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ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
AMDC	Additional Manual Data Collection
API	Application Programming Interface
CA	Car Availability
GC	Generalized Cost
GIS	Geographic Information System
GV	Goods vehicle
GTFS	General Transit Feed Specification
HHS	Household Survey
IVT	In-Vehicle Time
LRT	Light Rail Transit
MRS	Marshrutka
NCA	Non-Car Availability
OD	Origin–Destination
OSM	OpenStreetMap
PCU	Passenger Car Unit
PED	Pedestrian
PrT	Private Transport
PuT	Public Transport
SUB	Subway
SUMP	Sustainable Urban Mobility Plan
TAZ	Transportation Analysis Zone
ToR	Terms of Reference
TUDA	LEPL Tbilisi Transport and Urban Development Agency
UDA	User-Defined Attribute
VOC	Vehicle Operating Cost
VoT	Value of Time

1. INTRODUCTION

The assignment titled “**Data Collection and Model Update Related to Transport in Tbilisi**” funded by ADB and implemented with the Tbilisi City Hall (TCH), Executing Agency (EA), and Tbilisi Development Funds (TDF), Implementing Agency (IA), via the LEPL Tbilisi Transport and Urban Development Agency (TUDA), collected data reflecting citizens’ transport habits and update the transport demand model to improve transport services within Tbilisi contributing to the promotion of sustainable urban transport network.

The contract for this assignment has been awarded to the Consortium led by Lattanzio KIBS with REDAS Engineering and ACT Global (hereafter “The Consortium”) in July 2024. The Contract came into force and effect on 1st July 2024, date set out as Effective Date (ED).

The specific objectives of the assignment are to:

- Carry out an **update of the Household Survey (HHS)** done in 2016, which would help in updating the knowledge on the travel habits of the citizens of Tbilisi (Task 1).
- Conduct **Additional Manual Data Collection (AMDC)**, including surveys on public transport, so that it can adequately support the definition, evaluation, and possible implementation of mobility management policies in line with the recently developed Tbilisi Transport Plan (SUMP) (Task 2).
- Update the **Tbilisi Transport Demand Model** (Task 3).
- Conduction of **Capacity Building** activities on the updated model, to provide knowledge transfer and training to the Client’s technical team (Task 4).

This document describes the update of the **Tbilisi Transport Demand Model** and falls under Task 3. Under this task, the model was revised using new data, collected during the project, including the 2024 Household Survey (HHS), passenger flow surveys, and other transport and socio-economic datasets.

The updated model reflects current traffic and mobility conditions in Tbilisi, providing a solid analytical basis for future transport strategy development.

It serves as a key analytical tool for understanding current mobility patterns, assessing policy impacts, and forecasting future transport demand under different development and infrastructure scenarios.

Earlier versions of the model were developed and refined through several studies – the 2011 LRT Feasibility Study, the 2019 Bus Network Restructuring Study, and the 2020 Sustainable Urban Mobility Plan (SUMP).

1.1. Objectives of the transport model

The main objective of the transport demand model update was to develop an accurate and reliable representation of travel demand and transport supply in Tbilisi, consistent with current socio-economic and network conditions. The updated model provides a quantitative basis for evaluating transport policies, investment scenarios, and infrastructure improvements.

Specifically, the model aims to:

- accurately represent the road and public transport networks, including updated the service characteristics;
- provide calibrated and validated outputs for the trip generation, distribution, mode choice, and assignment;
- serve as a decision-support tool for ongoing and future transport planning activities of the City of Tbilisi and TUDA.

1.2. Scope of the study

In accordance with the Terms of Reference (ToR), this task covered the update of the existing transport demand model for Tbilisi using the most recent data collected in 2024, with a focus on the morning peak hour (8:30–9:30 a.m.). This decision was made to keep the updated version of the model fully aligned with the

previous one and to have the possibility to use all data collected during the surveys made according to the ToR requirements. The following key activities were undertaken:

- Zoning system update: A new zonal system was developed in accordance with the project framework. For the cases, where the updated zoning extended beyond the limits of the previous model, additional road network information was collected and integrated, including the number of lanes and their directionality, speed limits, and other relevant network attributes.
- Public transport coding: Detailed coding of public transport routes and stops was performed. Each bus and minibus route was represented as a separate public transport line within the model.
- Model update, calibration, and validation: The transport demand model was updated using the 2024 HHS data and other datasets, recalibrated, and validated to ensure its accuracy and consistency with observed travel behaviour and network performance.

As a key deliverable of this task, a fully updated, calibrated, and validated transport model in PTV Visum was developed and submitted. This submission is complemented with following technical report, in which the methodology and results of the model calibrations are described.

2. MODEL ZONING SYSTEM

This section describes the development and refinements to the zoning system used in the updated transport model for Tbilisi. In line with the ToR, the zoning system was revised and expanded based on the 2022 base model, the results of the HHS, and other spatial and socio-economic datasets collected during the project.

Where necessary, existing zones were divided in smaller ones or adjusted to better represent areas of high trip generation or attraction, newly developed urban districts, and significant changes in land use or population distribution since the 2016 HHS. Attention was given to neighbourhoods and adjacent municipalities that have undergone notable development or demographic shifts.

As a result, the updated zoning system ensures a more accurate representation of travel demand and improves the reliability of the transport model calibration and forecasting.

2.1. General information about Tbilisi and the modelling area

Tbilisi has historically played a pivotal role as the political, cultural, and economic center of the Caucasus region, strategically positioned at the crossroads of major transport routes connecting Europe and Asia.

The city of Tbilisi is administratively divided into 10 districts (Figure 1):

- Gldani
- Saburtalo
- Nadzaladevi
- Didube
- Vake
- Mtatsminda
- Chungureti
- Isani
- Krtsanisi
- Samgori

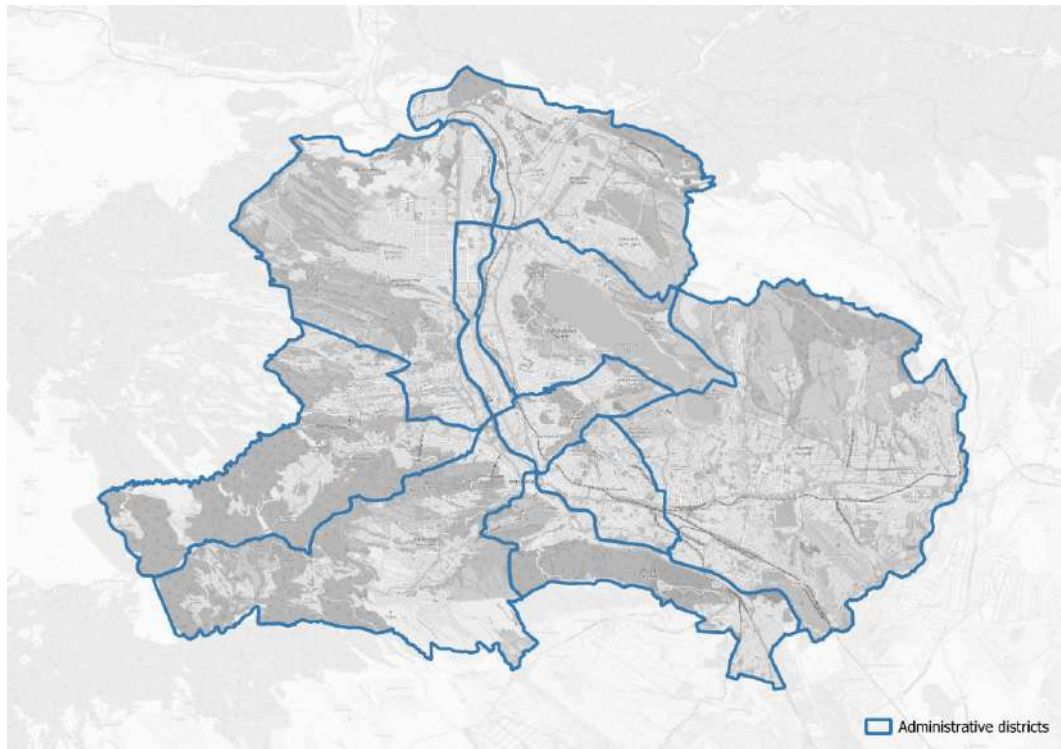


Figure 1. Division of the city into administrative districts

In the 2022 transport model, the cities of Tbilisi, Rustavi, Gardabani, and Mtskheta were divided into 398 traffic analysis zones (TAZs) to support the development of the model (Figure 2).

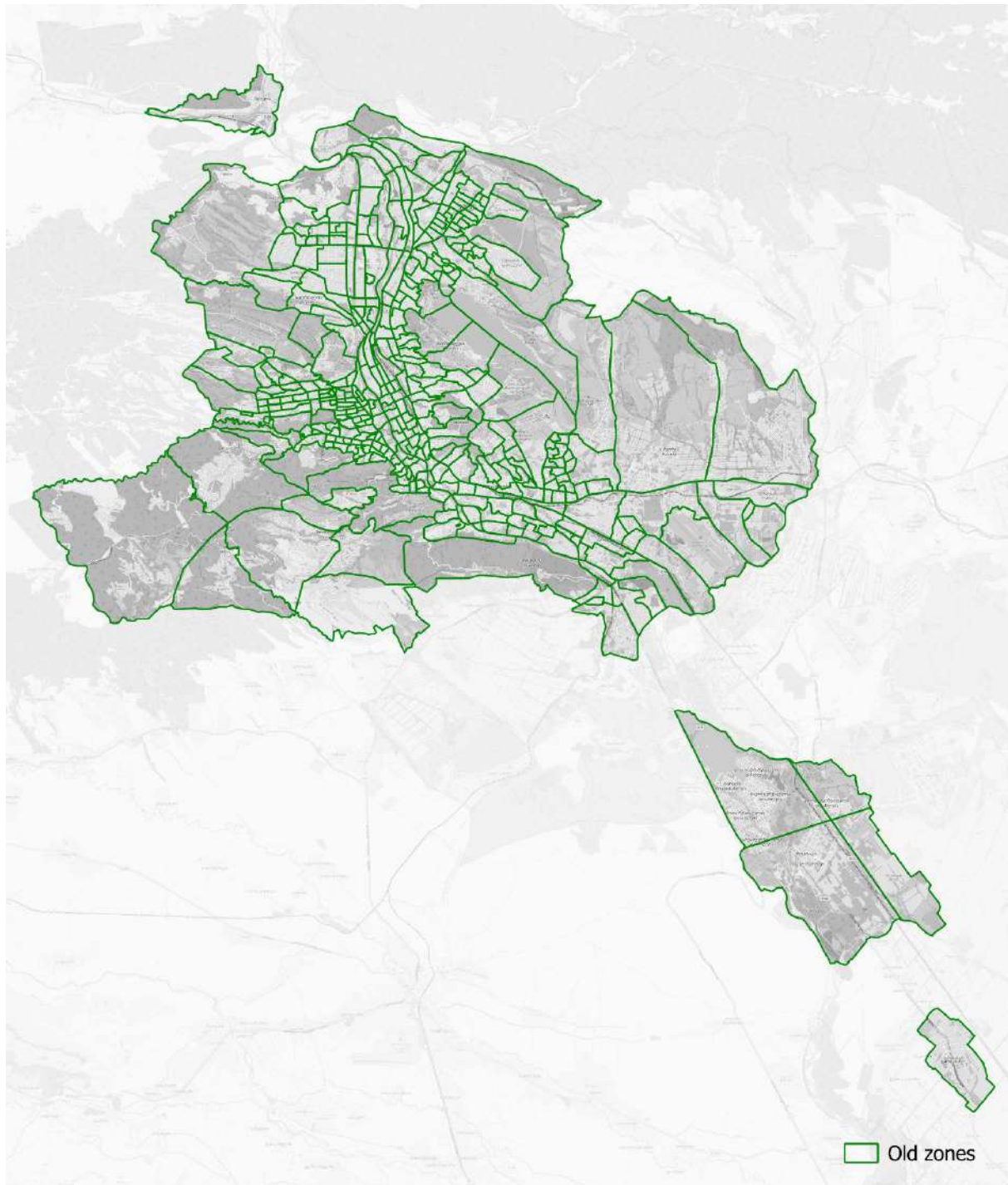


Figure 2. Division of the city into transport analysis zones in 2022

2.2. Expansion of the modelling area

The ToR for updating the transport model included the expansion of the modelling area. The following settlements were incorporated into the extended zone:

- West: Mukhatstkaro, Napetvrebi, Mskhaldidi, Bevreti, Nakhshirgora, Tskluleti;
- Northwest: Mukhatgverdi, Saguramo, Natakhtari, Tserovani IDP;
- Northeast/East: Norio, Martkopi, Vaziani;
- South: Kumisi, Karajalari.

Following the expansion, the modelling area adopted the configuration shown in Figure 3.

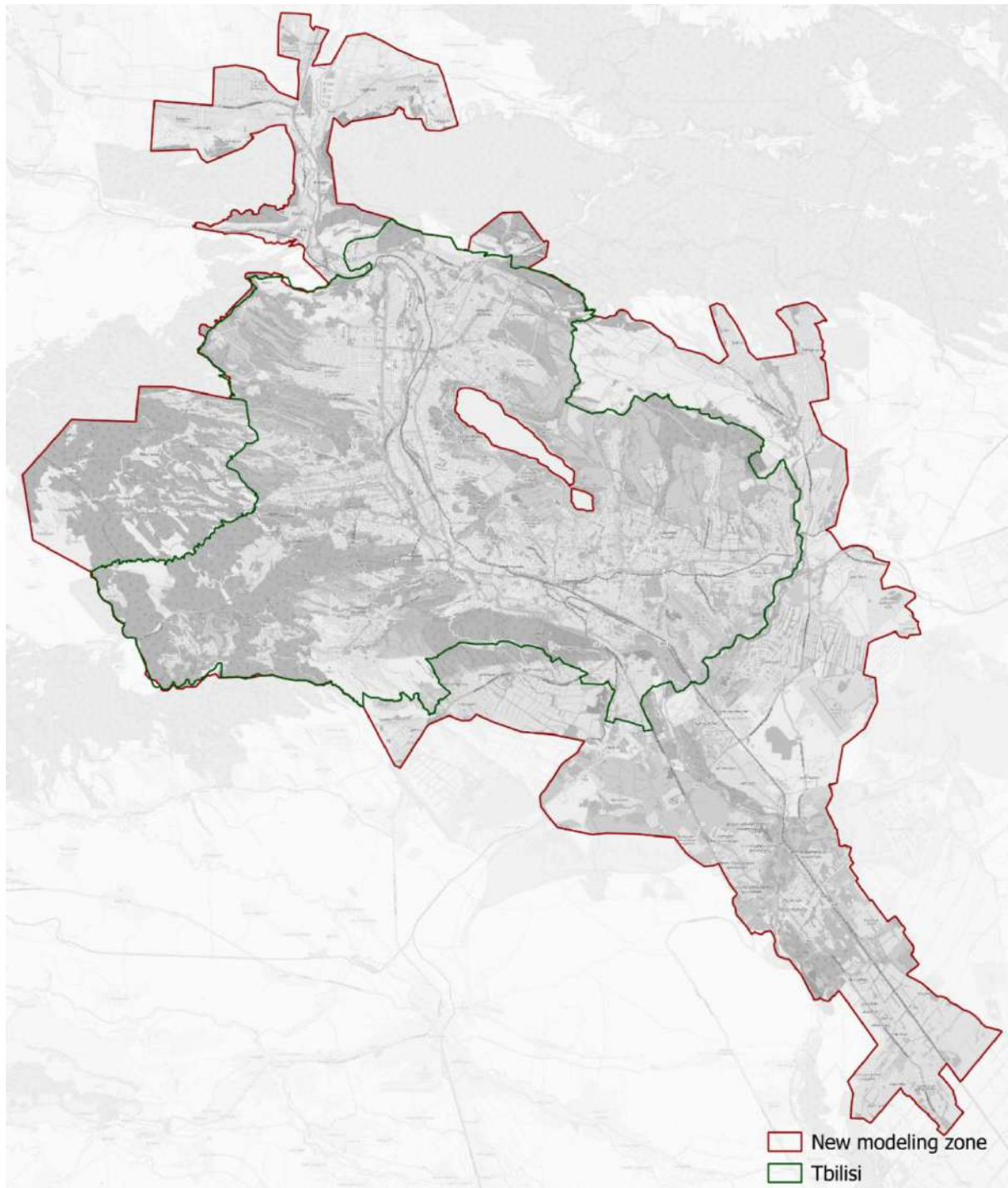


Figure 3. New modelling area

The transport analysis zones (TAZs) of Tbilisi also required a revision and specific refinements. The ToR specified the reassessment of the following zones due to changes in development patterns and potential shifts in land use:

- Vake (micro-zones: 5801, 5605, 5604, 5603, 5602, 5601, 5807, 0101, 0102, 0103, 0104, 0105, 0201, 0202, 0205, 0504);
- Saburtalo (micro-zones: 4705, 4704, 4703, 4701, 5401, 5407, 5406, 5405, 5404, 5403, 5402, 5203, 5201, 5204, 5205, 5102, 5104, 5101, 5106, 5301, 5302, 5304, 5305, 5306, 5501, 5502, 5503, 5504, 5702, 5701, 5703, 4903, 4904, 5001, 5002, 5003, 5004, 5005, 5006, 5007);
- Nutsubidze Plateau (micro-zones: 4901, 4803, 4802, 4801, 4805, 4804);

- Didi Dighomi (macro-zones: 4407, 4406, 4405, 4404, 4403, 4402, 4401);
- Zhvania Street – Shatberashvili Street (micro-zones: 0203, 0204, 0301);
- Village Dighomi (micro-zones: 4607, 4606, 4409);
- Jikia Street (micro-zones: 4902, 4905);
- Bagebi (micro-zones: 5802, 5803);
- Hippodrome (micro-zones: 5103, 5105, 5106, 5303, 5505);
- Hualing (micro-zone: 1701).

The boundaries of TAZs are defined by streets and natural landmarks such as rivers, lakes, parks, and forested areas. Each zone encompasses territories with generally homogeneous development. The boundaries of the TAZs also consider the administrative division of the modelling area. Under no circumstances the boundaries intersect buildings, as this could lead to inaccuracies in socio-economic statistics.

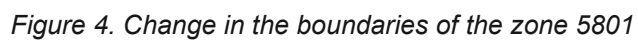
2.3. Changes to TAZ boundaries

Below several key aspects of the transformation of these TAZ have been examined in detail.

- TAZ 5801

Under the previous version of the model, within this zone, TAZ 5820 included the university, while its boundary with TAZ 5821 ran along existing buildings and a soccer field. Isolating educational or medical institutions into separate enclaves complicates access between zones during traffic assignment in the modelling process - particularly if the zone lacks a defined network graph. Additionally, splitting buildings or high-attraction facilities across multiple zones complicates the collection of socio-economic data, that could potentially affect the model's accuracy (Figure 4).

The zoning adjustment included removing the enclave and incorporating the university into the surrounding TAZ. The boundary with TAZ 5821 was shifted to align with the nearest driveway.



- TAZ 5102

This zone featured a bottleneck on its eastern side, where a hospital was separated from the main body of the zone and placed within a distinct TAZ (Figure 5). In this case, the zoning revision involved eliminating the bottleneck by integrating the narrow corridor and the southern portion of TAZ 5102 into the adjacent zone where the hospital is located.

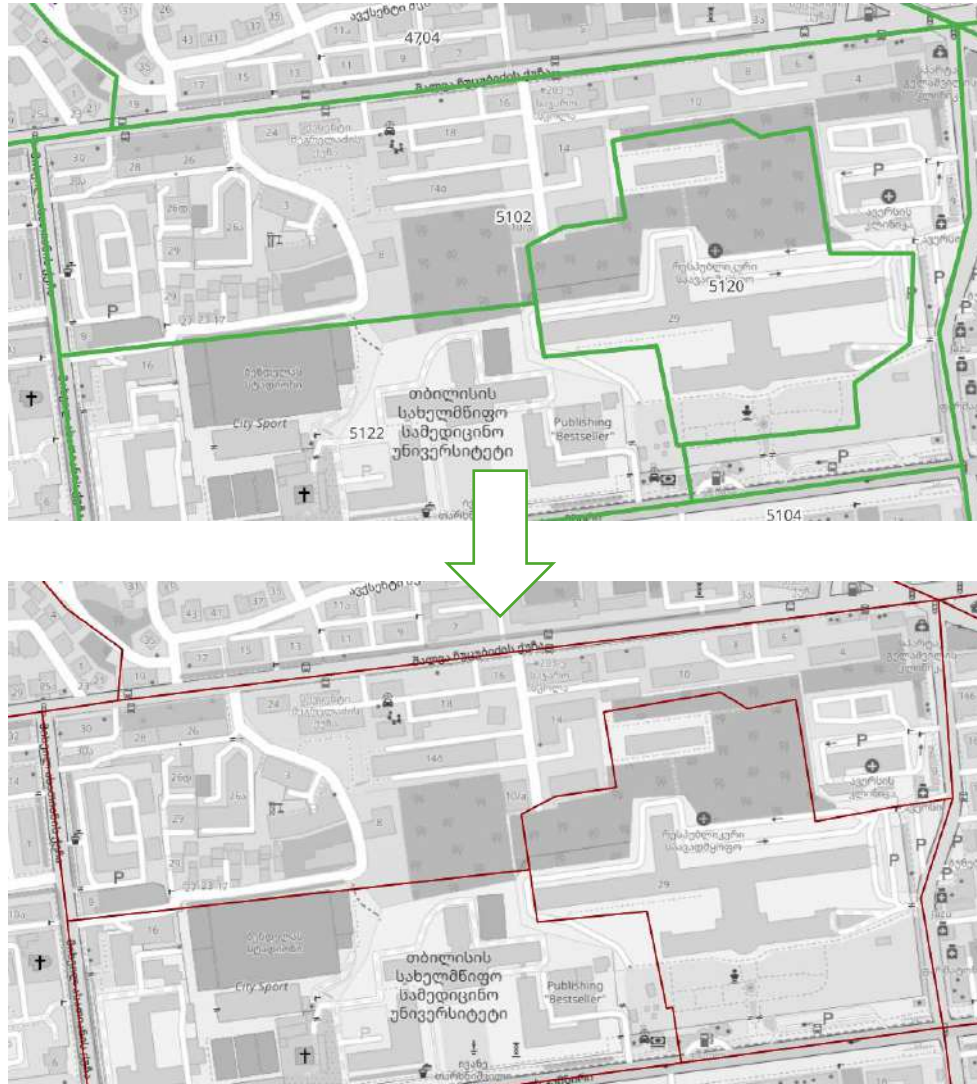


Figure 5. Change in the boundaries of the zone 5102

- TAZ 4803

The eastern boundary of this zone was designed through a built-up area, which could negatively impact the accuracy of socio-economic data collection and, consequently, the reliability of transport model calculations (Figure 6). The zoning adjustment in this case involved reducing the size of TAZ 4803, realigning its boundaries along the streets and natural features, and designating the eastern built-up portion as a separate transport analysis zone.

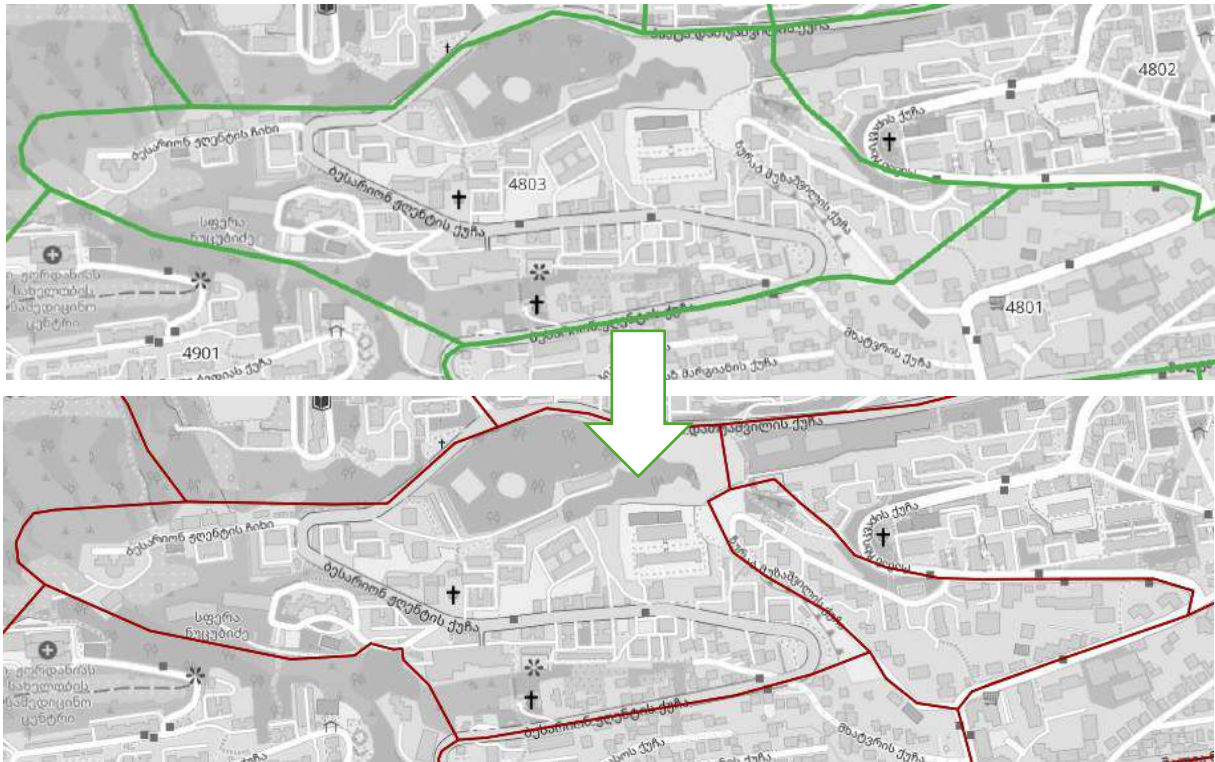


Figure 6. Change in the boundaries of the zone 4803

- TAZ 4406

This zone had an elongated shape, encompassing a mix of building types, and its boundaries were intersecting some existing buildings (Figure 7). The zoning revision in this case required a complete redesign of the TAZ, based on the classification of building types and in full compliance with the established rules for delineating TAZ boundaries.

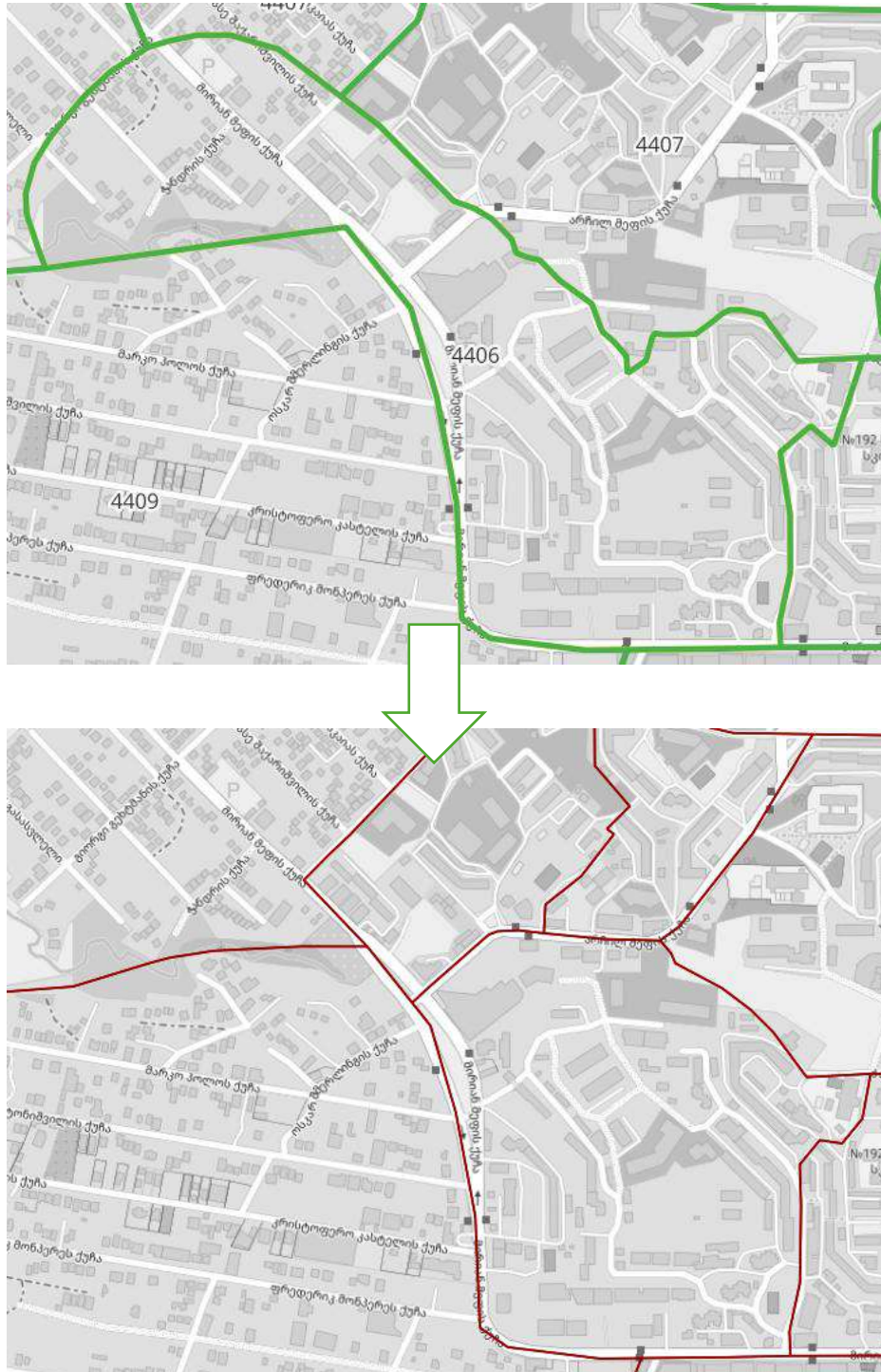


Figure 7. Change in the boundaries of the zone 4406

- TAZ 1701

This zone was quite large and included diverse types of urban development. To enhance the quality of socio-economic data collection and improve the accuracy of transport model calculations, the zone was divided into several smaller transport analysis zones, in accordance with the established zoning guidelines for transport planning (Figure 9).



Figure 9. Change in the boundaries of the zone 1701

All the above TAZ were reviewed following the same principles. In addition, the remaining zones were systematically checked to ensure that no transport area boundaries were intersecting any building.

As a result, in accordance with the ToR requirements, the transport zoning was revised within Vake, Saburtalo, Nutsubidze Plateau, Didi Dighomi, Zhvania Street – Shatberashvili Street, Village Dighomi, Jikia Street, Bagebi, Hippodrome, and Hualing (Figure 10 – Figure 19).

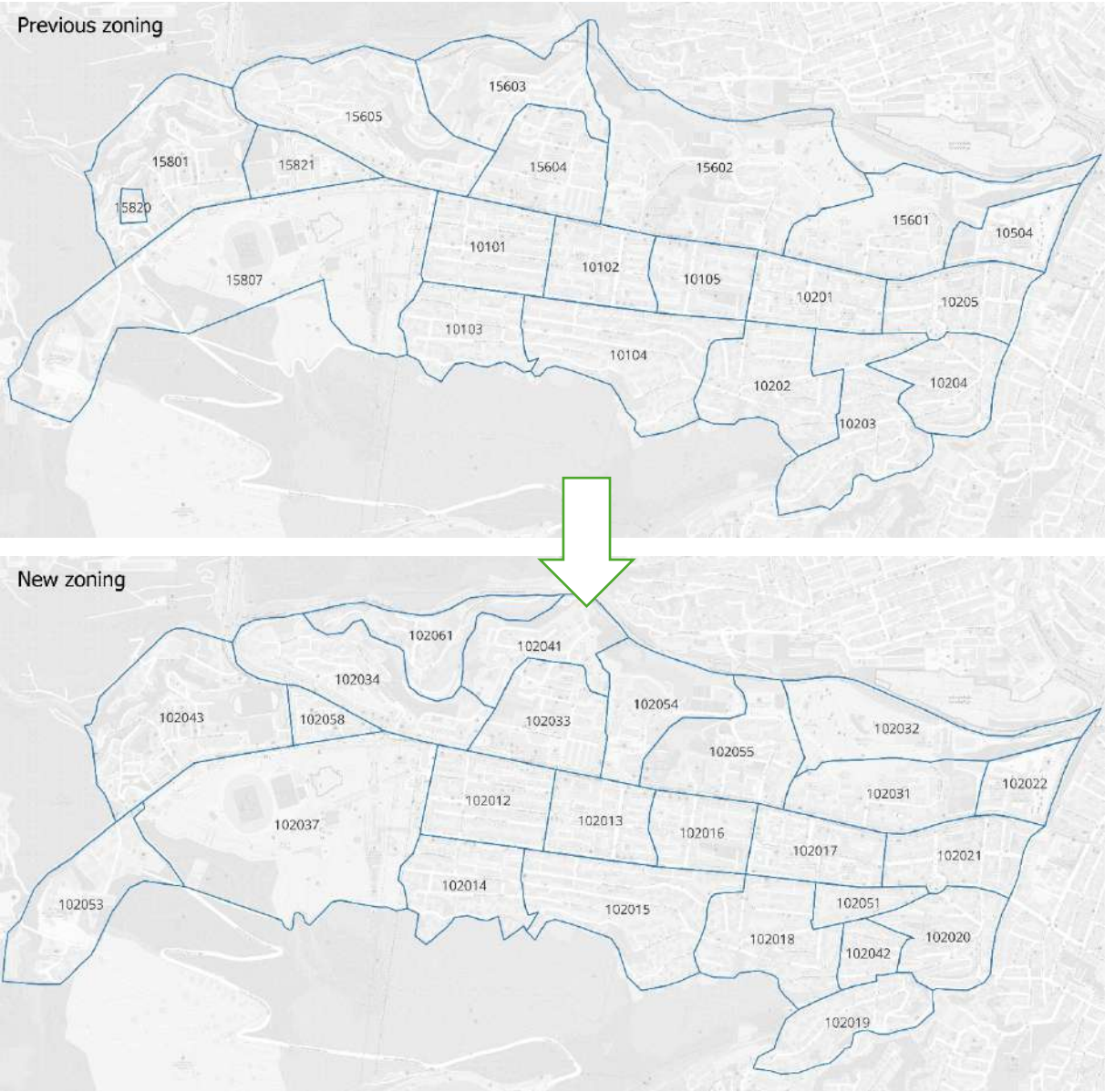


Figure 10. TAZ changes within Vake

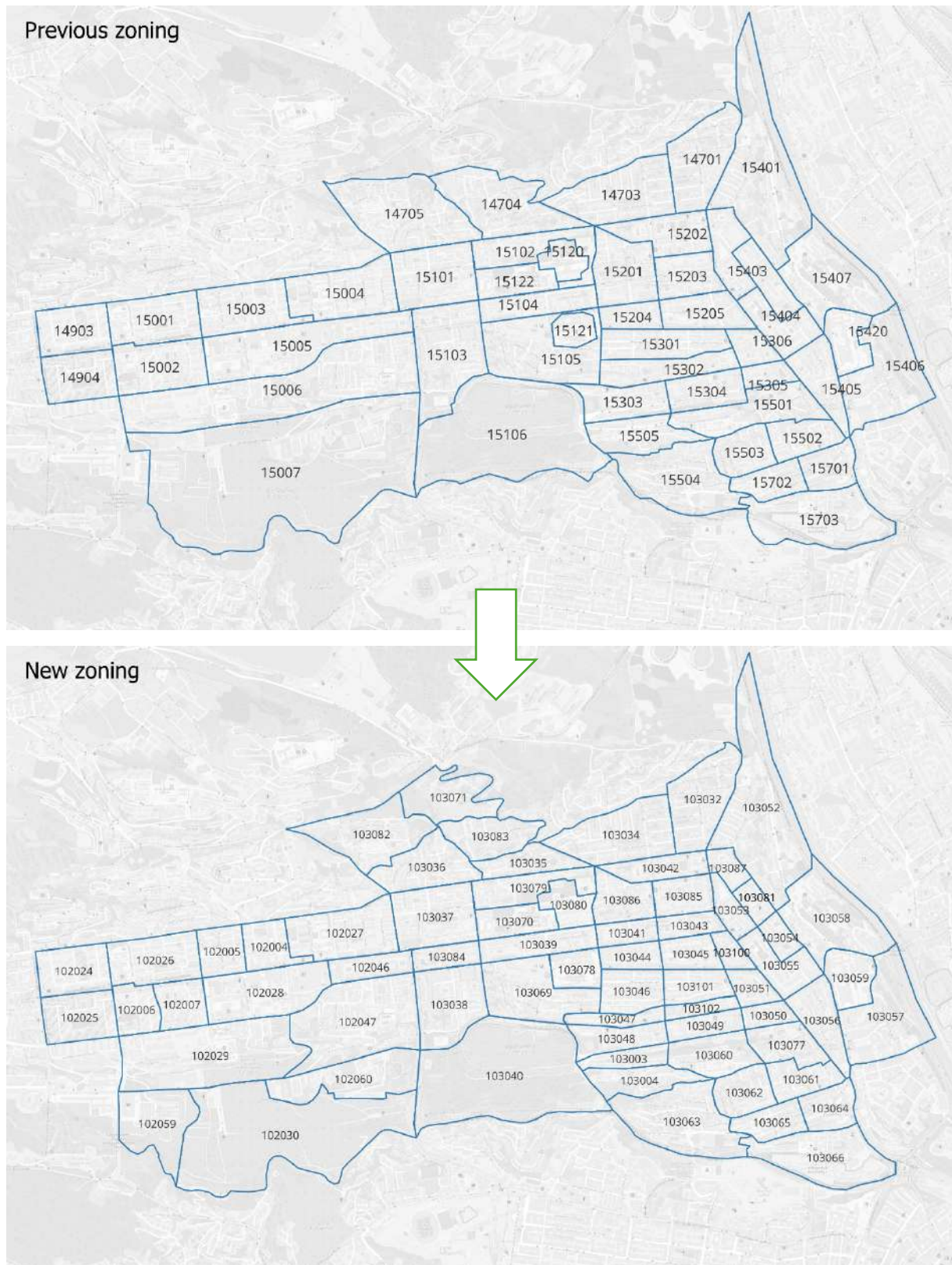


Figure 11. TAZ changes within Saburtalo

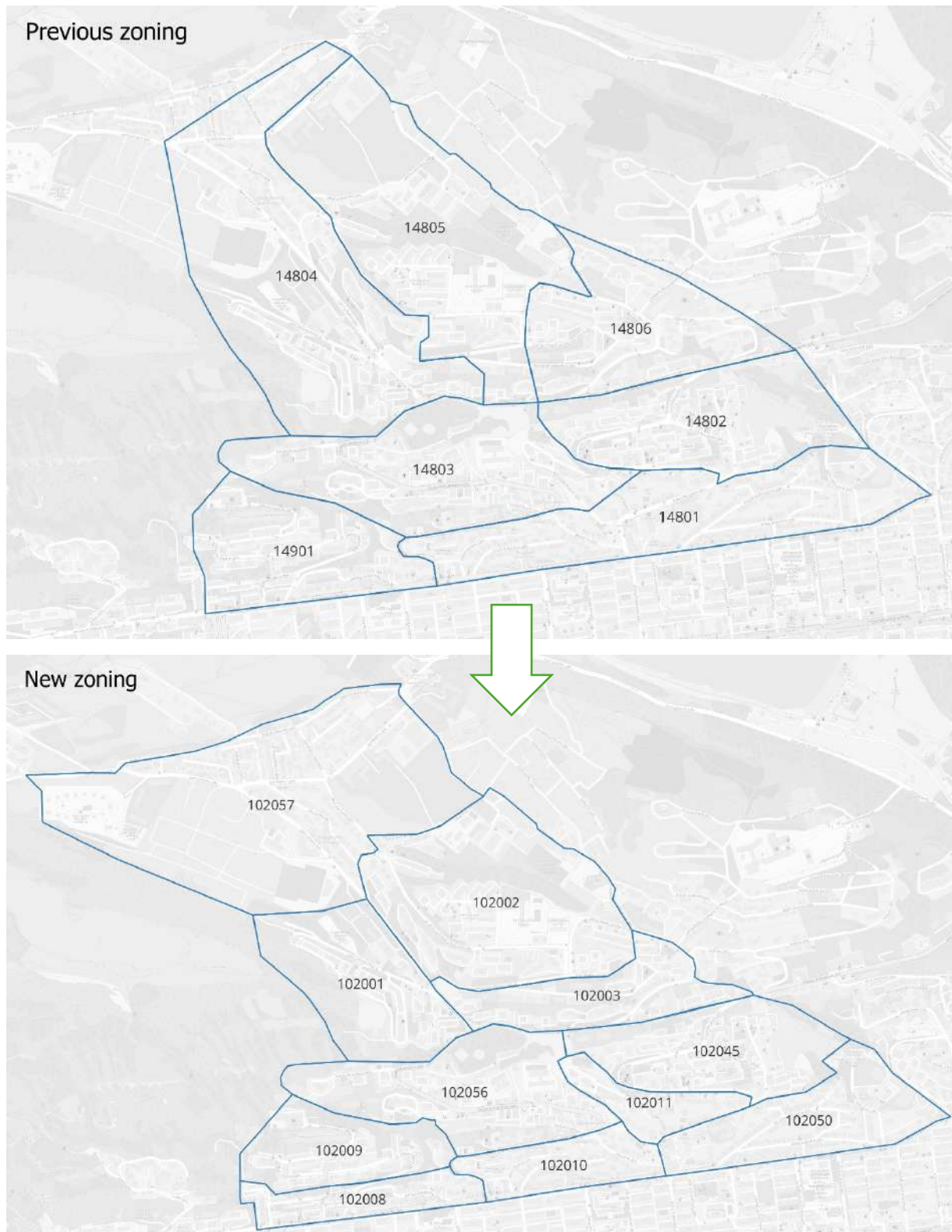


Figure 12. TAZ changes within Nutsubidze plateau

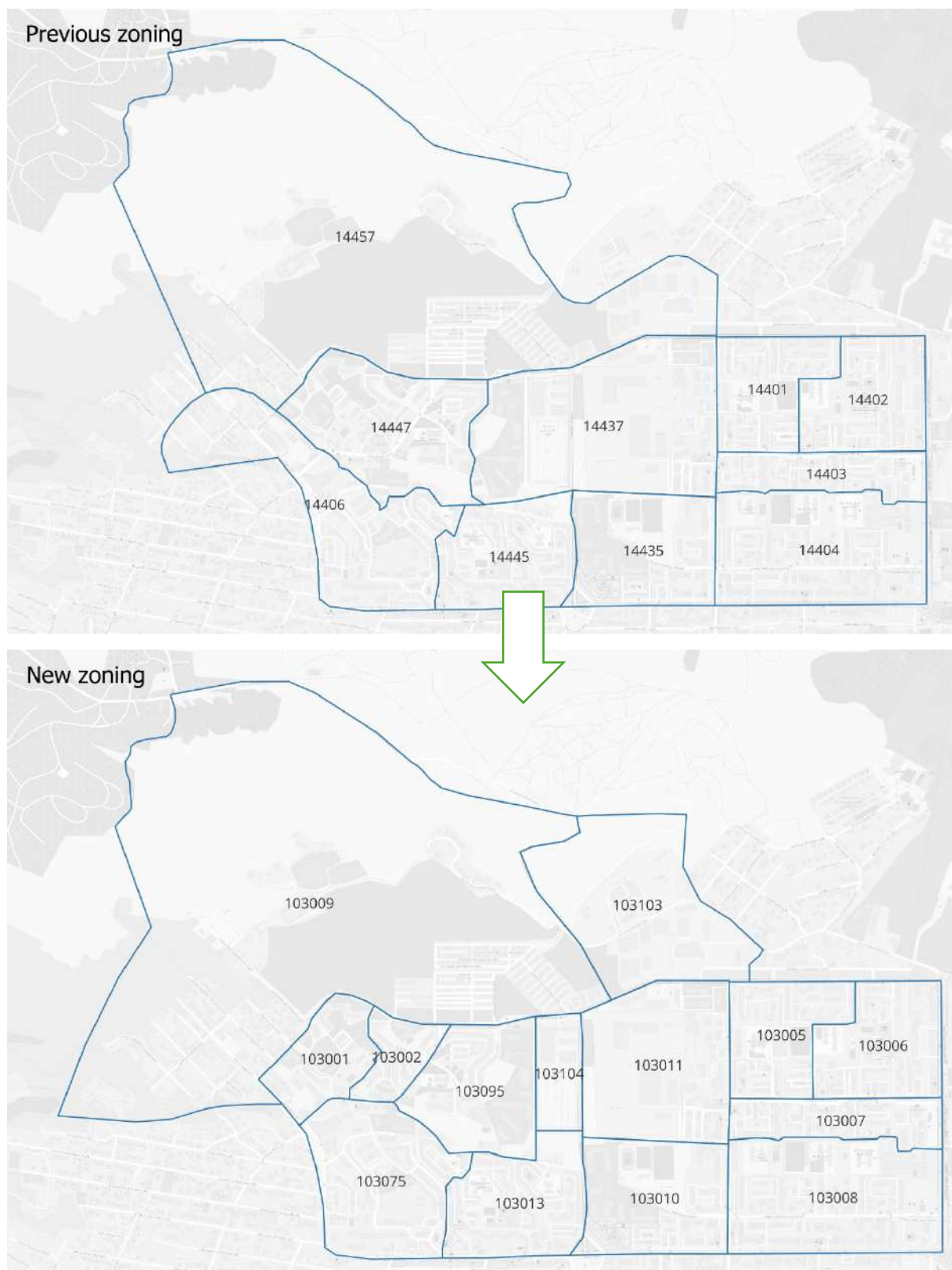




Figure 14. TAZ changes within Zhvania street – Shatberashvili street

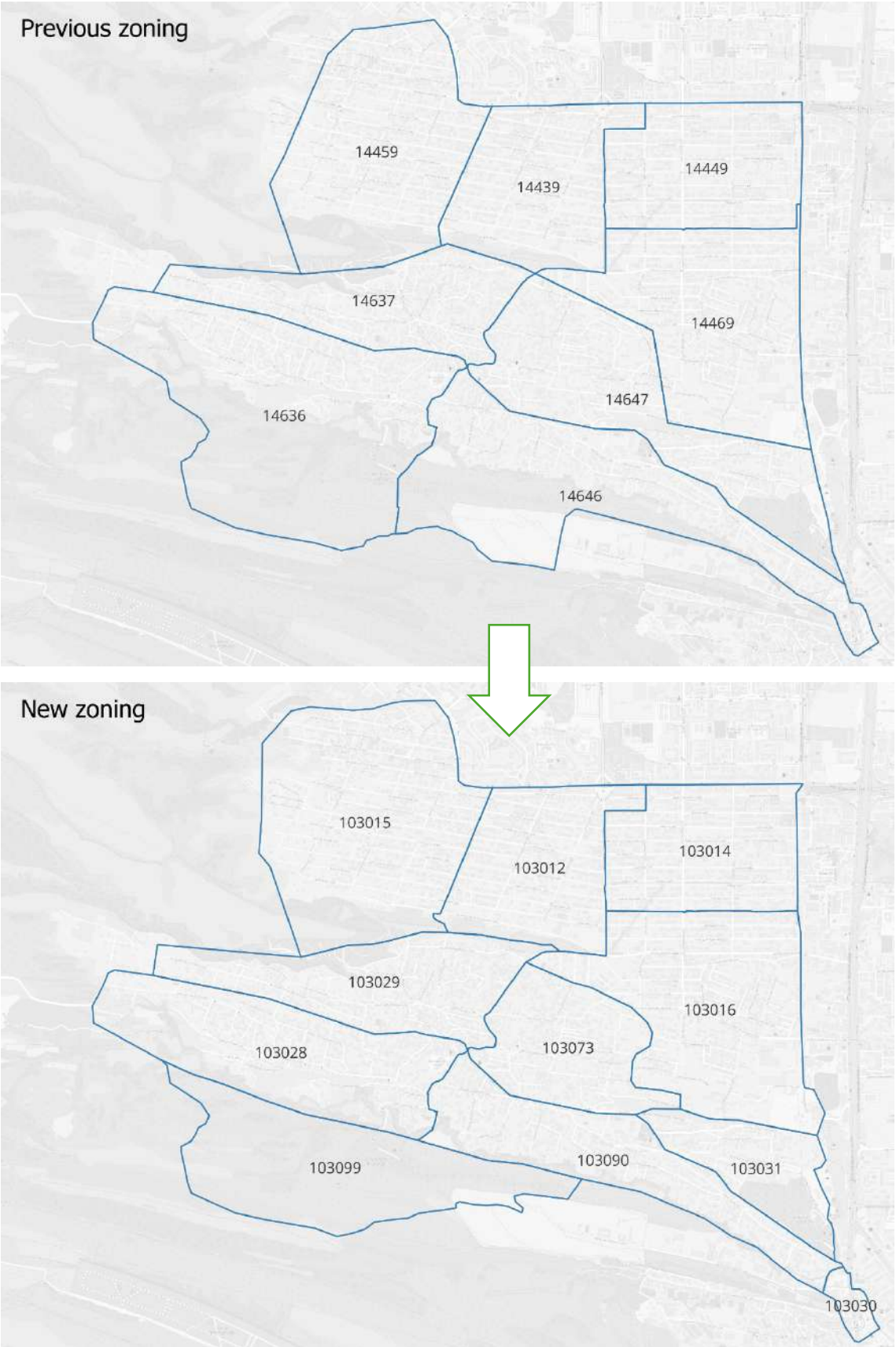


Figure 15. TAZ changes within Village Dighomi

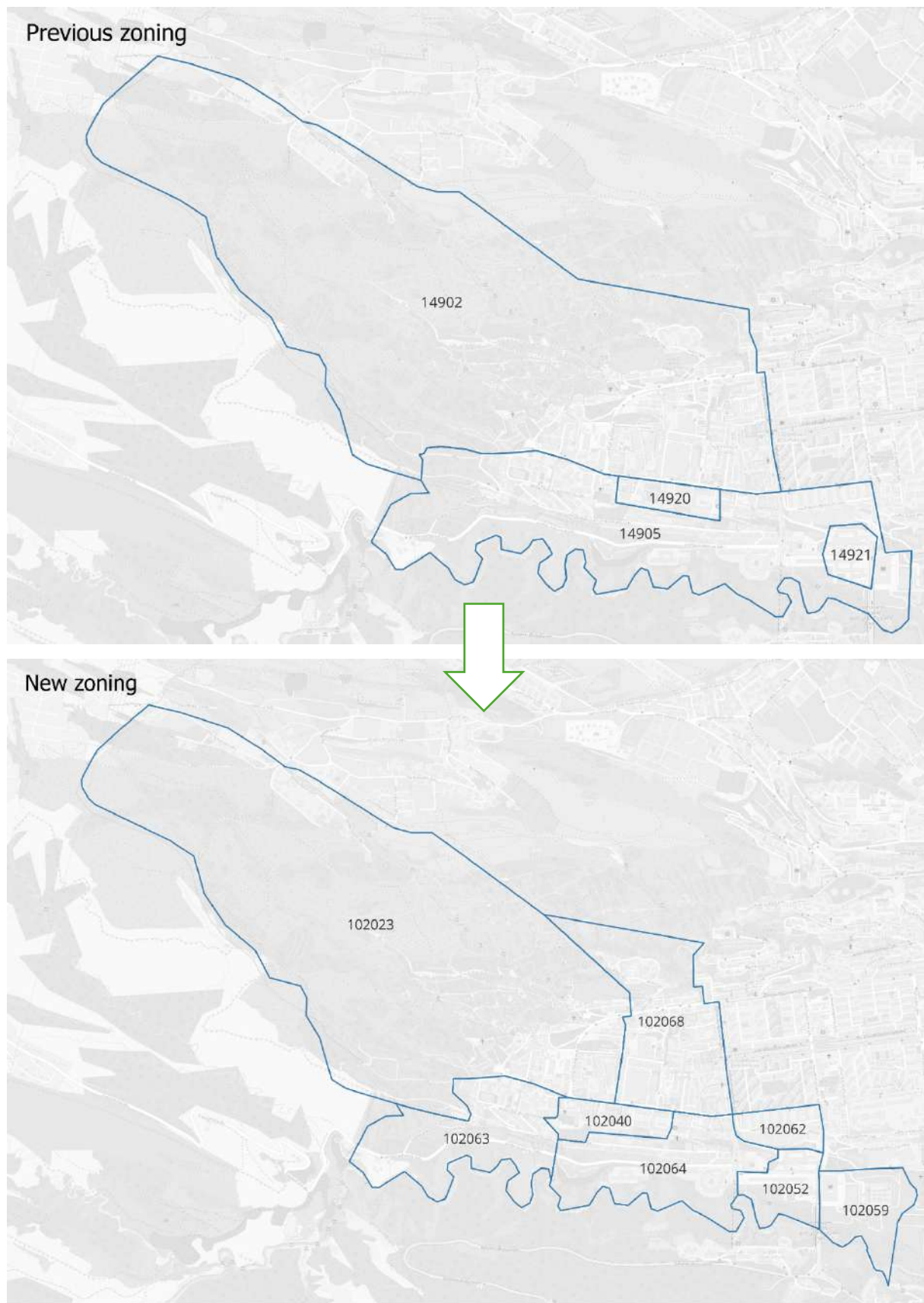


Figure 16. TAZ changes within Jikia street

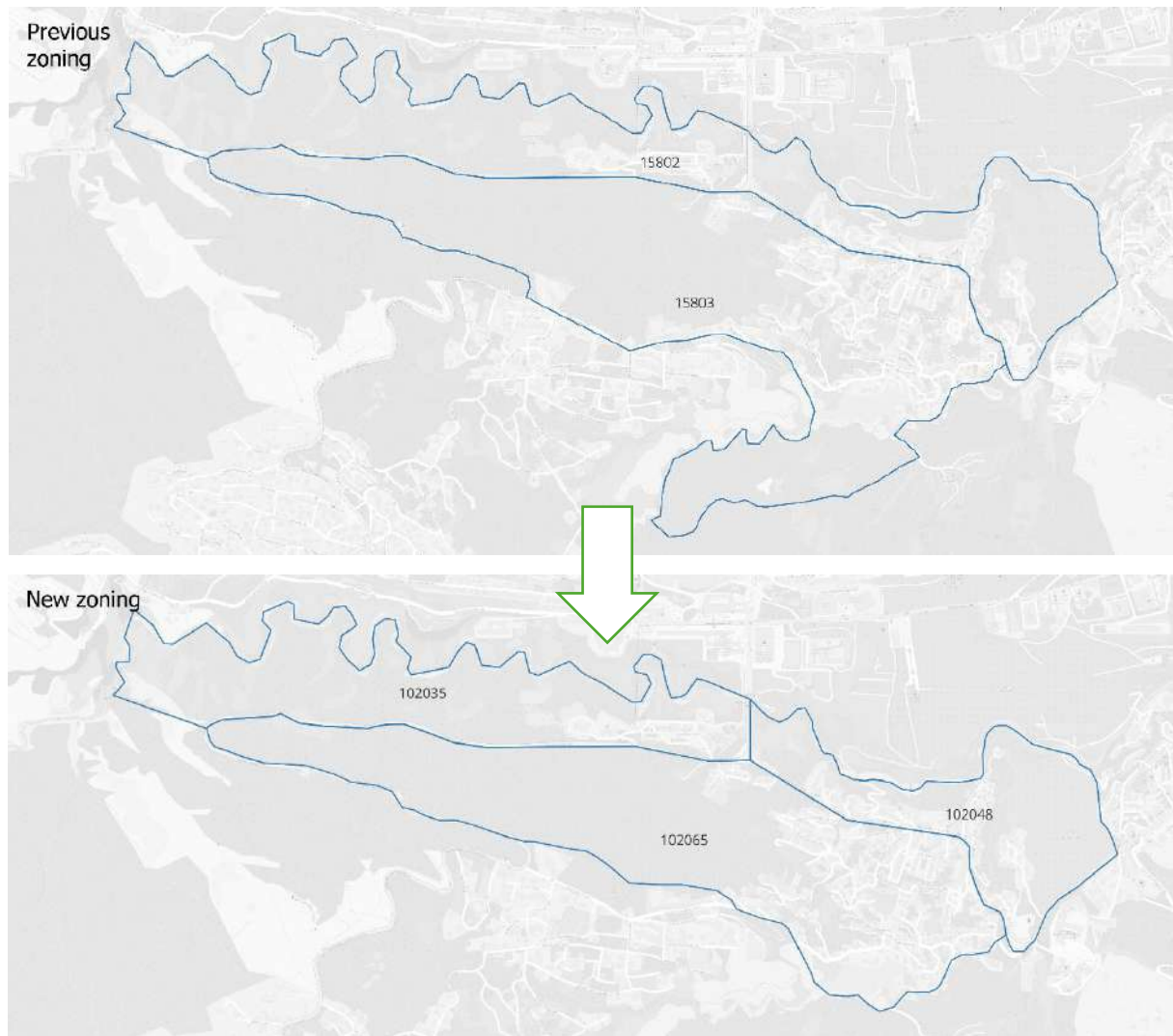


Figure 17. TAZ changes within Bagebi

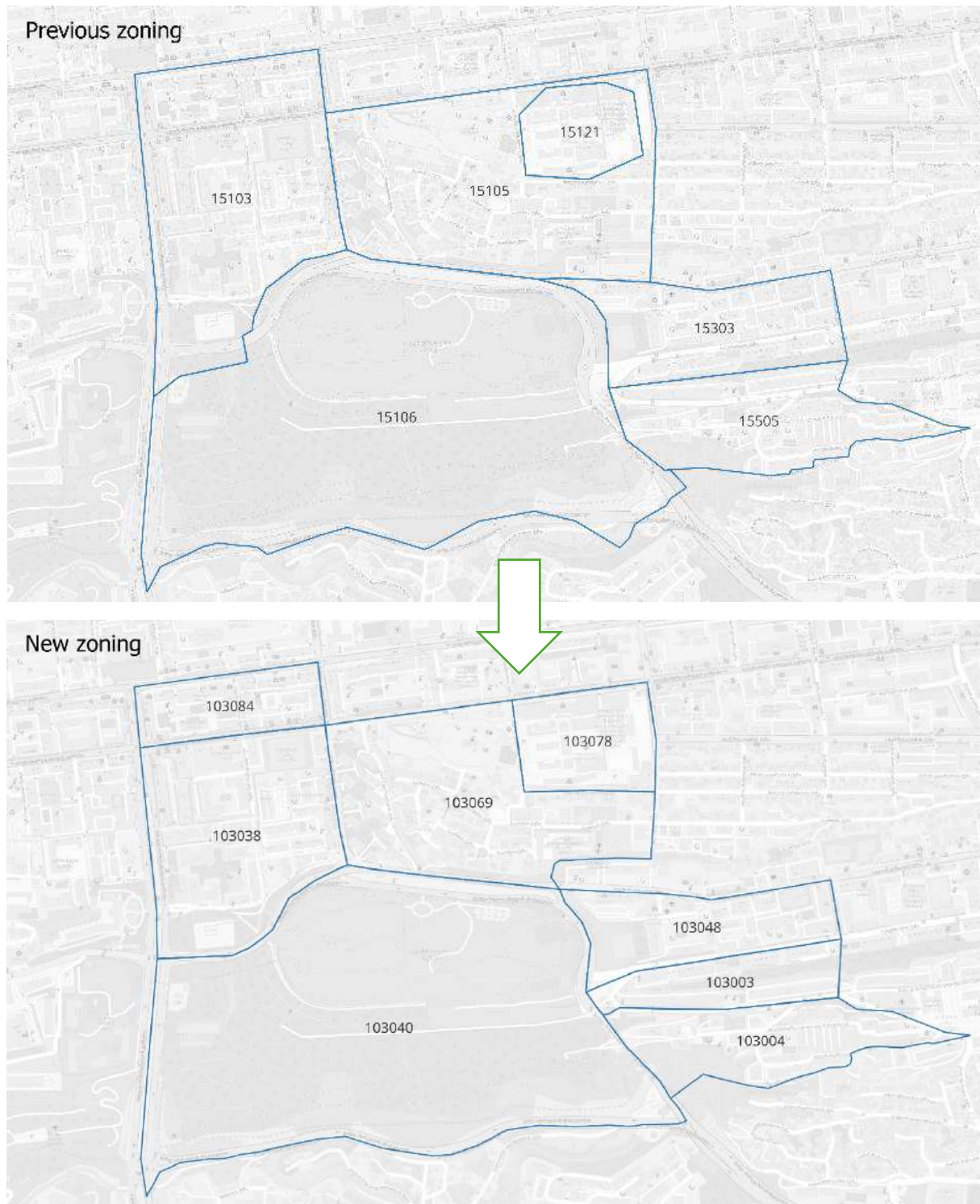


Figure 18. TAZ changes within Hippodrome

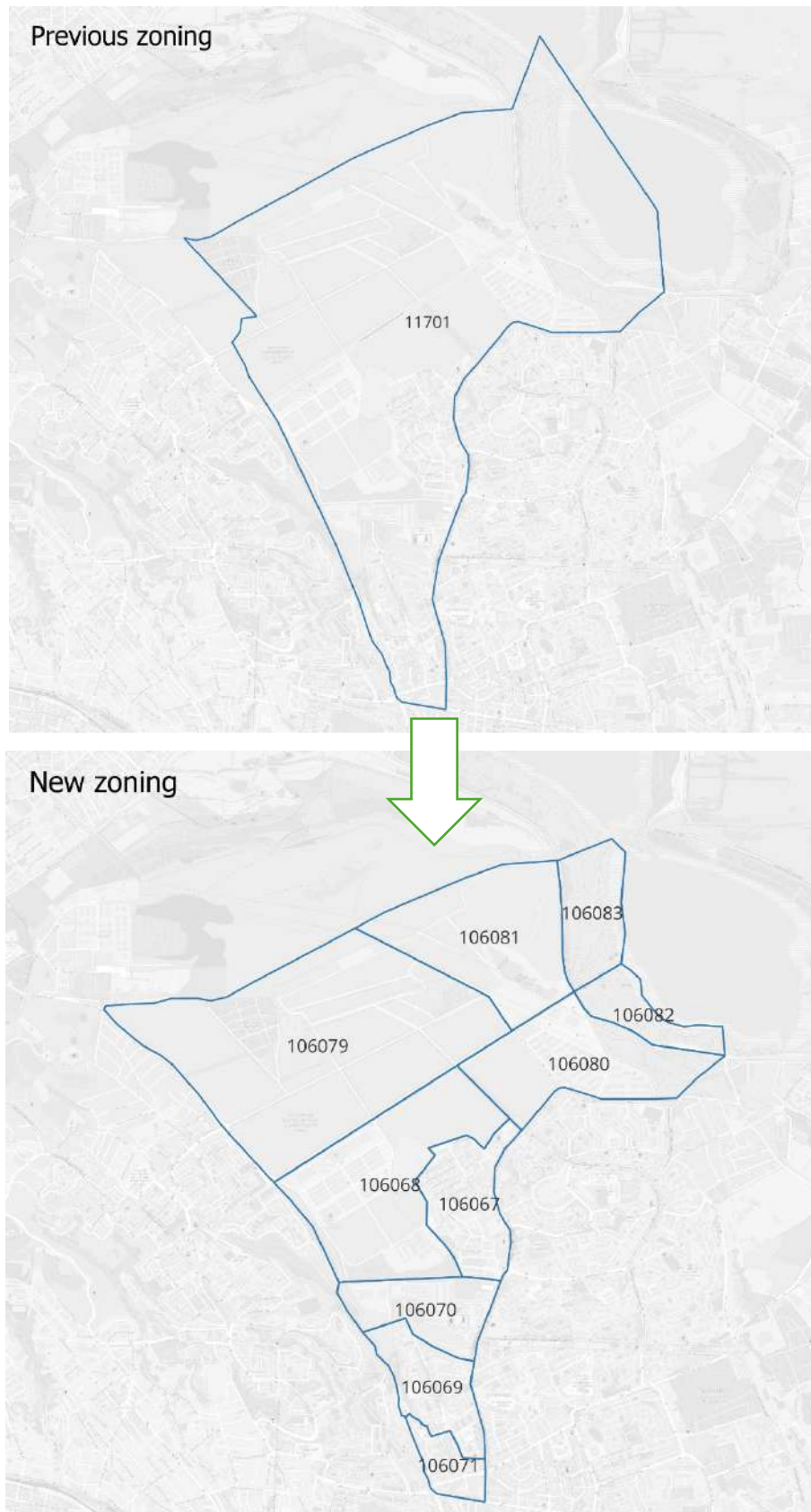


Figure 19. TAZ changes within Hualing

As a result of this comprehensive review and adjustment process, the updated transport model now consists of **666** TAZ (Figure 20).

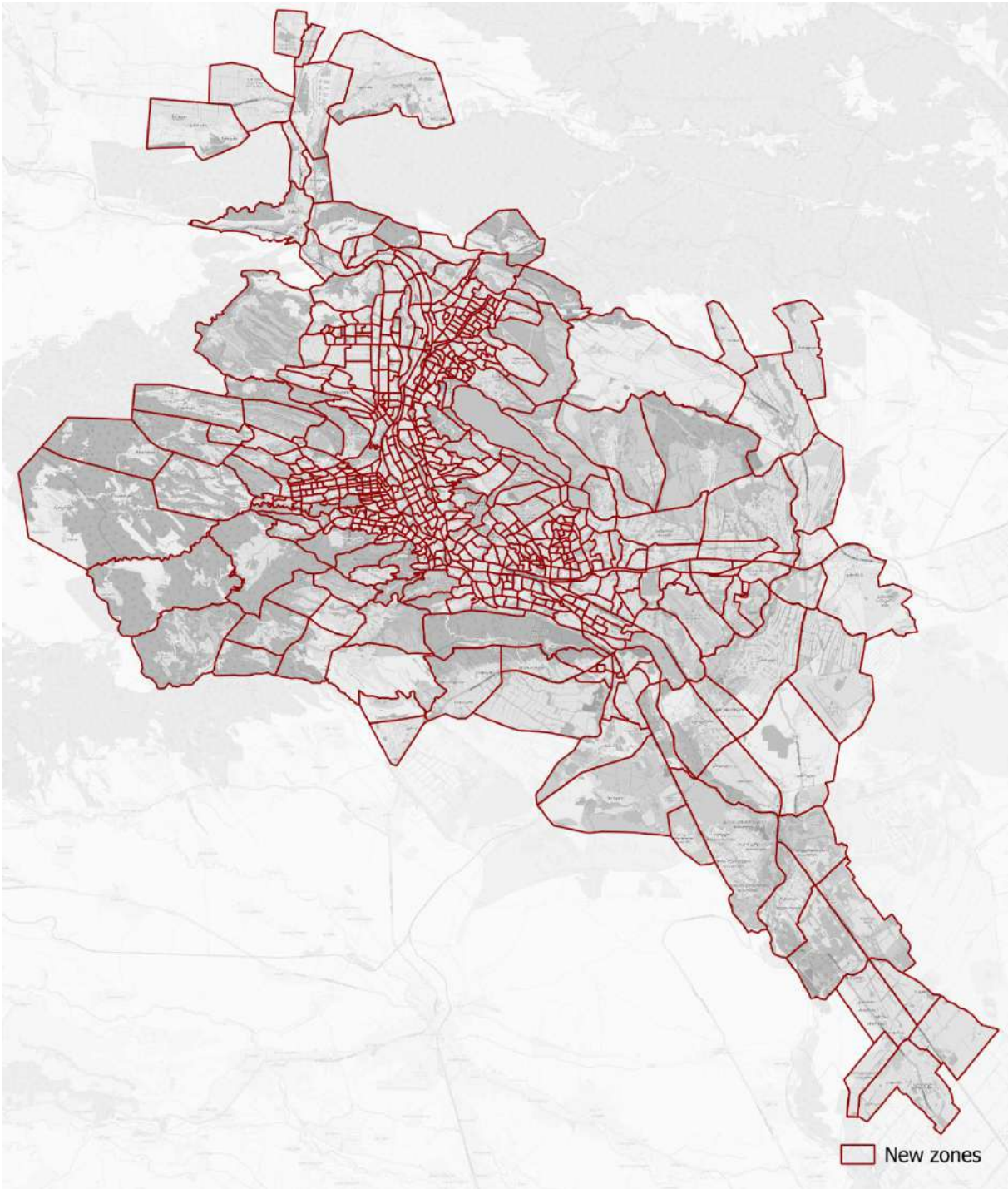


Figure 20. Updated TAZ

In addition, the updated model includes 17 external TAZs including 12 car zones, 3 bus stations, 1 railway station, and 1 airport. These are zones located at the periphery of the model area and serve as entry and exit points for transport flows to and from the model. In the model, they are represented as centroids instead of the usual polygons. They function as a gateway between the study area and the broader transport system beyond its boundaries. In this case, external TAZs are not limited to the geographic periphery – they also include bus terminals, the airport, and railway stations, as these locations likewise serve as gateways for transport and passenger flows. The map of external TAZs is presented in *Figure 21. External TAZs*. As a result, the total number of TAZs in the model is **683**.

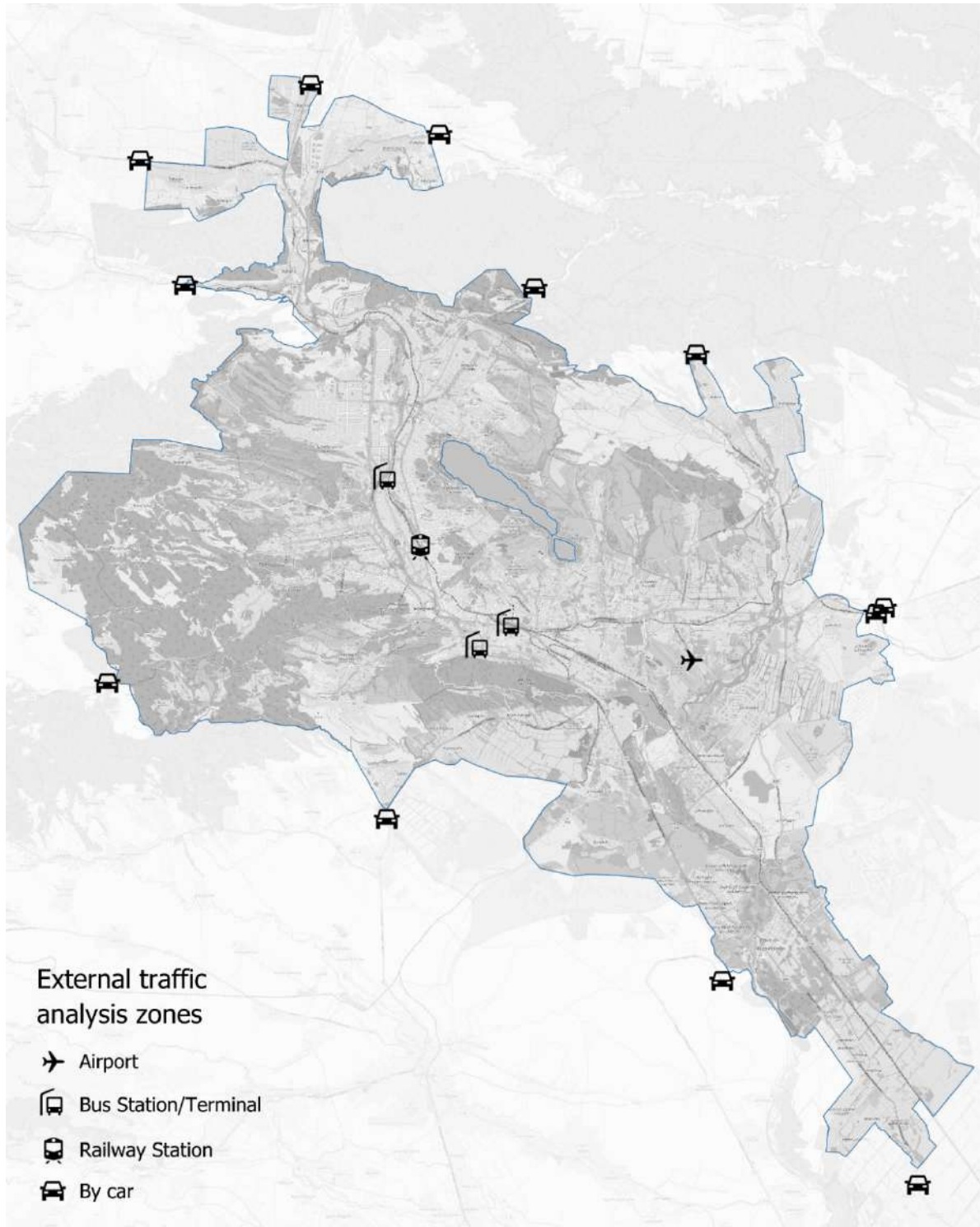


Figure 21. External TAZs

3. COLLECTION OF SOCIO-ECONOMIC STATISTICS

The next step in the development of the transport model involved collecting the relevant socio-economic data. The following indicators were required for the model:

- Total population
- Population by age group (0–5, 6–18, 19–24, 18–64, 65 and older)
- Number of workplaces
- Number of workplaces in the service sector
- Places in kindergartens
- Places in schools
- Places in higher education institutions (universities and colleges)

3.1. Population Analysis

Georgia has not conducted a national population census for an extended period, and data from the 2025 census are still being processed. As a result, it was not possible to access up-to-date population data at the address level. Consequently, the assumptions described below were developed.

As for the update of the model, it is required to have the relevant number of residents for each TAZ, to achieve this goal, data from the 2022 transport model was used as the baseline. Based on the total population in that model, the share of population allocated to each TAZ was calculated as a percentage of the overall population. Subsequently, the official total population figure for 2025 was obtained from the Georgian statistics portal¹, and this updated total was redistributed across the TAZs according to the previously derived proportional shares. That is how the estimated population for each of the previous TAZs was calculated for the year 2025.

Where the TAZ structure differed from the 2022 model, population redistribution was applied within the affected zones. In such cases, the estimated 2025 population, calculated using the 2022 TAZ structure as a baseline, was allocated to the newly defined zones based on observed residential development patterns.

For TAZs whose boundaries remained fully consistent with the 2022 zoning system, the recalculated population was transferred directly without additional internal redistribution. Following the initial population assignment, all TAZs were reviewed individually to verify the plausibility of population levels in relation to observed residential density and building typology. Where necessary, minor adjustments were applied to ensure consistency between assigned population values and the physical characteristics of the built environment.

These population figures then had to be reconciled with the updated zoning scheme:

- for all TAZs with boundaries fully aligned with the old zoning, the recalculated population was directly transferred.
- for the updated or newly delineated zones, different from any TAZ of the previous model, additional expert assessments were required. These evaluations considered building types, number of structures, floor counts, and assessment of the development density to proportionally allocate population figures.

The example of the calculation is provided in the Appendix 10.1.

For suburban areas, population estimates were based on data available from the open sources². However, the reliability of this information was uncertain, as the figures refer to different years, some from as early as 2014, others from 2019.

¹ <https://www.geostat.ge/en/modules/categories/316/population-and-demography>

² For example

https://web.archive.org/web/20190302090626/http://www.geostat.ge/cms/site_images/files/georgian/census/2014/01_mosaxleobis%20ricxovnoba%20administraciul-teritoriuli%20erTeulebis%20da%20sqesis%20mixedviT.xls and the data from 2014 official census <https://www.geostat.ge/index.php/ka>

At the same time, population data for 2014, disaggregated by transport zones, was obtained from the National Statistics Office of Georgia.

According to the ToR, special attention was required for specific areas where changes in the scale or type of the development could have led to the population growth. The TAZs identified for review are listed in Paragraph 2.2 of this report. A more detailed breakdown of population changes in these areas is provided below. These data show the projected population growth calculated in 2025 according to the updated model, compared to population data 2014.

- Vake (Figure 22). The number of population in 2014 was 33,991. The number of population in 2025 is 38,417. The increase amounted to 13.0%.

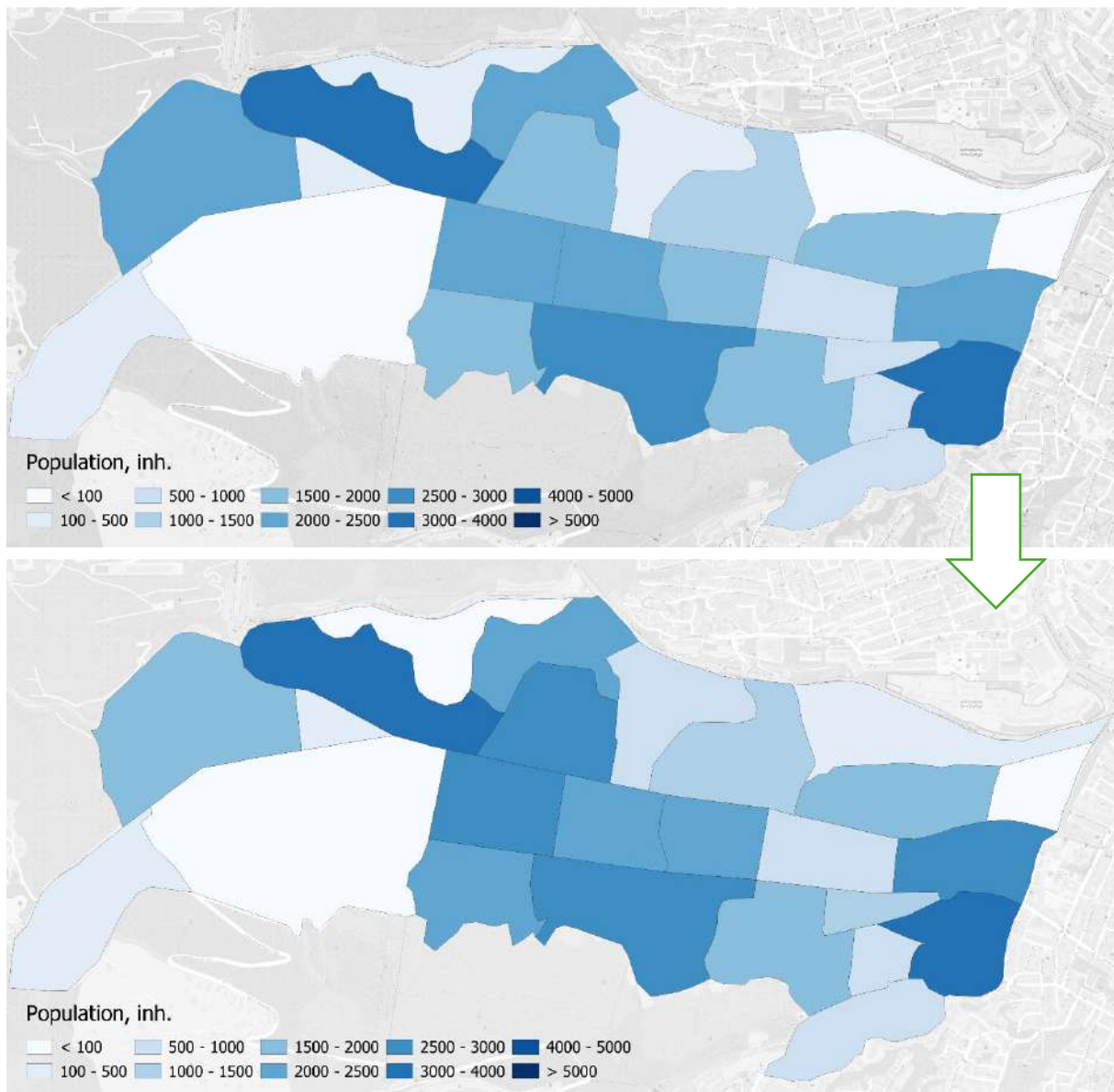


Figure 22. Changes in the population of Vake

- Saburtalo (Figure 23). The population in 2014 was 116,072. The population in 2025 is 134,866. The increase was 16.2%.

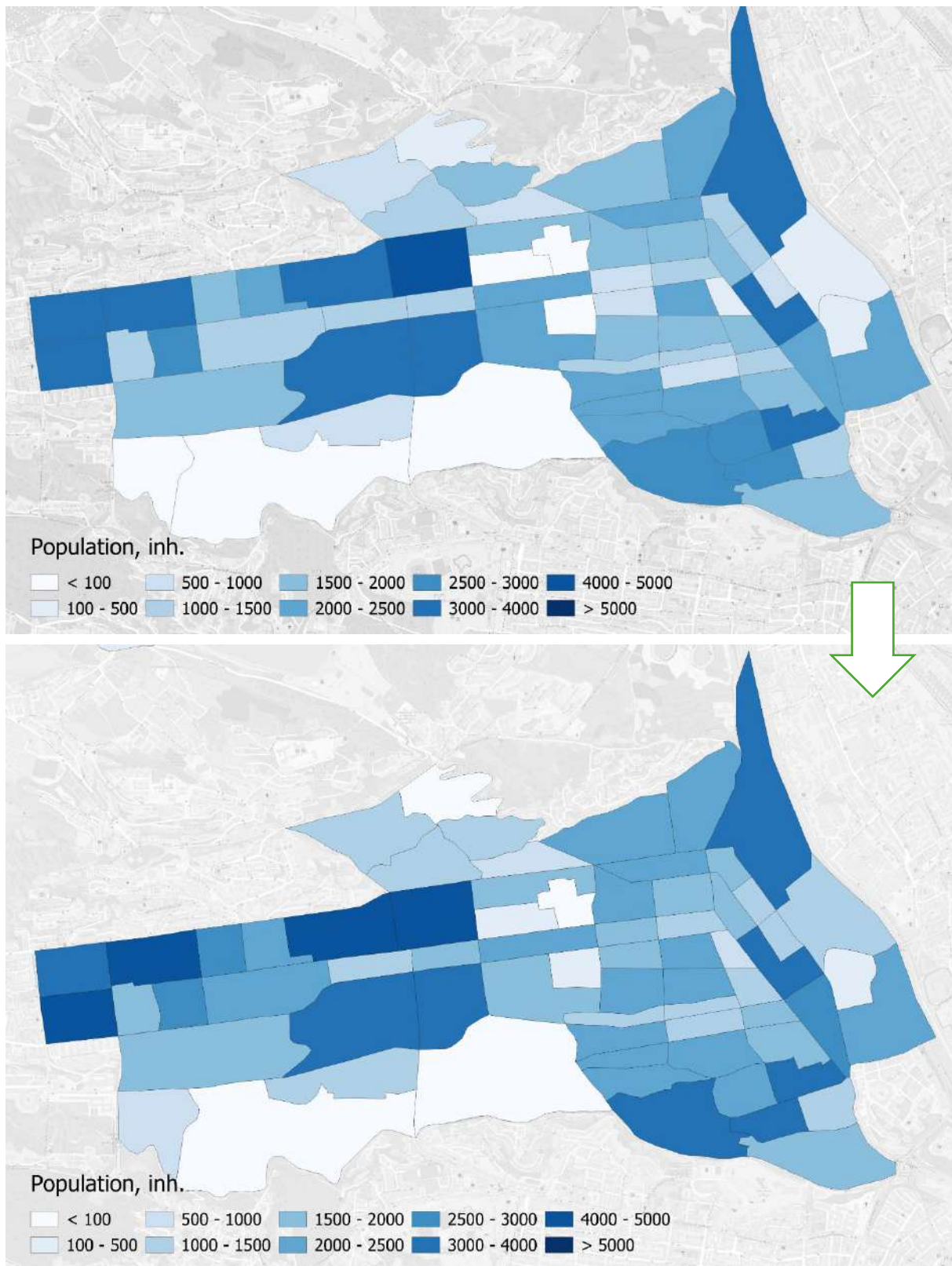


Figure 23. Changes in the population of Saburtalo

- Nutsubidze plateau (Figure 24). The population in 2014 was 27,105. The population in 2025 is 31,045. The increase was 14.5%.

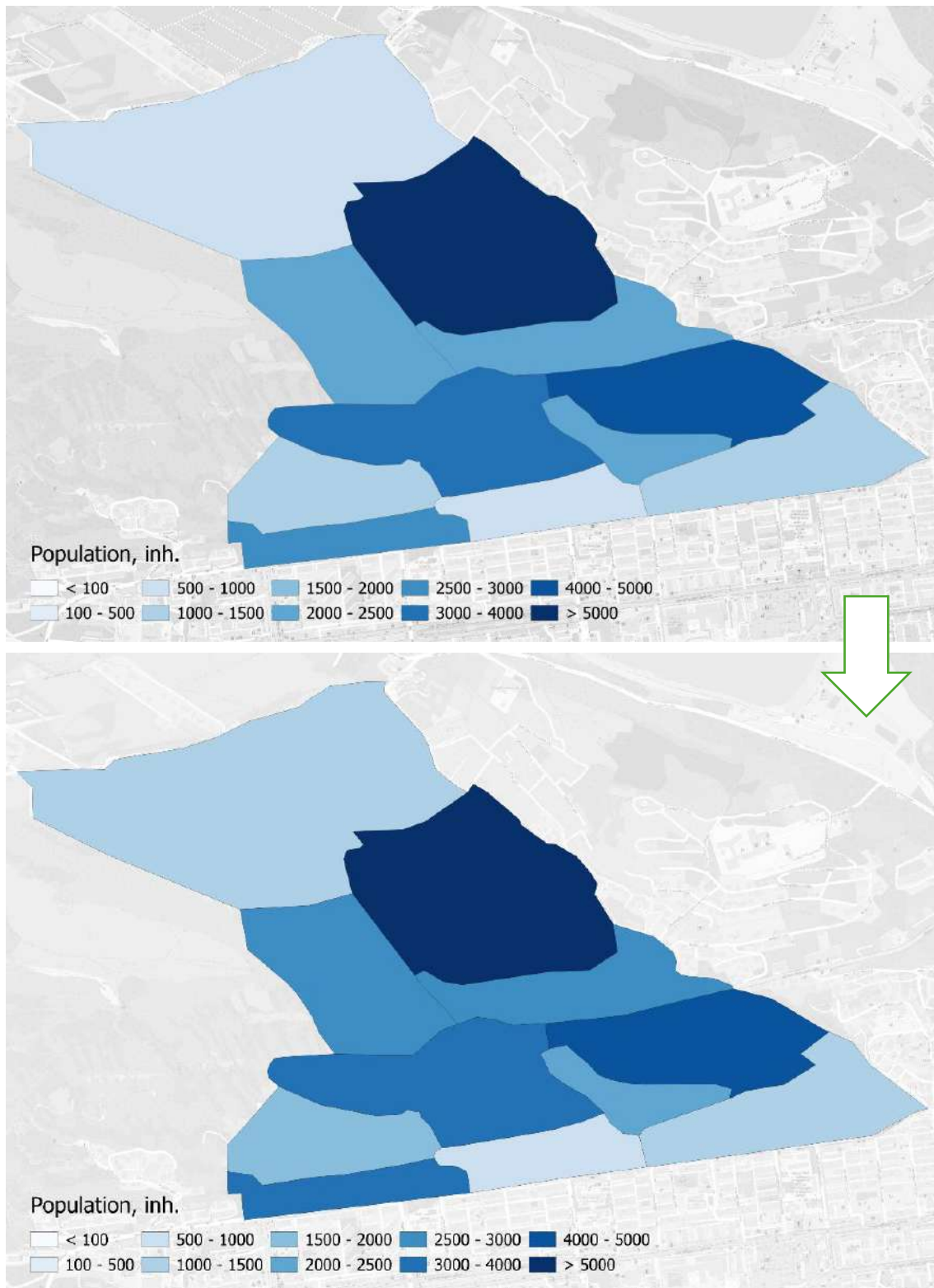


Figure 24. Changes in the population of Nutsubidze plateau

- Didi Dighomi (Figure 25). The population in 2014 was 26,368. The population in 2025 is 32,168. The increase was 22.0%.

The example of the calculation is provided in the Appendix 10.2.

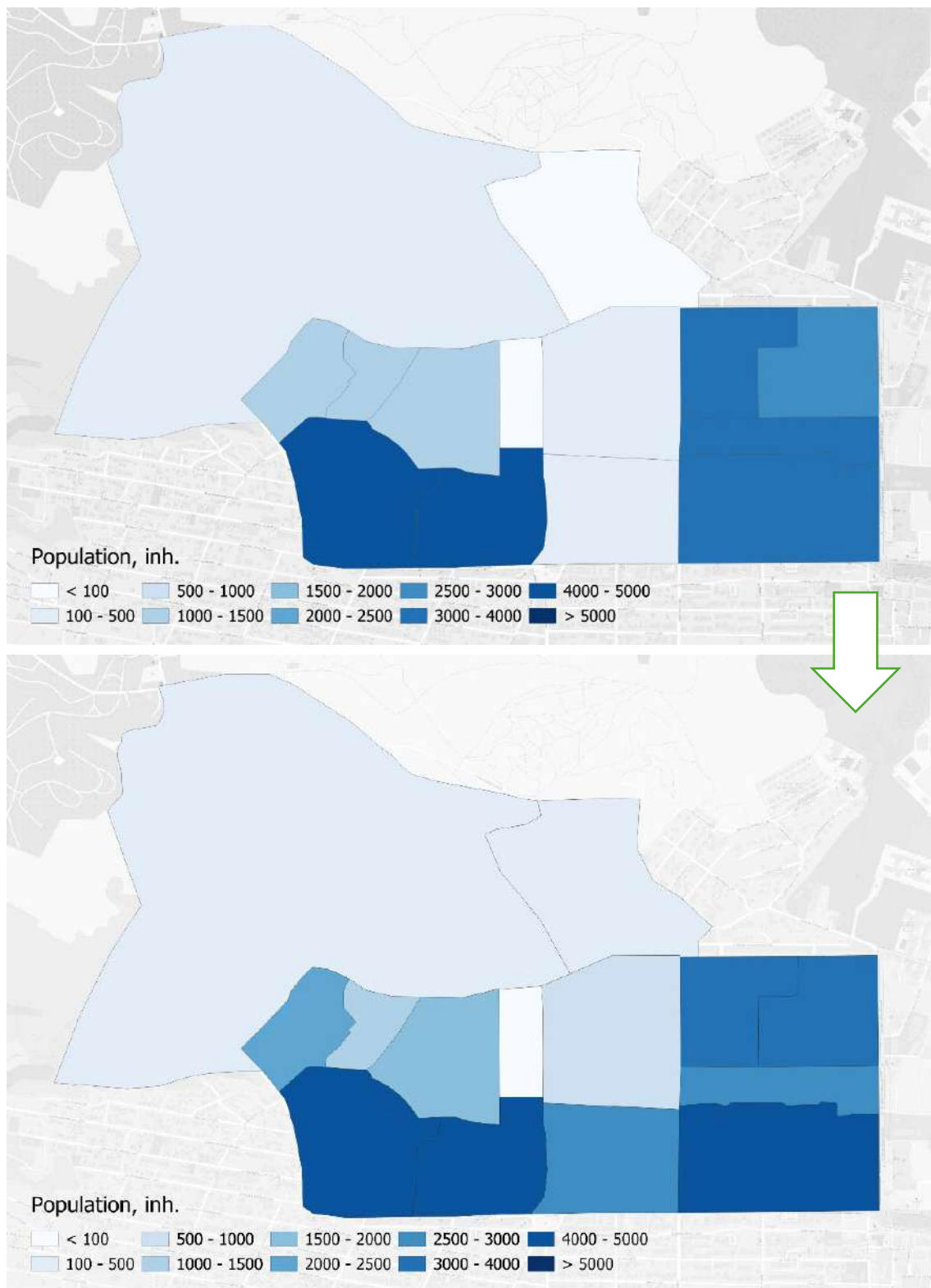


Figure 25. Changes in the population of Didi Dighomi

- Zhvania street - Shatberashvili street (Figure 26). The population in 2014 was 7,799. The population in 2025 is 9,093. The increase was 16.6%.

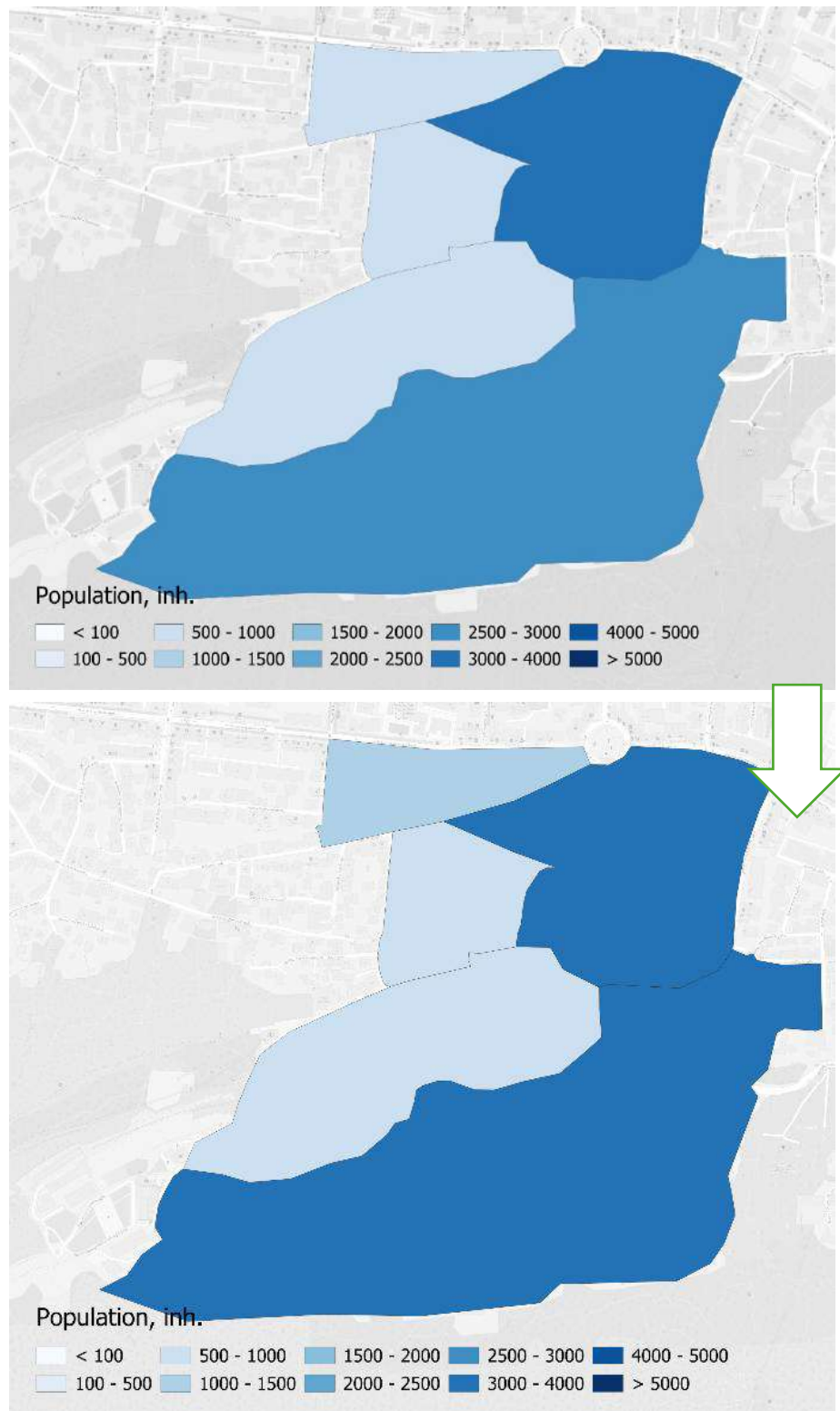


Figure 26. Changes in the population of Zhvania street – Shatberashvili street

- Village Dighomi (Figure 27). The population in 2014 was 10,039. The population in 2025 is 13,168. The increase was 31.2%.
Village Digomi is a distinct residential area of low-rise housing within the city. It borders Didi Digomi to the north, a mountain range to the south, and Digomi Massive to the east.

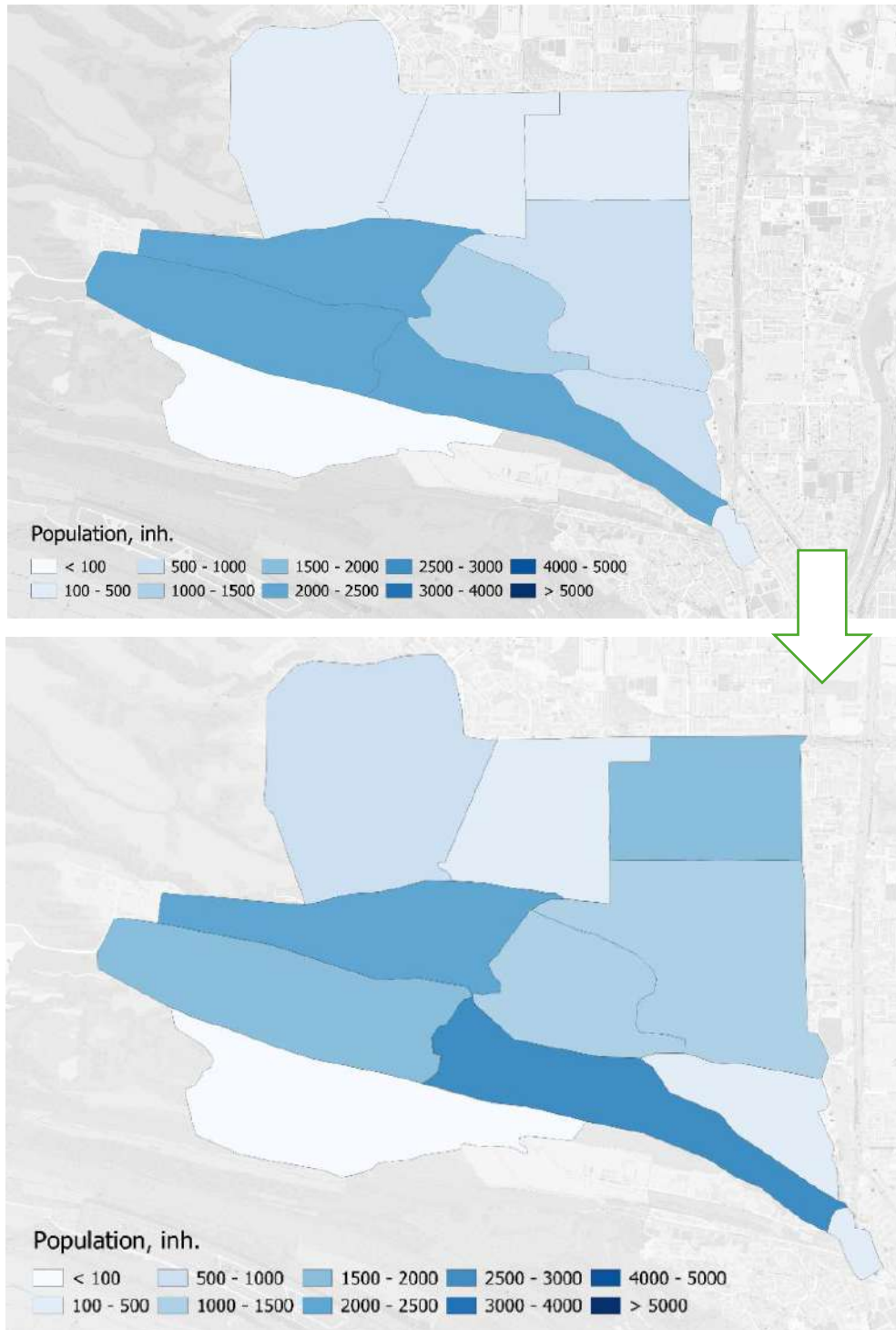


Figure 27. Changes in the population of Village Dighomi

- Jikia street (Figure 28). The population in 2014 was 6,367. The population in 2025 is 9,521. The increase was 49.5%.

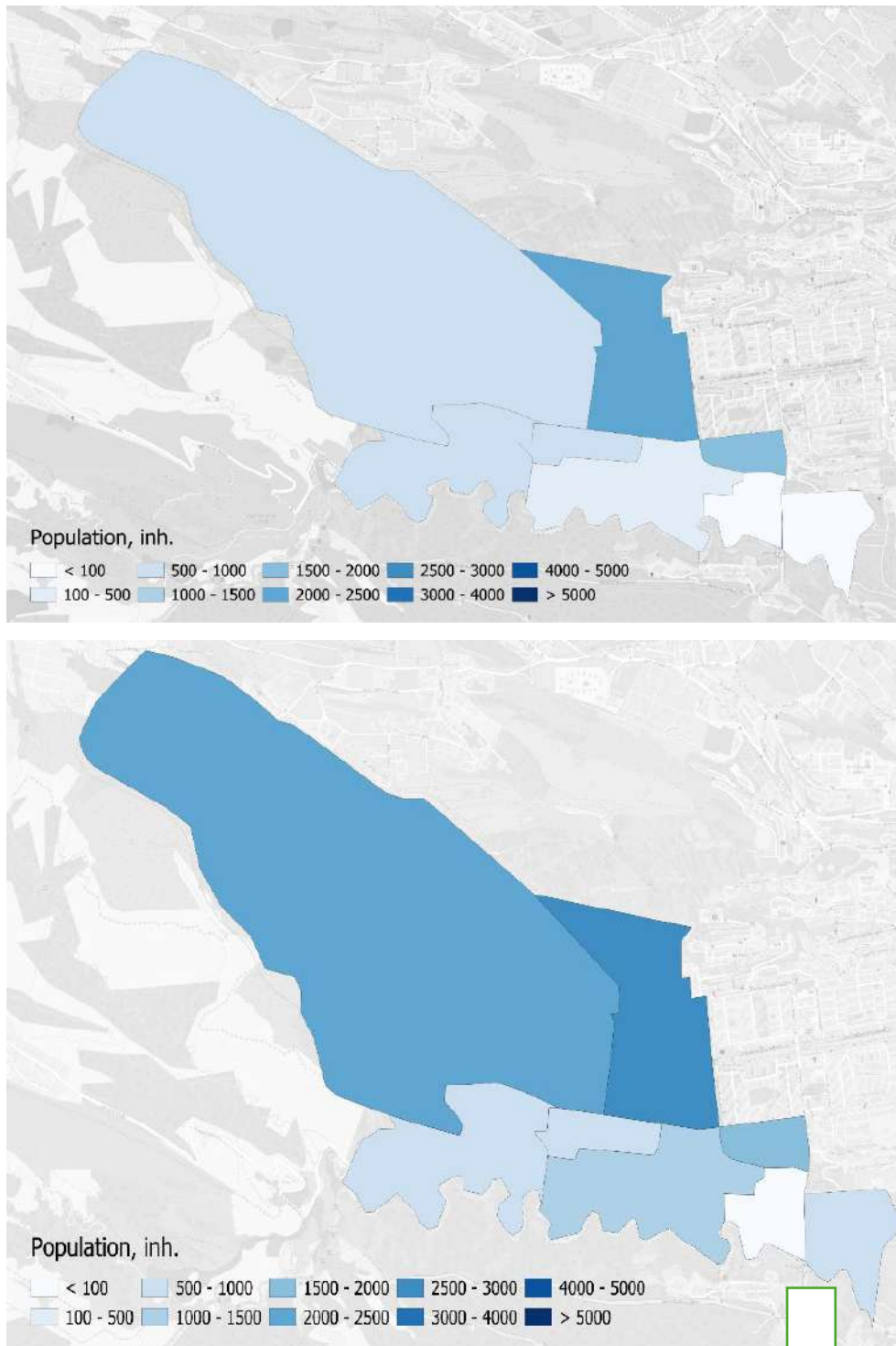


Figure 28. Changes in the population of Jikia street

- Bagebi (Figure 29). The population in 2014 was 4,866. The population in 2025 is 6,118. The increase was 25.7%

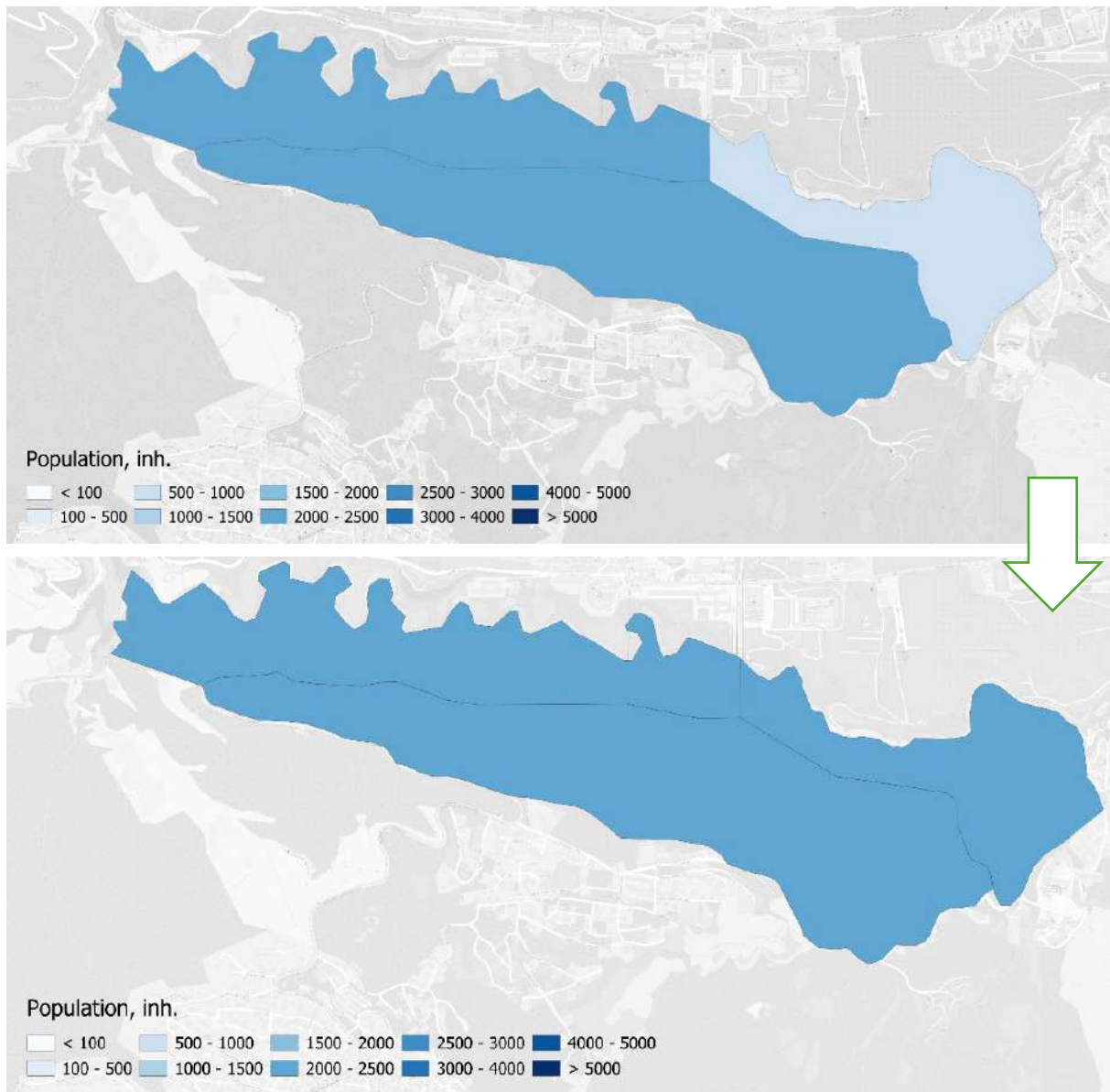
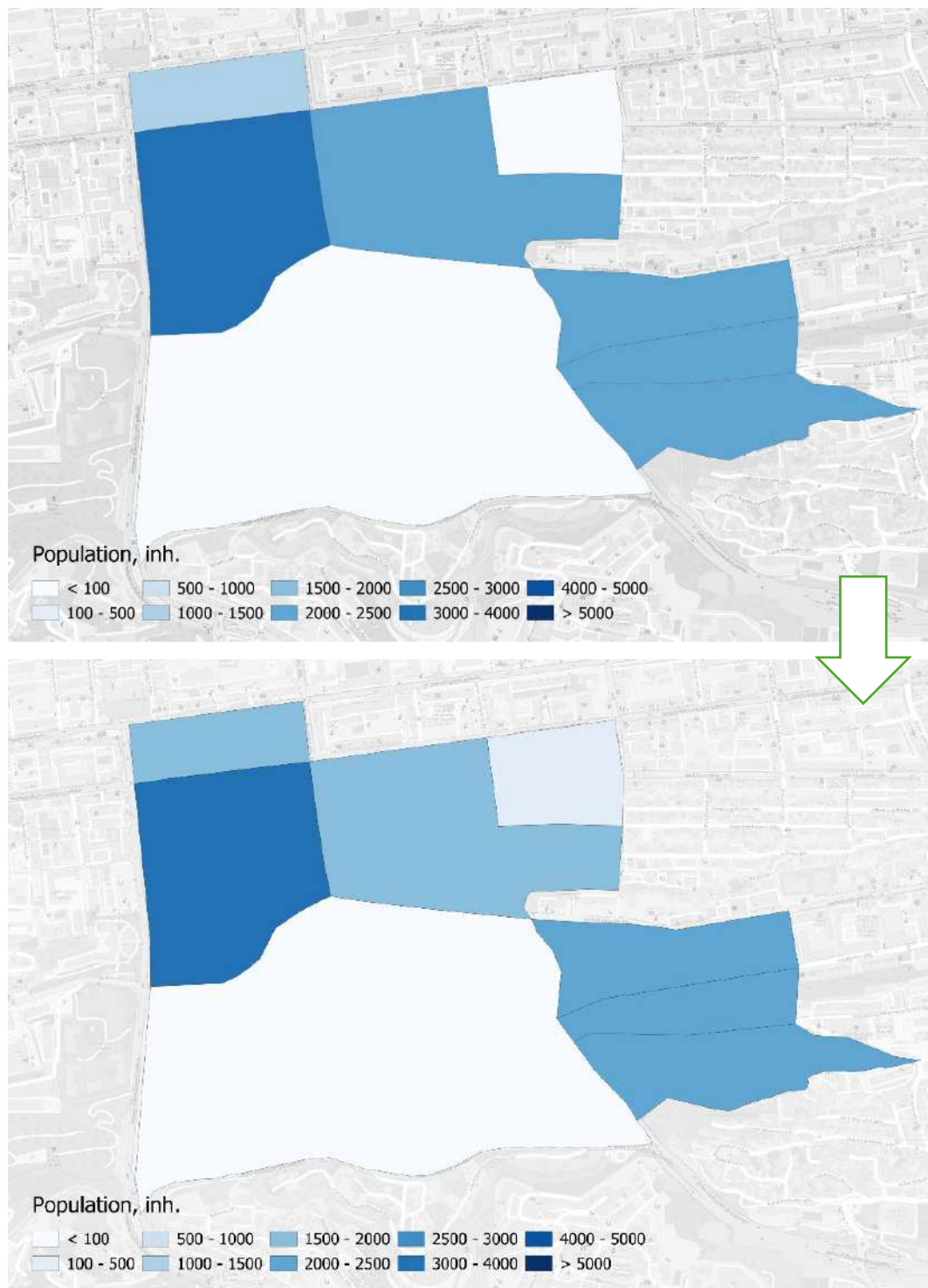


Figure 29. Changes in the population of Bagebi

- Hippodrome (Figure 30. The population in 2014 was 13,040. The population in 2025 is 14,482. The increase was 11.1%.



- Hualing (Figure 31). The population in 2014 was 6,181. The population in 2025 is 10,675. The increase was 72.7%.

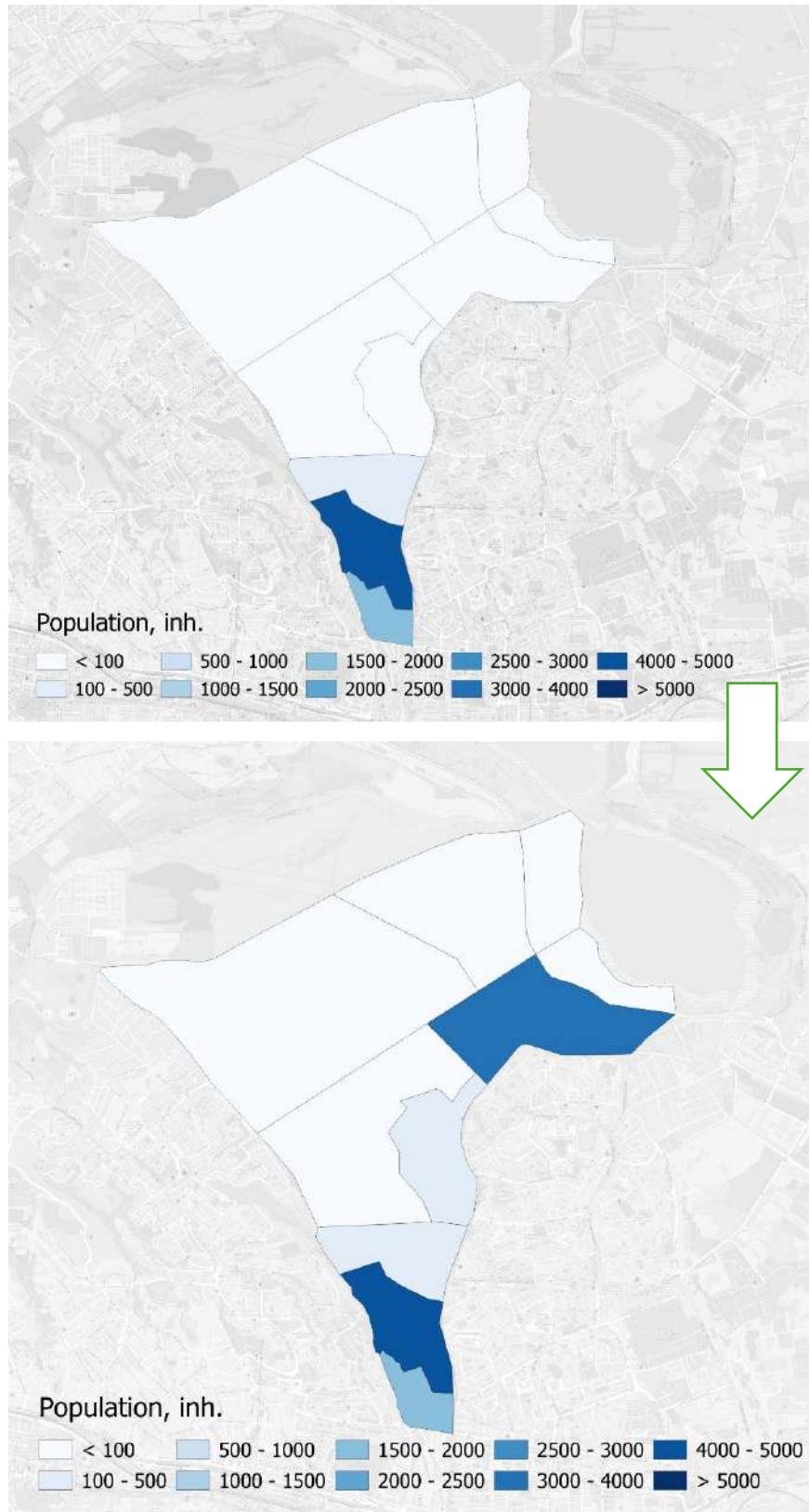


Figure 31. Changes in the population of Hualing

Currently, the population across the new TAZs in the modelling area is distributed as shown in Figure 32.

This data has also been imported into the updated Tbilisi transport model as shown in Figure 33.

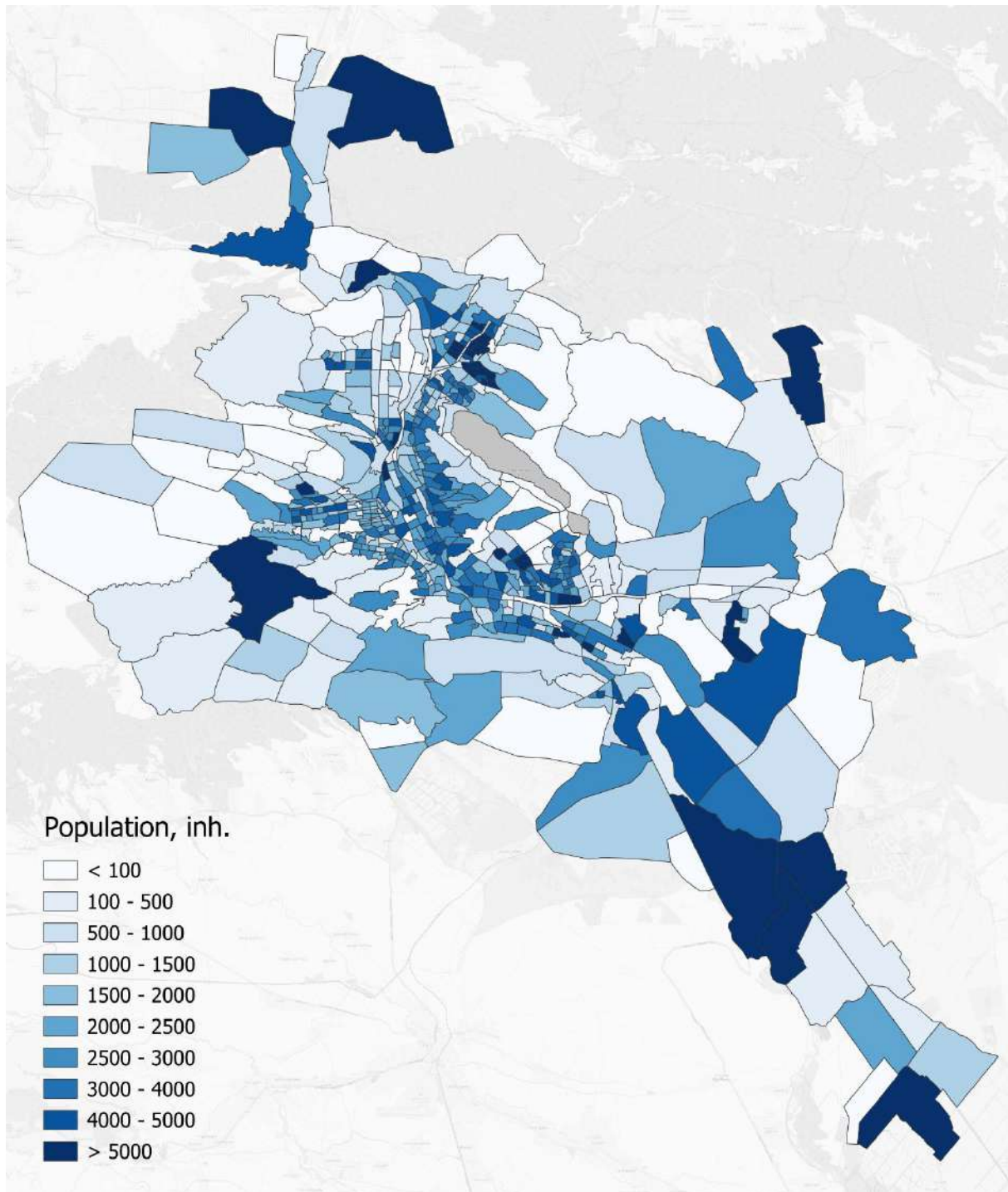


Figure 32. Distribution of the population by new TAZs

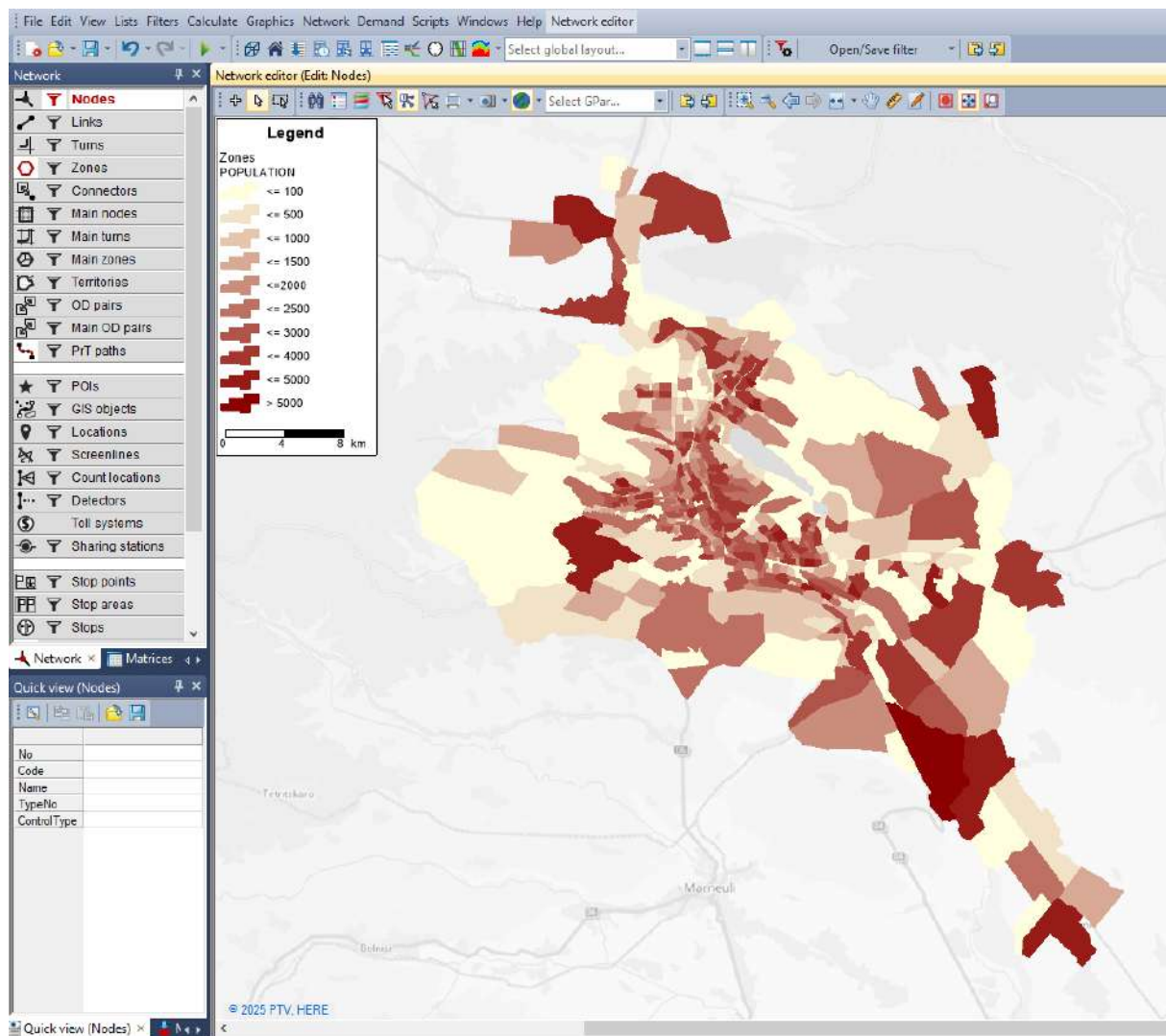


Figure 33. Distribution of the population in the updated Tbilisi Transport Model

3.2. Distribution of Population by Age Group

To accurately develop the transport model, it is essential to consider specific age groups, as each exhibits distinct mobility patterns and travel needs. With this regard, the population was divided into the following age categories (Figure 34):

- 0 – 5 years – preschoolers;
- 6 – 18 years – schoolchildren;
- 19 – 24 years – students;
- 18 – 64 years – working-age population;
- Over 65 years – retired people.

Since the most recent census data is outdated, it was not possible to obtain reliable population figures by age group for Tbilisi and its suburban areas. To address this, national-level demographic statistics were used to determine the proportional distribution of each age group related to the total population. These percentages were then applied as coefficients to estimate the age-group distribution for each transport analysis zone.

Number: 681	No	POPULATION_0_5	POPULATION_18_64	POPULATION_19_24	POPULATION_6_18	POPULATION_OVER_65
1	1	201	1757	201	488	481
2	2	466	4079	468	1133	1116
3	3	204	1785	205	496	489
4	4	13	115	13	32	31
5	5	149	1308	150	363	358
6	6	7	64	7	17	18
7	7	187	1638	187	454	449
8	8	208	1819	209	505	498
9	9	732	6333	725	1758	1732
10	10	497	4355	498	1209	1191
11	11	185	1621	186	450	444
12	12	210	1842	211	512	504
13	13	289	2529	290	702	692
14	14	214	1876	215	521	513
15	15	290	2540	291	706	695
16	16	332	2905	333	807	795
17	17	156	1364	156	379	373
18	18	173	1518	174	421	415
19	19	287	2511	288	697	687
20	20	286	2507	287	696	686
21	21	473	4144	475	1151	1134
22	22	123	1076	123	299	295
23	23	539	4722	541	1311	1292
24	24	258	2259	259	628	618
25	25	248	2172	249	603	594
26	26	205	1796	206	499	492
27	27	726	6361	728	1766	1740
28	28	148	1297	149	360	355
29	29	311	2720	312	755	744
30	30	218	1906	219	529	522
31	31	225	1973	226	548	540
32	32	214	1874	215	521	513
33	33	354	3100	355	861	848
34	34	424	3710	426	1030	1015
35	35	245	2147	246	596	588
36	36	214	1874	215	520	513
37	37	71	617	71	171	169
38	38	202	1771	203	492	485
39	39	290	2540	291	706	695
40	40	141	1231	141	342	337
41	41	182	1593	183	442	436
42	42	302	2044	234	568	559
43	43	265	2317	266	644	634
44	44	146	1281	147	356	351
45	45	153	1338	153	372	366
46	46	220	1929	221	536	528
47	47	107	937	107	260	256
48	48	294	2571	295	714	704
49	49	214	1872	215	520	512
50	50	185	1618	186	449	443

Figure 34. Excerpt from the table of age groups by TAZs

3.3. Distribution of Workplaces

When dealing with workplaces and their distribution in the defined traffic zones, a quite articulated process was developed and some assumptions were required.

The number of workplaces was estimated in relation to the population. According to the national statistics portal³, Georgia's total population is 3,704,500, while the labour force comprises 1,633,600 individuals. These figures were used to calculate the ratio of the labour force to the total population for Tbilisi and suburban area. This ratio was then applied to the population of the different traffic zones to estimate their labour force.

As a next step, to assess distribution of workplaces between different economical segments (joined into industrial and service groups), the data from the analysis of labour market of Ministry of Economy of Georgia⁴ was considered. This study provided ratios for distribution of labour force between different areas of economic activity. This ratio, applied to the general number of labour force, provided estimates for people employed in different economic areas.

Subsequently, the total number of workplaces for each area of economic activity was distributed across the TAZs based on the number and size of industrial and service sector establishments within each zone. This information was obtained mainly from Open Street Map (OSM) service⁵ and supplemented by data from official company websites or other open sources. In cases where publicly available data were incomplete, local team members provided expert judgement based on their knowledge of major employers and local economic conditions to support the estimation.

As a result, the number of workplaces in the modelling area is distributed as illustrated in Figure 35 - Figure 36. It should be noted that the total number of workplaces can be divided into two groups: the number of workplaces in industry and the number of workplaces in services. The number of workplaces in industry includes workplaces in agriculture, mining and manufacturing, electricity, water and gas supply, construction, etc. Service sector jobs are all other workplaces not involved in industry. These can be in trade, administrative management, education, medicine, service personnel, security, transport and logistics services, postal activities, cultural or financial activities, etc. The number of workplaces in the service sector is shown in Figure 37. This data is reflected in the transport model as shown in Figure 38.

³ <https://www.geostat.ge/ka/modules/categories/316/mosakhleoba-da-demografia>

⁴ <https://www.geostat.ge/ka/modules/categories/683/dasakmeba-umushevroba>

⁵ <https://www.openstreetmap.org/>

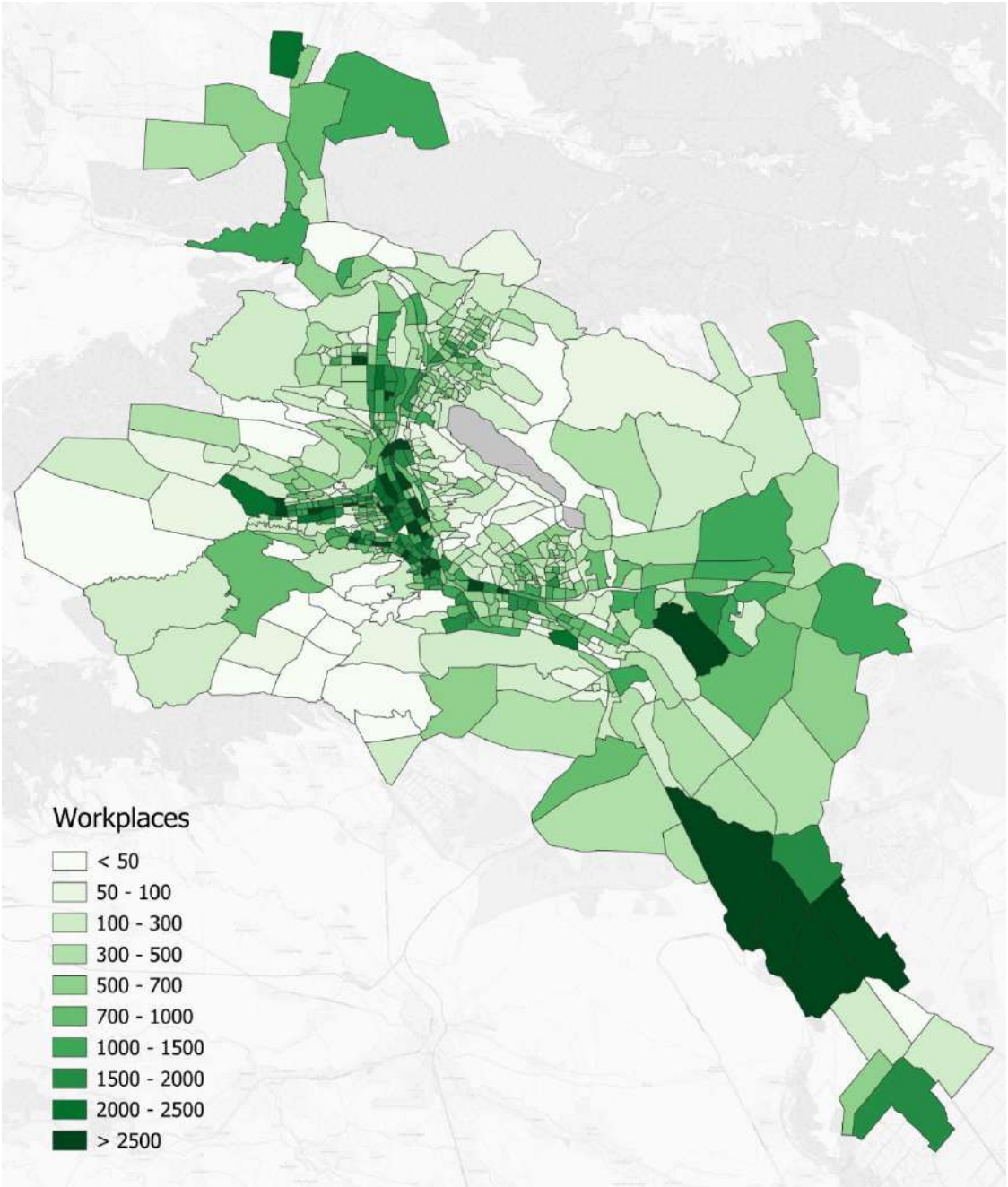


Figure 35. Estimated distribution of workplaces for 2025 by new TAZs

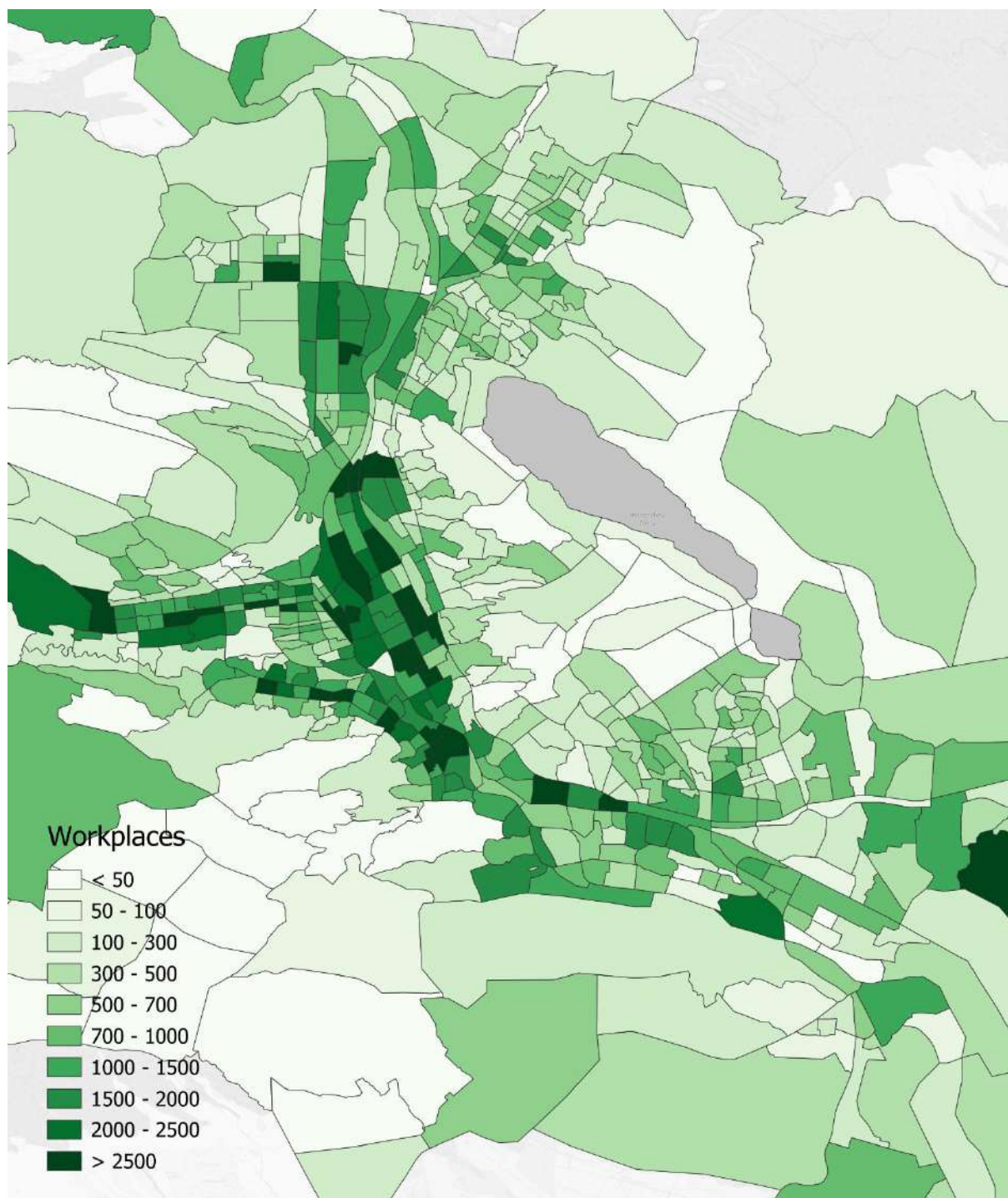


Figure 36. Distribution of workplaces by new TAZs in Tbilisi

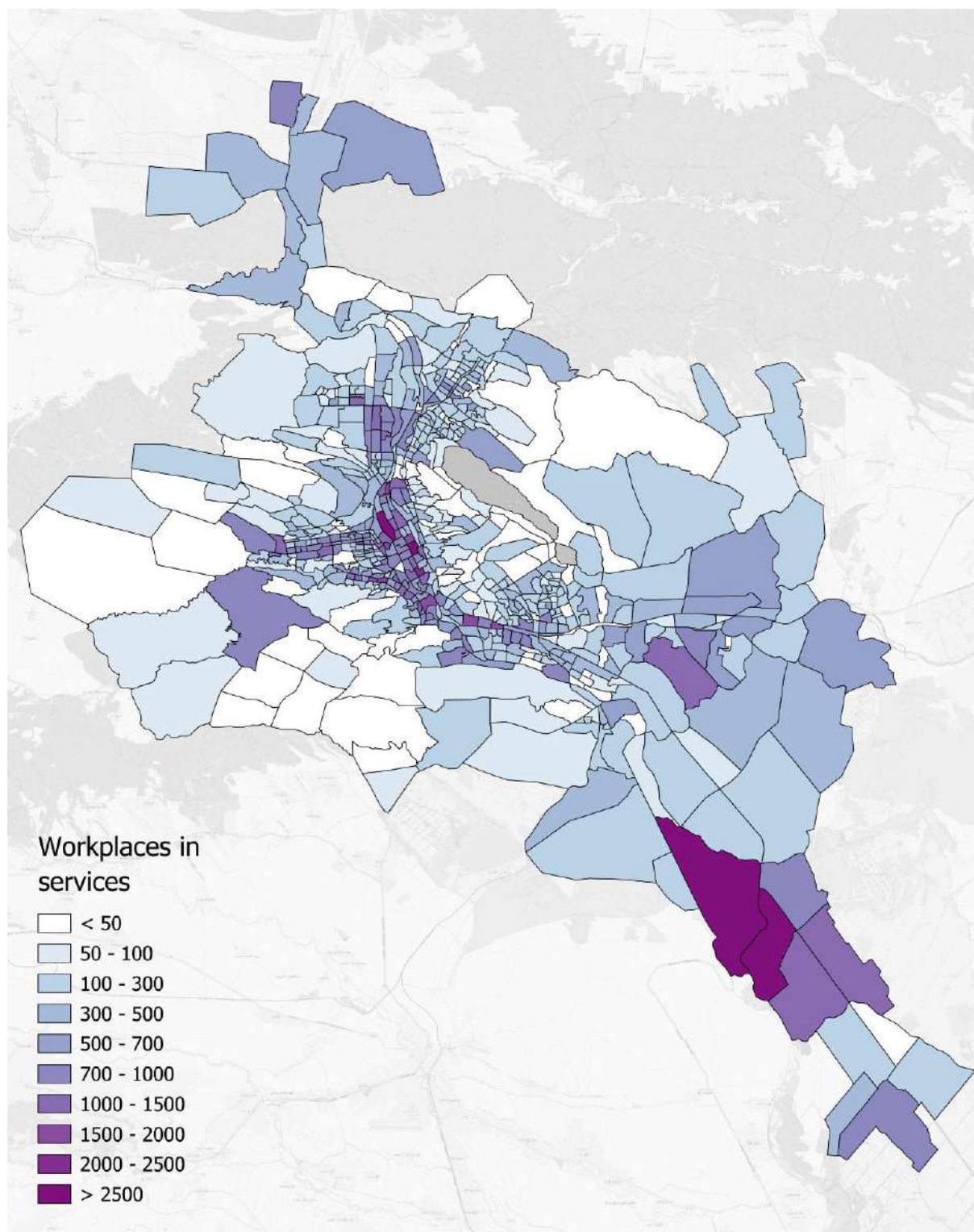


Figure 37. Distribution of the workplaces in services by TAZ in the model

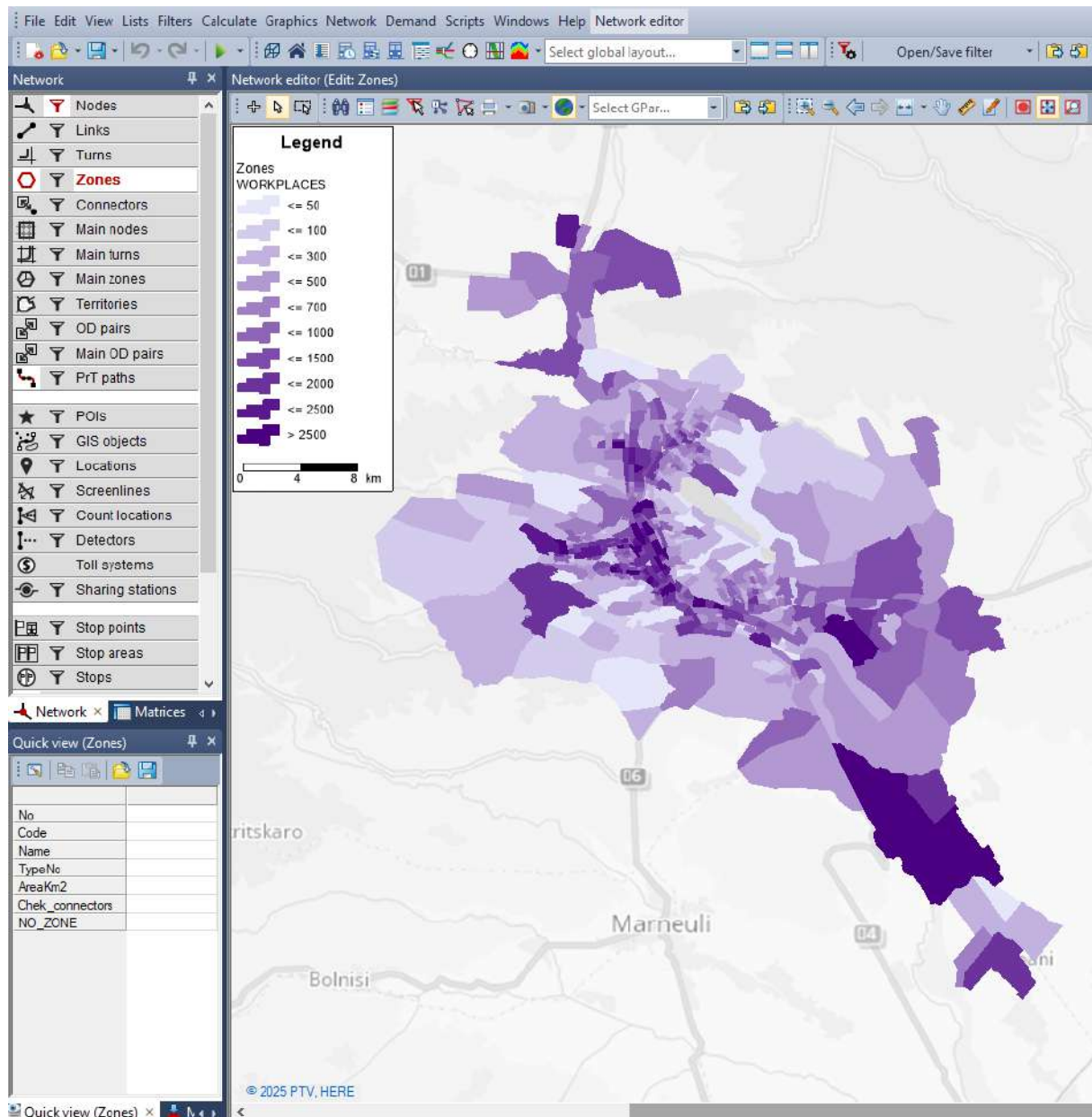


Figure 38. Distribution of the workplaces by TAZ in the model

3.4. Kindergartens

Data on the locations and number of children attending kindergartens⁶ were provided by the City Authorities. All addresses were geolocated and were attributed to the corresponding TAZs. The total number of kindergartens is 190. Based on this information, the spatial distribution of kindergartens within the modelling area is shown in Figure 39.

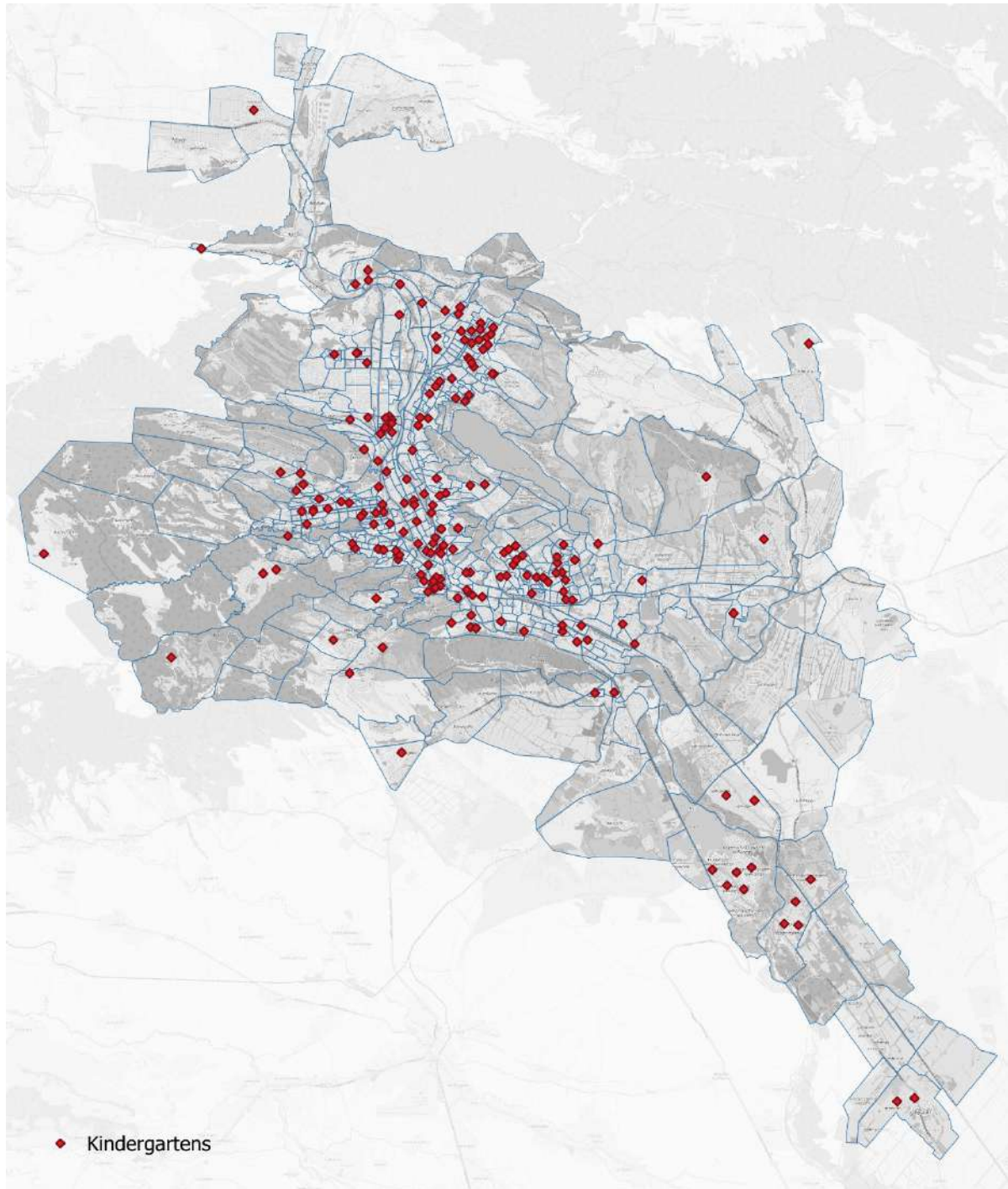


Figure 39. Locations of kindergartens

⁶ Kindergartens – educational institutions that provide early childhood education and care for children, typically between the ages of 3 and 6, preparing them for primary school

Due to the lack of detailed data on the number of places in kindergartens, it was assumed that the number of children attending them corresponds to the number of places in the respective institution. The number of children in kindergartens was obtained by TUDA in response to an official request to the Tbilisi municipality and then matched to TAZs according to their location. The distribution of kindergarten places across the modelling area is as follows (Figure 40).

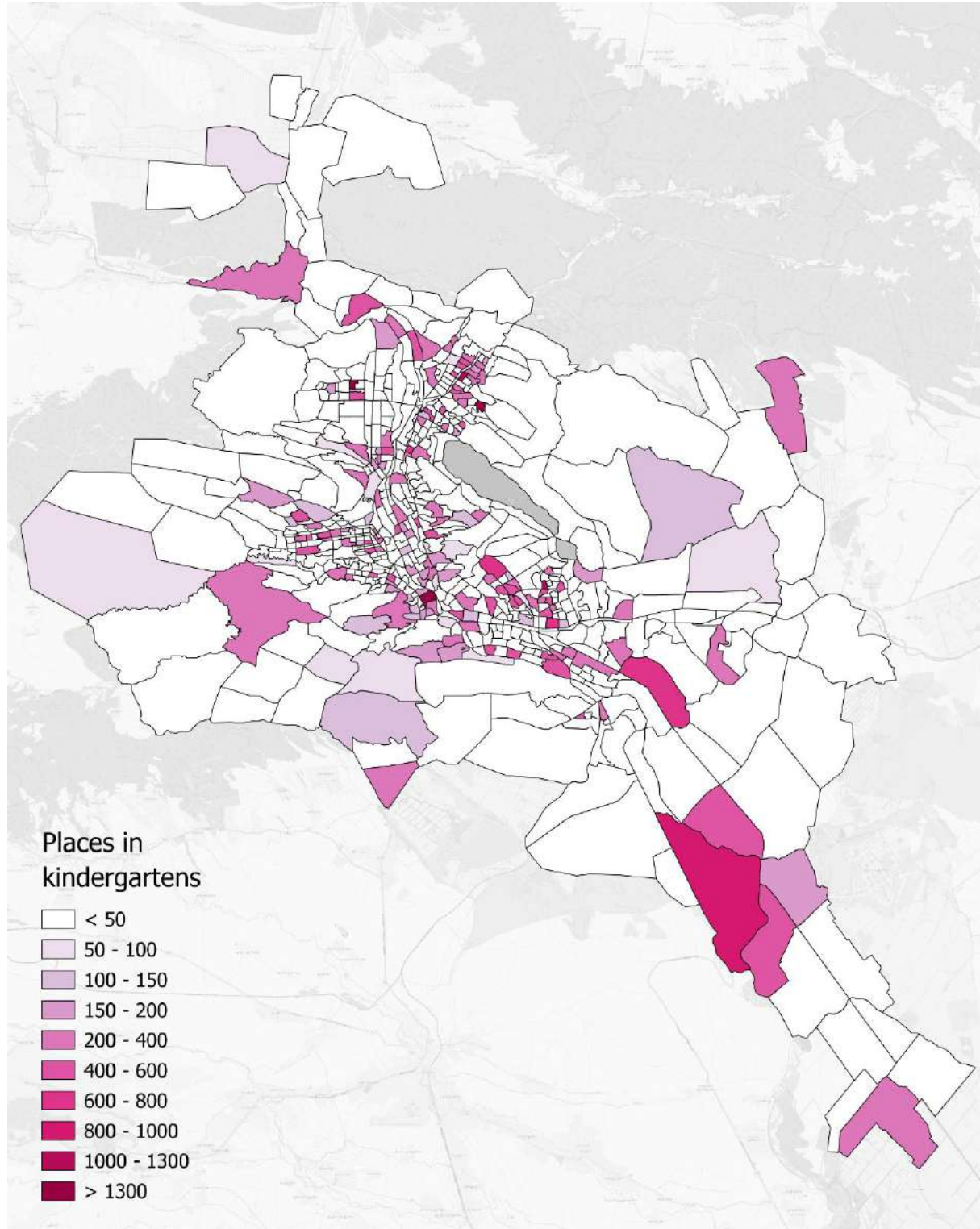


Figure 40. Distribution of kindergarten places by TAZs

3.5. Schools

Similarly, city authorities provided data on the locations of schools ⁷ (both public and private) and their associated statistics. The same approach used for kindergartens was applied to schools: the number of pupils set equal to the number of places available in the institution. The spatial distribution of schools and the number of available places is presented in Figure 41 and Figure 42. The total number of schools is 389.

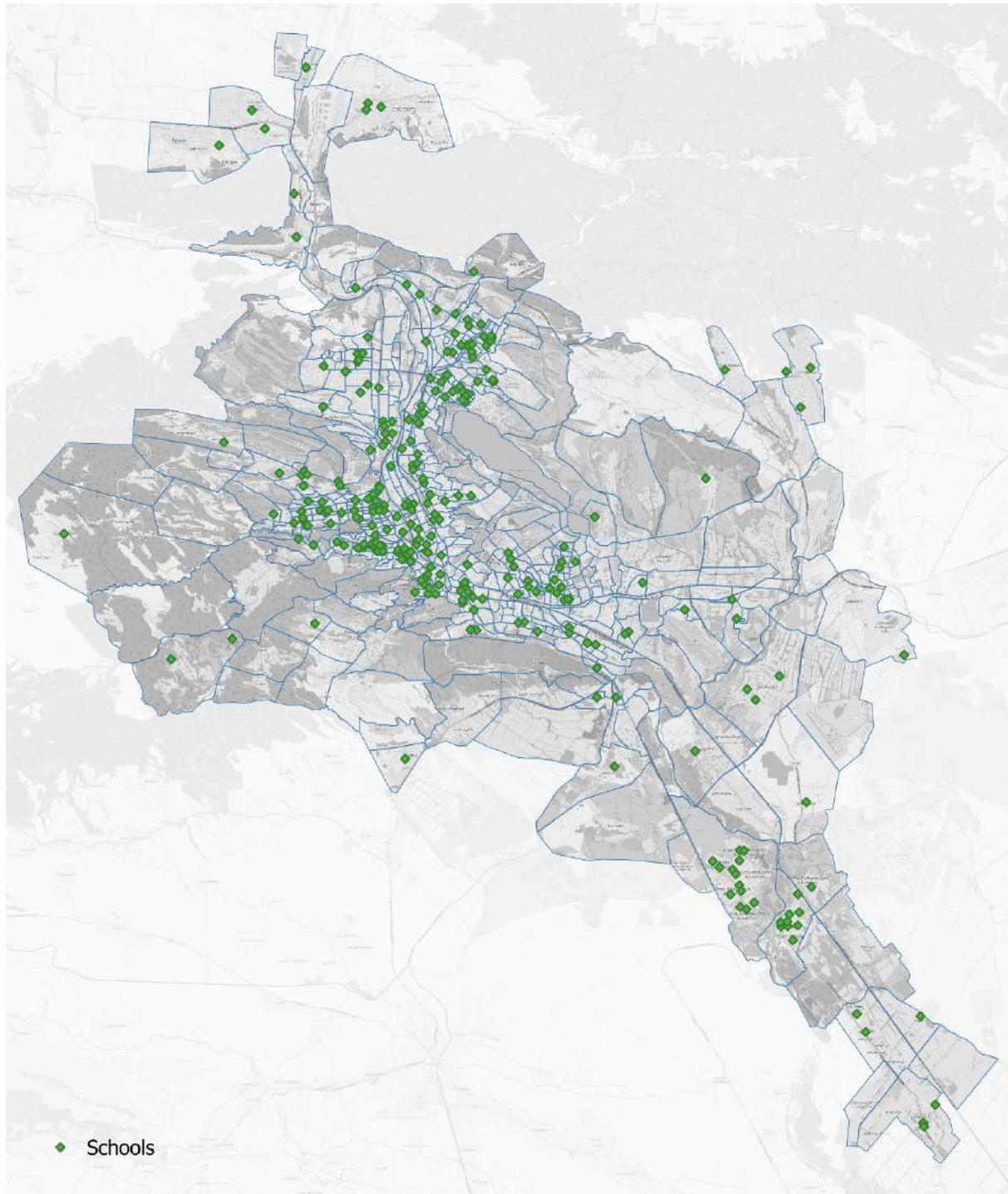


Figure 41. Locations of schools

⁷ In Georgia, children begin primary education at the age of 6. The full cycle of general education lasts 12 years

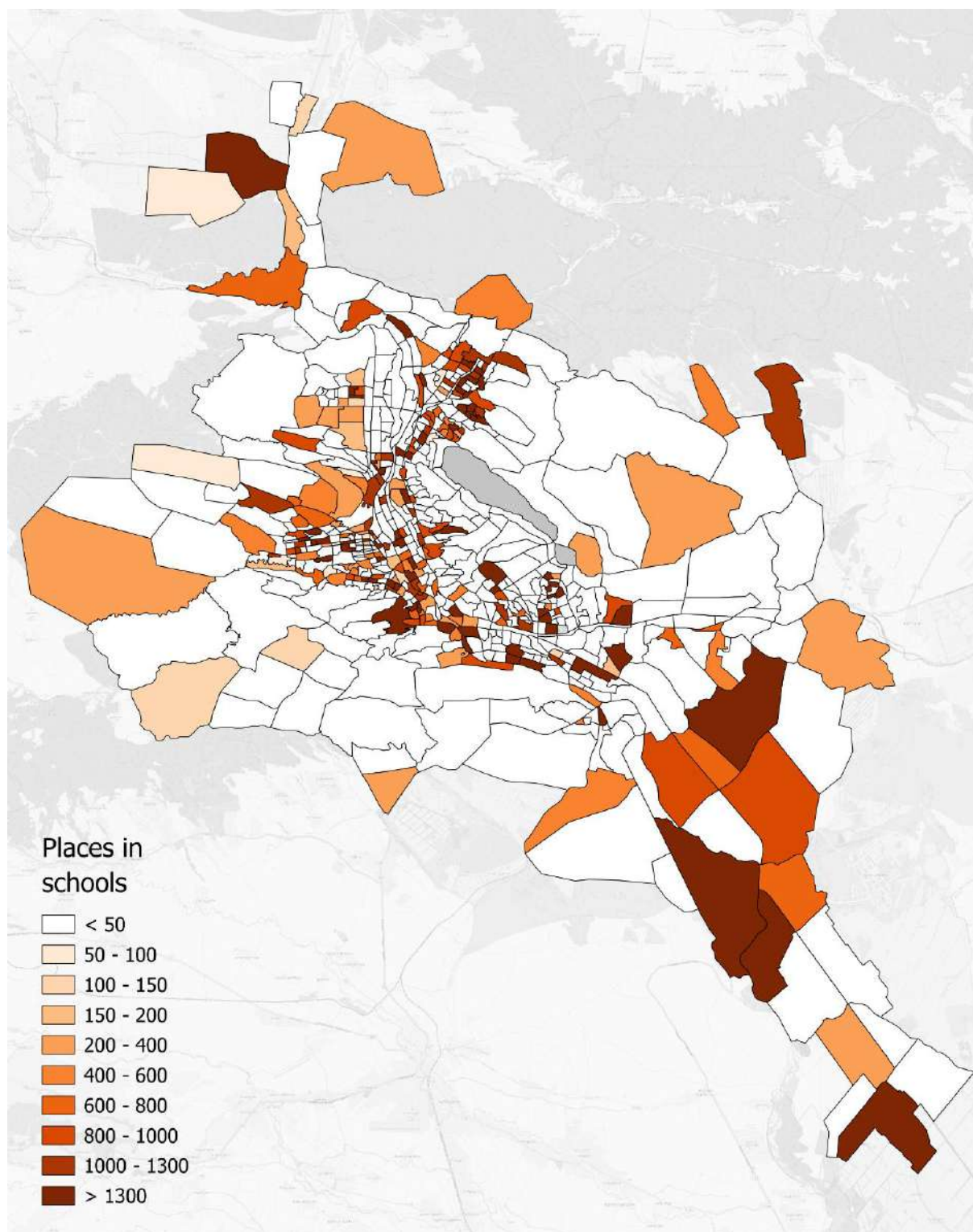


Figure 42. Distribution of school places by TAZs

3.6. Universities and colleges

Data on the locations of universities and the number of enrolled students were provided by the city authorities. The total number of universities and colleges is 64. However, a challenge arose with larger institutions, as only the total number of students was typically available, while their campuses might be dispersed across different parts of the city. In such cases, the total number of students was evenly distributed among the campuses.

Furthermore, this data layer includes not only universities but also colleges.

Accordingly, the distribution of universities and colleges, and places at universities and colleges across the modelling area, is presented in Figure 43 and Figure 44. Similarly to kindergartens and schools, the number of students at universities and colleges was assumed to be equal to the number of places available at each site.

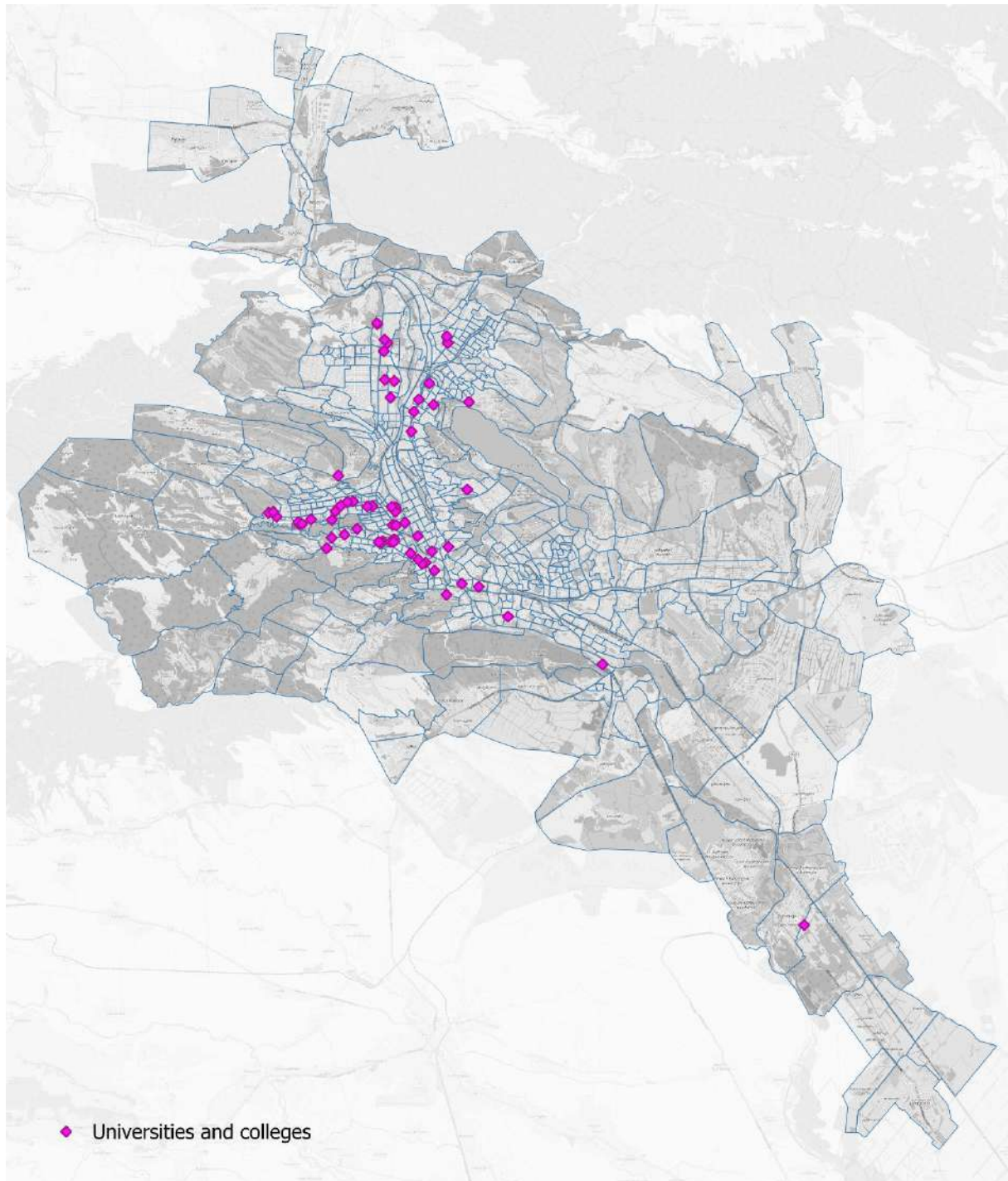


Figure 43. Locations of universities and colleges

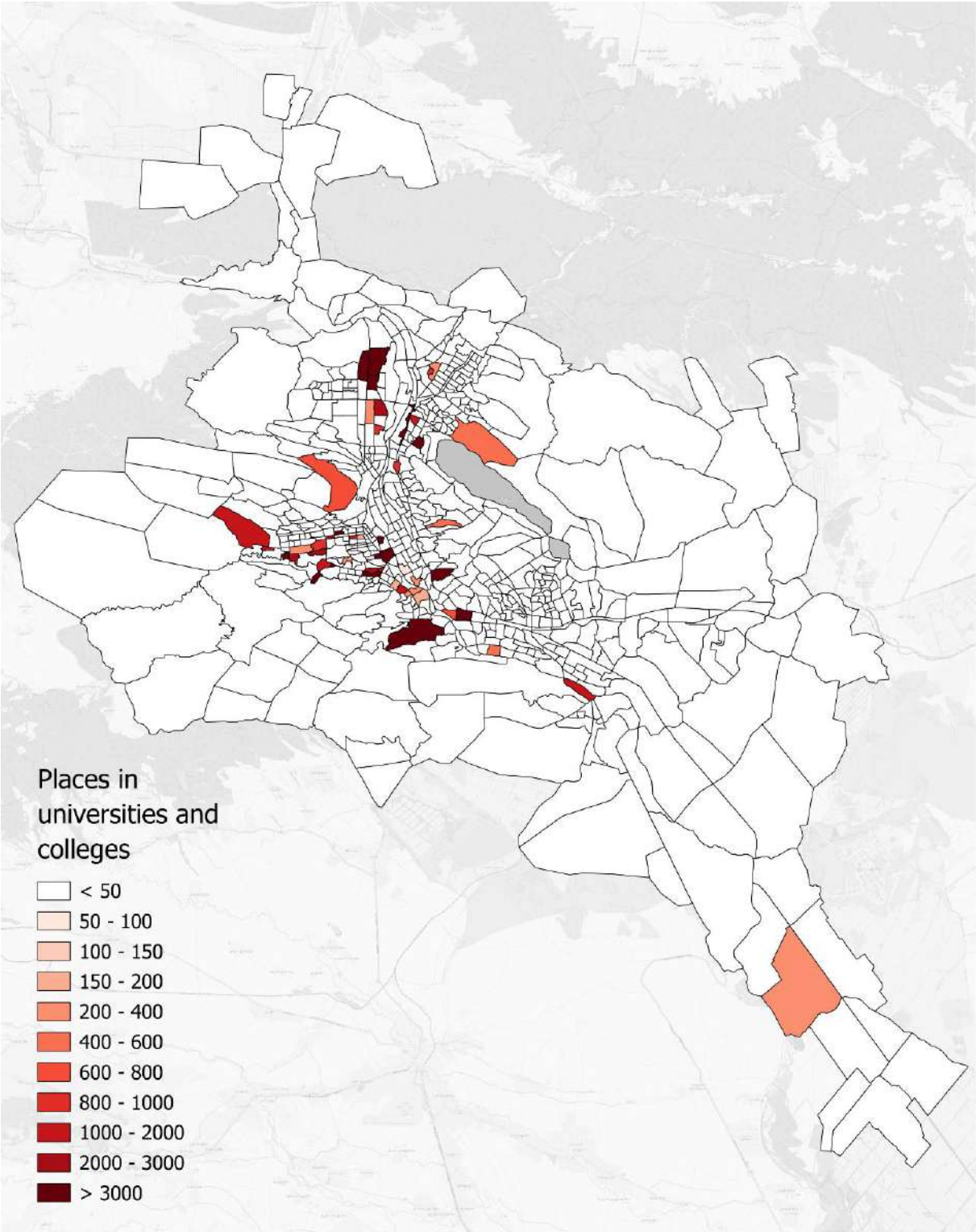


Figure 44. Distribution of places at universities and colleges

The socio-economic data described above was included in specific User-Defined Attributes (UDAs) for each TAZ as shown in

Figure 45.

Number: 681	No	POPULATION	WORKPLACES	PLACES_IN_KINDERGARDENS	PLACES_IN_SCHOOL	PLACES_IN_UNIVERSITY
1	1	2896	724	109	0	0
2	2	6724	564	563	681	0
3	3	2943	282	0	0	0
4	4	189	1634	0	0	0
5	5	2157	100	0	0	0
6	6	105	253	0	0	0
7	7	2700	778	0	0	0
8	8	2998	373	151	2203	0
9	9	10440	780	599	0	0
10	10	7180	409	254	0	0
11	11	2672	426	0	1737	0
12	12	3037	100	296	0	0
13	13	4170	464	277	926	0
14	14	3092	620	356	0	0
15	15	4188	847	0	1477	0
16	16	4789	213	0	0	0
17	17	2248	921	0	1829	0
18	18	2502	97	0	0	0
19	19	4140	250	0	0	0
20	20	4134	261	146	0	0
21	21	6832	562	1381	1184	0
22	22	1774	520	0	0	0
23	23	7784	510	452	0	0
24	24	3725	836	0	87	400
25	25	3581	1050	0	103	0
26	26	2961	850	368	0	0
27	27	10488	313	0	1669	0
28	28	2139	420	86	729	0
29	29	4484	350	0	953	0
30	30	3143	920	452	0	0
31	31	3254	515	414	1500	0
32	32	3090	320	0	0	493
33	33	5110	505	411	954	0
34	34	6117	911	292	0	0
35	35	3540	207	0	0	0
36	36	3089	604	0	671	0

Figure 45. TAZ User-Defined Attributes (UDAs)

4. TRANSPORT SUPPLY DATA

The transport supply in the updated Tbilisi transport model comprises various components and characteristics of the urban transport system that serve travel demand. The key elements include:

- transport systems, which define available travel options, their attributes, and their interactions within the transport system;
- road network, encompassing primary and secondary streets, roadways, traffic management features, and other relevant network attributes;
- public transport network, including routes, stops, timetables, and fleet characteristics;
- connectors, linking TAZs to the road network and enabling interaction between land use and transport demand.

Each component is described in detail in the following sections, highlighting their update, coding, and calibration in the context of the 2022 base model and of the data collected during the project.

4.1. Classification of transport

To model the structure and composition of transport flows that generate traffic on the transport network of the region under analysis, data on the different types of vehicles used were integrated into the model.

In the transport model, different modes of transport are represented by transport systems. The list of transport systems, traffic modes and demand segments adopted in the model is presented in Table 1.

The table also shows the values of passenger car units (PCUs) used in the model for each transport.

Table 1. Classification of transport in the Tbilisi transport model

Code	Transport systems	PCU	Demand modes/segments
BUS	Bus	2.0	PuT
MRS	Marshrutka	1.5	
SUB	Subway	–	
C	Cable	–	
F	Funicular	–	
PUTW	PuT Walk	–	
CAR	Car	1.0	CAR, CAR_Pass
PED	Pedestrians	–	PED
BIKE	Bike	0.5	BIKE
GV	Goods vehicle	2.5	GV

According to Table 1, the model includes five PuT systems: cars, pedestrians, bicycles, and freight transport. The model also includes an additional transport system—“transfer pedestrians” (PuT Walk). While “pedestrians” are individuals who do not use any other transport system, “transfer pedestrians” are those who walk to access transport stops or to transfer between different modes of transport.

The list of transport systems in the Tbilisi transport model is shown in Figure 46.

Transport systems / Modes / Demand segments

Number: 10	Code	Name	Type	Modes	DSeg
1	BIKE	Bike	PrT	BIKE	BIKE
2	CAR	Car	PrT	C,Car_Pass	C,Car_Pass
3	GV	Goods vehicle	PrT	GV	GV
4	PED	Pedestrians	PrT	PED	PED
5	BUS	Bus	PuT	PuT	PuT
6	C	Cable	PuT	PuT	PuT
7	F	Funicular	PuT	PuT	PuT
8	MRS	Marshrutka	PuT	PuT	PuT
9	PUTW	PuT Walk	PuTWalk	PuT	PuT
10	SUB	Subway	PuT	PuT	PuT

Operations: Create, Edit, Delete

OK Cancel

Figure 46. List of transport systems in PTV Visum

Figure 47 below demonstrates the relationship between transport systems, modes, and demand segments.

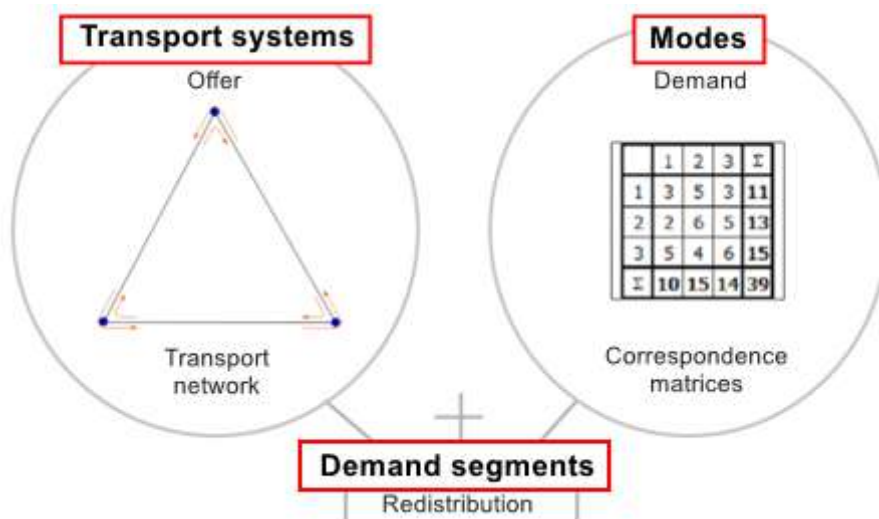


Figure 47. The relationship between transport systems, modes, and demand segments

4.2. Road Network

In the initial phase of preparing the transport supply, all the data relating to the road network already integrated into the previous version of the model were verified. The following elements of the road network were considered:

- Links – roadway segments representing streets, railways, metro lines, cable cars etc.
- Nodes – intersections and junctions.
- Turns – permitted or restricted movements between links at nodes.

4.2.1. Road network verification

The 2022 Tbilisi transport model had more than 80 types of links that include Primary, Secondary and Tertiary roads grouped based on the number of lanes, speed and type of terrain. The transport model also included additional link types for the metro, cable car, and bus systems. An example of link types is shown in the Figure 48.

Network: Base year2022.ver - PTV Visum Expert 2021 (SP 1-6) - [List (Link types)]

File Edit View Lists Filters Calculate Graphics Network Demand Scripts Windows Help List (Link types)

Network

Links: Default values... Adjust link types... Group by global type

Number: 188	No	GType	Name	Strict	Rank	TSysSet	NumLanes	CapPrT	VOPrT
115	114	10	Primary Urban 2L 30kmph	☒	1	10,3,Cyc,F,HGV,PC,T,W	2	2200	30km/h
116	115	10	Primary Urban 1L 80kmph	☒	1	10,3,Cyc,F,HGV,PC,T,W	1	1475	80km/h
117	116	10	Primary Urban 1L 60kmph	☒	1	10,3,Cyc,F,HGV,PC,T,W	1	1325	60km/h
118	117	10	Primary Urban 1L 40kmph	☒	1	10,3,Cyc,F,HGV,PC,T,W	1	1275	40km/h
119	118	10	Primary Urban 1L 30kmph	☒	1	10,3,Cyc,F,HGV,PC,T,W	1	1200	30km/h
120	119	10	Primary Urban 1L 25kmph	☒	1	10,3,Cyc,F,HGV,PC,T,W	1	1200	25km/h
121	120	11	Primary Rural 5L 80kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	5	8000	80km/h
122	121	11	Primary Rural 4L 80kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	4	6400	80km/h
123	122	11	Primary Rural 4L 70kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	4	6100	70km/h
124	123	11	Primary Rural 4L 60kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	4	5800	60km/h
125	124	11	Primary Rural 4L 40kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	4	5100	40km/h
126	125	11	Primary Rural 3L 80kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	3	4800	80km/h
127	126	11	Primary Rural 3L 70kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	3	4575	70km/h
128	127	11	Primary Rural 3L 60kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	3	4350	60km/h
129	128	11	Primary Rural 3L 40kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	3	3825	40km/h
130	129	11	Primary Rural 2L 80kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	2	3200	80km/h
131	130	11	Primary Rural 2L 70kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	2	3050	70km/h
132	131	11	Primary Rural 2L 60kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	2	2900	60km/h
133	132	11	Primary Rural 2L 50kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	2	2700	50km/h
134	133	11	Primary Rural 2L 40kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	2	2550	40km/h
135	134	11	Primary Rural 1L 80kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	1	1600	80km/h
136	135	11	Primary Rural 1L 70kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	1	1525	70km/h
137	136	11	Primary Rural 1L 60kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	1	1450	60km/h
138	137	11	Primary Rural 1L 50kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	1	1350	50km/h
139	138	11	Primary Rural 1L 40kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	1	1275	40km/h
140	139	11	Primary Rural 1L 30kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	1	1200	30km/h
141	140	11	Primary Rural 1L 25kmph	☒	2	10,3,Cyc,F,HGV,PC,T,W	1	1200	25km/h
142	141	12	Secondary 4L 80kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	4	4400	80km/h
143	142	12	Secondary 4L 60kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	4	4000	60km/h
144	143	12	Secondary 3L 80kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	3	3300	80km/h
145	144	12	Secondary 3L 60kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	3	3000	60km/h
146	145	12	Secondary 3L 40kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	3	2625	40km/h
147	146	12	Secondary 2L 80kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	2	2200	80km/h
148	147	12	Secondary 2L 60kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	2	2000	60km/h
149	148	12	Secondary 2L 40kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	2	1750	40km/h
150	149	12	Secondary 2L 30kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	2	1650	30km/h
151	150	12	Secondary 1L 80kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	1	1100	80km/h
152	151	12	Secondary 1L 60kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	1	1000	60km/h
153	152	12	Secondary 1L 40kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	1	875	40km/h
154	153	12	Secondary 1L 30kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	1	825	30km/h
155	154	12	Secondary 1L 25kmph	☒	3	10,3,Cyc,F,HGV,PC,T,W	1	825	25km/h
156	155	13	Tertiary 4L 60kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	4	2700	40km/h
157	156	13	Tertiary 4L 40kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	4	2400	40km/h
158	157	13	Tertiary 3L 60kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	3	2025	40km/h
159	158	13	Tertiary 3L 40kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	3	1800	40km/h
160	159	13	Tertiary 2L 80kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	2	1500	40km/h
161	160	13	Tertiary 2L 60kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	2	1350	40km/h
162	161	13	Tertiary 2L 40kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	2	1200	40km/h
163	162	13	Tertiary 2L 30kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	2	1150	30km/h
164	163	13	Tertiary 1L 80kmph	☒	4	10,3,Cyc,F,HGV,PC,T,W	1	750	40km/h

Quick view (Links) Network editor List (Link types)

Figure 48. Example of link types in the transport model of Tbilisi 2022

However, such classification of the road network included types of links, the further use of which would not allow to correctly model the movement of both private and public transport. For example, in the 2022 model the types of links where private mobility is prohibited such as “Buses - 40r”, “Buses - 25r” and “Segregated Buses - 40r”, were widely used (Figure 49). The number of links of these types was 19,279, representing approximately 54% of the total number of links.

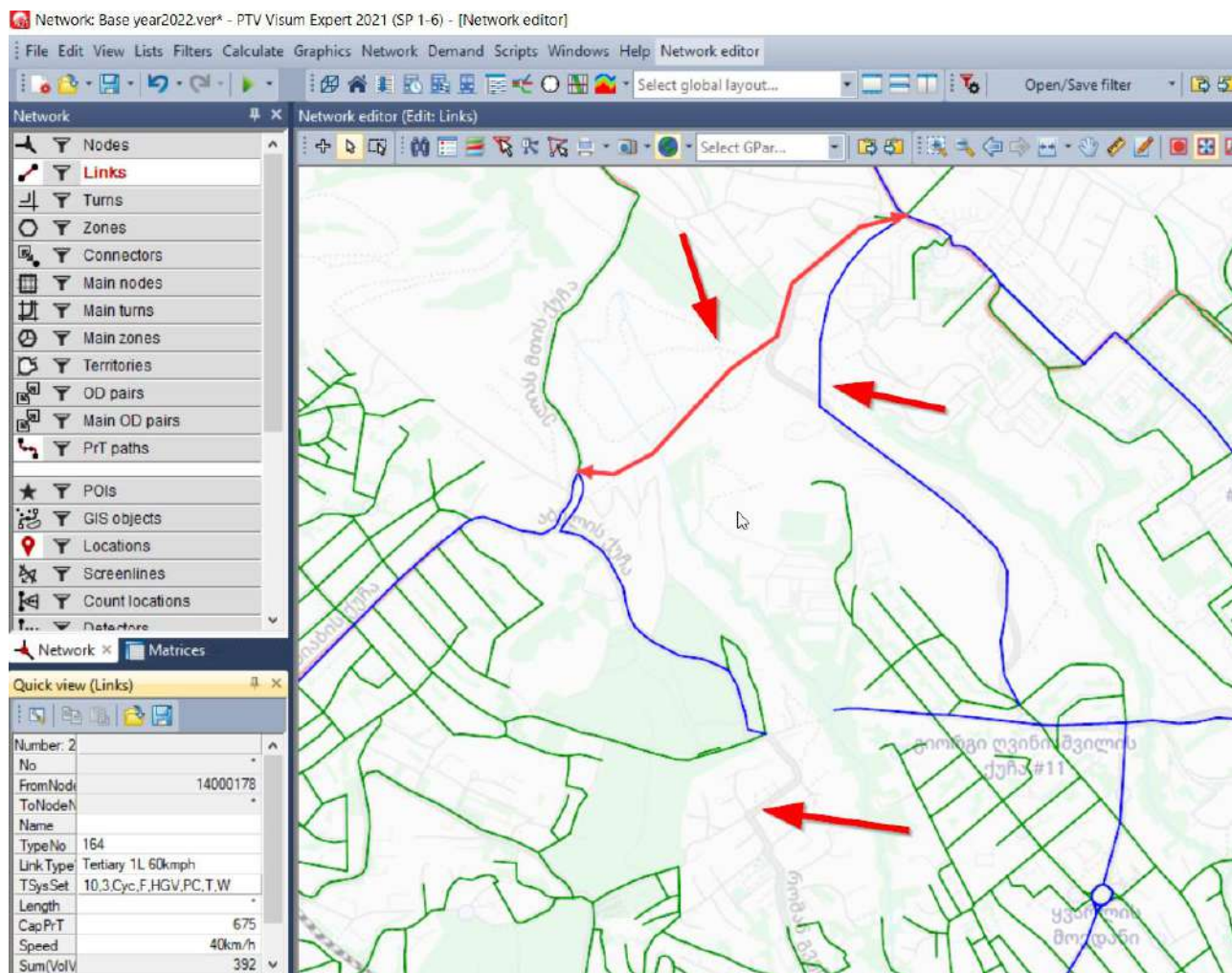
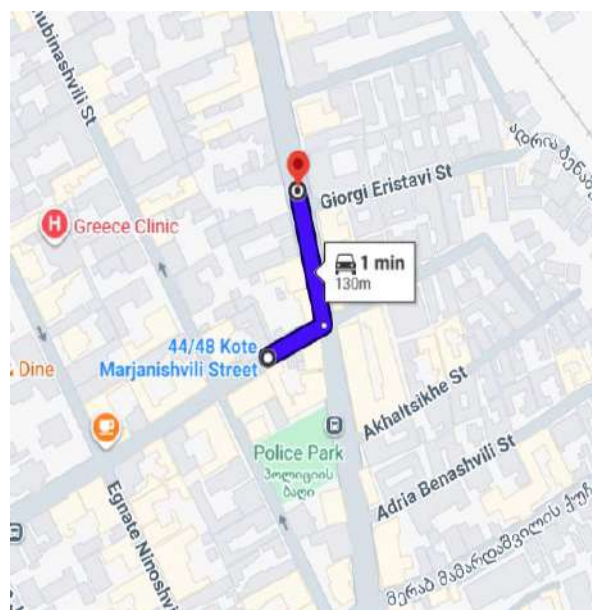


Figure 50. A fragment of the road network in the transport model of Tbilisi 2022, which highlights mistakes in the model network

Additional detailed analysis revealed aspects requiring verification and refinement with regard to turning movements at intersections, in order to more accurately simulate real-world traffic conditions. One example is the left turn from Kote Marjanishvili Street to Giorgi Chitaia Street, which was considered prohibited in the model despite being permitted in reality. (Figure 51).



Left turn in the model



Turn in the map

Figure 51. Left turn from Kote Marjanishvili street to Giorgi Chitaiia street

According to the requirements of the ToR, the modelling area was significantly increased due to inclusion of the suburban areas (for more details, see *Model zoning system*, Figure 3). As a result, it was necessary to expand the road network to cover new transport zones. In light of the above, it was decided to prepare a new road network layer to integrate any required details or characteristics of the road network. The road network from the open data source OpenStreetMap (OSM)⁸ was used as a basis (Figure 52).

⁸ <https://www.openstreetmap.org/>

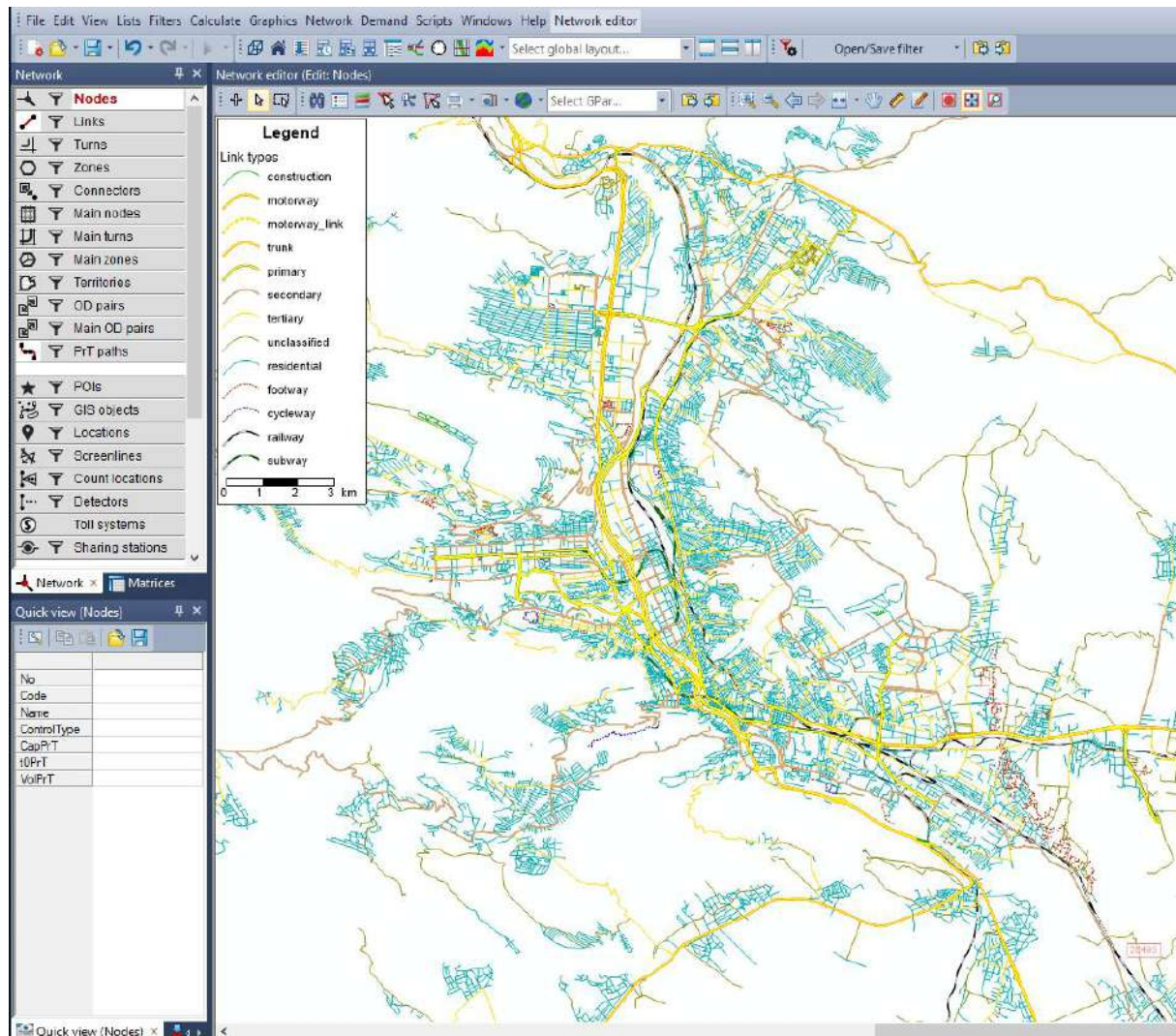


Figure 52. Road network with OSM

The network imported from OSM, included 32 types of links (Figure 53).

List (Link types)

Select list layout...

Links: Default values... Adjust link types... Group by global type

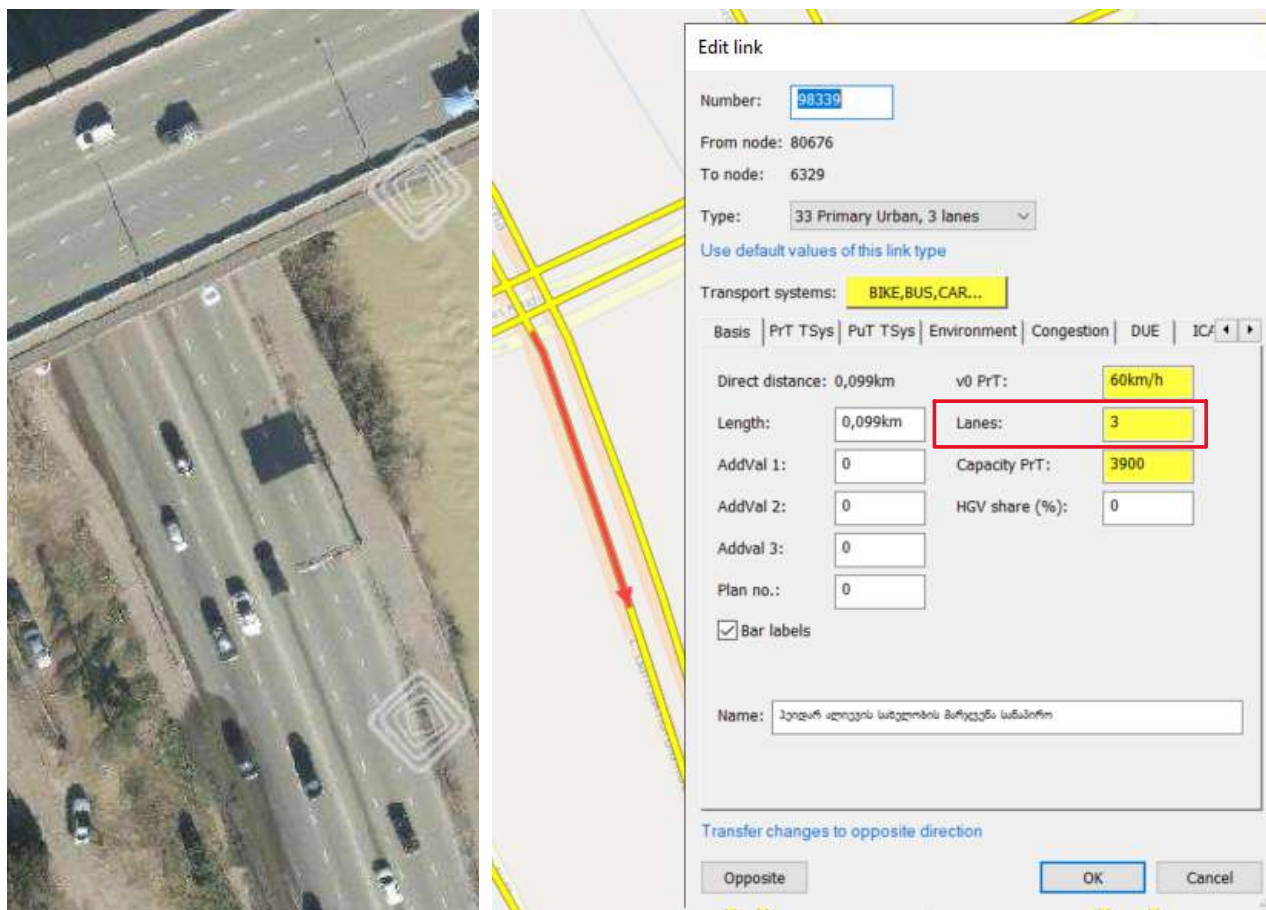
Number: 100	No	GType	Name	Strict	Rank	TSysSet	NumLanes	CapPrT	VOPrT
1	0	0	Blocked Oneway	☐	1	BIKE,PED	0	0	0km/h
2	1	0	Construction	☐	1	...	0	0	0km/h
3	2	0	NA	☐	1	BIKE,PED	0	0	0km/h
4	3	0	NA	☐	1	BIKE,PED	0	0	0km/h
5	4	0	NA	☐	1	BIKE,PED	0	0	0km/h
6	5	0	NA	☐	1	BIKE,PED	0	0	0km/h
7	6	0	NA	☐	1	BIKE,PED	0	0	0km/h
8	7	0	NA	☐	1	BIKE,PED	0	0	0km/h
9	8	0	NA	☐	1	BIKE,PED	0	0	0km/h
10	9	0	NA	☐	1	BIKE,PED	0	0	0km/h
11	10	1	Motorway, 1 lane	☐	1	CAR,HGV	1	1500	130km/h
12	11	1	Motorway, 2 lanes	☐	1	CAR,HGV	2	3000	130km/h
13	12	1	Motorway, 3 lanes	☐	1	CAR,HGV	3	4500	130km/h
14	13	1	Motorway, 4 lanes	☐	1	CAR,HGV	4	6000	130km/h
15	14	1	NA	☐	1	BIKE,CAR,HGV,PED	0	0	0km/h
16	15	1	NA	☐	1	BIKE,CAR,HGV,PED	0	0	0km/h
17	16	1	NA	☐	1	BIKE,CAR,HGV,PED	0	0	0km/h
18	17	1	NA	☐	1	BIKE,CAR,HGV,PED	0	0	0km/h
19	18	1	Motorway_link, 1 lane	☐	1	CAR,HGV	0	1100	80km/h
20	19	1	Motorway_link, 2 lanes	☐	1	CAR,HGV	0	1200	80km/h
21	20	2	Trunk, 1 lane	☐	1	BUS,CAR,HGV	1	1500	100km/h
22	21	2	Trunk, 2 lanes	☐	1	BUS,CAR,HGV	2	3000	100km/h
23	22	2	Trunk, 3 lanes	☐	1	BUS,CAR,HGV	3	4500	100km/h
24	23	2	NA	☐	1	BIKE,BUS,CAR,HGV,PED	0	0	0km/h
25	24	2	NA	☐	1	BIKE,BUS,CAR,HGV,PED	0	0	0km/h
26	25	2	NA	☐	1	BIKE,BUS,CAR,HGV,PED	0	0	0km/h
27	26	2	NA	☐	1	BIKE,BUS,CAR,HGV,PED	0	0	0km/h
28	27	2	NA	☐	1	BIKE,BUS,CAR,HGV,PED	0	0	0km/h
29	28	2	Trunk_link, 1 lane	☐	1	BUS,CAR,HGV	1	1100	80km/h
30	29	2	Trunk_link, 2 lanes	☐	1	BUS,CAR,HGV	2	1200	80km/h
31	30	3	Primary, 1 lane	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	1	1300	100km/h
32	31	3	Primary, 2 lanes	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	2	2600	100km/h
33	32	3	Primary, 3 lanes	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	3	3900	100km/h
34	33	3	NA	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	2	0	0km/h
35	34	3	NA	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	2	0	0km/h
36	35	3	NA	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	2	0	0km/h
37	36	3	NA	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	1	0	0km/h
38	37	3	NA	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	1	0	0km/h
39	38	3	NA	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	1	0	0km/h
40	39	3	Primary_link	☐	1	BIKE,BUS,CAR,HGV,PED,PUTW	1	1000	40km/h
41	40	4	Secondary, 1 lane	☐	1	BIKE,BUS,CAR,HGV,PED	1	1000	80km/h
42	41	4	Secondary, 2 lanes	☐	1	BIKE,BUS,CAR,HGV,PED	2	2000	80km/h

Figure 53. Fragment of a list of link types from the road network graph from OSM

This road network was subsequently refined and detailed. At the initial stage of work, the number of lanes and types of links were verified. As a source data, the data from the Tbilisi city geocadastre (as of 2024)⁹ was used. The adopted classification of road network links and the corresponding number of traffic lanes reflect their general geometric characteristics. At the same time, when determining the actual number of lanes available for traffic, the presence of on-street parking is additionally taken into account. The primary source of data on parking arrangements in Tbilisi was a dedicated layer, “პარკინგები”, from the Tbilisi city geocadastre. On links where on-street parking is permitted, the effective number of traffic lanes is reduced compared to the nominal number of lanes defined according to the link type.

The level of detail of the provided data allowed to verify with sufficient accuracy the geometric parameters of the road network (Figure 54).

⁹ <https://ms.gov.ge/msmap/#C=44.7888803-41.7472493@Z=12>



Data from the geocadastre

Data from the model

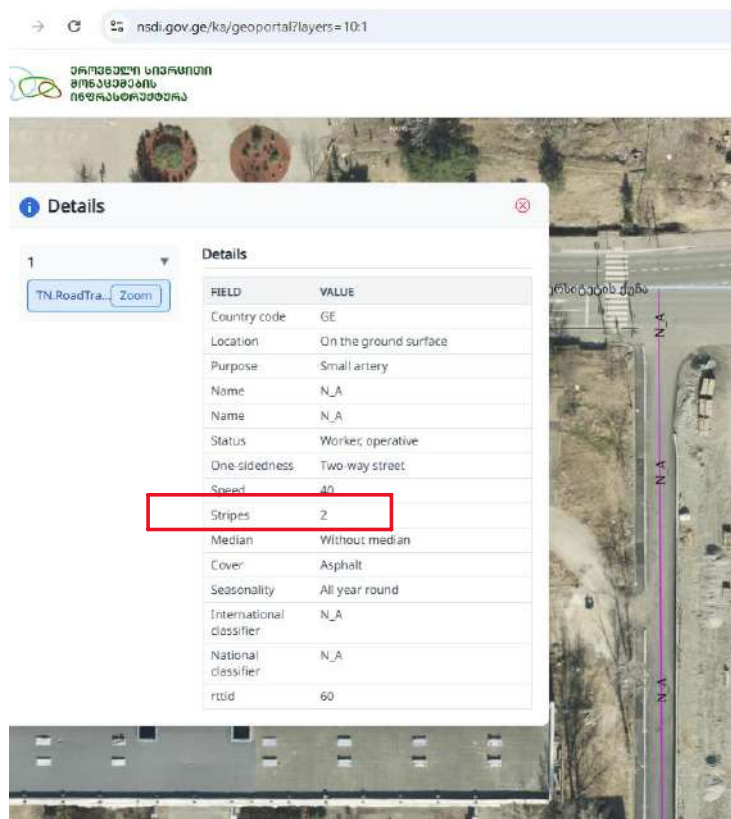
Figure 54. Using satellite images from the geocadastre to verify the road network

The number of traffic lanes outside the territory, that had been represented in the Tbilisi city geocadastre, was checked using the data from GoogleMaps¹⁰, YandexMaps¹¹ cartographic services and general Georgia cadastral data¹² (Figure 55).

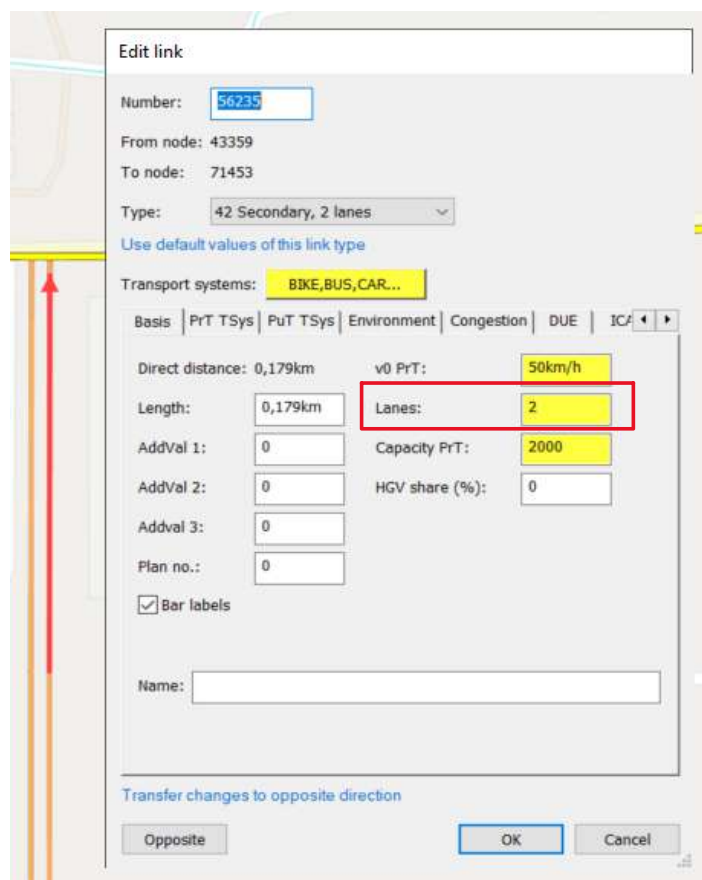
¹⁰ <https://www.google.com/maps/>

¹¹ <https://yandex.com/maps/>

¹² <https://nsdi.gov.ge/ka/geoportat?layers=10:1>



Data from National Geoportal



Model data

Figure 55. Using geocadastre data to verify the road network

In the 2022 transport model, specific Mobility vs Accessibility research was conducted to classify link types (Figure 56).

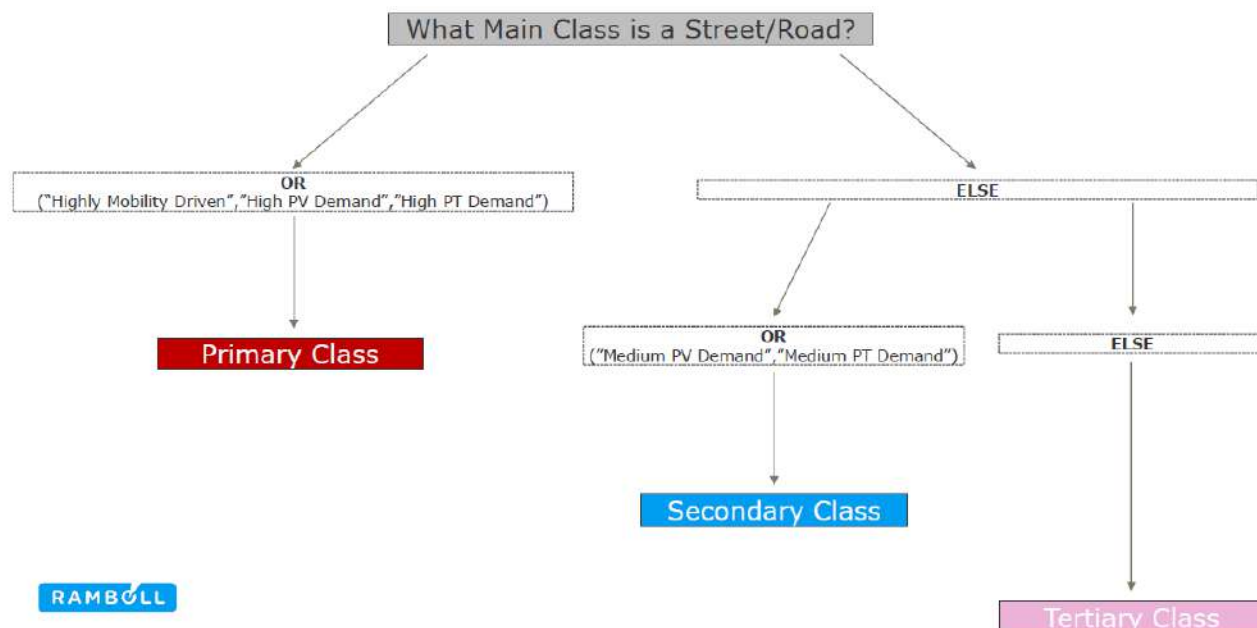


Figure 56. The concept of link classification in the Tbilisi 2022 transport model

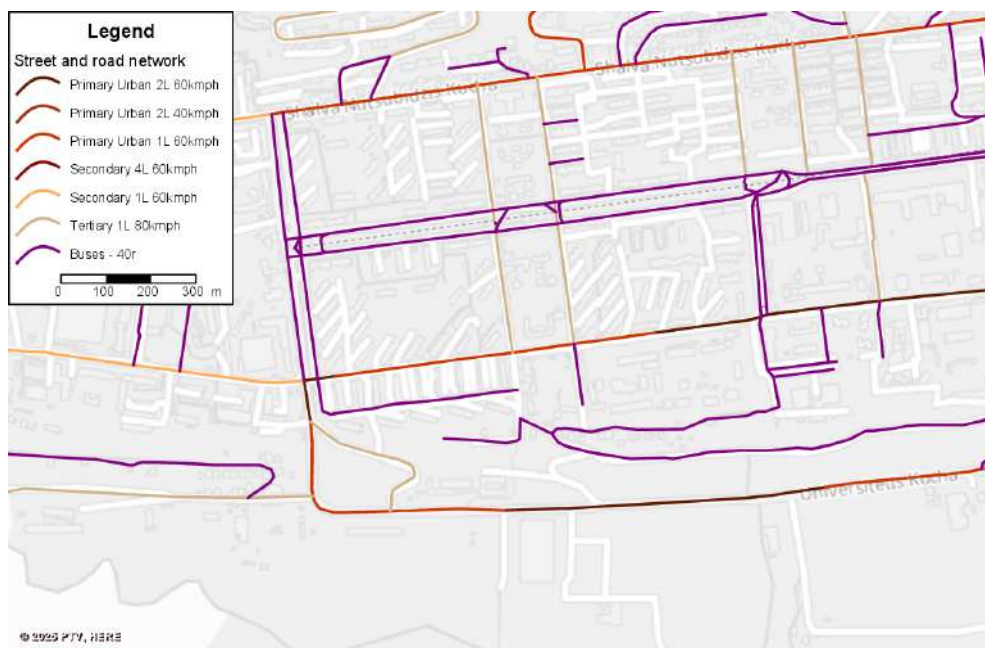
The presented classification of the road network was verified during the 2021 workshop, and it was considered as one of the data sources for the update of the transport model. However, since the road network of Tbilisi has changed in last years, the previously defined classification was used only partially when classifying link types. For listed purpose, the attribute information about the link types and names in the previous transport model was “linked” to the road network in the updated model (Figure 57).

List (Links)

Number	17 No	FromNodeNo	ToNodeNo	TypeNo	Change_Rambool_Linktype	Name link types_Rambool	Number link types_Rambool	VD link types_Rambool	TSysSet	Length	NumLanes	CapP-T	VOP-T
1	3	4	5	21	☒	Primary Rural 1L 70kmph	135	70km/h	BIKE,BUS,CAR,HGV,MS,PED	0.463km	1	1500	80km/h
2	3	5	4	21	☒	Primary Rural 1L 70kmph	135	70km/h	BIKE,BUS,CAR,HGV,MS,PED	0.463km	1	1500	80km/h
3	4	6	7	34	☒	Primary Urban 3L 60kmph	108	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.061km	4	5200	60km/h
4	4	7	6	34	☒	Primary Urban 3L 60kmph	108	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.061km	4	5200	60km/h
5	5	8	9	38	☒	Primary Urban 1L 60kmph	116	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.077km	1	1000	40km/h
6	6	10	35619	32	☒	Primary Urban 2L 60kmph	112	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.148km	2	2600	60km/h
7	6	35619	10	32	☒	Primary Urban 2L 60kmph	112	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.148km	2	2600	60km/h
8	8	12	13	31	☒	Primary Urban 2L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.014km	1	1300	60km/h
9	8	13	12	31	☒	Primary Urban 2L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.014km	1	1300	60km/h
10	11	17	26821	22	☒	Primary Rural 2L 80kmph	129	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.115km	2	3000	80km/h
11	12	26821	18	22	☒	Primary Rural 2L 80kmph	129	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.366km	2	3000	80km/h
12	13	19	20	22	☒	Primary Rural 2L 80kmph	129	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.174km	2	3000	80km/h
13	14	21	22	22	☒	Primary Rural 2L 110kmph	184	110km/h	BIKE,BUS,CAR,HGV,MS,PED	0.578km	2	3000	80km/h
14	15	23	26750	32	☒	Primary Urban 2L 80kmph	110	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.291km	2	2600	60km/h
15	16	26750	54	32	☒	Primary Urban 2L 80kmph	110	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.084km	2	2600	60km/h
16	17	54	24	32	☒	Primary Urban 2L 80kmph	110	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.176km	2	2600	60km/h
17	18	25	26737	32	☒	Primary Rural 2L 80kmph	129	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.060km	2	2600	60km/h
18	19	26737	26	32	☒	Primary Rural 2L 80kmph	129	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.314km	2	2600	60km/h
19	20	27	12725	22	☒	Primary Rural 2L 110kmph	184	110km/h	BIKE,BUS,CAR,HGV,MS,PED	0.418km	2	3000	80km/h
20	21	12725	28	22	☒	Primary Rural 2L 80kmph	129	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.240km	2	3000	80km/h
21	22	29	30	32	☒	Primary Urban 1L 60kmph	112	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.243km	2	2600	60km/h
22	23	31	32	38	☒	Primary Urban 1L 60kmph	116	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.155km	1	1000	40km/h
23	24	33	34	31	☒	Primary Urban 1L 60kmph	116	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.161km	1	1300	60km/h
24	26	37	38	31	☒	Primary Urban 1L 60kmph	116	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.244km	1	1300	60km/h
25	27	39	3752	31	☒	Primary Urban 1L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.426km	1	1300	60km/h
26	27	3752	39	31	☒	Primary Urban 1L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.426km	1	1300	60km/h
27	28	3752	28140	31	☒	Primary Urban 1L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.885km	1	1300	60km/h
28	28	28140	3752	31	☒	Primary Urban 1L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.885km	1	1300	60km/h
29	29	40	28140	31	☒	Primary Urban 1L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	1.105km	1	1300	60km/h
30	29	28140	40	31	☒	Primary Urban 1L 80kmph	115	80km/h	BIKE,BUS,CAR,HGV,MS,PED	1.105km	1	1300	60km/h
31	30	41	42	38	☒	Primary Urban 1L 60kmph	116	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.116km	1	1000	40km/h
32	32	32079	36100	32	☒	Primary Urban 2L 80kmph	110	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.083km	2	2600	60km/h
33	33	36100	44	32	☒	Primary Urban 2L 80kmph	110	80km/h	BIKE,BUS,CAR,HGV,MS,PED	1.142km	2	2600	60km/h
34	34	45	31081	31	☒	Primary Urban 3L 80kmph	106	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.023km	1	1300	60km/h
35	35	31081	46	31	☒	Primary Urban 3L 80kmph	106	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.135km	1	1300	60km/h
36	36	47	48	31	☒	Primary Urban 2L 80kmph	110	80km/h	BIKE,BUS,CAR,HGV,MS,PED	0.236km	1	1300	60km/h
37	38	50	8329	32	☒	Primary Urban 1L 60kmph	116	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.039km	2	2600	60km/h
38	38	8329	50	31	☒	Primary Urban 1L 60kmph	116	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.039km	1	1300	60km/h
39	39	51	52	51	☐	Buses - 40r	169	40km/h	BIKE,BUS,CAR,HGV,MS,PED	0.078km	1	800	40km/h
40	39	52	51	51	☐	Buses - 40r	169	40km/h	BIKE,BUS,CAR,HGV,MS,PED	0.078km	1	800	40km/h
41	41	52	55	51	☐	Buses - 40r	169	40km/h	BIKE,BUS,CAR,HGV,MS,PED	0.663km	1	800	40km/h
42	41	55	52	51	☐	Buses - 40r	169	40km/h	BIKE,BUS,CAR,HGV,MS,PED	0.663km	1	800	40km/h
43	42	56	57	51	☐	Buses - 40r	169	40km/h	BIKE,BUS,CAR,HGV,MS,PED	0.039km	1	800	40km/h
44	42	57	56	51	☐	Buses - 40r	169	40km/h	BIKE,BUS,CAR,HGV,MS,PED	0.039km	1	800	40km/h
45	43	50	58	0	☐	Buses - 40r	169	40km/h	PED	0.054km	0	0	0km/h
46	43	58	50	51	☐	Buses - 40r	169	40km/h	BIKE,BUS,CAR,HGV,MS,PED	0.054km	1	800	40km/h
47	44	59	2660	41	☒	Secondary 1L 60kmph	151	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.036km	1	1000	50km/h
48	44	2660	59	41	☒	Secondary 1L 60kmph	151	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.036km	1	1000	50km/h
49	45	2660	3711	41	☒	Secondary 1L 60kmph	151	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.174km	1	1000	50km/h
50	45	3711	2660	41	☒	Secondary 1L 60kmph	151	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.174km	1	1000	50km/h
51	46	2662	3711	41	☒	Secondary 1L 60kmph	151	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.190km	1	1000	50km/h
52	46	3711	2662	41	☒	Secondary 1L 60kmph	151	60km/h	BIKE,BUS,CAR,HGV,MS,PED	0.190km	1	1000	50km/h

Figure 57. List of links with attributes from the transport model of Tbilisi 2022

All links in the 2022 model that were categorized under the same type but had different speeds were grouped together. These links were assigned a unified type in the road network of the updated model. When the link type changed several times along short sections of the same street (not always in a logical manner), a single link type was assigned to the entire length of the road (for example, Figure 58 reveals different segments of the same road set to Primary Urban type).



Model 2022



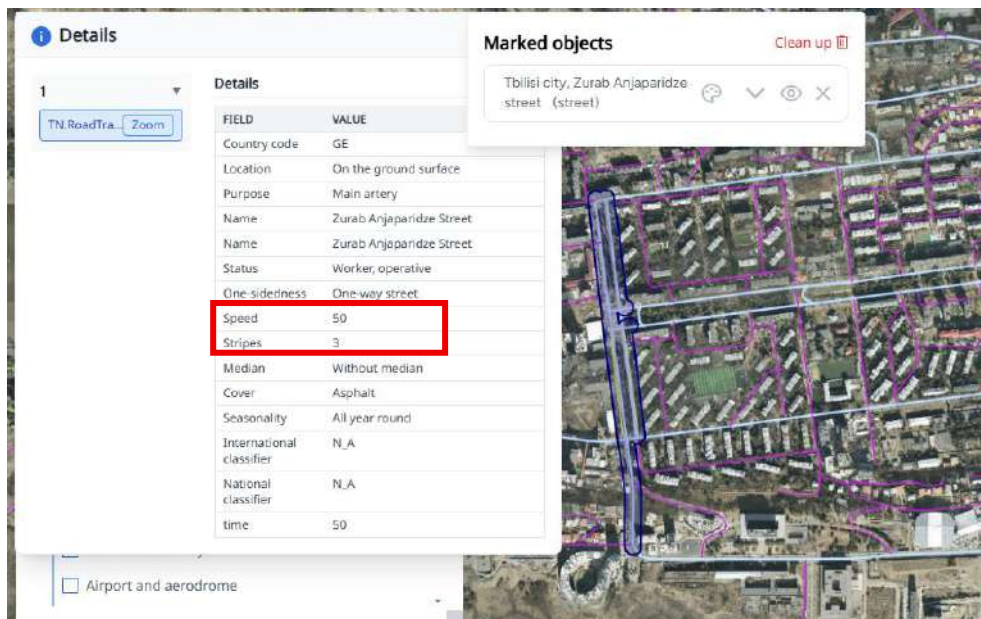
Updated Model

Figure 58. Comparison of link types for a road network fragment

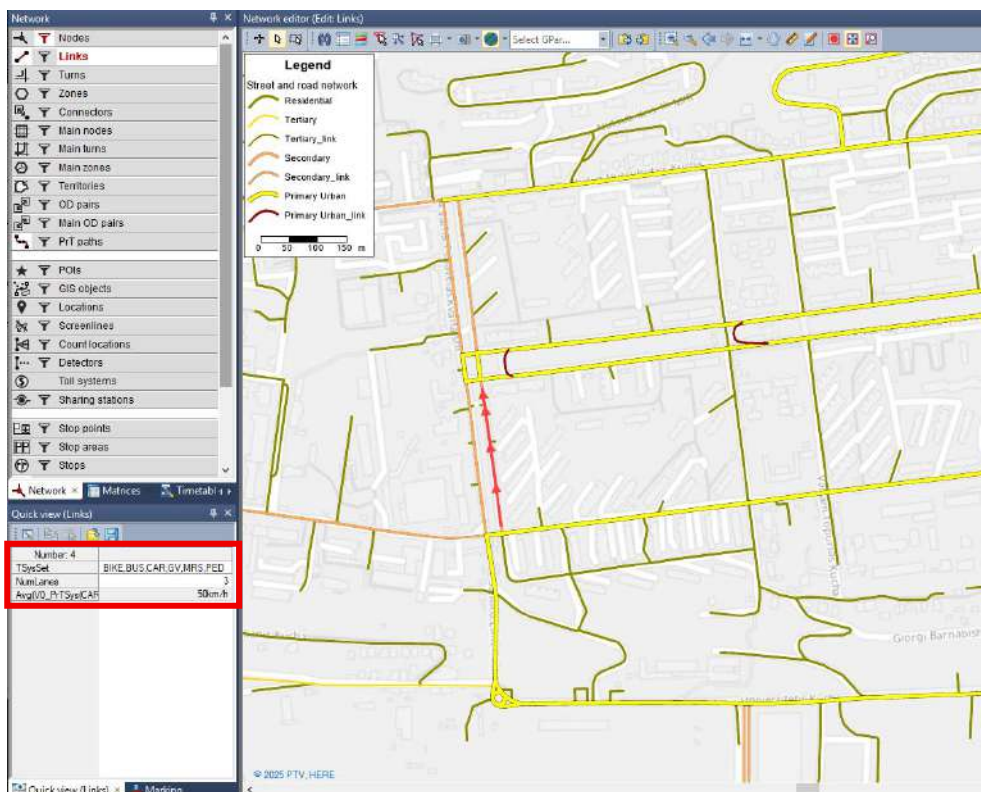
For all road sections that were not included in the 2022 transport model, the link type was assigned based on the OSM classification and on the previously adopted classification for adjacent sections.

In the final stage of the road network verification, cadastral data for the whole of Georgia¹³ was used. At this stage, data about street categories, traffic speeds, and number of lanes in the model and in the reference cadastre were selectively verified (Figure 59).

¹³ <https://nsdi.gov.ge/ka/geoportat?layers=10:1>



Cadastral data



Data from the model

Figure 59. Using cadastral data to verify the road network

In addition to the network links, the node types and the permitted/prohibited turns for each of them were checked. All nodes exported from OSM were assigned with two node control types by default: “unknown” and “signalized.” (Figure 60).

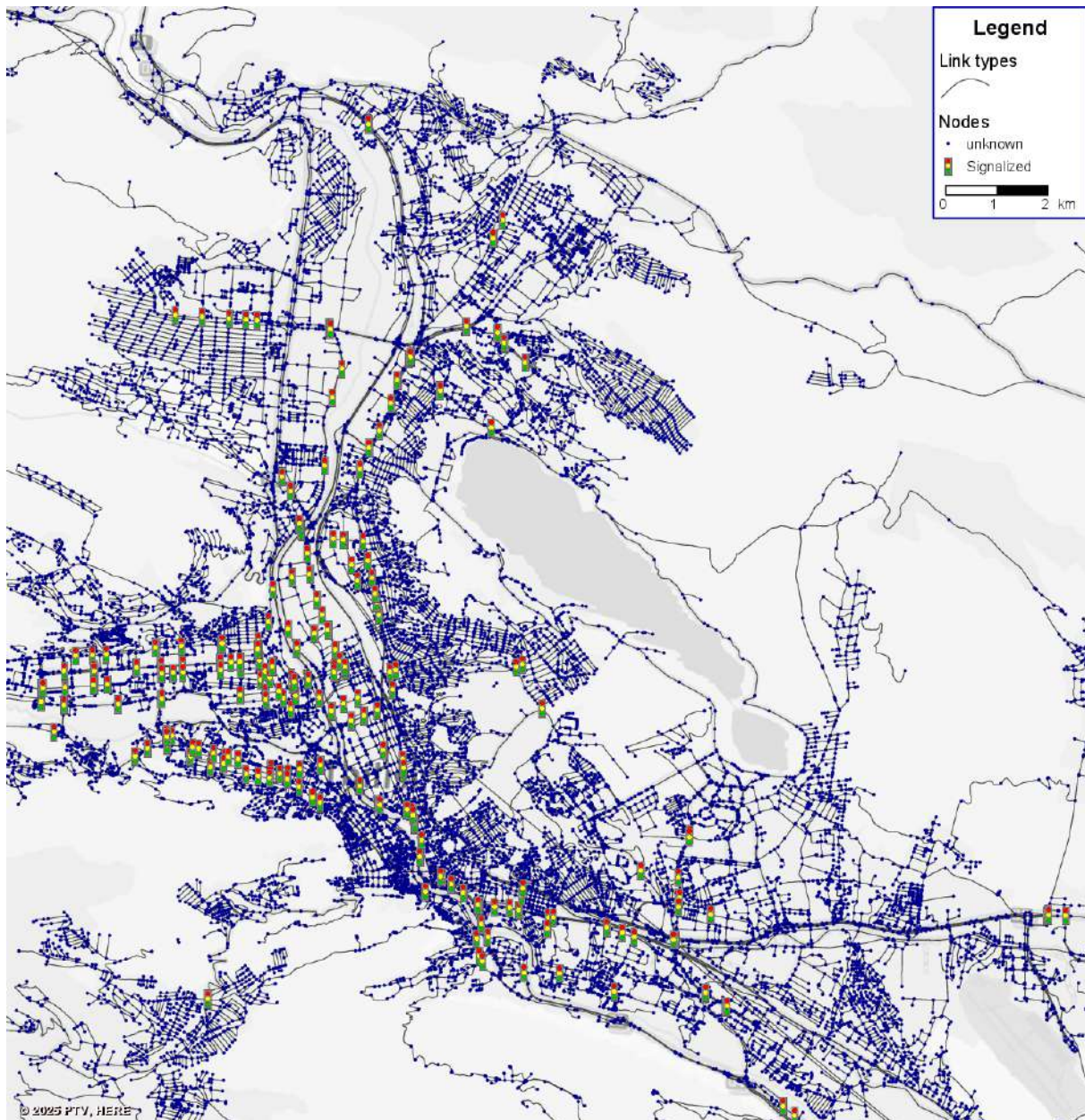


Figure 60. Road network nodes as a result of data export from OSM

A list of signalized intersections was obtained from TUDA as a source data. This data was used to verify nodes when updating the road network (Figure 61).

The official dataset contains a significantly higher number of signalized intersections, while the OSM-based data used in the previous figure has more limited and incomplete coverage of traffic signal control.

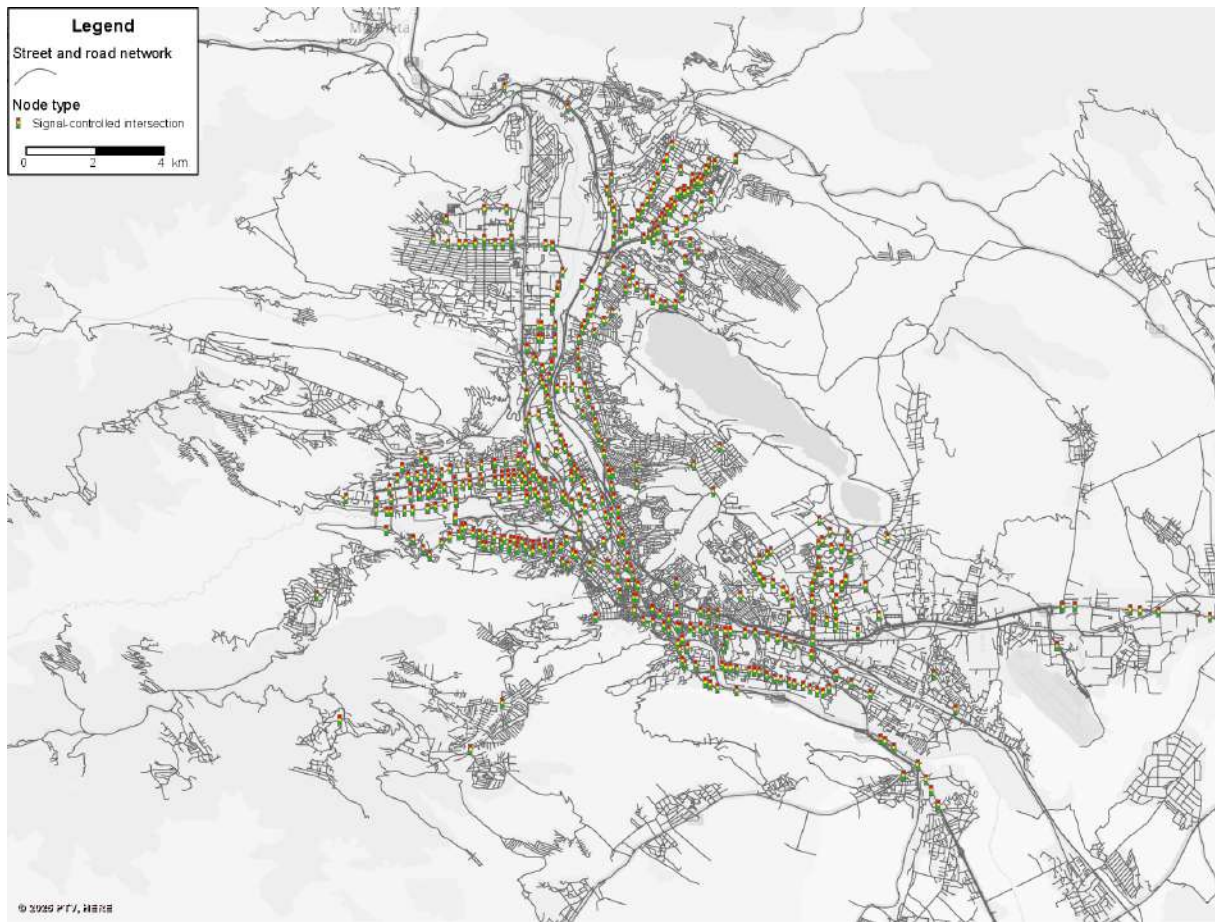


Figure 61. Signal-controlled nodes were verified based on data provided by TUDA

To enable the modelling of different scenarios involving changes to the road network, an additional node type—“Two-way yield” – was introduced. This node type is used for unsignalized intersections where traffic flows from different directions have different priorities, and movements follow a “give way” rule (Figure 62).



Figure 62. Two-way yield intersections

After that, permitted/prohibited turns were checked at all intersections with traffic light control and two-way yield type.

Roundabouts are represented using links and nodes of the type “two-way yield.” An example of such a node is shown in Figure 63.

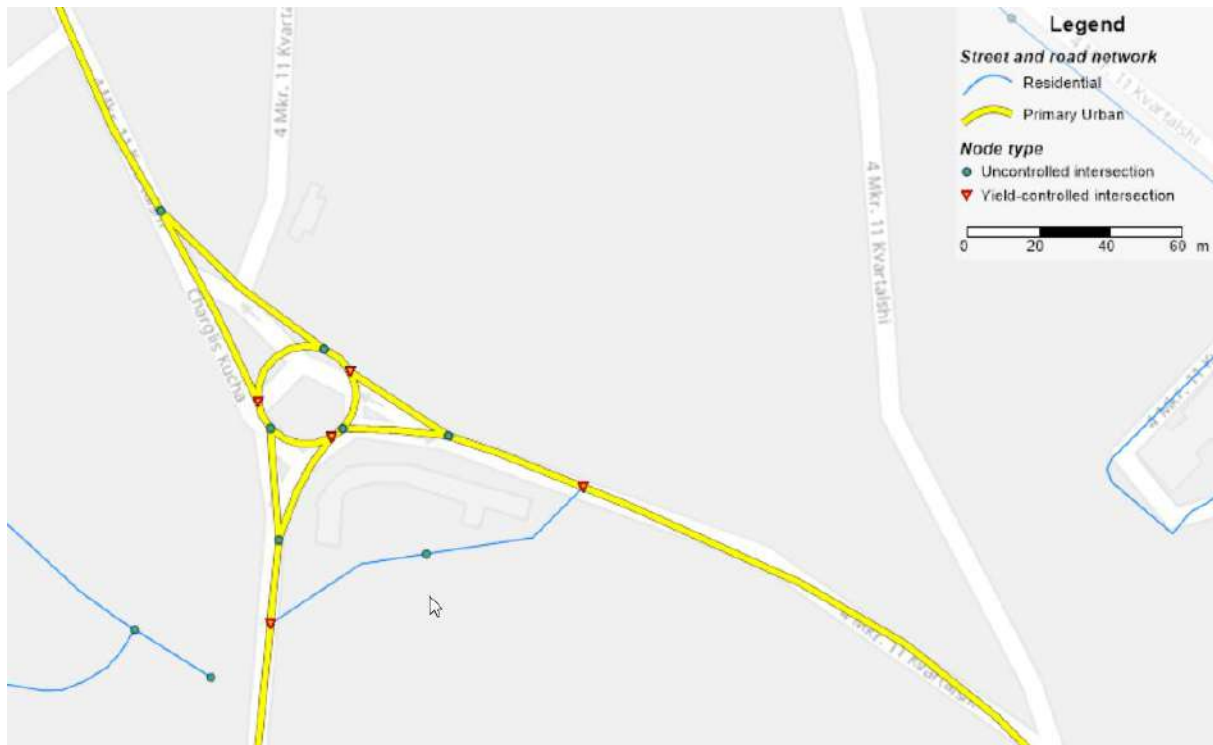
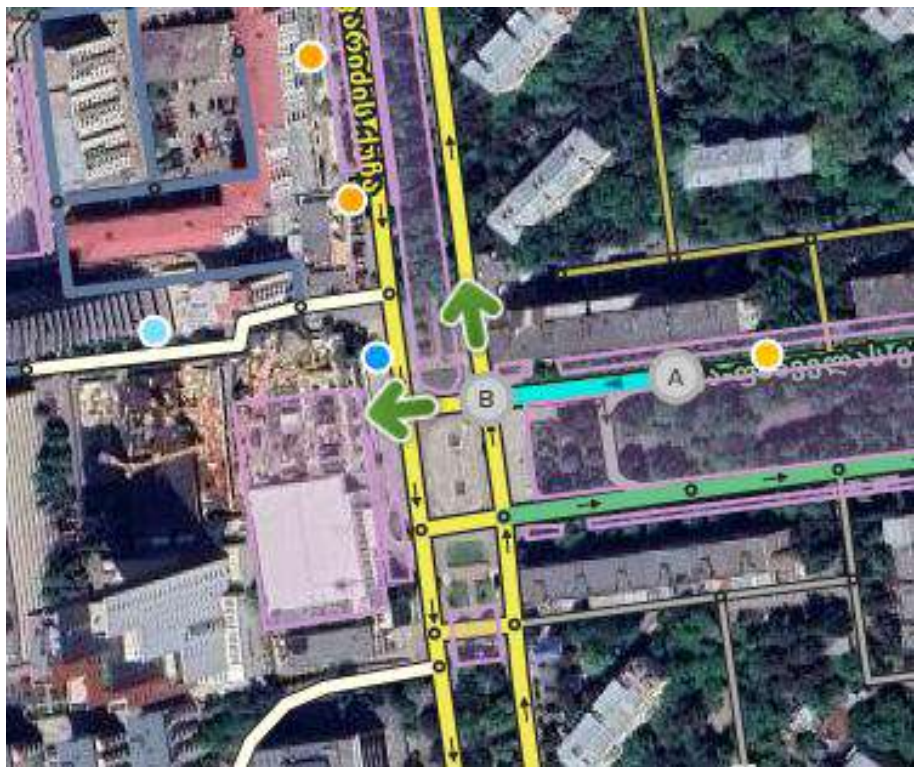


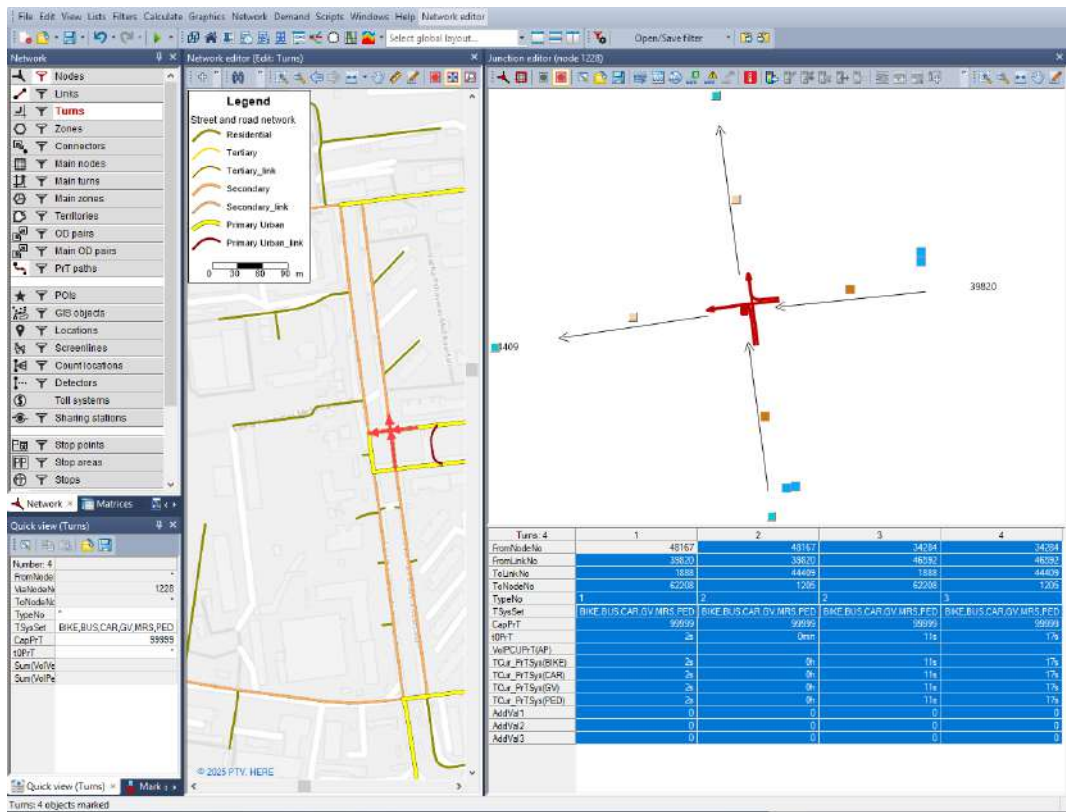
Figure 63. A roundabout at the intersection of Gia Romelashvili and Chargali Street

For this verification, Waze¹⁴ data was used as the key data source. An example of using Waze data to verify turning movements at nodes in the transport model is shown in (Figure 64). Allowed movements at intersections in the model were checked by comparing them with permitted turns derived from Waze data.

¹⁴<https://www.waze.com/editor/?env=row>



Waze data



Model data

Figure 64. Using Waze data to verify turns - the example of the intersection of Zurab Anjaparidze Street and Vazha - Pshavela Avenue

For additional verification, data from other open sources, such as the Tbilisi city geocadastre¹⁵, the Google Maps¹⁶ and Yandex Maps¹⁷ cartographic services, was used. As a result, these changes allowed to prepare the final version of the network, which was further used in the updated Tbilisi transport model (Figure 65).

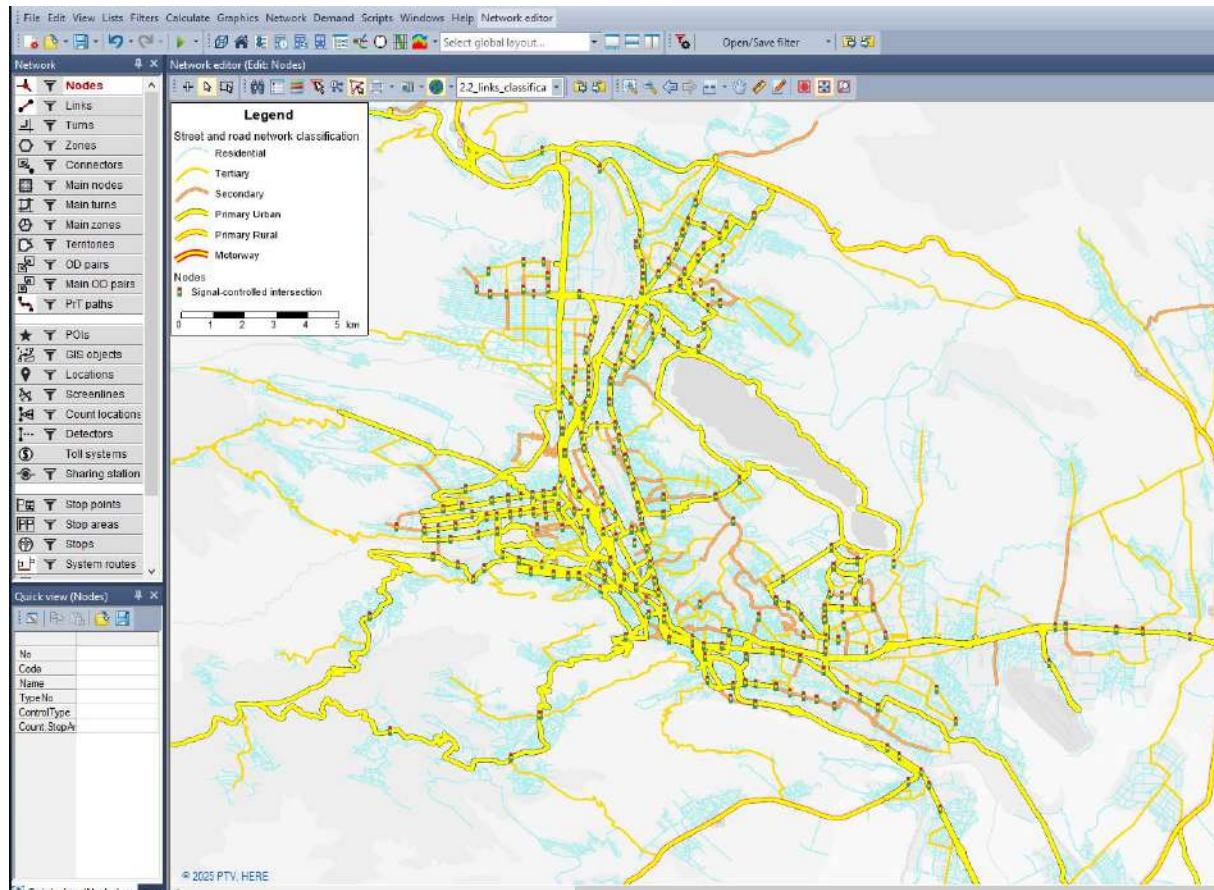


Figure 65. Illustration of the verified road network in the updated model

The visualisation of the road network links, classified according to the number of lanes per direction (excluding parking lanes), is given in Figure 66.

¹⁵ <https://ms.gov.ge/msmap/#C=44.7888803-41.7472493@Z=12>

¹⁶ <https://www.google.com/maps/>

¹⁷ <https://yandex.com/maps/>

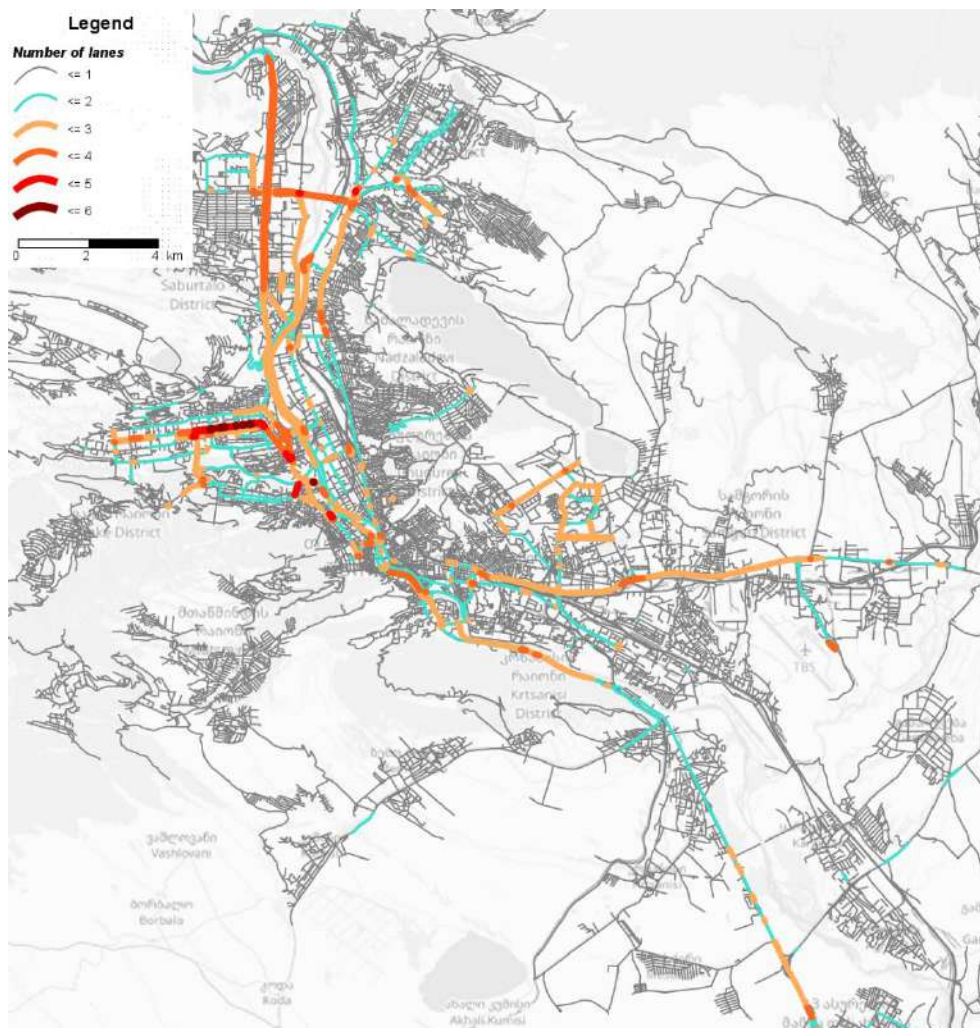


Figure 66. Number of lanes on the road network

4.2.2. Links

A **link** represents a **road segment** within the transport network. Each link is characterised by attributes:

- Length
- Number of lanes
- Speed limits
- Traffic capacity
- Permitted transport systems

From a modelling perspective, the functional classification of streets and roads is translated into road link types, each one having distinct attributes, including:

- NAME – Link type name
- RANK – Hierarchical level
- TSYSSET – Permitted transport systems
- NUMLANES – Number of lanes
- CAPPRT – Traffic capacity
- V0 PRT – Free-flow speed for private vehicles

The list of link types and their key attributes used in the model is provided in Table 2.

Table 2. Sample of Road Link Types in the Transport Model

No	Name	Rank	TSysSet	Num Lanes	CapPrT	V0PrT
1	Blocked Oneway	99	PED	0	999999	5km/h
2	Construction	99		0	999999	0km/h
3	Subway	99	SUB	0	999999	0km/h
4	Cycleway	99	BIKE	1	999999	15km/h
5	Busway	19	BIKE,BUS,MRS,PED	1	0	5km/h
6	Cable	99	C	0	0	0km/h
7	Funicular	99	F	0	0	0km/h
8	Motorway, 1 lane	4	BIKE,BUS,CAR,GV,MRS,PED	1	1500	110km/h
9	Motorway, 2 lanes	3	BIKE,BUS,CAR,GV,MRS,PED	2	3000	110km/h
10	Motorway, 3 lanes	2	BIKE,BUS,CAR,GV,MRS,PED	3	4500	110km/h
11	Motorway, 4 lanes	1	BIKE,BUS,CAR,GV,MRS,PED	4	6000	110km/h
12	Primary Rural, 1 lane	13	BIKE,BUS,CAR,GV,MRS,PED	1	1500	70km/h
13	Primary Rural, 2 lanes	12	BIKE,BUS,CAR,GV,MRS,PED	2	3000	80km/h
14	Primary Rural, 3 lanes	11	BIKE,BUS,CAR,GV,MRS,PED	3	4500	110km/h
15	Primary Rural, 4 lanes	10	BIKE,BUS,CAR,GV,MRS,PED	4	6000	110km/h
16	Primary Rural_link, 1 lane	15	BIKE,BUS,CAR,GV,MRS,PED	1	1100	40km/h
17	Primary Rural_link, 2 lanes	14	BIKE,BUS,CAR,GV,MRS,PED	2	2200	40km/h
18	Primary Urban, 1 lane	25	BIKE,BUS,CAR,GV,MRS,PED	1	1300	60km/h
19	Primary Urban, 2 lanes	24	BIKE,BUS,CAR,GV,MRS,PED	2	2600	65km/h
20	Primary Urban, 3 lanes	23	BIKE,BUS,CAR,GV,MRS,PED	3	3900	65km/h
21	Primary Urban, 4 lanes	22	BIKE,BUS,CAR,GV,MRS,PED	4	5200	65km/h
22	Primary Urban, 5 lanes	21	BIKE,BUS,CAR,GV,MRS,PED	5	6500	70km/h
23	Primary Urban, 6 lanes	20	BIKE,BUS,CAR,GV,MRS,PED	6	7800	70km/h
24	Primary Urban_link, 1 lane	27	BIKE,BUS,CAR,GV,MRS,PED	1	1000	40km/h
25	Primary Urban_link, 2 lane	26	BIKE,BUS,CAR,GV,MRS,PED	2	2000	40km/h
26	Secondary, 1 lane	33	BIKE,BUS,CAR,GV,MRS,PED	1	1000	50km/h
27	Secondary, 2 lanes	32	BIKE,BUS,CAR,GV,MRS,PED	2	2000	55km/h
28	Secondary, 3 lanes	31	BIKE,BUS,CAR,GV,MRS,PED	3	3000	55km/h
29	Secondary, 4 lanes	30	BIKE,BUS,CAR,GV,MRS,PED	4	4000	60km/h
30	Secondary_link, 1 lane	35	BIKE,BUS,CAR,GV,MRS,PED	1	800	30km/h
31	Secondary_link, 2 lane	34	BIKE,BUS,CAR,GV,MRS,PED	2	1600	30km/h
32	Tertiary, 1 lane	42	BIKE,BUS,CAR,GV,MRS,PED	1	800	40km/h
33	Tertiary, 2 lanes	41	BIKE,BUS,CAR,GV,MRS,PED	2	1600	40km/h
34	Tertiary, 3 lanes	40	BIKE,BUS,CAR,GV,MRS,PED	3	2400	40km/h
35	Tertiary_link	43	BIKE,BUS,CAR,GV,MRS,PED	1	800	20km/h
36	Residential, 1 lane	51	BIKE,BUS,CAR,GV,MRS,PED	1	400	40km/h
37	Residential, 2 lane	50	BIKE,BUS,CAR,GV,MRS,PED	2	800	40km/h

The naming conventions for link types include:

- Blocked Oneway – Links where access is blocked for all transport system, except PED
- Construction – Planned or under-construction roads
- Subway – Links for rapid transit system, an underground electric railway
- Cycleway – Dedicated cycling infrastructure
- Busway – Public transport lanes against the direction of traffic
- Cable – Links of Railway that uses a cable, rope or chain to haul trains
- Funicular – Links type of cable railway system that operates on a steep slope
- Motorway – A wide road for fast-moving traffic
- Primary Rural – Intercity expressways
- Primary Urban – Major roads with signalised intersections
- Secondary – Secondary roads with signalised intersections
- Tertiary – Tertiary roads with signalised intersections
- Residential – Residential and industrial streets
- *_link – exit/ entrance from/to road

4.2.3. Nodes and main nodes

Nodes serve as start and end points for links, representing intersections or junctions where traffic occurs. Nodes were categorised based on traffic control types, as shown in Table 3.

Table 3. Node Classification by Traffic Control Type

Node Type	Traffic Control
0	<i>Unsignalised</i>
3	<i>Signalised</i>
6	<i>Yield/Give Way</i>

Complex intersections composed of multiple nodes were consolidated into higher-order (main) nodes. This approach is used to simplify traffic flow modelling and to enhance accuracy in delay estimation, as it enables to reflect interactions between all entry and exit points within an intersection (Figure 67). Main nodes act as a combination of several similar (usually Signalised) nodes, like in Figure 68. This approach allows to reproduce more accurately the traffic conditions in the complex traffic intersections of Tbilisi.



Figure 67. Locations of main nodes in the Transport Model



Figure 68. Example of a main node in the Transport Model

4.2.4. Turns and main turns

Time delays for turns and main turns are assigned based on the accepted turn types. Delays were implemented based on the node types, link hierarchy, and manoeuvre type. Considering the traffic conditions in the study area, time delays for the turns and main turns are set according to assumptions listed in the Table 4: data were derived from research made using microsimulation modelling.

Table 4. Classification of time delays for different types of turns at the intersections

No	Node Type	Turn Type	Traffic Flow Hierarchy	T0_PrT (s)
1	0	1	??	5
2	0	2	??	0
3	0	3	??	5
4	0	4	??	15
5	3	1	??	25
6	3	2	??	20
7	3	3	??	30
8	3	4	??	35
9	6	1	--	15
10	6	1	-+	10
11	6	1	+ -	0
12	6	1	++	0
13	6	2	--	20
14	6	2	-+	15
15	6	2	+ -	0
16	6	2	++	0
17	6	3	--	20
18	6	3	-+	20
19	6	3	+ -	10
20	6	3	++	0
21	6	4	??	25

The traffic flow hierarchy indicated in Table 4 defines the relationship between the functional classes of the incoming and outgoing links involved in a turning movement. The following notation is used:

- “++” – turning movement from a higher-rank link to another higher-rank link (e.g. arterial to arterial);
- “--” – turning movement from a lower-rank link to another lower-rank link (e.g. local street to local street);
- “+ -” – turning movement from a higher-rank link to a lower-rank link;
- “-+” – turning movement from a lower-rank link to a higher-rank link;
- “??” – turning movement where the hierarchy of the involved links is not differentiated and the same delay is applied regardless of link rank.

This classification is applied to reflect typical operational conditions at intersections. In general, turning movements originating from lower-rank links towards higher-rank links are assumed to experience higher delays due to yielding and priority control, while movements along higher-rank links are associated with lower or zero delays under free-flow conditions.

The parameter T0_PrT represents the assumed base delay (in seconds) under free-flow conditions and is applied in the transport model for turn and main-turn movements.

In the Visum, the following classification of turn types is used: 1 – Right, 2 – Straight, 3 – Left, 4 – U-turn.

The full list of turning traffic delays and configurations is implemented within the settings of the **Turn Standards** in the model (Figure 69).

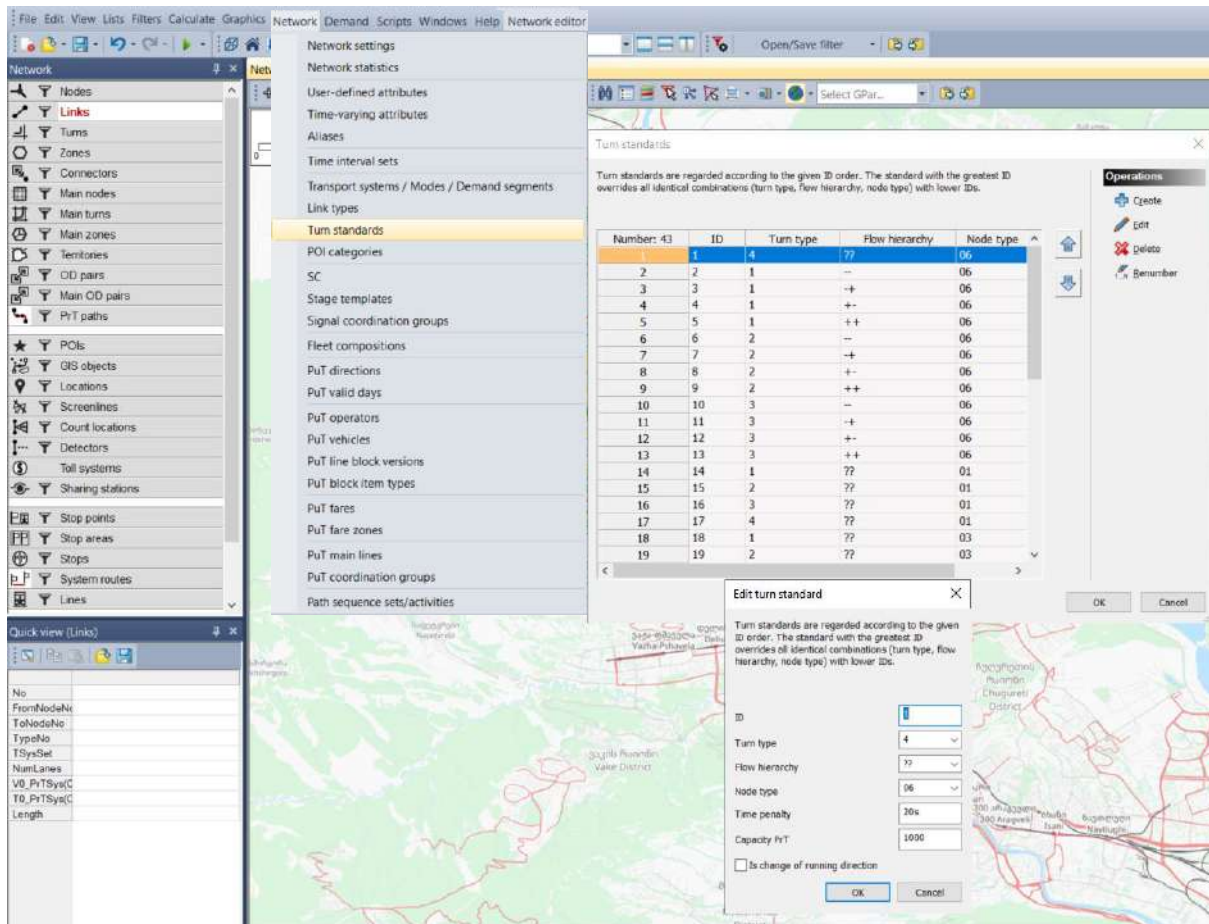


Figure 69. Turning standards settings

The example of turn traffic and associated delays at a **signalised node** is shown in Figure 70.

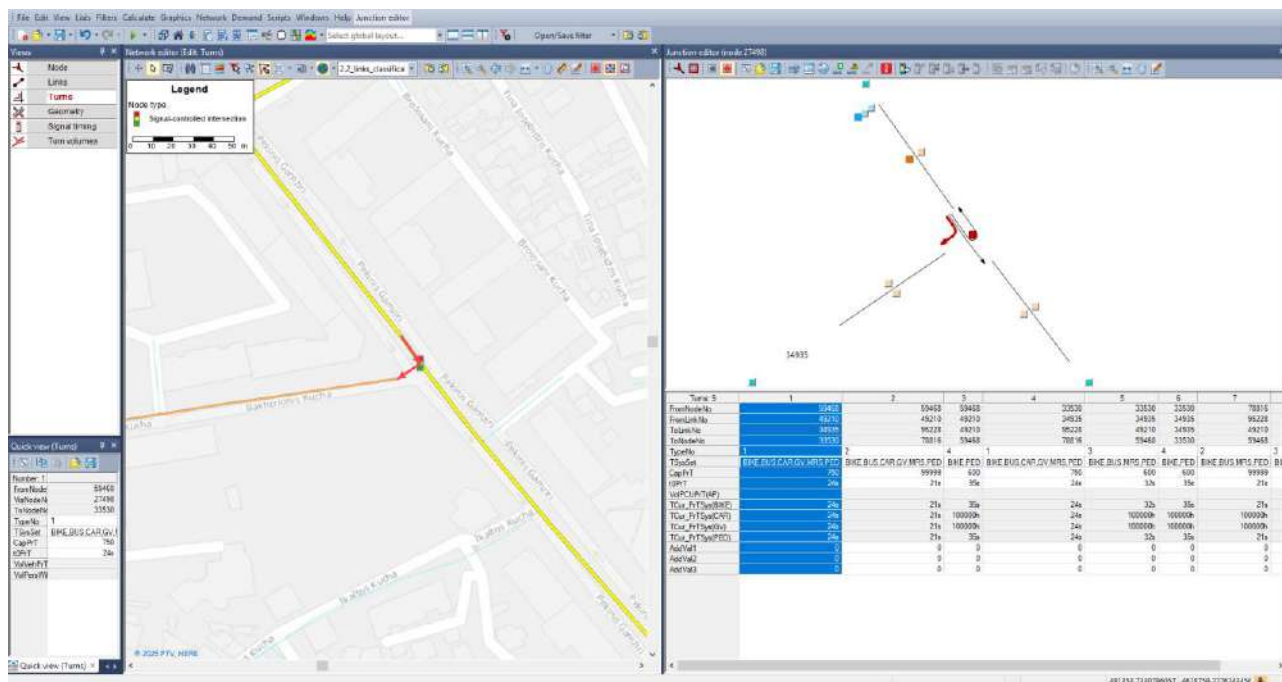


Figure 70. Example of turn delays at a signalised node

The time delays for performing the main turns are similar to those defined for turns. The setup of main turns for a main node is illustrated in Figure 71.

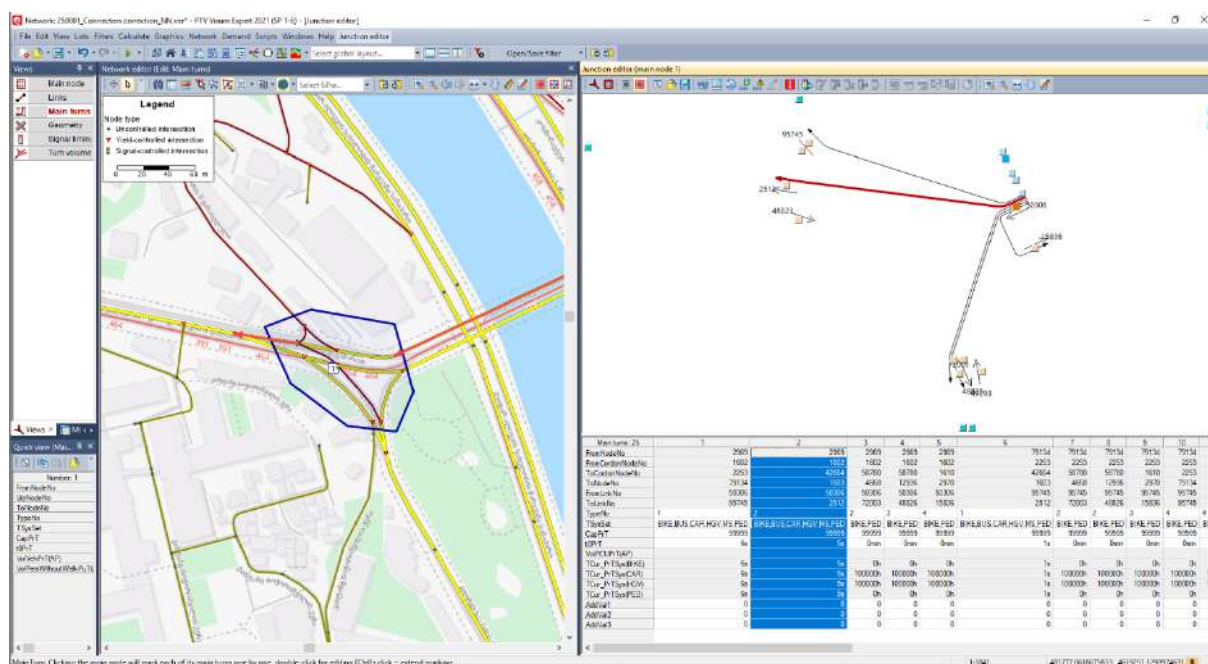


Figure 71. Example of turn delays at the main node (left: representation of the main node; right: main turning movements)

The final version of the modelled road network consists of the following elements:

- Links: over 84,000
- Nodes: over 34,000
- Main Nodes: more than 130

4.3. Public Transport Network

The public transport network, which is a major component of the transport supply model, includes detailed information about all routes and stops, the vehicle types and their capacity, service schedules, and transfer points.

4.3.1. Public transport

The preliminary analysis of the public transport network that is integrated in the 2022 model, revealed the need of improvements and refinements. In fact, quite often this component didn't match with the real traffic management regulations. Figure 72 highlights a mistake made in integrating the M302: in fact, the route was implemented in both directions on the same side of the carriageway.

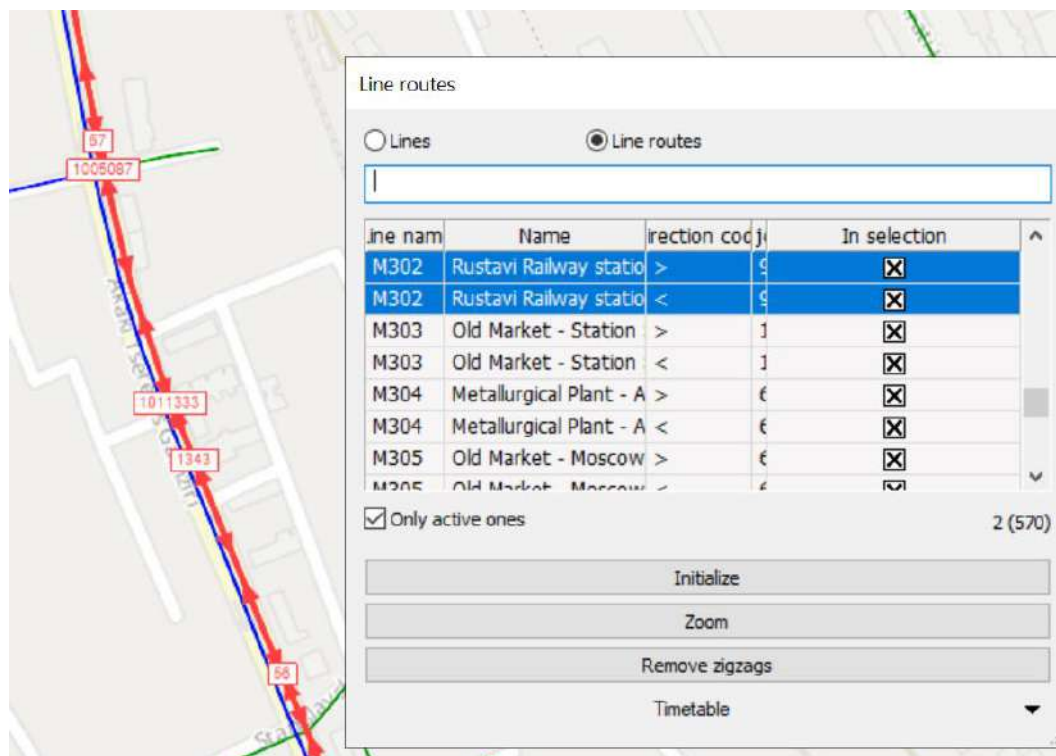


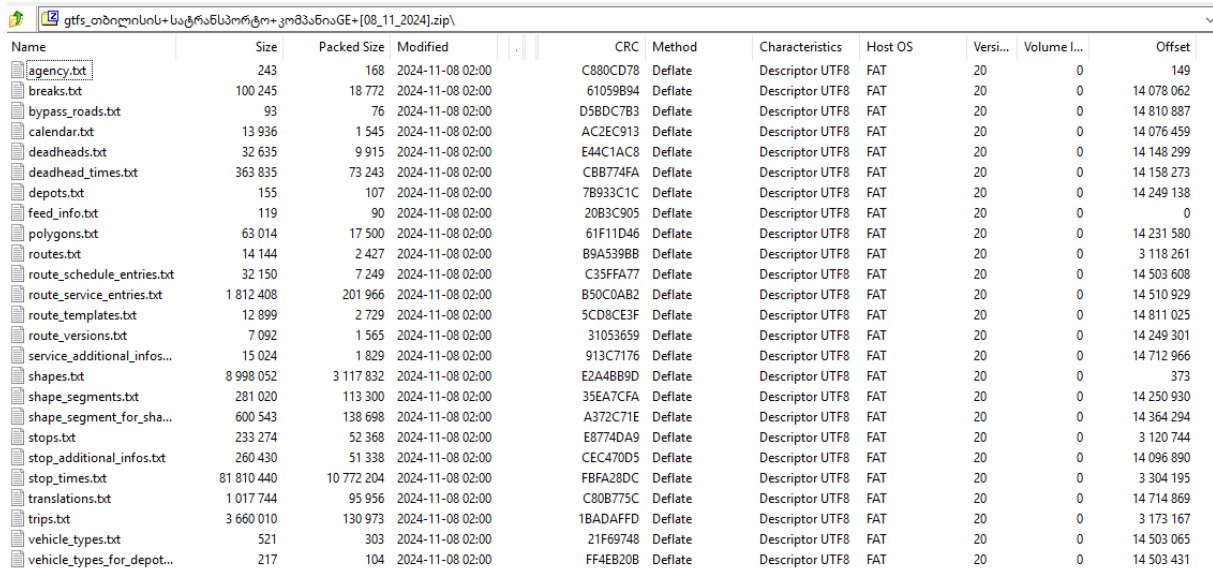
Figure 72. A part of the M302 route in the Tbilisi transport model

These settings do not allow to properly consider the impact of the congestion of the road network on the effective travel time of public transport services, and, consequently, generate the relevant risk to significantly reduce the reliability and the functionality of the transport model. To guarantee a full and correct integration of the Public Transport network and its characteristics in the model, it was decided to re-do completely this part of the supply model

The primary data sources used in this work phase are the following: General Transit Feed Specification (GTFS)¹⁸ and public transport network data provided to TUDA in the zip archive `gtfs_თბილისის სატრანსპორტო კომპანია GE+ [08_11_2024]`, with volume of 14,1Mb (Figure 73). The provided materials contain information on PuT routes, timetables, vehicles, and PuT stops in the area included in the new transport model of Tbilisi.

¹⁸ <https://gtfs.org/>

Data collection and Model update related to transport in Tbilisi – Update the Transport Demand Model



Name	Size	Packed Size	Modified	CRC	Method	Characteristics	Host OS	Versi...	Volume L...	Offset
agency.txt	243	168	2024-11-08 02:00	C880CD78	Deflate	Descriptor UTF8	FAT	20	0	149
breaks.txt	100 245	18 772	2024-11-08 02:00	61059B94	Deflate	Descriptor UTF8	FAT	20	0	14 078 062
bypass_roads.txt	93	76	2024-11-08 02:00	D5BDC7B3	Deflate	Descriptor UTF8	FAT	20	0	14 810 887
calendar.txt	13 936	1 545	2024-11-08 02:00	AC2EC913	Deflate	Descriptor UTF8	FAT	20	0	14 076 459
deadheads.txt	32 635	9 915	2024-11-08 02:00	E44C1AC8	Deflate	Descriptor UTF8	FAT	20	0	14 148 299
deadhead_times.txt	363 835	73 243	2024-11-08 02:00	C8B774FA	Deflate	Descriptor UTF8	FAT	20	0	14 158 273
depots.txt	155	107	2024-11-08 02:00	7B933C1C	Deflate	Descriptor UTF8	FAT	20	0	14 249 138
feed_info.txt	119	90	2024-11-08 02:00	20B3C905	Deflate	Descriptor UTF8	FAT	20	0	0
polygons.txt	63 014	17 500	2024-11-08 02:00	61F11D46	Deflate	Descriptor UTF8	FAT	20	0	14 231 580
routes.txt	14 144	2 427	2024-11-08 02:00	B9A539B8	Deflate	Descriptor UTF8	FAT	20	0	3 118 261
route_schedule_entries.txt	32 150	7 249	2024-11-08 02:00	C35FFA77	Deflate	Descriptor UTF8	FAT	20	0	14 503 608
route_service_entries.txt	1 812 408	201 966	2024-11-08 02:00	B50C0A82	Deflate	Descriptor UTF8	FAT	20	0	14 510 929
route_templates.txt	12 899	2 729	2024-11-08 02:00	5CD8CE3F	Deflate	Descriptor UTF8	FAT	20	0	14 811 025
route_versions.txt	7 092	1 565	2024-11-08 02:00	31053659	Deflate	Descriptor UTF8	FAT	20	0	14 249 301
service_additional_infos...	15 024	1 829	2024-11-08 02:00	913C7176	Deflate	Descriptor UTF8	FAT	20	0	14 712 966
shapes.txt	8 998 052	3 117 832	2024-11-08 02:00	E2A4B89D	Deflate	Descriptor UTF8	FAT	20	0	373
shape_segments.txt	281 020	113 300	2024-11-08 02:00	35EA7CFA	Deflate	Descriptor UTF8	FAT	20	0	14 250 930
shape_segment_for_sha...	600 543	138 698	2024-11-08 02:00	A372C71E	Deflate	Descriptor UTF8	FAT	20	0	14 364 294
stops.txt	233 274	52 368	2024-11-08 02:00	E8774DA9	Deflate	Descriptor UTF8	FAT	20	0	3 120 744
stop_additional_infos.txt	260 430	51 338	2024-11-08 02:00	CEC470D5	Deflate	Descriptor UTF8	FAT	20	0	14 096 890
stop_times.txt	81 810 440	10 772 204	2024-11-08 02:00	FBFA28DC	Deflate	Descriptor UTF8	FAT	20	0	3 304 195
translations.txt	1 017 744	95 956	2024-11-08 02:00	C80B775C	Deflate	Descriptor UTF8	FAT	20	0	14 714 869
trips.txt	3 660 010	130 973	2024-11-08 02:00	1BADAFFD	Deflate	Descriptor UTF8	FAT	20	0	3 173 167
vehicle_types.txt	521	303	2024-11-08 02:00	21F69748	Deflate	Descriptor UTF8	FAT	20	0	14 503 065
vehicle_types_for_depot...	217	104	2024-11-08 02:00	FF4EB20B	Deflate	Descriptor UTF8	FAT	20	0	14 503 431

Figure 73. Set of GTFS data provided

This data was imported into the model in two steps:

- Initially, public transport network data was imported into a PTV Visum file that did not include any other object. (Figure 74, Figure 75).

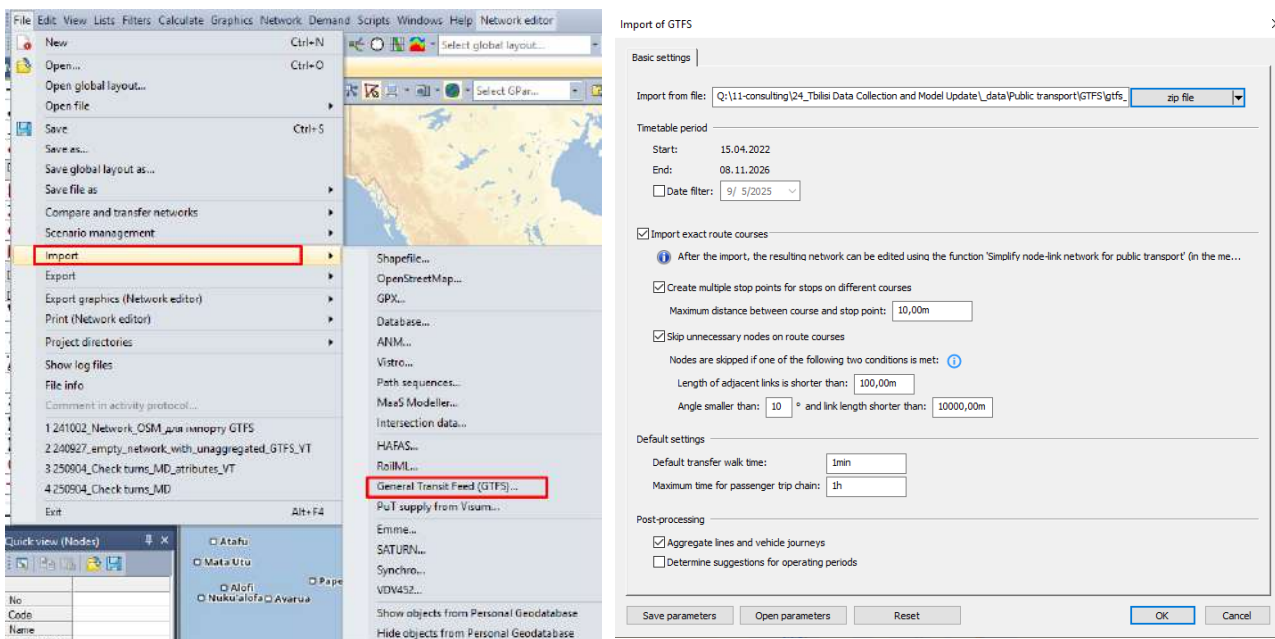


Figure 74. The process of importing GTFS data into PTV Visum

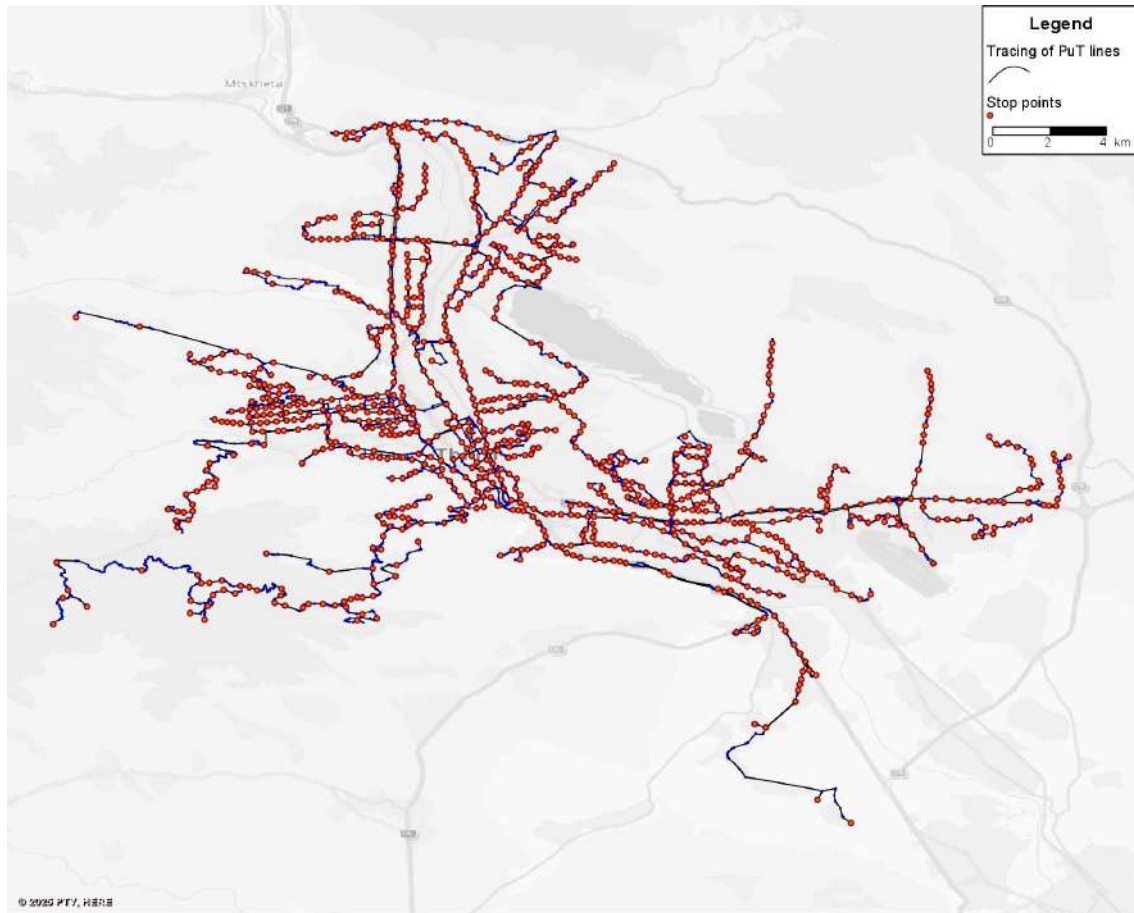


Figure 75. Result of GTFS data import (step 1)

2. In the second step, the data that had been previously imported into PTV Visum was matched with the prepared road network. (Figure 76, Figure 77).

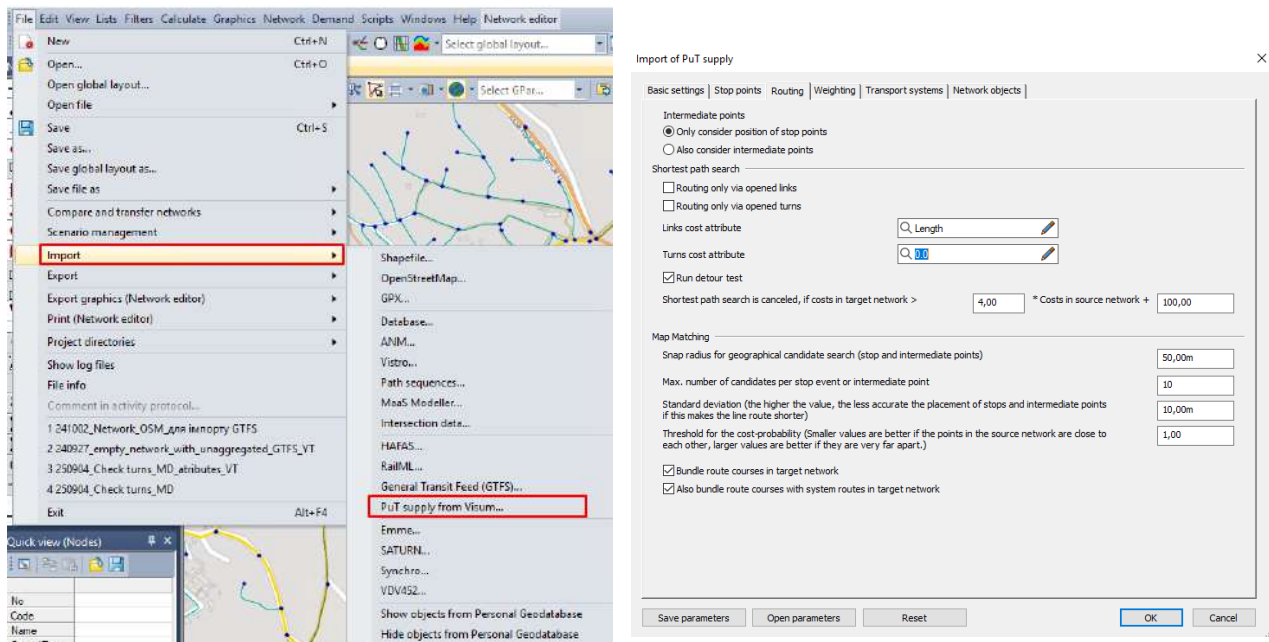


Figure 76. Configuring the process of matching PuT network data with the road network

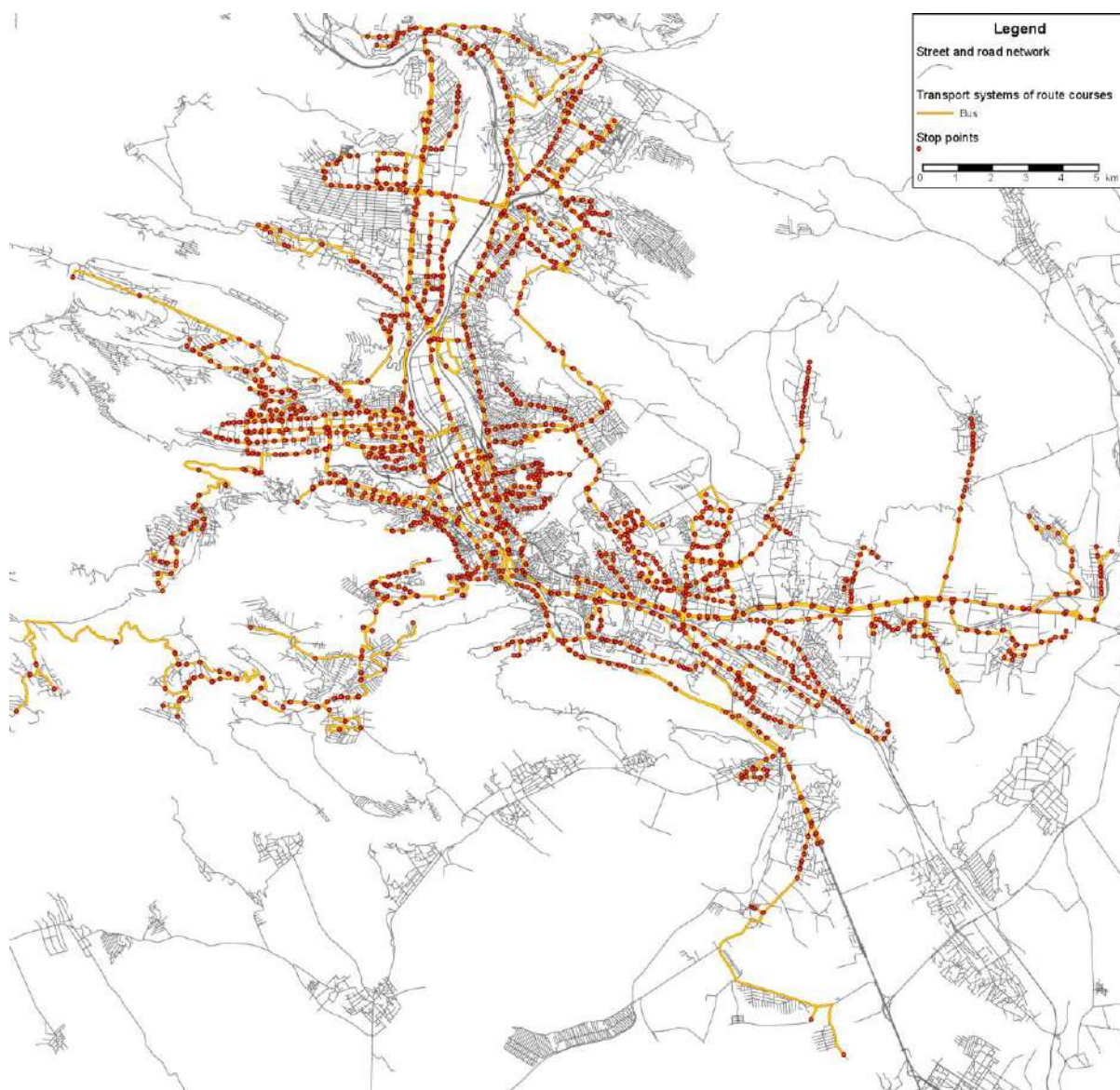


Figure 77. Imported GTFS data in the second step

All data was updated and verified based on datasets from TTC¹⁹, TUDA, Google Maps²⁰, Yandex Maps²¹ and the results of boarding-alighting surveys. A detailed description of the boarding-alighting survey methodology and its results is presented in the Additional Manual Data Collection (AMDC) Report²².

¹⁹ <https://ttc.com.ge/>

²⁰ <https://www.google.com/maps/>

²¹ <https://yandex.com/maps/>

²² Boarding-alighting survey was conducted by surveyors' teams in morning peak hours for all routes with usage of TransitWand application, that allowed to record for each stop route time, coordinates, number of passengers that board and alight. Survey was conducted as a part of the project in spring and autumn of 2025.

4.3.2. Line routes

In PTV Visum, PuT routes follow a **hierarchical structure**, that consists of:

- Lines – The overall transit route structure.
- Line routes – Different operational directions (e.g., inbound and outbound services).

An example of PuT route hierarchy is provided in Table 5.

Table 5. PuT Route Structure Example

Line Name	Line routes Name	Direction
Bus_№304_Gldani Lake - State University H/B	№304_Gldani Lake	>(straight)
	№304_State University H/B	< (reverse)

The graphical representation of the PuT route network and sample routing variants is illustrated in Figure 78.

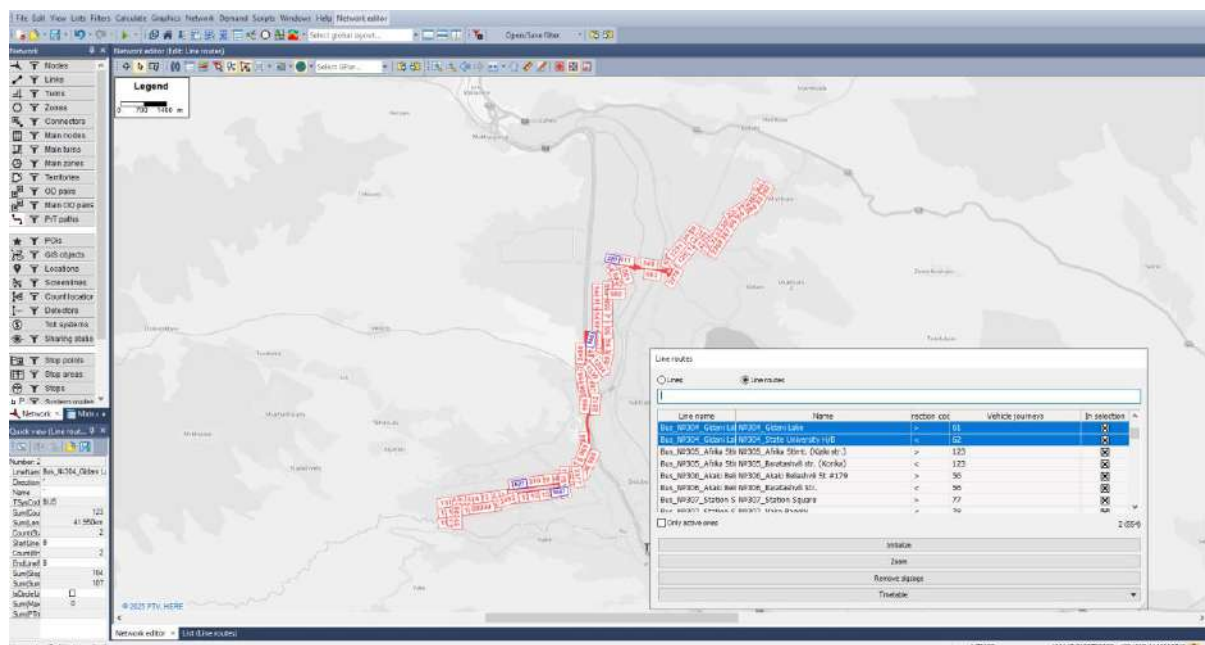


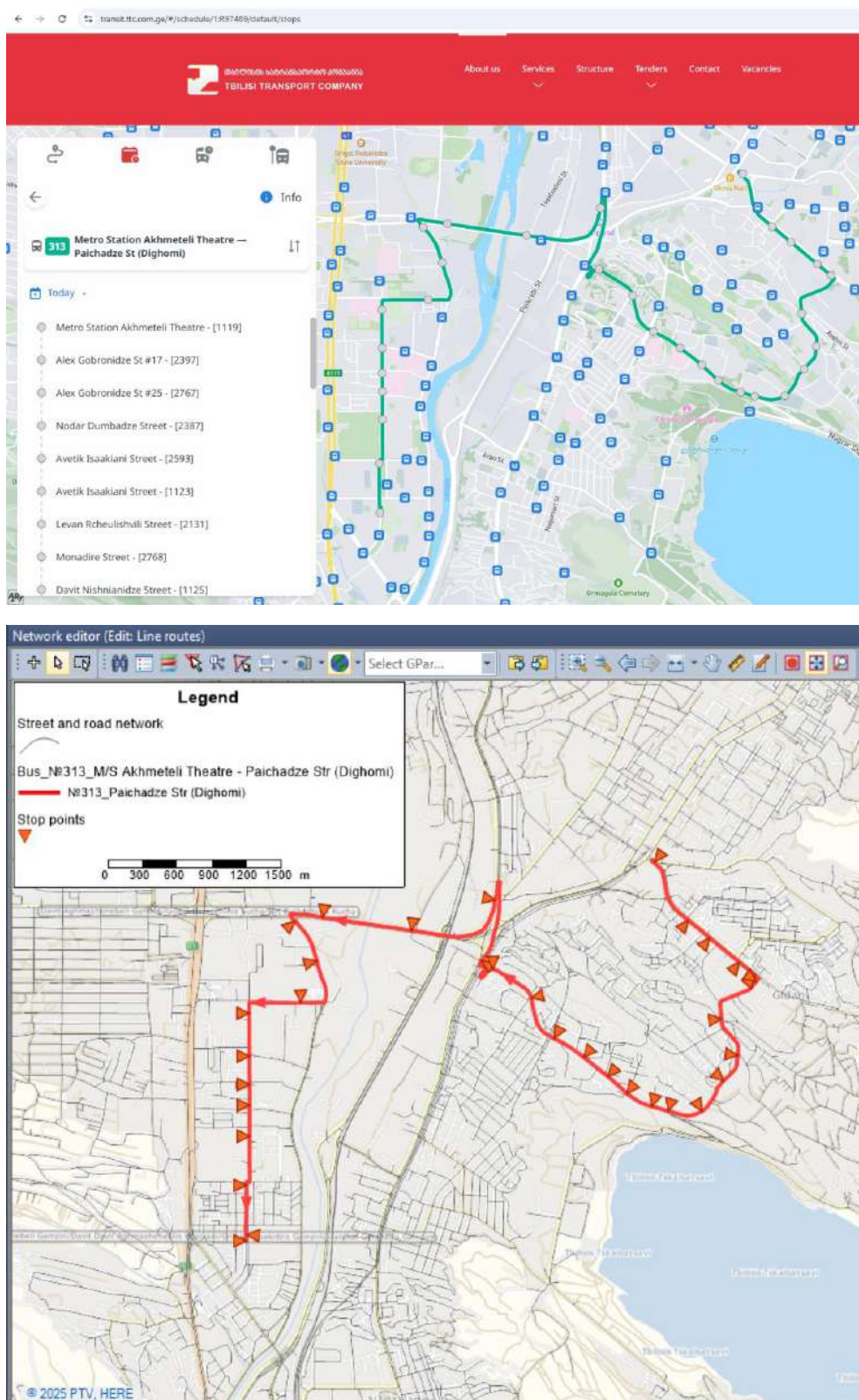
Figure 78. Line routes for Bus № 17 in PTV Visum

After importing all routes from the GTFS data, several adjustments were required. This was because, during the import of the GTFS data onto the road network, parts of the routes were partially misaligned or incorrectly interpreted. Although the GTFS data provided by the Client significantly facilitated the public transport data input process, the entire public transport network was nevertheless thoroughly reviewed and manually verified using additional data sources, including TTC datasets.

In particular, the route alignment and the sequence of stops for each public transport line were carefully checked using various reference datasets, such as [Transit.ttc.com.ge](https://transit.ttc.com.ge/#/realtime)²³ and [rustavi-bus.azrycloud.com](https://rustavi-bus.azrycloud.com/#/realtime/1:R826/default/stops/)²⁴ (Figure 79).

²³ <https://transit.ttc.com.ge/#/realtime>

²⁴ <https://rustavi-bus.azrycloud.com/#/realtime/1:R826/default/stops/>



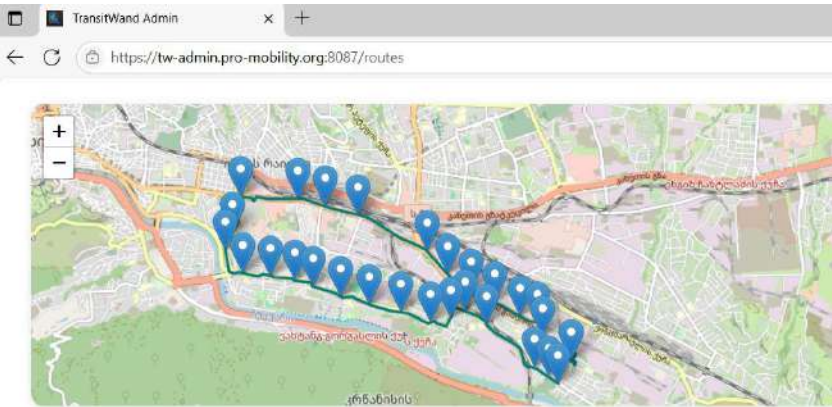
TTC data

Data in the updated model

Figure 79. Using TTC data to verify routing and stops for line routes

In some cases, discrepancies were identified between the results of field observations and the available source data. These discrepancies were limited to minibus services and did not affect municipal public transport operated by TTC. Moreover, the share of routes with differing alignments did not exceed 10%.

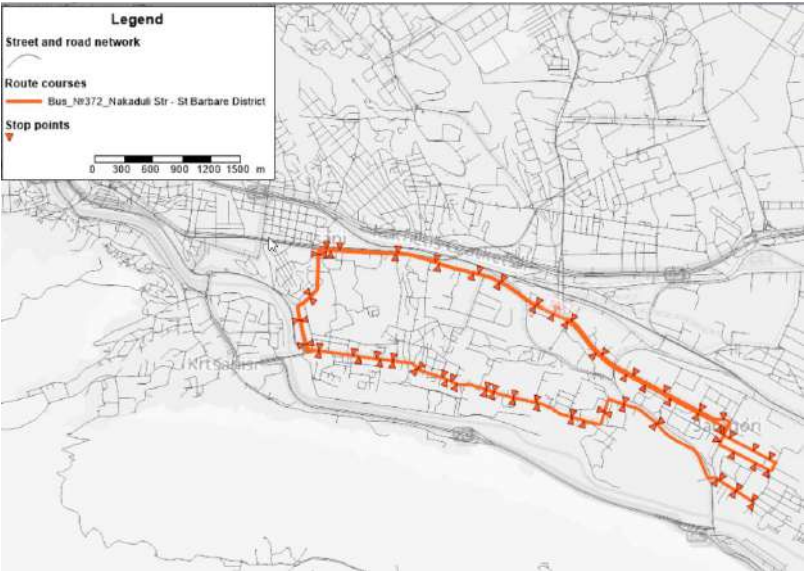
Where such discrepancies occurred, the results of field surveys were used as the primary reference. These data were further cross-checked using the results of boarding/alighting surveys, that were performed by ACT in 2025 using TransitWand application ²⁵(Figure 80).



TransitWand data

Route Information

Route Name	372-HNQ-1
Route ID	1145
Description	nakadulis q -ism. barbares ubani
Notes	2
Vehicle Capacity	3
Multi-Doors	Yes



Data in the updated model

²⁵ <https://tw.pro-mobility.org:8085/form>

Figure 80. Using TransitWand data to verify routing and stop points for line routes

Using this approach, the urban public transport routes in Tbilisi and all the suburban routes from Rustavi were verified. However, the modelling area also includes other suburban areas, for which there was no publicly available information on bus connections or previously imported GTFS data. In these cases, for each direction, the information on suburban connections was clarified separately based on various data sources. The various used approaches are clarified further.

- **Suburban bus routes** Tbilisi – Mtskheta, Tbilisi – Tserovani, Tbilisi – Saguramo. Route tracing was determined based on surveys of drivers at the Didube bus station. This data was obtained from TUDA in the form of Google Maps (Figure 81).

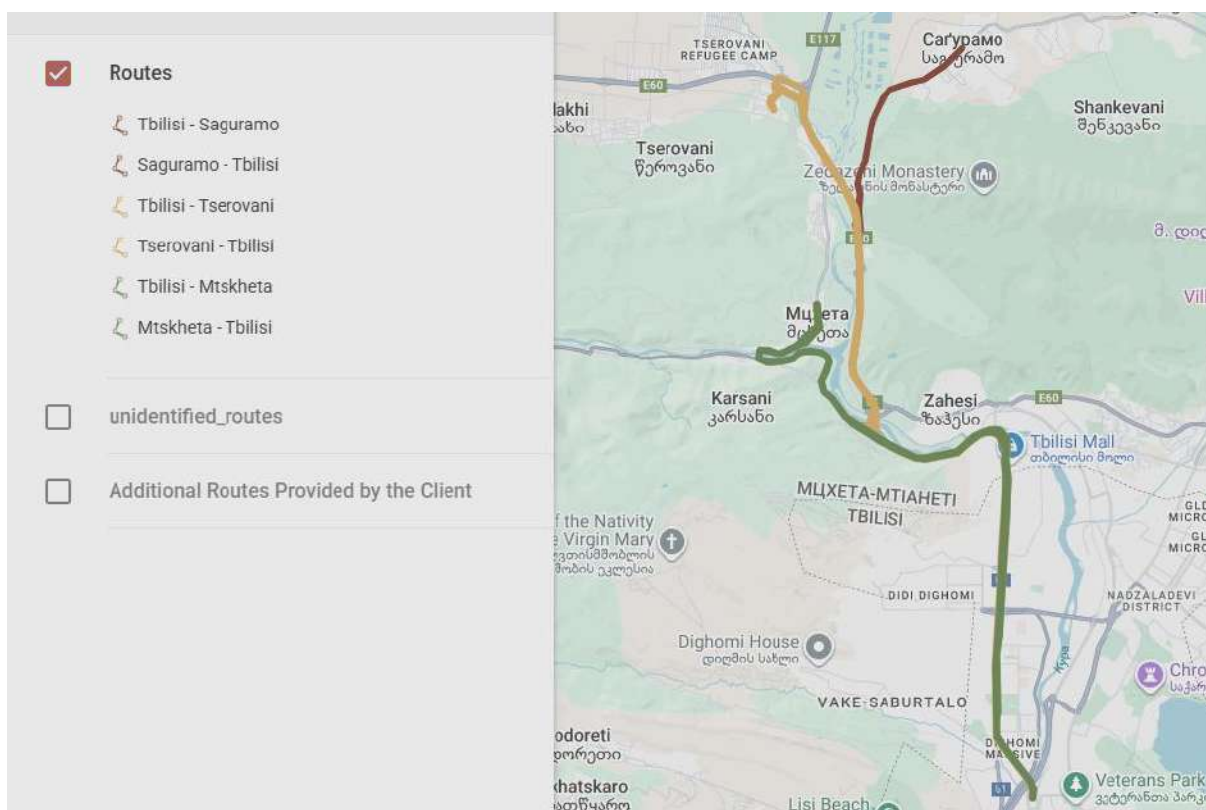
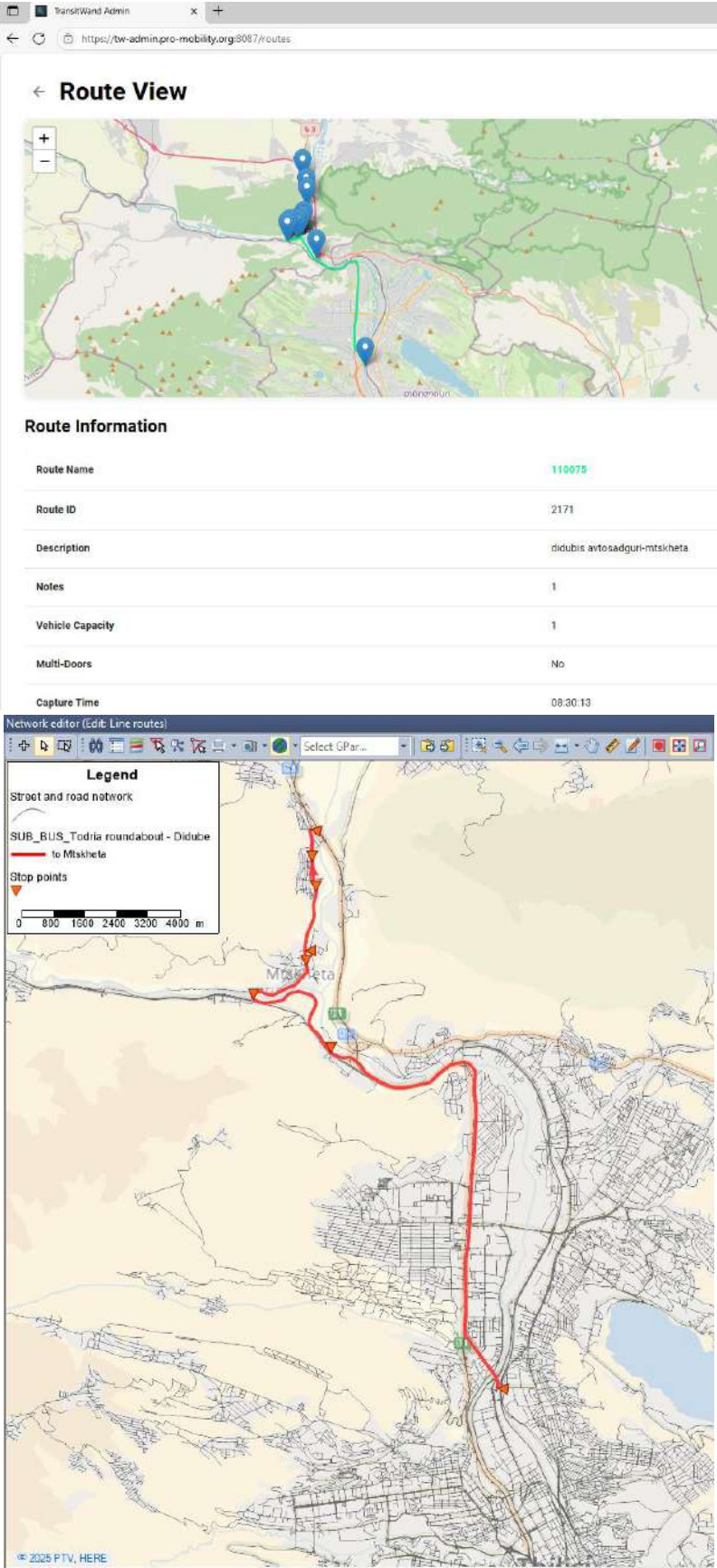


Figure 81. Data on suburban bus routes from Mtskheta, Tserovani, and Saguramo, provided by drivers on those routes.

As the provided data did not include information on stops along the routes, the collected data on route alignments and the sequence of stops were defined based on the results of the boarding/alighting surveys conducted using the Transit Wand application. (Figure 82).



TransitWand data

Data in the updated model

Figure 82. Using TransitWand data to verify routing and stops for line routes

- **Suburban bus routes Tbilisi-Gardabani and minibuses Tbilisi – Rustavi** (Todria roundabout – Didube, Station Square – Old Market (Batumi Str.), Old market (Batumi Str.) – M/S Samgori, East Point (Mall) – Old Market, Meskhishvili – Leonidze Intersection – Station Square, 19th M/R – State University (X Building), Javakheti Str. (aka Svani's market) – Heroes square (Friendship ave), Sports Palace (Saburtalo) – Phirosmani Str. 38, m/s Akhmeteli – Metallurgy Administration, M/S Akhmeteli – Metallurgy Administration).

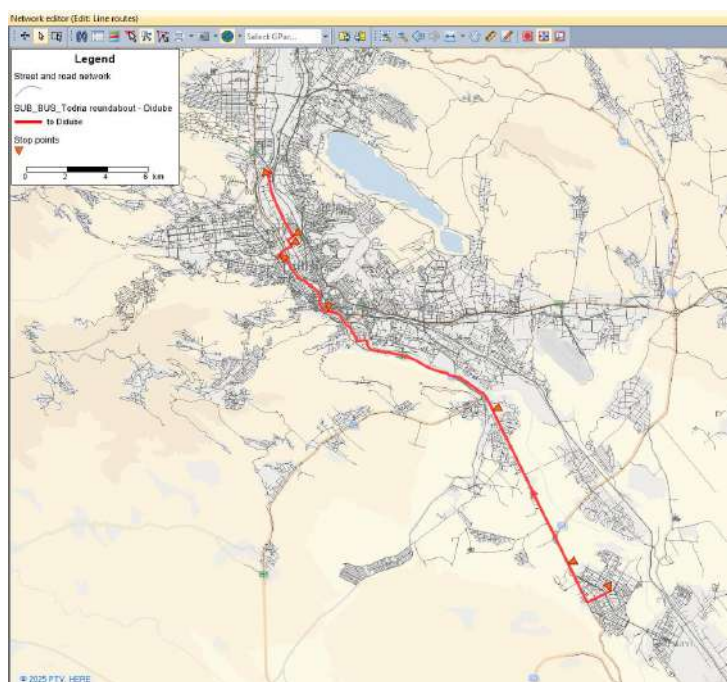
Since there was no official information available on the routes of suburban buses connecting Tbilisi and Gardabani and suburban minibuses connecting Tbilisi and Rustavi, this data was added based only on the results of the on-field boarding-alighting surveys. (Figure 83).



Route Information

Route Name	106-110038
Route ID	2160
Description	rustavi- qveda didube
Notes	1
Vehicle Capacity	1
Multi-Doors	No

TransitWand data



Data from the model

Figure 83. Using TransitWand data to draw the route and stops of a minibus connection Station Square – Old Market (Batumi Str), as no previous data existed for verification

- **Other suburban bus routes.** Due to the lack of detailed data on bus connections with suburban settlements, the so-called “aggregated” routes were added to the model. Such routes have the same routing within the study area but differ outside of it. These routes were designed based on the open data on intercity bus connections in Georgia²⁶. (Figure 84). This approach allowed to integrate in the new transport model of Tbilisi, the possibility of traveling by public transport, even if exact information about each route is missing.

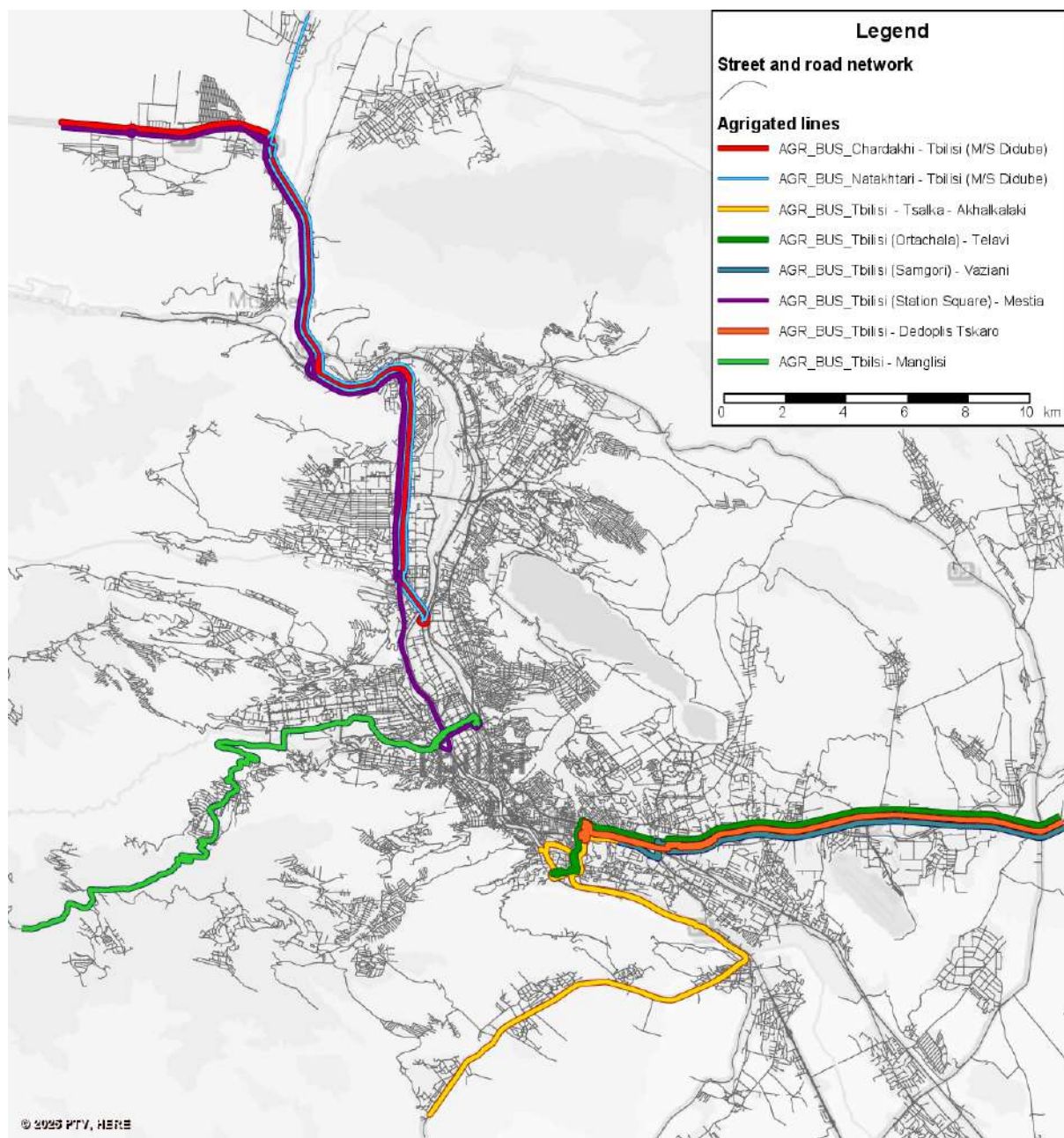


Figure 84. Aggregated PuT routes

To integrate the connections between Tbilisi and the areas of Gamarjveba, Vaziani, Martkofi, and Norio, which were not covered by public transport routes, local experts from the Consortium determined the routes (Figure 85).

²⁶ <https://marshrutka.info/city/65f58ae339fd45017a7658b9>

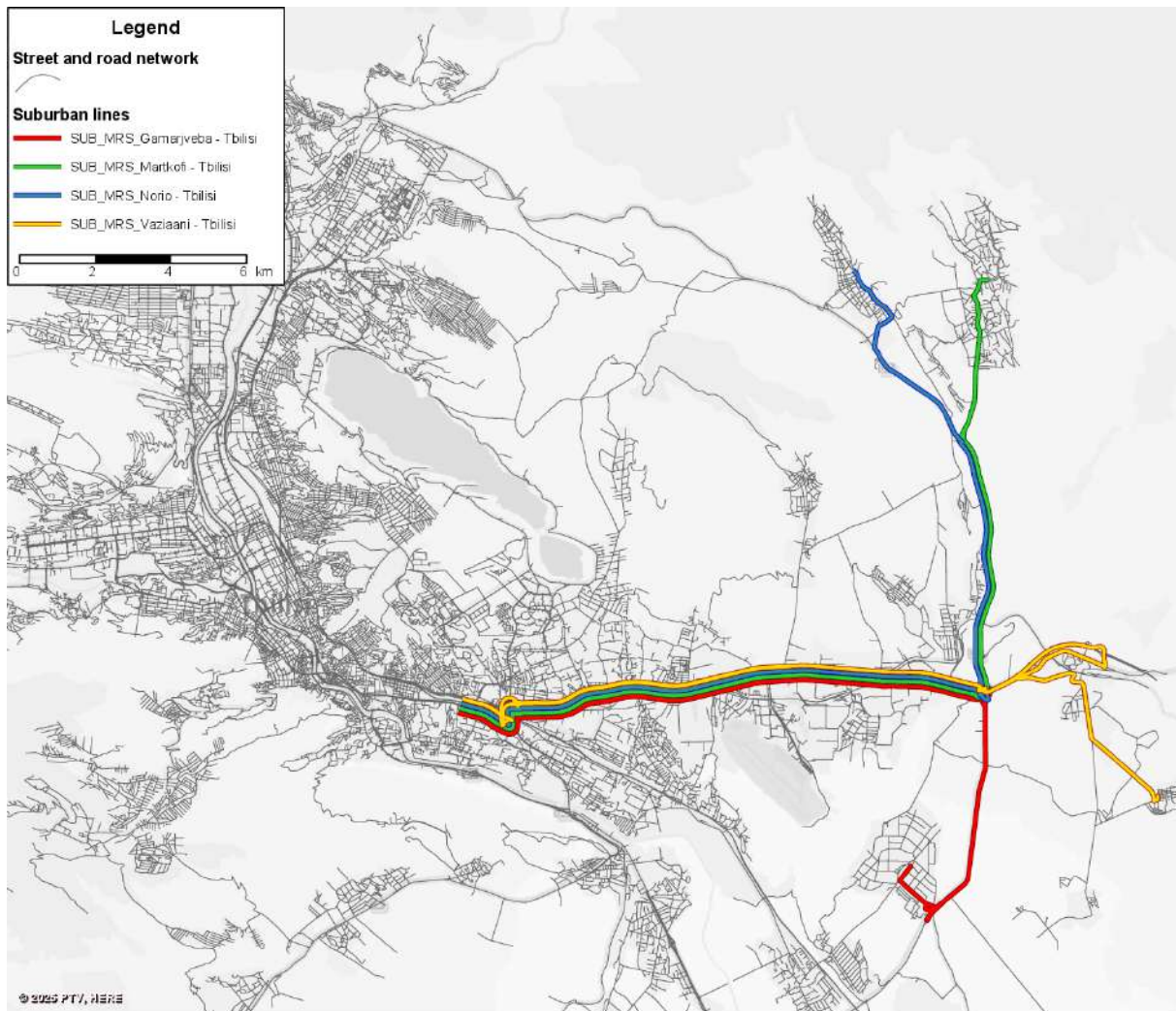
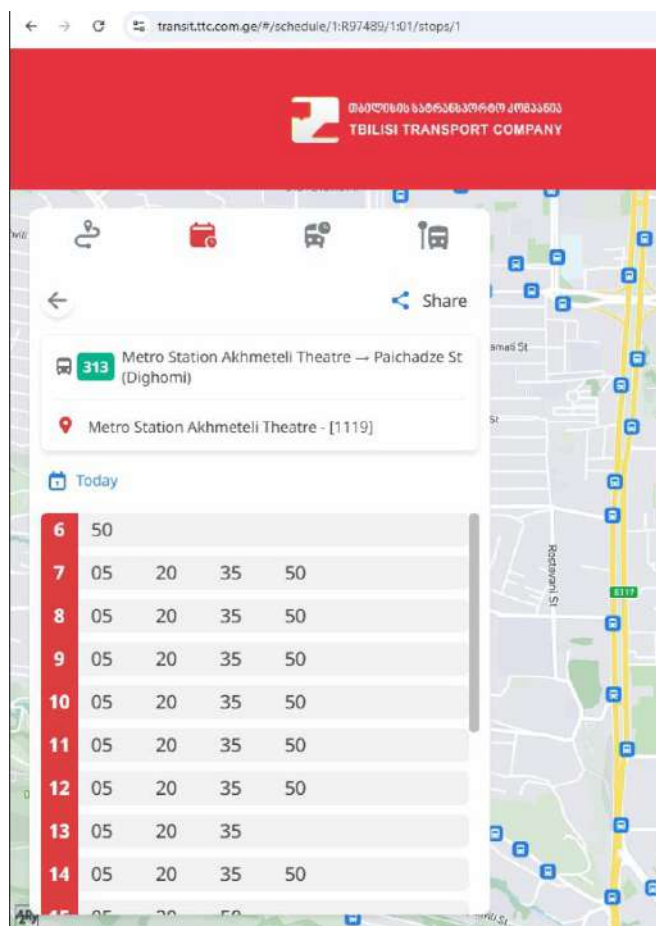


Figure 85. Suburban bus routes to Gamarjveba, Vaziani, Martkofi and Norio

For each line route in the model, the timetable was specified based on the data obtained from the service «Transit.ttc.com.ge»²⁷ (Figure 86).

²⁷ <https://transit.ttc.com.ge/#/realtime>



TTC data

No	65 vehicle journeys	30485	30486	30487	30488	30489
Name						
LineName		Akhmeteli Theatre - Paichadze St	Akhmeteli Theatre - Paichadze St	Akhmeteli Theatre - Paichadze St	Akhmeteli Theatre - Paichadze St	Akhmeteli Theatre - Paichadze St
DirectionCode		<	<	<	<	<
LineRouteName		#313_Paichadze Str (Dighomi)	#313_Paichadze Str (Dighomi)	#313_Paichadze Str (Dighomi)	#313_Paichadze Str (Dighomi)	#313_Paichadze Str (Dighomi)
TimeProfileName		1	1	1	1	1
OperatorIdentifier		ლონის სატრანსპორტო კომპანია	ლონის სატრანსპორტო კომპანია	ლონის სატრანსპორტო კომპანია	ლონის სატრანსპორტო კომპანია	ლონის სატრანსპორტო კომპანია
ServTripPatNo		0	0	0	0	0
Count:VehJourneySections		1	1	1	1	1
FromTProfileIdentifier		1: 552 B	1: 552 B	1: 552 B	1: 552 B	1: 552 B
ToTProfileIdentifier		33: 551 B	33: 551 B	33: 551 B	33: 551 B	33: 551 B
Dep		06:50:00	07:05:00	07:20:00	07:35:00	07:50:00
Arr		07:23:14	07:38:14	07:53:14	08:08:14	08:23:14
IsCoupled		☐	☐	☐	☐	☐

Data in the updated model

Figure 86. Using TTC data to determine the timetable for line routes

For those routes without any timetable in the Transit.ttc.com.ge, required information were collected during the on-field surveys and/or defined by local experts of the work group.

The timetable data was entered directly into the PTV Visum model for each of line routes separately (Figure 87).

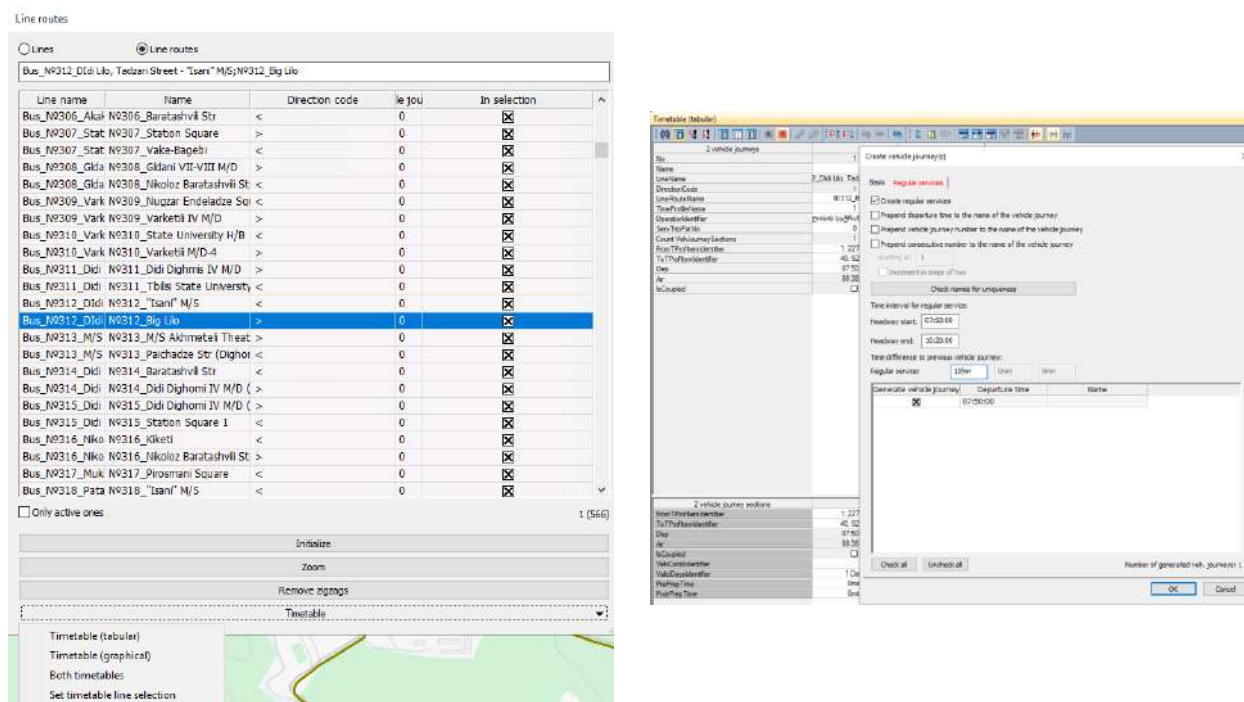


Figure 87 Input of line routes timetables

As a result, data on more than 25,000 scheduled trips for all public transport routes was entered into the model.

Additionally, data on vehicles obtained from the Department of Transport and Communications and Busphoto²⁸ open internet source, was integrated. For routes where vehicle type information was recorded by surveyors, the vehicle capacity data were further verified against the results of field observations. This dataset includes seating and total passenger capacities for municipal buses and minibuses (marshrutkas) (Table 6).

Table 6. List of vehicle units

NO	NAME	TSYSSET	SEATCAP	TOTALCAP
1	MAN A21 Lion's City NL313 CNG	BUS,MRS	37	87
2	BMC Procity 12LF CNG	BUS,MRS	34	90
3	Isuzu Novociti Life	BUS,MRS	32	53
4	MAN A47 Lion's City M 10.5 NL293	BUS,MRS	26	84
5	MAN 18G Lion's City NG320	BUS,MRS	49	165
6	FORD TRANSIT460E	MRS	9	21
7	Metro	SUB	48	264
8	Otokar Centro	BUS	17	34
9	Otokar Kent C 10	MRS	27	90
10	Anadolu Isuzu NovoCiti	BUS	21	55
11	Mercedes-Benz Sprinter T1N	BUS	18	18

For each route and scheduled departure for line routes, the type of rolling stock was assigned (Figure 88).

²⁸ <https://busphoto.eu/city/4015/>

Lines

☒ Lines ☐ Line routes

Bus_Nº021_Rustavi - Tbilisi (Sports Palace)

Name	Vehicle	journeys	le
Bus_Nº021_Rustavi - Tbilisi (Sports Palace)	208	☒	
Bus_Nº022_Zh Shartava Avenue #15 - M/S (Didube)	138	☒	
Bus_Nº023_University high-rise building - Gagarini Str	134	☒	
Bus_Nº024_Station Square - Rcheulishvili Str #10a	152	☒	
Bus_Nº101_Krtsanisi Vill - Varketili-3 IV M/D	72	☒	
Bus_Nº102_#6 Penitentiary Institution - Baratashvili	72	☒	
Bus_Nº107_Tsodoreti Vill - M/S Delisi	19	☒	
Bus_Nº292_M/S Akhmeteli Theatre - Tbilisi Mall	150	☒	
Bus_Nº293_M/S Sarajishvili - Didi Dighomi I-II M/D	97	☒	
Bus_Nº294_M/S Akhmeteli - Mukhiani III M/R	141	☒	
Bus_Nº295_Afrika Stlmt - M/S Varketili	97	☒	
Bus_Nº296_St Barbare Ubani - M/S Isani	274	☒	
Bus_Nº297_Gldani Lake Setl - M/S Akhmeteli Theatr	166	☒	
Bus_Nº298_Square Station 2 - Saburtalo Blocks	126	☒	
Bus_Nº299_Liuhliana str - M/S Didube	94	☒	

☐ Only active ones 1 (315)

Initialize

Zoom

Remove zigzags

Timetable

Edit line Bus_Nº021_Rustavi - Tbilisi (Sports Palace)

Name: 021_Rustavi - Tbilisi (Sports Palace)

Transport system: BUS Bus

Main line: ---

Standard vehicle combination: 8 Otokar Centro

Standard operator:

Fare systems:

Basis | User-defined attributes

Number of line routes: 2

Number of time profiles: 2

Number of veh. journ: 208

AddValue 1: 0

AddValue 2: 0

AddValue 3: 0

OK Cancel

Figure 88. Vehicle units for Bus route Nº021 Rustavi - Tbilisi (Sports Palace)

For the subways, the funicular, and the cable cars, the routes, the list of stops, the timetables, and the type of rolling stocks have been incorporated into the model based on the data provided by TTC (Figure 89).

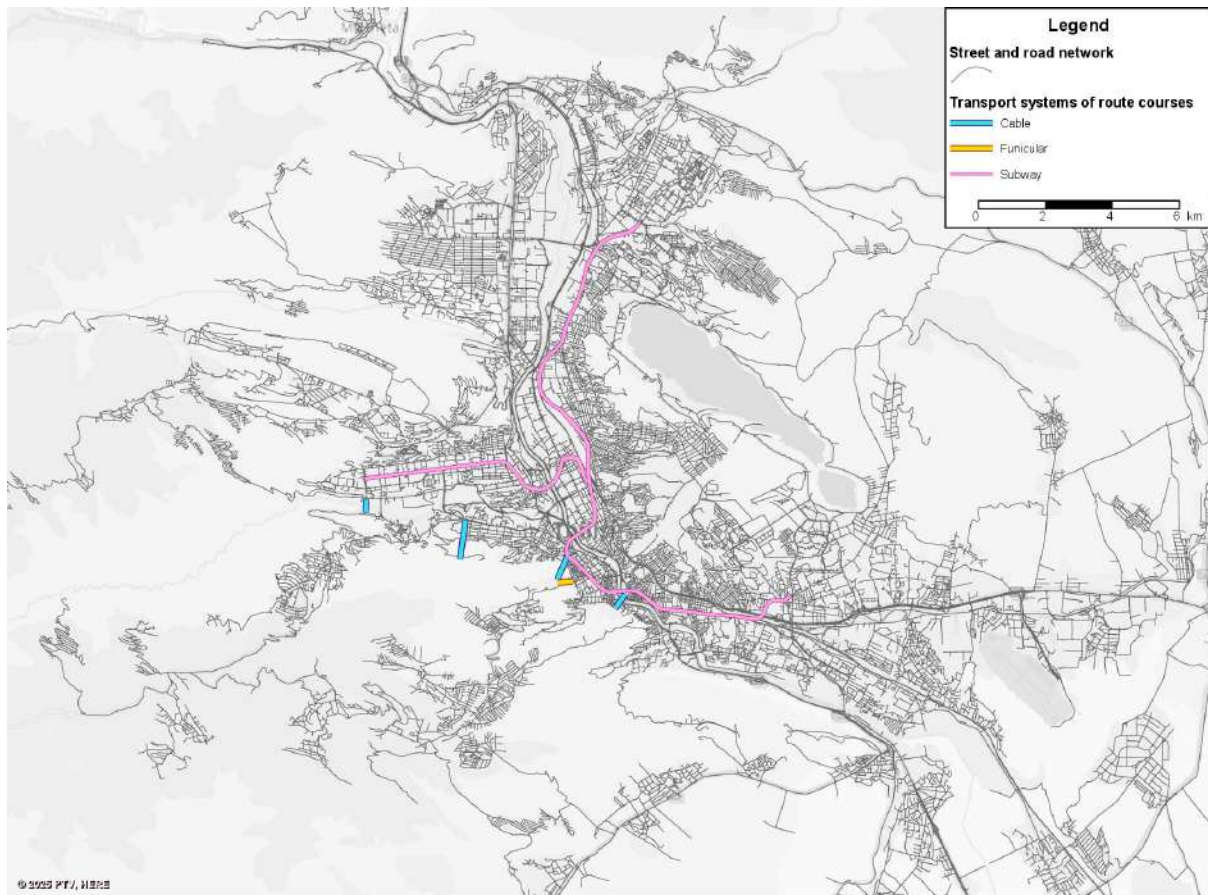


Figure 89. Tracing of the subway, funicular, and cable cars

As a result, the updated transport model for Tbilisi includes 316 routes with 574 routes.

The total number of active routes by type is listed below:

- Buses: 132 routes, 249 line routes.
- Cable: 4 routes, 8 line routes.
- Funicular: 1 route, 2 line routes.
- Marshrutkas: 177 routes, 313 line routes.
- Subway: 2 routes, 4 line routes.

The distribution of PuT routes across the model network by transport systems is shown in Figure 90.

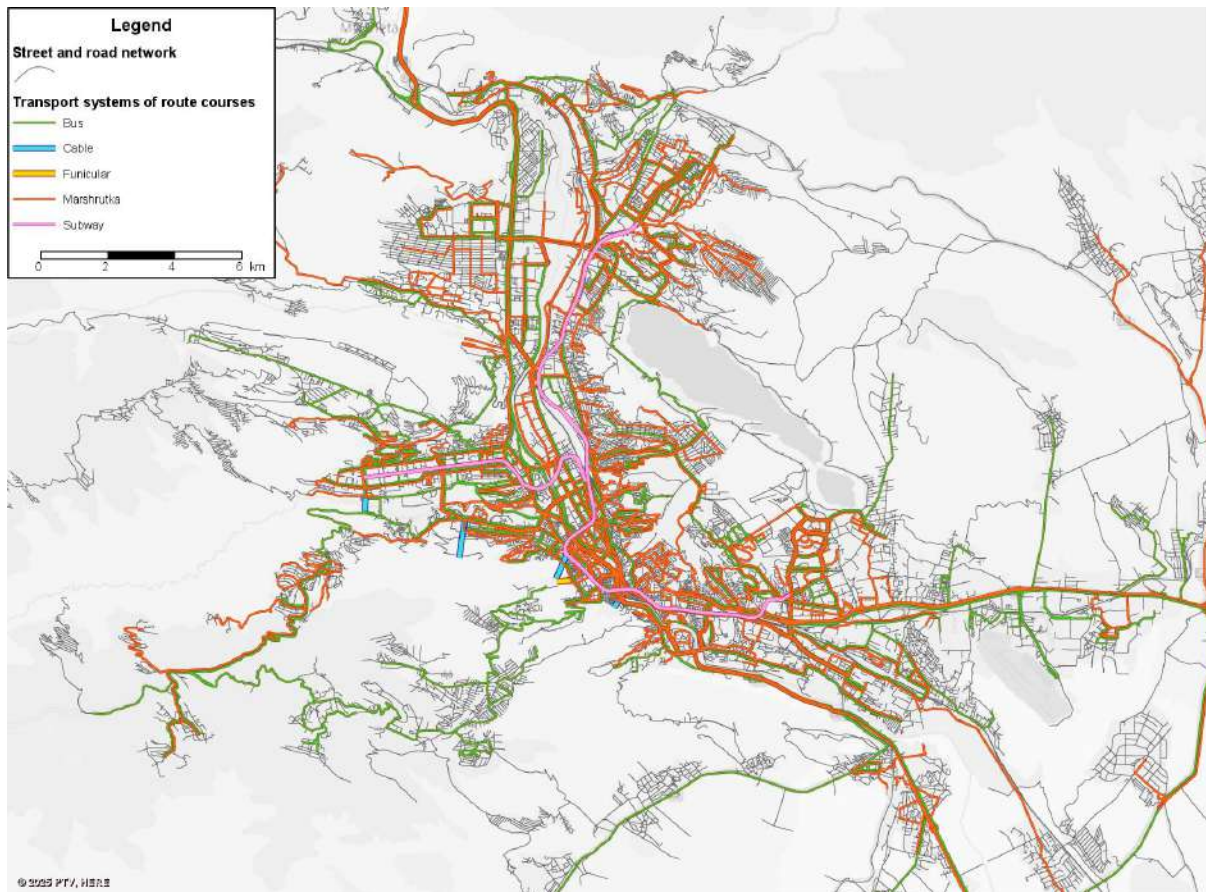


Figure 90. PuT Route Network in the Tbilisi Transport Model

The number of routes on each section of the road network is shown in Figure 91.

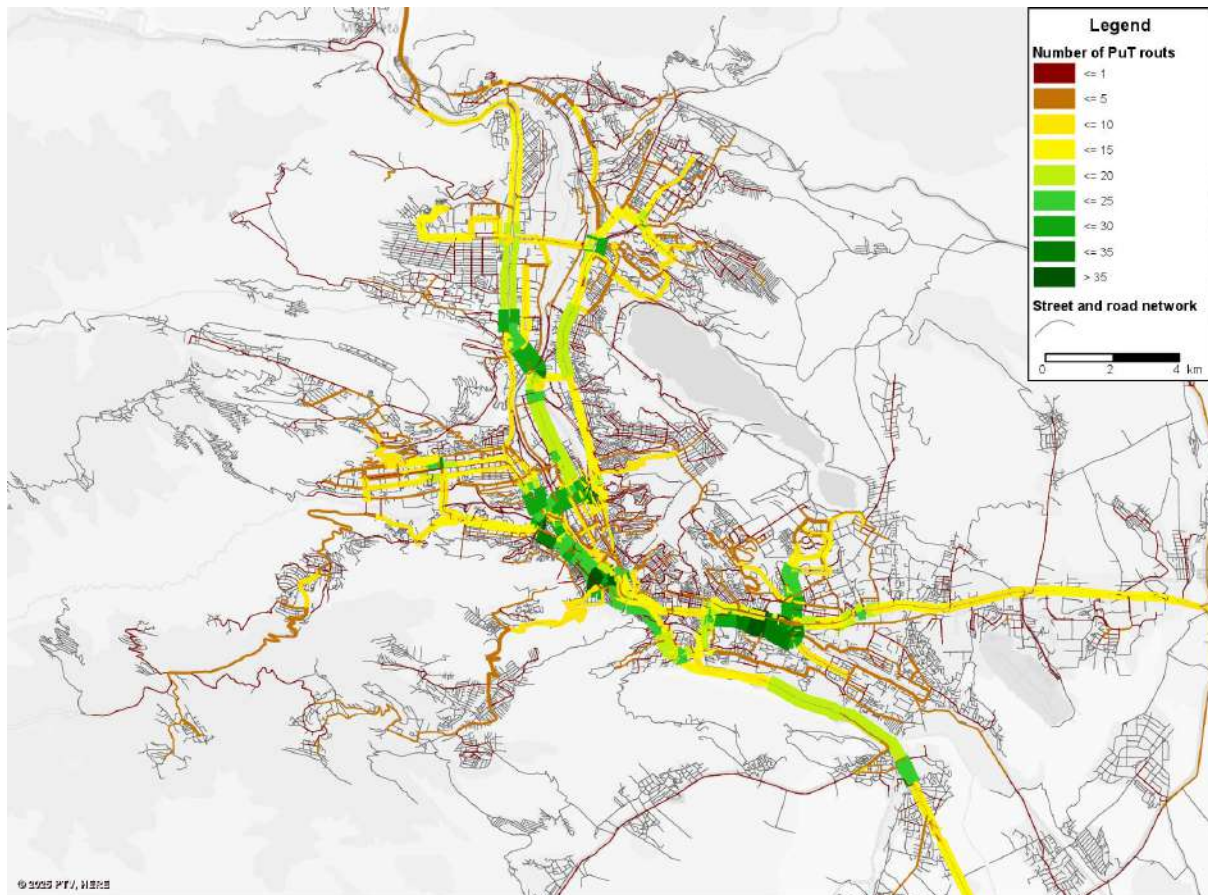


Figure 91. Number of PuT routes on road network

4.3.3. Stops

The stops were imported into the model along with public transport routes according to Figure 77, following a double checked. Each stop, stop area, and stop point was assigned with a unique identifier and name.

The PuT stops in PTV Visum were modelled using a hierarchical structure consisting of (Figure 92):

- Stop Points – the exact locations where passengers board and alight.
- Stop Areas – areas encompassing multiple stop points where passengers can transfer without time penalties.
- Stops – designated locations where transfers involve a time cost.

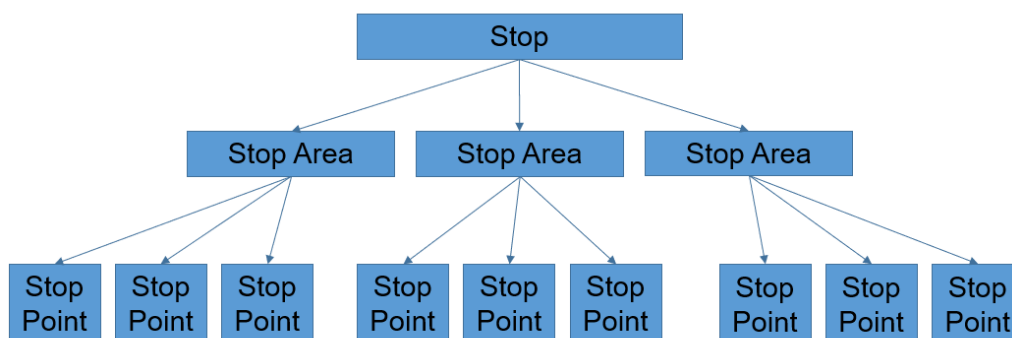


Figure 92. Hierarchical structure of stops in PTV Visum

This structure allows combining several stops into transfer nodes with the possibility of transferring between different routes and types of PuT (Figure 93).

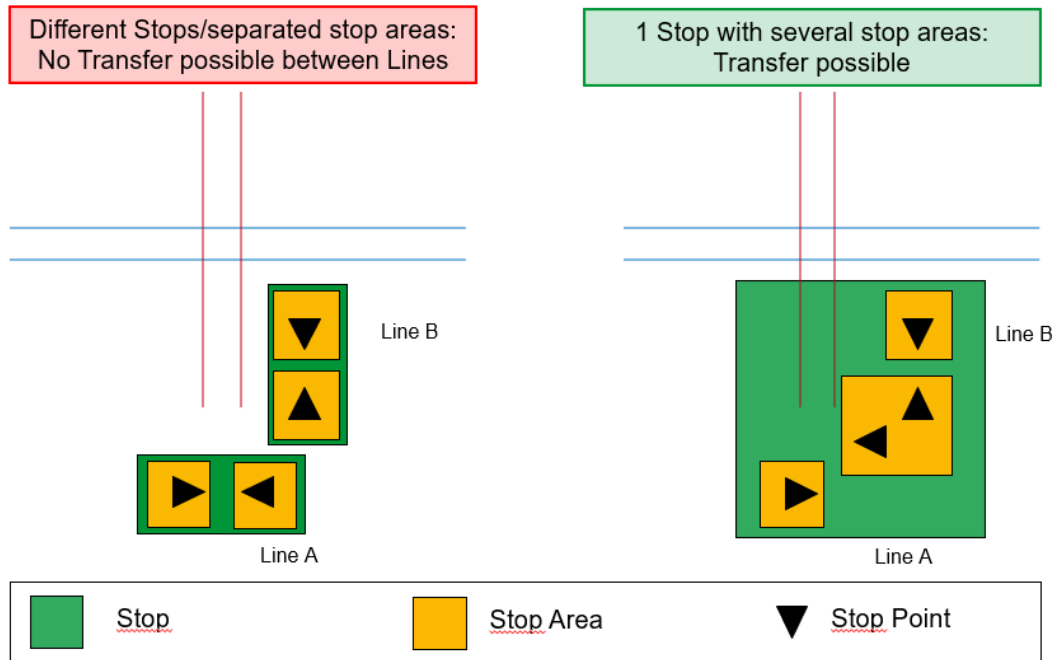


Figure 93. Formation of transfers within stops

A stop time of 30 seconds was set for all stops. The accepted stop time indicator corresponds to common practices in transport modelling, and it is consistent with the results of on-field observations.

To account for transfer time, the time spent between stop zones within a single stop was specified. Its value was determined based on the distance that a passenger travels during transfer between different stop areas. The transfer time was calculated using the following algorithm:

1. Minimum transfer time between stops $t_0 = 0,5$ min.
2. For the remaining items, the following formula applies:

$$t = t_0 + \frac{\sqrt{2} * l * 60}{V_{ped}},$$

where $t_0 = 0,5$ min.

l - distance between points as the crow flies, m;

V_{ped} - pedestrian walking speed, 5 km/h;

$\sqrt{2}$ - diagonal coefficient.

Using this approach and data, a matrix for each transfer hub was estimated to show the duration in minutes of the walking distance between two stops. An example of such a matrix at the “Railway Station” stop is given at Figure 94.

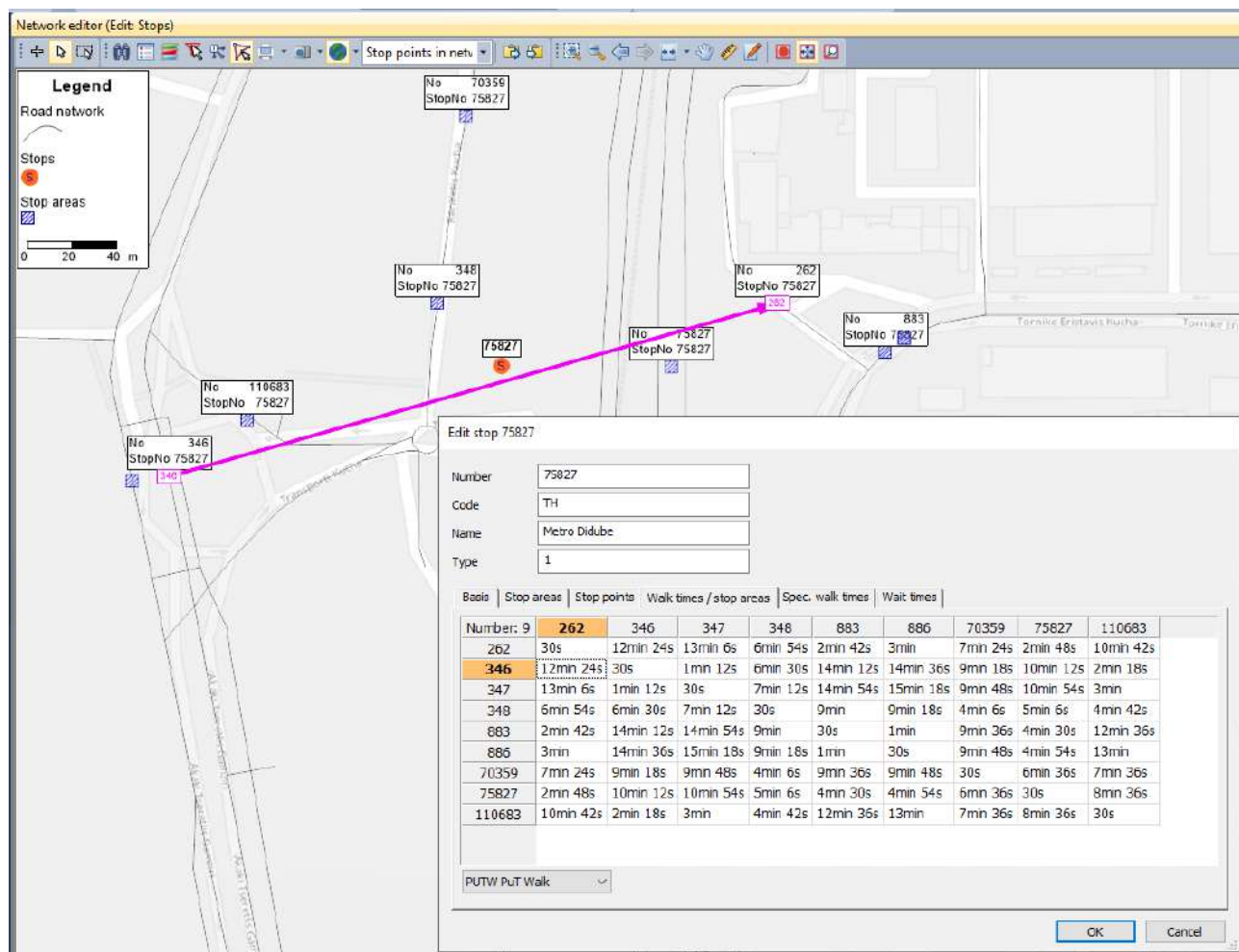


Figure 94. Transfer Time at Shota Shalikashvilis Bridge Stop in PTV Visum

The model includes the following PuT infrastructure elements:

- **Stops:** more than 1.700.
- **Stop Areas:** more than 2.700.
- **Stop Points:** more than 3.300.

The locations of PuT stops in the updated version of the Tbilisi transport model are shown on Figure 95.

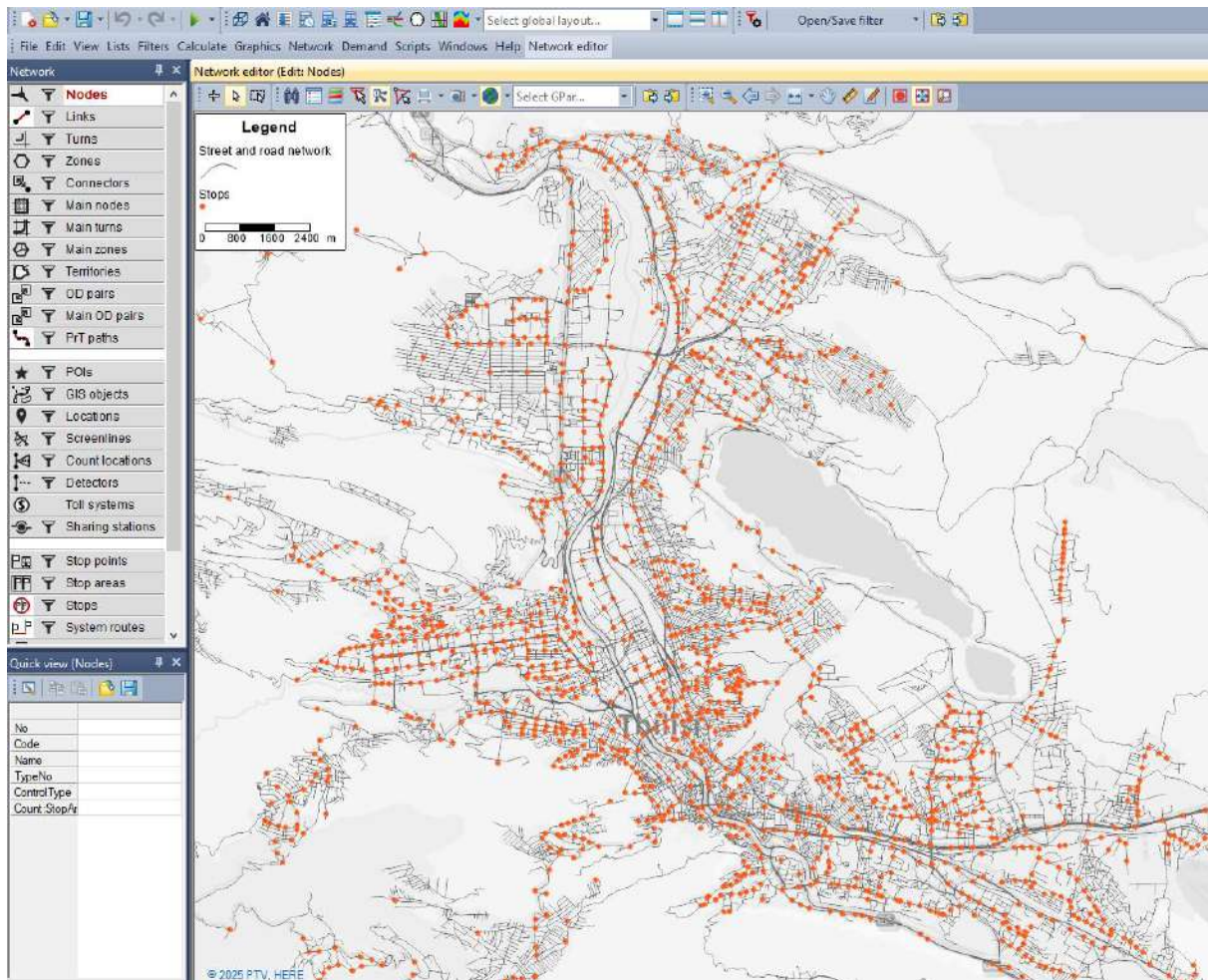


Figure 95. PuT stops in the Tbilisi model

4.3.4. Connectors

To facilitate travel demand distribution and impedance matrix calculations, TAZ centroids were connected to both the road and the PuT network via connectors.

The model has the different types of connectors:

- Type 1 PrT (Private Transport) – connecting TAZ centroids to road network access points (over 7,800 connectors).
- Type 2 PuT (Minibus/Marshrutka) – linking TAZ centroids to PuT stop nodes (over 6,500 connectors).
- Type 5 PuT (Subway) – linking TAZ centroids to subway station stop nodes (over 400 connectors).
- Type 8 PrT (Border) – linking border/Bus station/Railway station TAZ centroids to road network access points (over 30 connectors).
- Type 9 PuT (Border) – linking border/Bus station/Railway station TAZ centroids to stop nodes (over 30 connectors).

Each connector type was assigned with a specific set of permitted transport systems (Figure 96).

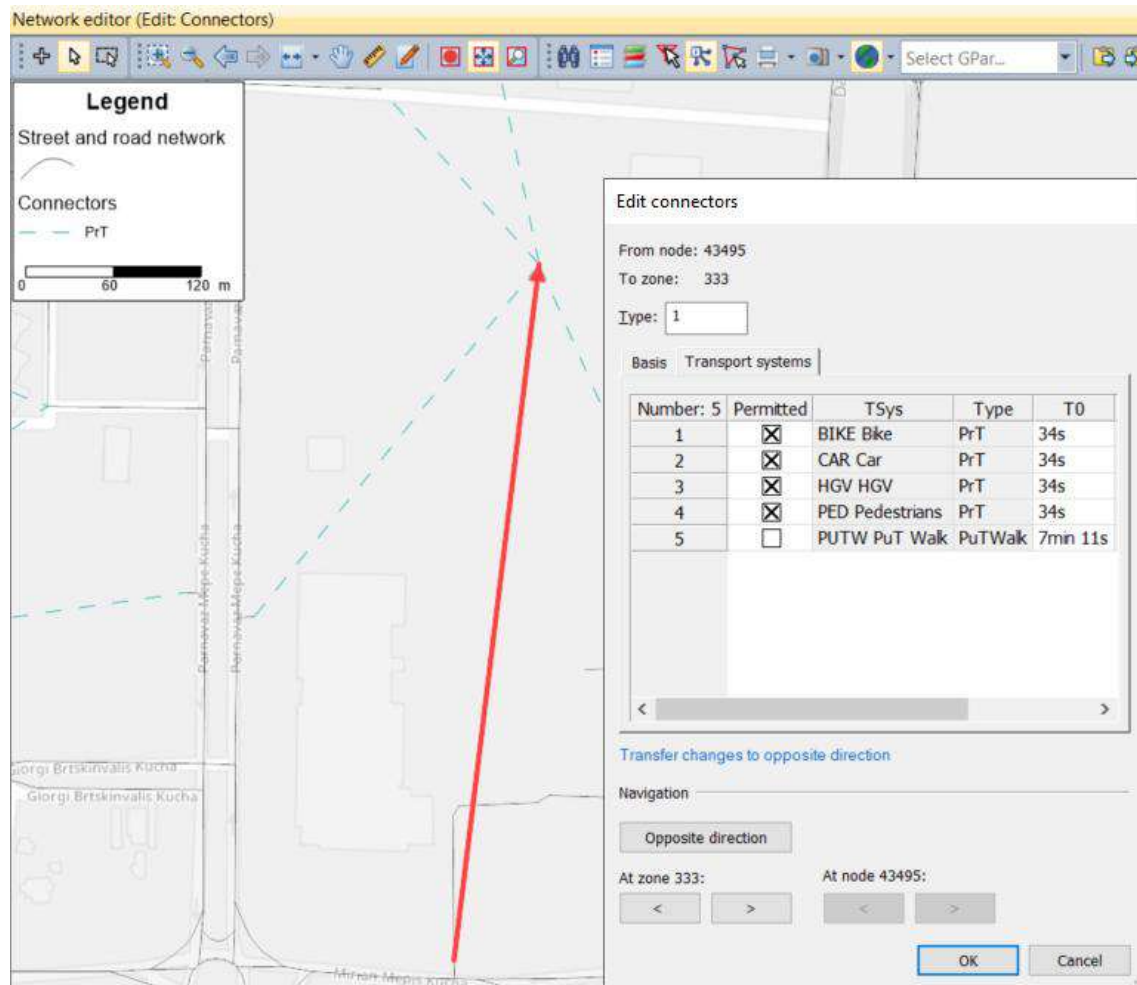


Figure 96. Example of transport systems open to traffic for type 1 connectors

Private transport connectors are positioned at driveway exits, parking lots, garages, and on-street parking zones (Figure 97).

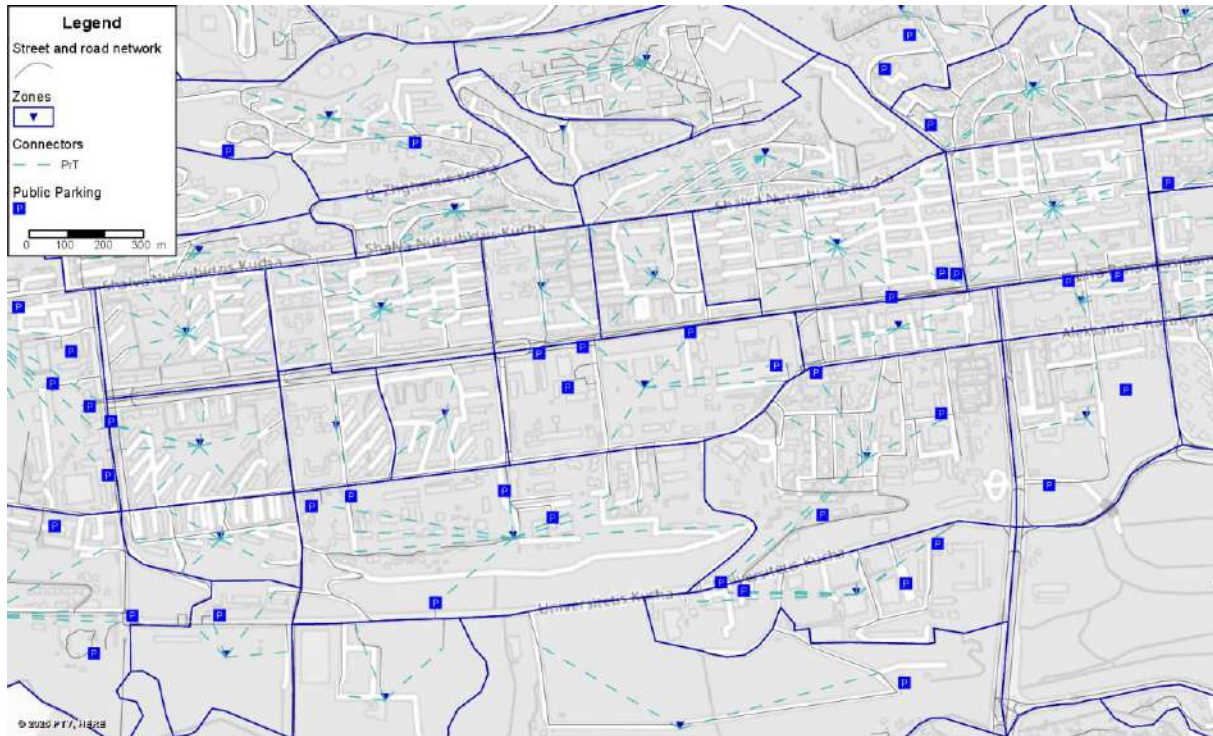


Figure 97. PrT Connector Placement in PTV Visum

PuT connectors were designed to **ensure pedestrian accessibility** to PuT routes within **500-1,000 metres** of TAZ centroids. Within this range, the **nearest PuT stops and transfer nodes were identified**, and connectors were established accordingly (Figure 98).

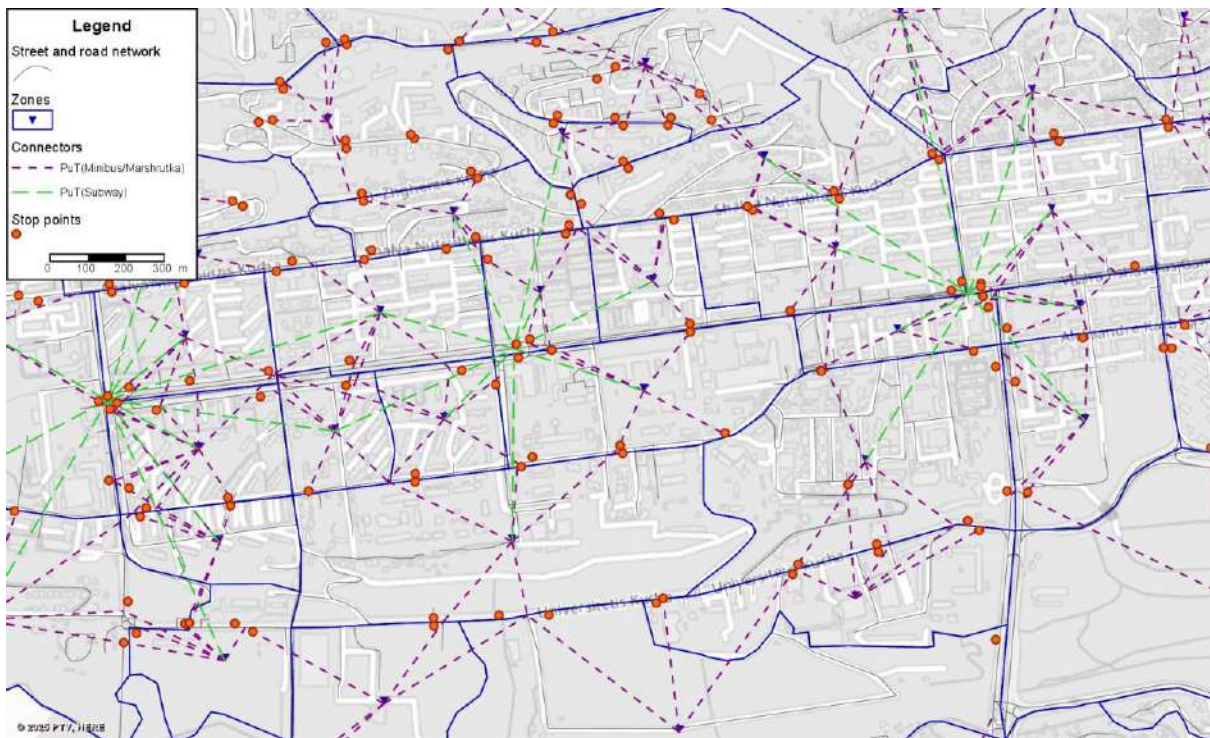


Figure 98. PuT Connectors in PTV Visum

4.4. Network check

During the development of the transport model, the standard Network Check tool in the PTV Visum software environment was used to verify the integrity and correctness of the network. This function allows to identify possible errors and inconsistencies in the transport network (Figure 99), including:

- isolated nodes in the network;
- interconnection of the road network;
- transport areas without connectors for private and public transport, etc.

Check network						
Start of the last network check: 27.10.2025 15:57:12						
Name	Transport systems	Parameters	Result	Details	Messages	Description
General						
☒ Isolated nodes			✓			Finds nodes that are not connected to a link.
☒ Turns and main turns that do not make sense	BIKE, BUS, C, CAR,...		✓			Finds turn and main turns that are open for a transport system for which the From- or To-link is closed.
☐ Multiple straight turns and main turns						Finds nodes and main nodes that have more than one straight (main) turn per incoming link. The number of turns taken into account is defined in the parameters.
☒ Invalid matrix values		Edit	✓			Finds matrices that contain invalid matrix values. Invalid are NaN (Not a Number) and Inf (Infinite).
PrT						
☒ Zones without PrT connection			✓			Finds zones without a connection to the PrT network due to missing connections and closed PrT transport systems. For zones without a connection to the PrT network, the type of pairs is defined in the parameters.
☒ Check network consistency	BIKE, CAR, GV, PED	Edit	✓			Finds OD pairs between which no path exists. The type of pairs is defined in the parameters.
☒ Dead-end roads PrT	BIKE, CAR, GV, PED		✓			Finds links to one-leg, unconnected nodes for which the U-turn at the node or the opposite direction of the link is closed.
☒ Links without succeed. link	BIKE, CAR, GV, PED		✓			Finds links with no connection to the network, whose succeeding links are closed for the currently selected transport systems.
☒ Links with Capacity PrT = 0 or v0 = 0			✓			Finds open PrT links with a PrT capacity or a speed of 0. Such links are like closed links as no traffic can enter them during assignment.
☒ Viability for ICA			✓			Checks the correct modeling of nodes and main nodes for the ICA calculation (turn types, signalization, geometry, ...). Partial nodes are not supported.
☒ Viability for ANM export	BIKE, CAR, GV, PED		✓			Finds lane turns with closed inbound or outbound lanes, single inbound lanes with transport systems without permitted turns, (main) ...
☐ Viability for Balance / Epics						Checks whether links, turns and detectors can be used in Balance and Epics.
PuT						
☒ Zones without PuT connection			✓			Finds zones without a connection to the PuT network due to missing connections and closed PuT transport systems. For zones without a connection to the PuT network, the type of pairs is defined in the parameters.
☒ Links with PuT-Walk time = 0			✓			Finds walk links with time zero.
☒ Links with PuT-Aux time = 0			✓			Finds PuT-Aux links with time zero.
☒ Links with PuT-run time = 0			✓			Finds links that meet the following conditions: 1. The link is traversed by a line route of a particular transport system. 2. The link run time is zero.
☐ Find line and system routes with zigzags	BUS, C, F, MRS, SUB		✓			Finds zigzags on line and system routes.
☒ Vehicle combinations without vehicle unit			✓			Finds vehicle combinations whose valid days or lengths overlap, or which do not begin and end at stop points.
☐ Inconsistent couplings			✓			Finds stop areas of the same stop, which have the same access node and thus allow direct transfers in time zero.
☐ Stop areas with the same node			✓			
☒ PuT connector nodes without stop area			✓			Finds PuT connector nodes with either no stop areas or at least one stop area with no line departure (origin connector) or no line arrival (destination connector).
☒ PuT connector nodes without lines			✓			Finds chained up vehicle journey sections to which applies: origin or destination vehicle journey section do not run on the scheduled time.
☒ Invalid chained up vehicle journey sections			✓			
☒ Lines without a fare system			✓			
☐ Parallel vehicle journeys of a time profile			✓			Finds vehicle journeys which run at the same time on a common time profile in terms of the analysis period.
☒ Vehicle journey items without vehicle journey sections			✓			

Figure 99. Network check in the transport model

Regular usage of Check network procedure during the development and update of the transport network allowed to timely detect and eliminate technical errors that could have affected further calculations. These ensured the logical consistency and completeness of the transport network data, which was critical for the correct operation of the model.

5. DEMAND MODEL METHODOLOGY

The demand model is based on the results of a sociological survey, that was conducted within the scope of the assignment between November 2024 and March 2025 (considering temporary breaks during the winter holidays and public demonstrations that took place in Tbilisi at that time). A detailed description of the survey methodology and its results is presented in the “HHS Report” prepared and delivered by the Consultant. In this report, the survey results are presented with a high level of detail, focusing mainly on the outcomes to be used to update the Tbilisi transport model.

A four-stage demand model was used to develop the Tbilisi transport model. This approach makes it possible to accurately describe all stages of the mobility demand estimate, working with aggregated data.

The demand calculations are conducted for separate demand strata, each corresponding to specific trip purposes of city residents. The computational algorithm produces trip matrices, along with calculated traffic volumes and passenger flows across the road network.

The four-stage model consists of the following phases:

1st Stage: Trip Generation

In this stage for each transport zone, the total trip productions (originating trips) and trip attractions (destination trips), disaggregated by demand strata, are calculated. The results are presented as row and column totals in the trip matrices.

2nd Stage: Trip Distribution.

In this stage, trip volumes between all transport zones are computed once again disaggregated by demand strata, but without assigning specific transport modes to any trip. The outputs of this estimating phase are represented by the single elements of the trip matrices.

3rd Stage: Mode Choice.

In the mode choice stage, the model calculates trip matrices for each transport mode separately. Each matrix represents the number of trips made using a specific mode of transport, while still maintaining demand strata differentiation.

4th Stage: Assignment.

The final stage assigns all trips to specific routes, distinguishing between different transport modes. This stage provides modelled traffic and passenger flow volumes, as well as network load levels for each section of the road network. Additionally, completing this stage allows to evaluate the operational transport performance indicators, the accessibility levels, and the network efficiency. The route assignment phase marks the completion of the demand modelling cycle.

The sequence of the four-stage demand modelling process is visually represented in Figure 100.

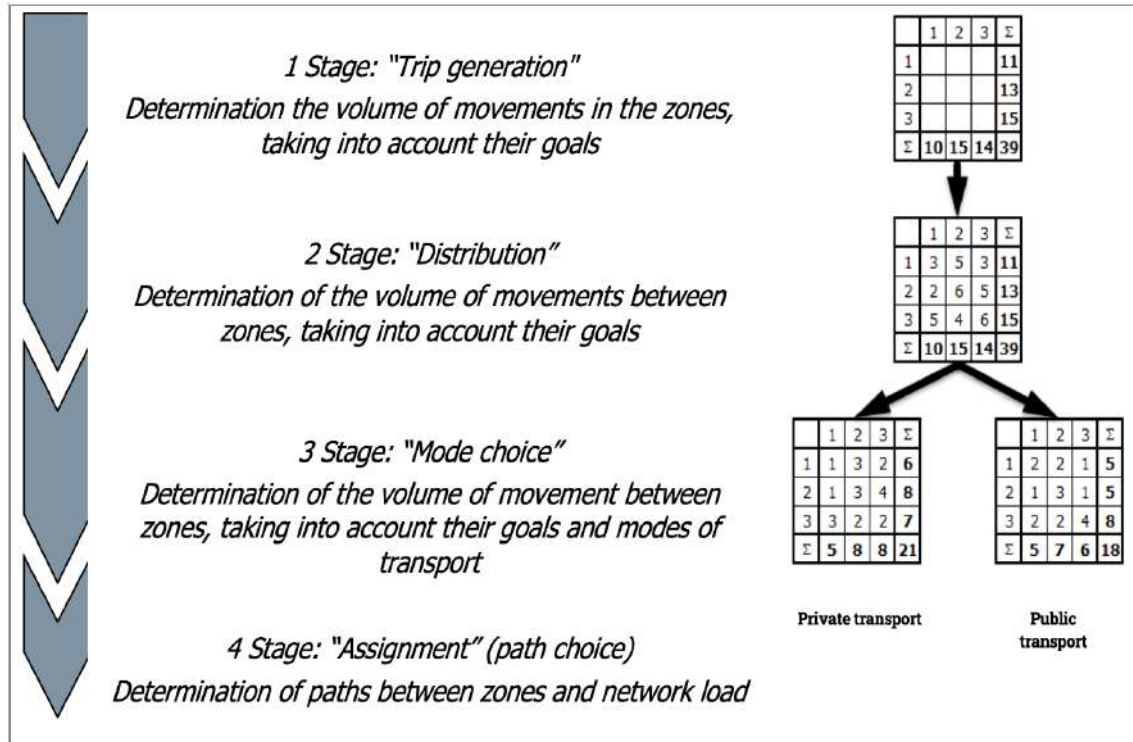


Figure 100. Sequence of the Transport Demand Modelling Process

The implementation of this methodology results in a multimodal transport model, that can be considered as a comprehensive digital representation of the city's transport infrastructure. This model serves as a versatile tool, enabling (not exhaustively):

- Storage, organisation, and visual representation of transport and socio-economic data to facilitate structured analysis of the city's mobility system.
- Development of transport forecasts based on various "what-if" scenarios, supporting informed decision-making.
- Consideration of daily travel variability, distinguishing between weekday and weekend travel patterns.
- Calculation of current and projected trip volumes, along with an evaluation of the impacts of different transport conditions based on predefined performance indicators.
- Assessment of network performance using key quality indicators such as transport accessibility and service availability for different population groups.
- Evaluation of the impact of new public transport (PuT) services and routes, optimising the overall efficiency of the transport system.
- Preparation of feasibility studies for investment projects aimed at developing urban transport infrastructure.
- Design of integrated transport network development programmes, covering all modes of transport.

The transport model provides a comprehensive analytical framework for effective transport system management and urban infrastructure planning.

5.1. Demand segments

For the AM peak model, it was important to select and group enough demand strata to achieve two aims:

- 1) to be able to define and set a different logic for the mode distribution for those strata that, according to observed statistics, depicted differences in the mode choice process.
- 2) to have enough data to calculate utility functions and other parameters that require more thorough distribution of cases.

First, a complete database of all trips from the Household Survey (HHS) was formed, with additional attributes describing the person who performed the trips. Particularly, a car access indicator for the trips described by interviewed people was added to properly consider the effective availability of a car and the possible need to agree with other household members for the use of the car.

Afterwards, the distribution of trips on the time basis was also analysed. The general distribution is depicted at Figure 101 – that reveals that the highest peak hours are during evening from 17:30 to 19:00. The morning peak is less intense and lasts more than 1 hour.

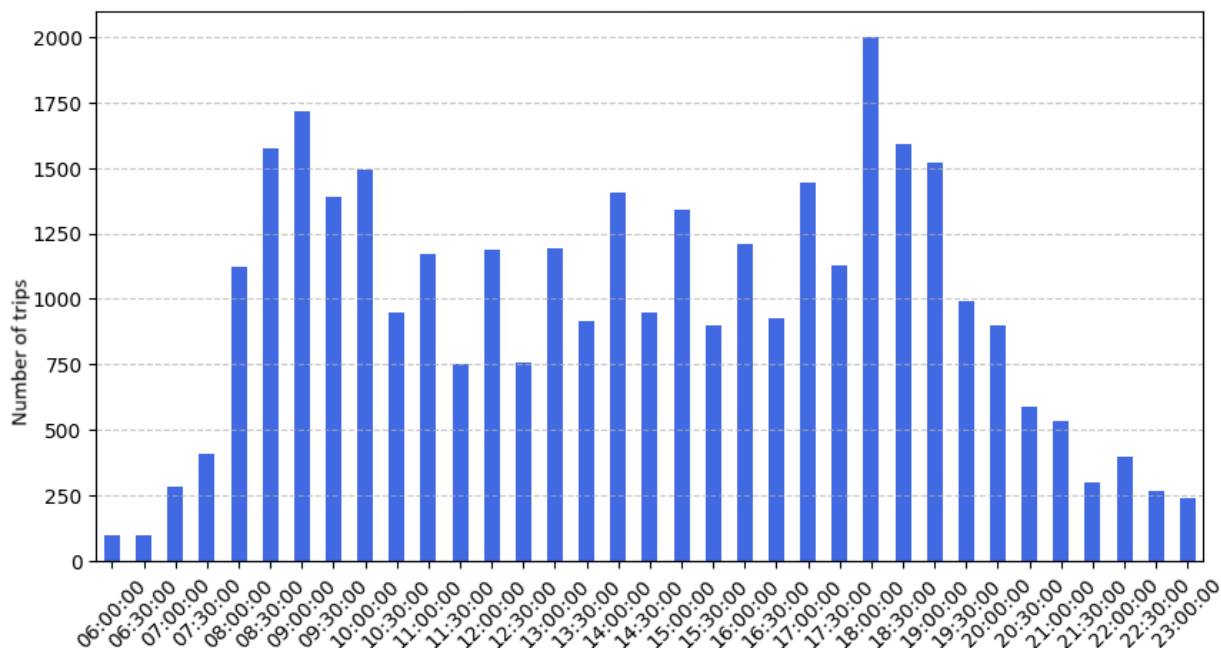


Figure 101. General distribution of trips by time when they were performed, by 30 min intervals

Figure 102 presents the origin-destination matrix for trips made during the narrow morning peak disaggregated by car availability. Rows represent trip origins, columns represent destinations, and each cell reports two values: the number of trips made by people with a car available and by people without a car available. The matrix shows that many origin-destination pairs contain very low or zero counts. Therefore, it was assumed that if we had taken trips only for narrow morning peak, it wouldn't give enough data for calculating shares and functions.

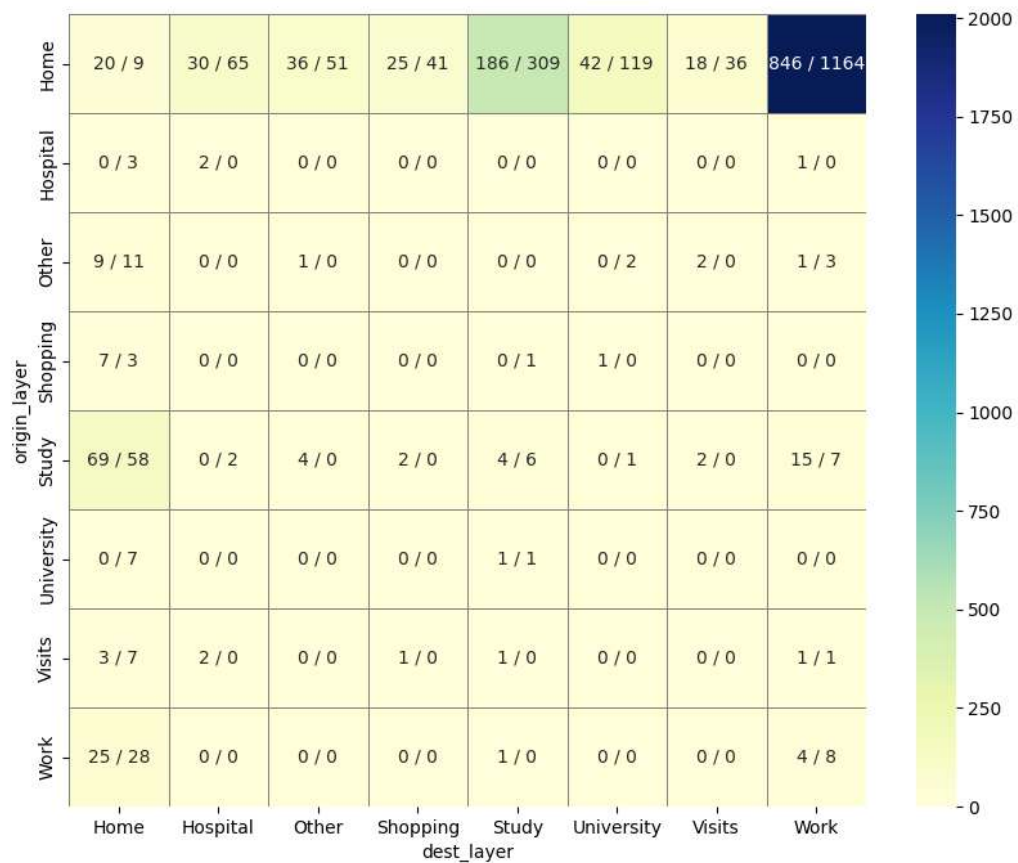


Figure 102. Matrix of origins and destinations of trips for narrow morning peak (split by car availability)

A more detailed analysis reveals that the total number of on-going trips remains relatively high throughout the period between 7:50 and 10:10 exceeding values of more than 1000 on-going trips in almost every 10-minutes interval (Figure 103). This period of the day can be considered as a “wide morning peak”.

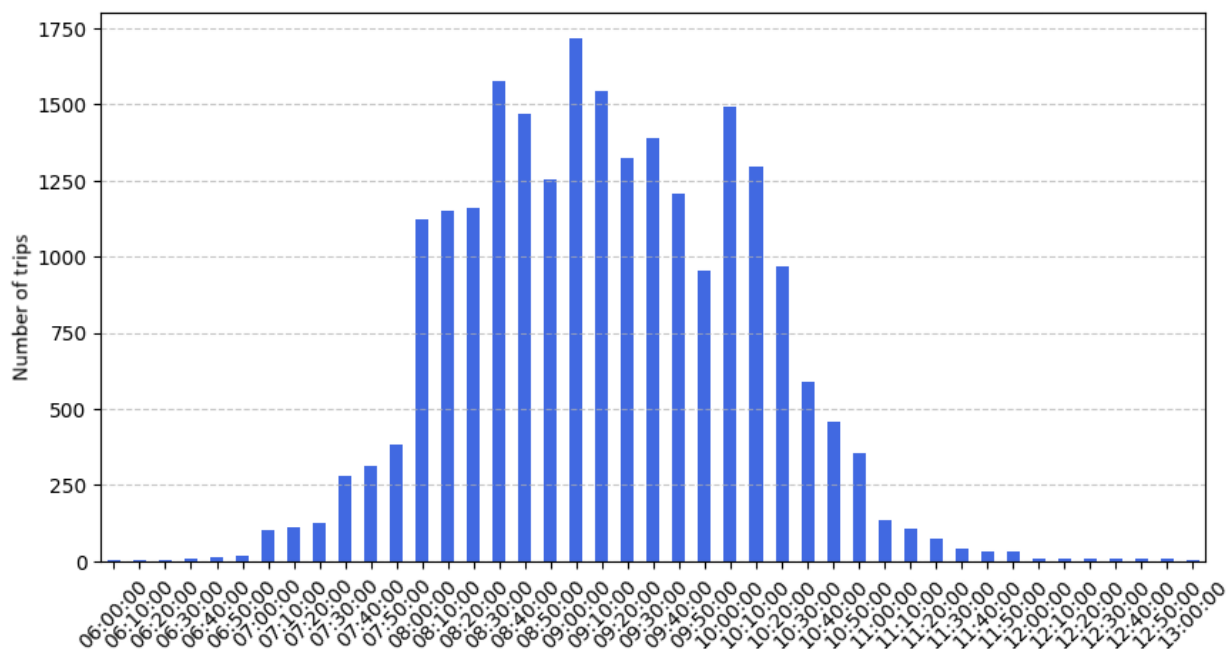


Figure 103. Morning distribution of trips by time when they were performed, by 10 min intervals

Another detailed analysis was made to better assess possible differences in the mode distribution when considering two groups of people: those always having a car available and those who have not. A comparison was conducted to also determine if the household car ownership or the car availability have an impact on the observed differences in modal split. The outcome of this analysis reveals that car availability has a much more significant impact in mobility behaviour than the household car ownership (Figure 104, Figure 105).

Mode	Car Ownership		Car Availability	
	No Car in Ownership	Car in Ownership	Car Not Available	Car Available
Public transport	76.65%	40.04%	75.84%	24.24%
Private car as driver	1.56%	40.59%	2.02%	58.01%
Private car as passenger	4.72%	8.70%	5.55%	9.34%
Taxi and ridehailing	2.11%	1.31%	2.08%	0.98%
Only by foot	13.69%	8.03%	13.36%	5.87%
Motorcycles	0.09%	0.30%	0.09%	0.40%
Bikes, light personal vehicles	0.14%	0.06%	0.09%	0.09%
Mix of modes	0.82%	0.79%	0.78%	0.85%
Other modes	0.23%	0.18%	0.19%	0.22%
	100.00%	100.00%	100.00%	100.00%

Figure 104. Distribution of wider AM peak trips by mode used (split by car ownership and car availability)

Because the estimated number of trips was quite low, there was a need to reduce the amount of demand strata. Nearly all trips that start from home could be selected separately for prior analysis of modes distribution, as most cells have enough trips within (Figure 105). However, some strata were grouped to ensure a sufficient sample size for the analysis. More specifically, the strata “Home-Shopping”, “Home-Other”, “Home-Hospitals”, and “Home-Visits” were merged into a single group named “Home-Other”.

Among the other OD pairs, “Study-Home” and “Work-Home” were considered separately, while any other trip heading back to home was merged into the group “Other-Home”; trips heading to any work place were merged into “Other-Work”, and the remaining trips were considered as part of the “Other-Other” (Figure 105). In this procedure, the split by car availability remained unchanged. Table 7 depicts logic of grouping.

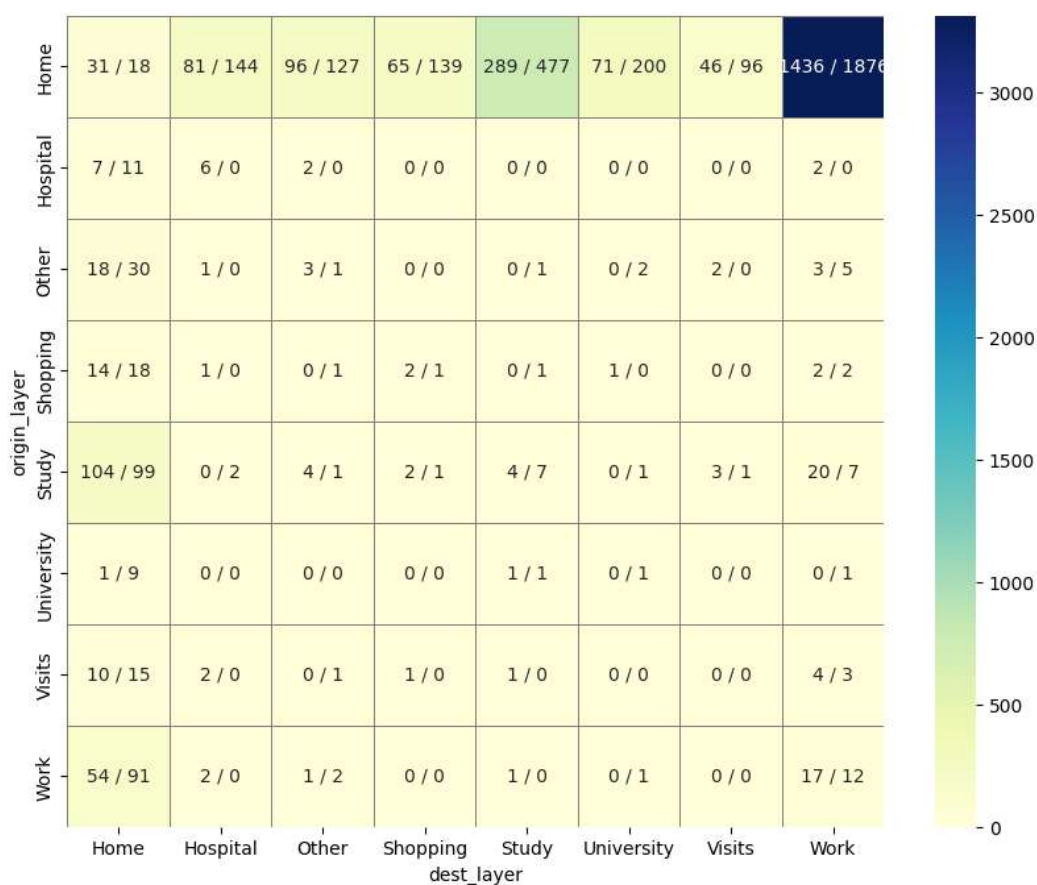


Figure 105. Matrix of origins and destinations for wide morning peak (split by car availability)

Table 7 Grouping respondent's trips by purpose pairs

	Home	Hospital	Other	Shopping	Visits	Study	University	Work
Home		Home-Other				Home-Study	Home-University	Home-Work
Study	Study-Home	Other-Other						Other-Work
Work	Work-Home							
Other	Other-Home							
Shopping								
University								
Visits								
Hospital								

Modal split analysis revealed quite different mode choices for each of the selected demand strata. Therefore all 9*2 strata were considered (Figure 106).

Demand-Strata	Bikes & LPT	Pedestrians only	Private transport as driver	Private Transport as passenger	Public transport
Non Car Available - Total	0.26%	13.53%	2.17%	8.16%	75.87%
Home-Other_NCA	0.38%	13.36%	2.29%	10.88%	73.09%
Home-Study_NCA	0.21%	29.35%	0.84%	9.01%	60.59%
Home-University_NCA	0.00%	4.00%	0.00%	2.50%	93.50%
Home-Work_NCA	0.32%	9.49%	2.67%	8.48%	79.05%
Other-Home_NCA	0.00%	20.48%	4.82%	8.43%	66.27%
Other-Other_NCA	0.00%	26.92%	3.85%	3.85%	65.38%
Other-Work_NCA	0.00%	10.00%	3.33%	10.00%	76.67%
Study-Home_NCA	0.00%	34.34%	1.01%	1.01%	63.64%
Work-Home_NCA	0.00%	4.40%	1.10%	2.20%	92.31%
Car Available - Total	0.17%	5.77%	59.15%	10.78%	24.14%
Home-Other_CA	0.00%	4.39%	56.74%	18.50%	20.38%
Home-Study_CA	0.00%	16.26%	40.48%	20.07%	23.18%
Home-University_CA	1.41%	4.23%	21.13%	4.23%	69.01%
Home-Work_CA	0.21%	3.76%	63.86%	8.08%	24.09%
Other-Home_CA	0.00%	4.00%	66.00%	14.00%	16.00%
Other-Other_CA	0.00%	10.00%	62.50%	12.50%	15.00%
Other-Work_CA	0.00%	4.17%	75.00%	2.08%	18.75%
Study-Home_CA	0.00%	11.54%	66.35%	7.69%	14.42%
Work-Home_CA	0.00%	1.85%	61.11%	5.56%	31.48%

Figure 106. Demand strata distribution by modal split (split by car availability)

At the end of this analysis, the demand strata presented in Figure 107 were formed for the AM peak model.

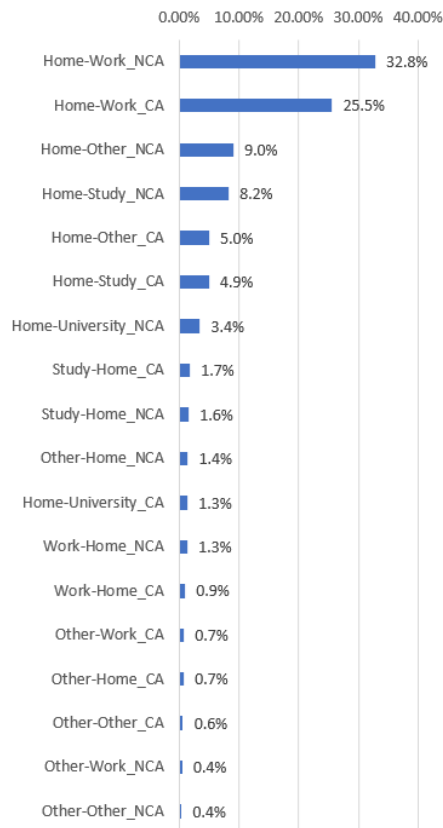


Figure 107. Final demand strata distribution

When configuring the passenger demand model for Tbilisi in PTV Visum, all person groups, activity pairs, and demand strata were integrated. (Figure 108).

Demand models

Select demand model: PT Passenger trip

Basis | Person groups | Activity pairs | Demand strata

Number: 4	Code	Name
1	01_CA	Car available
2	02_NCA	Non-car available
3	03_CA_aggl	Car available agglomeration
4	04_NCA_aggl	Non-car available agglomeration

Select demand model: PT Passenger trip

Basis | Person groups | Activity pairs | Demand strata

☒ Show user-defined attributes

Number: 26	Code	Name	Demand segment set	Person groups	Activity pair
1	01_HW_CA	...	...	01_CA	01_HW
2	01_HW_NCA	...	...	02_NCA	01_HW
3	02_WH_CA	...	...	01_CA	02_WH
4	02_WH_NCA	...	...	02_NCA	02_WH
5	03_HS_CA	...	...	01_CA	03_HS
6	03_HS_NCA	...	...	02_NCA	03_HS
7	04_SH_CA	...	...	01_CA	04_SH
8	04_SH_NCA	...	...	02_NCA	04_SH
9	05_HUNI_CA	...	...	01_CA	05_HUNI
10	05_HUNI_NCA	...	...	02_NCA	05_HUNI
11	06_HO_CA	...	...	01_CA	06_HO
12	06_HO_NCA	...	...	02_NCA	06_HO
13	07_OH_CA	...	...	01_CA	07_OH
14	07_OH_NCA	...	...	02_NCA	07_OH
15	08_OO_CA	...	...	01_CA	08_OO
16	08_OO_NCA	...	...	02_NCA	08_OO
17	09_OW_CA	...	...	01_CA	09_OW
18	09_OW_NCA	...	...	02_NCA	09_OW
19	21_HC_CA_aggl	...	...	03_CA_aggl	10_HC
20	21_HC_NCA_aggl	...	...	04_NCA_aggl	10_HC
21	22_HNC_CA_aggl	...	...	03_CA_aggl	11_HNC
22	22_HNC_NCA_aggl	...	...	04_NCA_aggl	11_HNC
23	23_HS_CA_aggl	...	...	03_CA_aggl	03_HS
24	23_HS_NCA_aggl	...	...	04_NCA_aggl	03_HS
25	24_OO_CA_aggl	...	...	03_CA_aggl	08_OO
26	24_OO_NCA_aggl	...	...	04_NCA_aggl	08_OO

Figure 108. Passenger demand model configuration window in PTV Visum

5.2. Trip generation

The trip generation stage examines the trip production and attraction process, estimating the volume of arrivals and departures for each TAZ, detailed by demand strata. The result of this stage is an estimation of the total incoming and outgoing trips for each TAZ. In other words, it generates the row and column totals of the O/D trip matrices (the sum of all elements in a matrix row or column) for each demand stratum. These values serve as input data for the trip distribution stage.

The number of trips produced and attracted by each TAZ, segmented by demand strata, was computed based on socio-economic statistics (Table 8) and trip production/attraction coefficients.

Table 8. Socio- Socio-economic Data for Trip Generation

№	Demand Stratum	Production	Attraction
1	01_HW_CA	POPULATION_18_64_CAR	WORKPLACES
2	01_HW_NCA	POPULATION_18_64_NCA	WORKPLACES
3	02_WH_CA	WORKPLACES	POPULATION_18_64_CAR
4	02_WH_NCA	WORKPLACES	POPULATION_18_64_NCA
5	03_HS_CA	POPULATION_6_18_CAR; POPULATION_0_5_CAR	PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS;
6	03_HS_NCA	POPULATION_6_18_NCA; POPULATION_0_5_NCA	PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS;
7	04_SH_CA	PLACES_IN_SCHOOL;PLACES_IN_KIND ERGARDENS;	POPULATION_6_18_CAR; POPULATION_0_5_CAR
8	04_SH_NCA	PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS;	POPULATION_6_18_NCA; POPULATION_0_5_NCA
9	05_HO_CA	POPULATION_CAR	POPULATION; WORKPLACES_SERVICE; MEDICINE_AREA; SHOPPING_AREA
10	05_HO_NCA	POPULATION_NCA	POPULATION; WORKPLACES_SERVICE; MEDICINE_AREA; SHOPPING_AREA
11	06_OH_CA	POPULATION; WORKPLACES_SERVICE; MEDICINE_AREA; SHOPPING_AREA	POPULATION_CAR
12	06_OH_NCA	POPULATION; WORKPLACES_SERVICE; MEDICINE_AREA; SHOPPING_AREA; PLACES_IN_UNIVERSITY	POPULATION_NCA
13	07_OW_CA	POPULATION; WORKPLACES_SERVICE; PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS; MEDICINE_AREA; SHOPPING_AREA	WORKPLACES
14	07_OW_NCA	POPULATION; WORKPLACES_WORKPLACES_SERVIC E; PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS; WORKPLACES; SHOPPING_AREA; PLACES_IN_UNIVERSITY	WORKPLACES
15	08_OO_CA	POPULATION; WORKPLACES_SERVICE; PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS; MEDICINE_AREA; SHOPPING_AREA	POPULATION; WORKPLACES_SERVICE; PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS; MEDICINE_AREA; SHOPPING_AREA
16	08_OO_NCA	POPULATION; WORKPLACES_SERVICE; PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS; WORKPLACES; SHOPPING_AREA; PLACES_IN_UNIVERSITY	POPULATION; WORKPLACES_SERVICE; PLACES_IN_SCHOOL; PLACES_IN_KINDERGARDENS; MEDICINE_AREA; SHOPPING_AREA; PLACES_IN_UNIVERSITY

№	Demand Stratum	Production	Attraction
17	09_HUNI_CA	POPULATION_19_24_CAR	PLACES_IN_UNIVERSITY
18	09_HUNI_NCA	POPULATION_19_24_NCA	PLACES_IN_UNIVERSITY

The trip production/attraction coefficient represents the average number of departures/arrivals per demand layer over a given period, calculated per representative unit of the reference group using the formula:

$$Kg = Vg / Ng,$$

where

Kg – Trip production/attraction coefficient;

Vg – Total number of departures/arrivals for reference group g .

Ng – Total number of individuals in reference group g within the analysis area.

A reference group is a socio-economic population segment that generates or attracts trips for specific purposes. Reference groups were established based on mobility survey results (see Paragraph 5.1).

Example Calculation of Trip Production/Attraction Coefficients for the Work-Home_CA strata:

- Trip Production:

1.1. $Vg = 3290$ (total departures for Work-Home_CA strata);

1.2. $Ng = 473\,503$ (total workplaces);

$Kg = 3290 / 473503 = 0,00694821$ (trip production coefficient);

- Trip Attraction:

1.3. $Vg = 3290$ (total arrivals for Work-Home_CA strata);

1.4. $Ng = 273\,168$ (working-age population with car access);

$Kg = 3290 / 273\,168 = 0,01204387$ (trip attraction coefficient).

The calculated trip production/attraction coefficients for each demand layer were integrated into PTV Visum for further calculations (Figure 109).

Demand stratum	Matrix balancing	Production function	Attraction function
01_HIV_CA	Production total	0,352859778597786 * (POPULATION_18_04_CA)	0,203307870021905 * (WORKPLACES)
02_VNI_CA	Attraction total	0,00694821363328215 * (WORKPLACES)	0,0120438704387044 * (POPULATION_18_04_CA)
03_HS_CA	Production total	0,270651514752024 * (POPULATION_6_18_CA) + 9,206285372866703 * (POPULATION_0_5_CA)	0,0032810550769643 * (PLACES_IN_SCHOOL) + 0,124087169309621 * (PLACES_IN_KINDERGARDENS)
04_SH_CA	Attraction total	0,02139381814563458 * (PLACES_IN_SCHOOL) + 0,0283242451685084 * (PLACES_IN_KINDERGARDE...	0,0682990816586672 * (POPULATION_6_18_CA) + 0,0470686177195735 * (POPULATION_0_5_CA)
05_HUNI_CA	Production total	0,00711488504693979 * (POPULATION_19_24_CA)	0,0086099264902781 * (PLACES_IN_UNIVERSITY)
06_HO_CA	Production total	0,0107037125648387 * (POPULATION_CA)	0,00023144338893506 * (POPULATION) + 0,0003110134333984 * (WORKPLACES_SERVICE) + 0,00120137009710226 * (HBOICHS...
07_OH_CA	Attraction total	0,00318661919769924 * (POPULATION) + 0,0368672147007392 * (WORKPLACES_SERVICE) + 0,001...	0,0434434713903452 * (POPULATION_CA)
08_OO_CA	Mean of both tab	0,000368778923647664 * (POPULATION) + 0,00479676111964954 * (WORKPLACES_SERVICE) + 0,0...	0,00046096365455958 * (POPULATION) + 0,00586270803439089 * (WORKPLACES_SERVICE) + 0,00144518029283456 * (PLACES_IN...
09_OIV_CA	Attraction total	0,000183226474491425 * (POPULATION) + 0,00597829254170065 * (WORKPLACES_SERVICE) + 0,0...	0,006001267637544491 * (WORKPLACES)

Figure 109. Trip Production/Attraction Coefficients in PTV Visum (Passenger Trip generation_CA_Tbilisi)

The final output consists of the total number of trips produced and attracted by each TAZ in the transport model, detailed by demand stratum (Figure 110).

Demand models

Select demand model
PT Passenger trip

Basis | Person groups | Activity pairs | Demand strata

☐ Show user-defined attributes

Number: 18	Code	Name	Demand segment set	Person groups	Activity pair
1	01_HW_CA	...	...	01_CA	01_HW
2	01_HW_NCA	...	...	02_NCA	01_HW
3	02_WH_CA				
4	02_WH_NCA				
5	03_HS_CA				
6	03_HS_NCA				
7	04_SH_CA				
8	04_SH_NCA				
9	05_HUNI_CA				
10	05_HUNI_NCA				
11	06_HO_CA				
12	06_HO_NCA				
13	07_OH_CA				
14	07_OH_NCA				
15	08_OO_CA				
16	08_OO_NCA				
17	09_OW_CA				
18	09_OW_NCA				

Define productions/attractions

Code: 01_HW_CA

Name:

Number: 684	Zone	Productions	Attractions
1	101001	273.46632841	71.59500431
2	101002	140.08533210	245.28318698
3	101003	498.94372694	291.35489671
4	101004	461.18773063	416.37578037
5	101005	62.45618081	650.19511470
6	101006	182.07564576	508.30290071
7	101008	81.86346863	174.55337910
8	101009	100.21217712	259.55892802
9	101010	50.45894834	356.24462871
10	101011	102.68219557	265.61530301
11	101012	73.04197417	501.81392751
12	101013	81.15774908	347.59266444
13	101014	109.73939114	325.09755735
14	101015	102.32933579	612.12647192
15	101016	239.59178967	747.96231092
16	101017	240.47186247	172.02078525

OK Cancel

Create Delete Productions/attractions...

Figure 110. Example of Production/Attraction Volumes by Demand strata HW_CA

5.3. Distribution

The trip distribution procedure is part of the 4-stage model, with sequential calculation of the stages. The productions and attractions calculated in the trip generation procedure determine only the constraints of the total demand matrix of a demand stratum. The elements of the matrix themselves are calculated in the trip distribution procedure. On the one hand, the allocation of a certain destination zone to a given origin zone is based on its attractiveness for the demand stratum (measured by its destination demand = attractions), on the other hand the impedance of the trip from origin to destination zone is vital (measured by the skim matrices for journey time, fares and other elements of generalized costs).

The Gravity model is a mathematical model for trip distribution calculation. It is based on the assumption that the trips made in a planning area are directly proportional to the relevant origin and destination demand in all zones and the functional values of the utility function between the zones ²⁹.

The gravity model calculates a complete matrix of traffic relations F_{ij} , using the OD pairs of marginal totals (origin and destination traffic of the individual zones).

The gravity model works with distribution parameters, therefore with values within the utility function, which map the reaction of road users to distance or time relations. These parameters are determined by comparing the demand per OD pair determined by the model, with the counted demand per OD pair.

²⁹ Ortúzar, J. de D., & Willumsen, L. G. (2001). Modelling Transport. Chichester: Wiley. 499 p.

General form of the distribution formula

$$F_{ij}=k_{ij} \cdot Q_i \cdot Z_j \cdot f(U_{ij})$$

Where:

F_{ij} = trips from origin zone iii to destination zone jjj

Q_i = number of trips produced in zone iii (productions)

Z_j = number of trips attracted to zone jjj (attractions)

U_{ij} = utility (or generalized cost, e.g., distance, time, cost) between zones i and j

$f(U_{ij})$ = deterrence/attraction function (describes how impedance reduces attractiveness)

k_{ij} = scaling factor to adjust special cases (e.g., borders, calibration factors)

The parameters of the utility function $f(U_{ij})$ are determined by the following formulas:

- Logit: $f(U_{ij}) = e^{(cU)}$
- Kirchhoff: $f(U_{ij}) = U^c$
- BoxCox: $f(U_{ij}) = e^{[c (U^b - 1) / b]}$
- Combined: $f(U_{ij}) = a U^b e^{(cU)}$
- TModel: $f(U_{ij}) = 1/(U^b + cU^a)$

$$\begin{cases} \sum_j F_{ij} = Q_i \\ \sum_i F_{ij} = Z_j \end{cases} - \text{boundary conditions of the distribution model}$$

For further calculations, Direct Distance matrix was chosen as the impedance of travel from the departure zone to the destination zone.

To estimate Direct Distance, travel data from HHS was analysed, and the results are presented in Table 9.

Table 9. Trip Distribution by Direct Distance for Demand Stratum

Stratum	Direct Distance													
	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-15	15-17.5	17.5-20	20-22.5	22.5-25	25-27.5	27.5-30	30-32.5	32.5+
	Car Access													
Home-Work	25%	23%	17%	15%	8%	6%	2%	2%	1%	0%	0%	0%	0%	0%
Work-Home	23%	15%	21%	19%	10%	4%	4%	4%	0%	0%	0%	0%	0%	0%
Home-Study	52%	24%	10%	8%	3%	1%	1%	0%	1%	0%	0%	0%	0%	0%
Study-Home	50%	26%	14%	6%	1%	1%	0%	0%	2%	0%	0%	0%	0%	1%
Home-University	23%	18%	17%	27%	10%	3%	1%	0%	0%	1%	0%	0%	0%	0%
Home-Other	34%	19%	16%	8%	12%	5%	1%	2%	1%	1%	0%	0%	1%	0%
Other-Home	39%	20%	18%	7%	7%	2%	2%	2%	0%	0%	2%	0%	0%	0%
Other-Work	27%	10%	17%	17%	15%	6%	4%	2%	0%	2%	0%	0%	0%	0%
Other-Other	28%	33%	13%	8%	5%	5%	0%	8%	0%	0%	0%	0%	0%	0%
	Non-Car Access													
Home-Work	27%	25%	16%	14%	9%	5%	2%	1%	1%	0%	0%	0%	0%	0%
Work-Home	24%	22%	13%	17%	12%	4%	1%	1%	1%	1%	0%	2%	0%	0%
Home-Study	64%	19%	7%	5%	3%	0%	0%	0%	0%	1%	0%	0%	0%	0%
Study-Home	76%	19%	3%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Home-University	19%	23%	17%	21%	14%	3%	3%	1%	0%	0%	1%	0%	1%	0%
Home-Other	38%	20%	15%	11%	8%	5%	1%	0%	1%	0%	0%	0%	0%	0%
Other-Home	37%	23%	16%	10%	5%	5%	2%	1%	0%	0%	0%	0%	0%	0%
Other-Work	20%	27%	10%	17%	10%	10%	0%	0%	7%	0%	0%	0%	0%	0%
Other-Other	38%	35%	4%	12%	8%	4%	0%	0%	0%	0%	0%	0%	0%	0%

To ensure convergence between observed and modelled values, mathematical function selection was carried out for each demand stratum. The **Combined** function was identified as the best fit, with the parameter values provided in Table 10.

Table 10. Parameters of the Combined function

Demand Stratum	Combined		
	a	b	c
Car Access			
Home-Work_CA	0.96601	0.39246	-0.24474
Work-Home_CA	0.77787	0.84310	-0.31328
Home-Study_CA	0.97268	-0.19482	-0.21489
Study-Home_CA	1.31060	-0.62261	-0.15133
Home-University_CA	0.72784	1.17996	-0.41079
Home-Other_CA	0.85220	0.28258	-0.20913
Other-Home_CA	0.95912	0.03680	-0.19021
Other-Work_CA	0.66939	0.88587	-0.29316
Other-Other_CA	1.35917	-0.34485	-0.13155
Non-Car Access			
Home-Work_NCA	1.01656	0.29238	-0.23894
Work-Home_NCA	0.99405	0.23635	-0.19655
Home-Study_NCA	0.88724	-0.71391	-0.10134
Study-Home_NCA	1.69452	-1.77338	-0.12791
Home-University_NCA	0.91573	0.70316	-0.30912
Home-Other_NCA	0.84879	0.31550	-0.23891
Other-Home_NCA	0.97688	0.13981	-0.22681
Other-Work_NCA	1.09722	0.08604	-0.16078
Other-Other_NCA	1.29776	-0.35414	-0.17256

The obtained data on the parameters of the function and the Direct Distance matrix were integrated into the parameters of the trip distribution procedure for further calculations (Figure 111).

Data collection and Model update related to transport in Tbilisi – Update the Transport Demand Model

Parameters: Trip distribution

☐ For active OD pairs only
☐ Exclude OD pairs connecting passive zones
☒ Set any result demand matrix to 0 prior to calculation
☐ Apply estimated parameters

	Demand stratum	Utility function	Function type	a	b	c	Direction parameters
1	01_HW_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.96601	0.39246	-0.24474	Productions, Doubly constrained, Scaling: production total
2	02_WH_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.77787	0.8431	-0.31328	Attractions, Doubly constrained, Scaling: attraction total
3	03_HS_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.97268	-0.19482	-0.21489	Productions, Doubly constrained, Scaling: production total
4	04_SH_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	1.3106	-0.62261	-0.15133	Attractions, Doubly constrained, Scaling: attraction total
5	05_HUNI_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.72784	1.17996	-0.41079	Productions, Doubly constrained, Scaling: production total
6	06_HO_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.8522	0.28258	-0.20913	Productions, Doubly constrained, Scaling: production total
7	07_OH_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.95912	0.0368	-0.19021	Attractions, Doubly constrained, Scaling: attraction total
8	08_OO_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	1.35917	-0.34485	-0.13155	Productions, Doubly constrained, Scaling: mean value
9	09_OW_CA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.66939	0.88587	-0.29316	Attractions, Doubly constrained, Scaling: attraction total

Apply to all DStrata

OK Cancel

Parameters: Trip distribution

☐ For active OD pairs only
☐ Exclude OD pairs connecting passive zones
☐ Set any result demand matrix to 0 prior to calculation
☐ Apply estimated parameters

	Demand stratum	Utility function	Function type	a	b	c	Direction parameters
1	01_HW_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	1.01656	0.29238	-0.23894	Productions, Doubly constrained, Scaling: production total
2	02_WH_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.99405	0.23635	-0.19655	Attractions, Doubly constrained, Scaling: attraction total
3	03_HS_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.88724	-0.71391	-0.10134	Productions, Doubly constrained, Scaling: production total
4	04_SH_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	1.69452	-1.77338	-0.12791	Attractions, Doubly constrained, Scaling: attraction total
5	05_HUNI_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.91573	0.70316	-0.30912	Productions, Doubly constrained, Scaling: production total
6	06_HO_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.84879	0.3155	-0.23891	Productions, Doubly constrained, Scaling: production total
7	07_OH_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	0.97688	0.13981	-0.22681	Attractions, Doubly constrained, Scaling: attraction total
8	08_OO_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	1.29776	-0.35414	-0.17256	Productions, Doubly constrained, Scaling: mean value
9	09_OW_NCA	Matrix([NAME]="TripDistImpedance_DDIs ...)	Combined	1.09722	0.08604	-0.16078	Attractions, Doubly constrained, Scaling: attraction total

Apply to all DStrata

OK Cancel

Figure 111. Trip Distribution procedure parameters

As a result of this procedure, a trip matrix was generated for each demand stratum, determining the number of movements between every TAZ pair (Matrices No. 91-118) (Figure 112).

No	Code	Name	MatrixType	ObjectTypeRef	Sum
90	-----Trip Distribution Matrices-----	-----Trip Distribution Matrices-----	OD demand	Zone	0.000
91		Distribution 01_HW_CA	OD demand	Zone	102786.085
92		Distribution 02_WH_CA	OD demand	Zone	3370.863
93		Distribution 03_HS_CA	OD demand	Zone	32373.957
94		Distribution 04_SH_CA	OD demand	Zone	6813.256
95		Distribution 05_HUNI_CA	OD demand	Zone	2933.667
96		Distribution 06_HO_CA	OD demand	Zone	9921.613
97		Distribution 07_OH_CA	OD demand	Zone	20080.832
98		Distribution 08_OO_CA	OD demand	Zone	5827.083
99		Distribution 09_OW_CA	OD demand	Zone	2870.000
100		Distribution 21_HC_CA_aggl	OD demand	Zone	4163.487
101		Distribution 22_HNC_CA_aggl	OD demand	Zone	4973.123
102		Distribution 23_HS_CA_aggl	OD demand	Zone	4741.844
103		Distribution 24_OO_CA_aggl	OD demand	Zone	1557.035
104		Distribution 01_HW_NCA	OD demand	Zone	250566.964
105		Distribution 02_WH_NCA	OD demand	Zone	10906.994
106		Distribution 03_HS_NCA	OD demand	Zone	186211.553
107		Distribution 04_SH_NCA	OD demand	Zone	32808.802
108		Distribution 05_HUNI_NCA	OD demand	Zone	5888.044
109		Distribution 06_HO_NCA	OD demand	Zone	36067.576
110		Distribution 07_OH_NCA	OD demand	Zone	66547.104
111		Distribution 08_OO_NCA	OD demand	Zone	11897.834
112		Distribution 09_OW_NCA	OD demand	Zone	6378.520
117		Total Distribution	OD demand	Zone	1320999.448
118		Agr Distribution	OD demand	Main zone	1320999.448

Figure 112. List of calculated Correspondence Matrices at the Trip Distribution Stage (extract)

A comparison of trip distribution by travel duration based on survey data (Table 9) and modelled values is illustrated in (Figure 113).

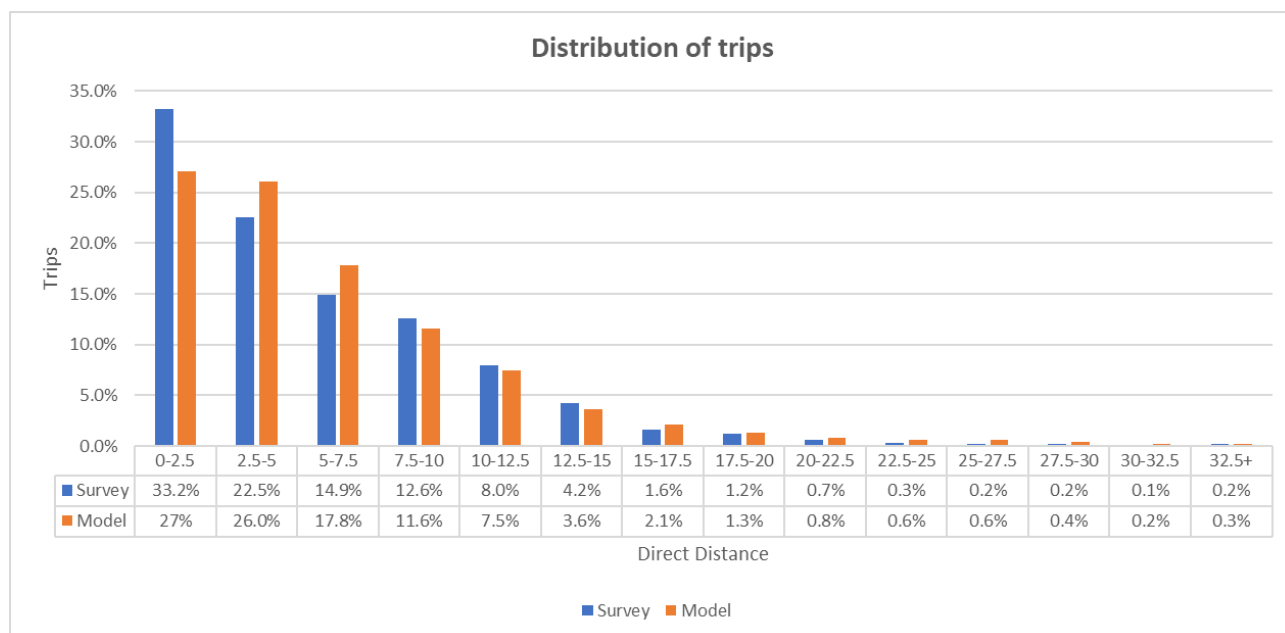
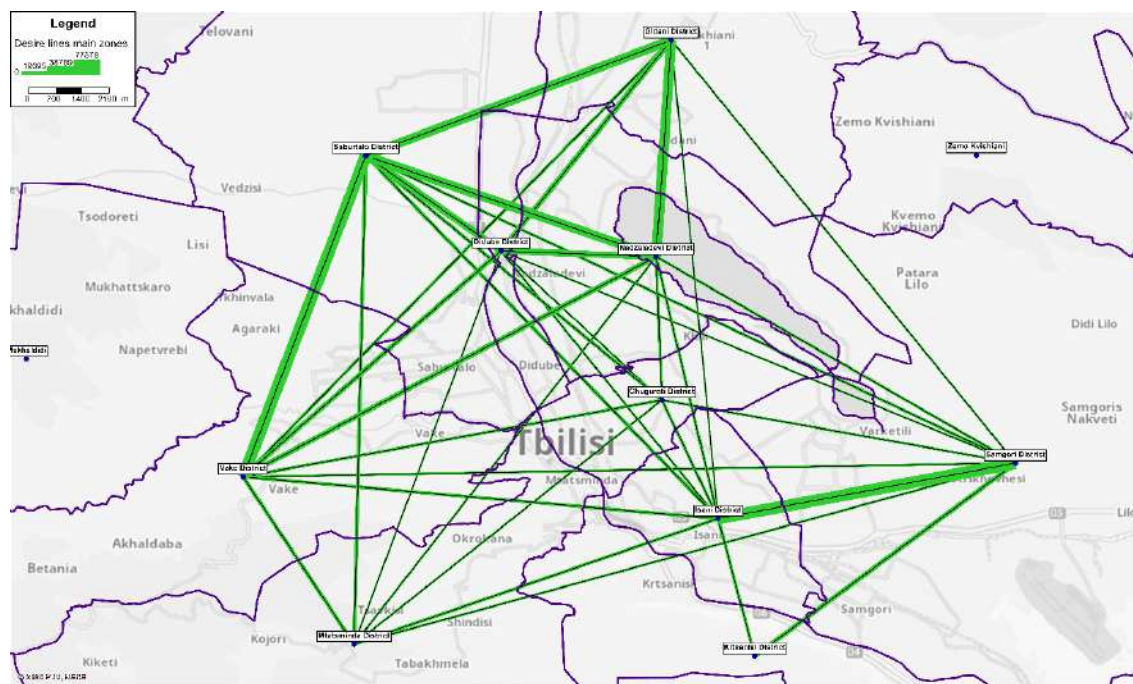
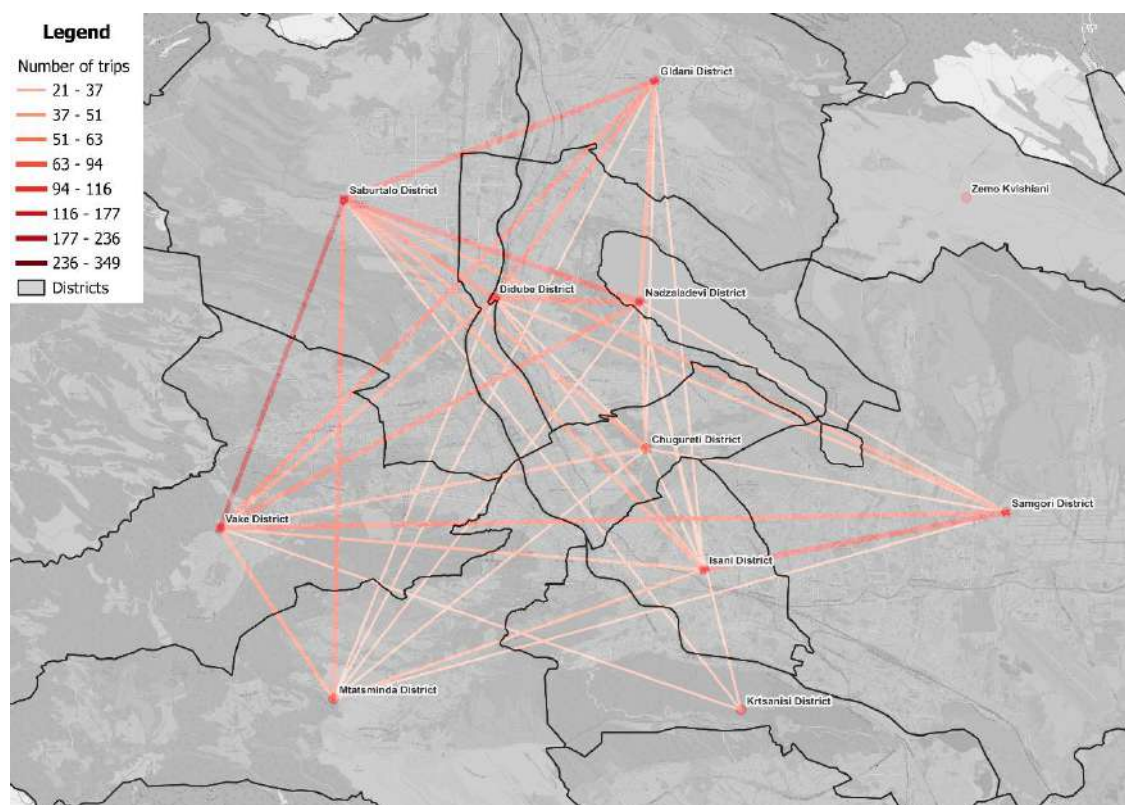


Figure 113. Comparison of Observed vs Modelled Trip Distribution by Travel Duration

A comparison of the distribution of the largest number of trips between the main zones in the model (city districts) and the HHS data is shown in Figure 114.



Model



HHS

Figure 114. Distribution of trips (highest volume) between Districts

The correlation coefficient between the survey results and the model equals 0.96, indicating a very strong positive relationship. This demonstrates that the model successfully reproduces the shape of the observed distribution of trip distances and zones. Minor deviations are mainly observed in the short-distance range; however, the overall trend in the model is consistent with the survey data, confirming the reliability of their use for further calculations.

In the next stage, distribution matrices served as the foundation for the Modal Choice (transport mode selection) calculation.

5.4. Mode choice

In transport modelling, various approaches exist for setting up modal choice procedures, as this stage inherently involves simulating individuals' subjective selection of travel modes from available alternatives. The household survey follows the Revealed Preference (RP)³⁰ approach.

5.4.1. Value Of Time Estimation

The estimation of the Value of Time (VoT) in the model is based on the methodology and coefficients recommended in the World Bank report "Meta-analysis of the Value of Travel Time Savings in Low- and Middle-Income Countries", adapted to the local socio-economic conditions using data collected from the household survey.

In simple terms, the Value of Time represents how much individuals are willing to pay to save time while travelling. Following the World Bank's convention, the VoT was expressed as a proportion of the average hourly wage rate. The difference in VoT across travel modes primarily reflects variations in user groups and their respective income levels. For example, public transport users are expected to value travel time lower than private transport users, due to generally lower income levels. Wage rates also tend to differ between respondents with and without car availability.

To reflect local travel behaviour and ensure realistic VoT estimation, the VoT was obtained using the base coefficients from the report and the income data collected during the household survey.

The base coefficients were obtained for in-vehicle travel time (IVT), along with the corresponding coefficients for walking, waiting, and access/egress time³¹. Coefficients were also distinguished by trip purpose, as the VoT values reflect the different willingness to pay for travel time savings between commuting trips (home–work and home–study purposes) and non-commuting trips (leisure, shopping, other discretionary travel). Based on this, the demand segments were also grouped by the trip purpose into the following groups:

Commute (Home – Work and Home – Study related trips)

- Home–Work_CA
- Home–Work_NCA
- Work–Home_CA
- Work–Home_NCA
- Home–Study_CA
- Home–Study_NCA
- Study–Home_CA
- Study–Home_NCA
- Home–University_CA
- Home–University_NCA

Non-Commute (all other non-work and non-study related trips, including home – other, leisure and discretionary travel):

- Home–Other_CA
- Home–Other_NCA
- Other–Home_CA
- Other–Home_NCA
- Other–Work_CA

³⁰ Modelling Transport / Juan de Dios Ortuzar, Luis G. WilluMRSen. – Fourth edition (2011), John Wiley & Sons, Ltd - p. 323

³¹ <https://documents1.worldbank.org/curated/en/099032124211022462/pdf/P1775471cf971e0ee1becd1a1faab55d1d7.pdf> (Annex C, Table C1)

- Other–Work_NCA
- Other–Other_CA
- Other–Other_NCA

As a result, the percentages valuation presented in Table 11 were used.

Table 11. Valuations as a Proportion of the Wage Rate

	Non-Commute	Commute
IVT	0.74	0.9768
Walk/Bike	0.999	1.31868
Access/egress	1.0656	1.406592

To account for the differences in income level, the users were distinguished by car availability and mode used into the following groups, Table 12.

Table 12. Average hourly wage rates for different user groups (USD/h)

	No car available	Car available
Bike	2.72	
Ped	2.34	2.35
PrTr	3.97	
PrTr_Pass	3.14	2.75
PuT	2.94	3

At this stage, it was decided to not distinguish bike users and car drivers by car availability, due to the little amount of data in these groups.

Accordingly, separate VOT values were defined for private transport, private transport passengers, public transport, pedestrians, and cyclists. For each segment, coefficients were applied to in-vehicle time, access, and egress components.

Below a numerical example of the calculation of VOT for PrT users:

The average hourly wage for private transport users taken from the survey was 3.97 USD/h. Value of in-vehicle time is calculated using base coefficients:

$$VOT_{IVT} = \begin{cases} 3.97 * 0.74 \text{ USD per hour,} & \text{non - commute,} \\ 3.97 * 0.9768 \text{ USD per hour,} & \text{commute.} \end{cases}$$

VOT for access/egress time:

$$VOT_{AT} = \begin{cases} 3.97 * 1.0656 \text{ USD per hour,} & \text{non - commute,} \\ 3.97 * 1.406592 \text{ USD per hour,} & \text{commute.} \end{cases}$$

Table 13 represents the coefficients for each transportation mode with regards to commuting/non-commuting and car availability.

Table 13. Value of time for different modes of transport and types of activities

		Commute		Non-commute	
		Access/egress	IVT	Access/egress	IVT
PrTr_Pass	CA	3.86	2.68	2.93	2.03
	NCA	4.42	3.07	3.35	2.33
PrTr	CA	5.59	3.88	4.23	2.94
	NCA	5.59	3.88	4.23	2.94
PuT	CA	4.22	2.93	3.2	2.22
	NCA	4.14	2.88	3.14	2.18
Bike	CA		3.59		2.72
	NCA		3.59		2.72
Ped	CA		3.1		2.35
	NCA		3.09		2.34

The VoT framework implemented in the model reflects both internationally established parameters and local socio-economic conditions, ensuring realistic representation of user preferences across trip purposes, modes, and accessibility groups.

The above VoT values are integrated in the model as UDAs for demand strata, Figure 115.

List (Demand strata)											
Select list layout...											
Number: 18	Code	VOT_CP_ACT	VOT_CP_EGT	VOT_CP_IVT	VOT_C_ACT	VOT_C_EGT	VOT_C_IVT	VOT_PuT_IVT	VOT_PUT_WKT	VOT_B_TT	VOT_P_TT
1	01_HW_CA	3.863	3.863	2.683	5.587	5.587	3.880	2.930	4.219	3.594	3.095
2	01_HW_NCA	4.423	4.423	3.071	5.587	5.587	3.880	2.875	4.141	3.594	3.087
3	02_WH_CA	3.863	3.863	2.683	5.587	5.587	3.880	2.930	4.219	3.594	3.095
4	02_WH_NCA	4.423	4.423	3.071	5.587	5.587	3.880	2.875	4.141	3.594	3.087
5	03_HS_CA	3.863	3.863	2.683	5.587	5.587	3.880	2.930	4.219	3.594	3.095
6	03_HS_NCA	4.423	4.423	3.071	5.587	5.587	3.880	2.875	4.141	3.594	3.087
7	04_SH_CA	3.863	3.863	2.683	5.587	5.587	3.880	2.930	4.219	3.594	3.095
8	04_SH_NCA	4.423	4.423	3.071	5.587	5.587	3.880	2.875	4.141	3.594	3.087
9	05_HUNI_CA	3.863	3.863	2.683	5.587	5.587	3.880	2.930	4.219	3.594	3.095
10	05_HUNI_NCA	4.423	4.423	3.071	5.587	5.587	3.880	2.875	4.141	3.594	3.087
11	06_HO_CA	2.927	2.927	2.032	4.232	4.232	2.939	2.220	3.196	2.722	2.345
12	06_HO_NCA	3.350	3.350	2.327	4.232	4.232	2.939	2.178	3.137	2.722	2.338
13	07_OH_CA	2.927	2.927	2.032	4.232	4.232	2.939	2.220	3.196	2.722	2.345
14	07_OH_NCA	3.350	3.350	2.327	4.232	4.232	2.939	2.178	3.137	2.722	2.338
15	08_OO_CA	2.927	2.927	2.032	4.232	4.232	2.939	2.220	3.196	2.722	2.345
16	08_OO_NCA	3.350	3.350	2.327	4.232	4.232	2.939	2.178	3.137	2.722	2.338
17	09_OW_CA	2.927	2.927	2.032	4.232	4.232	2.939	2.220	3.196	2.722	2.345
18	09_OW_NCA	3.350	3.350	2.327	4.232	4.232	2.939	2.178	3.137	2.722	2.338

Figure 115 – VoT for demand strata

5.4.2. Generalized Cost Estimation

The mobility survey, conducted among residents of Tbilisi and the suburbs, provided sufficient data to analyse the respondents' preferences in choosing a transport mode. Usually, the choice of transport mode depends on various factors, such as travel time and cost of travel. Bringing these factors to the same basis allowed comparing transport modes in terms of attractiveness to the user.

For uniformity, the Generalized Cost (GC) indicator was used. GC combined both real financial costs and time costs translated into monetary equivalent using the Value of Time (VOT) indicator. Thus, GC reflected the conditional total cost of a trip made by a user with a specific mode of transport, and allows combining both time components (trip duration, accessing a stop, etc.) and actual financial costs (fare, fuel costs, parking).

- **Generalized costs for private transport users**

The calculation formula was as follows:

$$GC_{PrT} = IVT * VOT_{PrT_{IVT}} + AT * VOT_{PrT_{AT}} + ET * VOT_{PrT_{ET}} + VOC * D + P,$$

Where:

- *AT* - access time, i.e., walking time from origin to the car (h);
- *ET* - egress time, i.e., walking time from the car to destination (h);
- *IVT* - in-vehicle travel time (h);
- *D* - travel distance (km);
- *P* - parking costs (USD);
- *VOC* - vehicle operating costs (fuel cost per km, USD/km);
- $VOT_{PrT_{IVT}}, VOT_{PrT_{AT}}, VOT_{PrT_{ET}}$ - values of IVT, access time, egress time for private transport users (USD/h).

Based on HHS data, access and egress times were established at an average of 2 minutes. These values were entered into the zones as UDAs: Access time car and Egress time car.

The average **fuel cost per kilometre** in Tbilisi was estimated using average annual fuel prices in Georgia (2024), typical fuel consumption rates by vehicle type, and the composition of the registered vehicle fleet in Tbilisi: the estimated average value is **0.26 GEL/km** (0,096 USD/km).

The **cost of parking** was set to **1 GEL/h**³² (0,37 USD/h).

The values of average fuel cost per kilometre were entered as UDA for the network - **FUEL_COST_USD_KM**, and cost of parking as UDA for zones - **PARKING_COST**.

For private transport **passengers**, the generalized cost excluded the VOC and P components, as they generally **do not incur parking or fuel costs**:

$$GC_{PrTPass} = IVT * VOT_{PrTPass_{IVT}} + AT * VOT_{PrTPass_{AT}} + ET * VOT_{PrTPass_{ET}},$$

Where:

- *AT* - access time, i.e., walking time from origin to the car (h);
- *ET* - egress time, i.e., walking time from the car to destination (h);
- *IVT* - in-vehicle travel time (h);
- $VOT_{PrTPass_{IVT}}, VOT_{PrTPass_{AT}}, VOT_{PrTPass_{ET}}$ - values of IVT, access time, egress time for private transport passengers (USD/h).

³² <https://ms.gov.ge/msmap/#C=44.7669170-41.7317738@Z=13>

- **Generalized costs for public transport users**

$$GC_{PuT} = IVT * VOT_{PuT_{IVT}} + AT * VOT_{PuT_{AT}} + ET * VOT_{PuT_{ET}} + WT * VOT_{PuT_{WT}} + C$$

Where:

- *AT* - access time, i.e., walking time from origin to the stop (h);
- *ET* - egress time, i.e., walking time from the stop to destination (h);
- *WT* - waiting time (h);
- *IVT* - in-vehicle travel time (h);
- $VOT_{PuT_{IVT}}, VOT_{PuT_{AT}}, VOT_{PuT_{ET}}$ - values of IVT, access time, egress time for public transport users (USD/h).
- *C* - fare for a trip, USD;

For calculations, the **cost of a trip in public transport** was calculated depending on the duration:

- **up to 90 minutes - 1 GEL**³³ (0,37 USD³⁴)
- **from 90 to 180 minutes – 2 GEL** (0,074 USD)
- **Generalized costs for bicycle users**

For cycling trips, the generalized cost consisted only of the time component, expressed in monetary terms:

$$GC_{Bike} = T * VOT_{Bike}$$

Where:

- *T* - trip duration (h);
- VOT_{Bike} - value of time of bicycle users (USD /h).

- **Generalized costs for pedestrians:**

$$GC_{Ped} = T * VOT_{Ped}$$

- *T* - travel time (h);
- VOT_{Ped} - time cost for pedestrians (USD /h).

The calculation in the model was implemented based on the group of procedures about the **Generalized costs**, separately for each mode of transport, Figure 116.

Procedure sequence							
Number: 184	Execution	Active	Procedure	Reference object(s)	Variant/file	Messages	
101		☒	Group Generalized costs	102 - 106		10 messages	Generalized costs
102		☒	Combination of matrices and vectors	ForEach(DEMANDSTRATUM D; D[CODE] in {"01_HW_CA";"01_HW ...		219 messages	GC_Bike
103		☒	Combination of matrices and vectors	ForEach(DEMANDSTRATUM D; D[CODE] in {"01_HW_CA";"01_HW ...		219 messages	GC_Car
104		☒	Combination of matrices and vectors	ForEach(DEMANDSTRATUM D; D[CODE] in {"01_HW_CA";"01_HW ...		219 messages	GC_Car Passenger
105		☒	Combination of matrices and vectors	ForEach(DEMANDSTRATUM D; D[CODE] in {"01_HW_CA";"01_HW ...		219 messages	GC_Pedestrian
106		☒	Combination of matrices and vectors	ForEach(DEMANDSTRATUM D; D[CODE] in {"01_HW_CA";"01_HW ...		219 messages	GC_PuT

Figure 116. Group of GC calculation procedures for modes of transport

An example of the procedure for calculating **GC for Car** is presented on Figure 117.

³³ <https://ttc.com.ge/en/tariff/10>

³⁴ <https://www.google.com/finance/quote/GEL-USD?sa=X&ved=2ahUKEwjaksGStYORAxVIRvEDHaMpF-QQmY0JegQIlhAv>

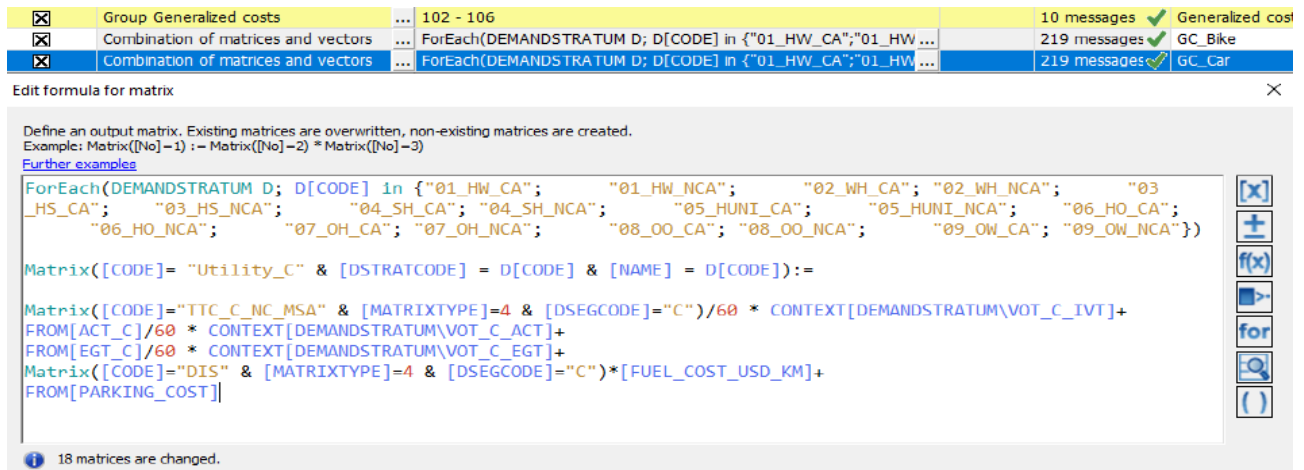


Figure 117. Calculation of GC for Car

5.4.3. Setting up the Mode Choice procedure

The modal distribution is determined using discrete choice models, i.e. Logit models. The most widely used discrete choice models are multinomial (MNL) and nested (NL) logit model. Multinomial logit models imply a larger set of alternatives in the final data set (e.g. alternatives can be car, bicycle, walking, bus), while nested models consist of a group of similar alternatives grouped in a nest, in which each alternative belongs to only one nest. A multinomial logit model was used in this case:

$$P_n(i) = \frac{e^{\mu V_{in}}}{\sum_{j \in C_n} e^{\mu V_{jn}}}$$

- $P_n(i)$ = probability of choosing an alternative i ,
- μ = calibration parameter,
- V_{in} = utility of mode i .

The utility function was defined for each transport mode where the travel time of each option was considered:

- $V1 = ASC_CAR + B_TIME * GC_CAR$,
- $V2 = ASC_CAR \text{ passengers} + B_TIME * GC_BIKE$,
- $V3 = ASC_BIKE + B_TIME * GC_BIKE$,
- $V4 = ASC_PUT + B_TIME * GC_PUT$,
- $V5 = ASC_PED + B_TIME * GC_PED$

Where:

- ASC_CAR - Alternative Specific Constant for car mode;
- $ASC_CAR \text{ passengers}$ - Alternative Specific Constant for car passengers mode;
- ASC_BIKE - Alternative Specific Constant for bike mode;
- ASC_PUT - Alternative Specific Constant for public transport mode;
- ASC_PED - Alternative Specific Constant for pedestrian mode;
- B_TIME - coefficient that shows the importance of time for the user.

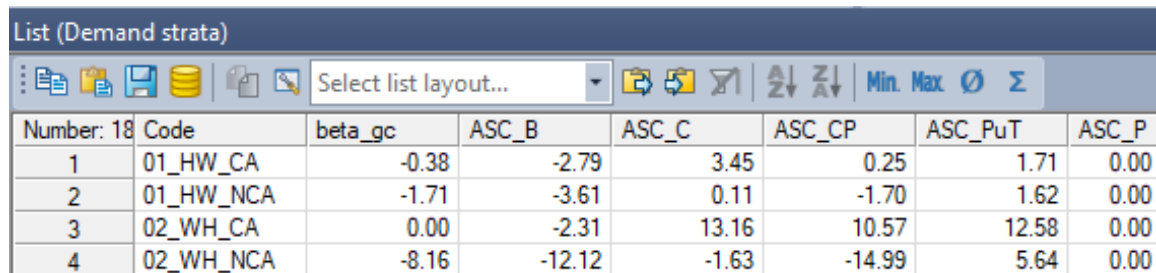
The values of the utility function parameters were calculated using Pandas Biogeme³⁵. The results of the estimated parameters for each mode of transport are shown in Table 14.

³⁵ <https://biogeme.epfl.ch/>

Table 14. Estimated mode choice parameters

Demand stratum	beta_gc	ASC_Car	ASC_Car_Pas	ASC_Bike	ASC_PuT
01_Home-Work_CA	-0.375621	3.447182	0.251266	1.706249	-2.793617
01_Home-Work_NCA	-1.711648	0.112058	-1.700732	1.616824	-3.614826
02_Work-Home_NCA	0.000000	13.158963	10.566615	12.581519	-2.313686
02_Work-Home_CA	-8.160381	-1.632297	-14.988639	5.636349	-12.122000
03_Home-Study_CA	-2.936254	3.266280	-2.149501	1.748572	-12.114672
03_Home-Study_NCA	-3.943600	-1.101318	-5.227245	2.358664	-12.353725
04_Study-Home_CA	-4.042111	4.046029	-5.137157	1.934792	-12.210953
04_Study-Home_NCA	-13.918942	-0.201318	-38.227245	10.027840	-10.992081
05_Home-University_CA	-1.995838	2.459018	-2.541358	2.898978	-1.858040
05_Home-University_NCA	-1.909272	-10.613121	-0.983960	3.462678	-11.372766
06_Home-Other_CA	-0.171551	3.057898	1.110884	1.421853	-10.945536
06_Home-Other_NCA	-2.073472	-0.360620	-2.302454	1.185198	-3.685765
07_Other-Home_CA	-0.372141	2.967281	0.535933	1.122554	-10.945038
07_Other-Home_NCA	-0.755281	-1.691671	-2.247573	0.155426	-12.897940
08_Other-Other_CA	-0.855334	2.643669	-1.239793	0.332314	-11.574843
08_Other-Other_NCA	-4.632897	-1.301318	-5.227245	2.158664	-12.353725
09_Other-Work_CA	-2.493788	4.487561	-4.192769	1.043837	-11.787471
09_Other-Work_NCA	-3.675797	1.434459	-5.760413	0.681862	-12.726257

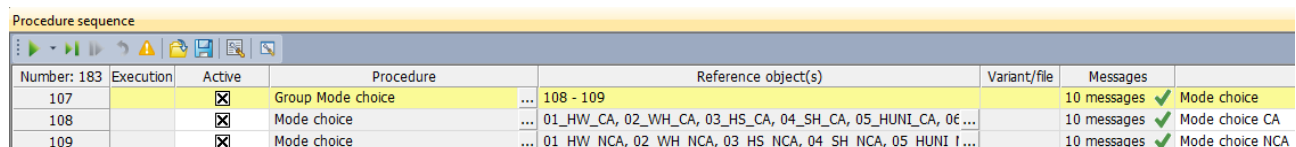
ASC for pedestrians for all demand stratum is equal 0. The estimated parameters were entered as UDA for demand stratum, Figure 118.



Number: 18	Code	beta_gc	ASC_B	ASC_C	ASC_CP	ASC_PuT	ASC_P
1	01_HW_CA	-0.38	-2.79	3.45	0.25	1.71	0.00
2	01_HW_NCA	-1.71	-3.61	0.11	-1.70	1.62	0.00
3	02_WH_CA	0.00	-2.31	13.16	10.57	12.58	0.00
4	02_WH_NCA	-8.16	-12.12	-1.63	-14.99	5.64	0.00

Figure 118. Example of UDA utility function value

To calculate the mode choice, two procedures were created separately for the CA and NCA demand strata, Figure 119.



Number: 183	Execution	Active	Procedure	Reference object(s)	Variant/file	Messages	Mode choice
107		☒	Group Mode choice	108 - 109		10 messages	Mode choice
108		☒	Mode choice	01_HW_CA, 02_WH_CA, 03_HS_CA, 04_SH_CA, 05_HUNI_CA, 06...		10 messages	Mode choice CA
109		☒	Mode choice	01_HW_NCA, 02_WH_NCA, 03_HS_NCA, 04_SH_NCA, 05_HUNI_NCA, 06...		10 messages	Mode choice NCA

Figure 119. Procedures for calculating the mode choice

An example of setting up the Utility Function procedure for Mode Choice is shown in Figure 120.

Data collection and Model update related to transport in Tbilisi – Update the Transport Demand Model

Parameters: Mode choice

☒ Set any result demand matrix to 0 prior to calculation

Key	Demand stratum	Mode	Utility function	Function type	a	b	c	
1 01_HW_CA/BIKE	01_HW_CA	BIKE Bicycle	CONTEXT[DEMANDSTRATUM]ASC_B]+CONTEXT[DEMANDSTRATUM]BETA_GC]*Matrix([CODE]="Utility_B" & [NAME]="01_HW_CA"...	Logit	0	0	1	...
2 01_HW_CA/C	01_HW_CA	C Car	CONTEXT[DEMANDSTRATUM]ASC_C]+CONTEXT[DEMANDSTRATUM]BETA_GC]*Matrix([CODE]="Utility_C" & [NAME]="01_HW_CA"...	Logit	0	0	1	...
3 01_HW_CA/C_P	01_HW_CA	C_P C_Pass	CONTEXT[DEMANDSTRATUM]ASC_CP]+CONTEXT[DEMANDSTRATUM]BETA_GC]*Matrix([CODE]="Utility_CP" & [NAME]="01_HW_CA"...	Logit	0	0	1	...
4 01_HW_CA/PED	01_HW_CA	PED Pedestrian						
5 01_HW_CA/PuT	01_HW_CA	PuT PuT						
6 02_WH_CA/BIKE	02_WH_CA	BIKE Bicycle						
7 02_WH_CA/C	02_WH_CA	C Car						
8 02_WH_CA/C_P	02_WH_CA	C_P C_Pass						
9 02_WH_CA/PED	02_WH_CA	PED Pedestrian						
10 02_WH_CA/PuT	02_WH_CA	PuT PuT						
11 03_HS_CA/BIKE	03_HS_CA	BIKE Bicycle						
12 03_HS_CA/C	03_HS_CA	C Car						
13 03_HS_CA/C_P	03_HS_CA	C_P C_Pass						
14 03_HS_CA/PED	03_HS_CA	PED Pedestrian						
15 03_HS_CA/PuT	03_HS_CA	PuT PuT						
16 04_SH_CA/BIKE	04_SH_CA	BIKE Bicycle						
17 04_SH_CA/C	04_SH_CA	C Car						
18 04_SH_CA/C_P	04_SH_CA	C_P C_Pass						
19 04_SH_CA/PED	04_SH_CA	PED Pedestrian						
20 04_SH_CA/PuT	04_SH_CA	PuT PuT						
21 05_HUNL_CA/BIKE	05_HUNL_CA	BIKE Bicycle						
22 05_HUNL_CA/C	05_HUNL_CA	C Car						
23 05_HUNL_CA/C_P	05_HUNL_CA	C_P C_Pass						
24 05_HUNL_CA/PED	05_HUNL_CA	PED Pedestrian						
25 05_HUNL_CA/PuT	05_HUNL_CA	PuT PuT	CONTEXT[DEMANDSTRATUM]ASC_PUT]+CONTEXT[DEMANDSTRATUM]BETA_GC]*Matrix([CODE]="Utility_PuT" & [NAME]="05_HU...	Logit	0	0	1	...

Utility definition for demand stratum/mode 01_HW_CA/BIKE

Demand stratum/mode: 01_HW_CA/BIKE

Utility U =

The output matrix is defined by the following expression.

CONTEXT[DEMANDSTRATUM]ASC_B]+CONTEXT[DEMANDSTRATUM]BETA_GC]*Matrix([CODE]="Utility_B" & [NAME]="01_HW_CA")

OK Cancel

Figure 120. An example of a utility function formula in the mode choice procedure

As a result of the calculation, 90 matrices were calculated (18 demand stratum*5 modes), Figure 121.

List (Matrices)

Matrix filter: Matrix([NO] > 0)

Number: 28	No	Code	Name	MatrixType	Object TypeRef	Sum
195	220	-----Mode Choice Matrices-----	-----Mode Choice Matrices-----	OD demand	Zone	0.000
196	221		Mode choice 01_HW_CA x BIKE	OD demand	Zone	331.182
197	222		Mode choice 01_HW_CA x C	OD demand	Zone	64605.436
198	223		Mode choice 01_HW_CA x C_P	OD demand	Zone	9730.250
199	224		Mode choice 01_HW_CA x PED	OD demand	Zone	1685.879
200	225		Mode choice 01_HW_CA x PuT	OD demand	Zone	26433.338
201	226		Mode choice 01_HW_NCA x BIKE	OD demand	Zone	766.742
202	227		Mode choice 01_HW_NCA x C	OD demand	Zone	9159.100
203	228		Mode choice 01_HW_NCA x C_P	OD demand	Zone	11695.356
204	229		Mode choice 01_HW_NCA x PED	OD demand	Zone	1198.989
205	230		Mode choice 01_HW_NCA x PuT	OD demand	Zone	103282.791
206	231		Mode choice 02_WH_CA x BIKE	OD demand	Zone	0.000
207	232		Mode choice 02_WH_CA x C	OD demand	Zone	1938.243
208	233		Mode choice 02_WH_CA x C_P	OD demand	Zone	168.543
209	234		Mode choice 02_WH_CA x PED	OD demand	Zone	0.004
210	235		Mode choice 02_WH_CA x PuT	OD demand	Zone	1264.072
211	236		Mode choice 02_WH_NCA x BIKE	OD demand	Zone	0.288
212	237		Mode choice 02_WH_NCA x C	OD demand	Zone	70.364
213	238		Mode choice 02_WH_NCA x C_P	OD demand	Zone	164.736
214	239		Mode choice 02_WH_NCA x PED	OD demand	Zone	5.974
215	240		Mode choice 02_WH_NCA x PuT	OD demand	Zone	5212.135

Figure 121. Fragment of the list of calculated matrices at the Mode choice stage

5.4.4. Results of mode choice

The results of the mode choice stage presented in Figure 122, reveal the level of likeness between the model outcomes and the mode share from the HHS 2025 by demand segment.

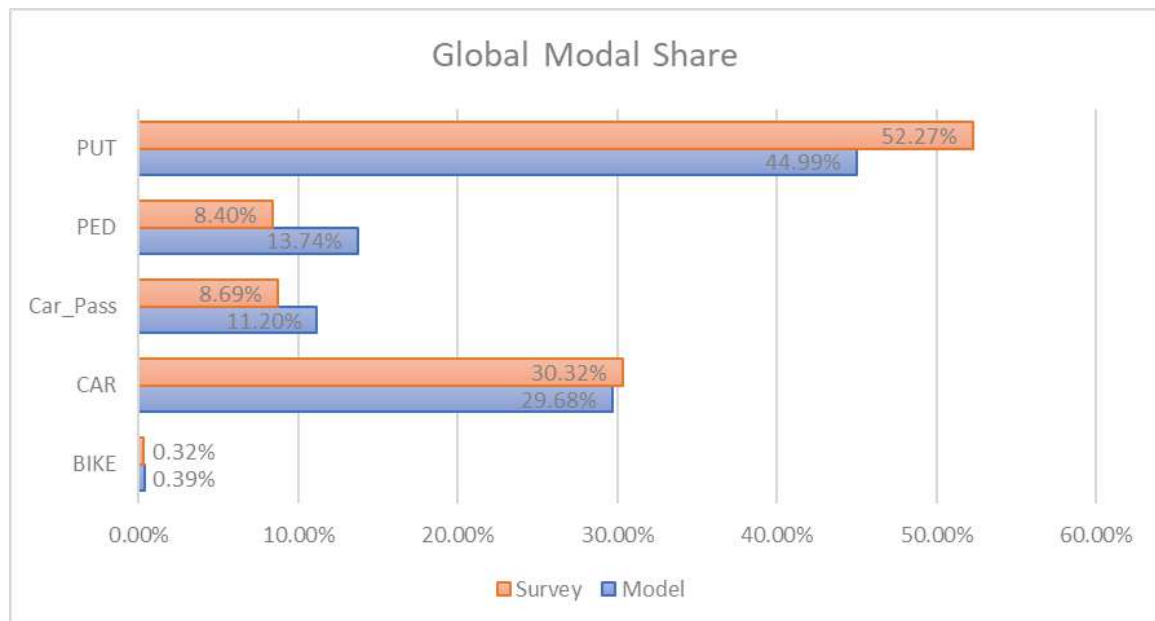


Figure 122. Mode share results

5.5. External trips

A key task in the development of the Tbilisi transport model was estimating external trips, which were characterised by the following aspects:

- The origin and/or destination of these trips was outside the modelled area.
- The generalised cost of travel was not defined for these trips, as part of the journey took place out of the area.

To account for these trips, specific external zones were defined as part of the TAZ system, as it is shown in

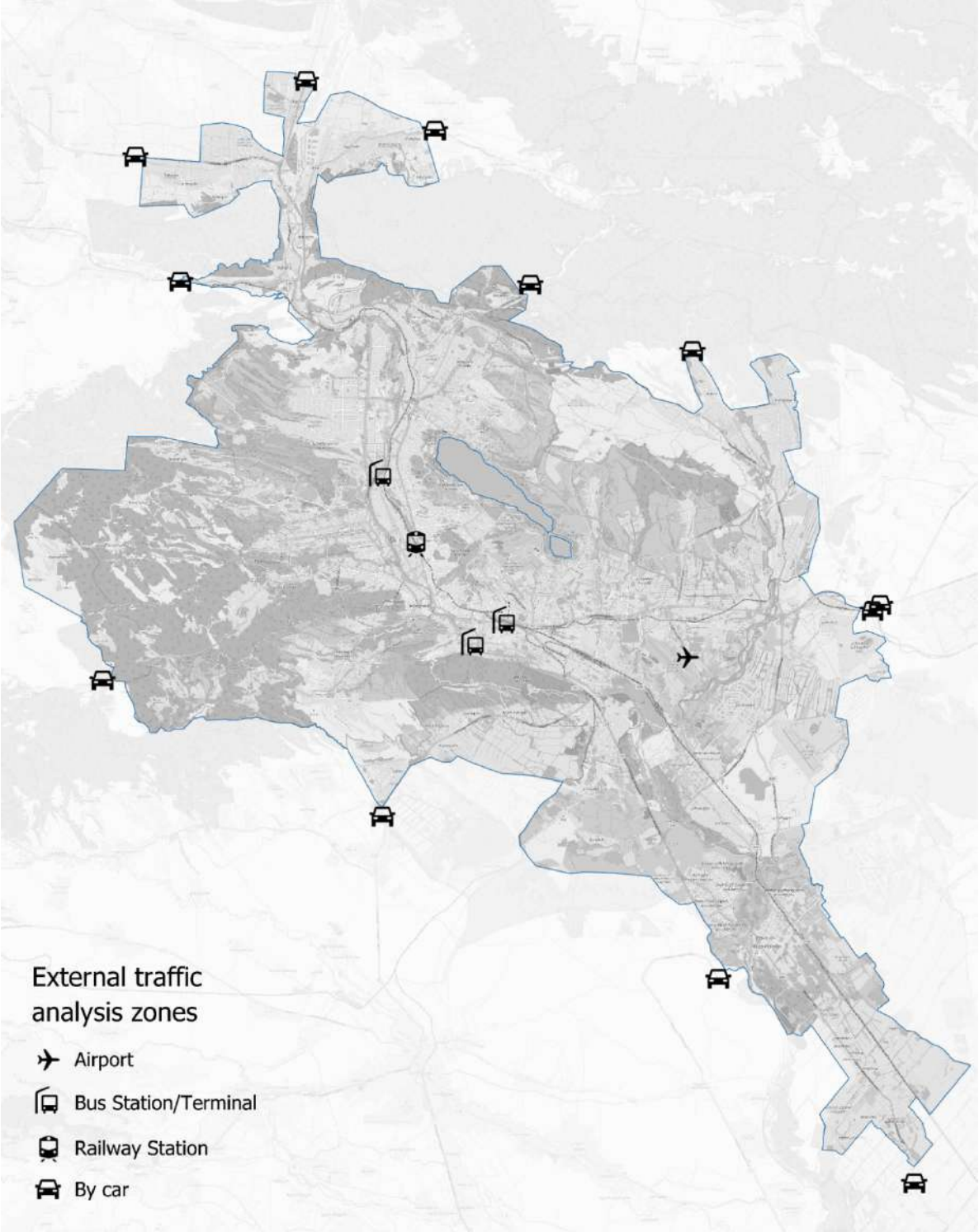


Figure 21. *External TAZs*The volumes of arrivals and departures for external zones were determined based on traffic flow volume data (vehicles per day, both directions) on major roads in the modelling area. This data was obtained from the TUDA and further refined during model calibration (Table 15).

Table 15. *Arrivals and Departures for External Zones*

Direction	Entry / Exit	Volume
to Marneuli	Entry	248

Direction	Entry / Exit	Volume
	Exit	106
to Gazakh	Entry	86
	Exit	37
to Sagarejo	Entry	300
	Exit	100
to Stepantsminda	Entry	300
	Exit	200
to Gori	Entry	419
	Exit	179
to Tsalka	Entry	19
	Exit	8
to Dzegvi	Entry	139
	Exit	60
to Rustavi	Entry	196
	Exit	84
to Tskhvarichamia	Entry	20
	Exit	10
to Tokhliauri	Entry	300
	Exit	100
to Kotoraantkari	Entry	70
	Exit	30
to Martkopi Monastery	Entry	10
	Exit	5

The share of transit traffic was assumed at 10% for primary roads and 5% for secondary roads based on expert judgement. These values reflect the functional role of the road network and were applied as input parameters in the calibration of the Tbilisi transport model.

The obtained traffic flow and passenger demand data were incorporated as UDAs for the external zones in the Tbilisi transport model (Figure 123).

List (Zones)							
Number: 12	No	Code	Name	TypeNo	INCOMING_FLOW_CAR	OUTCOMING_FLOW_CAR	TRANSIT_SHEET_CAR
1	300001	Kordon	to Mameuli	9	248	106	0,10
2	300002	Kordon	to Gazakh	9	86	37	0,10
3	300003	Kordon	to Sagarejo	9	300	100	0,10
4	300004	Kordon	to Stepantsminda	9	300	200	0,10
5	300005	Kordon	to Gori	9	419	179	0,10
6	300006	Kordon	to Tsalka	9	19	8	0,05
7	300007	Kordon	to Dzegvi	9	139	60	0,05
8	300008	Kordon	to Rustavi	9	196	84	0,05
9	300009	Kordon	to Tskhvarichamia	9	20	10	0,05
10	300010	Kordon	to Tokhlauri	9	300	100	0,10
11	300011	Kordon	to Kotoraantkari	9	70	30	0,05
12	300012	Kordon	to Martkopi Monastery	9	10	5	0,05

Figure 123. UDAs of External Zones

5.5.1. Calculation Algorithm for External Zone Traffic

The traffic flow calculation for external zones was implemented by **dividing the overall trip matrix into four quadrants** (Figure 124).

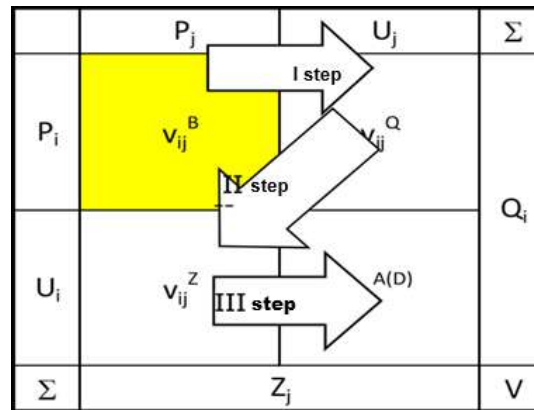


Figure 124. External Zone Traffic Calculation Steps

The matrix division represents the sequential steps in the **external zone traffic estimation** between the 4 main areas. The **first quadrant**, corresponding to **internal trips within the modelled area**, is already calculated using the **four-stage model**. The **second and third quadrants** represent **traffic flows to and from external zones**, while the **fourth quadrant** accounts for **through-traffic between external zones**. The external zone trip calculation is performed in the following steps:

- Estimating trips from external zones to modelled areas.
- Estimating trips from modelled areas to external zones.
- Estimating transit trips between external zones.

Each step is detailed in the next paragraphs.

5.5.2. Estimating Traffic from Modelled Areas to External Zones

The **second quadrant** of the trip matrix (Figure 124) represents trips from the modelled area to the external zones. These trips were calculated using a **weighted Logit model**, as defined by the equation:

$$v_{ij} = \frac{e^{-\beta A_{ij} \cdot E_i}}{\sum_k e^{-\beta A_{ik} \cdot E_k}} \cdot Z_j,$$

Where:

β – Coefficient of the Logit model;

A_{ij} – Generalised travel cost between zone i and external zone j ;

Z_j – Incoming traffic volume for external zone j ;

E_i – Target attribute of **zone** i -(e.g., population, employment).

5.5.3. Estimating Traffic from External Zones to Modelled Areas

The **third quadrant** of the trip matrix (Figure 124) represents trips from the external zones to the modelled area. These trips were also calculated using a **weighted Logit model**:

$$v_{ij} = \frac{e^{-\beta A_{kj}} \cdot E_j}{\sum_k e^{-\beta A_{kj}} \cdot E_k} \cdot Q_i ,$$

Where:

β – Coefficient of the Logit model;

A_{ij} – Generalised travel cost between zone i and external zone j ;

Q_i – outgoing traffic volume from external zone j ;

E_i – Target attribute of **zone** i -(e.g., population, employment).

The source data for external zones (

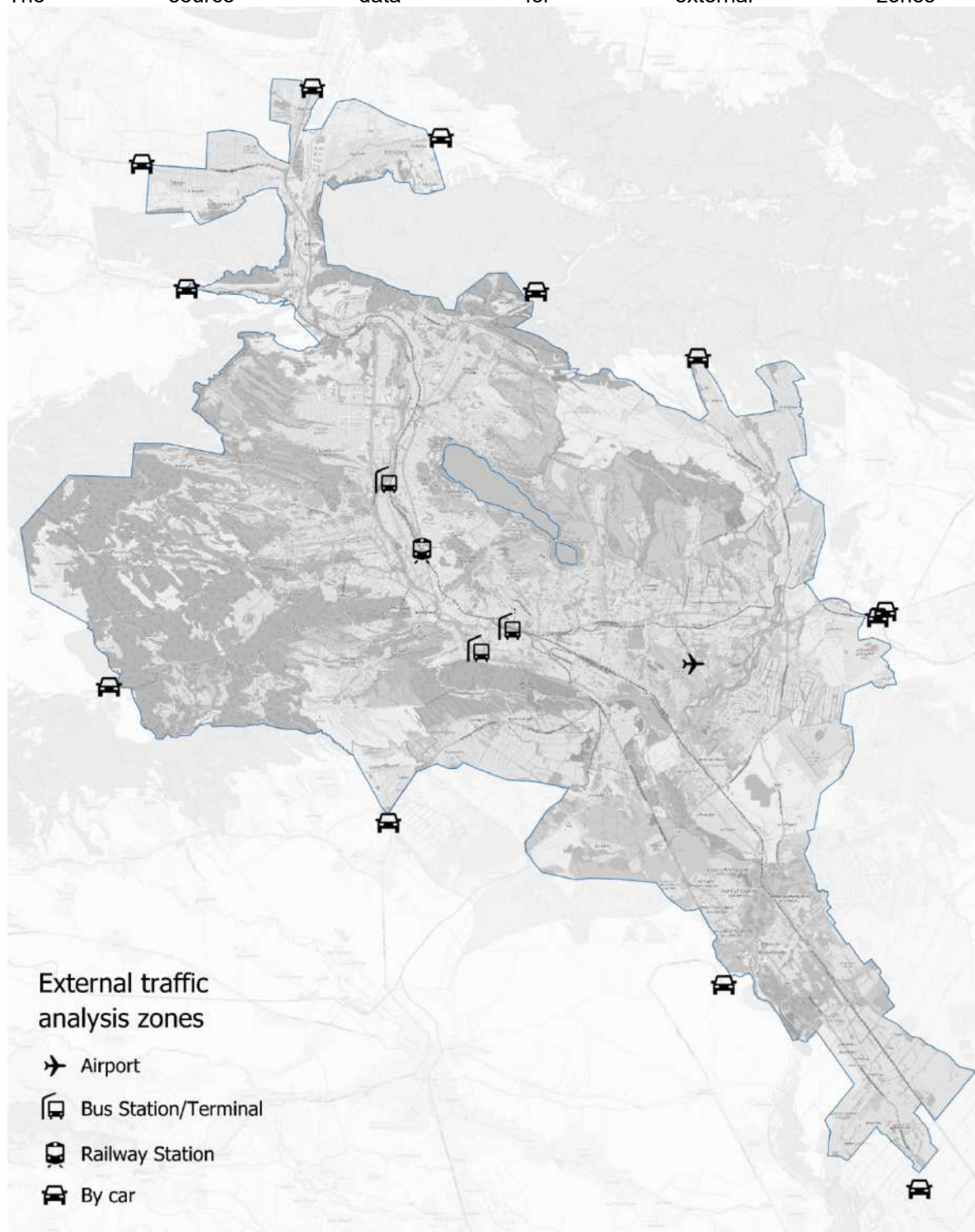


Figure 21. External TAZs) was based on information about the average daily number of passenger arrivals at and departures from Tbilisi Shota Rustaveli International Airport for the period June–September 2025, as well as the average daily number of passenger arrivals and departures through Tbilisi Railway Station for the period January–September 2025 (Figure 125). This data was provided by TUDA through available sources for detailed information about mobility flows at the Tbilisi Airport and at the Tbilisi Railway Station.

Passenger Flow							
<i>Year</i>	<i>Origin</i>	<i>Destination</i>	<i>January</i>	<i>February</i>	<i>March</i>	<i>April</i>	<i>May</i>
2024	Tbilisi	Various stations	54 186	44 505	53 085	49 945	59 986
2024	Various stations	Tbilisi	56 247	39 913	51 766	45 856	55 776
			110 433	84 418	104 851	95 801	115 762
2025	Tbilisi	Various stations	59 718	46 732	48 946	55 851	54 423
2025	Various stations	Tbilisi	49 846	34 705	45 060	47 763	42 043
			109 564	81 437	94 006	103 614	96 466

Figure 125. Fragment of data on passenger turnover of the Tbilisi airport

Since passengers typically arrive at airports and railway stations prior to departure and leave them with a certain delay after arrival, focusing exclusively on the number of flights or trains scheduled between 8:30 and 9:30 did not allow for an accurate assessment of the related transport activity during the morning peak hour. Therefore, an hourly concentration coefficient was applied to convert average daily passenger flows into parameter that is relevant for modelling the morning peak hour. In accordance with international best practices for transport modelling and passenger facility planning ³⁶³⁷, the share of daily passenger traffic during peak hours usually ranges from 5% to 15% of the average daily volume. Based on the mentioned guidelines, it was assumed that the share of passengers arriving at and departing from the airport and railway station between 8:30 and 9:30 a.m. amounts to 10% of the average daily passenger flow (Table 16).

Table 16. Estimated passenger turnover of the Tbilisi airport and Tbilisi railway station for the morning peak hour

Facility	Daily passenger flows, pax.		Passenger flows in the morning peak hour, pax.	
	Arriving passengers	Departing passengers	Arriving passengers	Departing passengers
Railway	1809	2084	181	208
Airport	8871	8936	887	894

In addition, passenger flow during the morning peak hour was calculated for each of key bus stations in Tbilisi, including Station Square, Didube, Ortachala, and Samgori. These bus stations were also included as the external transport zones of Tbilisi (Figure 21).

There was no up-to-date data available on passenger turnover at Tbilisi bus stations. Therefore, information on intercity trips from Tbilisi bus stations in 2011-2012, provided by TUDA as source data, was used. The provided data set contained information on the route names, the number of trips carried out on the route during the average day, and the corresponding operating bus station (Figure 126).

³⁶https://www.researchgate.net/publication/274381999_Modeling_pedestrian_flows_in_train_stations_The_example_of_Lausanne_railway_station

³⁷ https://www.iata.org/en/iata-repository/publications/economic-reports/the-busiest-hour-at-the-busiest-airport-in-the-world/?utm_source=chatgpt.com

dedaqalaqSi moqmedi avtosadgurebi 2011-2012						
dasaxeLeba	misamarTi	marSrutebi mimarTuleba	reisebis raodenoba	avtobusis kategoria		SeniSvna
				M2	M3	
			1490	1017	55	
avtosadguri "nige"	karaleTis 4 (didube)	Tbilisi-borjomi	7	15		129
avtosadguri "nige"	karaleTis 4 (didube)	waRveri	2	3		37
avtosadguri "nige"	karaleTis 4 (didube)	cemi	1	2		18
avtosadguri "nige"	karaleTis 4 (didube)	bakuriani	2	4		37
avtosadguri "nige"	karaleTis 4 (didube)	aspinZa	2	4		37
avtosadguri "nige"	karaleTis 4 (didube)	duSeTi	39	16		718

Figure 126. Fragment of the data on the intercity trips from Tbilisi bus stations

To extrapolate this data to up-to-date passenger turnover volumes at Tbilisi bus stations, it was assumed that passenger turnover had increased by 15% since that time and that the average capacity of passenger vehicles was approximately 16 persons (based on local experts' assessments). Daily estimations of passenger flows on routes are grouped by the bus stations that operate them.

The share of passengers who arrived and departed from bus stations between 8:30 and 9:30 a.m. was assumed to be the same as for the airport and railway stations and amounted to 10% of the average daily passenger flow. This was accepted as a basic assumption in the absence of data on the distribution of passenger flows by the directions.

Table 17. Estimated passenger turnover of Tbilisi bus stations

Facility	Daily passenger flows, pax.		Passenger flows in the morning peak hour, pax.	
	Arriving passengers	Departing passengers	Arriving passengers	Departing passengers
Didube	11978	11978	1198	1198
Ortachala Station	2134	2134	213	213
Samgori Station	6918	6918	692	692
Station Square	2889	2889	289	289

In order to distribute passengers according to travel modes for all external zones within the modelling area, the assumption was made that 60% of users arrived and departed to/from these zones by private transport, and 40% were public transport users. This assumption is based on observations by local experts. The obtained data was entered as an attribute information into transport zones. Considering that Station Square bus station is located near Tbilisi railway station, thus forming a single transport transfer hub, they were combined into one external zone, which covered the passenger turnover of both Railway station and Station Square bus station.

The estimated passenger turnovers of Tbilisi airport, railway station and bus stations in the PTV Visum application are shown in Figure 127Figure 126.

List (Zones)							
Number: 5	No	Code	Name	INCOMING_FLOW_CAR	INCOMING_FLOW_PUT	OUTCOMING_FLOW_CAR	OUTCOMING_FLOW_PUT
1	300013	Kordon	Tbilisi Railway Station	492	328	508	339
2	300014	Kordon	Airport	532	355	536	357
3	300015	Kordon	Ortachala	128	85	128	85
4	300016	Kordon	Samgori	415	277	415	277
5	300017	Kordon	Didube	719	479	719	479

Figure 127. The estimated passenger turnovers of Tbilisi airport, railway station and bus stations

To take into account external trips at the main motorway approaches to the modelling area, data on traffic intensity, provided by TUDA was used (for more details, see 7.1).

It is important to note that incoming traffic and outgoing traffic are adjusted based on the share of transit traffic within external zones.

5.5.4. Estimating Transit Traffic

The **fourth quadrant** of the trip matrix (Figure 124) accounts for **transit trips and external flows**.

The calculation produced external trip matrices, whose impact was then considered within the overall **street road network** of the modelled area.

Figure 128 shows the results of the above-described sequence of steps using the example of the external zone "to Gori" in Visum.

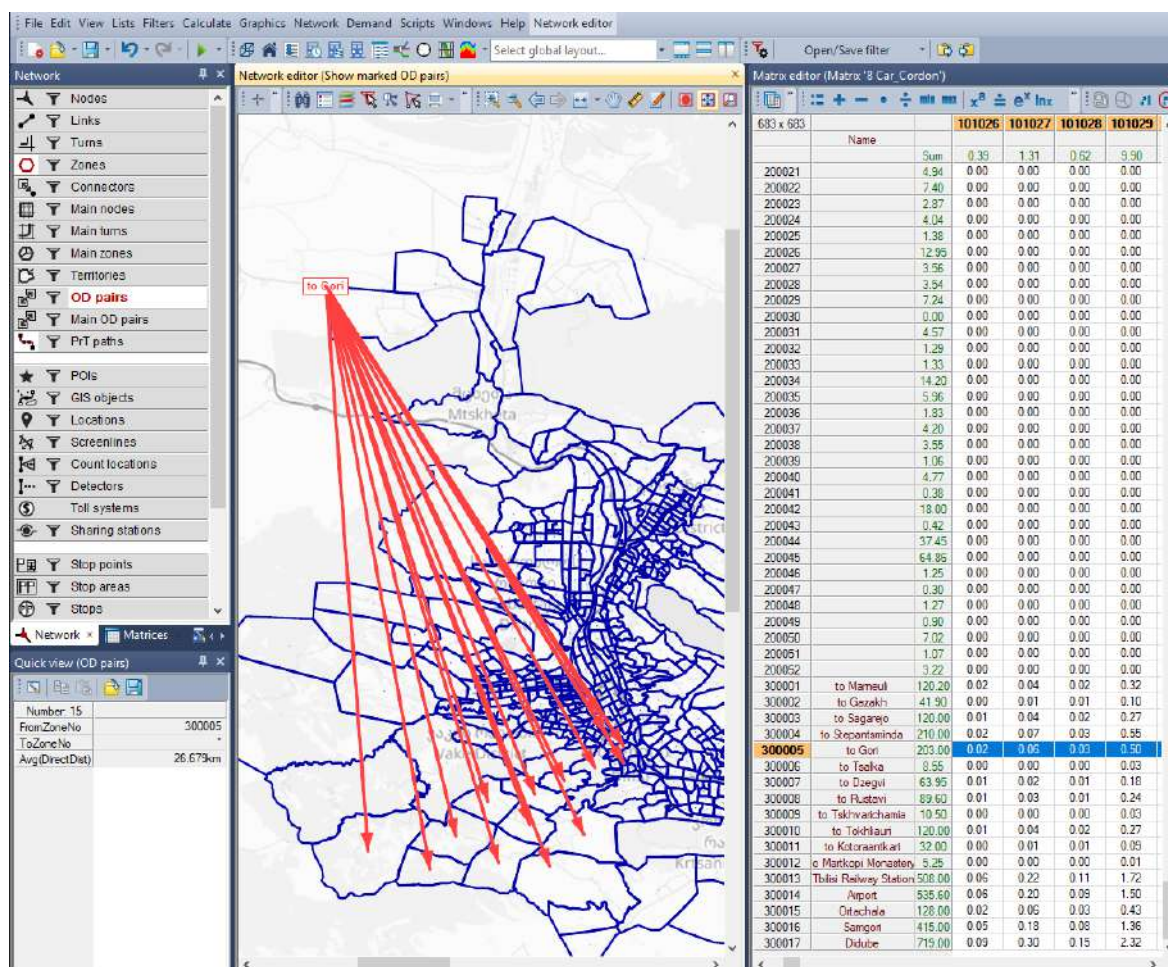


Figure 128. Example of External Trip Calculations for the Gori zone

5.6. Matrix of goods vehicles

To ensure realistic traffic conditions on the road network within the modelling area, goods vehicles (GV) were considered when updating the Tbilisi transport model. However, since no detailed studies of freight logistics characteristics in the city had been conducted, it was decided to calculate the GV correspondence matrix based on surveys of transport volumes and the location of their potential generation and attraction objects.

5.6.1. Calculation of goods vehicles matrices

The calculation of goods vehicles (GV) OD matrices was performed in two stages. In the first stage of the calculation, the share of GV in the overall transport flow structure was determined. Data for 2024 and 2025 from available counting points within the analysis area was used for this task (Figure 129).

Code	Name	GV	Total_flow	GV_share
Data Sheet (26.03.2025) Location 7	7.3_7.6	3	529	0,00567
Data Sheet (26.03.2025) Location 7	7.1_7.4	2	522	0,00575
Data Sheet (26.03.2025) Location 7	7.2_7.5	1	154	0,00649
Data Sheet (26.03.2025) Location 7	7.1_7.2	3	403	0,00993
Data Sheet (26.03.2025) Location 7	7.3_7.4	0	173	0,00000
Data Sheet (26.03.2025) Location 7	7.5_7.6	3	629	0,00477
Data Sheet (25.03.2025) Location 1	1.2_1.6	0	13	0,00000
Data Sheet (25.03.2025) Location 1	1.3_1.4_1.7	3	1354	0,00295
Data Sheet (25.03.2025) Location 1	1.1_1.5_1.8	8	1917	0,00417
Data Sheet (25.03.2025) Location 1	1.7_1.8	6	1224	0,00490
Data Sheet (25.03.2025) Location 1	1.4_1.5_1.6	2	1889	0,00106
Data Sheet (25.03.2025) Location 1	1.1_1.2_1.3	3	1198	0,00334
Data Sheet (25.03.2025) Location 2	2.3_2.5	2	874	0,00229
Data Sheet (25.03.2025) Location 2	2.1_2.4	3	571	0,00701
Data Sheet (25.03.2025) Location 2	2.2	2	808	0,00248
Data Sheet (25.03.2025) Location 2	2.5	0	373	0,00000
Data Sheet (25.03.2025) Location 2	2.1_2.2	5	1356	0,00442
Data Sheet (25.03.2025) Location 2	2.3_2.4	2	524	0,00382
Data Sheet (17.03.2025) Location 2	2.2_2.6_2.11	18	755	0,02384

Figure 129. Fragment of the data on traffic volumes and calculation of GV share

The analysis revealed that the average share of GV in the transport flow is 1.534%. Therefore, to obtain the basic GV matrix, the passenger car matrix was multiplied by the respective coefficient – 0,01534 (Figure 130).

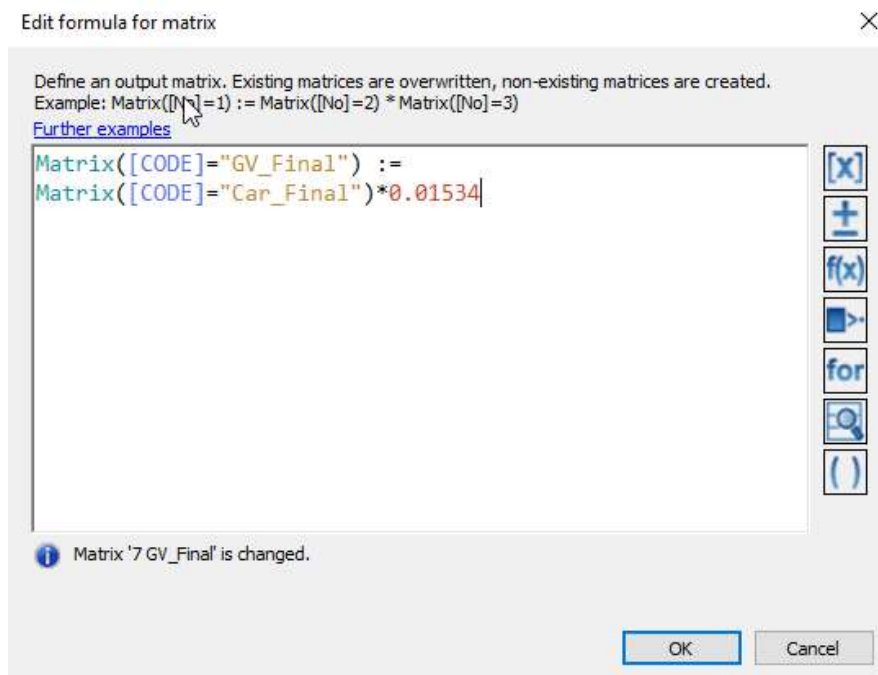


Figure 130. Procedure of calculation of base GV matrix in PTV Visum

The following step applied the Least squares method, which allowed the basic freight transport matrix to be corrected in accordance with the actual volume of its traffic. The matrix corrected process was carried out as described in Figure 131.

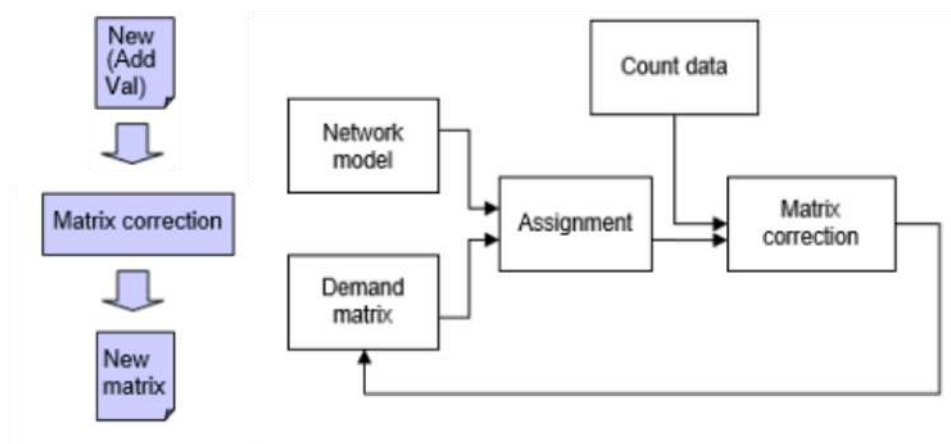


Figure 131. Freight transport matrix corrected process

In accordance with the diagram shown in Figure 131, relevant calculation procedures had been developed and configured in PTV Visum. An example of setting up a matrix correction procedure for the GV is shown in Figure 132.

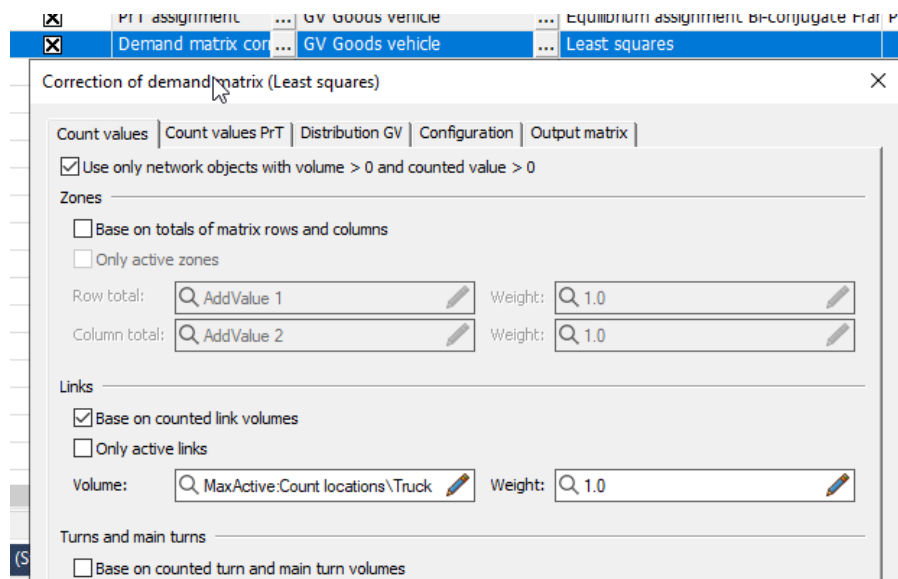


Figure 132. Configuring a matrix correction procedure for the GV

As a result, the final OD matrix for GV was obtained.

6. ASSIGNMENT

The Assignment stage represents the step in which the calculated transport demand (OD matrices) is loaded onto the transport network, distributing trips across links and routes according to network characteristics such as capacity, travel speeds, delays, and route choice behaviour.

As a result, traffic flows, passenger flows, and key network performance indicators are obtained.

6.1. Matrix combination

Matrix combination involves **grouping previously calculated matrices** (detailed in section 5.4) by **demand segments**.

Active	Procedure	Reference object(s)	Variant/file	Messages	Comment
☒	Group Aggregation of matrices by mode ...	122 - 126			Aggregation of matrices by mode
☒	Combination of matrices and vectors ...	Matrix([CODE]="Ped_Final") := SUM(MatrixLi ...		32 messages ✓	Summation of matrices by demand stratum with mode Pedestrians_peak hour factor from H
☒	Combination of matrices and vectors ...	Matrix([CODE]="Bike_Final") := SUM(MatrixLi ...		32 messages ✓	Summation of matrices by demand stratum with mode Bike_peak hour factor from HHS
☒	Combination of matrices and vectors ...	Matrix([CODE]="Car_Pass") := SUM(MatrixLi ...		32 messages ✓	Calculation of the number of Car Passengers_peak hour factor from HHS
☒	Combination of matrices and vectors ...	Matrix([CODE]="Car_Final") := Matrix([CODI ...		32 messages ✓	Calculation of the number of Car_Car occupancy rate
☒	Combination of matrices and vectors ...	Matrix([CODE]="PuT_Final") := SUM(MatrixL ...		32 messages ✓	Summation of matrices by demand stratas with mode PuT_peak hour factor from HHS

Figure 133. A group of procedures for summing up matrices of demand segments

The matrices calculated at the **modal choice stage** for each demand stratum were summed **separately** for each demand segment (**Car, Car Passenger, Public Transport, Bicycle, Pedestrian**).

Scaling factors were also applied for peak hours from 08:30 to 09:30 (Figure 134).

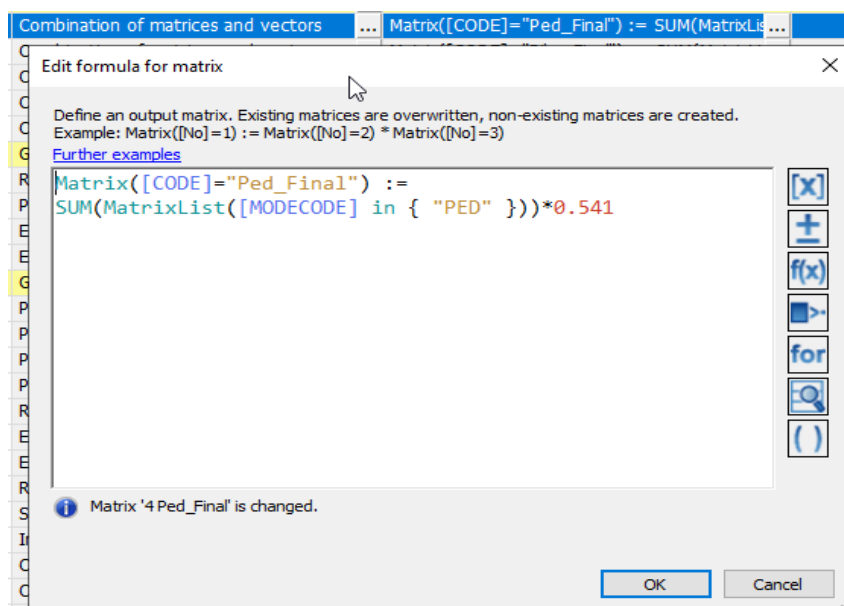


Figure 134. Example of the sum of pedestrian matrices by demand stratum and peak hour factor

The Car matrix considered the sum of the matrices of drivers, passengers and the occupancy rate – 1.36, to convert to the number of vehicles.

For the Car and Public Transport matrices, external flow matrices were added (Figure 135).

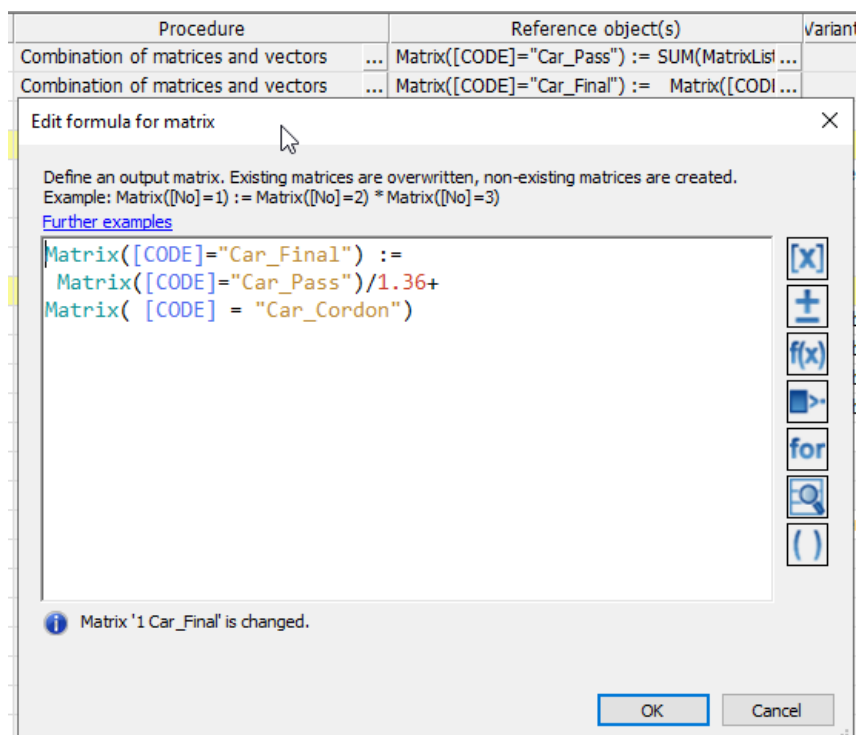


Figure 135 Example of external trip matrix consideration

The final **matrices** for each demand segment were produced (Figure 136):

- № 1_Car_Final – Car segment;
- № 3_PuT_Final – Public Transport segment;
- № 4_Ped_Final – Pedestrian segment
- № 5_Bike_Final – Bicycle segment

These demand matrices were subsequently **assigned to the transport supply model** for further calculations.

OD demand data

Demand segments Standard time series Demand time series					
Number: 6	Demand segment code	Demand segment name	Demand time series	Matrix	Matrix
1	BIKE	Bicycle	1 Default	Matrix([CODE]="Bike_Final")	5 Bike_Final
2	C	Car	1 Default	Matrix([CODE]="Car_Final")	1 Car_Final
3	C_P	C_Pass	1 Default	Matrix([CODE]="Car_Pass")	2 Car_Pass
4	GV	Goods vehicle	1 Default	Matrix([CODE]="GV_Final")	7 GV_Final
5	PED	Pedestrians	1 Default	Matrix([CODE]="Ped_Final")	4 Ped_Final
6	PuT	PuT	1 Default	Matrix([CODE]="PuT_Final")	3 PuT_Final

Figure 136. Demand segment matrices for assignment

6.2. Matrix assignment

The Tbilisi transport model employed different approaches for the assignment of public transport and private transport trips. Additionally, the assignment method varied across private transport demand segments.

For the private transport (Car) segment, the Equilibrium Lohse assignment method was applied. This method distributes traffic flows across the network to achieve equilibrium between demand and supply, ensuring optimal route choices for drivers based on network congestion levels and travel times. The configuration of this assignment method is shown in Figure 137.

Parameters: Equilibrium assignment Bi-conjugate Frank-Wolfe

☒ Use classical convergence criteria
☐ Use extended convergence criteria

Termination conditions

Maximum number of iterations: 1000
Maximum gap: 0.001

Convergence statistics

The following settings are only effective in the PrT assignment quality data list.

Relative difference between previous and current iteration (%):

Link volume <= 1
Link impedance <= 1
Turn volume <= 1
Turn impedance <= 1

Ignore links and turns with a volume < 1

OK Cancel

Figure 137: Assignment Procedure Configuration for Car

For the bicycle (Bike) segment, a Stochastic Assignment approach was used. This method accounts for cyclists' subjective perception of routes, their incomplete information, and individual preferences. Demand is distributed among alternative routes using behavioural models, such as the Logit model, allowing for a more realistic representation of route choices. The configuration of this assignment method is presented in Figure 138.

Parameters: Stochastic assignment

Basis | Impedance BIKE | Smoothing | Search | Preselection | Choice | Skims

☐ Use current assignment result as initial solution

Global termination condition

Maximum number of iterations: 10

Termination condition for network balancing

Maximum number of iterations: <=3:10, <=6:20, >6 ...

$$ABS (R (t) - R ' (t-1)) < MIN (0.01 * MAX (R (t), R ' (t-1)) + 1 , 5)$$
 and

$$ABS (Vol (t) - Vol (t-1)) < MIN (0.01 * MAX (Vol (t), Vol (t-1)) + 0.005 , 0.01)$$

$R (t)$ = impedance of a network object in iteration step t
 $R ' (t)$ = smoothed impedance of a network object in iteration step t
 $Vol (t)$ = Route volume during iteration step t in [Volume units]

Figure 138. Assignment Procedure Configuration for Bike

For the PuT segment, the **Timetable-Based Assignment** approach was implemented. This method assigns passenger flows according to the public transport schedule, considering arrival and departure times for services operating between 08:30 and 09:30. This ensures that passenger movements are modelled in accordance with real service schedules. Additionally, this approach incorporates vehicle capacity constraints for each route. The configuration of this assignment method is shown in Figure 139.

☐	Group PuT Assignment	...	152 - 158
☒	Read filter	...	Current_routes.fil
☒	PuT assignment	...	PuT PuT
		...	Timetable-based

Parameters: Assignment procedure: Timetable-based

Basis

Search

Branch and Bound search

Dominance

Shortest path search

Preselection

Impedance

Choice

Skim matrices

Extended consideration transpor

Connection export

Risk of delay

Fail to board

Basis

☒ Calculate assignment
☐ Use connector shares

☐ Calculate skim matrices
☒ Save detailed log files

☐ Analyze risk of delay

☒ Calculate service frequency

Restrict demand data

OD pairs considered for assignment: All

Restrict origin zones: ⓘ

From origin zone number:

To origin zone number:

Assignment time period

From: 08:30:00

To: 09:30:00

Pre-assignment period: 0min

Post-assignment period: 24h

Figure 139: Assignment Procedure Configuration for Public Transport

For the pedestrian segment, trip assignment was not applied in the model. This is due to the local nature of pedestrian movements, the absence of route competition, the complexity of data collection, and the minimal impact of pedestrian trips on network congestion. Instead, pedestrian trips are considered as a static component.

7. MODEL CALIBRATION AND VALIDATION

7.1. Traffic volumes

As the ToR did not provide for the calculation of traffic volumes on the road network within the analysis area, existing datasets from various sources were used for further model validation.

The primary data source consists of traffic volume counts provided by TUDA. These data were collected through field surveys conducted between 2023 and 2025 (during the periods of 9:00–10:00 and 18:00–19:00), as part of street redesign projects. The datasets are categorized by 15-minute time intervals and by vehicle type, including Car, Microbus, Bus, Truck, Special vehicular, Motorcycle, Bicycle (Figure 140).

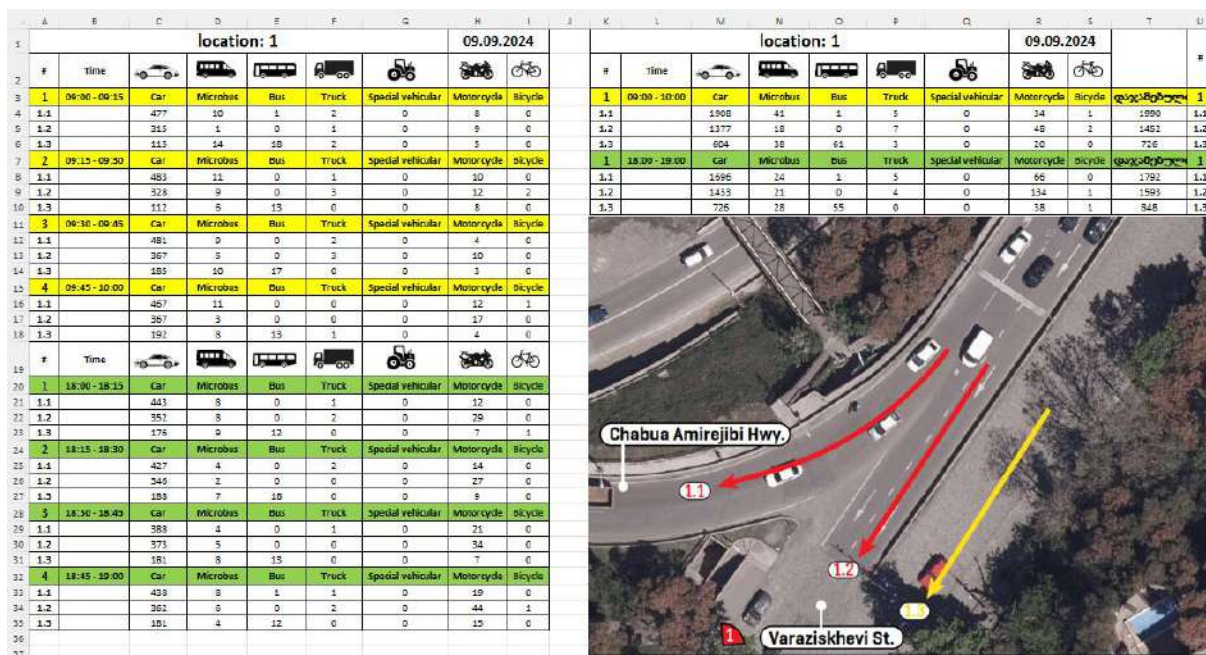


Figure 140. Example of traffic volume dataset provided by TUDA

As these data covered the period from 9:00 to 10:00, while according to the terms of reference the model was developed for the 8:30–9:30 time period, an assumption of identical traffic volumes on the analysed network links for these time periods was adopted. The traffic volume data were entered into the model as UDAs for the network element Count locations, specifically:

- Bicycle – traffic volume for bicycles;
- Bus – traffic volume for large passenger buses;
- Car – passenger car traffic volume;
- Microbus – traffic volume for small passenger vans or minibuses;
- Motorcycle – traffic volume for motorcycles, mopeds, and scooters;
- Special_vehicular – traffic volume for special-purpose vehicles (e.g., emergency vehicles, utility trucks, road maintenance equipment);
- Truck – traffic volume for freight and commercial trucks (typically over 3.5 tons).

An example of UDAs for Count locations in Visum is shown in Figure 141.

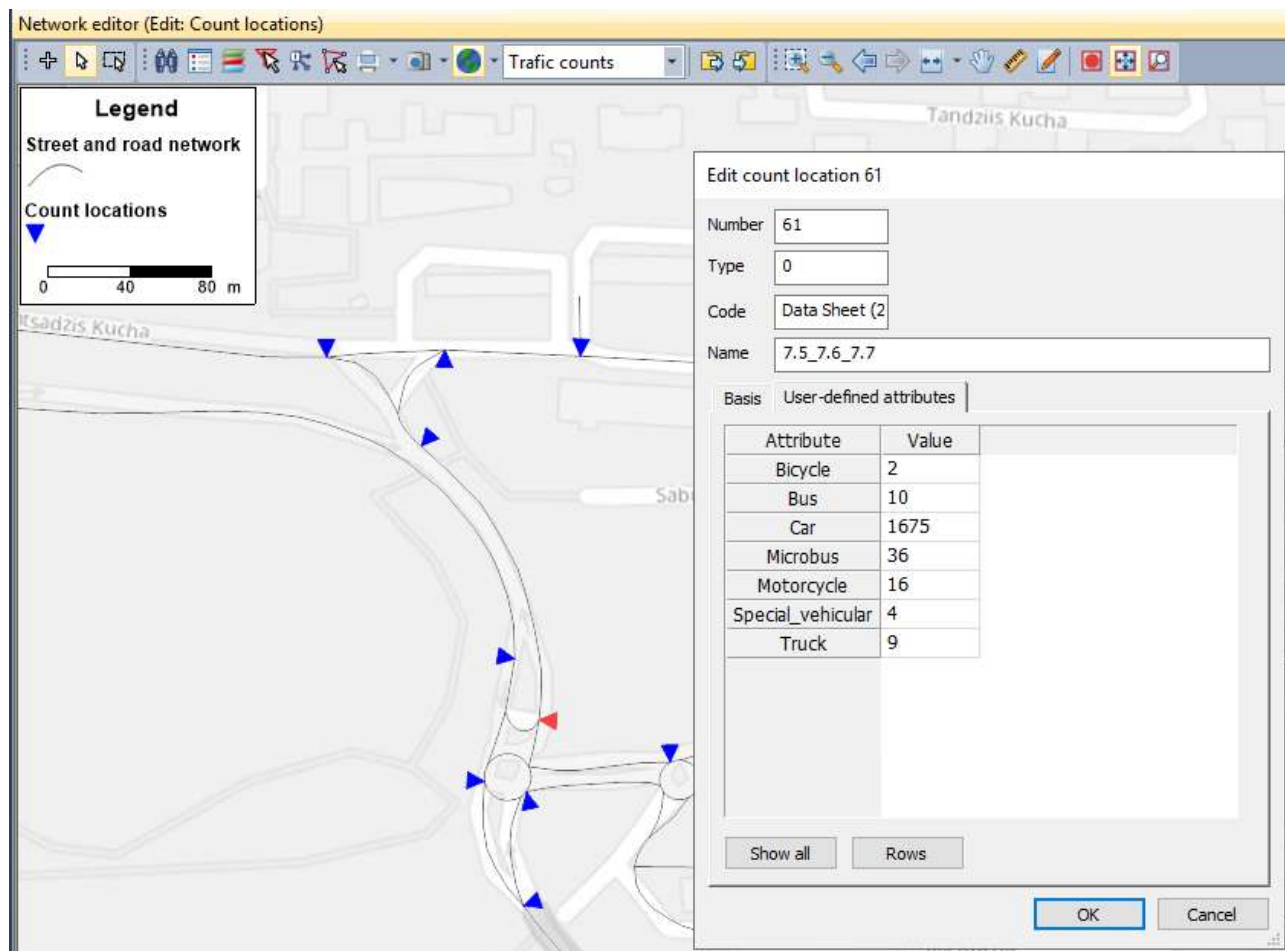


Figure 141. Example UDAs for Count locations

The positions of traffic Count locations established during field surveys are displayed on the Tbilisi model network graph in Figure 142.

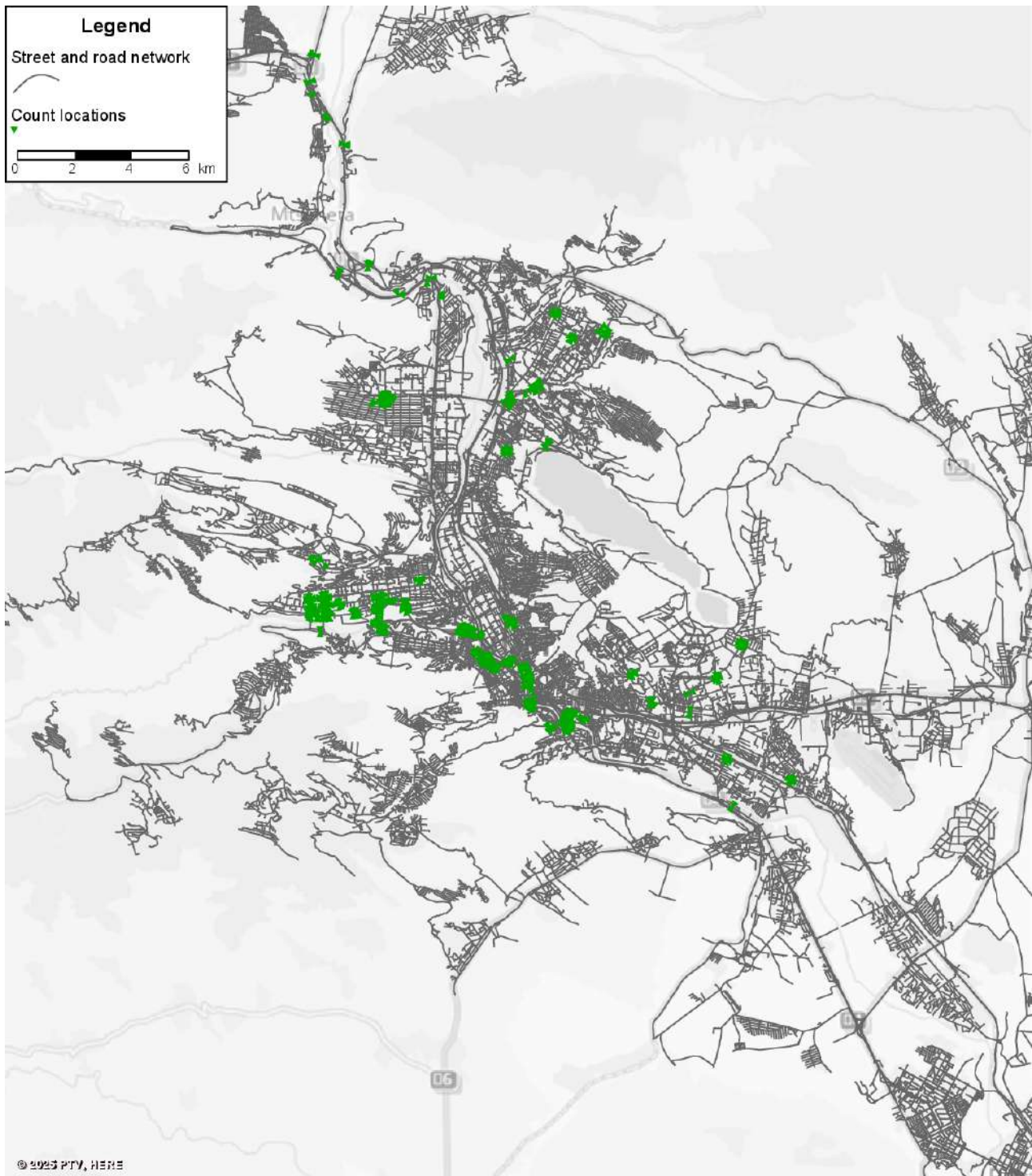


Figure 142. Location of the Count locations derived from field surveys

Another input dataset consisted of traffic volume data without differentiation by vehicle type. These data were collected from automatic traffic detectors between 11 March 2025 and 27 March 2025 for the time periods from 7:00 to 11:00 and from 17:00 to 21:00. Traffic volumes were recorded in 15-minute intervals. An example of these traffic volume data is shown in Figure 143.

start	end	camera	count
2025-03-11 07:00	2025-03-11 07:15	tb005	80
2025-03-11 07:15	2025-03-11 07:30	tb005	73
2025-03-11 07:30	2025-03-11 07:45	tb005	137
2025-03-11 07:45	2025-03-11 08:00	tb005	139
2025-03-11 08:00	2025-03-11 08:15	tb005	227
2025-03-11 08:15	2025-03-11 08:30	tb005	305
2025-03-11 08:30	2025-03-11 08:45	tb005	311
2025-03-11 08:45	2025-03-11 09:00	tb005	319
2025-03-11 09:00	2025-03-11 09:15	tb005	333
2025-03-11 09:15	2025-03-11 09:30	tb005	309
2025-03-11 09:30	2025-03-11 09:45	tb005	300
2025-03-11 09:45	2025-03-11 10:00	tb005	195
2025-03-11 10:00	2025-03-11 10:15	tb005	200
2025-03-11 10:15	2025-03-11 10:30	tb005	180
2025-03-11 10:30	2025-03-11 10:45	tb005	185
2025-03-11 10:45	2025-03-11 11:00	tb005	178
2025-03-11 17:00	2025-03-11 17:15	tb005	285
2025-03-11 17:15	2025-03-11 17:30	tb005	291
2025-03-11 17:30	2025-03-11 17:45	tb005	302
2025-03-11 17:45	2025-03-11 18:00	tb005	298
2025-03-11 18:00	2025-03-11 18:15	tb005	290
2025-03-11 18:15	2025-03-11 18:30	tb005	282
2025-03-11 18:30	2025-03-11 18:45	tb005	283
2025-03-11 18:45	2025-03-11 19:00	tb005	270
2025-03-11 19:00	2025-03-11 19:15	tb005	251
2025-03-11 19:15	2025-03-11 19:30	tb005	235
2025-03-11 19:30	2025-03-11 19:45	tb005	209
2025-03-11 19:45	2025-03-11 20:00	tb005	161
2025-03-11 20:00	2025-03-11 20:15	tb005	181
2025-03-11 20:15	2025-03-11 20:30	tb005	192
2025-03-11 20:30	2025-03-11 20:45	tb005	166
2025-03-11 20:45	2025-03-11 21:00	tb005	191

Figure 143. Example of traffic volume data based on detectors

From the entire dataset, only the data for the 8:30–9:30 time interval was entered into the transport model as a UDA **AVG_VC_8.30–9.30** for Count locations (Figure 143).

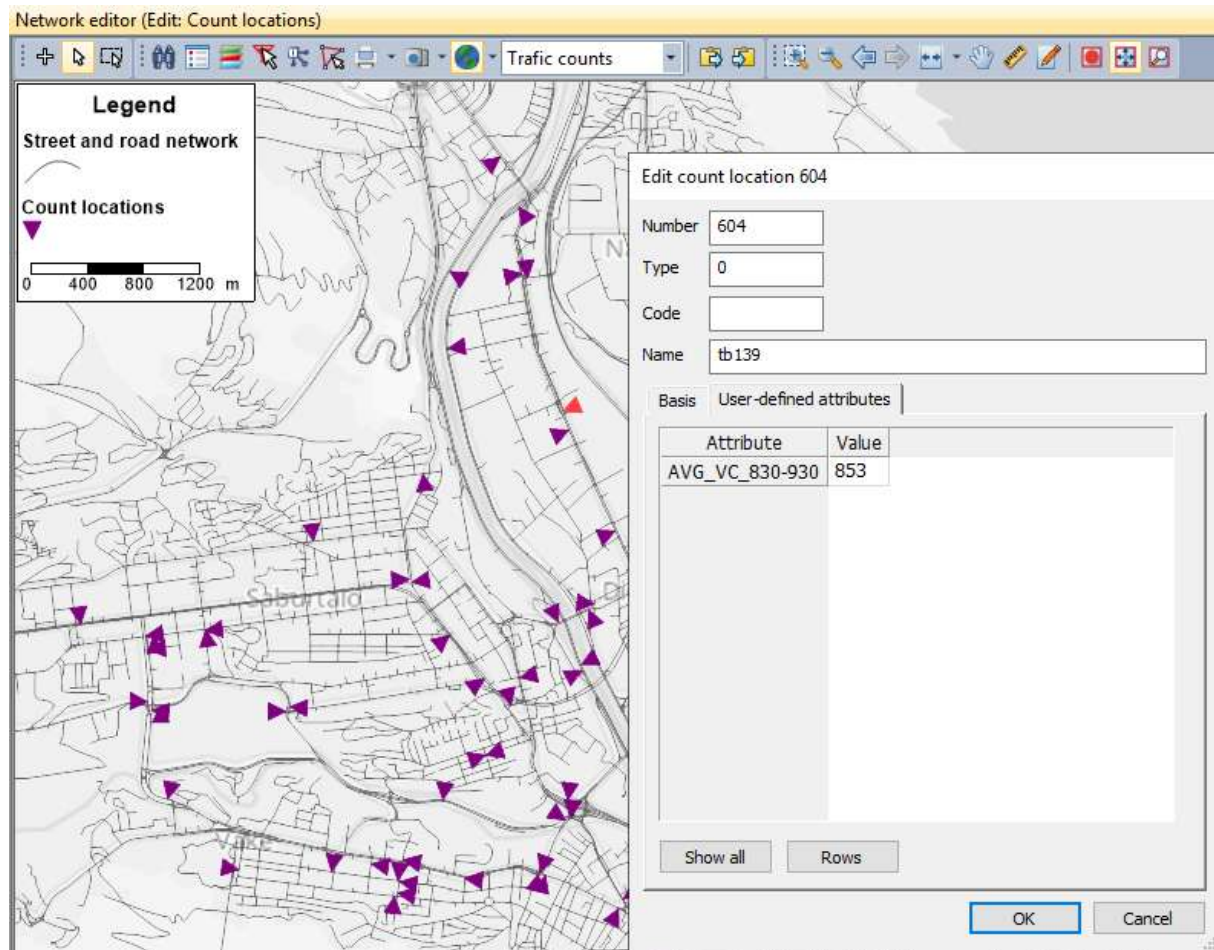


Figure 144. Example UDAs for Count locations based on detectors

The location of Count locations with traffic volume measurements from detectors on the network graph of the Tbilisi model is shown in Figure 145.

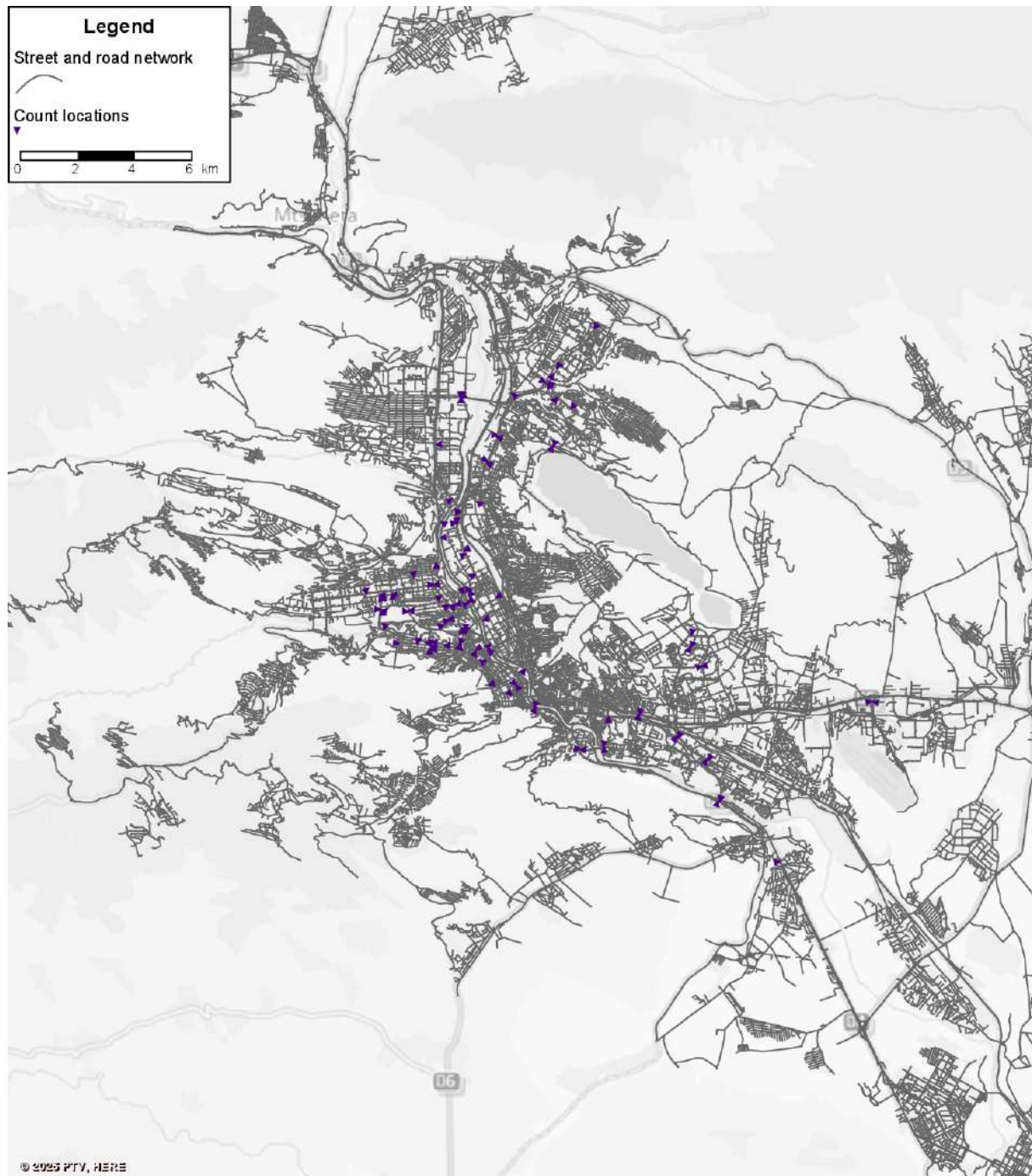


Figure 145. Location of the Count locations based on detectors data

Additionally, traffic volumes at the entries to the modelling area were obtained from TUDA as input data. The data covered the time period from 8:00 to 11:00 with a 30-minute interval for the period from 15 to 20 September 2025 and were provided for both travel directions without disaggregation by vehicle type (Figure 146).

	DAY_	HALF_HOUR_SLOT	LPR_NAME_SHORT	რაოდენობა	უნიკალურის რაოდენობა
1	15.09.2025	08:00	ga240	152	143
2	15.09.2025	08:00	ga380	486	485
3	15.09.2025	08:00	hwy004	736	736
4	15.09.2025	08:00	mc248	584	579
5	15.09.2025	08:00	mc259	173	167
6	15.09.2025	08:00	mc263	34	32
7	15.09.2025	08:00	mc270	208	199
8	15.09.2025	08:00	mc337	106	104
9	15.09.2025	08:00	ru497	134	133
10	15.09.2025	08:00	ter214	202	190
11	15.09.2025	08:00	tet226	12	12
12	15.09.2025	08:30	ga240	303	271
13	15.09.2025	08:30	ga380	381	379
14	15.09.2025	08:30	hwy004	686	686
15	15.09.2025	08:30	mc248	687	676
16	15.09.2025	08:30	mc259	245	237
17	15.09.2025	08:30	mc263	61	58
18	15.09.2025	08:30	mc270	230	219
19	15.09.2025	08:30	mc337	150	140
20	15.09.2025	08:30	ru497	136	135
21	15.09.2025	08:30	ter214	303	290
22	15.09.2025	08:30	tet226	25	23
23	15.09.2025	09:00	ga240	336	296
24	15.09.2025	09:00	ga380	349	349

Figure 146. Example of traffic volume data at the entries to the modelling area.

To enable further use of these data for updating the Tbilisi transport model, they were converted into a format suitable for modelling. First, the average traffic volume during the morning peak hour (8:30–9:30) for weekdays was calculated. At the following stage, the total traffic flow was split into two vehicle categories: CAR and HGV. The HGV share was assumed to be 1.5% of the total flow, which corresponded to the average value for the city of Tbilisi (see 5.6.1). Accordingly, the remaining 98.5% was assigned to CAR. In addition, an assumption was made regarding the directional distribution of traffic flow: 70% towards Tbilisi and 30% in the opposite direction. While we do not have specific studies for Tbilisi, in cities with a monocentric urban structure – where the majority of workplaces are concentrated in the city center and large residential districts (such as Gldani, Varketili, and Didi Dighomi) are located on the periphery – a similar distribution is typically observed. The estimated traffic volume values on the entries to the modelling area were entered into the model as **Count locations** (Figure 147).

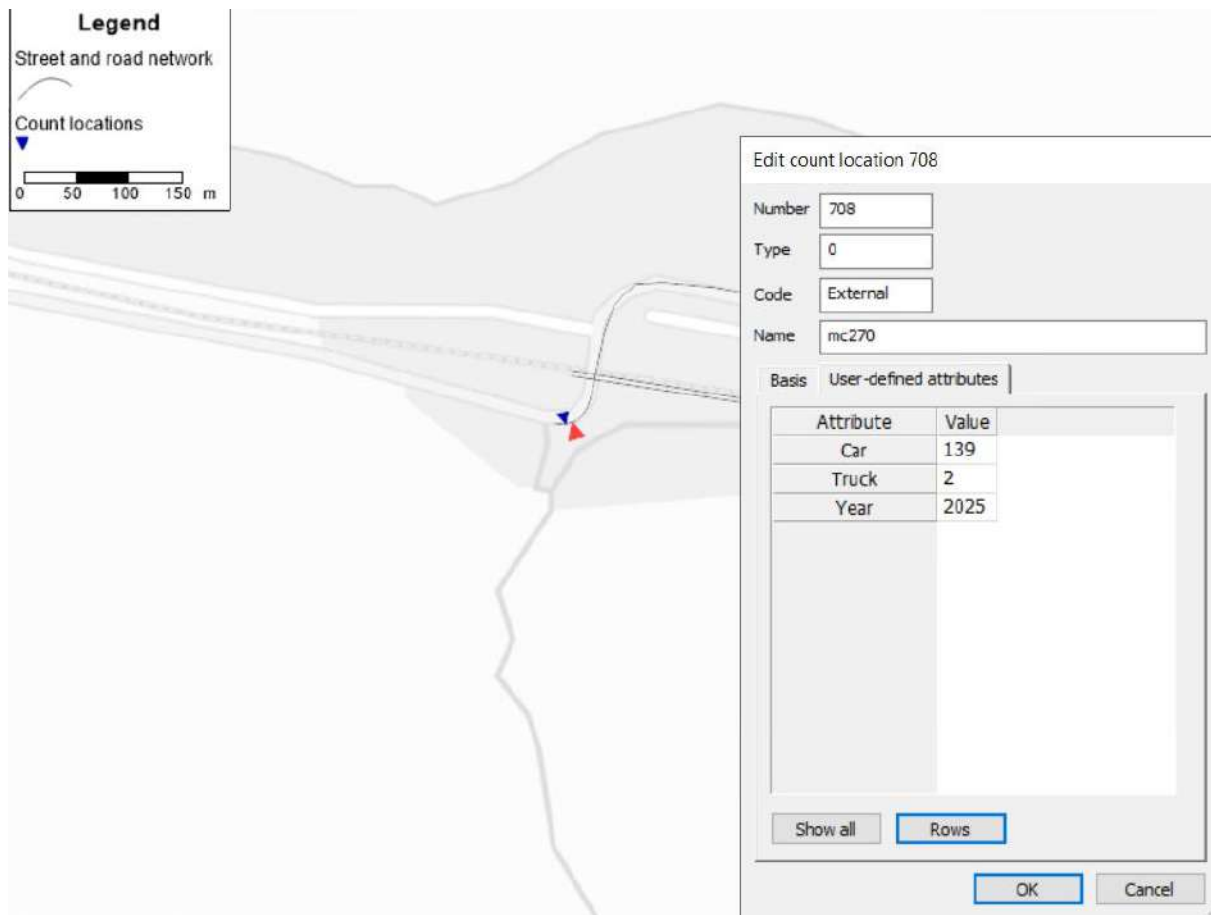


Figure 147. Example UDAs for Count locations on entries to the modelling area

The location of Count locations with traffic volume measurements at the entries to the modelling area is shown in Figure 148.

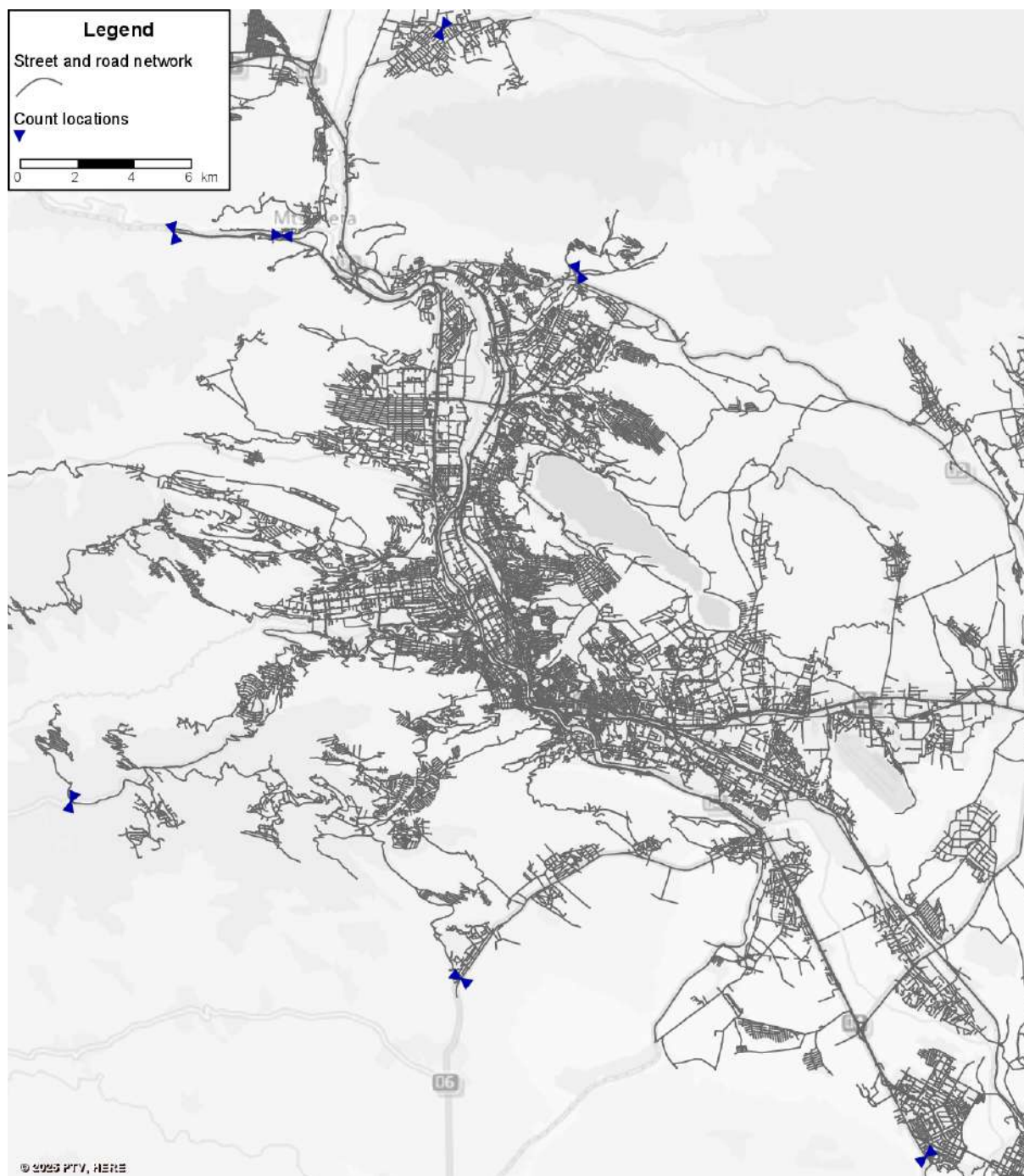


Figure 148. Location of Count locations with traffic volume data at the entries to the modelling area

The data from the detectors were used only partially and only at locations where no data from field surveys were available, as not all detectors covered all traffic lanes.

All other traffic volume data was used during the verification and calibration of private transport assignment in the transport model.

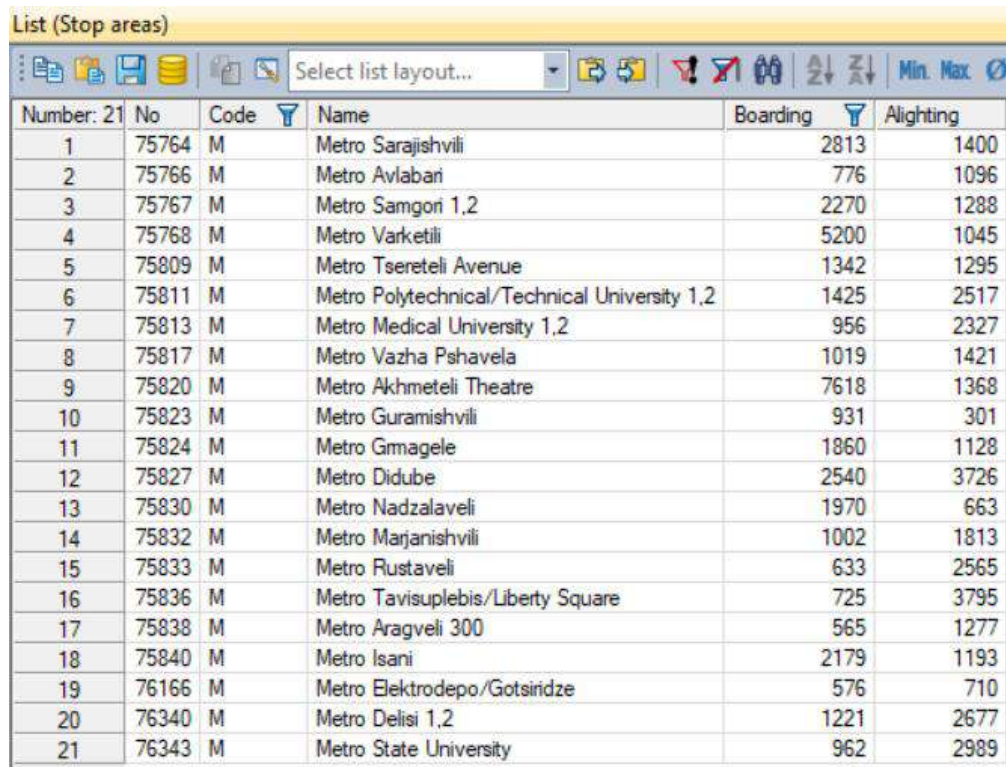
7.2. Passenger flows

For bus and minibus routes, passenger flow data obtained from surveys was entered as UDA - Passenger_flow_survey_upd for the Line network element. An example of attributes is shown in Figure 149.

Number	Name	TSysCod	Passenger_flow_survey
1	Bus_N°101_Krtsanisi Vill - Varketili-3 IV M/D	BUS	801
2	Bus_N°102_6 Penitentiary Institution - Baratashvili str	BUS	441
3	Bus_N°107_Tsodoreti Vill - M/S Delisi	BUS	171
4	Bus_N°292_M/S Akhmeteli Theatre - Tbilisi Mall	BUS	552
5	Bus_N°293_M/S Sarajishvili - Didi Dighomi I-II M/D	BUS	846
6	Bus_N°294_M/S Akhmeteli - Mukhiani III M/R	BUS	462
7	Bus_N°295_Afrika Stlmt - M/S Varketili	BUS	642
8	Bus_N°296_St Barbare Ubani - M/S Isani	BUS	1880
9	Bus_N°297_Gldani Lake Setl - M/S Akhmeteli Theatre	BUS	1595
10	Bus_N°298_Square Station 2 - Saburtalo Blocks	BUS	243
11	Bus_N°299_Ljubljana str - M/S Didube	BUS	284
12	Bus_N°300_Saarbrücken - SqMarjani str	BUS	457
13	Bus_N°301_Ana Politkovskaia Street - St Barbare District	BUS	1452
14	Bus_N°302_Didi Dighomi IV M/D - Tbilisi State University H/B	BUS	1321
15	Bus_N°303_Varketili-3 IV M/D - M/S Varketili	BUS	715
16	Bus_N°304_Gldani Lake - State University H/B	BUS	930
17	Bus_N°305_Afrika Stlmt (Kiziki str) - Baratashvili str (Konka)	BUS	2496

Figure 149. Example of AM peak hour (8:30 – 9:30) passenger flows by route (in both directions)

Passenger volume data for metro stations obtained from surveys were entered as UDAs: Boarding and Alighting for the Stop areas network element. An example of attributes is presented at Figure 150.



Number: 21	No	Code	Name	Boarding	Alighting
1	75764	M	Metro Sarajishvili	2813	1400
2	75766	M	Metro Avlabari	776	1096
3	75767	M	Metro Samgori 1,2	2270	1288
4	75768	M	Metro Varketili	5200	1045
5	75809	M	Metro Tsereteli Avenue	1342	1295
6	75811	M	Metro Polytechnical/Technical University 1,2	1425	2517
7	75813	M	Metro Medical University 1,2	956	2327
8	75817	M	Metro Vazha Pshavela	1019	1421
9	75820	M	Metro Akhmeteli Theatre	7618	1368
10	75823	M	Metro Guramishvili	931	301
11	75824	M	Metro Gmagele	1860	1128
12	75827	M	Metro Didube	2540	3726
13	75830	M	Metro Nadzalaveli	1970	663
14	75832	M	Metro Marjanishvili	1002	1813
15	75833	M	Metro Rustaveli	633	2565
16	75836	M	Metro Tavisuplebis/Liberty Square	725	3795
17	75838	M	Metro Aragveli 300	565	1277
18	75840	M	Metro Isani	2179	1193
19	76166	M	Metro Elektrodepo/Gotsiridze	576	710
20	76340	M	Metro Delisi 1,2	1221	2677
21	76343	M	Metro State University	962	2989

Figure 150. Example of passenger volumes at metro stations

7.3. Speed data

For the calibration of private transport speeds on the road network, speed data were collected. For this purpose, Google Maps Directions API was used³⁸. This allowed us to obtain traffic speeds on segments of the road network during a specified period. This data is not a complete equivalent of traffic speeds measurements, but it is an alternative source of knowledge.

The Google Maps Directions API used in this project is a well-known analogue of the Google navigation system, adopted for in-code using.

To enable the calculation of average speeds and travel times, segments on the road network relevant to the analysis were reconstructed using GIS tools. As a result, a total of 385 segments were generated. (Figure 151).

³⁸ [Google Maps Platform Documentation | Directions API \(Legacy\) | Google for Developers](#)

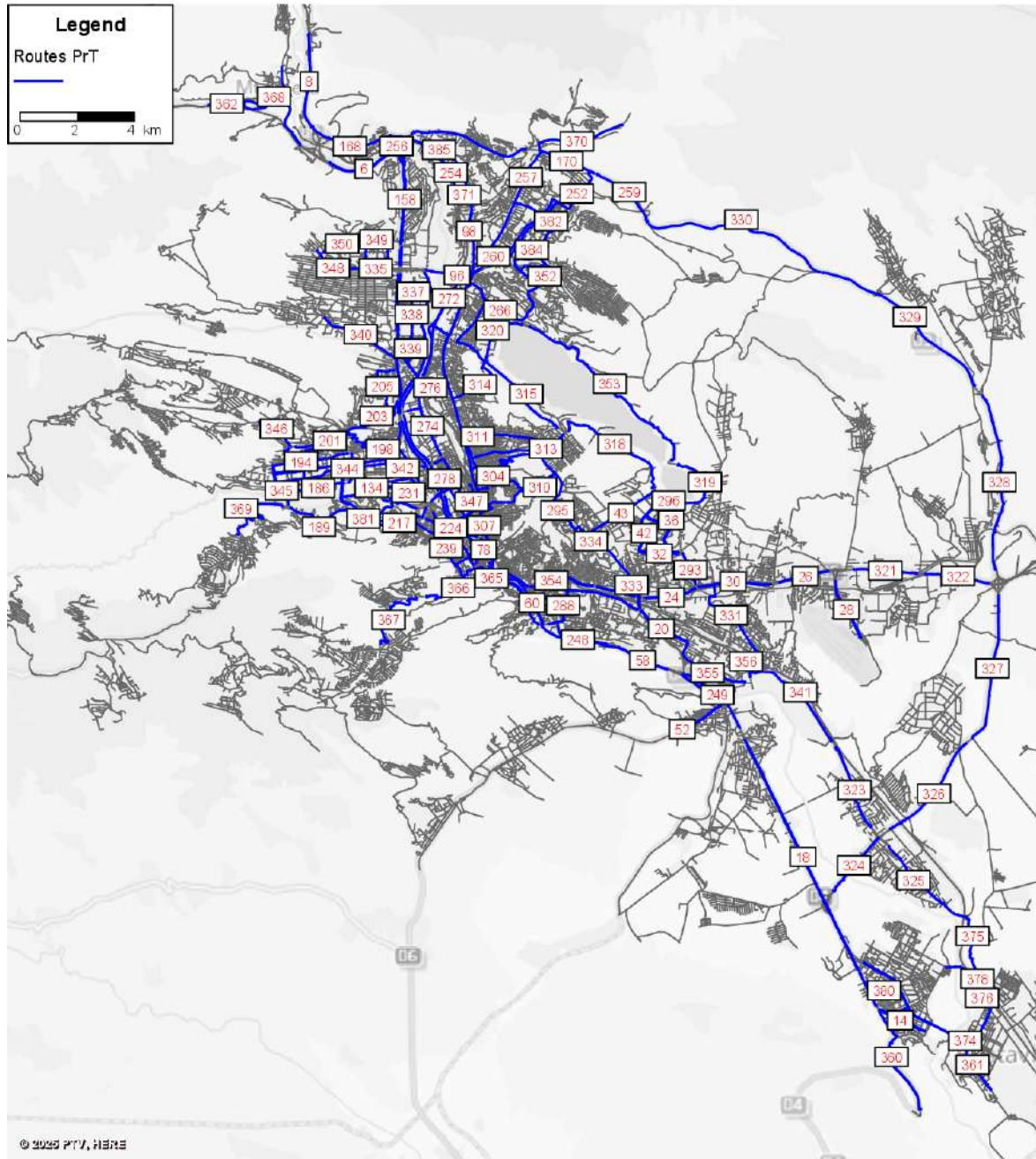


Figure 151. Analysed road network segments.

For each segment, an API request was generated to perform route calculation and to obtain the corresponding distance (D_i) and travel time (T_i). Based on these outputs, the vehicle operating speed (V_i) was calculated for each segment:

$$V_i = \frac{D_i}{T_i} \times 3.6$$

The separate requests were executed for three weekdays (22.05.2025, 27.05.2025 and 28.05.2025) and for each 15-minute interval between 7:00 and 10:00. These data were subsequently aggregated to derive representative average speed and travel time. As a result, a dataset containing estimated average speeds and corresponding travel times for each analysed segment was obtained (Figure 152).

route_id	Name	Average_speed (km/h)	Average_time (s)	route distance (m)
573	Line 1_reverse	54,9	51,5	780
574	Line 295_reverse	52,6	178,3	2590
575	Line 289_reverse	74,8	128,7	2665
576	Line 300_reverse	80,5	162,7	3633
577	Line 301_reverse	27,8	242,1	1868
578	Line 302_reverse	31,8	70,9	622
579	Line 303_reverse	37,1	180,9	1863
580	Line 304_reverse	20,9	238,3	1379
581	Line 305_reverse	78,2	425,1	9230
582	Line 306_reverse	20,5	348,1	1936
583	Line 307_reverse	14,3	163,7	568
584	Line 308_reverse	76,7	94,3	2008
585	Line 309_reverse	84,8	87,4	2057
586	Line 310_reverse	50,4	170,5	2385
587	Line 311_reverse	82,9	114,7	2641
588	Line 312_reverse	25,9	205,7	1476
589	Line 313_reverse	27,4	245,9	1864
590	Line 314_reverse	39,5	39,5	433
591	Line 315_reverse	23,6	102,9	672
592	Line 316_reverse	30,3	34,6	287
593	Line 317_reverse	26,5	179,2	1316

Figure 152. Example of average speed and travel time data

These values were imported into the transport model as the UDAs (Average_time, Average_speed) for Screenlines (Figure 153).

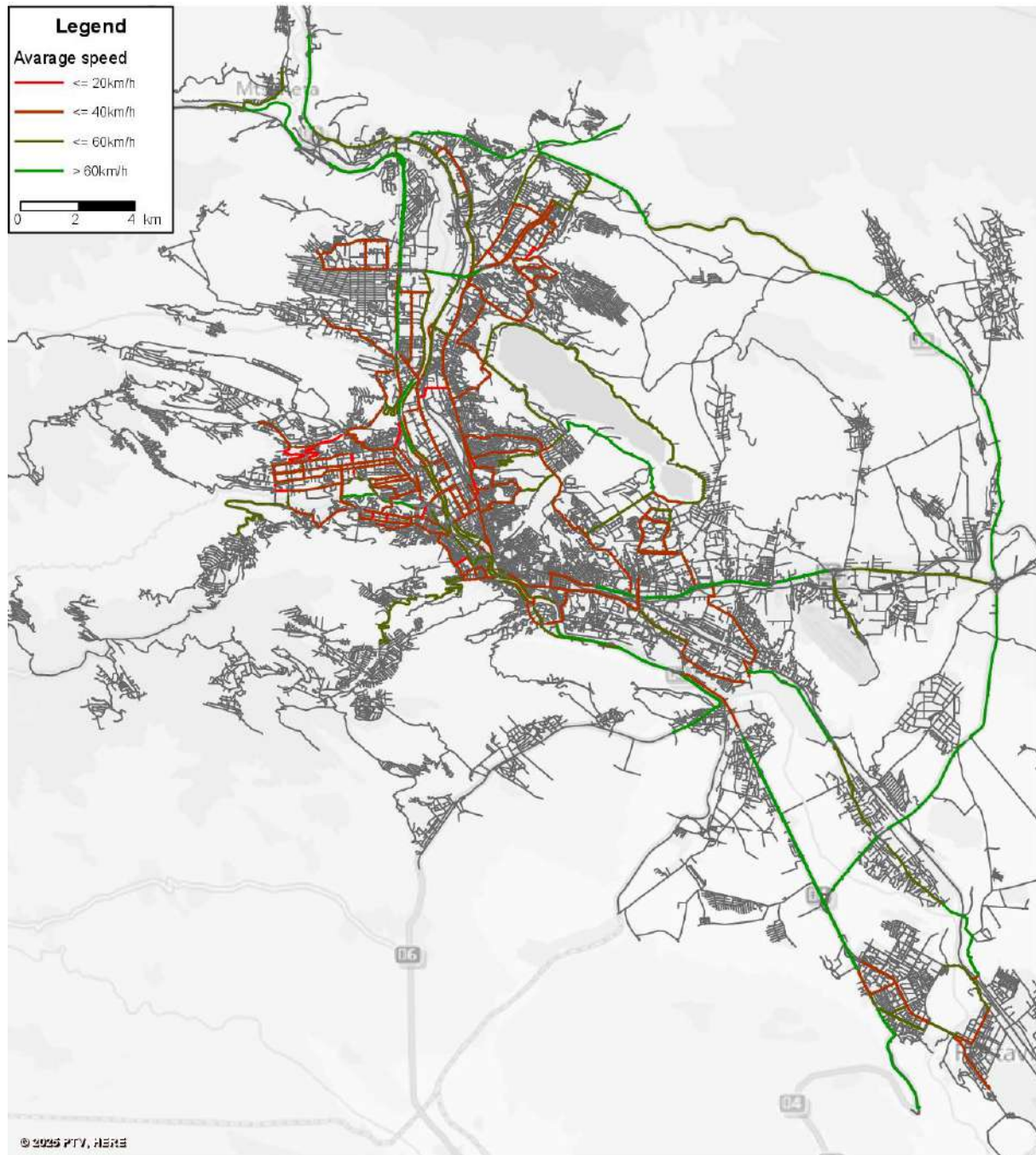


Figure 153. Screenlines with an estimated speed in transport model

To calibrate the speed and travel time of public transport, data were collected based on BA surveys. The average speed and travel time were calculated for each trip of the corresponding public transport route. The total travel time for each direction was calculated by summing up all the time intervals between consecutive points of the corresponding trips. This data was entered into the model as user attributes for line routes: ROUTE_SPEED and ROUTE_TIME (Figure 154).

List (Line routes)

Number: 33	TSysCode	Name	DirectionCode	ROUTE_SPEED	ROUTE_TIME
91	BUS	Nº387_Vake	<	9km/h	68min
92	BUS	Nº390_Baratashvili Str	<	17km/h	41min
93	BUS	Nº390_Oqrokana	>	18km/h	34min
94	BUS	Nº391_Gotua Str	<	10km/h	54min
95	BUS	Nº391_M/S Avlabari	>	13km/h	43min
96	BUS	Nº392_State University H/B	<	7km/h	81min
97	BUS	Nº392_Station Square	>	12km/h	50min
98	BUS	Nº393_Kvareli Street (Metromsheni)	>	14km/h	29min
99	BUS	Nº393_Nikoloz Baratashvili Street	<	11km/h	43min
100	BUS	Nº396_Airport Settlement	>	16km/h	49min
101	BUS	Nº396_M/S Isani	<	18km/h	54min
102	BUS	Nº397_Saburtalo	<	11km/h	92min
103	BUS	Nº398_M/S Delisi	<	7km/h	63min
104	BUS	Nº398_Nutsubidze M/D II-IV-V	>	10km/h	42min
105	MRS	Nº401_Joseliani IV Lane	<	10km/h	13min
106	MRS	Nº401_M/S Technical University	>	11km/h	13min
107	MRS	Nº402_Mrgvali Bagi Square	>	12km/h	35min
108	MRS	Nº403_M/S Varketili	>	8km/h	21min
109	MRS	Nº403_Nikoloz Landia St #21	<	9km/h	16min
110	MRS	Nº405_M/S Crazy	>	7km/h	40min
111	MRS	Nº405_Nutsubidze Plato M/D-5	<	11km/h	24min
112	MRS	Nº406_M/S Varketili	>	9km/h	23min
113	MRS	Nº407_Shota Nadirashvili St	<	9km/h	33min
114	MRS	Nº408_M/S Rustaveli	>	11km/h	38min
115	MRS	Nº409_Batumi Street	<	14km/h	30min
116	MRS	Nº409_Kvemo Ponichala Center	>	13km/h	18min
117	MRS	Nº410_Ponichala Nature Reservation	<	12km/h	44min
118	MRS	Nº411_Aleksandre Beridze St #28	<	15km/h	11min
119	MRS	Nº411_E Mtskhiteli St	>	13km/h	14min
120	MRS	Nº412_Abkhazia St	>	12km/h	32min
121	MRS	Nº413_M/S Varketili	<	10km/h	18min
122	MRS	Nº413_Mikheil Gakhokidze St N56	>	14km/h	13min
123	MRS	Nº414_Dzmobi II Street	<	10km/h	16min
124	MRS	Nº415_M/S Varketili	>	14km/h	38min
125	MRS	Nº415_Military Settlement 2nd Street	<	16km/h	34min
126	MRS	Nº416_Public School #11	<	5km/h	87min
127	MRS	Nº417_David the Builder #100	<	16km/h	24min
128	MRS	Nº417_M/S Akhmeteli Theater	>	9km/h	38min
129	MRS	Nº418_Meri Shervashidze St	>	22km/h	16min
130	MRS	Nº418_Railway Passage Bridge	<	15km/h	25min
131	MRS	Nº419_M/S University	>	9km/h	48min
132	MRS	Nº419_Village of Agarakebi	<	16km/h	26min
133	MRS	Nº420_M/S Rustaveli	>	13km/h	25min
134	MRS	Nº421_M/S Guramishvili	>	19km/h	19min
135	MRS	Nº421_Sea Area Lane	<	14km/h	12min
136	MRS	Nº422_M/S Didube	>	12km/h	45min

Figure 154. Excerpt from a list of line routes with average speed and travel time data

7.4. Statistical indicators

A standard quality indicator of a transport model for the peak period is the GEH index³⁹, which reflects the overall level of traffic volumes according to the following formula:

$$GEH = \sqrt{\frac{2(c - m)^2}{c + m}}$$

Where:

m - traffic volume obtained from the results of transport modelling;

c - observed traffic volume determined during field surveys.

The quality of calibration is assessed based on the following criteria:

- GEH < 5: good calibration;
- 5 < GEH < 10: satisfactory calibration;
- 10 < GEH < 20: significant discrepancy between modelled and observed traffic.

The GEH index was calculated for all counting locations with available survey data for each demand segment (Table 18).

Table 18. GEH Index Values

Indicator	GEH Index			
	0-5	5-10	10-20	Total
Car				
Number of count location	181	155	113	449
Share of counting locations with the corresponding GEH, %	39,2	36,7	24,1	100%
GV				
Number of count location, units.	384	2	0	386
Share of counting locations with the corresponding GEH, %	99,7	0,3	0	100%

For the Car demand segment, 39,2% of counting locations demonstrate a good level of calibration, while an additional 36,7% achieve a satisfactory level; overall, 75,9%.

For the GV demand segment, 99,7% of counting locations demonstrate a good level of calibration, while an additional 0,3% reach a satisfactory level; overall, 100%.

The presence of 24,1% of counting locations for Car that do not meet the calibration requirements can be explained by survey data collected in different years and periods, which reflected a significant variability in possible routes within the network and the dynamic traffic conditions in the study area.

A separate tool for assessing the assignment analysis is the assignment diagrams. These diagrams are constructed by plotting observed versus modelled values on a coordinate system. Observed data are plotted along the X-axis, while modelled values are plotted along the Y-axis for each counting location. An approximation line is then fitted to these points, ideally aligning closely with the line $y = x$. Assignment diagrams for the Car, and GV demand segments are presented in Figure 155 -Figure 157.

³⁹ <https://assets.publishing.service.gov.uk/media/664dad464f29e1d07fadcc39/tag-m3-1-highway-assignment-modelling.pdf>

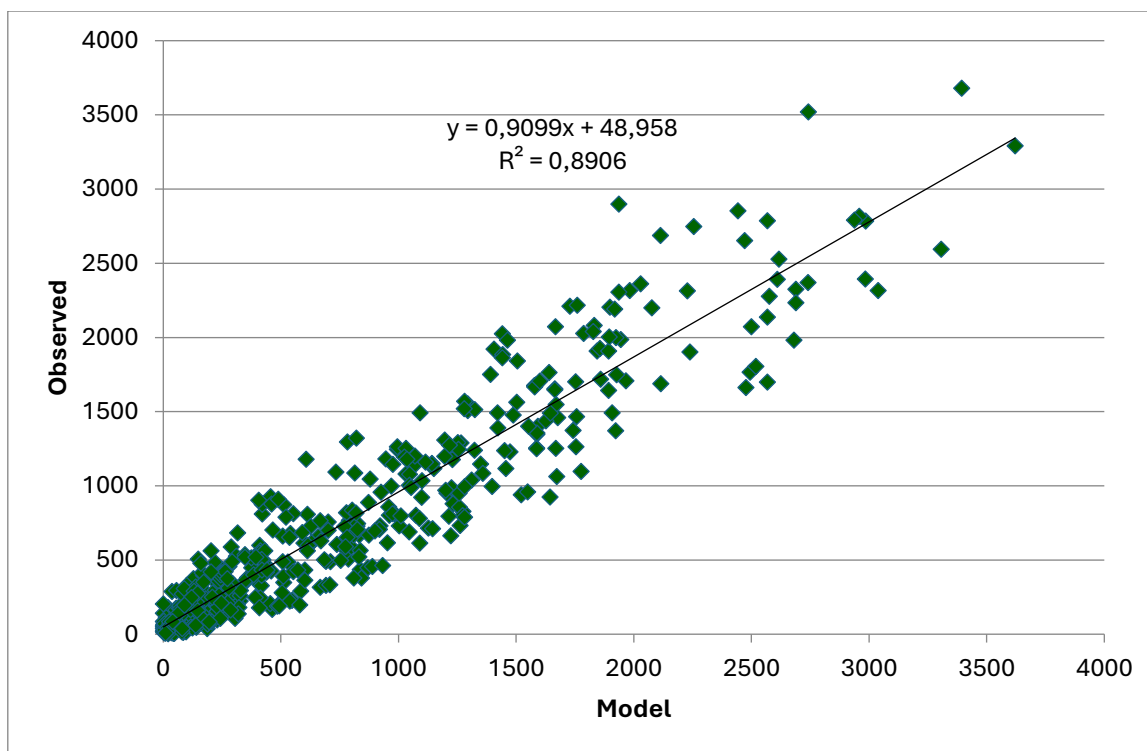


Figure 155. Assignment analysis chart for Car

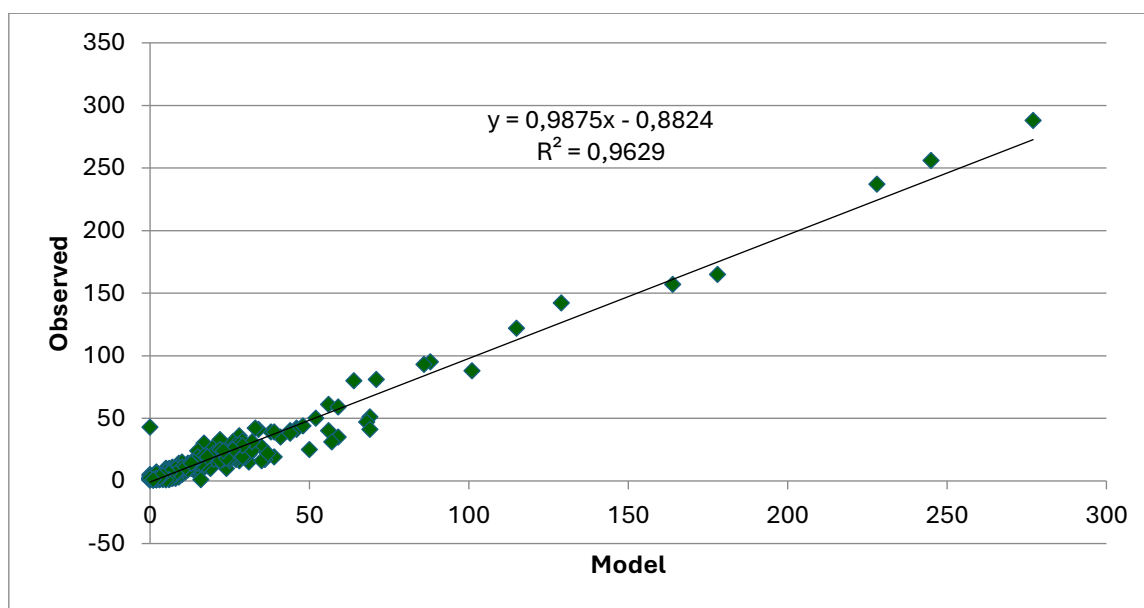


Figure 156. Assignment analysis chart for GV

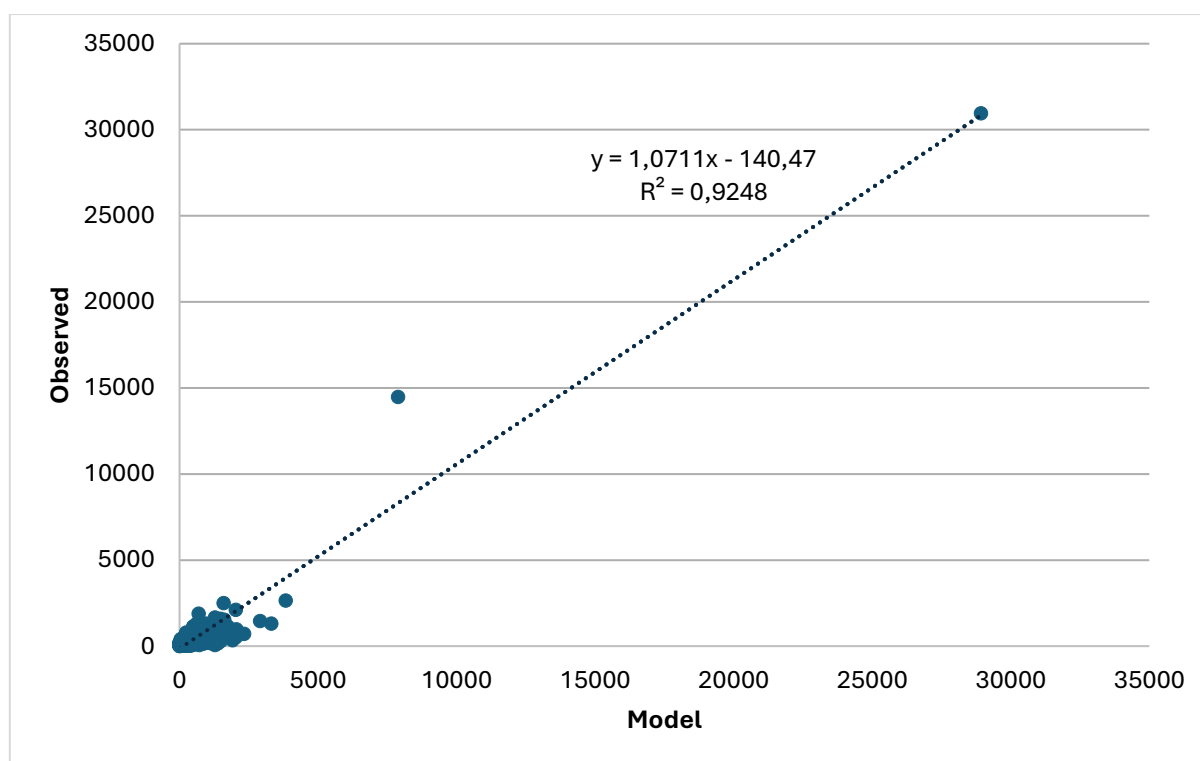


Figure 157. Assignment analysis chart for PuT

Assignment diagrams for bicycles were not constructed, as there were insufficient cyclist count data for a reliable analysis.

International standards ⁴⁰⁴¹ recommend assessing the quality of a model using the following indicators:

- R^2 – an indicator used in statistical models as a measure of the extent to which the variation of the dependent variable is explained by the variation of the independent variables. In other words, it reflects the accuracy of the match between deviations in observed and modelled values. The recommended value is $> 85\%$, with JASPER also recommended within the range of 0.80–0.85.
- Slope – shows the overall ratio of modelled values to observed values. Under perfect agreement, it equals 1; in the case of deviations, it may take any real value. The recommended range is 0.9–1.1.
- Mean relative error – recommended values are $< 30\%$.
- Correlation coefficient – measures the linear relationship between actual and calculated data. Its value ranges from -1 to +1; the closer the correlation coefficient is to 1, the more accurately the series of calculated load values approximates the actual data series.

The quality of the assignment results was assessed separately for each demand segment, with the results presented in Table 19.

⁴⁰ https://www.atap.gov.au/sites/default/files/T1_Travel_Demand_Modelling.pdf

⁴¹ <https://assets.publishing.service.gov.uk/media/664dad464f29e1d07fadcc39/tag-m3-1-highway-assignment-modelling.pdf>

Table 19. Quality indicators of traffic assignment

Demand segments	Number of Observation Points	R2	Slope	Mean relative error	Correlation Coefficient
Car	449	0,891	0,979	23,6%	0,944
GV	386	0,963	0,975	21,2%	0,981
PuT	282	0,925	0,863	53,3%	0,962

7.5. Validation of Speeds

The average modelled speeds of all vehicles assigned in the model are presented in Table 20. They show a good match with observed travel speeds during the AM peak.

Table 20. Comparison of average travel speeds by transport system

Transport system	Average speed of vehicles, AM-peak hour (km/h)	
	Model data	Observed data
Car	28	29
Bus	12	14
Minibus	13	13

8. MODEL RESULTS

Maps showing traffic volumes, V/C ratios, and passenger flows are presented below.

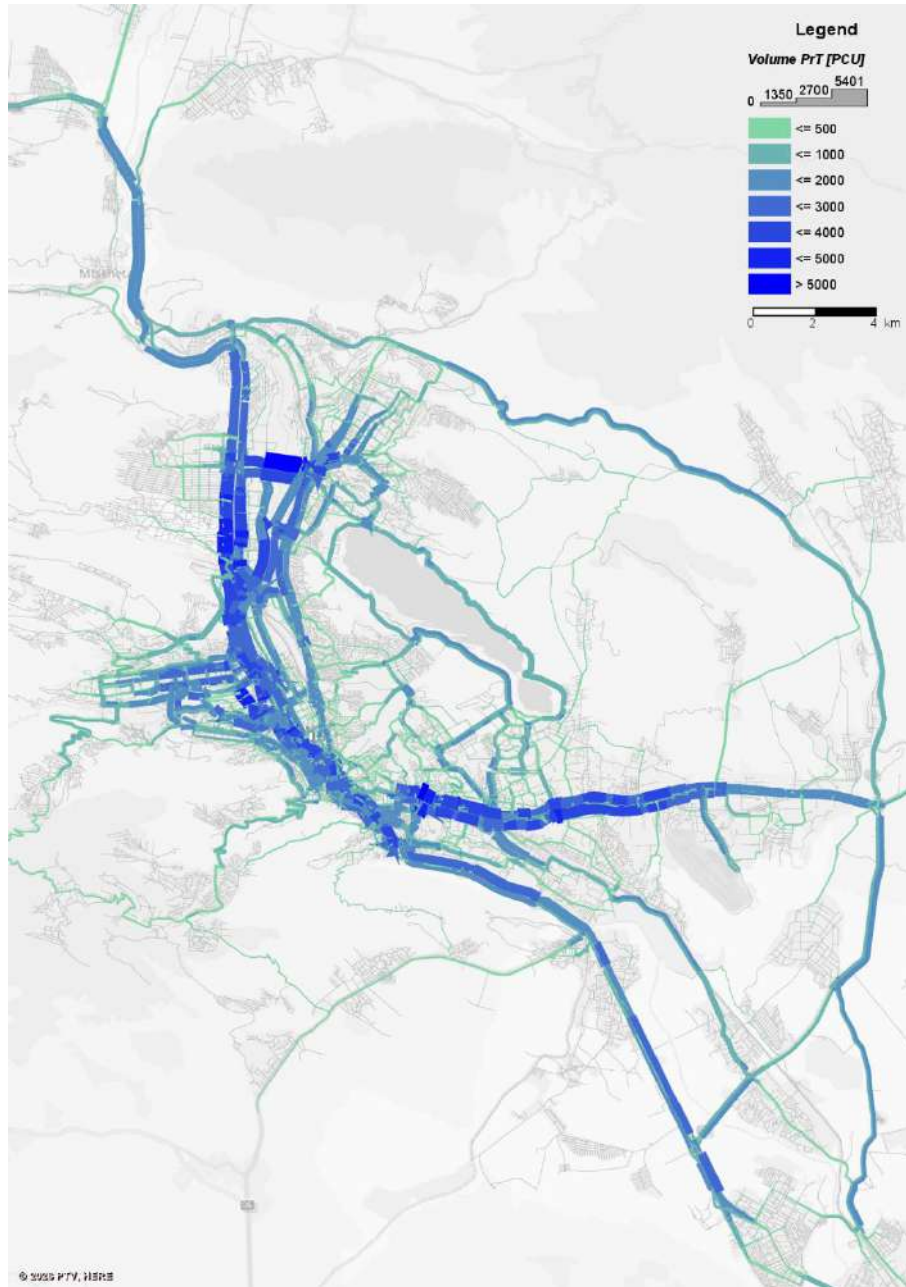


Figure 158 Traffic volumes map

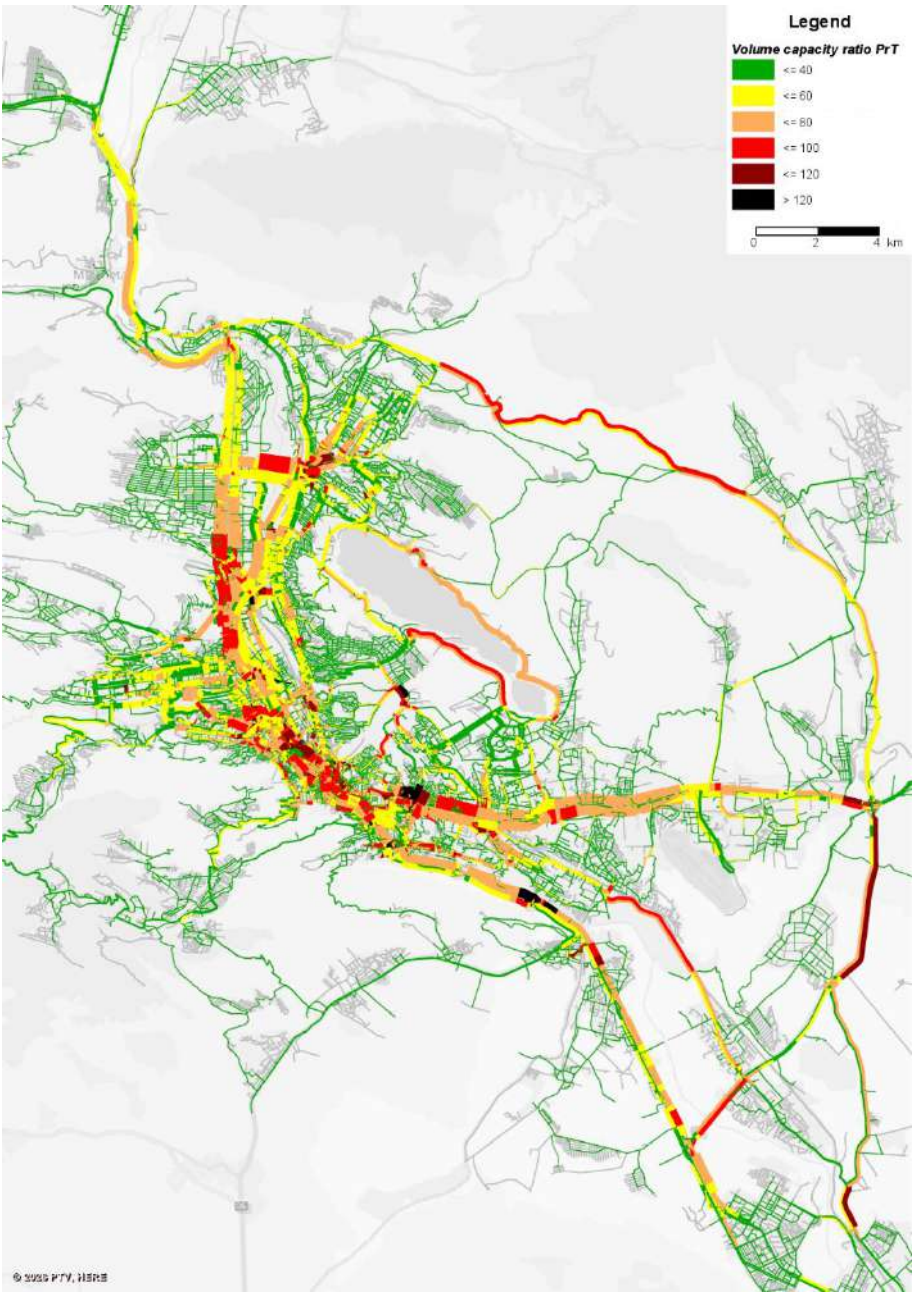


Figure 159 Volume/capacity map

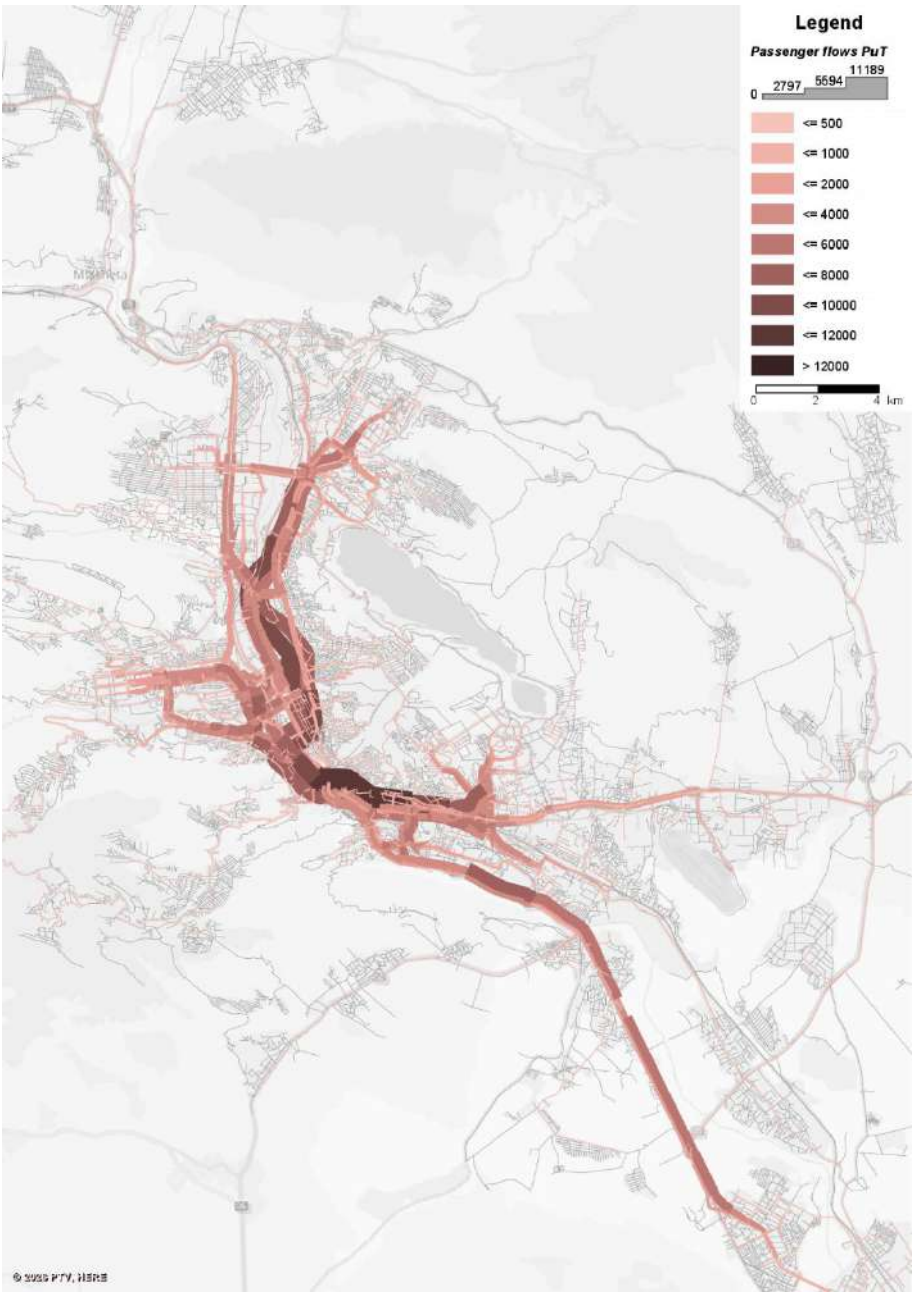
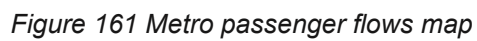


Figure 160 Passenger flows map



9. LIMITATIONS AND RECOMMENDATIONS

During the update of the Tbilisi transport model, several limitations related to the completeness, timeliness and level of detail of certain input datasets were identified. These limitations do not affect the suitability of the model for addressing the objectives defined within the scope of the current assignment; however, they highlight the need for ongoing maintenance and regular updates in order to ensure the robustness and reliability of modelling results over the medium and long term.

The key identified data gaps include:

- Limited availability of traffic volume and traffic composition data on the road network. The available datasets collected from multiple sources and across different periods between 2024–2025 are fragmented in nature, and do not provide full coverage of the entire modelling area;
- Insufficient availability of up-to-date socio-economic data, in particular with regard to population figures and the spatial distribution of jobs at the TAZ level (at the time of the model update, the 2025 population census data were not available);
- Limited data on suburban and interurban services, including passenger volumes, service frequencies and the level of integration between suburban transport and the urban transport system;
- Lack of up-to-date passenger throughput data at bus terminals and other transport hubs, which constrains further detailed analysis of suburban and interurban travel demand and its interaction with the urban transport network.

A detailed description of the assumptions applied to address these data limitations within the current model update is provided in the preceding sections of this report.

In order to ensure the long-term relevance, consistent quality and reproducibility of the transport model, the following measures are recommended:

- Establish a systematic and standardised programme for traffic data collection, including the use of automated traffic detectors, GPS-based data and information provided by public transport operators directly collected from the fare collection system;
- Regularly update socio-economic input data, including population, employment and land-use information at the TAZ level;
- Expand data collection and analysis related to suburban and interurban transport services, covering route networks, passenger volumes and their integration with the urban transport system;
- Implement systematic passenger count and monitoring procedures at bus terminals, railway stations and other key transport hubs, with regular updates of passenger throughput indicators in the transport model.

To support regular model updates, it is recommended that formal data requests be issued to relevant data custodians at least once per year, and that the transport model of Tbilisi be updated accordingly based on the newly obtained data. A systematic and institutionalised approach to the collection, updating and use of transport and socio-economic data will allow the Tbilisi transport model to be maintained as a reliable and up-to-date planning tool, supporting informed decision-making in the development of the city's transport system without the need for significant additional time or financial resources.

10. APPENDIX

10.1. Example of population data calculation by TAZ for 2025

For the update of the transport model, a consistent and spatially detailed estimate of the resident population for 2025 was required at the level of TAZs. As no official population data were available for 2025 at the TAZ level, the estimation was based on the spatial population distribution embedded in the 2022 transport model, combined with the official total population figure for 2025.

The population values assigned to each TAZ in the 2022 model⁴² were used as the baseline spatial structure. Based on these data, the share of population for each TAZ was calculated as a proportion of the total population represented in the 2022 model. This proportional distribution was assumed to reflect the underlying spatial pattern of residential settlement and was therefore considered appropriate for redistributing the updated total population value.

The official total population for 2025 was obtained from the Georgian national statistics portal⁴³. The updated total population was then redistributed across the TAZ system by applying the proportional shares derived from the 2022 model. As a result, the estimated population for each TAZ in 2025 was obtained while ensuring full consistency with the official aggregate population figure.

Below, two cases of recalculating the 2025 population are presented:

- assuming unchanged TAZ boundaries;
- assuming modified TAZ boundaries.

It should be noted that the examples provided illustrate the general methodological approach to population estimation at the TAZ level. In practice, the calculation procedure may vary for individual TAZs depending on specific local conditions or data availability.

Case 1: Unchanged TAZ boundaries

In cases where the TAZ boundaries in the updated model remained fully consistent with the 2022 zoning system, the recalculated 2025 population values were transferred directly to the new model without further internal redistribution.

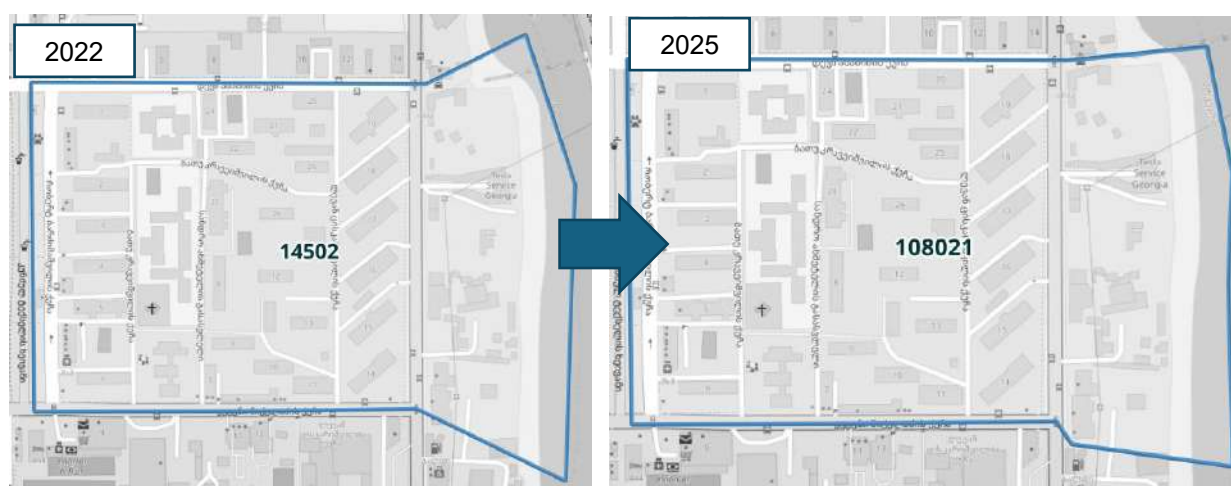


Figure 162 - Numbering of TAZs and their borders in the 2022 and 2025 models

Consider, for example, TAZ No. 14502 (numbers from the 2022 model) (Figure 162). The share of the population in this TAZ relative to the total population in 2022 is approximately 0.00369:

⁴² The total population for Tbilisi in the 2022 model is **1,184,704**

⁴³ <https://www.geostat.ge/en/modules/categories/41/population>

$$\text{Share_TAZ} = \text{Pop_TAZ, 2022} / \text{Pop_Total, 2022}$$

$$\text{Share_TAZ №14502} = 4367 / 1\,184\,704 = 0,00369$$

According to data from the Georgian national statistics portal, the population of Tbilisi in 2025 is 1,286,556, which is reflected in the updated model. To estimate the population of this TAZ in 2025, this proportion was multiplied by the total population:

$$\text{Pop_TAZ, 2025} = \text{Share_TAZ} * \text{Pop_Total, 2025}$$

$$\text{Pop_TAZ №14052} = 0,00369 * 1\,286\,556 = 4747.$$

Since the boundaries of the TAZ have not changed, the population data obtained for 2025 was assigned to the TAZ from the new model (new TAZ number - 108021) (Figure 163).

The difference of 2 people is attributed to rounding errors arising during the calculation process.

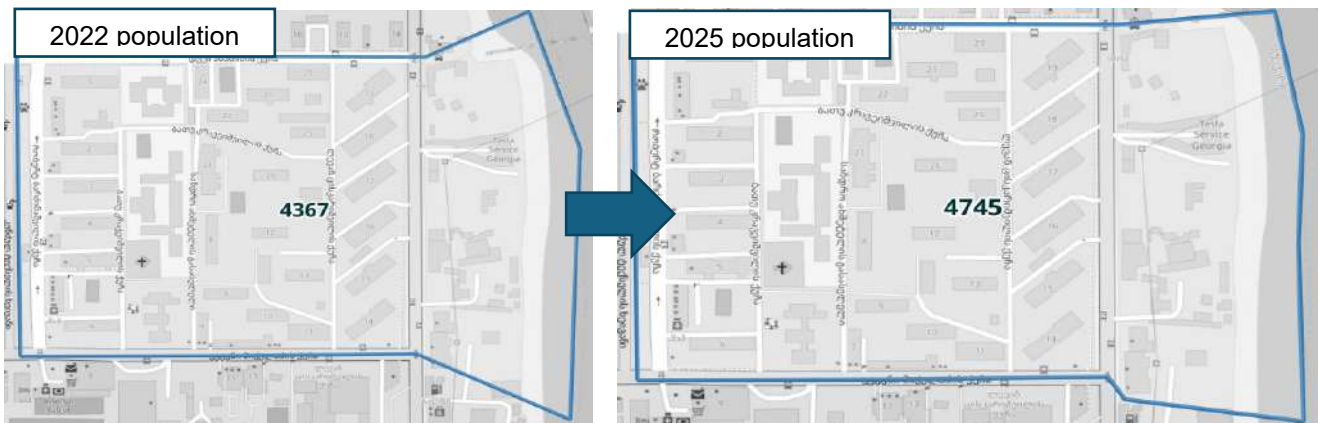


Figure 163 - Population change with unchanged TAZ boundaries

Case 2: Modified TAZ boundaries

Where the TAZ structure in the updated model differed from the 2022 model, additional population redistribution was required. This situation typically occurred when a single 2022 TAZ was subdivided into multiple smaller zones in the updated model. In such cases, the total estimated 2025 population corresponding to the original 2022 TAZ was first calculated using the proportional scaling approach, after which this population was allocated among the newly defined zones.

The redistribution within modified zones was based on observed residential development patterns. The relative intensity of residential use in each new zone was assessed using satellite imagery and available information on the number, type, and approximate number of floors of residential buildings. The population was then allocated to the new zones in proportion to their observed residential capacity, ensuring that areas with denser or taller residential development received a correspondingly higher share of the population.

Consider TAZ No. 11505 (old numbering) as an example. The total population for this TAZ was recalculated in the same way as in the previous case.

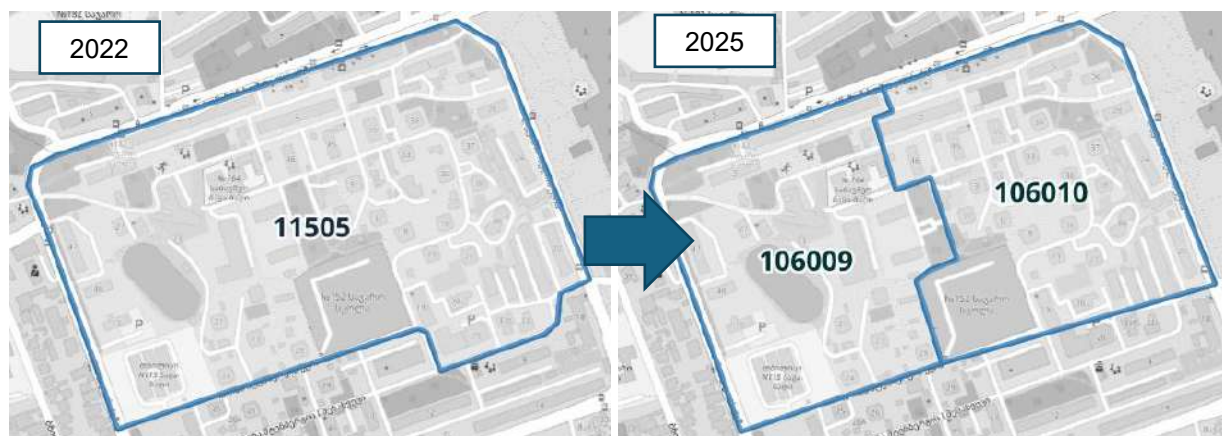


Figure 164 - Change in the TAZ boundaries in the 2025 model

$$\text{Share_TAZ №11505} = 5255 / 1\,184\,704 = 0,00444$$

$$\text{Pop_TAZ №14052} = 0,00444 * 1\,286\,556 = 5707$$

However, this TAZ was subdivided into two new TAZs in the updated model (Figure 164). Therefore, the 2025 population had to be distributed between them. It should be noted that in the lower-right corner of the original TAZ 11505, part of the area was assigned to a neighboring TAZ. Within this section, there are three 9-story buildings and one 5-story building. Accordingly, part of the population (321 people) was transferred to the adjacent TAZ containing these buildings.

The remaining population was distributed between the two new TAZs based on the density of residential development. For example, TAZ No. 106010 contains more residential buildings than TAZ No. 106009; therefore, a higher proportion of the population was assigned to TAZ 106010 (Figure 165).

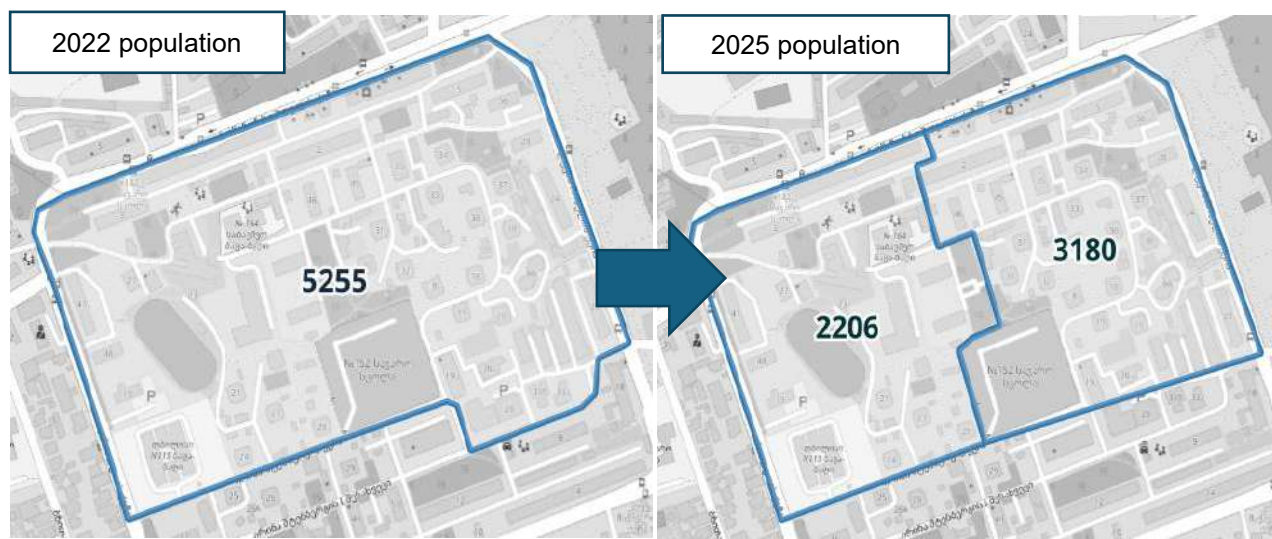


Figure 165 - Distribution of population according to new TAZs depending on development

This approach ensured that the population was allocated to reflect both the updated TAZ boundaries and the observed spatial distribution of residential development.

Population Verification and Adjustment

Following the initial population assignment, all 666 TAZs were reviewed individually to verify the plausibility of the estimated population values. This quality control step involved a visual comparison between the assigned population and the observed residential density and building typology within each zone. Where inconsistencies

were identified, minor adjustments were applied to better align the population estimates with the physical characteristics of the built environment, while preserving consistency with the official total population for 2025.

For example, consider TAZ No. 14402. Its share of the total population in 2022 was 0,00234. Based on the 2025 population, the population in this TAZ would initially be calculated as follows:

$$\text{Share_TAZ №14402} = 2767 / 1\,184\,704 = 0,00234$$

$$\text{Pop_TAZ №14402} = 0,00234 * 1\,286\,556 = 3005$$

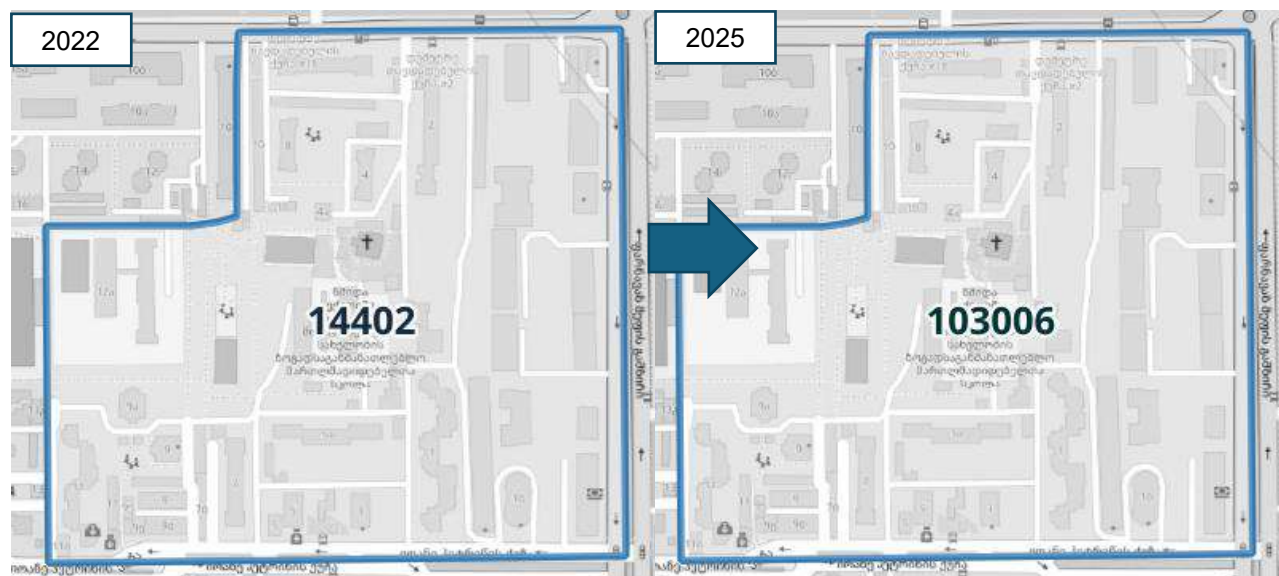


Figure 166 - Numbering of TAZs and their borders in the 2022 and 2025 models

However, certain changes in residential development occurred in this TAZ. Specifically, a new residential building was commissioned in the third quarter of 2024 at Demetre Tavaddebuli Street, 2. This required an upward adjustment of the population for this TAZ.

Taking into account the 55 occupied apartments in this new building and the average household size in Georgia⁴⁴ (3.2 persons in urban areas), the population increase is calculated as:

$$\Delta\text{Pop} = 55 \times 3.2 = 176 \text{ persons}$$

Accordingly, the adjusted population of TAZ 14402 for 2025 is: $3005 + 176 = 3181$ persons (Figure 167).

⁴⁴ <https://openknowledge.fao.org/server/api/core/bitstreams/2f1b1188-a8f2-433f-9fdf-5d4b1c205bdd/content>

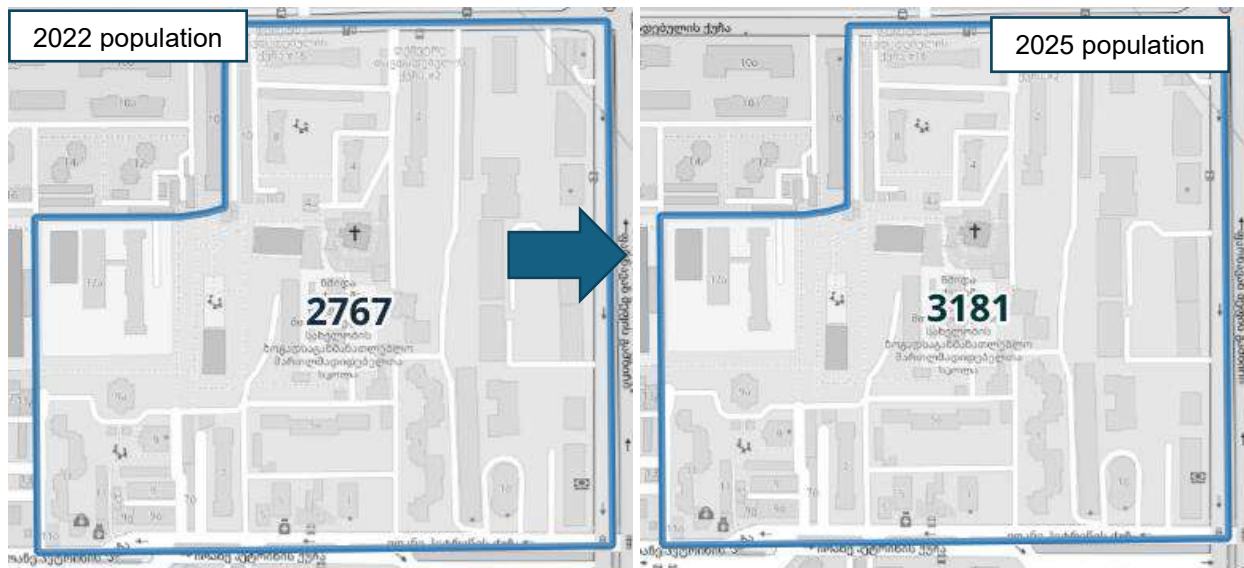


Figure 167 - Population change taking into account new buildings

10.2. Calculation of population growth

Population growth between 2014 and 2025 was calculated using a relative change approach. For each spatial unit, the absolute change in population was defined as the difference between the estimated population for 2025 and the corresponding population value for 2014. The percentage growth rate was calculated by dividing this absolute change by the 2014 population value and expressing the result as a percentage.

For example, in the Didi Dighomi area (Figure 168), the population increased from 26,368 residents in 2014 to 32,168 residents in 2025. This corresponds to an absolute increase of 5,800 residents and a population growth rate of approximately 21.9 rounded to 22% over the analysis period.

$$\text{Growth rate} = \frac{32168 - 26368}{26368} \cdot 100\% = 21.9\% \approx 22\%$$

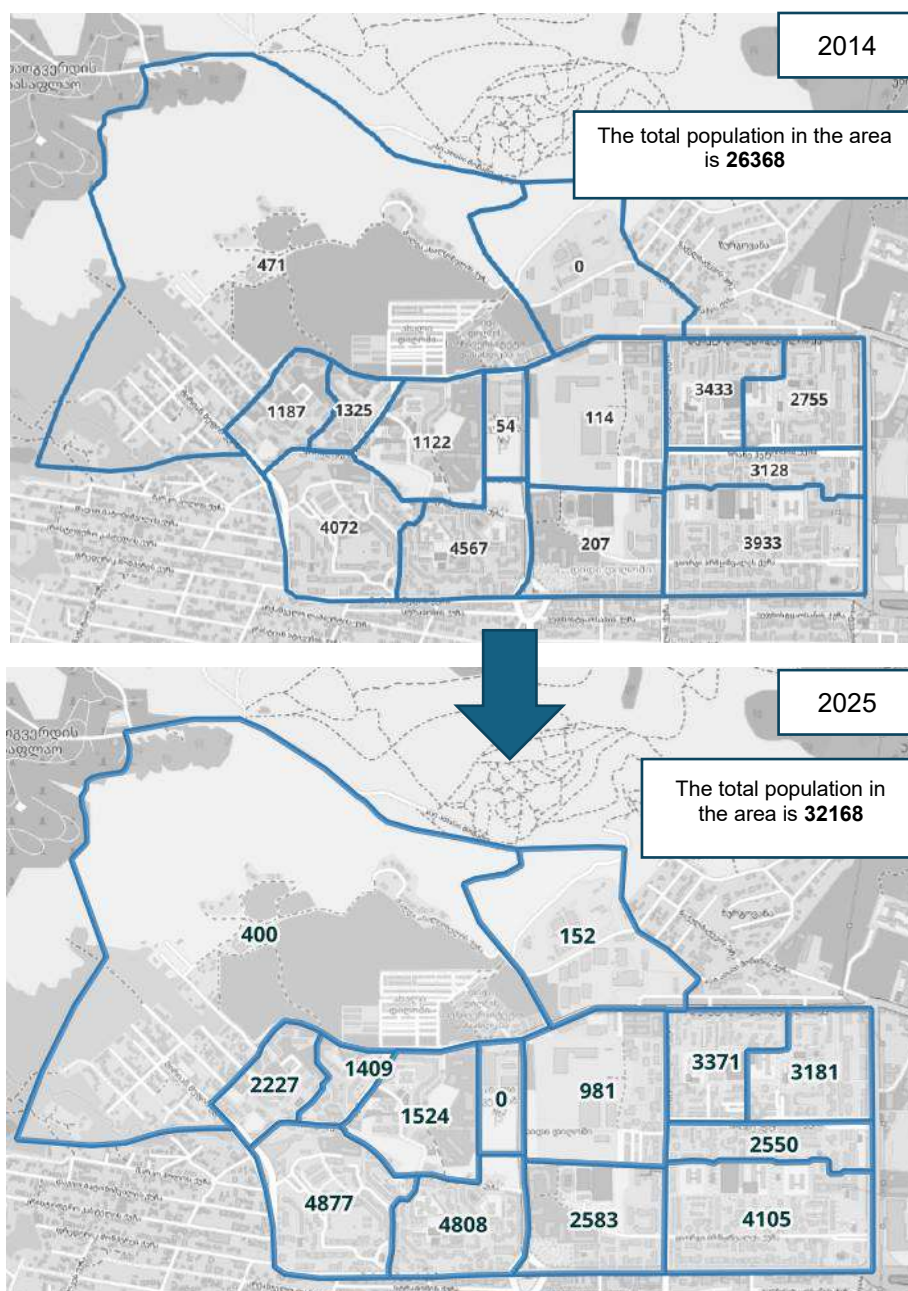


Figure 168 - Population in Didi Dighomi in the 2014 and 2025 models