvements, shared mobility services, public transport integration, and behavioural campaigns can be used as practical learning environments. In this way, students can observe and evaluate sustainable mobility not only as an abstract policy concept, but as a practical process of institutional change, behavioural adaptation, and urban transformation.

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1.3. SUSTAINABLE DEVELOPMENT GOALS (SDGs) AS THE METHODOLOGICAL BASIS OF THE ISDEGO PROJECT

This section outlines the role of the Sustainable Development Goals (SDGs) as the methodological foundation for the ISDEGO project, providing a conceptual framework for modernising transport education. It highlights how global sustainability priorities are translated into educational practices, shaping competencies, curricula, and learning approaches in the field of transport and urban mobility. Particular attention is given to the integration of SDG principles into higher education as a key driver of sustainable transformation.

Introduction: SDGs as a Global Framework for Transformation

The contemporary concept of sustainable development dates back to the 1970s; however, even earlier, the necessity of continuous economic growth had begun to be questioned. Attention was also increasingly drawn to the impact of the development of modern large-scale technologies on society and the environment. According to the classic definition formulated in 1987 in the report entitled "Our Common Future," prepared under the leadership of the then Prime Minister of Norway, Gro Harlem Brundtland, sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. This concept is based on two key notions:

- needs, in particular the basic needs of the world's poorest, which should be given the highest priority;
- limitations imposed by the level of technology and social organization on the environment's capacity to meet present and future needs.

Currently, the reference points are the Sustainable Development Goals (Figure 21), introduced in the document adopted by the General Assembly on 25 September 2015 entitled "Transforming our World: the 2030 Agenda for Sustainable Development," commonly referred to as the 2030 Agenda [2]. This is currently a key document referenced both in Polish legislation and in that of the European Union. These goals cover 17 topics [2]:

- Goal 1. End poverty in all its forms everywhere
- Goal 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
- Goal 3. Ensure healthy lives and promote well-being for all at all ages
- Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

- Goal 5. Achieve gender equality and empower all women and girls
- Goal 6. Ensure availability and sustainable management of water and sanitation for all
- Goal 7. Ensure access to affordable, reliable, sustainable, and modern energy for all
- Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
- Goal 10. Reduce inequality within and among countries
- Goal 11. Make cities and human settlements inclusive, safe, resilient, and sustainable
- Goal 12. Ensure sustainable consumption and production patterns
- Goal 13. Take urgent action to combat climate change and its impacts*
- Goal 14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
- Goal 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
- Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels
- Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

The Sustainable Development Goals (SDGs) constitute a comprehensive global framework aimed at addressing the most pressing economic, social, and environmental challenges facing modern society. The SDGs establish a unified set of priorities that guide national policy, international cooperation, and sectoral development, facilitating the transition to more sustainable, inclusive, and resilient systems. Unlike previous development paradigms, the SDGs highlight the interconnections between different sectors, emphasising the need for comprehensive solutions that balance economic growth, environmental protection, and social well-being.

In this context, the transport sector plays a crucial role in achieving the Sustainable Development Goals. Transport systems are essential for economic activity, territorial cohesion, and access to services; however, they are also responsible for a significant share of greenhouse gas emissions and environmental impacts. The transition to sustainable mobility, green logistics, and low-carbon transport systems requires not only technological innovation but also a fundamental transformation in the planning, management, and operation of transport systems. As noted in recent studies, the transport sector accounts for approximately 25% of total greenhouse gas emissions, underscoring the urgency of integrating sustainable development principles into transport development strategies. In the context of the transport systems development, the main problem areas include [1]:

- **the quality of production resources, logistics infrastructure, and transport systems** – this problem stems from infrastructure that is often outdated and not adapted to contemporary dynamics, which negatively affects both the efficiency of its use, and increasing costs and the environmental impact of processes carried out using it;
- **congestion** – this is a key problem in the execution of logistics processes in the context of supply chain operations;
- **social exclusion, resulting from the inability to use logistics or transport services, including mobility barriers** – this is one of the most important social issues, largely linked to the growing importance of first- and last-mile logistics and the accessibility of transport systems, and arises from the fact that people with disabilities and the elderly are often unable to use services due to their lack of adaptation to specific needs (mobility barriers, inability to use out-of-home delivery services, etc.);
- **the impact of logistics processes on health** – tasks performed within these processes may affect the health of those involved (e.g., through exposure to noise, unhealthy body posture during tasks, intensive use of computers and mobile devices contributing to vision or spine problems);
- **the costs of maintaining logistics and transport infrastructure** – both outdated infrastructure not adapted to current requirements and modern solutions equipped with advanced technological systems require significant expenditures for maintenance, servicing, modernisation, etc.;
- **the costs of transporting people and goods** – these costs are largely linked to congestion, but also to the need to purchase modern means of transport that meet environmental standards (e.g., electric vehicles);
- **the costs of accidents** – these costs are often overlooked in analyses but constitute a significant component of the overall costs of logistics systems, particularly transport systems;
- **the impact of logistics processes, especially transport, on climate change (water, air, and soil pollution), land use intensity of logistics systems, and noise generation** – this is a conglomerate of several closely interrelated issues that represent a major challenge for companies and require substantial investment to reduce these negative effects;
- **the depletion of non-renewable natural resources** – this issue is particularly evident in economies heavily reliant on fossil resources and, given the dynamics of digitalization processes, especially concerns electricity generation systems, which will play a dominant role in the coming years.

The way to reduce the above problems is the development of innovative, less energy-consuming, and integrated transport systems. Following that, a few general megatrends in sustainable transport development can be identified:

- **Electrification and Electric Vehicles (EVs)** – the shift towards electric vehicles. EVs are becoming more viable, offering longer ranges and faster charging times. The push for electrification aims to reduce emissions and dependence on fossil fuels.
- **Autonomous Vehicles (AVs)** – the development of autonomous vehicle technology, which enables fully self-driving cars, is transforming the road transport industry in the next 20-30 years. However, the dynamic development of different elements of vehicle automation is significant now. Nowadays, the 1st and 2nd level of autonomous driving are fully available. The 3rd level will be fully available in the next 2–3 years.
- **New communications patterns: Vehicle-to-Vehicle (V2V), Infrastructure-to-Vehicle (I2V), Vehicle-to-Infrastructure (V2I)** – vehicle communication technologies enable better exchange of information between vehicles (V2V) and between vehicles and infrastructure (V2I/I2V). This facilitates improved road safety and traffic efficiency by allowing vehicles to share data and communicate with traffic management systems. It is one of the most important challenges for tolling and enforcement systems.
- **Sustainability and Green Transport** – growing environmental awareness is driving the demand for sustainable transport solutions. Many countries are implementing regulations on emissions and promoting eco-friendly modes of transportation such as cycling, pedestrian-friendly spaces, public transport, and zero-vehicles or low-emissions zones.
- **Mobility Services, MaaS (Mobility as a Service)** – changing consumer preferences and advancements in mobility technology have led to the rise of mobility services such as car-sharing, ride-hailing (e.g., Uber, Lyft), and bike and scooter rentals. Many people are opting for these services instead of owning personal vehicles, contributing to a shift in how transportation is accessed and utilized.
- **Intelligent Transportation Systems (ITS) and Smart Cities** – information and communication technologies (ICT) integrate various components such as smart traffic signals, traffic monitoring, and parking management to optimize traffic flow and reduce congestion. This is one of the most important parts of the Smart City concept. Considering the development of that idea, the integration of tolling and enforcement systems with the other ITS services and subsystems will play a significant role in it.

Higher education institutions are key actors in this transformation process. They are responsible for preparing a new generation of professionals capable of addressing complex, interdisciplinary challenges related to sustainability, digitalization, and infrastructure development. The integration of SDGs into higher education is therefore not limited to the inclusion of sustainability topics in curricula, but involves a systemic shift toward competency-based education, interdisciplinary learning, and closer cooperation with industry and public stakeholders. In the field of transport and logistics, this includes the development of skills related to environmental impact assessment, digital transport systems, data-driven decision-making, and strategic planning.

The importance of SDGs is particularly evident in technical education, where the traditional focus on narrowly defined engineering knowledge is no longer sufficient (Fig.1). Modern transport specialists must combine technical expertise with an understanding of the environmental, social, and economic implications of their decisions. This requires the incorporation of sustainability principles, digital competencies, and systems thinking into educational programs. The transformation of technical education is therefore directly linked to the broader goals of sustainable development and to the need for aligning educational outcomes with labour market demands and global challenges.

In this regard, education emerges as a key tool for implementing the SDGs. By embedding sustainable development principles into curricula, teaching methods, and institutional strategies, universities contribute not only to knowledge generation but also to the practical implementation of sustainability goals. Thus, the integration of SDGs into higher education forms the methodological foundation for initiatives such as the ISDEGO project, where education serves as a driver of sustainable transformation in the transport sector.

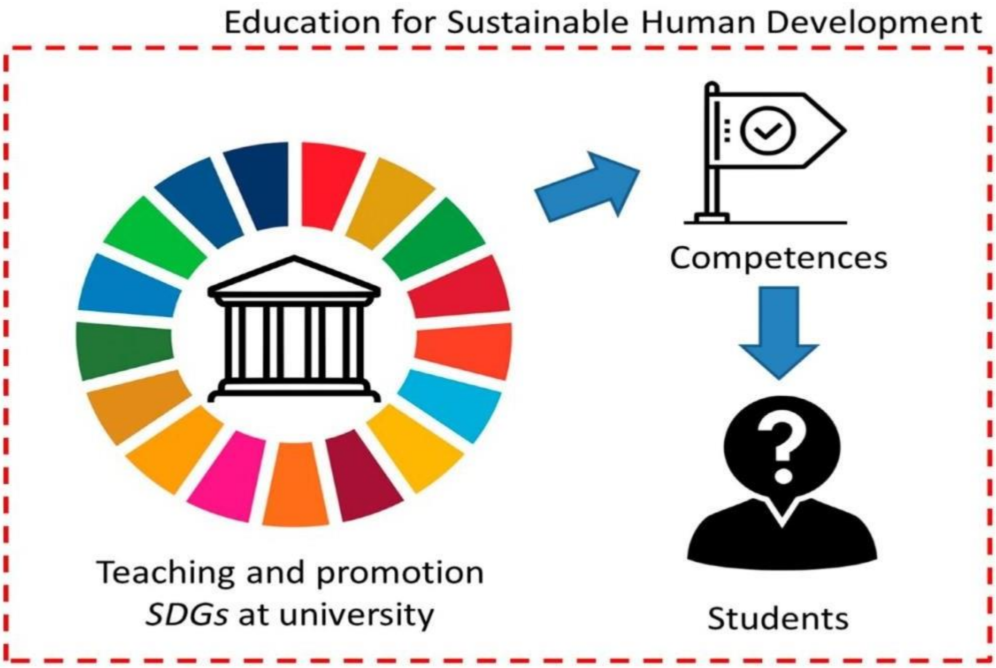

Figure 1. Education for Sustainable Human Development [3]

SDGs in Transport and Urban Development: The Central Role of SDG 11

The transport sector is inherently interconnected with the Sustainable Development Goals, as it directly influences economic productivity, environmental sustainability, and social inclusion. In the context of rapid urbanization, increasing mobility demand, and climate change, transport systems have become a critical domain in which the objectives of sustainable development must be operationalized. At the same time, transport is responsible for approximately 25% of total greenhouse gas emissions, making it one of the key sectors requiring urgent transformation toward low-carbon and resource-efficient solutions.

The key challenges shaping the transformation of transport systems include the growth of urban populations, which intensifies pressure on infrastructure; the increasing demand for mobility, which leads to congestion and environmental degradation; and the need to ensure accessibility and inclusiveness of transport services. These challenges require a systemic shift in how transport is planned and managed, moving from traditional infrastructure-focused approaches to integrated, sustainable mobility systems.

In this context, the main focus is on three interrelated areas. First, sustainable mobility aims to reduce environmental impact while ensuring efficient and accessible movement of people and goods. Second, green logistics emphasizes the optimization of urban freight transport, including last-mile delivery solutions and the reduction of emissions in supply chains. Third, digital transport systems enable data-driven management of traffic flows, improve operational efficiency, and support smart city development through the integration of technologies such as IoT, GIS, and artificial intelligence.

These directions are conceptually and practically consolidated within Sustainable Development Goal 11 (SDG 11) — “Sustainable Cities and Communities”, which serves as a central framework for understanding the role of transport in sustainable urban development. SDG 11 focuses on making cities inclusive, safe, resilient, and sustainable, and places particular emphasis on the development of accessible, efficient, and environmentally friendly transport systems (Fig.2).

Figure 2. Sustainable Development Goal 11 (SDG 11) — “Sustainable Cities and Communities”

Within the framework of SDG 11, transport is not considered as an isolated sector, but as a key element of urban systems, directly influencing spatial planning, infrastructure development, and logistics organization. The implementation of SDG 11 in the transport domain is reflected in several key directions: reducing greenhouse gas emissions through the transition to low-carbon mobility; improving accessibility of transport services for all population groups, including vulnerable users; and increasing the efficiency of transport systems through digitalization and integrated planning approaches.

Thus, SDG 11 provides a methodological bridge between global sustainability goals and practical transformations in transport systems. Its implementation requires not only technological solutions but also the development of new competencies among transport professionals. In this regard, urban mobility becomes a central concept that links sustainable development with transport education. By integrating the SDG 11 principles into educational programs, universities prepare specialists capable of designing and managing transport systems that meet the requirements of sustainability, efficiency, and inclusiveness.

Therefore, aligning transport development with SDG 11 reinforces the role of higher education as a key driver of sustainable urban transformation, ensuring that future professionals are equipped with the knowledge and skills needed to address complex challenges in modern cities.

Integrating SDGs into Transport Education: Policy Framework and Implementation Challenges

The integration of the Sustainable Development Goals (SDGs) into higher education—particularly in transport-related fields – represents a systemic transformation of educational paradigms rather than a simple curriculum update. This shift is characterized by the transition from traditional knowledge-based models toward competency-based education, where learning outcomes are aligned with real-world challenges such as decarbonisation, digital transformation, and sustainable infrastructure development. In this context, the Bologna Process and the European Qualifications Framework provide the structural foundation for harmonizing qualifications, ensuring transparency of learning outcomes, and enhancing student mobility across Europe.

Within transport education, SDG integration is operationalized through three interrelated dimensions: sustainability (environmental and social responsibility), digitalization (integration of Intelligent Transport Systems, big data, and AI), and interdisciplinary approaches (bridging engineering, urban planning, economics, and public policy). Universities act as key agents of change, not only equipping students with technical expertise, but also fostering systems thinking and long-term strategic orientation toward sustainable mobility.

European Policy Context: Strategic Alignment

The integration of SDGs into transport education is closely aligned with overarching European policy frameworks. The European Green Deal establishes the objective of achieving climate neutrality by 2050, significantly influencing transport curricula by prioritizing low-emission mobility, electrification, and modal shift strategies.

In parallel, the development of the Trans-European Transport Network defines infrastructure standards, interoperability requirements, and corridor-based planning approaches. This creates demand for professionals capable of addressing complex, integrated transport systems at both regional and continental scales.

Table 1. Key EU Policies and Their Implications for Transport Education

Policy / Initiative	Core Focus	Implications for Education
European Green Deal	Decarbonisation, climate neutrality	Courses on sustainable mobility, electric transport
TEN-T	Infrastructure, corridors	Training in integrated transport planning
Digital Europe Programme	Digital transformation	Data analytics, ITS, AI applications

Challenges in Implementing SDGs in Transport Education

Despite strong policy alignment, the implementation of SDGs in transport education faces several structural and systemic challenges.

1. Skills Gap

According to the European Commission [4, 5] and CEDEFOP [6], approximately 40–50% of employers in the European transport sector report shortages of professionals with adequate digital and green skills.

The most critical competencies include:

- digital skills (data analytics, ITS, artificial intelligence);
- environmental impact assessment (e.g., life-cycle analysis, carbon accounting);
- strategic and systems thinking.

2. Education–Labour Market Mismatch

A significant mismatch persists between academic training and labour market needs. According to the World Economic Forum [7-9], nearly 60% of graduates require additional training after entering the mobility and infrastructure sectors.

3. Institutional Barriers

The implementation of interdisciplinary and SDG-oriented curricula is often constrained by institutional factors such as rigid faculty structures, limited funding, and a lack of incentives for pedagogical innovation. These barriers hinder the integration of cross-sectoral knowledge essential for sustainable transport systems.

In response to these challenges, the ISDEGO project aims to modernise transport education systematically by integrating the SDG principles, digital technologies, and competency-based approaches into curricula. Through this, it seeks to bridge the gap between education and labour market needs and to prepare specialists capable of supporting sustainable and innovative transport systems.

Practical Implementation within ISDEGO

The practical implementation of Sustainable Development Goals (SDGs) within the ISDEGO project is realized through a comprehensive educational approach that combines the modernisation of educational programs, the creation of innovative infrastructure, and the introduction of new learning formats.

Integration of SDGs through Educational Components

At the core of ISDEGO is the development and introduction of new disciplines and updated curricula, designed in line with SDG 11 and current labour market needs. These programs integrate topics such as sustainable urban mobility, green logistics, digital transport systems, and environmental impact assessment, ensuring alignment between academic content and real-world challenges.

A key element of the practical implementation of the project is the creation of **Sustainable Urban Transport Laboratories (SUTLab)** at partner universities. These laboratories are equipped with modern hardware and software for traffic analysis, simulation, and environmental monitoring, enabling students to work with real data and advanced digital tools. SUTLabs function as platforms for applied learning, research, and innovation, directly supporting the integration of SDGs into the educational process.

In addition, the project introduces **micro-credentials** as flexible learning units that respond to rapidly changing labour market demands. Each partner university develops micro-credential courses in cooperation with EU institutions, focusing on digital logistics, smart mobility, and sustainable transport solutions. These micro-qualifications enhance employability and support lifelong learning in the transport sector

Application-Oriented Learning Approaches (Equipment-Based Implementation)

The ISDEGO project places strong emphasis on practice-oriented education, which is significantly enhanced through the use of specialized laboratory equipment and digital tools acquired within the project. Learning is structured around real-world case studies, simulations, and problem-based tasks, where students work directly with traffic data, environmental indicators, and transport system models. This approach strengthens analytical, technical, and decision-making skills in the context of sustainable urban mobility.

A key role in this process is played by the SUTLab infrastructure, which integrates modern hardware and software for applied training. In particular, students gain hands-on experience with traffic data collection and analysis systems, including radar-based monitoring, traffic cameras, video detectors, and panoramic imaging systems. These tools allow for real-time observation and analysis of traffic flows, supporting practical tasks in traffic management and urban mobility assessment.

In addition, unmanned technologies and visualisation tools – such as FPV drones and virtual reality (VR) equipment – are used to collect spatial data, model urban environments, and simulate transport scenarios. Platforms for 3D modelling and VR/AR visualisation enable students to explore infrastructure solutions and mobility patterns in an immersive and interactive way, reflecting current trends in digital transport planning.

The environmental dimension of sustainable transport is addressed through monitoring equipment, including gas analysers, air quality sensors, and noise detectors. These tools enable students to assess the environmental impact of transport systems, conduct field measurements, and integrate sustainability indicators into transport analysis and planning processes.

Complementing the hardware infrastructure, transport modelling software (such as PTV Vissim and PTV Visum) is used to simulate traffic flows, evaluate mobility scenarios, and support data-driven decision-making. The combination of real data collected via laboratory equipment and advanced simulation tools creates a comprehensive learning environment aligned with the digital transformation of the transport sector.

Furthermore, the project actively develops cooperation with cities, municipalities, and industry stakeholders. Data collected using laboratory equipment and analytical tools are applied in real urban contexts through stakeholder workshops, student projects, and collaborative activities with local authorities. This ensures that educational processes are closely linked to actual urban challenges and policy needs, supporting the co-creation of knowledge and the practical implementation of sustainable transport solutions.

Thus, the integration of advanced equipment within the ISDEGO project transforms traditional learning into an applied, data-driven, and interdisciplinary process, fully aligned with the principles of SDGs and modern transport education.

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INTRODUCTION

One of the key elements in modernising transport education is the creation of a contemporary learning environment that integrates theoretical training with the practical application of digital technologies, Intelligent Transport Systems (ITS), and urban mobility analysis tools. Within the framework of the **ISDEGO project**, particular emphasis has been placed on establishing a modern laboratory infrastructure. This base enables the conduct of practical sessions, applied research, and the modelling of real-world transport processes.

The utilization of specialized equipment and software facilitates a practice-oriented approach to learning, aligning with current European trends in the transport industry and the **Sustainable Urban Transport Laboratory (SUTLab)** concept. Modern digital tools ensure the collection and analysis of transport and environmental data, the visualisation of urban environments, the study of traffic flows, and the simulation of various operational scenarios for transport systems.

This chapter provides a detailed description of the equipment and software procured under the ISDEGO project to establish and enhance teaching laboratories at partner universities. The technical solutions presented encompass traffic analysis systems, environmental monitoring tools, data collection and visualisation technologies, and transport modelling software suites utilized in both the educational process and research activities.

2.1. INTELLIGENT SYSTEMS FOR TRAFFIC ANALYSIS AND MANAGEMENT

VEHICLE TRAFFIC COUNTER SR7

1. Introduction

1.1. Equipment Name and Purpose

- Vehicle Traffic Counter SR7
- Type: Hardware + Software online included via registration of Hardware
- Category – Vehicle Traffic Counter

1.2. Short Description

A mobile traffic detection device meeting the highest quality standards, the SR7 combines quick roadside mounting – requiring no construction work or traffic interruptions – with the highest level of accuracy in data detection. The device calibrates itself automatically to the course of the road, making installation as easy as possible. The internal radar even detects axles and the axle positions and uses this information for optimized classification of vehicles. Due to its energy-saving operation, the SR7 can gather traffic data on the roadside for a period of more than 2 weeks continuously (fig. 1). The collected data can easily be retrieved using any web browser on any system from everywhere.

Fig.1. Gathering traffic data

1.3. Components

- **List of main components:** Vehicle Traffic Counter SR7 (Fig.2), Battery Charger Mascot 2140, 12V 4A (Fig.3), Banner Battery GiV 12V-18Ah (Fig. 4)

Fig.2. Vehicle Traffic Counter SR7 Fig.3. Battery Charger Fig. 4. Banner Battery

1.4. Core Tasks: collection of initial data on the characteristics of road traffic and transport flows.

2. Purpose and Application in Education

2.1. Usage

- The equipment can be applied when delivering the following discipline: "Ecosystem Technologies for Sustainable Urban Transport."
- The equipment can be used when performing the laboratory/practical assignments: "Determination of traffic flow characteristics in the city's transport network."

2.2. Competencies

- **Technical:** installation of equipment Vehicle Traffic Counter SR7, equipment settings**.**
- **Digital:** transferring collected data to the server, saving processed data.
- **Analytical:** interpretation of processed data, design of digital models of transport system elements.

2.3. Link to Sustainable Development

- Creating digital models of transport system elements, considering the data collected by Vehicle Traffic Counter SR7, allows for making cities smarter, transport systems sustainable.

2.4. Expected Learning Outcomes

- The student can use modern equipment for collecting input data on road traffic and characteristics of traffic flows
- The student analyses the obtained data using software
- The student applies modern data processing methods to create models of elements of transport systems

3. Technical Specifications

Table 1. Technical Specifications and Package Composition of the SR7 Traffic Counter

Parameter	Value
Package content	1. Vehicle Traffic Counter SR7; 2. Battery Charger Mascot 2140 12V 4A; 3. Banner Battery GiV 12V-18Ah
Core specifications	1. Stores for every vehicle: date, time, length, speed, direction, and gap; 2. Bi-directional detection; 3. Vehicle classification in up to 8 + 1 categories; 4. Large internal memory for more than 1 million records.
Power supply	Banner Battery GiV 12V-18Ah
Interfaces	Battery Cable for 12V / 18Ah cells

3.1. Environment Requirements

- Hardware requirements. Input Voltage - 12V DC; Power Consumption - Low-Power Design < 0,5W; Operating temperature: -25 °C to 60 °C; Weight ~ 3 kg without Battery; Protection Degree Radar Module IP68.

Table 2. Electrical, Radar, and Mechanical Specifications of the SR7

Parameter	Value
Electrical Data	Input Voltage: 12 V DC Power Consumption: < 0.5 W (operating)
Radar Sensor	Operating Frequency: K-Band (24 GHz) Transmitting Power: 5 mW Certification: CE, FCC, IC approved Operating Speed: 3 … 199 km/h Accuracy: ± 3 %
Mechanical Data	Dimensions [Metric]: 30 × 20 × 15 cm Weight: approx. 3 kg (without battery) Enclosure: Glass-fibre reinforced plastic

	Protection Degree: IP68 Operating Temperature: –25°C … 60°C

- Software requirements: Sierzega SRA Web access via registration of Hardware (SR7 Serial Number, email, company). To use SRA Web (Fig.5 – Fig. 8), simply complete a one-time registration. Once your account is activated, you can log in and start analysing data right away.

Fig.5. Software interface

Fig.6. Traffic speed distribution

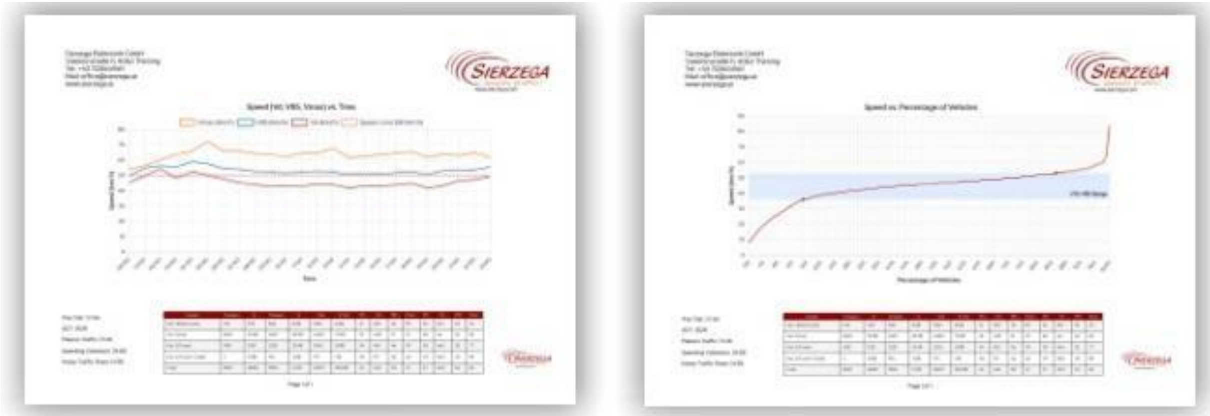


Fig.7. Speed and percentage of vehicles

Fig.8. Distribution of traffic intensity over time and days of the week

4. Installation and Setup

- Core installation steps: the rear of the SR7 must be mounted parallel to the road (Fig.9, Fig.10). Automatic calibration – The MIMO radar of the SR7 also looks to the side using several antennas and simultaneously detects the vehicles at different angles. This enables the SR7 to automatically determine the exact mounting angle and consider the results for further measurements and calculations.

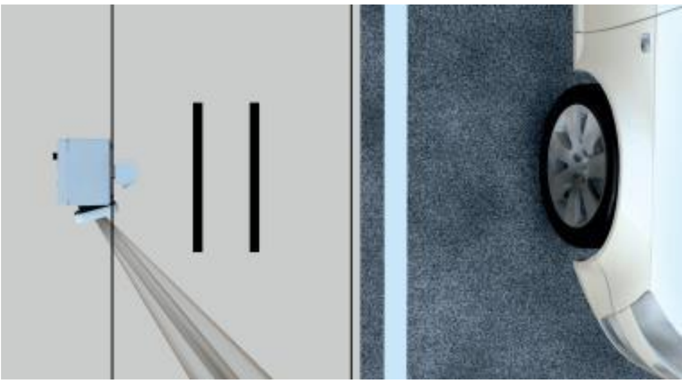


Fig.9. Alignment of the SR7

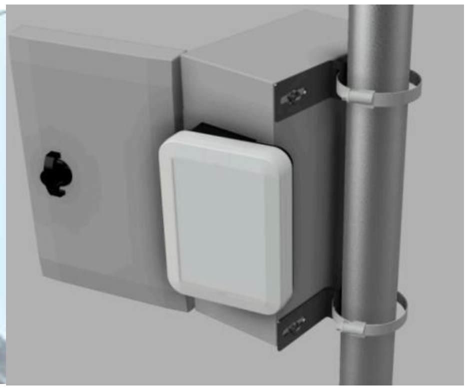


Fig.10 - Pole Brackets (for mounting the SR7 enclosure)

- Operating Speed: 3 … 199 km/h. Accuracy: ± 3 %
- Special features: real-time gathering of traffic data.

5. Functional Capabilities

• Core functions of the equipment are the data recordings, which consist of date, time, vehicle length, speed, direction, and the gap between vehicles, which allows for accurate vehicle classification

Typical tasks performed with this device primarily centre on comprehensive traffic flow analysis.

6. Safety and Ethical Considerations

Data processing using the Vehicle Traffic Counter SR7 ***does not contain*** visual information (vehicle licence plates and driver faces), which is confidential information and should not be made public or transferred to third parties.

7. References and Documentation

1. Sierzega - Electronics for Traffic Safety.– https://www.sierzega.com/en-us/products/traffic-counters
2. Traffic Radar SR7. Quick Start Guide. – https://www.sierzega.com/LinkClick.aspx?fileticket=zl1t-ZENWKM%3d&portalid=0&language=en-US
3. Traffic Radar SR7. DataSheet. – https://www.sierzega.com/LinkClick.aspx?fileticket=Y6PIZQTp0V4%3d&portalid=0

VIDEO DETECTION AND PANORAMIC SURVEILLANCE MODULES FLIR TRAFICAM 4TI ETH

1. Introduction

1.1. Equipment Name and Purpose

Table 1. Purpose of FLIR TrafiCam

Parameter	Value
Full Name	FLIR TrafiCam — Video Vehicle Presence Detector
Manufacturer	FLIR Intelligent Transportation Systems N.V. (Belgium)
Type	Hardware + Software Complex
Category	Traffic Flow Monitoring / Intelligent Transportation Systems
Part No. (camera)	10-6090/91 TrafiCam R8.00 V3.04
Part No. (4TI ETH interface)	10-6077, R1.00 V4.00
Configuration Software	TrafiCam PC Tool V301

1.2. Short Description

FLIR TrafiCam is a compact video vehicle presence detector that integrates a camera and a detection unit in a single stylish enclosure. The device is used to detect vehicles waiting at or approaching an intersection, as well as to count passing vehicles.

The system is based on the proven video detection technology developed by Traficon – a world leader in traffic recognition through video signal processing. TrafiCam can be easily integrated into existing and new traffic management infrastructure, providing input signals to traffic light controllers upon detection of vehicle presence.

The equipment supports two types of interface modules: 4TI ETH (connecting up to 4 cameras simultaneously via USB or Ethernet) and 1TI (single-camera, USB connection only), allowing flexible scaling of the system to meet the needs of a laboratory or a real-world installation.

1.3. Components

- TrafiCam video sensor (camera in a compact spherical enclosure)
- 4TI ETH interface module

- Mounting tube and bracket assembly
- Power cable connector (5-pin)
- TrafiCam PC Tool software
- Quick reference guide

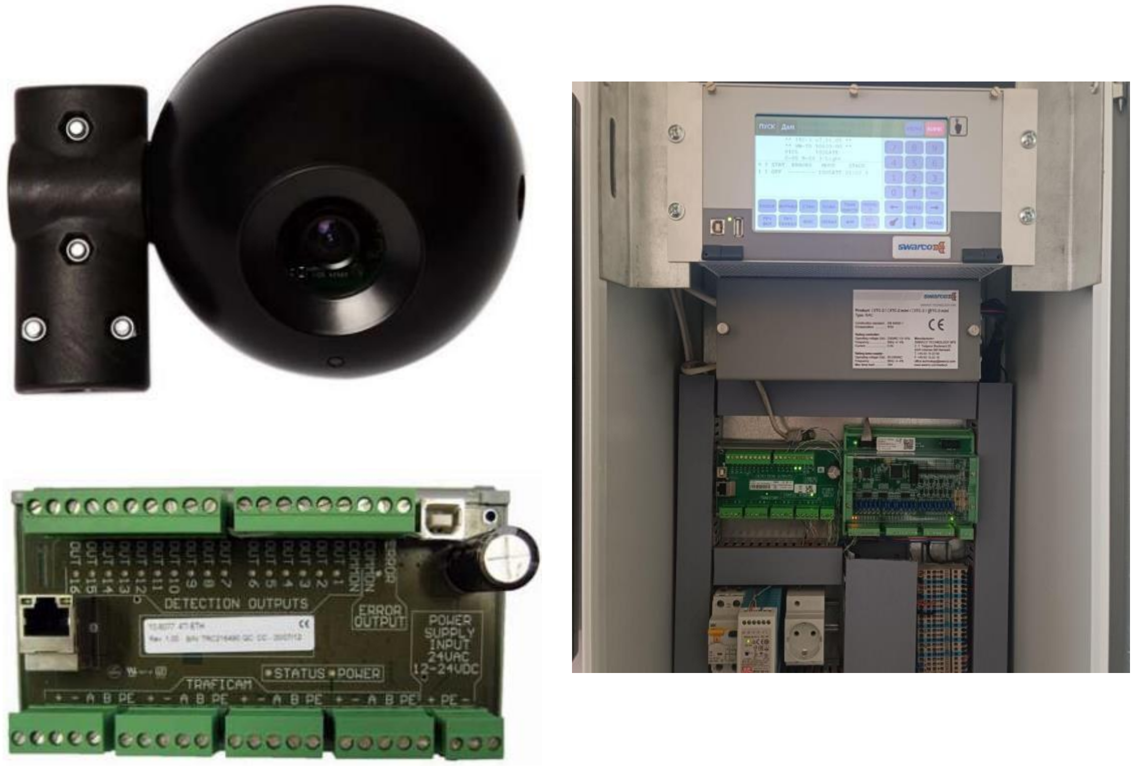


Figure 1. General view of the FLIR TrafiCam 4TI ETH

1.4. Core Educational and Research Tasks

- Study of real-time video vehicle detection principles
- Configuration of presence detection zones and detection parameters
- Traffic flow analysis and vehicle counting
- Study of Intelligent Transportation Systems (ITS) architecture
- Configuration of detector-to-traffic-controller integration

2. Purpose and Application in Education

2.1. Usage in Courses and Laboratory Studies

The FLIR TrafiCam equipment is intended for use in educational courses related to transport technologies, road safety, and smart cities. In particular, the system can be applied in the following academic disciplines:

- Intelligent Transport Technologies for Integrated Mobility
- Ecosystem Technologies for Sustainable Urban Transport
- Fundamentals of Intelligent Transport Systems
- Sustainable Transport in Urban and Rural Planning

Within these disciplines, the equipment may be used for the following practical and laboratory assignments:

- Lab work: “TrafiCam Video Detector Setup and Detection Zone Definition”
- Lab work: “Analysis of Traffic Flow Characteristics”
- Lab work: “Simulation of Traffic Flow”
- Research project: “Comparative Analysis of Inductive Loop and Video Detector Efficiency”
- Research project: “Optimization of Vehicle Detection Algorithms Under Low-Light Conditions”

2.2. Competencies Developed

Technical Competencies:

- Physical installation and wiring of equipment (camera, interface module, RS-485 power cables)
- System configuration via TrafiCam PC Tool software
- IP address and network settings configuration (4TI ETH)
- Definition of presence detection zones and adjustment of their parameters

Analytical Competencies:

- Processing and interpretation of traffic flow data
- Analysis of image quality (Im Q) and detection quality (Det Q) indicators
- Assessment of lighting conditions and weather effects on detection performance

Digital Competencies:

- Working with TrafiCam PC Tool software (sensor mode and interface mode)
- Real-time system status monitoring
- Network infrastructure configuration for remote monitoring

3. Link to Sustainable Development

FLIR TrafiCam equipment is directly linked to Sustainable Development Goal No. 11 “Sustainable Cities and Communities” (SDG 11). Specifically, the system contributes to the following sub-targets:

- SDG 11.2 – Providing safe, affordable, accessible, and sustainable transport systems for all. TrafiCam enables optimization of traffic light controller operation, reducing vehicle delays and improving intersection throughput.
- SDG 11.3 – Enhancing inclusive and sustainable urbanization. Installing video detectors instead of inductive loops allows road reconstruction without prolonged traffic closures.
- SDG 11.6 – Reducing the adverse environmental impact of cities. Optimized traffic management reduces congestion, directly decreasing CO_2 and other pollutant emissions from vehicles.

Thus, studying and applying FLIR TrafiCam equipment prepares students to develop and implement smart city solutions – a key direction for the sustainable development of urbanized areas.

4. Expected Learning Outcomes

Upon completing training with FLIR TrafiCam equipment, the student will be able to:

- independently install and configure a TrafiCam video detection system with a 4TI ETH interface module;
- analyse traffic flow data received from the video sensor and interpret image quality and detection quality indicators;
- apply presence detection zone configuration algorithms for various observation conditions (day/night, different mounting heights);
- evaluate the advantages and limitations of video detection systems compared to traditional vehicle counting methods;
- connect the principles of vehicle detection systems with sustainable urban development objectives.

5. Technical Specifications

5.1. Core Parameters

Table 2. Technical Specifications of FLIR TrafiCam

Parameter	Value
Standard Package Contents	TrafiCam camera, mounting hardware (tube, bracket), power cable connector, hex key, screwdriver, quick reference guide, installation CD
Lens Types	Wide angle (2.1 mm, 83·×99°, range 0–20 m); Narrow angle (6.0 mm, 24°×32°, range 15–75 m)
Number of Detection Zones	Up to 8 presence detection zones per sensor

Detection Modes	Presence (moving + stationary vehicles), Stop (stationary vehicles only), Loop (vehicle counting)
4TI ETH Interface — Outputs	16 detection outputs + 1 error output; connects up to 4 TrafiCam cameras
PC Connection (4TI ETH)	USB-B or Ethernet (RJ45); default IP: 192.168.0.3, subnet mask: 255.255.255.0
Camera–Interface Communication	RS-485 (5-wire cable: +power, −power, RS-485A, RS-485B, PE)
Maximum Cable Length	300 m between TrafiCam camera and interface module
Interface Power Supply	12–24 V DC ±10%, or 24 V AC
Camera Ingress Protection	IP67 (dust-tight and waterproof)
Maximum Mounting Height	Up to 15 m
Mounting Options	Horizontal or vertical pole; street lighting bracket
External Cable	Black UV-resistant sheath, Ø 4–8 mm, −40°C to +75°C, 5 wires (0.5 mm² / AWG20)
Firmware	TrafiCam R8.00 V3.04; 4TI ETH R1.00 V4.00
Configuration Software	TrafiCam PC Tool V301

5.2. Environment Requirements

Hardware Requirements (PC running TrafiCam PC Tool):

- Personal computer or laptop with a USB port or Ethernet (RJ45) network interface
- Operating system: Windows (compatible with TrafiCam USB drivers)
- USB type A to USB type B cable for interface connection
- CAT5 cable for 4TI ETH configuration via Ethernet

Figure 2. Installing and configuring the video detector FLIR TrafiCam 4TI ETH

Software Requirements:

- TrafiCam PC Tool V301
- Install PC Tool before connecting the interface to ensure correct driver installation
- When using Ethernet: the PC must be in the same subnet as the 4TI ETH interface (default: 192.168.0.x)

5.3. Installation And Setup

Core Installation Steps:

- Attach the mounting tube to the brackets.
- Secure TrafiCam to the pole using fixing clamps or bolts.
- Roughly position the camera and tighten the mounting brackets.
- Connect the 5-wire cable to the camera connector and to the corresponding interface connector.
- Install the interface module 4TI ETH on a DIN rail inside the controller cabinet.
- Connect the interface to the PC (USB or Ethernet) and to the traffic light controller.
- Launch TrafiCam PC Tool and search for cameras (General > Search for TrafiCam cameras).
- Check the camera image — the horizon must not appear in the frame.

Operating Modes:

- Sensor Mode (TrafiCam PC Tool) — configures the camera sensor itself: defining detection zones, outputs, delay, and extension timing parameters.

- Interface Mode (TrafiCam PC Tool) — configures the 4TI ETH module: output assignment, polling mode, IP settings.

6. Functional Capabilities

6.1. Core Functions of the Equipment

The FLIR TrafiCam system provides a broad range of functions for detecting and analysing traffic flows:

Detection and Measurement:

- Detection of the presence of moving and stationary vehicles within defined zones
- **Stop** mode – detects stationary vehicles only
- Vehicle counting in "Loop" mode (entry/exit from zone with pulse generation)
- Night-time detection based on vehicle headlight illumination
- Directional sensitivity to eliminate false activations caused by oncoming traffic

Detection Zone Configuration:

- Definition of up to 8 independent presence detection zones per sensor
- Flexible adjustment of zone shape, size, and direction
- Per-zone delay time (0–99.9 s) and extension time (0–99.9 s) settings
- Logical relationships between zones: OR (default) and AND (Boolean logic)
- Zone overlap capability to optimize area coverage

False Detection Suppression:

- Suppression of detection triggered by vehicles in opposing and adjacent lanes
- Camera motion suppression (e.g., due to wind-induced pole sway)
- Tree shadow suppression
- Headlight glare suppression (for cameras mounted above the roadway)
- Small object filtering (pedestrians, cyclists)

Visualisation and Monitoring:

- Live video image from the camera viewable via PC Tool
- Active detection zone overlay (green = no detection, red = detection active)
- Image quality monitoring (Im Q: 0–10) and detection quality monitoring (Det Q: 0–10)
- Camera-to-interface communication quality monitoring (Comm Q: 0–100%)
- Status indication via LEDs on both the camera and the interface module

6.2. Typical Tasks Performed

The following is a list of typical tasks that students may perform using FLIR TrafiCam equipment.

Table 3. Typical tasks that students may perform using FLIR TrafiCam equipment

Task Category	Specific Task
Traffic Flow Analysis	Measuring intersection traffic volume using the Loop counting mode
Traffic Control	Configuring detector outputs to send signals to a traffic light controller
Placement Optimization	Comparing lateral vs. overhead mounting effectiveness at varying installation heights
Night-time Detection	Studying vehicle detection performance under low-light conditions
System Diagnostics	Analysing Im Q, Det Q, and Comm Q indicators to assess system health

7. Safety and Ethical Considerations

7.1. Safety Rules for Working with the Equipment

- When mounting or dismounting the camera at height, comply with all working-at-height safety requirements (use of fall arrest systems, hard hats, etc.).
- Do not connect or disconnect cables while the power supply is on. Always disconnect the power supply before working with connectors.
- Do not exceed the maximum tightening torque for fastenings — over-tightening may damage the bracket or camera housing.
- When connecting the power cable, strictly observe polarity (+/−) and correct pin assignment (1: +power, 2: −power, 3: RS-485A, 4: RS-485B, 5: PE).
- Do not rotate assembled cable connectors — rotate only the metal locking ring. Violating this rule may damage the plug and compromise the camera's IP67 protection.
- Do not activate the camera motion suppression function and the tree shadow suppression function simultaneously — this may cause incorrect detection system behaviour.
- Adjusting video gain may reduce detection performance. Consult the manufacturer or supervisor before changing this parameter.

7.2. Usage Restrictions and Data Protection

The FLIR TrafiCam system is a video surveillance device deployed in public spaces. When using the equipment, the following requirements must be observed:

- Video recording and image processing in public areas must comply with applicable personal data protection legislation (GDPR in EU member states, relevant national regulations elsewhere).

- Installation of video sensors in real-world road network conditions requires approval from local authorities and road traffic management services.
- Collected traffic data (video recordings, vehicle count statistics) must not be used to track specific individuals.
- In educational settings, it is recommended to use the equipment in dedicated test areas or to simulate real conditions using training video recordings.
- The device firmware and system configurations are the intellectual property of the manufacturer; copying and distributing them without proper authorization is prohibited.

8. Technical Documentation

- https://www.manualslib.com/manual/900775/Traficon-Traficam.html
- https://fccid.io/VE7-10-6034-6035/User-Manual/revised-users-manual-841237
- Official TrafiCam website with FAQ section and setup resources: https://www.flir.com/en-eu/home/

2.2. TECHNOLOGIES FOR SPATIAL DATA COLLECTION AND VISUALISATION

FPV QUADROCOPTER DJI MINI 3

1. Introduction

1.1. Equipment Name and Purpose

The drone can be used to perform the following tasks:

- video recording of traffic flows on highways and roads;
- monitoring road traffic at intersections, transport interchanges, and highways;
- counting the number of vehicles;
- determining traffic intensity over time intervals;
- assessing traffic flow density;
- identifying congestion locations;
- analysing the capacity of road infrastructure;
- studying the behaviour of traffic flows;
- obtaining materials for further analytical processing in specialized software;
- creating photo and video materials for transport planning and reporting

1. 2. Short Description

The DJI Mini 3 is a compact unmanned aerial vehicle (UAV) that can be used as a mobile tool for collecting spatial and video data for the study of traffic flows and the analysis of road traffic intensity. Thanks to the combination of a high-quality camera, image stabilization, GPS navigation, and the ability to hover over a designated area for extended periods, the drone provides effective real-time monitoring of traffic conditions.

The use of UAVs for transport monitoring makes it possible to obtain up-to-date data without the need to install stationary surveillance cameras or involve a large number of field personnel. This is especially relevant for temporary studies, assessment of traffic situations on specific road sections, analysis of intersection performance, as well as monitoring traffic flows during peak load periods.

1.3. Components

The DJI Mini 3 (Picture 1) has technical characteristics that make it suitable for transport monitoring:

- a camera supporting 4K video recording, providing detailed visualisation of vehicles;
- a 3-axis mechanical stabilizer to reduce vibration and improve video quality;

- GPS/GLONASS positioning system for accurate coordinate holding;
- the ability to hover over a specified point;
- flight duration of up to 38 minutes, depending on weather conditions and battery configuration;
- real-time digital video signal transmission;
- compact dimensions and low weight, simplifying transportation and rapid deployment;
- support for automated flight scenarios and routes;
- support for photo and video recording from various angles.

Figure 1. General view of the FPV Quadrocopter DJI Mini 3

1.4. Core Educational and Research Tasks

During monitoring operations, the drone rises to a specified altitude that provides a wide viewing angle of the road section. The UAV camera performs continuous high-resolution video recording of traffic flows. The obtained materials can be analysed both in real time by the operator and after the flight using automatic vehicle recognition and video stream analysis software.

Thanks to camera stabilisation and positioning systems, a clear image is ensured even while hovering or moving. This allows accurate vehicle counting, assessment of transport movement speed, and determination of road congestion parameters.

2. Purpose and Application in Education

2.1 Advantages of Using UAVs for Traffic Analysis

The use of the DJI Mini 3 in transport research (Picture 2) has several advantages compared to traditional monitoring methods.

Mobility and Efficiency

The drone can be quickly delivered to the research site and deployed within a few minutes. This allows rapid response to changes in traffic conditions or conducting temporary inspections.

Large Coverage Area

Aerial imaging enables monitoring of a large road section or several transport hubs simultaneously, which is difficult to achieve using ground-based cameras.

High Data Informativeness

Video recordings from above make it possible to comprehensively assess traffic flow structure, movement directions, conflict points, and peculiarities of traffic organization.

Cost Reduction

Using a drone may be more economically beneficial compared to installing stationary video surveillance systems or involving a large number of operators.

Safety of Observations

Monitoring is carried out remotely without requiring personnel to remain directly near the roadway.

Figure 2. Traffic monitoring process

2.2 Areas of Application

The DJI Mini 3 can be used:

- in transport planning;
- during traffic intensity studies;

- for analysing traffic light operation;
- when assessing the efficiency of transport schemes;
- in urban transport infrastructure management;
- during road audits;
- for monitoring traffic incidents;
- in scientific and educational research;
- for creating transport models and GIS analytics.

2.3 Limitations of Use

Despite significant advantages, the use of the drone has certain limitations:

- dependence on weather conditions (wind, precipitation, fog);
- limited autonomous flight time;
- the need to comply with regulatory requirements for UAV use;
- the need for a qualified operator;
- possible flight restrictions in urban or special zones;
- the need for further video processing to automate analysis.

3. Conclusion

The DJI Mini 3 is an effective tool for collecting and analysing road traffic data. The use of an unmanned aerial vehicle makes it possible to carry out monitoring of traffic flows, obtain highly accurate video data, and conduct a comprehensive analysis of road infrastructure functioning. The combination of mobility, image quality, and affordability makes this drone an appropriate solution for transport research, urban planning, and engineering analysis of road traffic.

VIRTUAL AND MIXED REALITY SYSTEM PICO 4 ULTRA

1. Introduction

1.1. Equipment Name and Purpose

Table 1 provides a concise overview of the Pico 4 Ultra system's identification and classification.

Parameter	Value
Full Name	Pico 4 Ultra – Mixed Reality (MR) & Virtual Reality (VR) Headset
Manufacturer	ByteDance / Pico Technology Co., Ltd.
Type	Standalone Wireless HMD (Head-Mounted Display) with PC-VR support
Category	Spatial Computing / 3D Visualisation / Mixed Reality
Model/Storage	Pico 4 Ultra (Enterprise Edition / Ultra Series) 12 GB RAM / 256 GB
Tracking Technology	6DoF Inside-out Tracking with Dual 32MP Passthrough Cameras
Configuration Software	Pico Business Suite / Pico Connect (for PC-VR)

1.2. Short Description

The Pico 4 Ultra is a high-performance spatial computing device designed to bridge the gap between virtual environments and the physical world. Unlike standard consumer VR headsets, the 'Ultra' model features ultra-high-resolution colour passthrough (Mixed Reality), allowing users to overlay digital transport models onto real-world environments with high fidelity.

Equipped with the Snapdragon XR2 Gen 2 platform and 12 GB of RAM, the system is optimized for rendering complex 3D urban environments, large-scale BIM (Building Information Modelling) data, and real-time traffic simulations. Within the SUTLab framework, it serves as the primary tool for immersive audits of road networks and the visualisation of proposed infrastructure changes before physical implementation.

1.3. Components

- Pico 4 Ultra Headset: Featuring pancake optics and dual 32MP RGB cameras.

- 6DoF Motion Controllers: Two haptic feedback controllers with infrared tracking rings.
- Pico Motion Trackers (Optional): For full-body tracking or object anchoring in VR.
- Power Adapter and USB-C Cable: For charging and high-speed data transfer (up to 10Gbps).
- Face Cushion & Glasses Spacer: For ergonomic use during long research sessions.
- Pico Connect Software: For streaming high-fidelity models from a workstation.

Figure 1. General view of the Pico 4 Ultra set

1.4. Core Educational and Research Tasks

- Immersive Urban Planning: Experiencing proposed transport changes at a 1:1 scale.
- Behavioural Traffic Research: Studying pedestrian and driver reactions in a safe, simulated VR environment.
- MR Site Audits: Overlaying planned infrastructure (cycle lanes, bus stops) onto the real street view using high-resolution passthrough.
- Digital Twin Interaction: Collaborative review of PTV Vissim simulations in a 3D space.
- Safety Training: Simulating hazardous traffic scenarios for educational purposes without physical risk.

2. Purpose and Application in Education

2.1. Usage in Courses and Laboratory Studies

The Pico 4 Ultra system is a key component of the SUTLab digitization strategy, used in disciplines related to smart cities and transport psychology. The system can be applied in the following academic disciplines:

- Sustainable Transport in Urban and Rural Planning
- Intelligent Transport Technologies for Integrated Mobility
- Road Safety and Human Factors in Transport
- Digital Twins in Urban Engineering

Within these disciplines, the equipment is used for the following practical and laboratory assignments:

- Lab work: *Visualising Urban Space Changes using VR/MR Headsets*
- Lab work: *Evaluation of Intersection Visibility and Level of Service (LOS) via Immersive Simulation*
- Research project: *Comparing Pedestrian Crossing Behaviour in Real vs. Virtual Environments*
- Research project: *Mixed Reality Application for Real-Time Utility and Infrastructure Mapping*

2.2. Competencies Developed

Technical Competencies:

- Hardware calibration and boundary (Guardian) setup for safe operation.
- Configuring wireless/wired streaming between VR headsets and modelling workstations (Wi-Fi 7/Ethernet).
- Mastering Mixed Reality (MR) spatial anchoring and depth sensing.

Analytical Competencies:

- Assessing the ‘sense of presence’ and its impact on simulation validity.
- Identifying design flaws in transport infrastructure through first-person perspective (POV) analysis.
- Interpreting 3D spatial data and heatmaps within a virtual environment.

Digital Competencies:

- Operating within spatial computing operating systems (Pico OS).
- Using VR/MR collaboration platforms for remote technical reviews.
- Optimizing 3D assets for mobile XR hardware (Snapdragon XR2 Gen 2).

2.3. Link to Sustainable Development

Pico 4 Ultra equipment is directly linked to Sustainable Development Goal 11 “Sustainable Cities and Communities” (SDG 11).

- SDG 11.3 – Enhances inclusive urbanization by allowing stakeholders to 'walk through' planned spaces virtually and provide feedback.
- SDG 11.7 – Helps design safe and accessible green public spaces by simulating lighting, shade, and traffic interaction in a virtual twin.

Environmental impact – reduces the need for physical prototypes and minimizes travel for site visits, as field conditions can be digitized.

2.4. Expected Learning Outcomes

Upon successful completion of this laboratory module, the student will be able to:

- operate VR/MR hardware fluently, including calibration and network integration.
- visualise complex transport models (from PTV Vissim, Unity, or Unreal Engine) in an immersive environment.
- conduct virtual ‘Safety Audits’ of road infrastructure from the perspective of different road users.
- define the boundaries between Virtual and Mixed Reality applications in urban engineering.

3. Technical Specifications

3.1. Core Parameters

Table 2. Technical Specifications of Pico 4 Ultra system

Parameter	**Value**
Processor	Qualcomm Snapdragon XR2 Gen 2
Memory (RAM)	12 GB LPDDR5X
Storage	256 GB UFS 3.1
Resolution	4.3K+ (2160 × 2160 per eye)
Refresh Rate	72Hz / 90Hz
Optics	Pancake Lenses (minimal distortion)
Field of View (FOV)	105°
Passthrough	Dual 32MP Colour Cameras (8.0M pixel binning, 20.6 PPD)
Sensors	4 Environment Tracking Cameras, dual depth sensing
Wireless Connectivity	Wi-Fi 7 Supported (High-bandwidth, low-latency)
Battery	5700 mAh (Approx. 2–2.5 hours active use)
Weight	~580g (balanced rear-battery design)

Processor	Qualcomm Snapdragon XR2 Gen 2
Memory (RAM)	12 GB LPDDR5X
Storage	256 GB UFS 3.1

3.2. Environment Requirements

Hardware Requirements (PC-VR Streaming):

- GPU: NVIDIA RTX 3070 or higher (recommended for 4K modelling).
- Network: Wi-Fi 6E or Wi-Fi 7 router (5GHz/6GHz band) connected via Gigabit Ethernet to the PC.
- Operating System: Windows 10/11.

Physical Requirements:

- Safe Zone: Minimum 2m × 2m obstacle-free area for 'Roomscale' mode.
- Lighting: Even indoor lighting; avoid direct sunlight on lenses

3.3. Installation and Setup

- Charging: Ensure headset and controllers are fully charged via USB-C.
- Startup: Power on and follow the on-screen calibration for Floor Level and Boundary.
- Software: Install Pico Connect on the modelling workstation.
- Pairing: Connect the headset to the same high-speed Wi-Fi network as the PC.
- MR Setup: (If using Mixed Reality) Calibrate the room layout to define walls and furniture.

Figure 2. Control elements and interface layout of the Pico 4 Ultra system

4. Functional Capabilities

4.1. Core Functions

- High-Resolution Passthrough: Real-time colour view for MR tasks.
- Spatial Audio: 360-degree sound for realistic traffic noise simulation.
- Hand Tracking: Controller-free interaction with 3D models.
- PC-VR Streaming: Wireless connection to engineering software (Vissim).
- Spatial Multitasking: Multiple 2D windows alongside 3D models.

4.2. Typical Tasks

Task Category	Specific Task
Infrastructure Review	Virtual walk-through of a new bike lane to check for 'blind spots'.
Public Consultation	Showing citizens a 3D visualisation of a future pedestrian square.
Data Visualisation	Projecting 3D 'Pollution Heatmaps' over a city model.
Simulation	Immersing a user in a traffic flow model to assess psychological comfort.

5. Safety and Ethical Considerations

5.1. Safety Rules

- Motion Sickness: New users should limit sessions to 15–20 minutes.
- Boundary Awareness: Never ignore the 'Guardian' grid; it prevents collisions.
- Vision Correction: The Pico 4 Ultra does not support vision correction. If you need corrective lenses, make sure to wear your glasses during use.
- Sun exposure: Never expose the headset to direct sunlight or UV light, as it can cause permanent damage to the display.
- Lens Care: To avoid scratches and ensure a clear viewing experience, clean the headset lenses with a soft eyeglass cloth. Avoid using harsh cleaning chemicals.
- Physical Assistance: Use a 'spotter' when a user is in Full VR.

5.2. Usage Restrictions and Data Protection

- Spatial Privacy: Headset maps room geometry; restrict data sharing in settings.
- Biometric Data: Movement analysis must follow institutional ethical guidelines.
- Sanitization: Use non-alcoholic hygienic wipes between users.

6. References and Documentation

- Official Pico Business Support: https://business.picoxr.com/
- PICO 4 Ultra Setup Guide. SkillsVR. https://skillsvr.com/wp-content/uploads/2024/11/PICO-4-Ultra-Setup-Guide.pdf
- Pico 4 Ultra Technical Guides: https://www.picoxr.com/global/software/pico-os

2.3. ENVIRONMENTAL STATE MONITORING AND ASSESSMENT SYSTEMS

AZ-7755 PORTABLE AIR QUALITY ANALYSER

1. Purpose and Field of Application

The functional purpose of the AZ-7755 Air Quality Analyser is to provide comprehensive control over the primary microclimate parameters that directly affect the sanitary and hygienic state of the air environment. Primarily, the device is used to measure carbon dioxide (CO_2) concentration, which serves as a key indicator of ventilation quality: an increase in CO_2 levels signals insufficient air exchange. Additionally, the device simultaneously determines air temperature, which influences thermal comfort and human physiological state, as well as relative humidity – a parameter characterizing the water vapour content in the air that dictates heat exchange conditions, condensation risks, and the potential for microbial growth. Thus, the device provides multi-parameter control, allowing the air to be evaluated as a complex system rather than through isolated indicators.

Regarding operating conditions, the AZ-7755 Air Quality Analyser is primarily oriented toward indoor use across various functional settings. These include vehicle interiors, classrooms, office spaces, and industrial zones. In such environments, the device enables both periodic checks and continuous monitoring of air parameters. It is important to note that measurement results are representative only if the device is positioned correctly (at the height of the human breathing zone, away from local heat sources or drafts), which is directly linked to the research methodology.

The analyser serves several practical engineering and applied purposes:

- **Monitoring Ventilation Efficiency:** By tracking the dynamics of CO_2 concentration changes, one can estimate the air exchange rate and promptly identify underperforming ventilation and air conditioning systems.
- **General Air Quality Assessment:** Comparing measured values with regulatory or recommended levels established by sanitary standards.
- **Detection of CO_2 Thresholds:** Quickly identifying exceedances of maximum permissible CO_2 concentrations, which can negatively impact productivity, focus, and overall well-being.
- **Comfort Analysis:** Evaluating temperature and humidity levels to identify potential issues such as excessive dryness or high humidity

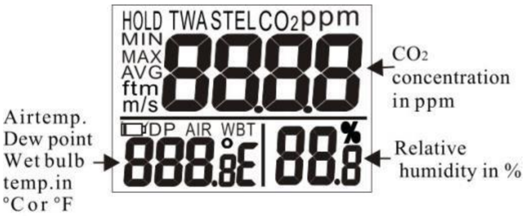
2. Design and Operating Principle of the Device

Structurally, the device is housed in a compact casing with an integrated digital display that shows measurement results in real-time. The front panel features control buttons for configuring operating modes and calibration (Fig. 1.1). The built-in sensing elements include a non-dispersive infrared (NDIR) sensor for CO_2 concentration measurement, as well as temperature and humidity sensors. Air sampling is carried out through specialised ventilation openings in the housing, ensuring direct contact between the sensors and the analysed environment.

Figure 1.1. AZ-7755 Air Quality Analyser Design

The display of the AZ-7755 Air Quality Analyser is a key component of the user interface, designed for real-time visualisation of measurement results. It features a liquid crystal display (LCD) with sufficient contrast and clarity to ensure easy data reading under various lighting conditions. Structurally, the display is integrated into the front panel, occupying the central portion to optimize ergonomics.

The screen simultaneously displays the primary measured parameters: CO_2 concentration (in ppm), temperature (°C), and relative humidity (%). The CO_2 level is the priority indicator, typically emphasized by a larger font or central placement. Auxiliary parameters (temperature and humidity) are shown as smaller numeric indicators in designated areas of the display. This information hierarchy allows for a quick assessment of the critical parameter while maintaining access to additional data (Fig. 1.2)



Symbols

TWA	Time weighted average(8 hours)
STEL	Short-term exposure limit (15minutes weighted average
HOLD	Readings are freezed unchanged
MIN/MAX	Minimum/Maximun readings
▭	Low battery indicator
DP	Dew point temp.
AIR	Air temperature
WBT	Wet bulb temp.
%	Unit of relative humidity
°E (C/F)	Celsius/ Fahrenheit
°AVG/ftm /m/s	Vain icons in these models

Figure 1.2. LCD display of an AZ-7755 Air Quality Analyser

The keypad of the AZ-7755 Air Quality Analyser is the primary control interface, allowing the user to interact with the device and manage essential settings and operating modes (Fig. 1.2). Structurally, it consists of a set of tactile buttons located on the front or side panel of the housing, ensuring convenient access during operation.

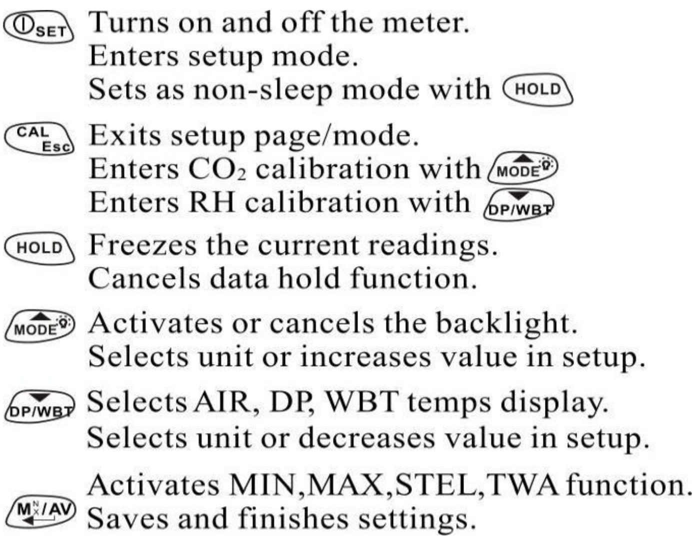


Figure 1.3. Keypad of an AZ-7755 Air Quality Analyser

Functionally, the keypad performs the basic control operations. The primary functions include: powering the device on and off, switching parameter display modes, activating the display backlight, and accessing calibration functions. Specific buttons can be used to view the maximum and minimum values of the measured parameters.

From an ergonomic standpoint, the buttons are sufficiently sized and provide clear tactile feedback, ensuring precise operation even in field conditions or when the operator's attention is limited. The button surface is made of an elastic polymer material, which increases wear resistance and protects against dust and moisture ingress into the housing. Labels on the buttons consist of symbols or icons that intuitively represent their functional purpose.

A key feature of the AZ-7755 Air Quality Analyser keypad is its focus on minimising user error. The controls are organised such that critical functions (e.g., calibration) require confirmation or a long press, reducing the risk of accidental setting changes. At the same time, simple operations, such as viewing readings or switching modes, are performed quickly without complex combinations.

The principle for measuring CO_2 concentration is based on non-dispersive infrared (NDIR) spectroscopy, which involves determining the absorption level of infrared radiation by gas molecules. Since CO_2 has characteristic absorption bands in the infrared spectrum, the signal intensity recorded by the sensor changes proportionally to the gas concentration. Temperature measurement is performed using a heat-sensitive element, while relative humidity is measured via a capacitive sensor, whose parameters change depending on the water vapour content in the air

3. Technical Specifications

The device is characterized by specific metrological parameters, including the CO_2 concentration measurement range, typical accuracy (error margin), response time, and stability of readings (Table 1.1). The use of a modern sensor module ensures sufficient precision for engineering monitoring; however, measurement results may depend on operating conditions such as temperature, humidity, and the presence of foreign impurities in the air. Consequently, adhering to the calibration schedule and ensuring proper device placement during measurements is essential.

The analyser is powered by an autonomous source, providing mobility and the capability for use in both stationary and field conditions. Functionally, the device supports continuous monitoring mode and can also be used for one-time (spot) measurements.

Table 1.1. Technical specifications of AZ-7755 Air Quality Analyser

Parameter	Specification
CO_2 Range	0…9999 ppm (2001…9999 ppm out of scale range)
CO_2 Resolution	1 ppm
CO_2 Accuracy	±50 ppm ±5 % of reading (0…2000 ppm), unspecified for other ranges
CO_2 Response Time	<30 Seconds (90% step change)
CO_2 Warm-Up Time	30 Seconds

Air Temperature Range	-10…+60 °C, 14…140 °F
Air Temperature Resolution	0.1°C; 0.1°F
Air Temperature Accuracy	±0.6°C, ±0.9°F
Air Temperature Response Time	<2 mins (90% step change)
Humidity Range	from 0.1 to 99.9% RH
Humidity Resolution	0.1 % RH
Humidity Accuracy	±3 % RH (at 25°C, 10…90% RH); others ±5 % RH
Humidity Response Time	<10 mins (90% step)
LCD Size	44(L)×26(W) mm
Meter Size	205(L)×70(W)×56(H) mm
Operating Temperature	0…50 ℃
Operating Relative Humidity (RH%)	0…95% RH (avoid condensation)
Storage Temperature	-20…+50 °C
Storage RH%	0…90% RH (avoid condensation)
Power Supply	Alkaline AA * 4 PCS
Battery Life	>24 hours (Alkaline Battery)
Weight	～200 g

4. Functional Capabilities and Operating Modes

The AZ-7755 Air Quality Analyser offers several features designed for comprehensive air quality assessment:

- Advanced NDIR Technology: Equipped with a Non-Dispersive Infrared sensor for stable and accurate CO_2 detection.
- Triple Display: Simultaneous monitoring of CO_2 levels, air temperature, and relative humidity.
- Real-time Analysis: Data updates every 2 seconds for immediate air quality feedback.
- Safety Standards Tracking: Calculates and displays TWA (Time Weighted Average for an 8-hour shift) and STEL (Short-Term Exposure Limit over 15 minutes).
- Enhanced Response Housing: The casing is designed with air-guiding vents to facilitate rapid air exchange and sensor reaction.
- Manual Calibration: Simplifies maintenance with manual CO_2 and humidity calibration (using AZ 33% / 75% salt solutions).
- Alert System: Features a programmable audible alarm that triggers when CO_2 levels exceed safety thresholds.
- User-Centric Design: High-resolution, large LCD with a backlight for operation in low-light environments.
- Versatile Power: Operates via batteries for mobility or an AC adapter for long-term monitoring.

The operating modes of the AZ-7755 Air Quality Analyser define the device's functional logic and the methods for acquiring, processing, and displaying measurement data.

In continuous monitoring mode, the device performs constant measurements of CO_2 concentration, temperature, and relative humidity at a fixed data update interval. The sensor system operates cyclically: air sampling occurs, followed by signal analysis and the updating of readings on the display. This mode allows for tracking parameter dynamics over time, which is particularly important when studying ventilation efficiency or the impact of variable loads (e.g., changes in room occupancy).

From an engineering perspective, continuous monitoring enables the identification of CO_2 concentration trends, the recording of peak values, the assessment of ventilation system inertia, and the detection of periodic parameter fluctuations. A drawback of this mode is its dependence on the sensor's response time: rapid environmental changes may be displayed with a delay.

Single (spot) measurement mode involves recording current parameter values at a specific moment in time. Its use is appropriate for conducting check measurements, comparing different points within a room, or in cases where a quick assessment is needed without long-term monitoring.

The device is equipped with a warning alarm function, which activates when specified parameter thresholds are exceeded. The alarm is implemented as an audible signal.
Due to the physical characteristics of the sensor and the gas diffusion process, the device has a specific response time. This means that rapid changes in CO_2 concentration are displayed with a delay, which can be critical when analysing short-term processes. Furthermore, measurement results may be distorted by temperature fluctuations, high or unstable humidity, the presence of dust or aerosols, and air currents (droughts).

The device is not intended for operation in aggressive or extreme environments (high dust levels, condensation, or explosive zones). Violating operating conditions may lead to sensor degradation or incorrect readings.

The advantages of the AZ-7755 Air Quality Analyser make it an effective tool for rapid engineering control of air quality, while its drawbacks define its limits of application. When used correctly and calibrated regularly, the device provides reliable results for most practical tasks; however, it cannot fully replace high-precision laboratory equipment.

In conclusion, the AZ-7755 Air Quality Analyser is an effective technical tool for assessing air quality under real operating conditions. It allows for the detection of deviations from regulatory parameters, the analysis of ventilation status, and the substantiation of measures to improve the microclimate. Its use is justified in practical engineering activities, provided that technical limitations are considered, and measurement methodologies are followed.

NOISE DETECTOR

1. Introduction

1.1. Equipment Name and Purpose

- Full name - **UNI-T UT352 Sound level meter**
- Type - **Hardware**
- Category - **Environmental monitoring**

1.2. Short Description

Sound Level Meter Model UT352 is a stable, safe and reliable sound level meter. The Meter is suitable to use in noise control, quality control, health care and all different kind of environmental noise testing. For example: factory, road, family, musical instrument and all kind of places which need noise testing.

1.3. Components

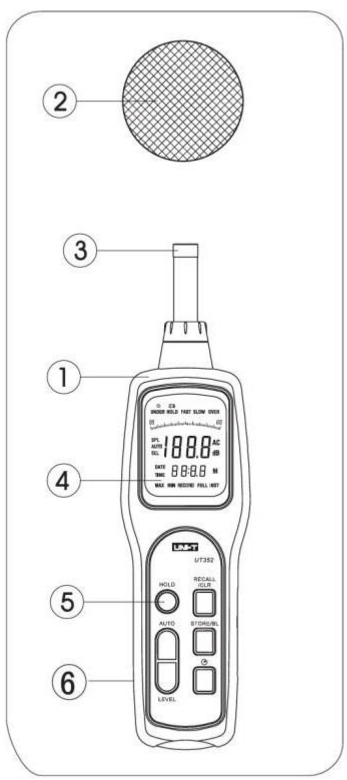


Figure 1. Noise detector components

1. Housing

2. Windscreen
3. Microphone
4. LCD Display
5. Functional Buttons
6. Signal output and power terminals

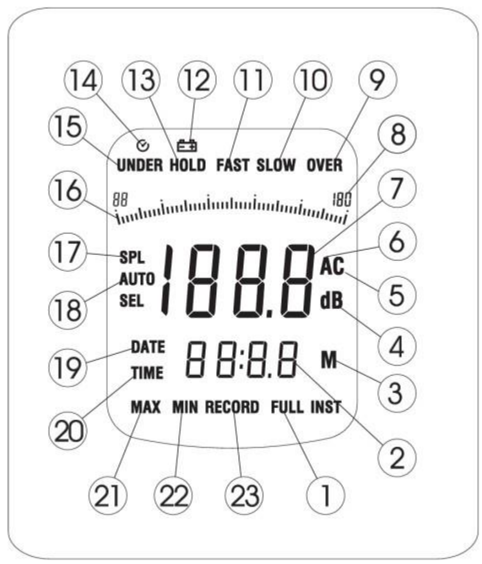


Figure 2. Display Symbols:
1 – Data Store is full; 2 – Date and Time display; 3 – Data Store; 4 – Decibel;
5 – C-Weighting; 6 – A-Weighting; 7 – Sound value display; 8 – Range display;
9 – Over range; 10 – Slow response; 11 – Fast response; 12 – Low battery display;
13 – Data Hold is on; 14 – Auto power off enabled; 15 – Under range;
16 – Analogue bar graph display; 17 – Symbol of Sound Pressure Level;
18 – Auto ranging enabled; 19 – Date display; 20 – Time display;
21 – Maximum value display; 22 – Minimum value display; 23 – Data Store enabled

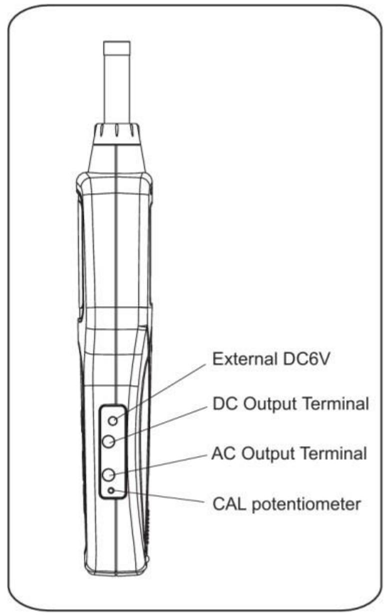


Figure 3. Side Panel:
1. DC Output Terminal: DC analogue signal output. Output impedance is around 100Ω (10mV/dB); 2. AC Output Terminal: AC analogue signal output. Output impedance is around 600Ω (0.707V/ each range scale); 3. CAL potentiometer: Calibration
4. External DC6V: Using power adaptor DC6V, output plug (Ø3.5 mm) to plug in the terminal. It can use 4pcs of 1.5V batteries or power adaptor to power up the meter

1.4. Core Tasks

The equipment is used for environmental state monitoring regarding the noise level measurement. During sound measurement, "A" or "C" frequency weighting can be selected. With "A" weighting selected, the frequency response of the meter is similar to the response of the human ear. "A" weighting is commonly used for environmental or hearing conservation programs. 'C" Weighting is a much flatter response and is suitable for the sound level analysis of machines, engines, etc.

2. Purpose and Application in Education

2.1. Usage

It is applied in the discipline "Environmental technique and protection" from the study plan "Engineering and management in automotive transport".

It is used for the next laboratory work: "Experimental research of the level of noise pollution in the urban environment and assessment of its impact on the environment".

2.1. Competencies

- **Technical:** operating the equipment, configuration/setup.
  - The ability to integrate knowledge from related fields (information technology, environmental sciences, urban planning) to model and solve complex engineering problems.
  - The ability to develop engineering solutions based on the principles of energy efficiency, circular economy, and environmental impact reduction, in correlation with the requirements of sustainable development.
- **Analytical:** data processing, interpretation.
  - Green skills – environmental impact assessment, design of sustainable transport solutions.
  - The competence to develop energy-efficient and environmentally friendly engineering solutions, in line with the principles of Sustainable Development Goal 11.
- **Digital:** working with software and digital models.
  - Advanced digital skills – data analysis, simulations, use of modern logistics management software.

2.2. Link to Sustainable Development

- Research on the level of noise pollution in urban environments aims to measure and analyse noise generated by traffic, industrial activities, and other urban sources. The study involves the use of specialized equipment to monitor decibel levels, map areas with high noise pollution, and assess their effects on the health of the population and the environment. The results allow the identification of critical areas and the substantiation of urban noise reduction strategies, such as traffic planning, noise barriers, and regulations on industrial activities. The relevance to SDG 11 is aimed at reducing noise pollution, increasing the quality of urban life, and protecting the health of the population. Furthermore, it develops skills for specialists in urban acoustics, environmental engineering, urban planning, and public health.

2.3. Expected Learning Outcomes

- The student will understand the principles of noise pollution and its effects on the health of the population and the urban environment.
- The student will know the methods and instruments for measuring environmental noise (sound level meters, acoustic monitoring systems).
- The student will identify the main sources of noise pollution in the urban environment (road traffic, public transport, industry, commercial activities).

- The student will understand the international and European regulations and standards regarding permissible noise levels.
- The student will carry out experimental measurements of noise levels in different urban areas.
- The student will analyse and interpret the data obtained, using acoustic processing and modelling software.
- The student will evaluate the impact of noise pollution on the environment and on the quality of urban life.
- The student will propose engineering and managerial solutions for noise reduction (green infrastructure, acoustic barriers, silent technologies).
- The student will integrate interdisciplinary knowledge (engineering, urban planning, ecology) for the development of sustainable projects.
- The student will report and communicate research results to authorities, communities and stakeholders, contributing to sustainable public policies.

3. Technical Specifications

Table 1. Technical Parameters

Parameter	Value
Display	3 1/2 digits, 1999 maximum
Overloading	Under range displays **UNDER** Over range displays **OVER**
Battery Deficiency	Change batteries as soon as is displayed.
Sampling Rate	Fast Speed: 125 microseconds Slow Speed: 1 second
Microphone	1/2” electret condenser
Drop Test	1 meter pass
Battery	4 × 1.5V batteries (AA)
Battery Life	Typical 20 hours continuous
Dimension	273 × 69 × 39 mm
Weight	around 386 g (including batteries)
A-Weighting and C-Weighting	30~130dB
Frequency Response	31.5~8kHz
DC analogue signal output	Output impedance around 100Ω, 10mV/dB
AC analogue signal output	Output impedance around 600Ω, 0.707V/ each scale

3.1. Environment Requirements

- For indoor use only.
- Altitude: 2000m
- Temperature and humidity:
  - Operating: 0 ~30 (≤80%R.H) 30 ~40 (≤75%R.H) 40 ~50 (≤45%R.H)
  - Storage: -20 ~ +60 (≤80%R.H)
- Safety/ Compliances: EN61326:1997+A1:1998+A2:2001+A3:2003, EN61672-1: 2002 Class 2 and IEC60641:1979 Type 2, ANSI S1.4:1983 Type 2
- Certification: CE

3. 2. Installation and Setup

After calibration is ready to use, no additional software setup is needed.
Calibration:
1. Turn the meter on.
2. Put the Meter in the "A" weighting mode, FAST response mode, range set to 60~110dB, lock to MAX.
3. Place the microphone onto the calibrator's 1/2 inches sound source hole.
4. Turn the calibrator on, using 94dB@1kHz standard sound source.
5. Adjust the Meter's CAL potentiometer located on the side panel until the LCD displays 94.0dB

4. Functional Capabilities

Turn the Meter on and off. Press once to turn the Meter on. Press and hold for around 1 second to turn the Meter off.

During sound measurement, press the A/C button to select "A" or "C" frequency weighting. With "A" weighting selected, the Meter's frequency response is similar to that of the human ear. "A" weighting is commonly used for environmental or hearing conservation programs. "C" Weighting is a much flatter response and is suitable for the sound-level analysis of machines, engines, etc. Most noise measurements are performed using "A" Weighting and SLOW Response.

HOLD feature: During sound measurement, press once to freeze the current reading in the display. Press the button again to resume normal operation.

Press to select a FAST (125ms) or a LOW (1 second) response time. Select FAST to capture noise peaks and noises that occur rapidly. Select the LOW response to monitor a sound source that has a consistent noise level or to average quickly changing levels. Select LOW response for most applications.

Press and hold the FAST/SLOW button to enable the display backlight. Press and hold the FAST/SLOW button again to disable the display backlight. For UT352, press the FAST/SLOW button to store data: Press the HOLD button to freeze data, the LCD displays HOLD and M symbol, and the data being stored. Press FAST/SLOW to store the data, the symbol RECORD, and the number of index blink for 0.5 seconds. The Meter will automatically exit HOLD mode. The Meter can store up to 63 pieces of data.

5. Safety and Ethical Considerations

Periodically wipe the case with a damp cloth and mild detergent. Do not use a chemical solvent. To clean the terminals with a cotton-tipped swab with detergent, as dirt or moisture in the terminals can affect readings. Press the Meter power off when it is not in use, and take out the battery when not using it for a long time. Do not store the Meter in place of humidity, high temperature, explosive, inflammable, or strong magnetic fields.

Do not attempt to repair or service your Meter unless you are qualified to do so and have the relevant calibration, performance test, and service information. To avoid electrical shock or damage to the Meter, do not get water inside the case. In order not to affect the Meter accuracy or damage the Meter, do not open the Meter housing.

6. References and Documentation

[UNI-T UT351 OPERATING MANUAL PDF Download | ManualsLib]

Figure 4. General view of UT352 Sound level meter

2.4. TRAFFIC AND TRANSPORT MODELLING SYSTEMS

PTV VISUM SOFTWARE

1. Introduction

1.1. Equipment Name and Purpose

- PTV Visum
- Type: Software
- Category: Software for macromodelling in transport systems

1.2. Short Description

PTV Visum (Visum) is a software system that allows you to model all private and public transport types in one single integrated model. It is complemented by the microscopic traffic simulation system PTV Vissim (Vissim). Using Visum, most basic data provided by transport information and planning systems can be managed consistently and maintained with the network editor. Unlike simple GIS systems, Visum allows complex relationships within single or several transport systems to be retained, enabling you to create a suitable transport model.

A transport model normally consists of a demand model, a network model based on Visum, and various impact models.

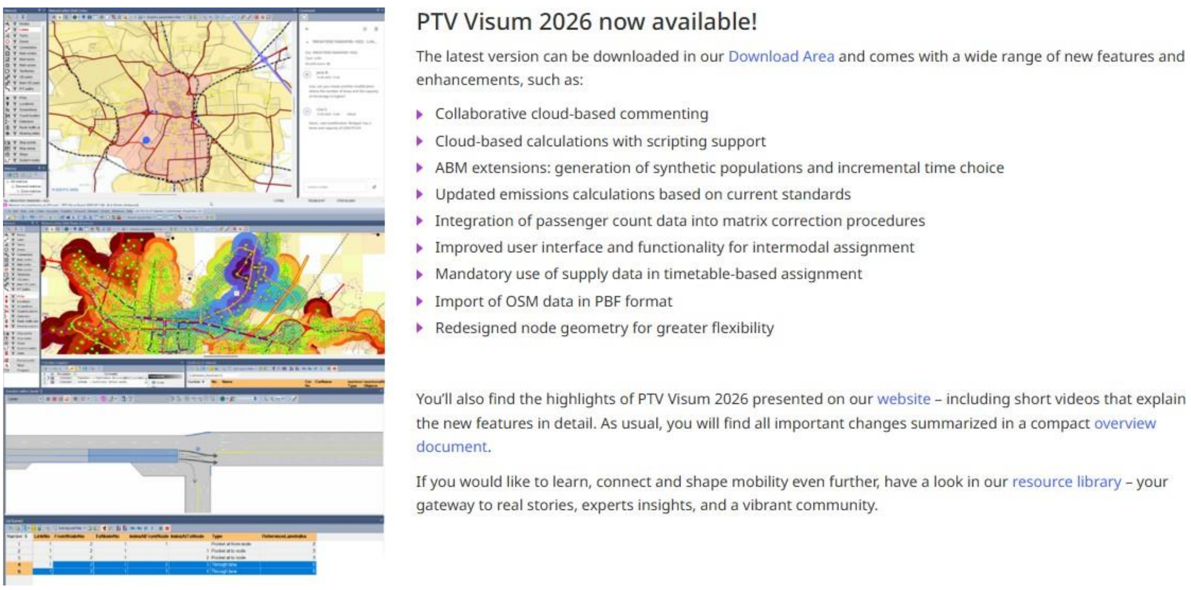


Fig.1. Start page of PTV Visum 2026

3. Components

- **List of main components:** network licence of the PTV Academic Package software for 3 (three) years

4. Core Tasks: Software for macromodelling in transport systems

2. Purpose and Application in Education

2.1. Academic Integration

- Discipline: "Ecosystem Technologies for Sustainable Urban Transport"
- Practical application: used extensively for the laboratory assignment "Creating a transport network model"

2.2. Core Competencies

- **Technical / Digital:** Installation, configuration, and management of professional engineering software on personal and workstation hardware).
- **Analytical:** Evaluating passenger transport characteristics, traffic management systems, and functional parameters of urban mobility networks.

2.3. Link to Sustainable Development

- PTV Visum supports **SDG 11** (Sustainable Cities and Communities) by enabling the creation of Digital Twins. These models allow planners to simulate sustainable infrastructure, optimize public transit, and reduce the carbon footprint of urban mobility.

2.4. Expected Learning Outcomes

- The student can install and use the basic functionality of the software.
- The student can analyse existing parameters of transport systems with parameters of transport systems as a result of modelling to verify the adequacy and accuracy of the simulation.
- The student can apply modelling skills to real transportation systems.

3. Technical Specifications

Table 1. Software and Licence Overview

Parameter	Value
Package content	Network licence
Core specifications	Without limitation of functionality. Possibility of modelling in large-scale transport networks
Licence time limits	3 (three) years
Interfaces	PTV Visum

3.1. Environment Requirements

Operating Systems: Microsoft Windows 11, latest release; Microsoft Windows 2016 Server, latest Service Pack; Microsoft Windows 2019 Server, latest Service Pack; Microsoft Windows 2022 Server, latest release.

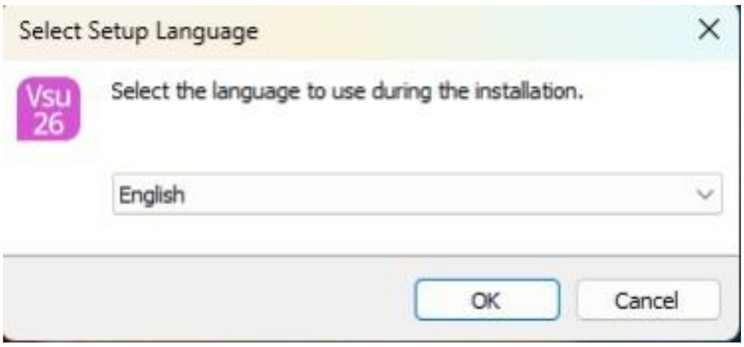
Table 1. Hardware requirements

Parameter	Minimum	Recommended for standard installation

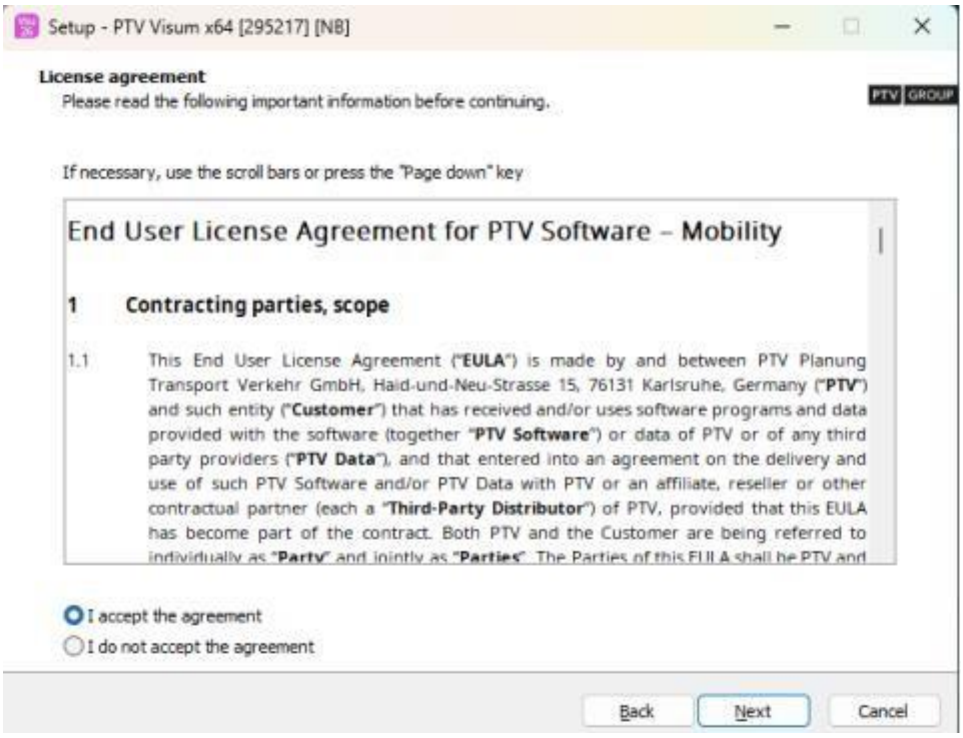
Processor	X64 processor with support for SSE4.2, e.g.: - Intel Core i5 / Core i7 / Core i9; - AMD Ryzen.	Recent multi-core processor, e.g.: - Intel Core i7-14700K, Core i9-14900K - Intel Xeon w9-3575X - AMD Ryzen 9 9950X, - AMD Ryzen Threadripper 9970X or better
Memory	4 GB	16-32 GB or more
Disk space (software)	2 GB free disk space per product for compact installation	5 GB free disk space per product for full installation
Monitor	Screen resolution 1280x800 or 1366×768 pixels	Full HD (1920×1080 pixels) or higher resolutions, multiple screens are supported
Graphics Card	For 3D Graphics OpenGL® 3.0 or DirectX 11 support is recommended	
USB / Network	- In case the licence is provided in relation with a hardware dongle, a full USB port is required for operation. - In case a network licence is provided, access to a licence server in the local network or the internet is required for operation. - In case a cloud licence is provided, a permanent internet connection is required. - An internet connection is required if background map services shall be used.	
Disk space (project data)	Sufficient storage capacity for project data handling, ideally on SSD	

3.2. Installation and Setup

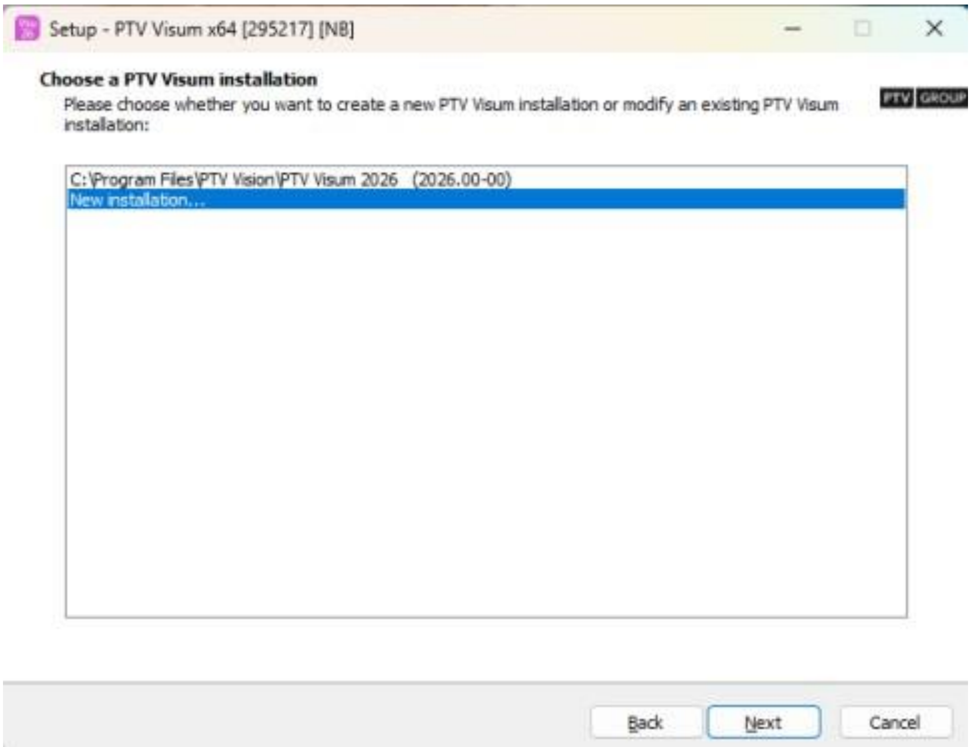
1. Open the Windows Explorer. 2. Go to the directory that contains the downloaded installation files. 3. Start the SETUP*.EXE file. The Select Setup Language window opens:



4. In the drop-down list, select English.
5. Confirm with **OK**.
6. Click the **Next** button



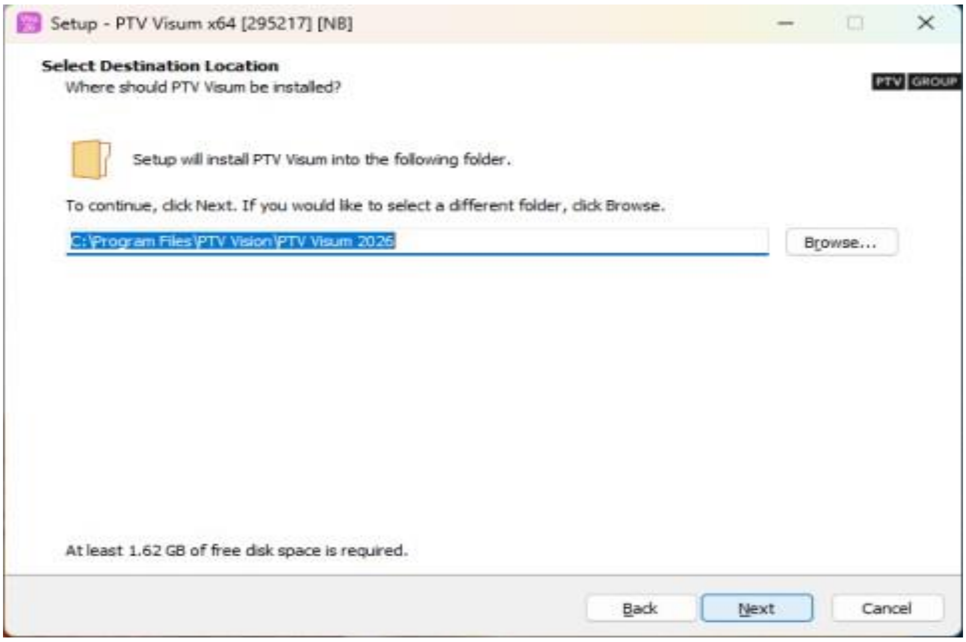
10. Read the **Data Privacy Statement**.
11. Select the option “I have read the **Data Privacy Statement**”.
12. Click the **Next** button. If PTV Visum is already installed, the **Choose an Installation** window opens. Otherwise, continue with step 17.



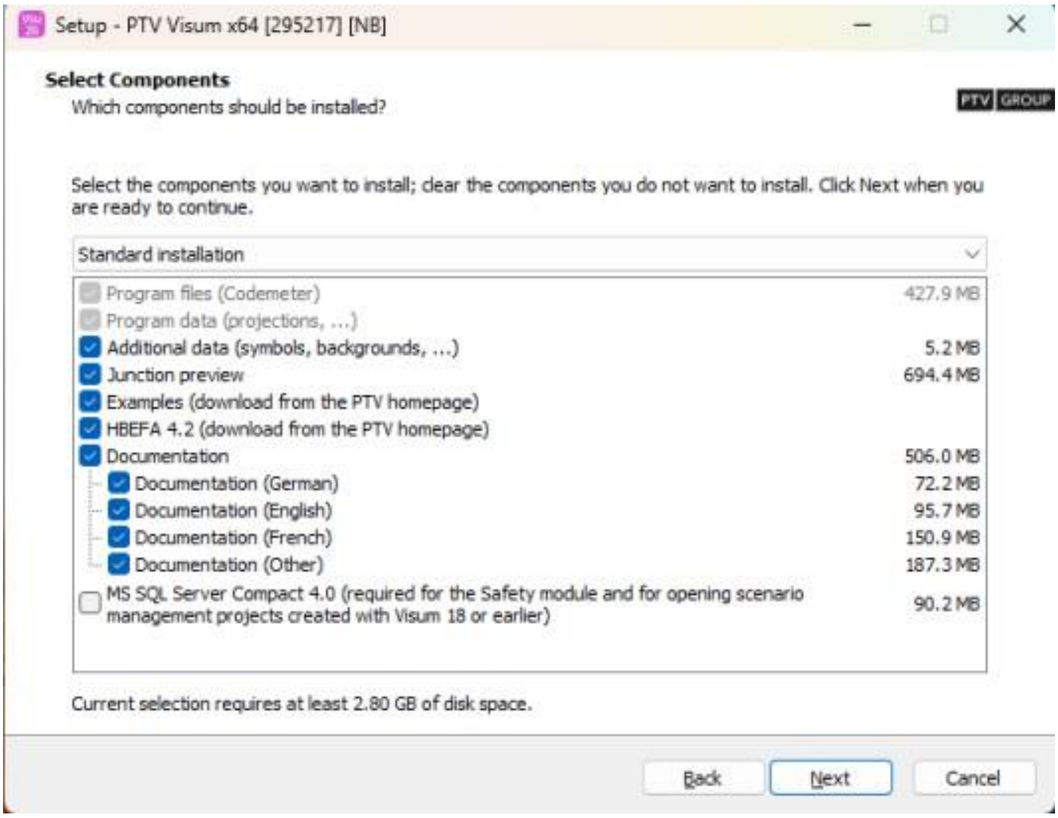
13. Make the desired changes:

Element	Description
Earlier installation of PTV Visum 2026	To replace a previous installation of PTV Visum 2026, choose the desired entry.
New installation...	If you want to reinstall PTV Visum, select this option. Note: This installation process displays fewer windows than when replacing a previous installation. In this document, skip the instructions for the windows that you do not see.

14. Click the **Next** button



15. Select a folder where PTV Visum 2026 shall be installed. We recommend using the proposed directory. 16.Click the **Next** button. In the following window, you can select the components that you want to install.



17. From the drop-down list, choose the desired installation. We recommend the Standard Installation.

4. Functional Capabilities

Core functions: designing of models of passenger and freight transport systems, traffic management systems.

Typical tasks: quantitative analysis, performance evaluation, and infrastructure optimization.

5. Safety and Ethical Considerations

To obtain adequate modelling data, verification, and validation of the initial data is necessary.

6. References and Documentation

1. PTV Visum 2026 – Manual. *Built into software*

CHAPTER 3. METHODOLOGICAL GUIDELINES FOR LABORATORY AND PRACTICAL CLASSES

INTRODUCTION

Practical training is an essential component of modern transport education, as it bridges the gap between theoretical knowledge and real-world challenges in urban mobility, transport modelling, and sustainable development. Amidst the digitalization of the transport sector, practice-oriented teaching methods – which involve hands-on experience with modern equipment, information systems, and transport process analysis software – have become increasingly vital.

Within the framework of the **ISDEGO project**, laboratory and practical sessions are designed to cultivate professional competencies in traffic flow analysis, field data collection and processing, transport systems modelling, environmental monitoring, and urban mobility performance assessment. Significant emphasis is placed on the use of modern digital technologies, Intelligent Transport Systems (ITS), geographic information tools, visualisation systems, and transport modelling software.

The methodological recommendations presented in this chapter are designed to facilitate the practical application of the equipment and software procured under the project. They cover the core areas of laboratory research, including the study of traffic flow characteristics, the analysis of traffic management, the assessment of transport infrastructure parameters, the modelling of transport networks, and the evaluation of the environmental indicators of transport system operations.

The proposed laboratory sessions are oriented toward developing data analysis skills, critical thinking, and decision-making capabilities in the field of sustainable transport. By completing these practical tasks, students can work with real-world transport and environmental data, investigate the impact of transport processes on the urban environment, and evaluate the effectiveness of modern approaches to urban mobility management.

FIELD DATA COLLECTION AND EMPIRICAL ANALYSIS

LABORATORY WORK 1

ANALYSIS OF TRAFFIC FLOW CHARACTERISTICS (USING RADAR-BASED DATA ACQUISITION SYSTEM)

Purpose and Scope

This laboratory work aims to explore the main characteristics of traffic flow using the video detection system and to develop hands-on skills in collecting, processing, and interpreting traffic data. During the exercise, students will work with actual traffic detection equipment and gain practical experience in observing and analysing transport processes under real or simulated urban conditions. The focus is placed not only on understanding theoretical traffic flow parameters, but also on applying modern intelligent transport technologies in practice.

As a result of completing this laboratory work, students are expected to: become familiar with the operating principles of video-based traffic detectors; learn how to configure and adjust detection zones for accurate data collection; identify and calculate key traffic flow parameters such as flow rate, speed, and density; analyse traffic behaviour and patterns, particularly at intersections, using collected data. This laboratory work contributes to the development of competencies in intelligent transport systems, data-driven decision-making, and modern traffic monitoring technologies.

Equipment Name and Purpose.

Video Detector FLIR TrafiCam 2 (Wide).

Type: Hardware + Software;

Category: Traffic monitoring system (video-based detection). TraciCam 4TI Video Detector Interface Module; Type: Hardware; Category: Traffic signal interface / data acquisition module.

Short Description.

The FLIR TrafiCam 2 (Wide) is a video-based traffic detection system designed for monitoring traffic flow at intersections and road segments. It uses camera-based image processing to detect vehicles, measure traffic parameters, and support intelligent traffic control systems. The TrafiCam 4TI module is a sixteen-channel interface unit used to connect the video detector to traffic signal controllers, enabling real-time data transmission and integration into traffic management systems.

Components

Video detector (FLIR TrafiCam 2 Wide camera unit); embedded image processing software; TrafiCam 4TI interface module (16-channel); communication interfaces (I/O channels); mounting and power supply components.

Core Tasks

Detection of vehicles in traffic streams; measurement of traffic flow parameters (intensity, speed, presence); monitoring of intersections and road segments; transmission of detection signals to traffic light controllers; support of intelligent transport systems and traffic management.

Theoretical Background

Traffic flow can be understood as a continuous movement of vehicles along a road network, where each driver's behaviour, road conditions, and control systems together shape the overall dynamics. To describe and analyse this process in a structured way, several key parameters are typically used. These indicators make it possible to move from simple observation to quantitative evaluation of traffic conditions. One of the primary characteristics is traffic flow intensity. It reflects how many vehicles pass a selected point over a certain period of time. In practice, this parameter is obtained by counting detected vehicles within a defined observation interval. A higher intensity usually indicates heavier traffic conditions, especially during peak hours.

$$q = N/T$$

where:

q – traffic flow intensity (veh/h);
N – number of vehicles observed;
T – observation time.

Another important parameter is the speed of traffic flow. In real traffic conditions, vehicles do not move at identical speeds, so the concept of average speed is commonly used. Radar-based systems estimate speed by tracking the motion of vehicles within the detection zone, often using the Doppler effect or time-based position changes. This makes it possible to obtain reliable speed data without direct contact with vehicles.

The third key parameter is traffic density, which describes how closely vehicles are spaced along a road segment. It is particularly important for understanding congestion levels, since higher density often corresponds to reduced speeds and unstable traffic conditions.

$$k = q / v$$

where:

k – traffic density (veh/km),
v – average speed (km/h).

These three parameters – intensity, speed, and density – are interrelated and form the basis of classical traffic flow theory. By analysing them together, it is possible to identify different traffic regimes, from free-flow conditions to congestion. Radar-based data acquisition systems provide a practical way to measure these characteristics. Unlike traditional contact sensors, radar devices operate remotely and are less sensitive to weather or lighting conditions. They detect moving objects, determine their speed, and register vehicle counts within defined zones. This makes them especially useful for real-time monitoring and for applications in intelligent transport systems. Understanding how these parameters are formed and measured is essential for interpreting traffic data correctly. It also allows students to evaluate the quality of measurements and recognize factors that may influence the results, such as traffic composition, road geometry, or environmental conditions.

Principle of Video Radar Operation

A video radar system combines two complementary approaches to traffic detection: radar sensing and video analysis. The radar part is responsible for detecting movement and estimating speed, while the video component provides visual context and helps define where and how vehicles are tracked.

The radar unit emits electromagnetic waves toward the roadway. When these waves encounter a moving vehicle, part of the signal is reflected to the sensor. Because the vehicle is in motion, the frequency of the reflected signal changes slightly – this is known as the Doppler effect. By analysing this shift, the system can determine the speed of each detected object with fairly high accuracy, regardless of lighting conditions.

At the same time, the video camera continuously captures the scene. The image is processed to identify vehicles, track their trajectories, and define virtual detection zones. These zones act like “invisible loops” on the road: whenever a vehicle crosses them, the system registers its presence. This allows for counting vehicles, classifying them by size or type, and linking radar measurements to specific road lines or directions of movement.

An important feature of video radar systems is the synchronization of these two data streams. Radar provides precise speed and movement detection, while video ensures spatial understanding – where exactly the vehicle is, which lane it occupies, and how it behaves in relation to others. Together, they form a more complete and reliable picture of traffic flow than either method alone.

In practice, the system operates continuously in real time. It collects raw data, filters out noise (such as irrelevant moving objects or environmental interference), and converts the information into usable traffic parameters: vehicle counts, speeds, and sometimes even headways or occupancy levels. The results can then be stored, visualised, or transmitted to traffic management systems.

Such systems are widely used in modern intelligent transport infrastructure because they are non-intrusive – they do not require installation within the pavement – and can function under a wide range of weather and lighting conditions. However, their performance still depends on proper calibration, correct placement, and thoughtful configuration of detection zones.

Understanding how video radar works helps students not only operate the equipment but also critically assess the data it produces and recognize possible sources of error in real-world applications.

Workflow Overview

The laboratory work is carried out step by step, allowing students to gradually move from familiarization with the equipment to obtaining and interpreting real traffic data. The process is organized in such a way that each stage builds on the previous one, helping to better understand how traffic parameters are formed in practice.

At the initial stage, students get acquainted with the radar-based data acquisition system and its interface. Attention is paid to the placement of the sensor, its orientation relative to the roadway, and the general working conditions. This step is important because even small changes in positioning can influence the accuracy of the collected data.

Next, the system is prepared for operation. Students configure the detection area, selecting the segment of the road where measurements will be carried out. Depending on the task, one or several lanes can be included in the observation zone. Proper configuration ensures that only relevant traffic is recorded, avoiding unnecessary interference.

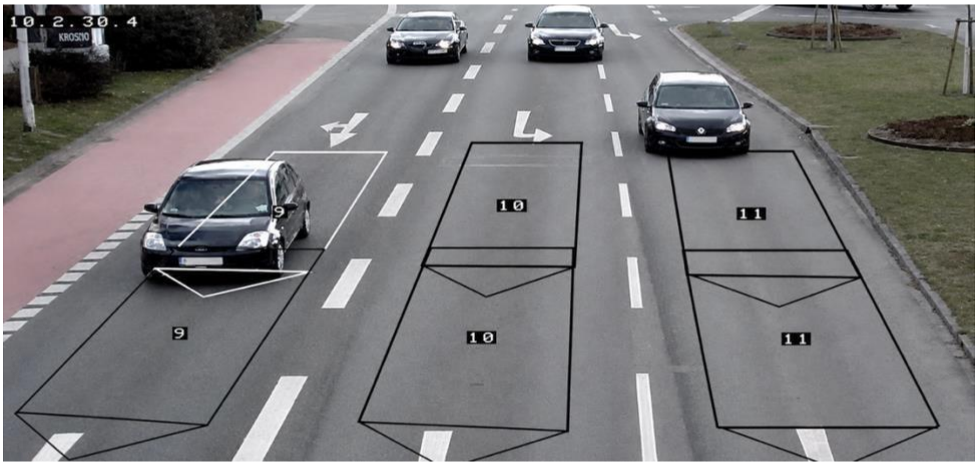


Figure 1. Visualisation of Traffic Monitoring and Detection Zones

Once the setup is complete, the data acquisition process begins. The system operates in real time, registering passing vehicles, measuring their speed, and storing the corresponding data. During this stage, students observe how traffic flow is captured and how raw information is formed. It is also possible to notice fluctuations in traffic intensity depending on the time interval or traffic conditions.

After collecting a sufficient amount of data, the focus shifts to processing and analysis. Students work with the obtained dataset to determine key traffic parameters such as flow intensity, average speed, and density. Calculations may be performed manually or using software tools, depending on the format of the laboratory work.

Particular attention is given to interpreting the results. Students compare the calculated values, identify patterns in traffic behaviour, and discuss possible reasons for observed changes–for example, signal control at intersections, traffic composition, or temporary disturbances.

At the final stage, the results are summarized and compiled into a report. The report should include a brief description of the setup, the obtained data, calculation results, and conclusions based on the analysis. Students are encouraged to reflect on the reliability of the measurements and to consider factors that may have affected the outcome.

Overall, the exercise is designed not only to demonstrate how radar-based systems work, but also to help students develop a practical understanding of traffic flow analysis and its application in real transport systems.

Experimental procedure

The experimental part of the laboratory work is organized as a sequential process, where each stage helps students better understand how traffic data is obtained and transformed into meaningful indicators. The procedure is designed to be clear and practical, allowing students to work directly with the radar-based system and observe real traffic conditions.

Step 1: Preparation

At the beginning, an appropriate observation location is selected. This can be an intersection or a road segment with stable traffic flow. It is important to ensure that all traffic lanes are clearly visible within the detection area. After that, the radar-based system is connected and checked for proper operation. Students should also briefly review safety and operational requirements before starting measurements.

Step 2: System Configuration

Once the equipment is ready, the detection zones are defined. These zones are usually set for individual lanes or specific control points; such as stop lines. The system parameters are then adjusted, including sensitivity levels and detection thresholds. Careful configuration at this stage is essential, as it directly affects the quality of the collected data.

Step 3: Data Collection

After configuration, the system begins recording traffic data in real time. The observation typically lasts about 15 minutes, depending on the task. During this period, the system registers passing vehicles, their movement, and occupancy within the defined zones. Students monitor the process and ensure that the system operates without interruptions.

Step 4: Data Recording

The collected information is organized into a structured form, usually as a table. For each lane or observation segment, the number of vehicles, observation time, and calculated traffic intensity are recorded. This step helps prepare the data for further analysis and ensures that all measurements are properly documented.

Step 5: Data Processing

At this stage, students process the recorded data. Key traffic parameters such as flow intensity and average speed are calculated. In addition, graphical representations may be created – for example, charts showing changes in traffic flow over time or diagrams illustrating lane utilization. This makes it easier to identify trends and compare different segments of the road.

Step 6: Analysis and Interpretation

At the final stage, the collected data is carefully analysed and interpreted. Students are expected not only to review the obtained values, but also to derive meaningful conclusions about traffic behaviour under the observed conditions. Students perform additional calculations based on the collected dataset. In particular, they determine the average speed, as well as the minimum and maximum values, which help to understand the variability of traffic movement.

Next, the data is visualised. Students construct a histogram of speed distribution, which shows how vehicle speeds are spread within the observed interval. In addition, a cumulative frequency curve is built, allowing for a clearer understanding of how speeds accumulate across the dataset. Based on these graphical representations, key statistical indicators are identified. Special attention is given to determining the 85th percentile speed, which is widely used in traffic engineering as an indicator of typical driving behaviour. The median speed is also calculated to provide a balanced measure that is less sensitive to extreme values.

After completing the calculations, students move on to interpreting the traffic conditions. Using the obtained results, they classify the traffic flow into one of the typical regimes:

- free flow;
- stable flow;
- congested conditions.

The measured speeds are compared with established speed limits and road safety standards. This comparison helps to evaluate whether the observed traffic behaviour corresponds to regulatory benefits and whether any potential safety concerns may arise. This stage is intended to develop students' ability to combine numerical analysis with practical interpretation, forming a more complete understanding of real traffic processes.

References:

1. Teledyne FLIR LLC. TrafiCam™. Available at: https://www.flir.com/products/traficam/
2. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). (2024). *Intelligent transport systems (ITS)*. https://transformative-mobility.org/wp-content/uploads/2024/01/GIZ_SUTP_SB4e_Intelligent-Transport-Systems_EN.pdf

LABORATORY WORK 2

DETERMINATION OF TRAFFIC FLOW CHARACTERISTICS IN THE CITY'S TRANSPORT NETWORK

The objective of the work is - to acquire practical skills in determining the characteristics of road traffic in the urban transport network.

Equipment and Software

Radar system for traffic data collection – Sierzega SR7

Theoretical Background

Radar traffic detectors are an essential element of transport telematics and intelligent transportation systems. Unlike speed cameras, which are designed to identify vehicles and drivers, radar detectors are used to detect and classify vehicles and traffic flows without visual identification. The data collected by these devices is generally processed statistically to provide information such as traffic volume over time, speed distribution of road users, and other key traffic flow characteristics.

These detectors are also commonly integrated with variable message signs (VMS), particularly when the signs display the speed of passing vehicles. Owing to their compact size and typical battery-powered operation, radar traffic detectors can be easily deployed at virtually any point within a transport network. This flexibility enables efficient measurement of traffic flow parameters, supporting the adaptation of traffic management strategies – such as speed limits, road priorities, and other control measures – to current road infrastructure conditions and the overall transport network configuration.

Practical Application

1. ***System Overview:*** orientation with the hardware configuration (Table. 1) and software interface (fig.1)

Analysing Software SRA Web

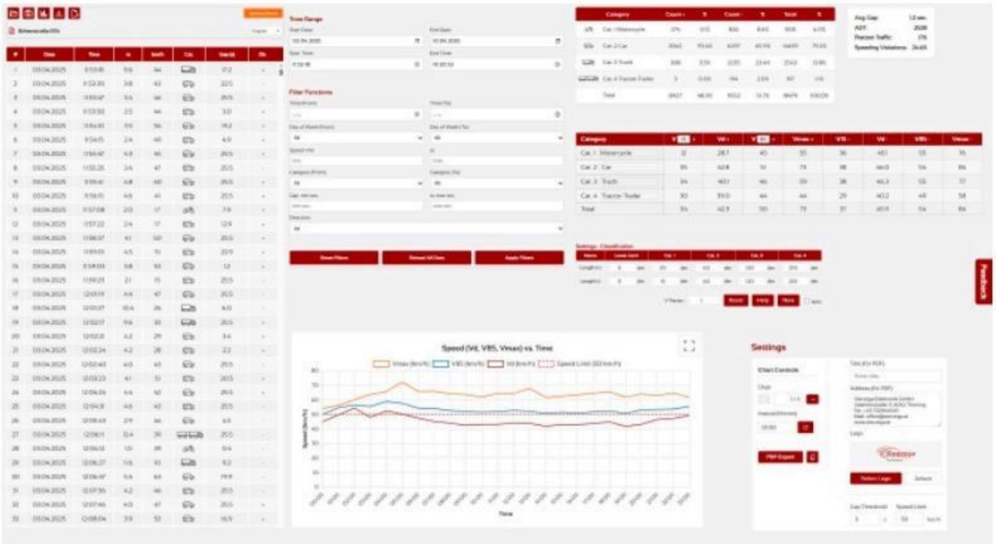


Fig.1. Software interface

2. Data Preparation: register equipment Sierzega SR7on the official website and get access to data processing software

3. Task Execution

3.1 Install the Radar system for traffic data collection - Sierzega SR7 according to the installation instructions (included in the delivery package).

List of main components: Vehicle Traffic Counter SR7 (fig.2), Battery Charger Mascot 2140, 12V 4A (fig.3), Banner Battery GiV 12V-18Ah (fig. 4)

Fig.2-Vehicle Traffic Counter SR7 Fig.3- Battery Charger Fig. 4 - Banner Battery

Core installation steps: the rear of the SR7 must be mounted parallel to the road (fig.5, fig.6). Automatic calibration - The MIMO radar of the SR7 also looks to the side using several antennas and simultaneously detects the vehicles at different angles. This enables the SR7 to automatically determine the actual exact mounting angle and consider the results for further measurements and calculations.

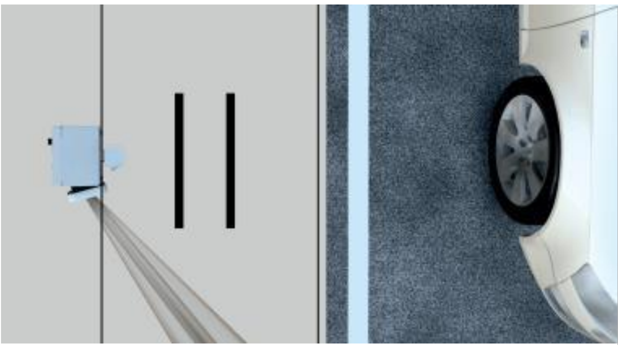


Fig.5 - Alignment of the SR7

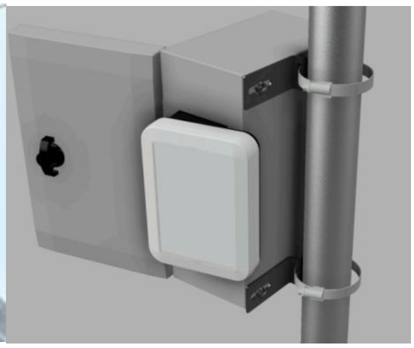


Fig.6 - Pole Brackets (for mounting the SR7 enclosure)

3. 2. Record the characteristics of traffic flows using the Radar system for traffic data collection – Sierzega SR7.

3.3. Process the received data on the characteristics of transport flows (fig. 7-9) using software on the site https://sra.sierzega.com/login?expired=true

Fig.7 Traffic speed distribution

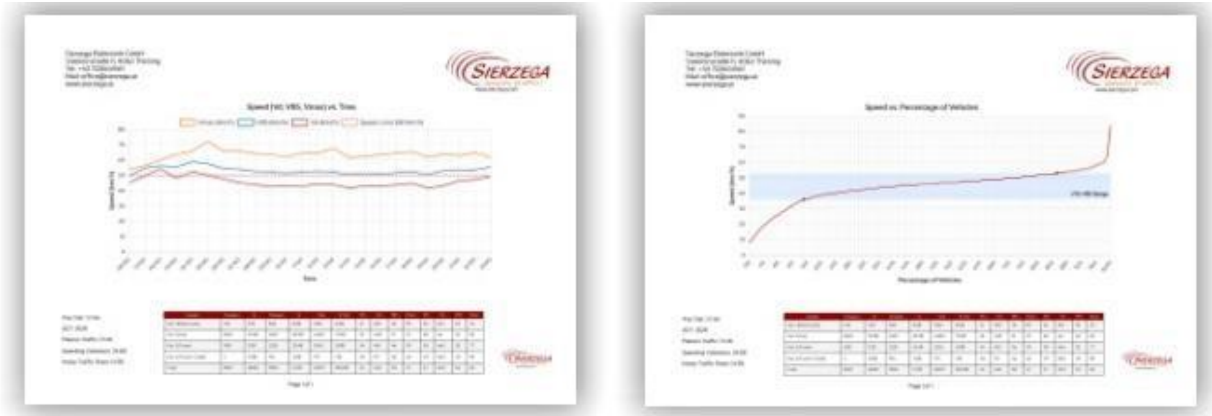


Fig.8 - Speed and percentage of vehicles

Fig.9 - Distribution of traffic intensity over time and days of the week

4. Results Analysis: Present the values of traffic intensity on links of the network in tabular form (Table 1).

Table 1. Values of traffic intensity

Links	Intensity field observations, cars/hour.
1-28	1201
28-1	851
20-30	1140
30-20	874
…	…
…	…
…	…
2-1	1064

2-29	852
29-2	448
19-20	470
20-19	93
4-19	33
19-4	173

5. Drafting conclusions and finalizing the technical report.

References and Resources

1. Sierzega – Electronics for Traffic Safety.– https://www.sierzega.com/en-us/products/traffic-counters
2. Traffic Radar SR7. Quick Start Guide. – https://www.sierzega.com/LinkClick.aspx?fileticket=zl1t-ZENWKM%3d&portalid=0&language=en-US
3. Traffic Radar SR7. DataSheet. – https://www.sierzega.com/LinkClick.aspx?fileticket=Y6PIZQTp0V4%3d&portalid=0

TRAFFIC MODELLING AND SIGNAL OPTIMISATION

LABORATORY WORK 3

ANALYSIS OF THE EFFECTIVENESS OF MULTI-PROGRAM TRAFFIC SIGNAL CONTROL AT AN ISOLATED INTERSECTION

Purpose and Scope

An experiment is being conducted at an existing intersection of city streets regulated in a rigid multi-program mode, during which the parameters of the traffic light regulation mode are determined that are optimal according to the criterion of minimizing delays for vehicles and pedestrians.

Equipment Name and Purpose.

FPV quadrocopter, Oculus device

Type: Hardware.

Theoretical Background

The average number of vehicles in the queue can be determined as follows:

$$\bar{n} = \frac{L}{\bar{l} + d},$$

where: L – the length of the queue, m;

l – weighted average length of the vehicle, m;

d – safety gap between stopped vehicles, m.

The weighted average length of a vehicle is established based on the analysis of the results of a study of the composition of the transit flow.

$$\bar{l} = \sum_{i=1}^{m}\left(\frac{l_i \alpha_i}{100}\right)$$

where: m – is the number of vehicle groups in the flow;

l_i – the length of the vehicle of the i-th group, m;

α_i – the share of vehicles belonging to the i-th group in the total flow, %.

The number of vehicles of the i-th type in the queue is set as follows:

$$n_i = \bar{n}\frac{\alpha_i}{100},$$

The total conditional cost of transport delays is determined as follows:

$$S = \sum_{j=1}^{k}\sum_{i=1}^{m}\left(n_i s_i t_j\right),$$

where: s_i – conditional cost of an hour of downtime of a vehicle of the *i*-th type, UAH;

t_j – time interval between observations, hours;

k – number of observations.

Principle of FPV Quadrocopter and Oculus Device Operation

The DJI Mini 3 is a compact unmanned aerial vehicle (UAV) that can be used as a mobile tool for collecting spatial and video data for the study of traffic flows and the analysis of road traffic intensity. Thanks to the combination of a high-quality camera, image stabilization, GPS navigation, and the ability to hover over a designated area for extended periods, the drone provides effective real-time monitoring of traffic conditions.

The use of UAVs for transport monitoring makes it possible to obtain up-to-date data without the need to install stationary surveillance cameras or involve a large number of field personnel. This is especially relevant for temporary studies, assessment of traffic situations on specific road sections, analysis of intersection performance, as well as monitoring traffic flows during peak load periods.

Functional Purpose.

The drone can be used for the following tasks:

- video recording of traffic flows on highways and roads;
- monitoring road traffic at intersections, transport interchanges, and highways;
- counting the number of vehicles;
- determining traffic intensity over time intervals;
- assessing traffic flow density;
- identifying congestion locations;
- analysing the capacity of road infrastructure;
- studying the behaviour of traffic flows;
- obtaining materials for further analytical processing in specialized software;
- creating photo and video materials for transport planning and reporting.

Operating Principle During Transport Monitoring

During monitoring operations, the drone rises to a specified altitude that provides a wide viewing angle of the road section. The UAV camera performs continuous high-resolution video recording of traffic flows. The obtained materials can be analysed both in real time by the operator and after the flight using automatic vehicle recognition and video stream analysis software.

Thanks to camera stabilization and positioning systems, a clear image is ensured even while hovering or moving. This allows accurate vehicle counting, assessment of transport movement speed, and determination of road congestion parameters.

Workflow Overview

During the laboratory session, students solve a holistic practical problem aimed at assessing the effectiveness of traffic light regulation modes that are actually used at a traffic light-controlled intersection. The assessment is carried out by comparing the total values of the conditional cost of an hour of downtime of vehicles of different types that make up the traffic flow at the approaches to the intersection. To perform the work, it is necessary to prepare the data: determine the time of changing the traffic light regulation program and measure the intensity of vehicle traffic at the approaches to the intersection in the time interval in the middle of which the moment of changing the programs is located.

Experimental procedure

Step 1: Preparation

Under the guidance of the teacher, students prepare the quadcopter for operation: they check the system performance, the presence of communication, and the battery charge.

Step 2: Shooting and video recording

From a predetermined angle, a video recording of one or more approaches to the intersection and a time interval is made, which includes the moment of changing the traffic light regulation mode at the intersection. After shooting, the quadcopter returns to the base.

Step 3: Viewing the video, recording data

The time intervals during which vehicles do not leave the queue or join it are determined on the captured video. The length of the queue is determined for these time intervals. In this case, they visually focus on the length of the road marking lines.

Step 4: Performing calculations

Calculations are made according to the formulas given in the Theoretical Background section.

Step 5: Conclusions

Based on the calculations performed, a conclusion is drawn as to which of the traffic light control modes corresponds to the shortest duration of traffic delays.

References:

1. Fornalchyk, Ye. Yu., Fornalchyk, E. Yu., Trushevskyi, V. E., & Trushevsky, V. E. (2018). Traffic management at signalized intersections in cities: Monograph.

LABORATORY WORK 4

CREATING A TRANSPORT NETWORK MODEL

The objective of the work is – to acquire practical skills in creating a transport network model.

Equipment and Software

PTV Visum macroscopic transport planning and traffic simulation tool

Theoretical Background

PTV Visum is a macroscopic transport planning and traffic simulation tool developed for modelling and analysing multimodal transportation networks. It is widely used by transport planners, engineers, and public authorities to forecast travel demand, evaluate infrastructure projects, and support strategic mobility planning.

The software enables users to model road traffic, public transport, pedestrian, and bicycle movements within urban and regional networks. Its core functionalities include traffic assignment, origin-destination demand modelling, public transport planning, accessibility analysis, and scenario evaluation.

PTV Visum is commonly applied in tasks such as traffic forecasting, assessment of transport policies, optimization of public transport services, and evaluation of intelligent transportation systems (ITS). Simulating different network and demand scenarios, it helps decision-makers improve mobility, reduce congestion, and enhance overall transport system efficiency.

Practical Application

1. System Overview: orientation with the hardware configuration (Table 1) and software interface (Fig.1).

Table 1. Hardware configuration

Parameter	Minimum	Recommended for standard installation
Processor	X64 processor with support for SSE4.2, e.g.: - Intel Core i5 / Core i7 / Core i9; - AMD Ryzen.	Recent multi-core processor, e.g.: - Intel Core i7-14700K, Core i9-14900K - Intel Xeon w9-3575X - AMD Ryzen 9 9950X, - AMD Ryzen Threadripper 9970X or better
Memory	4 GB	16-32 GB or more

Disk space (software)	2 GB free disk space per product for compact installation	5 GB free disk space per product for full installation
Monitor	Screen resolution 1280x800 or 1366x768 pixels	Full HD (1920x1080 pixels) or higher resolutions, multiple screens are supported
Graphics Card	For 3D Graphics OpenGL® 3.0 or DirectX 11 support is recommended	
USB / Network	- In case the license is provided in relation with a hardware dongle a full USB port is required for operation. - In case a network license is provided, access to a license server in the local network or the internet is required for operation. - In case a cloud license is provided, a permanent internet connection is required. - An internet connection is required if background map services shall be used.	
Disk space (project data)	Sufficient storage capacity for project data handling, ideally on SSD	

Fig. 1. Software interface.

2. Data Preparation: the necessary data were obtained as a result of laboratory work No. 1.
3. Task Execution
   3.1. Install and prepare for use the student (or other, if available) version of PTV Visum.
   3.2. Create transport network nodes.

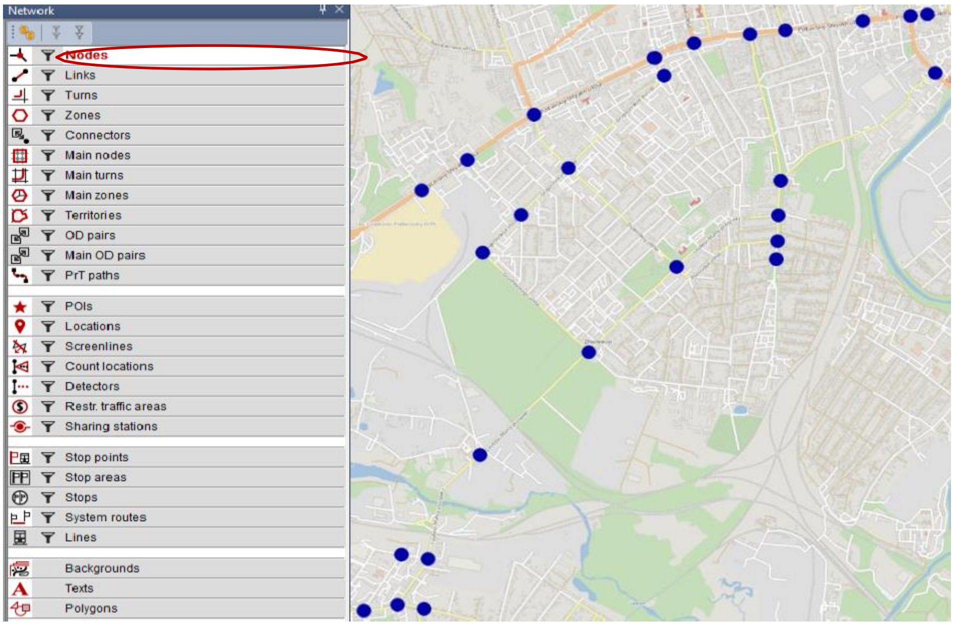
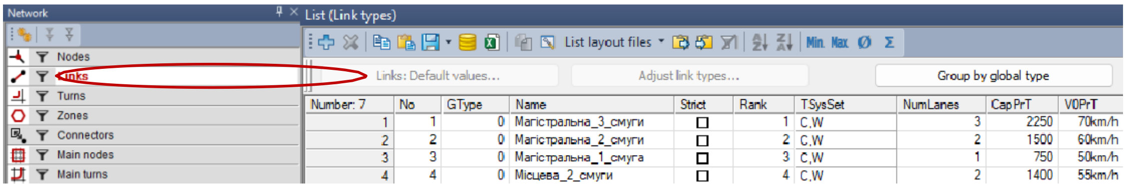


Fig. 2. Creating transport network nodes.

3.3. Create links' types taking according to existing road conditions in the transport network (number of lanes and capacity) and traffic flow conditions in it.



Number: 7	No	GType	Name	Strict	Rank	TSysSet	NumLanes	CapPrT	V0PrT
1	1	0	Магістральна_3_смуги	☐	1	C,W	3	2250	70km/h
2	2	0	Магістральна_2_смуги	☐	2	C,W	2	1500	60km/h
3	3	0	Магістральна_1_смуга	☐	3	C,W	1	750	50km/h
4	4	0	Місцева_2_смуги	☐	4	C,W	2	1400	55km/h

Fig. 3. Creating links' types

3.4. Connect transport network nodes with links.

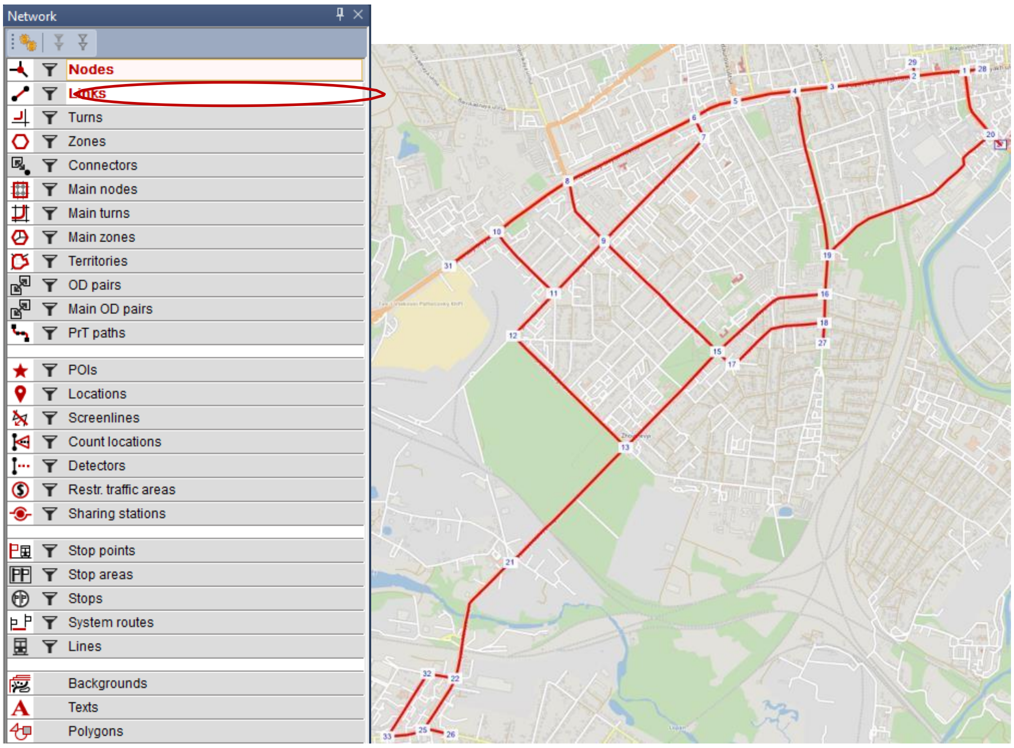


Fig. 3. Connecting transport network nodes with links

3.5. Create transport zones.

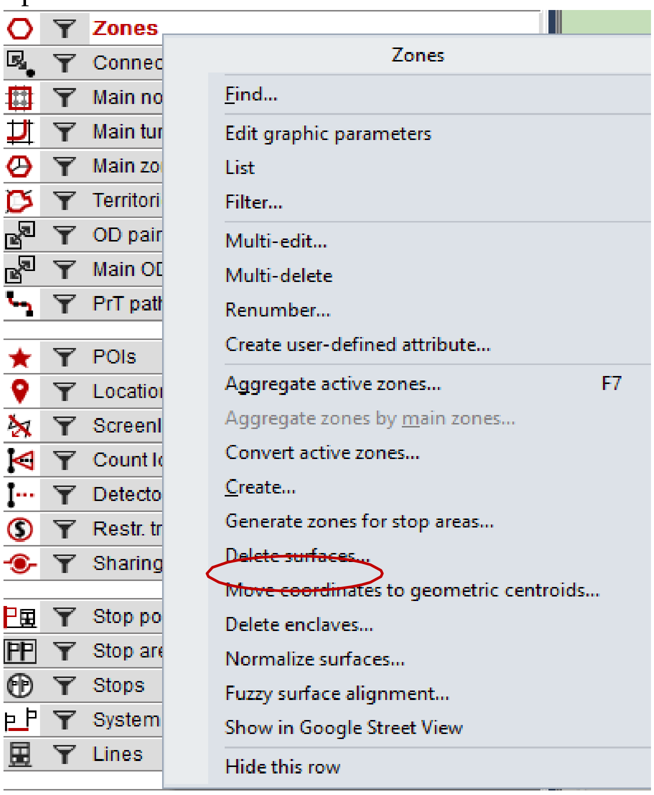


Fig. 4. Creating transport zones

3.6. Create a connector in the transport network.

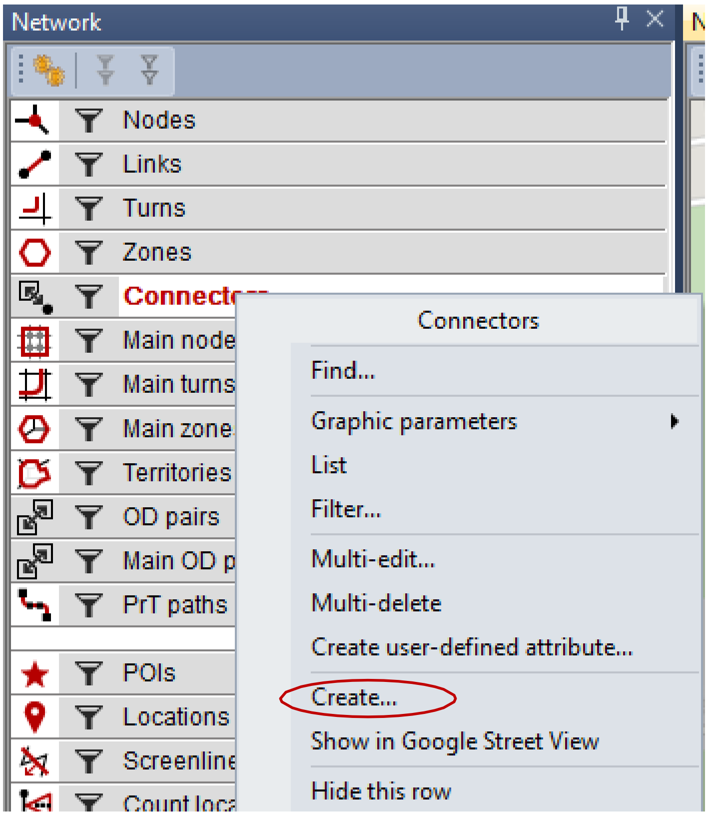


Fig. 5. Creating a connector in the transport network

3.7. Using data from previous work, determine demand at transport network nodes. Present data in tabular form.

Table 1. Demand at transport network nodes

Network node	Demand for departure, cars/hour	Demand for arrival, cars/hour
1	120	170
2	20	0
3	15	15
Sum*, cars/hour		

* - according the requirements for the closeness of transport systems, the demand for departure must be equal to the demand for arrival.

3.8. To form the initial correspondence matrix and balance the matrix using the gravity method.

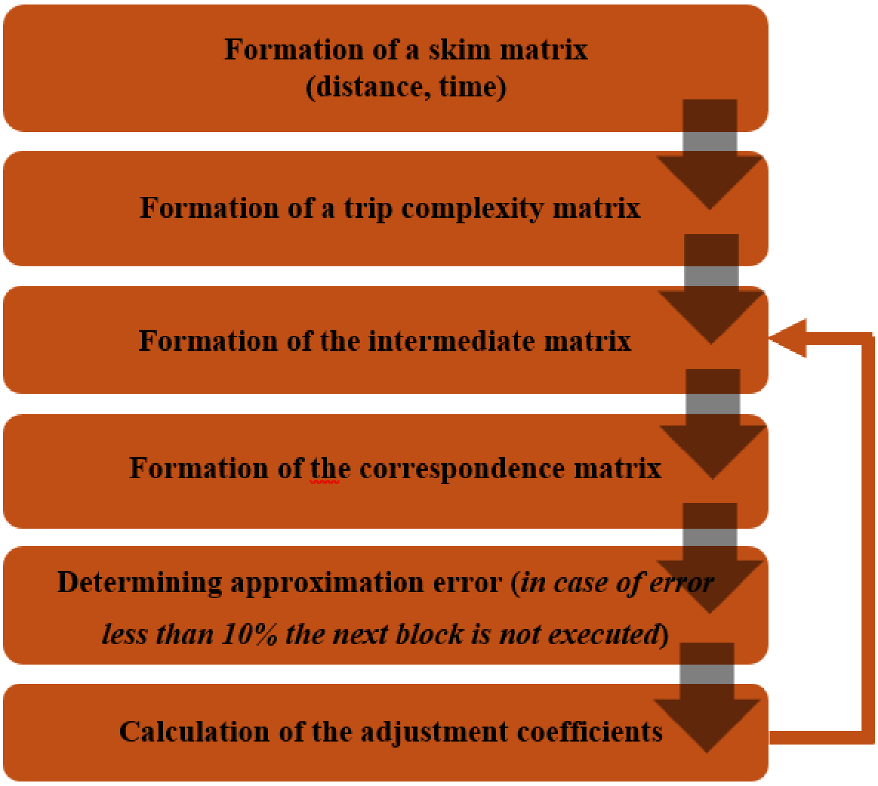
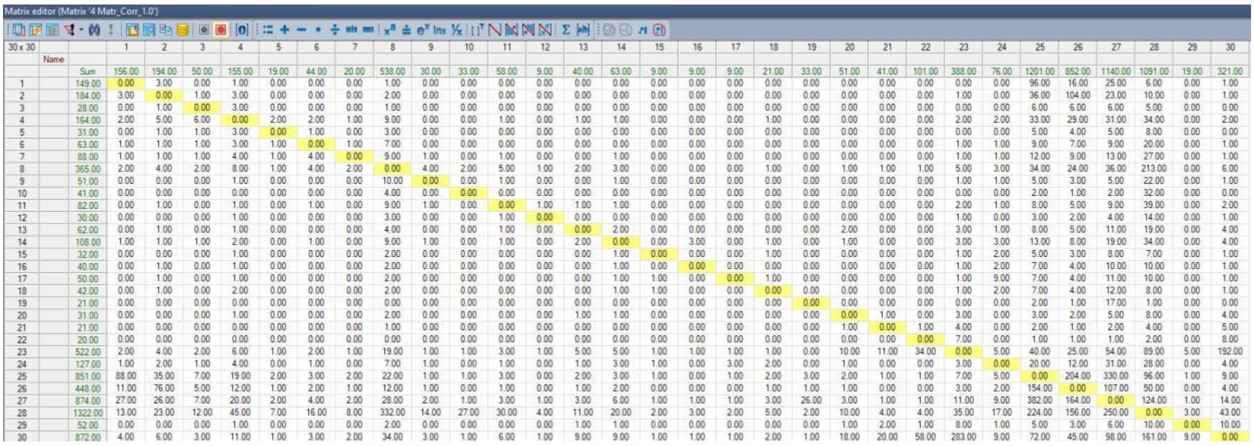


Fig. 6. Flowchart of the stages for forming a correspondence matrix

3.9. Distribute correspondence in the transport network using PTV Visum.

To distribute correspondence, insert the data obtained as a result of balancing the correspondence matrix into PTV Visum.



Matrix editor (Matrix '4 Matr_Corr_1.0')

30 x 30	Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Sum	156.00	194.00	50.00	155.00	19.00	44.00	20.00	538.00	30.00	33.00	58.00	9.00	40.00	63.00	9.00
1		149.00	0.00	3.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2		184.00	3.00	0.00	1.00	3.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3		28.00	0.00	1.00	0.00	3.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4		164.00	2.00	5.00	6.00	0.00	2.00	2.00	1.00	9.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00
5		31.00	0.00	1.00	1.00	3.00	0.00	1.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6		63.00	1.00	1.00	1.00	3.00	1.00	0.00	1.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7		88.00	1.00	1.00	1.00	4.00	1.00	4.00	0.00	9.00	1.00	0.00	1.00	0.00	0.00	1.00	0.00
8		365.00	2.00	4.00	2.00	8.00	1.00	4.00	2.00	0.00	4.00	2.00	5.00	1.00	2.00	3.00	0.00
9		51.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	10.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00
10		41.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11		82.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	9.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00
12		30.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	3.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
13		62.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	4.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00
14		108.00	1.00	1.00	1.00	2.00	0.00	1.00	0.00	9.00	1.00	0.00	1.00	0.00	2.00	0.00	0.00
15		32.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
16		40.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
17		50.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
18		42.00	0.00	1.00	0.00	2.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
19		21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20		31.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00
21		21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22		20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23		522.00	2.00	4.00	2.00	6.00	1.00	2.00	1.00	19.00	1.00	1.00	3.00	1.00	5.00	5.00	1.00
24		127.00	1.00	2.00	1.00	4.00	0.00	1.00	0.00	7.00	1.00	0.00	1.00	0.00	1.00	3.00	1.00
25		851.00	88.00	35.00	7.00	19.00	2.00	3.00	2.00	22.00	1.00	1.00	3.00	0.00	2.00	3.00	1.00
26		448.00	11.00	76.00	5.00	12.00	1.00	2.00	1.00	12.00	1.00	0.00	1.00	0.00	1.00	2.00	0.00
27		874.00	27.00	26.00	7.00	20.00	2.00	4.00	2.00	28.00	2.00	1.00	3.00	1.00	3.00	6.00	1.00
28		1322.00	13.00	23.00	12.00	45.00	7.00	16.00	8.00	332.00	14.00	27.00	30.00	4.00	11.00	20.00	2.00
29		52.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00
30		872.00	4.00	6.00	3.00	11.00	1.00	3.00	2.00	34.00	3.00	1.00	6.00	1.00	9.00	9.00	1.00

30 x 30	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Sum	9.00	9.00	21.00	33.00	51.00	41.00	101.00	388.00	76.00	1201.00	852.00	1140.00	1091.00	19.00	321.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	96.00	16.00	25.00	6.00	0.00	1.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	36.00	104.00	23.00	10.00	0.00	1.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.00	6.00	6.00	5.00	0.00	0.00
4	0.00	0.00	1.00	0.00	0.00	0.00	0.00	2.00	2.00	33.00	29.00	31.00	34.00	0.00	2.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	4.00	5.00	8.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	9.00	7.00	9.00	20.00	0.00	1.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	12.00	9.00	13.00	27.00	0.00	1.00
8	0.00	0.00	1.00	0.00	1.00	1.00	1.00	5.00	3.00	34.00	24.00	36.00	213.00	0.00	6.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	5.00	3.00	5.00	22.00	0.00	1.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00	2.00	32.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00	8.00	5.00	9.00	39.00	0.00	2.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	3.00	2.00	4.00	14.00	0.00	1.00
13	0.00	0.00	0.00	0.00	2.00	0.00	0.00	3.00	1.00	8.00	5.00	11.00	19.00	0.00	4.00
14	3.00	0.00	1.00	0.00	1.00	0.00	0.00	3.00	3.00	13.00	8.00	19.00	34.00	0.00	4.00
15	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	2.00	5.00	3.00	8.00	7.00	0.00	1.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00	7.00	4.00	10.00	10.00	0.00	1.00
17	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	9.00	7.00	4.00	11.00	10.00	0.00	1.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00	7.00	4.00	12.00	8.00	0.00	1.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00	17.00	1.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	1.00	0.00	3.00	0.00	3.00	2.00	5.00	8.00	0.00	4.00
21	0.00	0.00	0.00	0.00	1.00	0.00	1.00	4.00	0.00	2.00	1.00	2.00	4.00	0.00	5.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	0.00	1.00	1.00	1.00	2.00	0.00	8.00
23	1.00	1.00	1.00	0.00	10.00	11.00	34.00	0.00	5.00	40.00	25.00	54.00	89.00	5.00	192.00
24	0.00	3.00	2.00	0.00	1.00	0.00	0.00	3.00	0.00	20.00	12.00	31.00	28.00	0.00	4.00
25	0.00	1.00	2.00	3.00	2.00	1.00	1.00	7.00	5.00	0.00	204.00	330.00	96.00	1.00	9.00
26	0.00	0.00	1.00	1.00	1.00	0.00	0.00	3.00	2.00	154.00	0.00	107.00	50.00	0.00	4.00
27	1.00	1.00	3.00	26.00	3.00	1.00	1.00	11.00	9.00	382.00	164.00	0.00	124.00	1.00	14.00
28	3.00	2.00	5.00	2.00	10.00	4.00	4.00	35.00	17.00	224.00	156.00	250.00	0.00	3.00	43.00
29	0.00	0.00	0.00	0.00	1.00	2.00	1.00	8.00	1.00	5.00	3.00	6.00	10.00	0.00	10.00
30	1.00	1.00	2.00	1.00	18.00	20.00	58.00	283.00	9.00	72.00	45.00	98.00	161.00	9.00	0.00

Fig. 7. Inserting the data of balancing the correspondence matrix into PTV Visum

3.10. Perform the procedure for distributing correspondence in the transport network. Obtain traffic flow intensity maps.

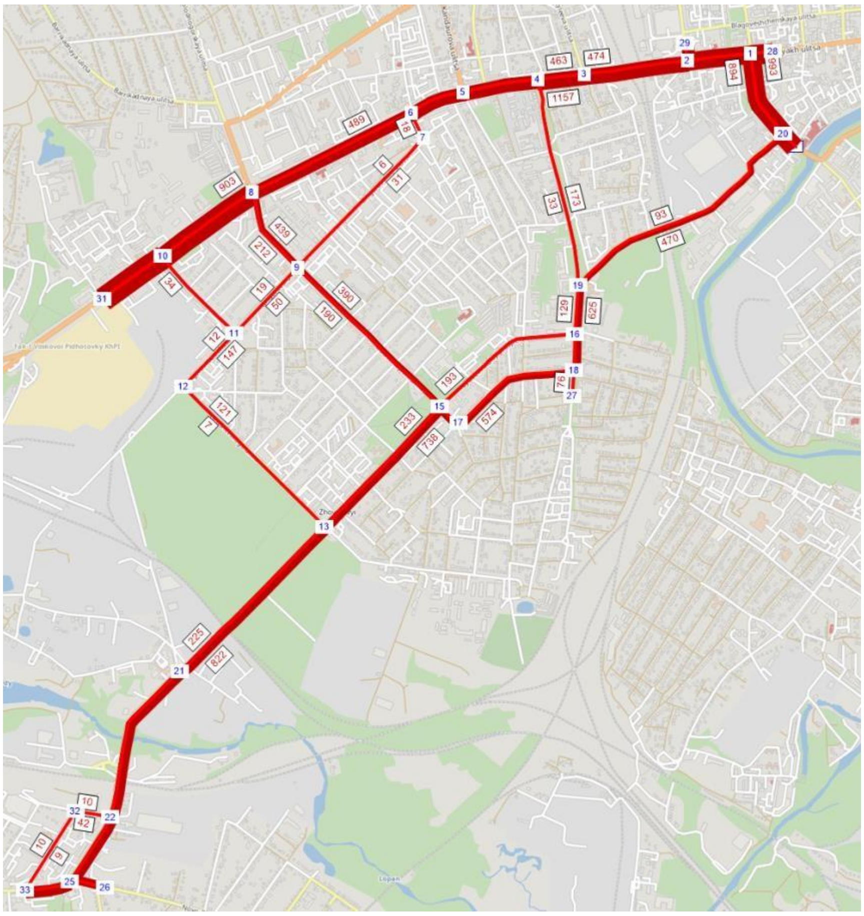
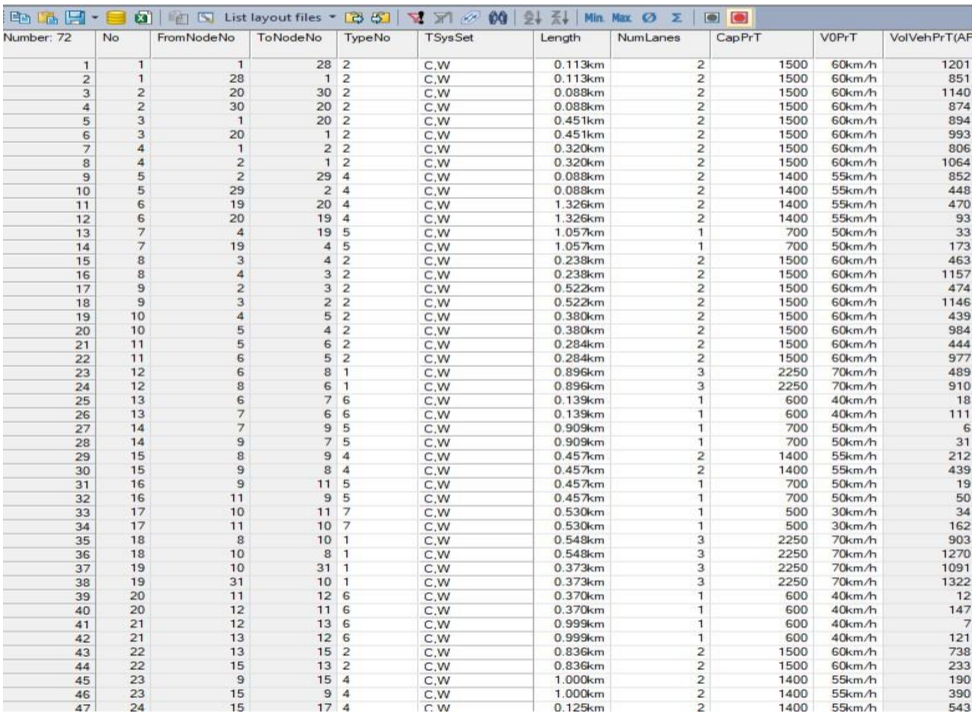


Fig. 8. Traffic flow intensity maps

3.11. Generate simulation results



Number: 72	No	FromNodeNo	ToNodeNo	TypeNo	TSysSet	Length	NumLanes	CapPrT	V0PrT	VolVehPrT(AP
1	1	1	28	2	C,W	0.113km	2	1500	60km/h	1201
2	1	28	1	2	C,W	0.113km	2	1500	60km/h	851
3	2	20	30	2	C,W	0.088km	2	1500	60km/h	1140
4	2	30	20	2	C,W	0.088km	2	1500	60km/h	874
5	3	1	20	2	C,W	0.451km	2	1500	60km/h	894
6	3	20	1	2	C,W	0.451km	2	1500	60km/h	993
7	4	1	2	2	C,W	0.320km	2	1500	60km/h	806
8	4	2	1	2	C,W	0.320km	2	1500	60km/h	1064
9	5	2	29	4	C,W	0.088km	2	1400	55km/h	852
10	5	29	2	4	C,W	0.088km	2	1400	55km/h	448
11	6	19	20	4	C,W	1.326km	2	1400	55km/h	470
12	6	20	19	4	C,W	1.326km	2	1400	55km/h	93
13	7	4	19	5	C,W	1.057km	1	700	50km/h	33
14	7	19	4	5	C,W	1.057km	1	700	50km/h	173
15	8	3	4	2	C,W	0.238km	2	1500	60km/h	463
16	8	4	3	2	C,W	0.238km	2	1500	60km/h	1157
17	9	2	3	2	C,W	0.522km	2	1500	60km/h	474
18	9	3	2	2	C,W	0.522km	2	1500	60km/h	1146
19	10	4	5	2	C,W	0.380km	2	1500	60km/h	439
20	10	5	4	2	C,W	0.380km	2	1500	60km/h	984
21	11	5	6	2	C,W	0.284km	2	1500	60km/h	444
22	11	6	5	2	C,W	0.284km	2	1500	60km/h	977
23	12	6	8	1	C,W	0.896km	3	2250	70km/h	489
24	12	8	6	1	C,W	0.896km	3	2250	70km/h	910
25	13	6	7	6	C,W	0.139km	1	600	40km/h	18
26	13	7	6	6	C,W	0.139km	1	600	40km/h	111
27	14	7	9	5	C,W	0.909km	1	700	50km/h	6
28	14	9	7	5	C,W	0.909km	1	700	50km/h	31
29	15	8	9	4	C,W	0.457km	2	1400	55km/h	212
30	15	9	8	4	C,W	0.457km	2	1400	55km/h	439
31	16	9	11	5	C,W	0.457km	1	700	50km/h	19
32	16	11	9	5	C,W	0.457km	1	700	50km/h	50
33	17	10	11	7	C,W	0.530km	1	500	30km/h	34
34	17	11	10	7	C,W	0.530km	1	500	30km/h	162
35	18	8	10	1	C,W	0.548km	3	2250	70km/h	903
36	18	10	8	1	C,W	0.548km	3	2250	70km/h	1270
37	19	10	31	1	C,W	0.373km	3	2250	70km/h	1091
38	19	31	10	1	C,W	0.373km	3	2250	70km/h	1322
39	20	11	12	6	C,W	0.370km	1	600	40km/h	12
40	20	12	11	6	C,W	0.370km	1	600	40km/h	147
41	21	12	13	6	C,W	0.999km	1	600	40km/h	7
42	21	13	12	6	C,W	0.999km	1	600	40km/h	121
43	22	13	15	2	C,W	0.836km	2	1500	60km/h	738
44	22	15	13	2	C,W	0.836km	2	1500	60km/h	233
45	23	9	15	4	C,W	1.000km	2	1400	55km/h	190
46	23	15	9	4	C,W	1.000km	2	1400	55km/h	390
47	24	15	17	4	C,W	0.125km	2	1400	55km/h	543

Fig. 9. Generating simulation results

3.12. Evaluate the adequacy of the obtained flow distribution model by comparing the modelled intensity and the intensity obtained as a result of field observations (laboratory work 1). Present the results in tabular form.

Table 2. Evaluation the adequacy of the obtained flow distribution model

links	Intensity:		Absolute deviation, cars/hour.	Approximation error ζ_{i-j}, %
	modelled, cars/hour.	field observations, cars/hour.		
1-28	1166	1201	35	3,00
28-1	890	851	39	4,38
20-30	1042	1140	98	9,40
30-20	933	874	59	6,32
…	…	…	…	…
…	…	…	…	…
…	…	…	…	…
2-1	1133	1064	69	6,13
2-29	808	852	44	5,45
29-2	490	448	42	8,57
19-20	452	470	18	4,08
20-19	102	93	9	9,14

4-19	32	33	1	3,13
19-4	179	173	6	3,35

4. Results Analysis: Assess the adequacy of the resulting distribution by comparing actual and simulated traffic flows.
5. Drafting conclusions and finalizing the technical report.

References and Resources

1. PTV Visum 2026 – Manual. *Built into software*

LABORATORY WORK 5

SIMULATION OF TRAFFIC FLOW (VISSIM PROGRAM INTERFACE)

Introduction to Operation

As a base, the student version of PTV Vissim 2026 is used. Upon the first launch, the user sees the window (Fig. 1.1).

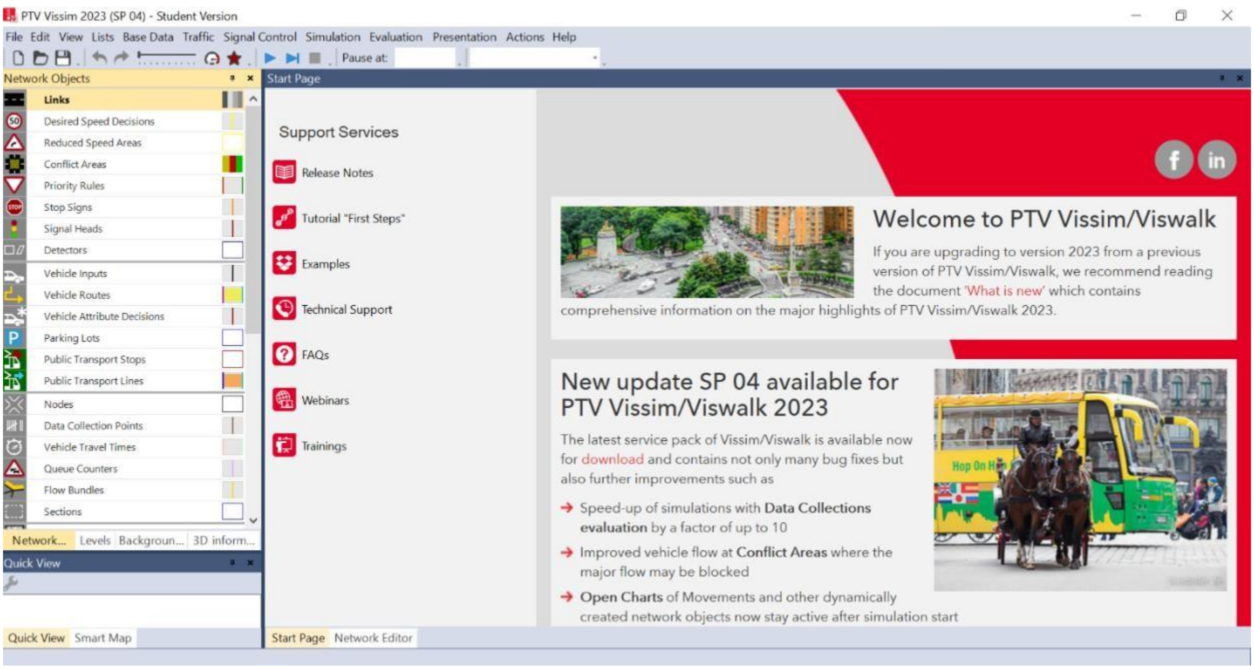


Figure 1.1. Main Program Window

If the network editing dialogue window did not appear during the first launch of the program and the World Map view is displayed, or if you want to change the settings, select Editor → User Preferences from the menu bar. In the window that opens, navigate to the User Interface tab in the left-hand menu, and then select Network Editor from the drop-down list (Fig. 1.2).

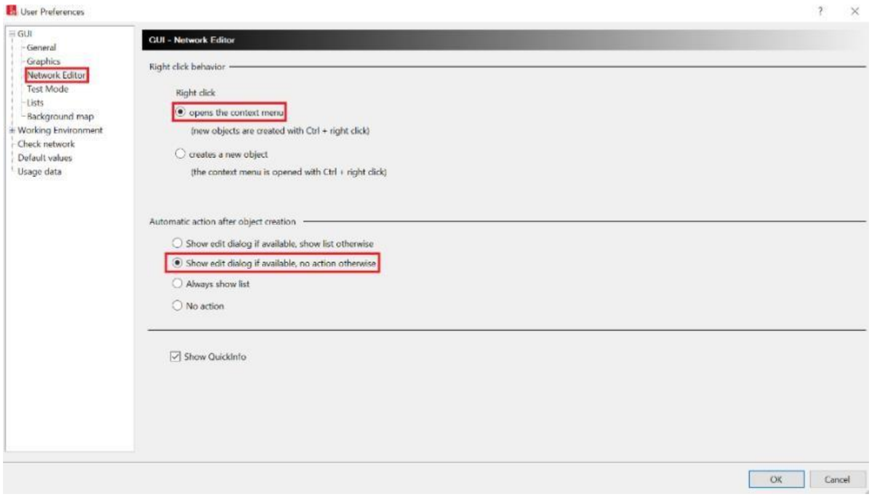


Figure 1.2. Window – User Interface – Network Editor

Changing the Interface Language

The program allows you to select one of several interface display languages. To switch the program to the Russian-language version, select Edit → User Preferences from the menu. In the dialog window, in the Language section, you can choose the language required for operation (Fig. 1.3). By default, the user interface language is English.

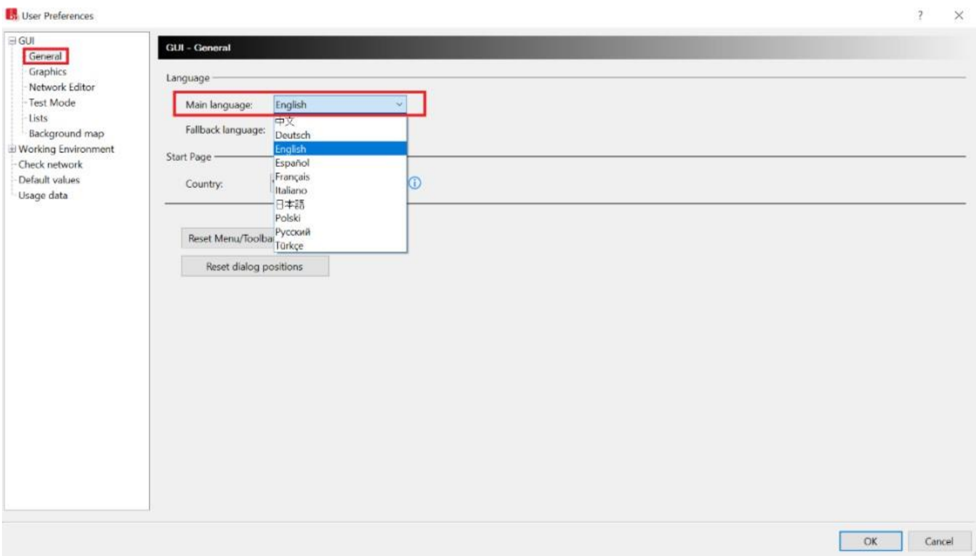


Figure 1.3. Selection of the user interface language

Side Panels

In the **View** menu, the user can select the sets of functions required for work and dock them within the program workspace. For example, it is possible to activate a number of windows (network objects, levels, backgrounds, etc.) and arrange them conveniently (Fig. 1.4) relative to the main window, or "dock" them into the left side panel.

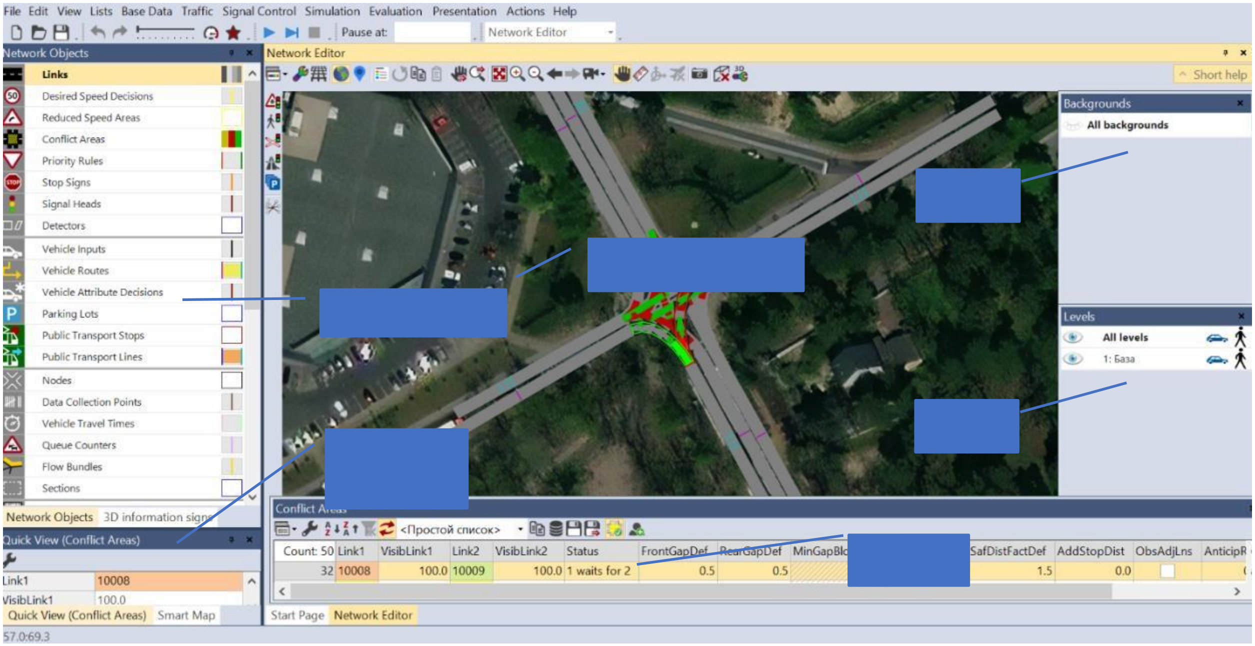


Figure 1.4. Side Panels

Network Objects Panel

In the Network Objects panel, there are five on-screen buttons for each type of network object (Fig. 1.5): **Visibility** (icon), **Selection** (lock symbol), **Insert Mode** (name), **Label** ("A"), and **Graphic Parameters** (preview)

The display of the **Selection**, **Label**, and **Graphic Parameters** columns can be deactivated in the context menu of the side panel. This also applies to rows of network objects that are relevant only for vehicle traffic or only for pedestrians.

For a better understanding of how the interface elements work, at this stage it is useful to load a test model from the examples folder via the **Help** menu.

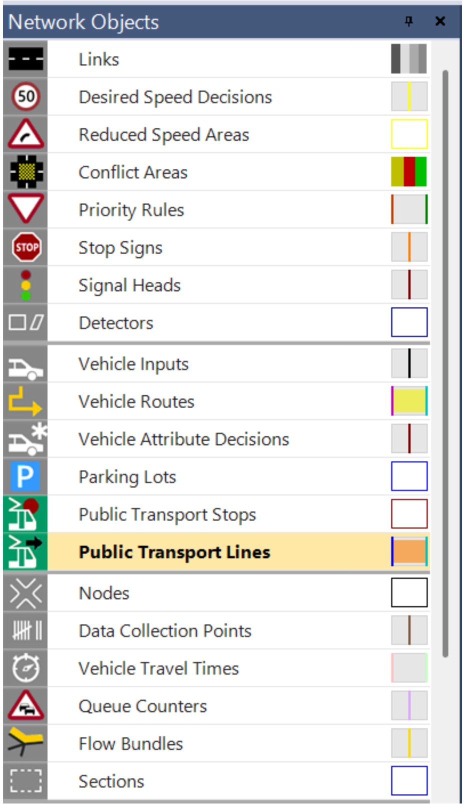


Figure 1.5. Network Objects Panel

By clicking the **Visibility** symbol, you can enable or disable the display of objects of this type in the network window. For example, this button can be used to show or hide conflict areas in a traffic model within the active network window. Activating the **lock symbol** for a visible object type prevents accidental modification of objects of this type, as well as their movement within the network window. For instance, when working with conflict areas, you can lock **Link** objects to avoid unintended changes. Invisible objects cannot be selected in any case.

The **Insert Mode** works as follows. Suppose you need to insert a new network segment. Select the **Links** network object, then press **Alt**, hold down the right mouse button, and drag. As a result, a new link will appear in the network window. In this way, any network object can be added.

The **Labels** ("A") function is used to show or hide labels for objects of this type in the network window. Finally, **Graphic Parameters** are used to modify the attributes of network objects (e.g., object colour, label colour, or font).

If multiple network windows are open, all these settings apply only to the most recently active network window. The object type selected for insert mode (by clicking on the type name, which highlights the entire row) is always visible and can be selected in all network windows (except when its level is hidden or locked).

For routes, zones, and obstacles, the subtype (e.g., Static / Partial Route / … or Polygon / Rectangle) that can be inserted is shown in parentheses (Fig. 1.6) and can be selected in the field that opens by clicking once on the small arrow (or by clicking again on the object type name).

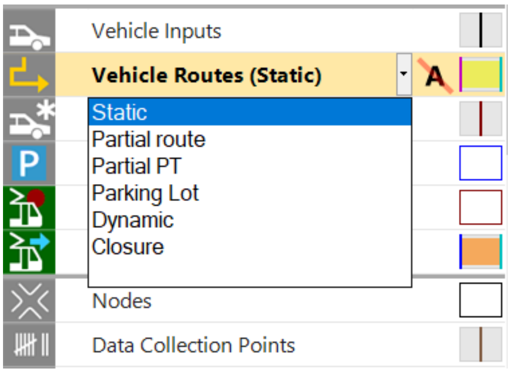


Figure 1.6. Vehicle Route Subtypes

Network Window

In this window (Fig. 1.7), the traffic model is created. Using the network window toolbar, you can access basic graphic settings and 3D graphic parameters, switch between the grid view (analogous to axes)—activated with **Ctrl + A**—and the normal view, as well as between **2D and 3D modes** (activated with **Ctrl + D**). It also allows you to control synchronization with list windows and other network windows (**Pan / Zoom**) and navigate within the network (**Zoom In / Zoom Out, Previous / Next View, Pan Mode; in 3D: Rotation Mode, Fly Mode, Camera Position, and Mouse Sensitivity**).

In **2D mode**, it is possible to run a fast simulation (**"Quick Mode" or Ctrl + Q**), where vehicles are not displayed, but the calculations are still performed. Next to this button is the **Simple Network Display Mode** button.

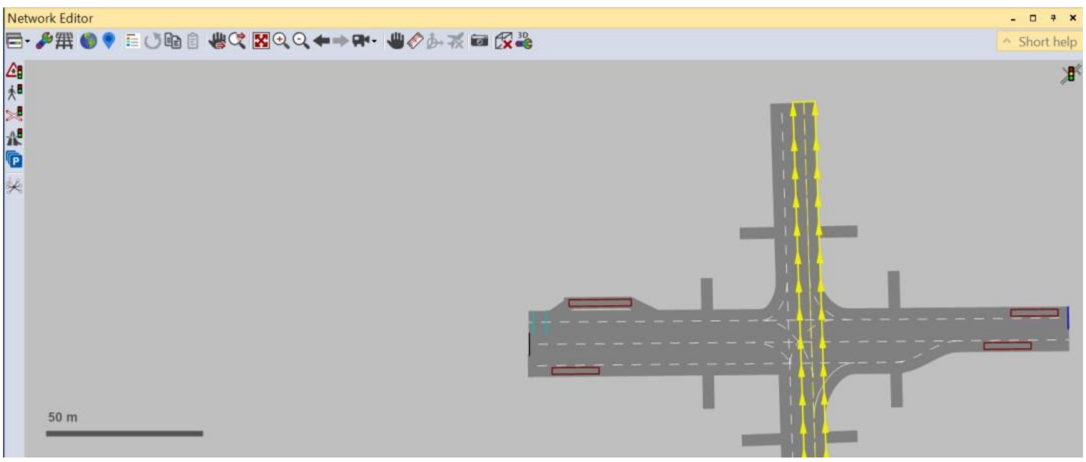


Figure 1.7. Network Window Interface Elements

Quick View Side Panel

The side panel displays the values of a subset of all attributes of the selected objects (in the network windows and synchronized list windows) for a specific user. The displayed attributes and their formatting can be configured by the user in the **Attribute Selection** window (Fig. 1.8), which is opened by clicking the **wrench icon** in this panel. This operation allows you to customize the display of the attribute list.

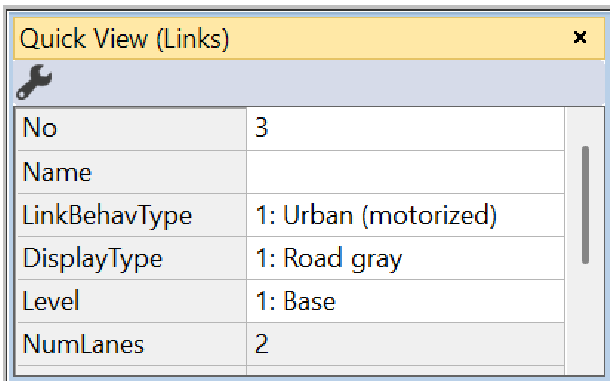


Figure 1.8. **Quick View** Window of the Selected Link

List Window

List windows (Fig. 1.9) can be opened via the **Lists** menu (for all network objects) or through the **Base Data**, **Traffic**, **Signal Control**, **Evaluation**, and **Presentation** menus (for the corresponding object types). They can also be opened from the context menu of the Network Objects panel (by right-clicking on the desired row) or from the context menu of the network window. Display option: **Lists** → **Network** → **Objects**. The list content can be sorted by any column.

Using the toolbar buttons (alphabet icons), any selected cells in the list can be copied to the clipboard and pasted into other programs (e.g., Microsoft Excel), and vice versa. The list window displays all network objects of a given type, with one row per object and one column for each attribute. The displayed attributes can be selected by the user in the **Attribute Selection** window, which opens by clicking the **wrench icon** on the list window toolbar.

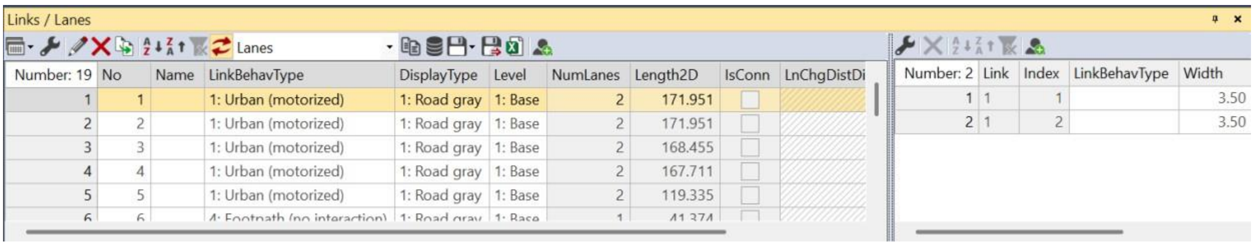


Figure 1.9. List Window

Importing a Raster Background

When launching PTV Vissim, the user is presented with a world map from OpenStreetMap (Fig. 1.10). This is a built-in raster background, which in the student version is available only as a plan view. The satellite map required for modelling is not available. Therefore, the map should be disabled using the wrench icon on the toolbar at the top of the model workspace. This can be done by unchecking the "Show Background Map" option or by using the globe icon (Fig. 1.11).
It should be noted that the map display function is not supported in **3D mode.**

Figure 1.10. World map

Figure 1.11. Turning the background map display on/off

To import a raster background from an external source, open a web browser, for example Google Chrome, and use the Google Maps platform (https://www.google.com/maps) to obtain a satellite image of the city. Then, locate the required intersection and take a screenshot of the selected area (alternatively, you can crop the area using the **Snipping Tool** in Windows) and save it in the project folder.

Next, in the side menu, select the **Backgrounds** option using the left mouse button. The active item in the side menu is highlighted, as shown in Fig. 1.12.

Figure 1.12. Choosing the background layer

To load a background, move the mouse cursor to an empty area of the workspace and press **Ctrl + right mouse button**. The following context menu will appear (Fig. 1.13).

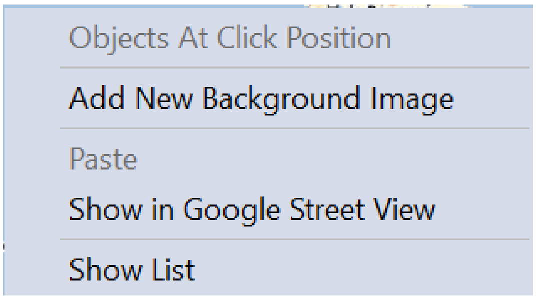


Figure 1.13. Context Menu for Working with Backgrounds

In the context menu, select **Add Background**, then in the dialog window choose the file containing the background (base map) for the project. Next, click **Show Entire Network** so that the background fits the screen.

Multiple background layers can be loaded into a single project. The procedure for adding a second background is the same as for the first one. You can view the list of available backgrounds via the context menu by right-clicking on any empty area of the workspace, or through the active **Backgrounds** tab in the side panel.

Scaling the Raster Background

The added raster background must be scaled. To do this, first select the inserted base map by clicking on it with the left mouse button, then right-click on it and choose **Scale Selection** from the context menu (Fig. 1.14).

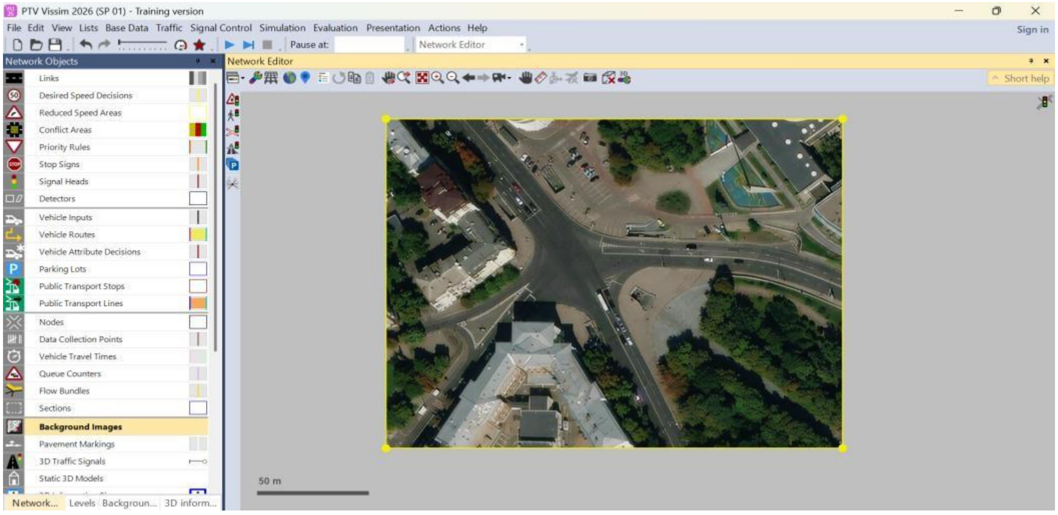


Figure 1.14. Scale Selection

The base map will be expanded to fit the size of the workspace. Next, while the base map you wish to scale is selected, right-click to open the context menu and select the **Set Scale** option (Fig. 1.15).

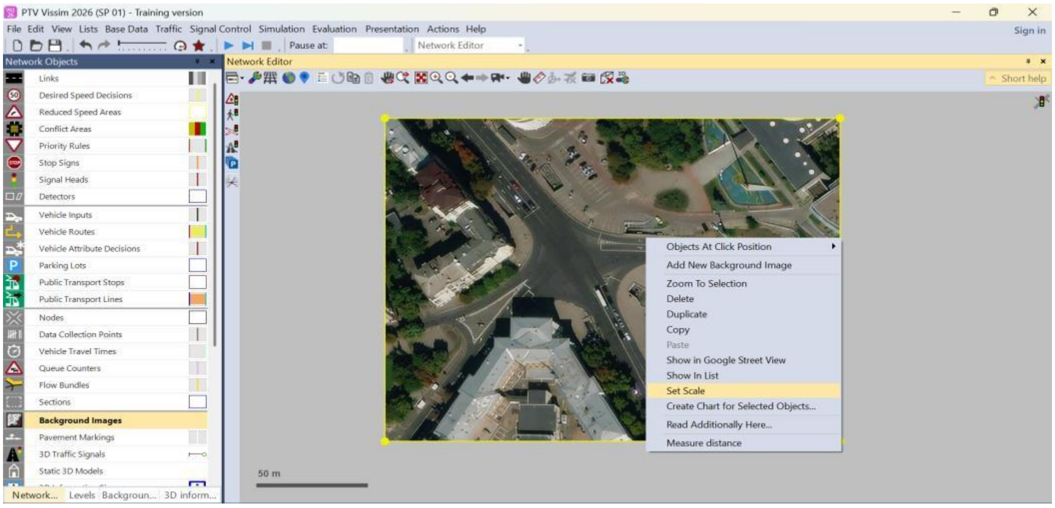


Figure 1.15. Selecting the **Set Scale** option

After that, click with the left mouse button and, without releasing it, draw a line along a real-world dimension known to you, for example, along the wall of a building. The distance can be measured using the **Ruler** tool in a map service. In the dialog window that opens, enter the measured value (Fig. 1.16).

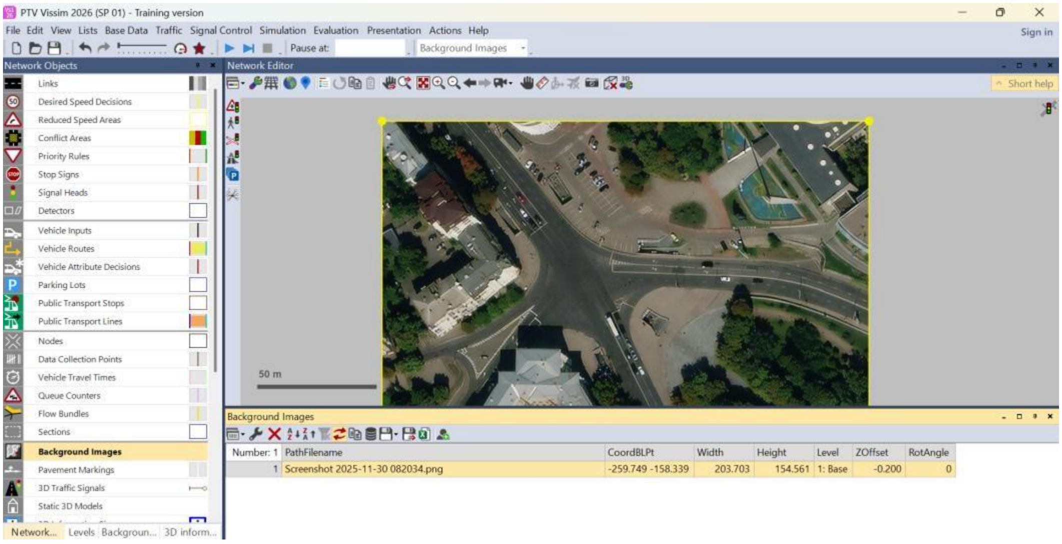


Figure 1.16. Window for Setting the Scale Value

The base map is now scaled. If necessary, you can adjust the position of the raster background relative to the coordinate grid (for example, if, after importing a project from another computer, the road network appears shifted relative to the raster). To do this, select the base map by clicking on it with the left mouse button. The background will be highlighted, and by holding down the left mouse button on it, you can move it.

Using **Pan Mode** (the open hand icon on the toolbar at the top of the workspace) and zooming with the mouse wheel, you can navigate to the area of interest. To prevent the base map from moving while adding new objects or interacting with existing ones, **Pan Mode** should be disabled (lock symbol in the **Backgrounds** button).

The scaled base map should be saved in the project folder. At this point, the introduction to the program interface is complete, and you can proceed to developing the traffic model.

The next mandatory step in creating a model of a real transport network segment is a thorough study of the site, either in the field or using electronic maps. During individual assignments students prepare to input into the VISSIM environment the actual parameters of the transport section: base map (background), scale, lanes, road markings, traffic signs, priority road, traffic volumes and composition, traffic signals, signal phases, pedestrian crossings, etc.

Laboratory Task Requirements

To successfully report your results, include the following:

1. A screenshot of a section of the road network that includes an intersection.
2. A description of the selected road network section.
3. Installation of PTV Vissim (https://your.visum.ptvgroup.com/vision-traffic-suite-students-en?_ga=2.65218350.1009680496.1675179585-1491835397.1674804063).
4. Modelling of the selected road network section.

LABORATORY WORK 6

MODELLING OF SIGNAL CONTROL OPERATION AT A PEDESTRIAN CROSSING

Purpose and Scope

On the existing transport model in PTV Visum, the sections of the street and road network with unregulated pedestrian crossings located on them are considered for the purpose of evaluating the effectiveness of the functioning of these infrastructure elements according to the criterion of the level of traffic convenience. According to the results of the analysis, after consultation with the teacher, a pedestrian crossing with a relatively low level of traffic convenience is selected. The option of introducing local single-program rigid traffic light regulation at this crossing is considered.

Equipment Name and Purpose.

PTV Group Software for transport modelling: PTV Vissim and PTV Visum.

Type: Software.

Theoretical Background

The minimum time required for pedestrians to cross the roadway is determined by the formula:

$$t_{nш} = \frac{H}{V_n} + 5, s$$

where H - width of the carriageway, m;

V_n - pedestrian speed (1.3 m/s)

This value is equal to the duration of the pedestrian phase.

The value of the transition interval for the pedestrian direction, t_{III}^{II} taking into account the green flashing signal, is 6; 7, or 8s.

When choosing this value, the following ratio should be followed:

$$t_{III}^{II} \geq \frac{H'}{V_n}$$

The value H' is chosen depending on road conditions and is equal to the maximum width of the carriageway that pedestrians must pass to reach the sidewalk, dividing strip, or dividing line of oncoming traffic lanes.

The duration of the main cycle of the pedestrian phase is calculated by the formula:

$$t_{om}^{II} = t_{nш} - t_{ПІ}^{II}$$

The duration of the transit interval of the transport phase depends on several parameters:

$$t_{ПІ}^{I} = t_{p} + \frac{V_k}{2a^k} + \frac{B_j + l_a}{V_k} + 2\ ,c$$

where: t_p – driver reaction time, s (1s);

V_k – speed, m/s;

a^k - deceleration, m/s^2 (4 m/s^2);

B_i - distance at the transition between stop lines, m;

l_a - length of the assembled car, m (we assume 5m).

The value of the control cycle is found by the Webster method.
We determine the control cycle:

$$T_{ц} = \frac{B}{2A} + \sqrt{\frac{B^2}{4A^2} - \frac{C}{A}}$$

where: $A = 1 - y^I$

$B = 2.5T_n - T_n y^I + t_{nш} + 5$

$T_n = (t_{ni}^{I} - 3) + (t_{ni}^{II} - 3)$

$C = (T_n + t_{om}^{II})(1,5T_n + 5)$

$$y^I = \frac{N}{M}$$

The nominal value of saturation flows is set based on the width of the roadway.

Table 1.1. Saturation flux values

H, m	3,0	3,3	3,6	4,2	4,8	5,2
Mн, vehicle/h	1850	1875	1950	2075	2475	2700

The duration of the main cycle of the transport phase is determined by the formula:

$$t_{om}^{I} = T_{ц} - t_{ПІ}^{II} - t_{ПІ}^{I} - t_{om}^{II}\text{, c}$$

Principle of PTV Vissim Operation

PTV Vissim is the world's leading software for microscopic and multimodal traffic modelling, developed by the German company PTV Group. The main essence of this program lies in its ability to reproduce real-world traffic conditions of traffic flows and pedestrians with unprecedented detail, where each traffic participant is considered as a separate object or agent with its own unique physical characteristics and behavioral patterns. Unlike macroscopic models that operate on averaged indicators of density and intensity of large flows, Vissim allows you to analyse every fraction of a second of the movement of a particular passenger car, truck, bus, or person. The algorithms for vehicle movement are based on the psychophysical model of following the leader, developed by the German scientist Rainer Wiedemann. It takes into account in detail the driver's reaction to changes in speed and distance to the car in front, the limits of human perception, as well as complex lane change algorithms that depend on the driver's level of aggressiveness, his target route, and traffic rules on a specific section.

One of the strongest sides of PTV Vissim is its absolute multimodality, that is, the ability to organically integrate different types of transport into a single, common modelling environment. The program allows you to reproduce the operation of urban public transport as accurately as possible, including regular and articulated buses, trams, trolleybuses, and light rail systems. An engineer or designer can set accurate schedules, specific routes, and associate vehicle types with their real dimensions, capacity, and dynamic acceleration and braking characteristics. In addition, the delay time at stops is modelled in detail, which is dynamically calculated depending on the number of passengers entering and exiting, and the door configuration.

Capacity analysis and traffic light optimization are other extremely powerful aspects of this software package. The program provides users with a flexible toolkit for creating intersections of any geometric complexity, from simple T-shaped uncontrolled junctions and classic roundabouts (turbo-rings) to multi-level transport nodes with dozens of exits and conflict points. PTV Vissim supports the simulation of a variety of traffic control systems: from conventional rigid (fixed in time) traffic light control to extremely complex adaptive systems, such as SCATS or SCOOT, which are able to change the duration of phases in real time depending on current traffic conditions.

After a simulation run, the program generates a huge array of statistical data necessary for engineers to objectively assess the effectiveness of the proposed transport solutions. The user can get detailed reports on average and maximum travel times, speeds on different sections of the network, duration and number of vehicle stops, maximum and average length of queues at intersections, as well as the overall level of traffic delays. In addition to purely infrastructure indicators, Vissim allows you to calculate the environmental impact of projects using built-in emission models. It is able to calculate the exact consumption of various types of fuel and emissions of harmful substances (such as nitrogen oxides, carbon dioxide, fine dust) into the atmosphere based on real acceleration and braking profiles of each car in the flow, which makes it an indispensable tool for environmental auditing. All these complex mathematical data are accompanied by two-dimensional and three-dimensional visualisations of the movement process. The ability to observe simulated traffic flow in 3D space with realistic asphalt textures, models of buildings, trees, road signs, markings, and detailed vehicles is not only a tool for checking logical errors by the engineer himself, but also an extremely powerful means of communication for presenting complex infrastructure projects to investors, municipal politicians, and the public, who can visually see how a new street will work before its construction begins.

Course of practice

Based on data on the intensity of vehicle and pedestrian traffic, geometric parameters of the roadway, the presence of a dividing strip, and the width of the pedestrian crossing, the parameters of the traffic light regulation mode are calculated. The durations of the main cycles and transition intervals of the transport and pedestrian phases of regulation are determined.

The pedestrian crossing is modelled in the PTV Vissim environment: the boundaries of the roadway, traffic lanes, stop lines, and conflict zones are determined. If there is a dividing strip, a safety island is formed.

The previously determined parameters of the traffic light mode are entered into the program, and a traffic light regulation cycle is created.

Experimental procedure

Step 1: Preparation

With the help of the teacher, the student selects a section of the street and road network on the model in PTV Visum, which is characterized by a low level of traffic convenience with an unregulated pedestrian crossing located on it.

Step 2: Calculation of the regulation mode

Using the methodology given in the Theoretical Background, the student calculates the parameters of the two-phase hard local mode of traffic light regulation at the specified pedestrian crossing.

Step 3: Simulation

Based on the collected data in the PTV Vissim environment, a regulated and unregulated pedestrian crossing is simulated. Using the determined parameters of the two-phase traffic light cycle, the student receives a cyclogram of traffic light regulation at the pedestrian crossing

Step 4: Definition of indicators

Measurement of travel time (Vehicle Travel Times) is used to analyse delays on sections of the network. The pedestrian crossing itself between the stop lines and both approach sections is used as a section, where vehicles concentrate in anticipation of the permitting traffic light signal.

A start marker (Start section) is set at the beginning of the section, and a destination marker (Destination section) is set at the end of the section. The system measures the time from the moment of crossing the first line to the moment of crossing the second. In the results (Travel

Time Results), a separate column displays not only the total travel time, but also the Delay, calculated automatically according to the algorithm described above.

Step 5: Conclusions

The conclusion is based on a comparison of the values of transport delays for the regulated and unregulated modes of operation of the pedestrian crossing.

References:

Hunter, M. "Vissim simulation guidance." (2021). https://rosap.ntl.bts.gov/view/dot/60642

ENVIRONMENTAL MONITORING

LABORATORY WORK 7

RESEARCHING AIR QUALITY PARAMETERS USING AZ-7755 AIR QUALITY ANALYSER

Objective: To study the operating principle of air quality analyser, acquire practical skills in measuring gas concentrations (*CO_2*), temperature, and humidity, and to evaluate the state of the air environment.

Equipment and materials:
- AZ-7755 Air Quality Analyser;
- working environment (classroom/laboratory, vehicle interior, public transport stops);
- sources of influence (room occupancy, ventilation system, opened/closed windows, air conditioning system).

1. Theoretical Background

The air quality in a working environment is determined by the concentration of carbon dioxide (CO_2), temperature, and relative humidity (Fig. 1). An elevated level of CO_2 (>1000 ppm) indicates insufficient ventilation and can negatively impact human well-being.

Figure 1. Researching the air quality of the working environment

The AZ-7755 Air Quality Analyser operates based on a non-dispersive infrared (NDIR) sensor to determine CO_2 concentration, which ensures sufficient accuracy and measurement stability.

2. Equipment Description

The meter measures CO_2 level, air temperature, dew point, wet bulb temperature and humidity (DP, WB, RH) and is an ideal instrument for indoor air quality (IAQ) diagnosis.

The CO_2 measurement is based on the method of non-dispersive infrared spectroscopy (NDIR). The sensor detects the absorption of infrared radiation by CO_2 molecules, allowing for an accurate estimation of their concentration.

The meter is powered by either 4 AA batteries (Fig. 2) or a DC adaptor (9V/1A output).

Figure 2. Installing the device power source - batteries

3. Preparation for work

1. The meter is powered by either 4 AA.
2. Install the batteries into the battery compartment on the rear and make sure they are in the correct polarity and good contact.
3. When an adaptor is used, it will cut off the power supply from the batteries.
4. When battery voltage gets low, ▭ and «Lob» will appear on the LCD (Fig. 3).

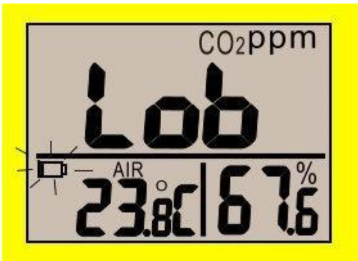


Figure 3. Low battery voltage display for the device

Importantly	The CO_2 sensor can't work under low voltage, so it beeps to indicate a failed CO_2 measurement (press any key, except ⓘSET , to stop the beeps) and the readings won't be displayed. Please replace with fresh batteries or connect with an adaptor.

4. Operation

<u>POWER ON/OFF</u>

Press ⓘSET to turn the meter on and off. When the power is on, it emits a short beep and performs 30-second countdowns (Fig. 4) for meter warm-up, then enters normal mode with current CO2, temp., and humidity readings displayed (Fig. 5).

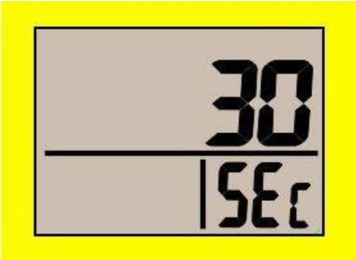


Figure 4. Setting up the device for operation

Figure 5. The device is ready for operation

<u>TAKING MEASUREMENTS</u>

The meter starts measurement when the power is on and updates readings every second. In the condition of operating environment change (ex. from high to low temp.), it takes 30 seconds to respond for the CO_2 sensor and 30 minutes for RH.

Importantly	Do not hold the meter close to faces in case exhalation affects CO_2 levels.

<u>AIR, DP, WBT</u>

Press [DP/WBT] to switch temp. display. The lower left display will cycle from air temp., dew point temp. (Fig. 6), and wet bulb temperature (Fig. 7).

Figure 6. Air temperature and dew point temperature

Figure 7. Wet bulb temperature

<u>DATA HOLD</u>

Press [HOLD] to freeze the readings, "HOLD" icon is displayed on the left top of the LCD (Fig. 8). All current readings are kept unchanged, except STEL and TWA. Press [HOLD] again to cancel the hold function.

Figure 8. Readings are frozen and remain unchanged

BACKLIGHT

Hold down for more than 1 second to activate and cancel the backlight function.

MIN, MAX, STEL, TWA

Under normal mode, press to see the minimum, maximum, and weighted average readings. Each press of , it displays MIN, MAX, STEL, and TWA in sequence and returns to normal mode.

In MIN and MAX modes, it shows the minimum and maximum readings of CO_2 on the upper LCD and of AIR or Dpor WB temp. and humidity on the lower LCD (Fig. 9).

Figure 9. Selection of readings (MIN, MAX, STEL, TWA)

In STEL and TWA modes, the upper LCD shows the weighted average of CO_2 readings for the past 15 minutes (STEL) and 8 hours (TWA). The lower LCD is the current AIR, DP/WB temp. and humidity (Fig. 10).

Figure 10. Displaying short-term exposure limit (STEL)

Importantly	NOTE: 1. If the meter is turned on for less than 15 minutes, the STEL value will be the weighted average of readings taken since power on. Same for TWA values appear before 8.
	2. It takes at least 5 minutes to calculate STEL and TWA. The LCD shows “ ---“ (Fig. 11) during the first 5 minutes from power on.
	3. While all readings are held unchanged, STEL and TWA will keep updating every 5 minutes.

Figure 11. Calculation of STEL and TWA

ALARM

The meter features an audible alarm to give warnings when the CO_2 concentration exceeds the limit. (See P1.0 in setup for setting the alarm threshold). It emits beeps (Abt 80dB) when the CO_2 level goes over the set value and stops when any key (except) was pressed or readings fell below the set value. It beeps again when the value goes over the limit.

Importantly	Restart the meter if the beeper can't be stopped.

AUTO POWER OFF

The meter turns off automatically after 20 minutes of inactivity. To override the function, hold down and for 2 sec to turn on the meter until "n" appears.

Importantly	Auto sleep function will be disabled during calibration mode.

5. Setup

Hold down under normal mode for more than 1 sec to enter setup mode. To exit setup, press in P1.0 or P3.0, and it returns to normal mode.

Note	P2.0 is not applicable in these models, but for future models

P1.0 CO_2 ALARM

When entering setup mode, P1.0 and "AL" (Fig. 12) are displayed on the LCD. Press to enter P1.1 for setting CO_2 alarm threshold. The current set value will be blinking on the LCD.

Press to enter P1.1 for setting CO_2 alarm threshold. The current set value will be blinking on the LCD (Fig. 13).

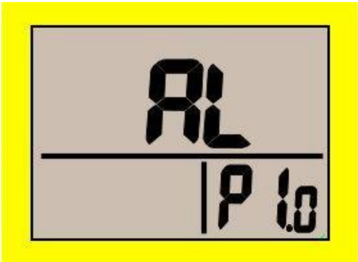


Figure 12. Set up mode for programming parameters (CO_2)

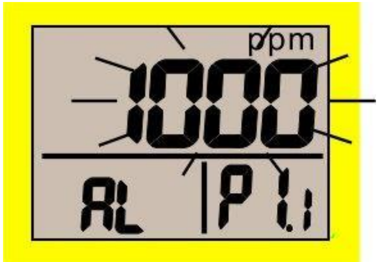


Figure 13. Setting the alarm threshold

Press to increase the value or to decrease. Each press tunes 100 ppm, and the alarm range is from 100 to 9900 ppm. When the preferred alarm value is set, press to save the setting or without saving and return to P1.0.

P3.0 TEMPERATURE SCALE

Press or in P1.0 to access P3.0 for setting up temp. Scale (Fig. 14). Press to enter P3.1 with blinking °C or °F current set (Fig.13) on the lower left LCD. To switch °C or °F, press and . Then press to save the setting or without saving and return to P3.0.

Figure 14. Setting the temperature scale

Figure 15. Selecting the temperature scale measurement unit (°C or °F)

CALIBRATION

CO_2 CALIBRATION

The meter is calibrated at a standard 400 ppm CO_2 concentration in the factory. It's suggested to do manual calibration regularly to maintain good accuracy.

Importantly 	Do not calibrate the meter in the air with an unknown CO_2 concentration. Otherwise, it will be calibrated as 400 ppm by default, which leads to inaccurate measurements. The manual calibration is suggested to be done in fresh outdoor air that is well ventilated and in sunny weather.

Place the meter in the calibration site. Turn on the meter and hold down the button, and simultaneously enter CO_2 calibration mode (Fig. 16). 400 ppm and “CAL” are blinking on the LCD while performing calibration.

Figure 16. CO_2 calibration

Wait about 5 minutes until the blinking stops and the calibration is completed automatically, and return to normal mode. To abort the calibration, turn off the meter at any time.

Importantly	Ensure the batteries are at full voltage during the calibration to prevent interruption or failed calibration.

RH CALIBRATION

The meter defaults to be calibrated for the humidity with 33% and 75% salt solution. The ambient condition is recommended to be at 25°C and stable humidity (better to be close to the calibrating value). To abort calibration, just turn off the meter.

Importantly	Do not calibrate the humidity without the default calibration salt. Otherwise, it will cause permanent damage.

Plug the sensor probe into 33% salt bottle. Hold down CAL/Esc and DP/WBT under normal mode to enter 33% calibration (Fig. 17). “CAL” and calibrating value (32.7% if at 25°C) are blinking on the LCD with current temperature at the left.

The meter is now calibrating and will finish in about 60 minutes when “CAL” and humidity stop blinking (Fig. 18).

Figure 17. 33% calibration

Figure 18. 33% calibration is complete

6. Procedure

1. Turn on AZ-7755 Air Quality Analyser.
2. Allow the device to stabilize for 5 minutes.
3. Record the initial readings:
- CO_2,
- temperature,
- humidity.
4. Conduct measurements under various conditions:
- in a closed room,
- after ventilation,
- with increased room occupancy.
5. Record the obtained results.

7. Measurement Results

Measurement results obtained using the AZ-7755 Air Quality Analyser are compiled into tables and visualised on a combined chart, allowing for a clear assessment of changes in CO_2 concentration, temperature, and relative humidity depending on the experimental conditions.

Table 1. Measurement results (as an example)

№	Measurement conditions	CO_2, ppm	Temperature, °C	Humidity, %
1	Initial condition	520	21,8	45
2	Without ventilation	1180	23,6	52
3	After ventilation	640	22,4	48

A combined chart for data obtained with the AZ-7755 Air Quality Analyser is structured by simultaneously displaying several parameters with different physical dimensions on a single graphical field (Fig. 19). The *x*-axis represents the experimental conditions (initial state, lack of ventilation or airing out), forming a categorical scale. The primary feature is the use of two y-axes: the left axis displays temperature and relative humidity, which have similar value ranges; the right axis displays CO_2 concentration, which differs significantly in scale. For each parameter, separate linear dependencies are plotted; the points correspond to experimental measurements and are connected to provide a clear visualisation of changes in the indicators. This approach avoids data distortion, ensures a correct visual comparison of parameters, and enables an engineering analysis of the impact of operating conditions on air quality.

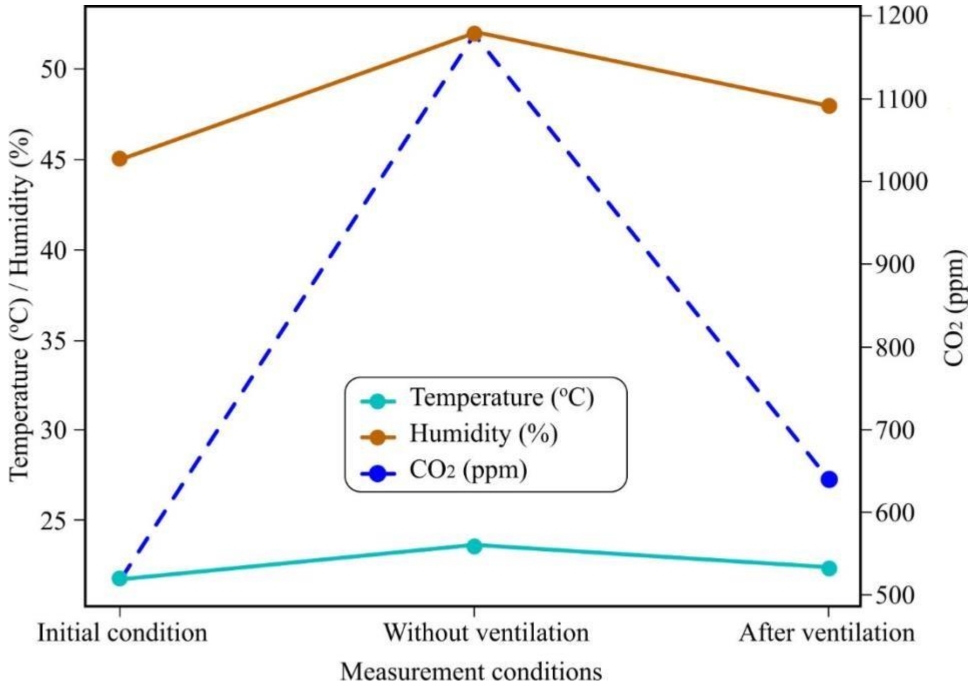


Figure 19. Combined microclimate parameter chart

The resulting combined chart shows a consistent change in microclimate parameters. As CO_2 concentration increases, a rise in temperature and humidity is observed, which is directly linked to the room occupancy. After ventilation, all parameters decrease and approach comfortable values. The most sensitive indicator of air quality is the CO_2 concentration, which confirms the effectiveness of using the analyser for ventilation control.

8. Analysis of results

The obtained values are compared with the following standard norms:
- *CO_2*: up to 800 ppm – good, 800–1000 ppm – acceptable, >1000 ppm – poor;
- humidity: 40-60% – optimal;
- temperature: 18-24°C – comfortable.

A conclusion is then drawn regarding ventilation efficiency and overall air quality.

9. Data interpretation

The analysis of experimental data obtained using the AZ-7755 Air Quality Analyser shows a clear correlation between microclimate parameters, room occupancy, and ventilation modes. In the initial state (empty room), the CO_2 concentration was about 520 ppm, which corresponds to a well-ventilated environment and is close to the natural background. Temperature (≈21,8°C) and relative humidity (≈45%) fell within comfortable values.

Room occupancy in the absence of ventilation led to a significant drop in air quality, with CO_2 levels reaching 1180 ppm. This exceeds safety norms and confirms poor air exchange. Simultaneously, an increase in temperature to 23.6°C and humidity to 52% was recorded, which is attributed to human metabolic heat and moisture emission.

After ventilating the room, there was a noticeable improvement in the parameters: the CO_2 level decreased to 640 ppm, the temperature to 22.4°C, and the humidity to 48%. This confirms the high efficiency of natural ventilation in restoring air quality.

Analysis of the combined diagram with separate scales shows that the most sensitive indicator of changes in the air state is the CO_2 concentration, while temperature and humidity change less intensely. Thus, it is the CO_2 control that is key for assessing the effectiveness of ventilation and the sanitary-hygienic state of the room.

Overall, the research results confirm that the lack of ventilation leads to a rapid deterioration in air quality, and regular ventilation is a necessary condition for maintaining a comfortable and safe microclimate.

10. Conclusion

During the laboratory session, air quality parameters were monitored using the AZ-7755 Air Quality Analyser. The results established that CO_2 concentration is highly dependent on ventilation rates and room occupancy. The device proved to be accurate and user-friendly, confirming its effectiveness for real-time microclimate monitoring.

11. Documentation

Air Quality Analyser AZ-7755: operation manual. (2026). Taiwan : AZ Instrument Corp.

LABORATORY WORK 8

STUDYING PUBLIC TRANSPORT ACCESSIBILITY IN QGIS AND KPI ANALYSIS

Objective: To study the methods for assessing public transport accessibility and the principles of spatial analysis in QGIS. To gain practical skills in calculating Key Performance Indicators (KPIs), specifically minimum travel time, cumulative opportunities, gravity-based indices, and 2SFCA, as well as to assess the population's level of transit provision.

Equipment and materials:
- personal computer;
- QGIS software;
- tabular data (Excel): residential areas, public transport stops;
- pedestrian accessibility matrix (OD matrix);
- digital maps (OpenStreetMap or other sources);
- working environment (classroom/laboratory, vehicle interior, public transport stops).

2. Theoretical Background

Public transport accessibility is one of the key performance indicators of a transport system and aligns with Sustainable Development Goal 11 (Sustainable Cities and Communities). A high level of accessibility contributes to a reduction in private vehicle use, lower emissions, and increased social equality.

Accessibility assessment is performed using the following methods:
- minimum travel time;
- cumulative opportunities;
- gravity-based index;
- two-step floating catchment area (2SFCA) method.

QGIS enables spatial analysis and the visualisation of results in the form of thematic maps.

2. Equipment Description

The work utilizes QGIS software and OpenStreetMap data, alongside specialized laboratory resources. These facilities include transport data collection systems, visualisation tools, and environmental monitoring equipment.

3. Preparation for work

- Prepare Excel tables (districts, stops);
- Generate the OD matrix (pedestrian travel time);
- Verify coordinate accuracy;
- Prepare digital maps (OpenStreetMap);

- Launch QGIS and create a new project.

4. Operation

1. *Data preparation*. Create Excel tables: residential districts (ID, name, coordinates, population); stops (ID, name, coordinates, number of departures). Prepare the pedestrian travel time matrix.

2. *Data Input in QGIS.*
Launch QGIS (https://qgis.org/thank-you/)

Go to the top menu and select: **Layer** → **Add Layer** → **Add Delimited Text Layer.**
Click **Browse** and select the **Districts** file.
Specify:
X Field → longitude
Y Field → latitude
In the **CRS** field, select WGS84 (EPSG:4326).
Click **Add**.
Repeat the same process to load the **Stops** file.

3. Object Visualisation
In the Layers Panel, verify that **Districts** and **Stops** are displayed.
Apply styling:
Districts → one colour (for example, blue);
Stops → another colour (for example, red).
Adjust symbol size if necessary.

4. Creating Accessibility Zones.
In the menu, select **Vector** → **Geoprocessing Tools** → **Buffer**
In the Input layer dropdown menu, select **Stops**
Distance → enter 800
Segments → enter 10
Click the **Run** button to create an 800m buffer
Repeat the operation for:
Distance → 1600
This generates:
10-minute walking zone
20-minute walking zone

5. Spatial Analysis.
Select:
Vector → Data Management Tools → Join attributes by location
Specify:
Input layer → districts
Join layer → buffer
Click **Run**
Result: Identification of districts falling within the accessibility zones.

6. KPI Calculation
6.1 Minimum travel time
Use the OD matrix. For each district, determine the minimum time to the nearest stop.
Add a field in the QGIS attribute table QGIS (Field Calculator) → min_time.
6.2 Cumulative Opportunities
Count the number of stops within 800 m.
Add a filed → **Opportunities**.

6.3. Gravity-Based Index
In the field **Calculator**, apply the following formula:

$$A = \sum \frac{S}{d^2}$$

where
S- stop departure intensity;
d- distance.

2SFCA Method
Calculate the following relationship:

$$R = \sum \frac{Stop}{Population}$$

For each district, calculate the sum of values within the accessibility zone.
Record the result in the 2SFCA field.

11. Consolidate KPI results into a summary table

Table 1. KPI Assessment of Transport Accessibility

District	min_time (min.)	opportunities	gravity	2SFCA
District 1	___	___	___	___
District 2	___	___	___	___

District 3	___	___	___	___
District 4	___	___	___	

Additional City-Wide Summary Metrics:

Population coverage (%): ____% *(percentage of the population within 800 m of stops)*

Average access time: ___ minutes *(mean value min_time across all districts)*

Accessibility inequality: ___ *(max(KPI) − min(KPI), indicates the imbalance between districts)*

7. *Visualisation of Results*

For each indicator:

Right-click the **District** layer

Select **Properties** → **Symbology** → **Graduated**

Select the target field:

min_time

opportunities

gravity

2SFCA

Click **Classify**

Select a colour ramp.

8. *Map composition*

Select **Project** → **New Print Layout**

Click **Add Map**

Add essential elements:

Legend

Scale bar

Title

Export:

Export as PNG / PDF

5. Laboratory Work Outcomes

5.1. KPIs are calculated

– minimum travel time
– cumulative opportunities
– gravity index
– 2SFCA

5.2. Accessibility mapping is completed

4 thematic maps visualising different accessibility metric are developed.

5.3. District comparative analysis is performed

Central districts: characterised by high accessibility

Intermediate districts: characterised by moderate accessibility

Peripheral districts: characterised by low accessibility

5.4. Key findings

Highest accessibility: identified in the central district

Lowest accessibility: identified in the peripheral district

6. Conclusion

As a result of this laboratory work, a spatial analysis of public transport accessibility was conducted using **QGIS software**. The findings indicate that accessibility is unevenly distributed across the city: central districts exhibit significantly better transport provision compared to peripheral areas.

The results obtained can be utilised to optimise the transit network and enhance urban infrastructure.

This guide was developed through the joint collaboration of the ISDEGO project consortium partners

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