Development of GIS-Based Simulations for Evaluating Interventions in Latvia's Transport System

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Abstract: This paper presents the development and testing of a user interface (UI) for the Transport Interventions outcomes simulation Model (TIM) as part of Latvia's efforts to comprehensively assess state interventions in its transport system. Following the design thinking process, the paper outlines stakeholder needs and proposes a centralized website for accessing transport system data and outcomes. The TIM UI facilitates data exploration, submission of proposals, and initial impact assessment. It integrates GIS technology for enhanced visualization and decision-making. Testing results inform improvements in navigation, clarity, visual design, and performance. The TIM UI contributes to sustainable transportation planning and policy formulation in Latvia by engaging stakeholders and enabling informed decision-making.

1 INTRODUCTION

This research is motivated by the requirement to comprehensively assess the outcomes of state interventions within Latvia's transport system. These interventions, extending beyond mere infrastructural enhancements, are linked to broader environmental (ESG) and regional development objectives. Consequently, the transport system assumes a pivotal role as an agent facilitating progress toward these multifaceted goals.

This publication serves as a follow-up to the initial phase of the design thinking process, which focuses on prototyping and understanding the needs of stakeholders. The previous paper (Hudenko et al., 2022) outlines the first two steps Scheer et al. (2012) based design thinking process: (1) Observation and (2) Synthesis. The observations of railway stakeholders were conducted through focus group discussions, involving representatives from railway policy makers, professionals (railway undertakers), and implementers of railway policy (the infrastructure manager and the capacity allocation body). The synthesis of stakeholder insights revealed varying levels of development and involvement in ESG processes among different stakeholder groups. While some stakeholders demonstrated a high level of engagement and accountability, others indicated a more passive approach, primarily driven by regulatory requirements. The results also highlighted stakeholders' perceptions and motivations regarding ESG activities, revealing areas of alignment and divergence among different groups. These findings underscore the importance of addressing stakeholders' varying levels of awareness and engagement in ESG activities within the railway sector, particularly in fostering effective communication and collaboration among stakeholders to advance sustainable strategies in transportation planning and execution.

This research bridges this gap and discusses the subsequent phases of the design thinking process: (3) Ideate; (4) Prototype; and (5) Testing. These phases involve the development and testing of an open-access Geographic Information System (GIS) based data and data simulation tool among stakeholders, so that they can understand broader objectives of transportation planning.

GIS technology coordinates a wide range of applications across different industries including

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regional planning, environmental management, transportation and allows users to understand patterns, relationships, and trends that are not always apparent in tabular data, thus enabling users to make informed decisions.

By leveraging GIS technology, this research seeks to empower policymakers, transport and regional development planners, and transportation stakeholders with actionable insights into the potential impacts of various interventions on Latvia's transport system. Furthermore, we seek to address challenges in this domain to both SIMULTECH society and practitioners.

In the following sections, this paper will delve into the methodological details of developing GIS-based simulations for interventions in Latvia's transport system. It will explore the underlying data sources, modelling techniques, and simulation methodologies employed, highlighting key insights and implications for urban planning and policy formulation.

2 THE IDEATION

In the ideation phase of our project, we propose the development of a comprehensive website aimed at providing a centralized platform for stakeholders to access information on existing transport system developments, planned interventions, and their outcomes (Fig. 1).

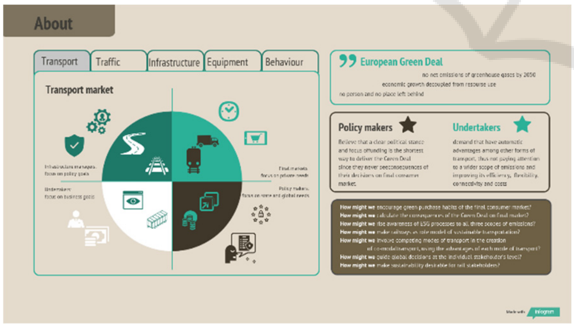

Figure 1: Conceptual Framework of Stakeholder Involvement in the Green Deal Website.

Figure 1 illustrates the ideation proposal regarding the involvement of various stakeholders in the Green Deal via the website. The website is structured into four main sections: transport (transports operators), infrastructure (policy makers), equipment (infrastructure undertakers), and behaviour (transport users).

Each section is tailored to focus on achieving the goals of the Green Deal within their respective domains by addressing these questions:

- Transport operators: "How might we make sustainability desirable for rail stakeholders?"
- Transport users: "How might we encourage green purchase habits of the final consumer market?"
- Policy makers: "How might we make railways as a role model of sustainable transportation?", "How might we involve competing modes of transport in the creation of co-modal transport, using the advantages of each mode of transport?" and "How might we guide global decisions at the individual stakeholder's level?"
- Infrastructure undertakers: "How might we calculate the consequences of the Green Deal on final market?" and "How might we raise awareness of ESG processes to all three scopes of emissions?"

If implemented, the proposed website would serve as a valuable tool for stakeholders by consolidating data and insights on ongoing and proposed transport interventions, providing accessible and up-to-date information. This platform would enable policymakers, urban planners, transportation engineers, and other stakeholders to gain valuable insights into the current state of the transport system, identify improvement areas, and explore potential intervention strategies.

The first testing of prototyped website asked to develop an intuitive interface that allows users to navigate through different sections, including a comprehensive database of existing transport system developments, detailed profiles of planned interventions, and comprehensive reports on the outcomes of previous interventions. Additionally, interactive maps and visualizations were asked to be incorporated to enhance the user experience and facilitate data exploration:

- The list of accepted infrastructure projects, those location, and details (Figure 2)
- Use studies (optional – not discussed)
- Possibilities to submit proposals (Figure 3).

Figure 2: Latvia Infrastructure Project Data Visualization.

Figure 2 depicts a visualization an accepted projects' explanation tool. It includes a map of Latvia infrastructure, divided into layers. Each layer has information about the project and associated investments as well as its outcomes such as infrastructure quality, regional connectivity, and incidents.

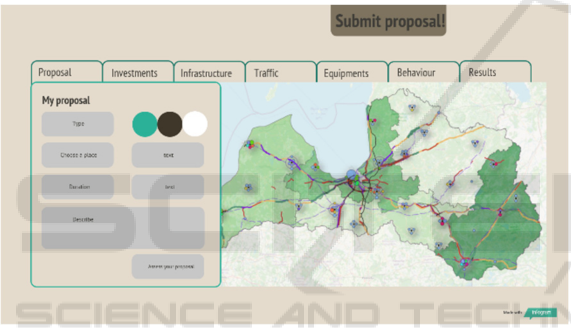

Figure 3: Project Proposal Submission Tool with Interactive Map Display.

Figure 3 illustrates the ideated proposal of submission interactive map, with multiple survey of information, including required interventions as well as affected infrastructure, traffic, equipment, and behaviour aspects. At the end there is a result section where stakeholders require an initial impact of their proposal where they can assess feasibility of the submitted proposal.

In summary, the ideation step of the prototyped website focused on developing an intuitive interface to allow users to navigate through various sections, including a comprehensive database of existing transport system developments, detailed profiles of planned interventions, and comprehensive reports on the outcomes of previous interventions. Additionally, interactive maps and visualizations were proposed to enhance the user experience and facilitate data exploration, allowing stakeholders to submit proposals and to make those initial assess. The next step discusses the prototype of the transport interventions initial assessment tool.

3 THE PROTOTYPE

This section will discuss the Transport Interventions outcomes simulation Model (TIM), which enables researchers, interested stakeholders, and policy analysts to calculate, in a comparable manner, the effects of taxes, investments, and other transport interventions on transport system outcomes for specific countries or groups of countries.

3.1 TIM Model

Figure 4 show a representation of the TIM model inputs, interactions, and outcomes.

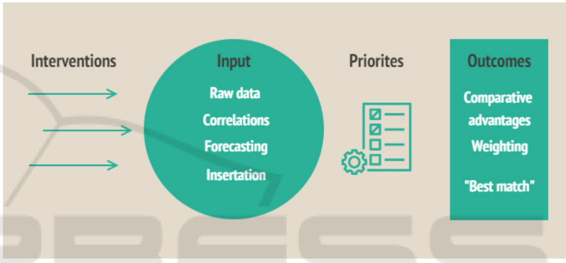

Figure 4: The TIM Model Overall Scheme.

Figure 4 summarizes the framework of the TIM and its core components:

- Interventions. Presently, our focus primarily encompasses investment strategies. Nevertheless, a supplemental investigation incorporates additional potential interventions, such as legal frameworks and taxation policies.
- Model Core ("Black Box"). This component serves as the central processing unit, where raw data undergoes correlation analysis, forecasting, weighting, and integration processes.
- Alignment with Decision Makers. This stage involves the identification of outcome priorities to ensure congruence with the preferences and objectives of decision-making entities.
- Outcomes. The model simulates the comparative advantages inherent in various intervention scenarios.

Subsequent sections will elucidate the constituent blocks of the model in reverse order.

3.1.1 The Outcomes and Capabilities

TIM can be used in many ways. For online users:

- Standard estimation of environment impact, mobility redistribution and productivity statistics under actual conditions.
- Budgetary effects.
- Illustrative changes to traffic redistribution on transport modes and public/private source of transport financing.

More advanced capabilities (outside of online version):

- *Ex-ante* and *ex-post* assessment of complex policy reforms e.g., Transport Development Master plan.
- Policy transfer's assessment e.g., how adopting a policy measure currently effective in country A would have effect in country B.
- Assessment of other "what if" questions effects and costs of EU-wide policy reforms.

In summary, we expect that TIM's comprehensive functionalities make it a valuable tool for policymakers, researchers, and stakeholders involved in transportation planning and policy analysis at both national and international levels.

3.1.2 Policy Priorities

The TIM model either reflects the intervention-benefit outcomes for a specific period (*ex-post* analysis) or the outcomes for an actual (planned) or imaginary intervention (*ex-ante*) scenario.

This is a fact that decision-making is not always as simple as the value of a specific parameter. Therefore, the primary output of the TIM model is an aggregated weighted of scenario comparable advantages of key performance indicators (KPIs) for various scenarios. This outcome is attained through the application of the Analytic Network Process (ANP) methodology. The output consists of two lists: evaluations of comparable advantages and those weights (policies).

Technically an evaluation of comparable advantages is the aggregate of input data correlations and forecasts as described below. These components in rare cases fractions can be either added or subtracted to build the unknown aggregate.

TIM policies are functions, which typically represent an eligibility for the intervention (*e.g.* better connectivity indicators leads "best match" to investments). The purpose of using policy functions as building blocks of the model is to provide a general structure, which can be seen as using a standardised language to describe transport policy instruments.

As a default TIM produces a table with forecasted KPIs, those weights and aggregated value. The KPI are divided into three groups:

- Productivity: Nominal labor productivity per hour in the transportation and storage sector; GDP per capita at purchasing power parity; Transport infrastructure index;
- Cohesion: Regional GDP disparity; Attraction of private investment in planning regions; Wage in planning regions;
- Sustainability: Share of energy generated from RES in transport; Share of zero-emission vehicles in the total number of vehicles; Reduction in the number of pedestrian fatalities in road traffic accidents.

The concept of "best match" refers to achieving an optimal system-dataset combination where no further improvements can be made in one aspect without sacrificing performance in another aspect, *e.g.* Pareto optimality.

Achieving a "best match" suggests that there may be multiple combinations of interventions that could be considered optimal, as it is not possible to improve one aspect (*e.g.* productivity) without compromising another aspect (*e.g.* sustainability). We use the concept of Pareto optimality for selecting the "best match" intervention/priorities combination by considering the trade-offs between different criteria and striving for an outcome where no further improvements can be made without sacrificing performance in other areas.

3.1.3 Data Input

TIM is based on two inputs: raw data and correlations coefficients.

Raw data or parameters contain the information the model needs to produce its output. These are the initial, unprocessed data inputs from transport sector stakeholders that serve as the foundation for analysis within TIM. They are stored in XML files and consist of factual information or observations collected from sensors, databases, or official statistics. Raw data consists of assessment unit, such as: Number of transport units on a road or rail section (for traffic dimension); Maximum transport unit available (for infrastructure dimension); Revenue generated by one transported unit (for behaviour dimension); Number of incidents per infrastructure unit (for equipment dimension). The assessment units consist of meta data e.g., definitions of e.g., what is a transport unit, when and how it is collected, etc. The meta data is also a part of the input data and requires extensional communication among data users.

Coefficients are numerical values or parameters used to quantify the relationships or correlations between different factors within the transportation system's row data. In the context of TIM, coefficients include regression coefficients, correlation coefficients, elasticity coefficients, and other coefficients derived from econometric models or empirical studies. These coefficients play a crucial role in estimating the effects of policy interventions, predicting outcomes, and assessing the impacts of various factors on transportation system performance. Coefficients mostly derived from statistical analyses or previous research and are used to represent the strength and direction of the relationships between variables.

Furthermore, while in an ideal research setting, assessing the outcomes of interventions for the year YYYY would involve the modification of data relevant to the same year, it is essential to acknowledge that in the real-world corresponding data is not consistently guaranteed. Therefore, datasets used for simulating several intervention years, are compiled by forecasting technics and alongside with user's adjustments develop baseline or base scenario.

These forecasting parameters reflect the dynamics of the transport system and represent the probable outcome in the absence of interventions. Additional parameters can be included by stakeholders to improve forecasting accuracy by users based on their knowledge and the specific context of the time series being modelled. Some examples of additional parameters mentioned during ideation were:

- Seasonal and cyclical patterns that repeat over fixed periods.
- Known cases or events (e.g., legal changes, end of related projects etc) that lead to gradual changes in the data over time.
- Influence of the external variable such as demography economic indicators, weather data, or any other relevant factors.
- System dynamics components such as saturation and delays in feedback.

The involvement of stakeholders provides a powerful framework for understanding and managing complex transportation systems, allowing policymakers, managers, and researchers to explore the dynamic behaviour of the system and design more effective strategies.

3.1.4 Interventions

The name of the model, reflects its core function of simulating outcomes resulting from interventions, including taxes, investments, and legal boundaries. Technically, the intervention file in the TIM model consists of multiple variables that aggregate a set of key performance indicators (KPIs) relative to a baseline scenario. The comparison of different intervention scenario allows to find the "best much" as described in section 3.1.2. The intervention file also consists of name, type, amount and starting year of intervention, affected row data sets and coefficient used for updating those values to the corresponding year.

For the online user the interventions are standardised (standard interventions), that means that online users can propose to change only specified data sets, which were used over the *ex-ante* assessment, as described in section 3.2.

Advanced users can introduce special intervention function, defining any variables and data sets as well as develop a list of interventions worked off in sequence when the TIM model performs its calculations called "policy". These is a file that define variables that aggregates the effect of each intervention to the sequent intervention and on the final output. The variables in the file capture both direct impacts and indirect influences, considering the spatial relationships and interactions among interventions.

Technically there is no difference between standard interventions and special interventions, both use ANP functions for their implementation and both need to be listed in the "policy" to be performed. Thus, calling some of them "special" is just a matter of better comprehensibility, that shows that user can influence the outcomes by defining of relationships and interconnections.

Through this approach, the TIM model refers to prevalent users' inquiries regarding the omission of certain transport interventions from simulation due to datasets typically lacking information on past contributions of the progressing transport system.

This will lead us to the next problem of "How might we guide global decisions at the individual stakeholder's level?", which on an ideational level is addressed through the introduction of a challenging user interface.

3.2 TIM User Interface

The user interface prototype was introduced in 2023 as a step forward in improving the user experience within simulation modelling and GIS applications, particularly in addressing the complex transport system dynamics of guiding "strategical level" decisions at the individual stakeholder's level. This milestone sets the foundation for continued research and development aimed at refining the interface's functionality and effectiveness in facilitating informed decision-making processes.

In the subsequent text, we will present the results from the testing phase of the developed prototype.

3.2.1 Explanatory Pages

By distinguishing between raw data inputs and coefficients primarily assessing data correlations, users can gain a clearer understanding of the various types of information integrated within TIM and their respective contributions to the analysis and decision-making process. Therefore, the key elements of the model are interpreted to users through the "About" window in the user interface.

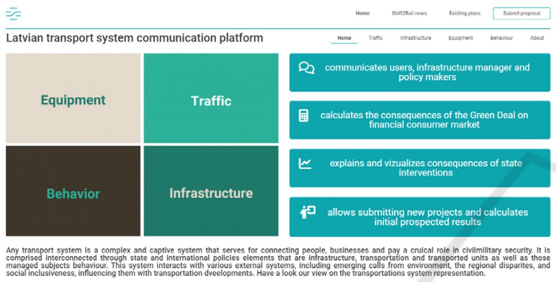

Figure 5: Clarifying Raw data Utilization in TIM: ″About″ window.

The "About" window sections presents aggregated data in four model dimensions:

- "Traffic" encompasses two distinct groups of indicators: (1) traffic flow intensity, reflecting the tangible load on the transportation infrastructure in terms of vehicles, and (2) turnover of transported units (passengers or freight tonnes). Traffic indicators are delineated by three dimensions: passenger and freight transport, intensity of public and commercial transport, and road transport and railway movement. Furthermore, efforts are made to delineate the regional distribution of traffic for GIS representation.
- "Infrastructure" distinct two groups of indicators: (1) throughput, delineating the maximum volume of vehicles passing through a designated section of the infrastructure per day, and (2) throughput capacity, representing the projected maximum capacity for both linear infrastructure and terminals. To ensure data comparability, the same dimensions employed for "Traffic" indicators are adopted."
- "Equipment" is characterized by three primary groups of indicators: (1) environmentally friendly equipment associated with the availability of environmentally safer modes of transport as electrified railway lines, cycling paths, alternative fuel filling stations etc., (2) safety (for passengers) and security (for freight) of transported units, as well as (3) Competitiveness and time efficiency that are influenced by infrastructure quality, with improved infrastructure correlating to reduced time losses.
- "Behaviour" assessed through three groups of indicators: (1) changes in behaviour patterns, like modal shift, management shift and spatial shift; (2) revenue, that pertains to the ability of individuals and businesses to meet the costs associated with transportation and make vehicle choices based on price considerations; (3) costs, where assessments consider separately allocated capital and operational costs, along with evaluating the cost burden on service users.

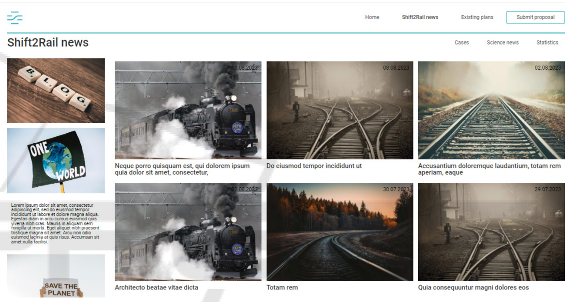

Figure 6: Clarifying Data Correlations in TIM: ″Shift2Rail″ window.

This section of the user interface displays all submitted use cases and statistics clarifying regression, correlation, and elasticity coefficients, derived from econometric models or empirical studies utilized within the TIM model. Additionally, we aim to present unexplained aspects of the model for future evaluations by scientists and students.

The "Existing plans" window explain in GIS and excel representation those plans that already approved and aimed to explain those outcomes and restrictions that appears in traffic during implementation (see Figure 7)

We aimed to provide enhancements across various categories of lanes to facilitate easier navigation. But in fact, we were engaged in extensive discussions with stakeholders regarding the level of detail in mapping, as well as the implementation of notifications for announced project changes. Additionally, considerations such as data accuracy (in terms of understanding of definitions), usability for final users, and stakeholder feedback were also prominent in our deliberations.

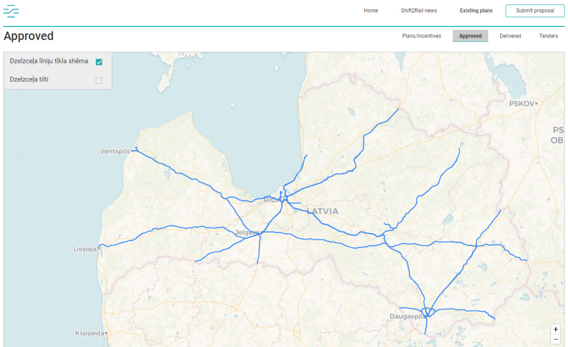

Figure 7: Clarifying Approved Interventions in the Transport System with GIS instruments.

3.2.2 TIM Public Access

In recent years, the development of user interfaces (UIs) for complex systems has garnered significant attention due to their crucial role in facilitating user interactions and improving overall user experience. The TIM UI, serves as a central access point for public usage, providing access to feedback to existing transport policy through the implementation of the "Submit Proposal" feature (see Figure 8)

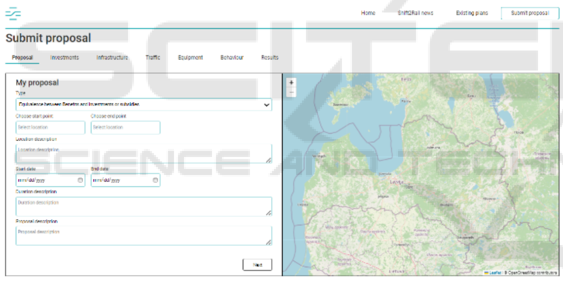

Figure 8: TIM User Interface's prototype.

By integrating the "Submit Proposal" feature into the TIM interface, we aim to address the question raised in the ideation part of the research: "How might we encourage green purchase habits of the final consumer market?" Our goal is to encourage users of the infrastructure to actively participate in social dialog. This approach fosters better public participation and allows us to demonstrate the logic behind intervention assessments. Users will be driven through the set of questions ensuring reliability and viability of the submitted proposals. This initial assessment will be shared with the final users, fostering transparency and trust in the decision-making process.

After the registration process, the "Submit Proposal" feature on the user interface's main window displays the following components:

- The "Type" ribbon allows users to access parameters related to the specific state intervention and switch between TIM parameters for customized calculations.
- Additional ribbons are available for specifying details such as prescription, location, duration, and description of the proposal. These details are stored and listed in the "Delivered" window of the user interface for easy reference and tracking.
- The delivered proposals are also shown on the map.

Once user click the "Next" button located at the bottom of the user interface, a run dialog is initiated to support the manipulation of intervention parameters. These dialogues enable the configuration of adjustments in traffic, infrastructure, equipment, and other input datasets, all of which are essential for simulating transportation system outcomes.

The TIM UI offers initial calculations based on built-in regression, correlation, and elasticity coefficients. These calculations not only facilitate standard computations but also aid in error identification and the assessment of consistency in various considerations. Users are encouraged to provide remarks and evidence to refine decision-making processes in line with real-world scenarios.

Each TIM model category is presented within its own window, and users can navigate between these windows by clicking on the respective flags. The "Results" window compiles all delivered proposals for policymakers, serving as a foundational resource for discussions and public involvement.

4 CONCLUSIONS

The paper introduces a proposed user interface to centralize information on transport system developments and intervention outcomes, particularly focusing on broader environmental and regional development objectives aligned with the European Green Deal. It emphasizes the importance of effective communication and collaboration among stakeholders to advance sustainable strategies in transportation planning and execution.

The TIM user interface facilitates user interaction and enhances the overall user experience, featuring a "Submit Proposal" feature to encourage public participation and demonstrate intervention assessment logic. It allows users to customize calculations, provide input data, and access detailed information on delivered proposals.

The users' feedback allowed us to improve some parts of the ideation process:

- Changing some parts and adding some features (such as buttons, ribbons, and dropdown menus) for intuitive navigation between different sections and windows within the interface.
- Wordings improvement for clarity of interface elements.
- Users appreciate better visual layout and design of the interface.

Further involvement of users in submission process would improve the functionality:

- We are aiming to increase the accuracy of calculations, ensuring that the results align with users' expectations.
- We are looking for feedback that the interface functions properly across different devices and screen sizes, including desktop computers, laptops, tablets, and smartphones.
- We are continuously improving performance under different load conditions to ensure that it can handle a high volume of user interactions without performance degradation.

In conclusion, the research contributes to advancing sustainable transportation strategies in Latvia by providing a comprehensive framework for evaluating state interventions, promoting stakeholder engagement, and facilitating informed decision-making processes in transportation planning and policy formulation.

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