ROAD AND TRANSPORTATION MASTER PLAN

WEST BANK AND GAZA STRIP

TA 2012013 PS 00 F10

Annex 16 – Transport Model Features and Calibration

SETTEMBER 30, 2016

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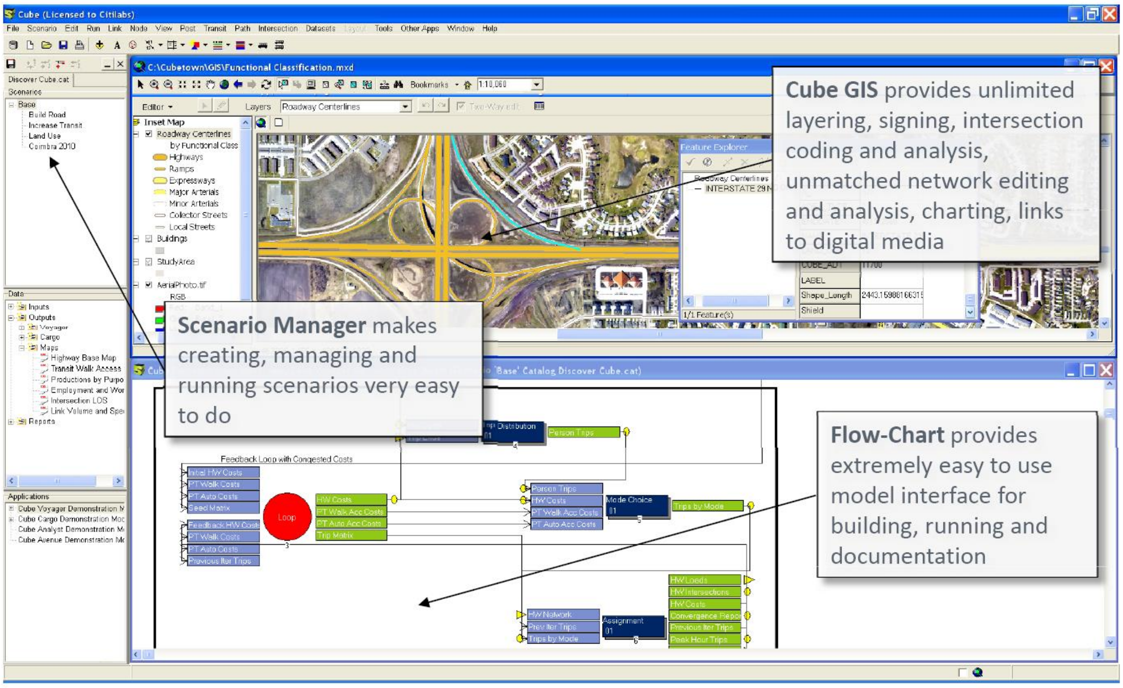
1. Introduction

This document is aimed to describe the model development and the calibration process, in order to provide evidence of the robustness and consistency of the tool and confirm the reliability of the model results described in the Project Report. All the input data and methodology applied are described in detail, as well as the assumptions at the basis of the estimation of the travel demand in the forecasting scenarios.
It is structured according to the following Chapters:
Chapters 2 describes the selected suite of modelling code;
Chapter 3 is mainly describes the most significant results of the traffic survey campaign specifically carried out for this assignment;
Chapter 4 and 5 outline respectively model zoning and the modelled road network;
Chapters 6 – 10 describes the entire analytical process, which based on the Four-Step structure, is defined as Demand Model, to include Trip Generation (Chapter 6), Matrix Estimation (Chapter 7) and Trip Distribution (Chapter 8), Modal Choice (Chapter 10), with a specific section for the estimation of freight's movements (Chapter 9);
Chapter 11 describes the assignment process and the calibration results of the baseline model;

2. The Cube Voyager Suite

The PTM was required to be developed by using an industry-standard transport modelling software package. To this end, the Cube Voyager Suite has been selected as commercial software to be used for the implementation of the PTM.
The software consists of a comprehensive transport planning software suite, produced by Citilabs Ltd and deeply integrated with ArcGIS products to provide a user-friendly Geographical Information System (GIS) interface for analysis and presentation of results. Macroscopic models are used for strategic planning to study major road networks and public transport systems. Cube is a modular, integrated and full-featured modelling software, specifically designed for the transportation planning process, covering passenger demand, freight demand, macrosimulation, etc.

Figure 1. Cube Voyager Suite key features (Citilabs)



The fundamental Cube modules that cover passenger demand modelling, or strategic planning, are Cube Base, Cube Voyager and Cube Analyst:

Cube Base is the system interface for all Cube modelling modules and extensions and it is used to design and apply the models, to edit and manage all input and output data and to run and analyze scenarios. This structure allows planners to add functions as required without the need to learn a new interface or create multiple planning databases. Cube Base has four main components: Scenario Manager, Application Manager, Transportation GIS and Cube Reports.

Scenario Manager provides tools to develop a customized user interface for the model and to create, run and manage the scenarios. It highlights key model parameters and data for easy creation and testing of scenarios. A set of input data is a Scenario, and "Scenario Manager" is the graphic interface for scenario creation, editing and management. An easy-to-use graphical interface allows users to run specific or all scenarios with no additional intervention.

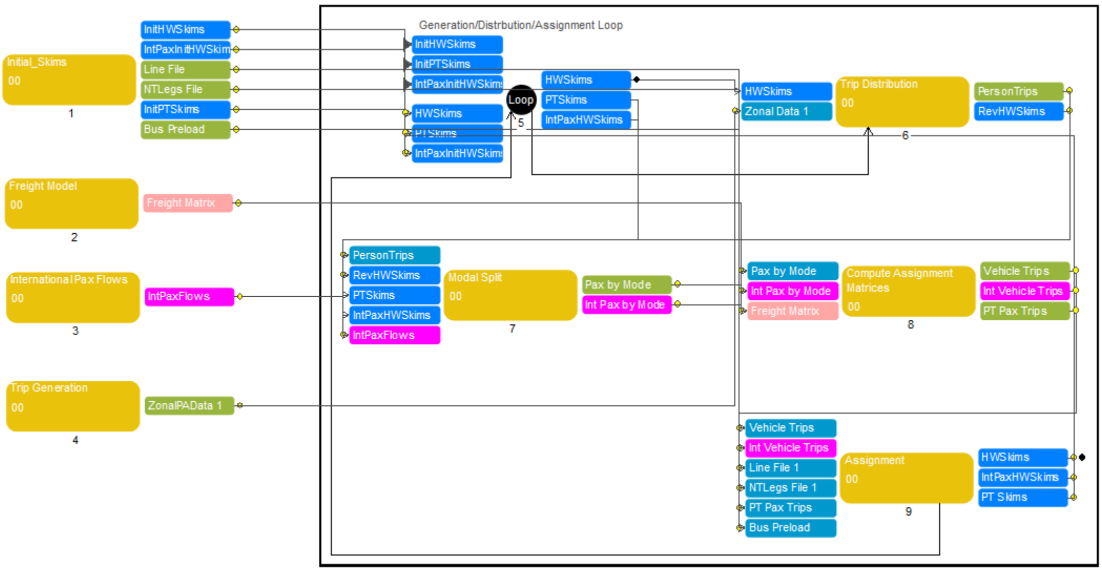
The basis of Cube scenario management is the "Catalog" feature, which contains information on what applications are to be run, the varying inputs to the application(s) –called "keys"– and scenario that define values for those keys for a particular test case. A scenario is defined by selecting/setting values for each of the keys. Multiple scenarios can be defined to allow variations in the inputs to be run and compared. The scenarios are hierarchical in nature. Having started with a Base scenario, then it is possible to add scenarios representing variations on the base situation.

Application Manager is the flow-chart component for designing and creating the model process. It provides: 1) a clear view of the individual processes that form the entire sequential process, the flow of data from one process to another and the order in which the processes are run; 2) a clear view of the data that is input to, and output from each process; 3) a convenient means of editing and viewing data; 4) an interface for running either part of the process, or the whole model. Application Manager is largely structured around the concept of applications, which are like "projects" so that the use of Cube models can be strongly linked with the varied interests and features of users' own sets of projects.

Transportation GIS: an important attribute of Cube which facilitates integration with GIS technology, developed based on an embedded version of ESRI's market leading ArcGIS, known as ArcGIS Engine. Citilabs developed a specialized application of this technology for transportation modelling by adding

transportation topology rules fully exploited within its geodatabase, and a large number of transportation-specific editing and analysis tools.
The GIS in Cube is an extremely powerful transportation GIS system that is directly compliant with ESRI technologies and provides many of ArcGIS's capabilities, for example, on-the fly projections. Using the GIS window, it would be possible to edit geodatabase data, create maps, analyze data, and submit map-based queries. The GIS window can be used to display and edit the geographic data in travel demand models, such as transportation networks and transportation analysis zones.
The GIS window represents geographic information as a collection of layers along with defined elements in a map. All data except for the trip table and the impedance data (matrices) are stored in the geodatabase. The user may also store data in Citilabs' formats such as *.net, *.lin, etc. By exploiting the geodatabase capability, data can be directly taken from any application using the ESRI geodatabase including ArcGIS. It provides the perfect transportation modelling solution for agencies and consultants that use ESRI products for their GIS.
The GIS window represents geographic information as a collection of layers along with defined elements in a map. All data except for trip table and impedance data (matrices) are stored in the geodatabase. The user may also store data in Citilabs' formats such as *.net, *.lin, etc. By exploiting the geodatabase capability, data can be directly taken from any application using the ESRI geodatabase including ArcGIS.
The integration between the two software, namely Cube Voyager and the embedded ArcGIS can in fact been conceived as a "live link" with possibility of automatic update, a relevant feature able to speed up any network editing/updating process.
Based on the above-mentioned features of Cube, the linkage between GIS and Cube Voyager facilitates the storage and management of a geodatabase all strategic CUBE files which can be populated with inputs from several resources and exported to external GIS platforms. However, because the data structure specifically required by the transport model is in most cases different from the methodology used to define external GIS layers, any GIS data used needs to be carefully verified for accuracy consistency.
Cube Reports: in addition to be able to use standard GIS systems for viewing and interrogating data from the model, Cube comes with built-in reporting tools. These are set up in advance as a library of reports in table and chart form for scenario analysis and comparisons. Once a new scenario has run, all reports in this "library" are available for viewing. The scenario manager helps organize these reports and any scenario specific outputs produced by the model in a user-defined and structured way, which makes it easy to find them.
Cube Voyager is the Cube Extension for personal travel forecasting. Cube Voyager uses a modular and script-based system flexible enough to incorporate methods ranging from four-stage to discrete choice to activity-based models. Advanced methodologies provide junction-based capacity restraint for highway analysis and multipath transit path-building and assignment. Other features include highly flexible network and matrix calculators and unrestricted data sizes. Cube Voyager allows unlimited link and node attributes stored and the network in both binary and ESRI geodatabase network formats, and can easily accommodate the many attributes needed to define and manager master network definitions.
Cube Analyst is the Cube Extension developed specifically for estimating and updating base year car, truck and public transit trip tables. Cube Analyst enables the user to exploit a wide variety of data that contributes to matrix updating and matrix development. It estimates and updates different layers of the Origin/Destination matrix, which represent the structure of existing and forecasted mobility structures and consists of one of the most valuable elements among all data in travel-demand forecasting.
Matrix in fact supports forecasting and almost all important comparative analyses. Cube Analyst uses mathematical techniques to find trip matrices consistent with observed transport demand and count data and it reproduces hand-based methods more accurately and more efficiently. To use Cube Analyst, user supplies observed travel-demand data like traffic-counts organized into screen- and cut-lines, or movement or path data identifying travelers' routes from origins to destinations.
The user can supplement this travel-demand data with quality weights which provide tolerance bands for the data observations; Cube Analyst uses maximum likelihood statistical techniques to estimate matrix values, meaning the values that best fit the observations and their quality weights.
The following figure show the modeling framework for the calibration phase and the final architecture to be used for the consultation of the base year model and for running the forecasting scenario.

Figure 2. PTM Model



3. Traffic Survey

Introduction

Origin - Destination Survey (OD) was carried out on August 3, 2015, at 46 survey locations. Manual Traffic Count Survey (MTC) was carried out on August 3, 2015, at 91 survey locations. (For more details, refer to AX.10 – MTC and OD Survey). The OD survey covered private vehicles, taxis, collective taxis and buses. Some motorcycles were also interviewed, but these numbers were very small, at 2 interviewed out of 7,445 counted.

This chapter presents a brief, functional analysis of the survey data as received. All data referred to in this report refers to data for the PM Daily Peak of 15:15 to 19:15, further to be known as "The Modelling Period", as this was determined to be the daily peak time.

Manual Traffic Counts

The Manual Traffic Count Data presented the counts by Vehicle type and by License plate color. The total number of vehicles counted in the MTC surveys is shown by the market segmentation in the table below, with both absolute values and percentages.

Tab 1. Market Segmentation of Vehicles Counted by Type and Registration

	M/Cycle	Car	LCV	Priv. Bus	Coll. Taxi	PT	HCV 1	HCV 2	Total
Total	**9,316**	**117,715**	**11,222**	**3,058**	**12,903**	**1,586**	**7,138**	**1,883**	**164,821**
White: Palestinian	8,726	83,859	9,020	2,490	-	-	6,285	1,434	111,814
Yellow: Israeli	590	23,374	2,202	568	-	535	853	449	28,571
Green: Public Service	-	10,482	-	-	12,903	1,051	-	-	24,436
Total	**5.7%**	**71.4%**	**6.8%**	**1.9%**	**7.8%**	**1.0%**	**4.3%**	**1.1%**	**100.0%**
White: Palestinian	5.3%	50.9%	5.5%	1.5%	-	-	3.8%	0.9%	67.8%
Yellow: Israeli	0.4%	14.2%	1.3%	0.3%	-	0.3%	0.5%	0.3%	17.3%
Green: Public Service	-	6.4%	-	-	7.8%	0.6%	-	-	14.8%

This shows that transportation in the surveyed areas is dominated by Passenger Cars and Taxis (71.4%). These survey sites are located in the Cube Voyager network and the survey results are loaded on the network using the standard highway assignment module.

OD Survey Analysis

Origin/Destination (OD) survey was conducted on the 3rd of August 2015. These surveys aimed to take a representative sample of trips passing the OD sites and determine origins, destinations, and trip purpose from a short interview. Nearly 12,000 interviews were undertaken out of 104,000 counted vehicles, a sample rate of nearly 11%. These sample rates are shown by vehicle type in the table below

Tab 2. Surveyed Vehicles and Sample Rates

Index	Vehicle Type	Counted Vehicles	Interviewed Vehicles	Interviewed People	Interviews Rate
1	Car	78,671	7,979	18,615	10%
2	Taxi	6,961	2,382	8,249	34%
3	Bus	3,181	389	2,146	12%
4	Collective Taxi	9,654	839	4,402	9%
5	motorcycle	7,445	2	4	0%
Total		105,912	11,591	33,416	11%

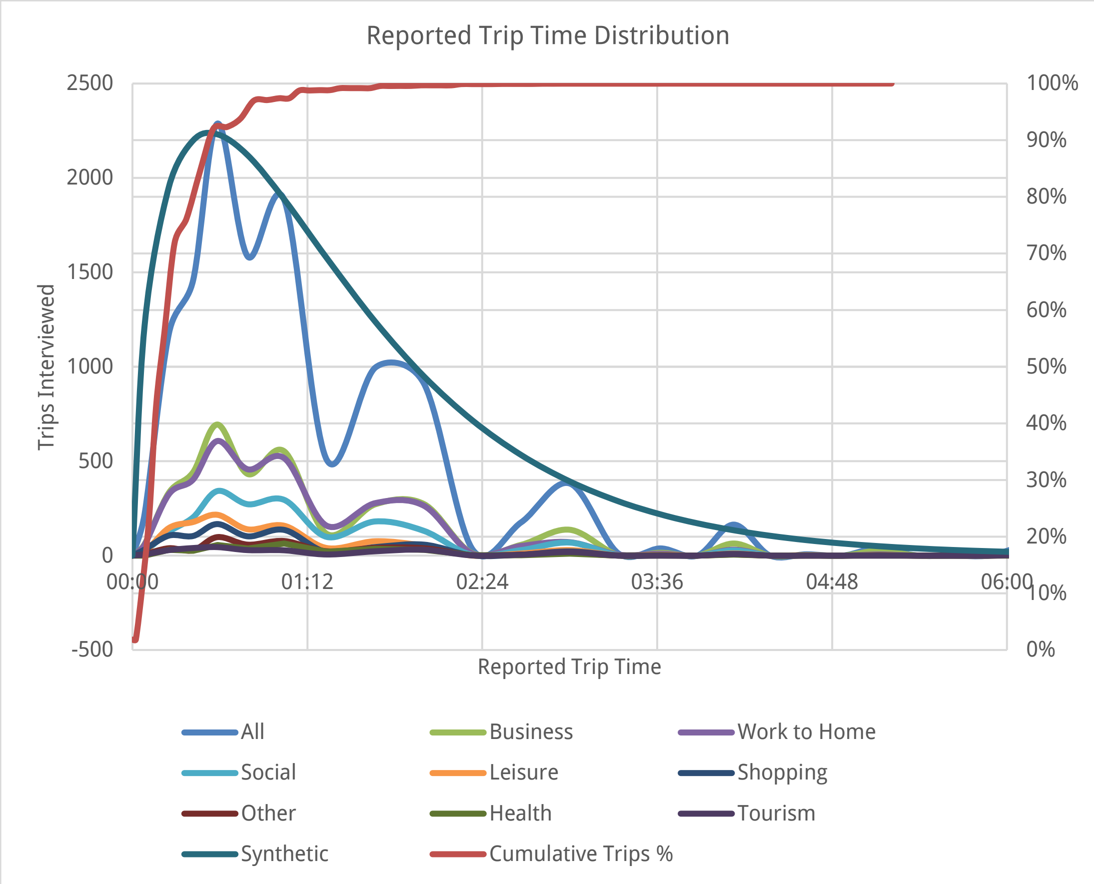
Trip Length Analysis

Estimate trip times were recorded in the interview process, and a distribution of Average reported/estimated trip times are shown in the table and figure below. It is widely accepted that travelers generally have a poor estimate of actual travel times, and a detailed analysis of trip lengths and trip times is generally taken from the modelled distances and times, as these are generally more reliable. The Trip Time Distribution as reported is shown in the table and chart below:

Tab 3. Reported Trip Time Distribution

Av. Trip Time	All	Cumulative Trip Total	Business	Work to Home	Social	Leisure	Shopping	Other	Health	Tourism
0:05	220	2%	61	58	22	17	32	7	0	6
0:15	1176	12%	333	325	126	146	106	39	30	29
0:25	1459	24%	442	403	203	178	104	28	25	40
0:35	2288	43%	694	607	342	216	167	98	56	45
0:47	1583	56%	432	457	272	139	102	58	38	29
1:02	1883	72%	552	516	295	158	136	77	64	28
1:20	507	76%	115	158	99	40	18	23	20	6
1:40	996	84%	272	278	181	76	45	41	35	23
2:00	911	92%	273	264	131	52	58	39	31	31
2:20	33	92%	12	10	3	0	1	2	2	1
2:40	176	94%	57	51	29	11	5	5	2	5
3:00	382	97%	137	71	69	29	22	13	11	19

Figure 3. Reported Trip Time Distribution



It is evident that 95% of trips are completed within 3 hours estimated duration, with a weighted average trip duration of approximately one and a half hours.

The trip distribution appears to fit well within the standard gamma curve as shown in the figure above as the synthetic curve.

Trip Purpose

The trip purposes from the interviews are summarised in the table below, in order of total trips per purpose.

Tab 4. Trip Purpose by Gender All Areas

Trip purpose	Purpose	Male	Female	Total	Male (%)	Female (%)	Total (%)	Cumulative
Business	5	7,460	2,023	9,599	30%	23%	28%	28%
Work to Home	1	7,332	1,614	9,232	29%	19%	27%	55%
Social	9	3,424	1,928	5,440	14%	22%	16%	71%
Leisure	6	2,370	1,253	3,627	9%	14%	11%	81%
Shopping	7	1,389	640	2,068	6%	7%	6%	87%
Other	11	936	275	1,228	4%	3%	4%	91%
Health	10	664	319	989	3%	4%	3%	94%
Tourism	8	624	286	947	2%	3%	3%	96%
School to Home	2	264	142	424	1%	2%	1%	98%
Work to non-home	3	283	85	383	1%	1%	1%	99%
Not Stated	NA	143	61	231	1%	1%	1%	99%
Home to Work	12	123	13	136	0%	0%	0%	100%
School to non-home	4	31	19	50	0%	0%	0%	100%
Home to School	13	5	3	8	0%	0%	0%	100%
		25,048	8,661	34,362	100%	100%	100%	

From the table, it is evident that there are significant trips differences in male and female trip making, however separating trip generation based on gender is beyond the scope of this project, and the model will concentrate on the total trips reported. Business trips, Work to Home trips, Social, Leisure, and Shopping trips make up more than 90% of the trip making.

Vehicle Occupancy

The average Vehicle Occupancy as surveyed is shown in the table below. This table shows the average for West Bank and Gaza Strip.

Tab 5. Average Vehicle Occupancy by Gender and total

Vehicle Types	Interviewed Vehicles	Male People	Female People	Total People	Occupancy Male	Occupancy Female	Occupancy Total
1) Car (1)	7,979	14,112	4,240	18,615	1.77	0.53	2.33
2) Taxi (2)	2,382	5,874	2,320	8,249	2.47	0.97	3.46
3) Bus	389	1,514	505	2,146	3.89	1.30	5.52
4) Collective Taxi	839	2,858	1,357	4,402	3.41	1.62	5.25
5) Motorcyc	2	2	0	4	1.00	0.00	2.00
Other	382	688	239	946	1.80	0.63	2.48
Total	11,973	25,048	8,661	34,362	2.09	0.72	2.87

In addition, the survey counted total vehicle occupancy and these results are presented in the table below.

Tab 6. Vehicle Occupancies per vehicle Type

		Occupancy Rate Vehicle											
Vehicle Type	On-board Pax Counted	1	2	3	4	5	6	7	8	9	10	11 / 20	21 / 99
Car	8,011	2,912	2,163	1,176	867	624	91	58	30	6	0	0	0
Taxi	2,390	363	394	394	540	500	86	68	28	1	0	0	0
Bus	396	95	82	40	15	19	12	27	31	7	11	30	13
Collective Taxi	858	100	96	50	58	71	81	182	136	16	15	12	3
m/cycle	2	0	2	0	0	0	0	0	0	0	0	0	0
Other	437	93	87	55	31	37	2	23	4	0	0	0	0

	12,124	3,563	2,824	1,715	1,511	1,251	269	352	227	30	33	46	16

As is usual with Surveys, there are some odd numbers reported, notably instances of 10 or more persons in a private car. However, this can be attributed to large families with many children, and no insistence on child restraints. In general, the data seems sensible, as shown in the following charts per vehicle type.

Figure 4. Total Persons per Private Car

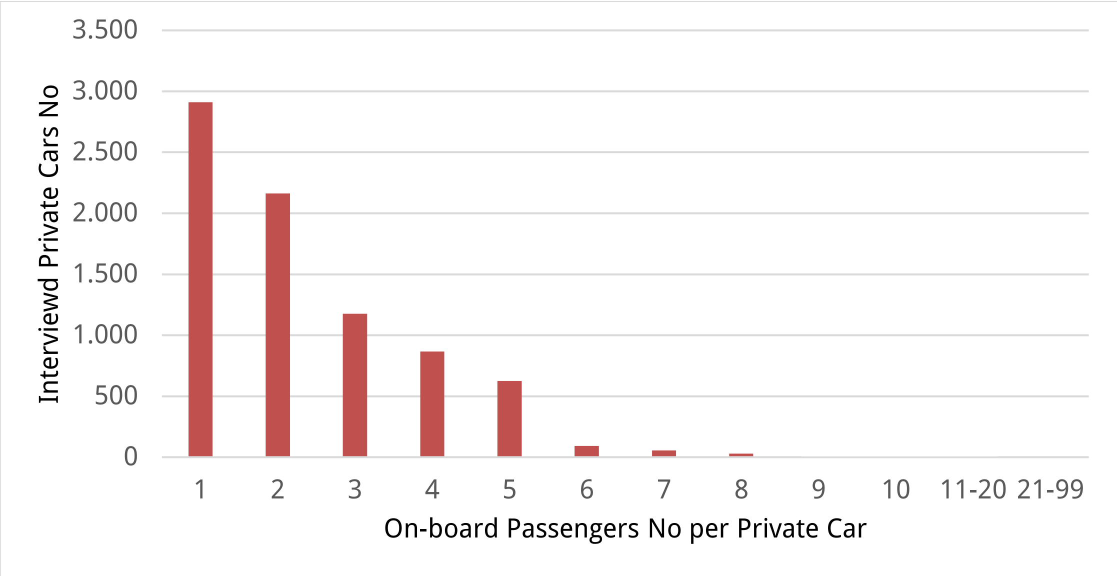


Figure 5. Total Persons per Taxi

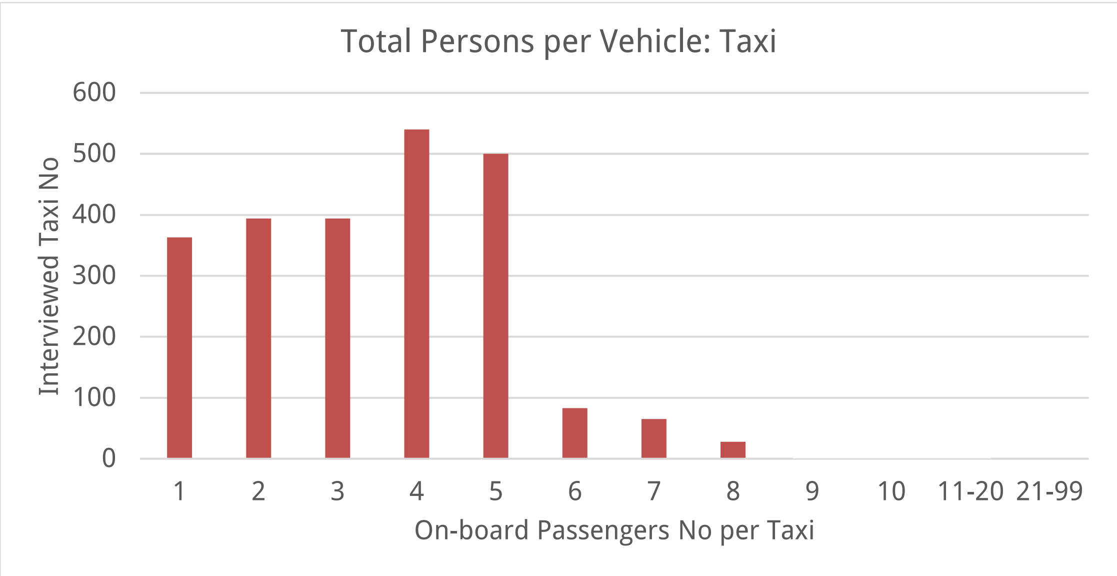


Figure 6. Total Persons per Bus

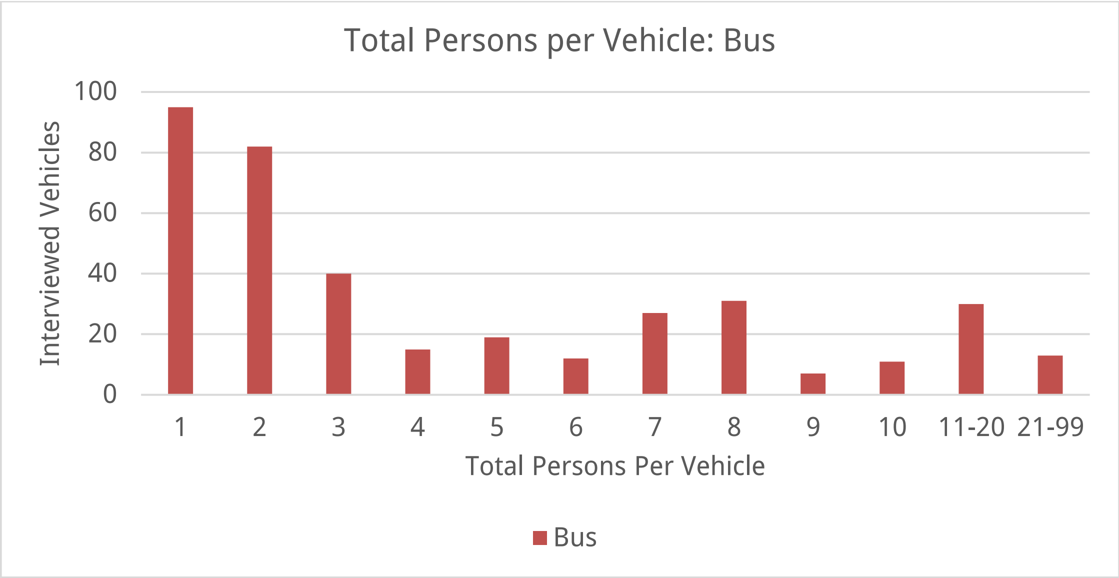
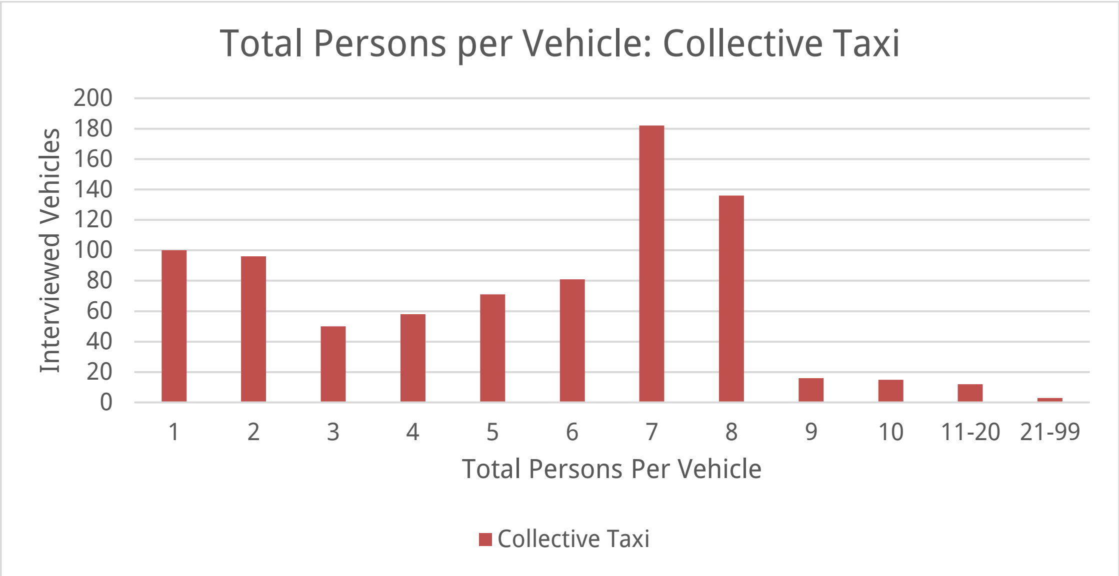


Figure 7. Total Persons per Collective Taxi



It is notable in general that the Bus occupancy is quite low, with most having less than 20 passengers.

Expansion of OD Trips

As the surveyed OD trips represent only a sample of all observed trips, it is necessary to expand them to the total observed flows. This is done by the following process:

- Calculate how many of a given vehicle type were observed;
- Calculate how many of the same vehicle type were interviewed;
- Calculate the ratio between interviewed and observed. (This ration is called the expansion factor, and is the inverse of the sample rate)

For example, if 100 vehicles were counted, and 10 interviewed, this would give a sample rate of 10%. It is necessary to factor up the interview OD trips by a factor of 10 to replicate the total counted trips.
This expansion factor is normally calculated by vehicle type, and this is why care must be taken to have consistent vehicle types across the interview surveys and the manual traffic counts. In addition, while the manual counts made a distinction between the various license plate colors, the interview surveys did not record this. This reduced the data, which could be compared between the two surveys to the following classes:

- Cars: including White and Yellow plates
- Taxis:
- Bus: including (private and public buses)
- Collective Taxis:

A brief summary of the comparison between the counted vehicle and the interview vehicles is shown in the table below. It is clear that the average sample rate for all vehicle types is around 11%, that is an acceptable sample rate. The motorcycle samples are included for completeness although the sample rate is low, so the expansion factor results very large to compensate.

Tab 7. Summary of expansion factors and sample rates

Vehicle	Vehicles	Passengers	Vehicles	Rate	Average Expansion
Car	7,979	18,615	78,671	10%	9.8598
Taxi	2,382	8,249	6,961	34%	2.9223
Bus	389	2,146	3,181	12%	8.1774
Collective Taxi	839	4,402	9,654	9%	11.5066
Motorcycle	2	4	7,445	0%	3,722.5
	11,591	33,416	105,912	11%	9.1374

These expansion factors were calculated on a per site and per direction basis and the expanded totals used to make the observed matrix. In many of the Gaza strip sites, Taxis were either not counted or not counted separately from cars. For these sites, the expansion factors have been calculated on the basis of taxis being counted as cars. This has reduced the number of cars, but increased the number of taxis overall.
The observed expanded matrix is used as basis for the calibration of the trip generation and matrix estimation modelling steps.

4. Zoning System

In a four-stage transport model, a zoning system is used to aggregate the individual households and premises into manageable blocks/portion of territory. The two main dimensions of a zoning system are the number and size, which, of course, are related. The study area is divided into Traffic Analysis Zones (TAZs) and their number depends on a number of elements, among which the aim of the model (more or less strategic, long term planning, etc.), its extension, population, employment and services density (urban or rural area), nature of land use, districts, etc.

The TAZs are represented by notional nodes or zone centroids (where all zones' attributes and properties are concentrated) which are linked to the multimodal network through centroid connectors, representing the average costs (time, distance) of joining the transport system for trips with origin or destination in that zone

Small zones are useful for microscopic or highly detailed models, looking at small area effects, while large zones are more useful for macroscopic models. These models are more concerned with the strategic impacts of large changes.

When building a national model, there is a balance to be struck between large zones for strategic movements, and smaller zones for regional movements. Local movements are not generally considered for this type of model.

From the PTM modelling perspective, the community boundaries form the largest possible strategic zoning system. This results in a base zoning system of 551 zones. This is shown the figures below, where the average population densities are color coded with increasing darkness. This is the most detailed zone system for which population data is available, and this zoning system would be a suitable starting point for a detail model.

It is important to note that some of the zones, especially those described as camps can be non-contiguous, and this is contra indicated from a modelling point of view. These have been reviewed on a case by case basis, resulting in the final zoning system composed 312 TAZs.

The road network presented in the following picture is very detailed, which doesn't comply with the strategic goal of the model. The road network was then accurately cleaned and simplified according to 5 main hierarchy classes.

Figure 8. Zones in the Gaza Strip Area

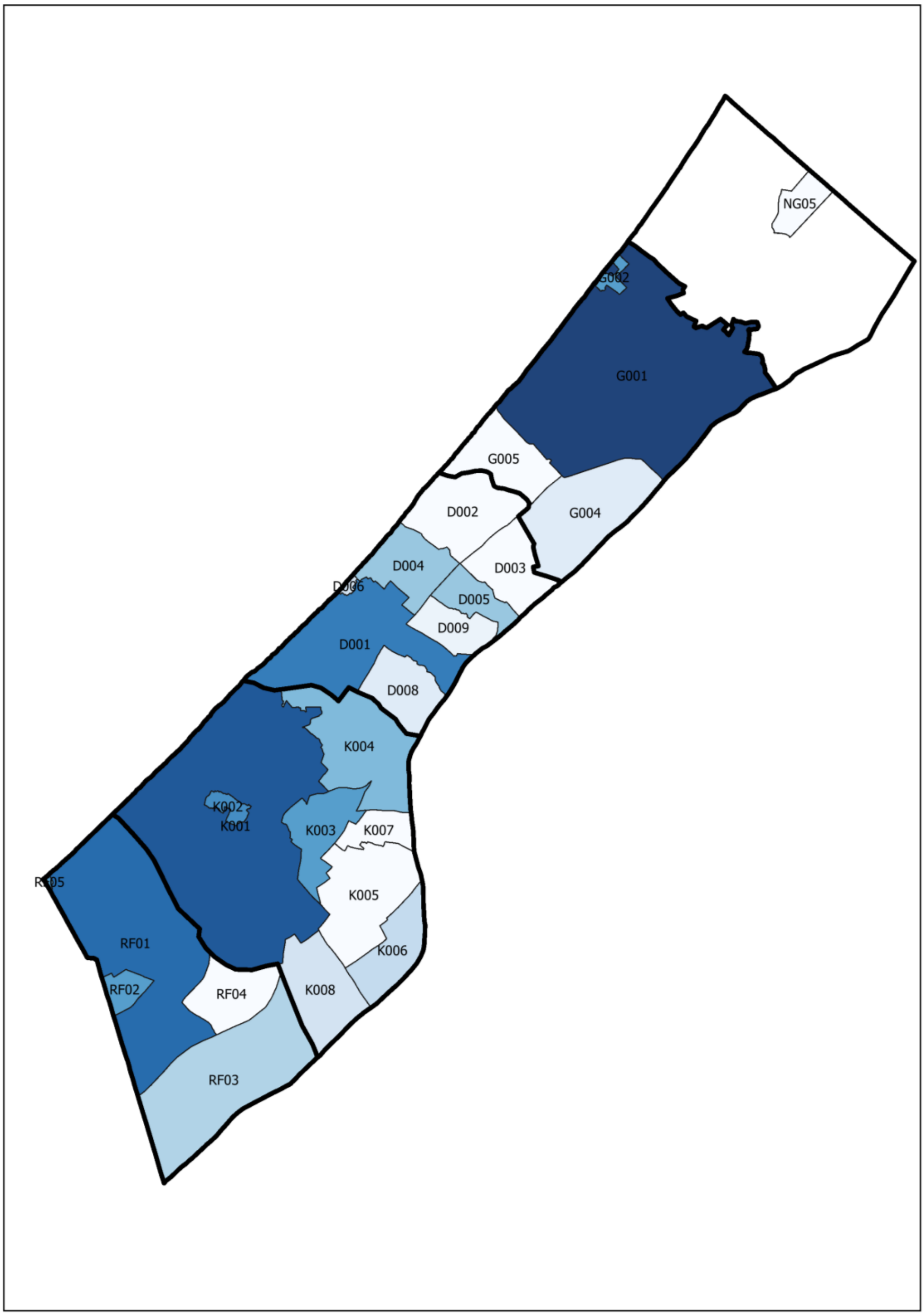
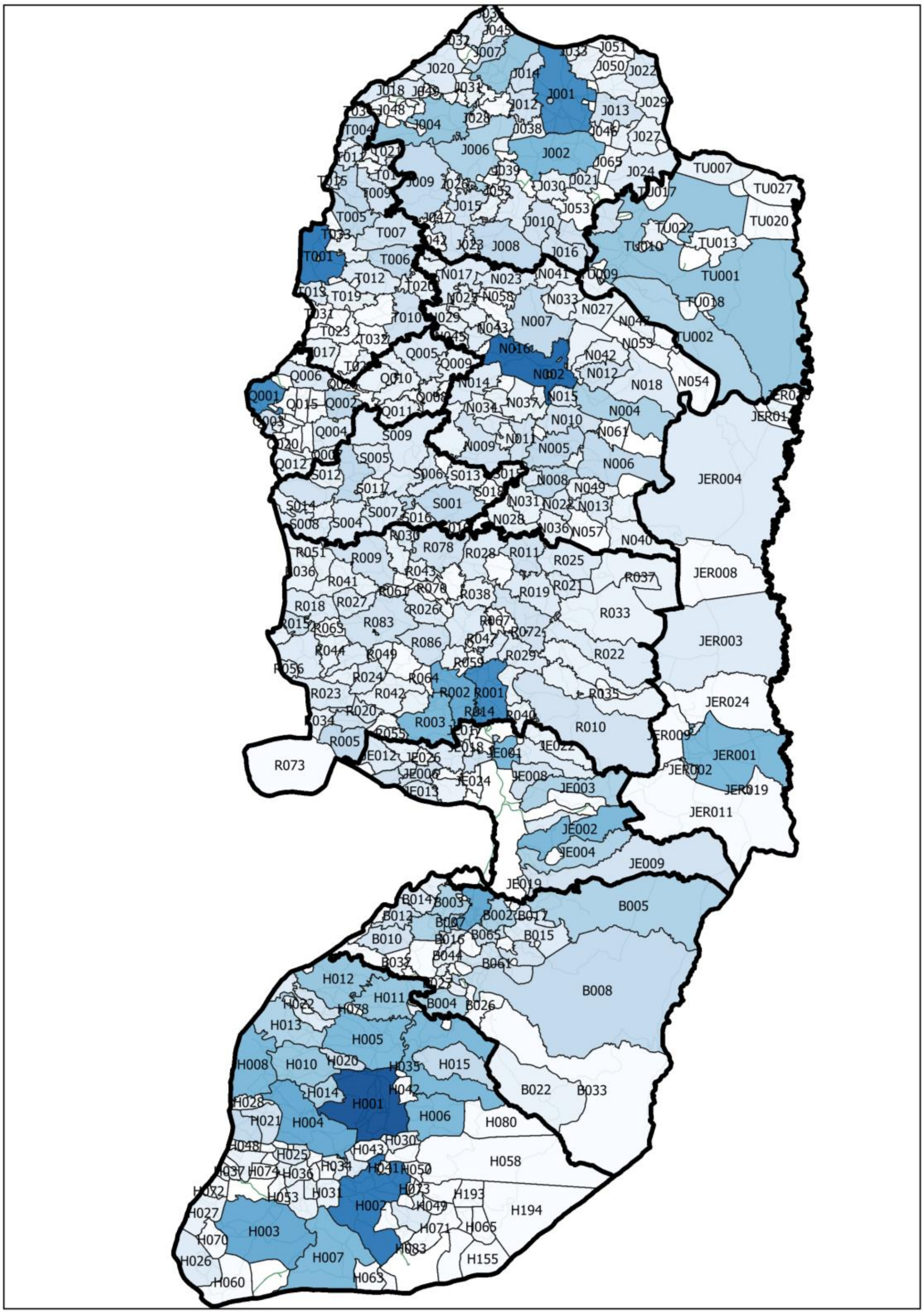


Figure 9. Zones in the West Bank Area



5. Road Network

The transport network represents a key component of the supply side of the modelling exercise, i.e. the provision of multimodal infrastructure and mobility services to satisfy the movement needs of trip makers in the study area. The description of a transport network in the model can be undertaken at different levels of detail and requires the specification of its structure, its properties or attributes and the relationship between those properties and traffic flows.
It is arguably the most important part of the model, as it reflects the connection between the physical reality of the situation on the ground with the synthesized model from Trip Generation, Distribution and Assignment.
The network is modelled as a directed graph, i.e. a system of nodes and links joining, where most nodes are introduced to represent road junctions, public transport stops (in a multimodal network) or significant either geometric or functional changes of the network attributes whereas links stand for homogeneous stretches of road between junctions. Links are characterized by several attributes.
The following pictures show close up views of the implemented road network and the hierarchical nature.

Figure 10. Road Network i the West Bank

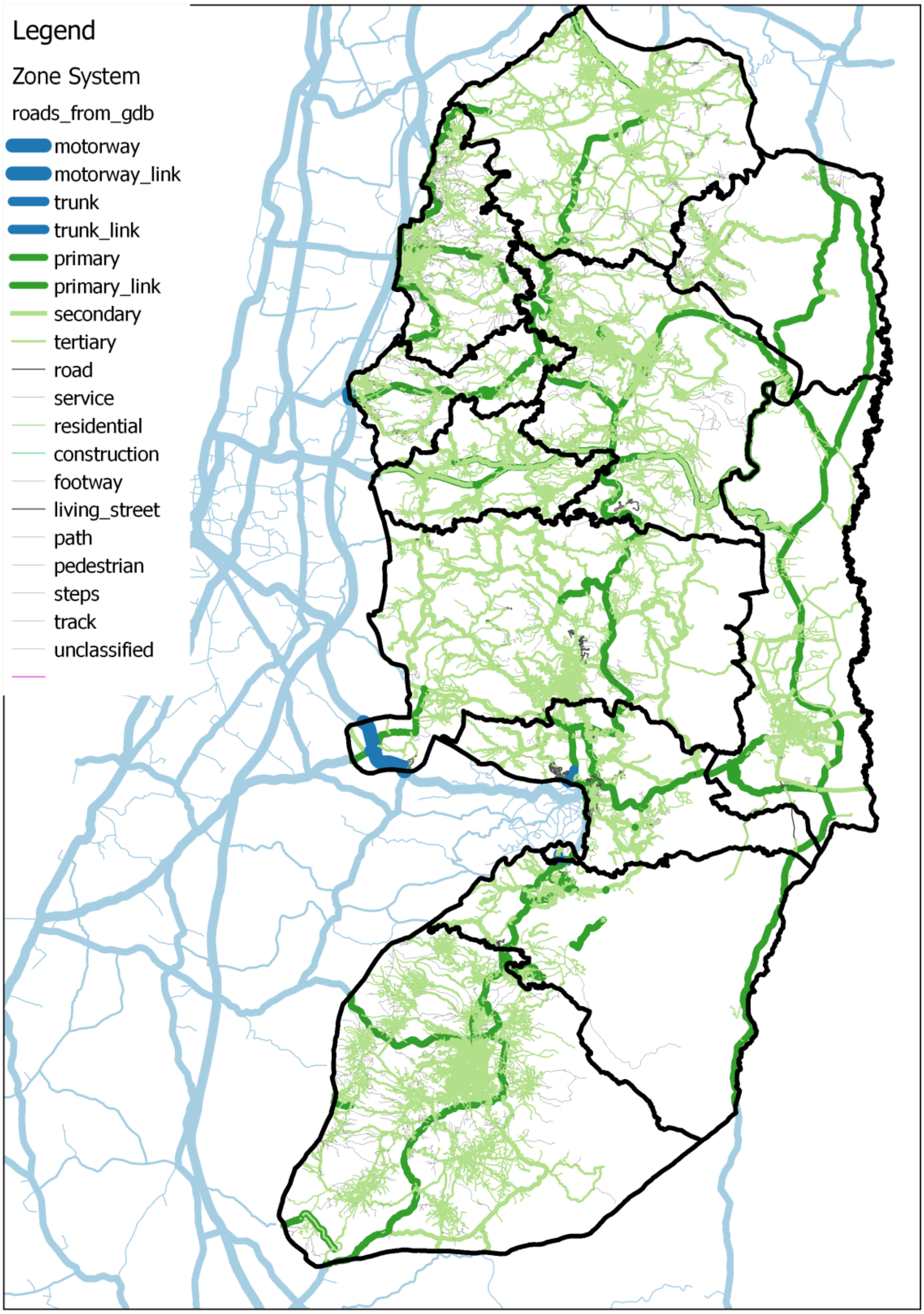


Figure 11. Road Network in The Gaza Strip

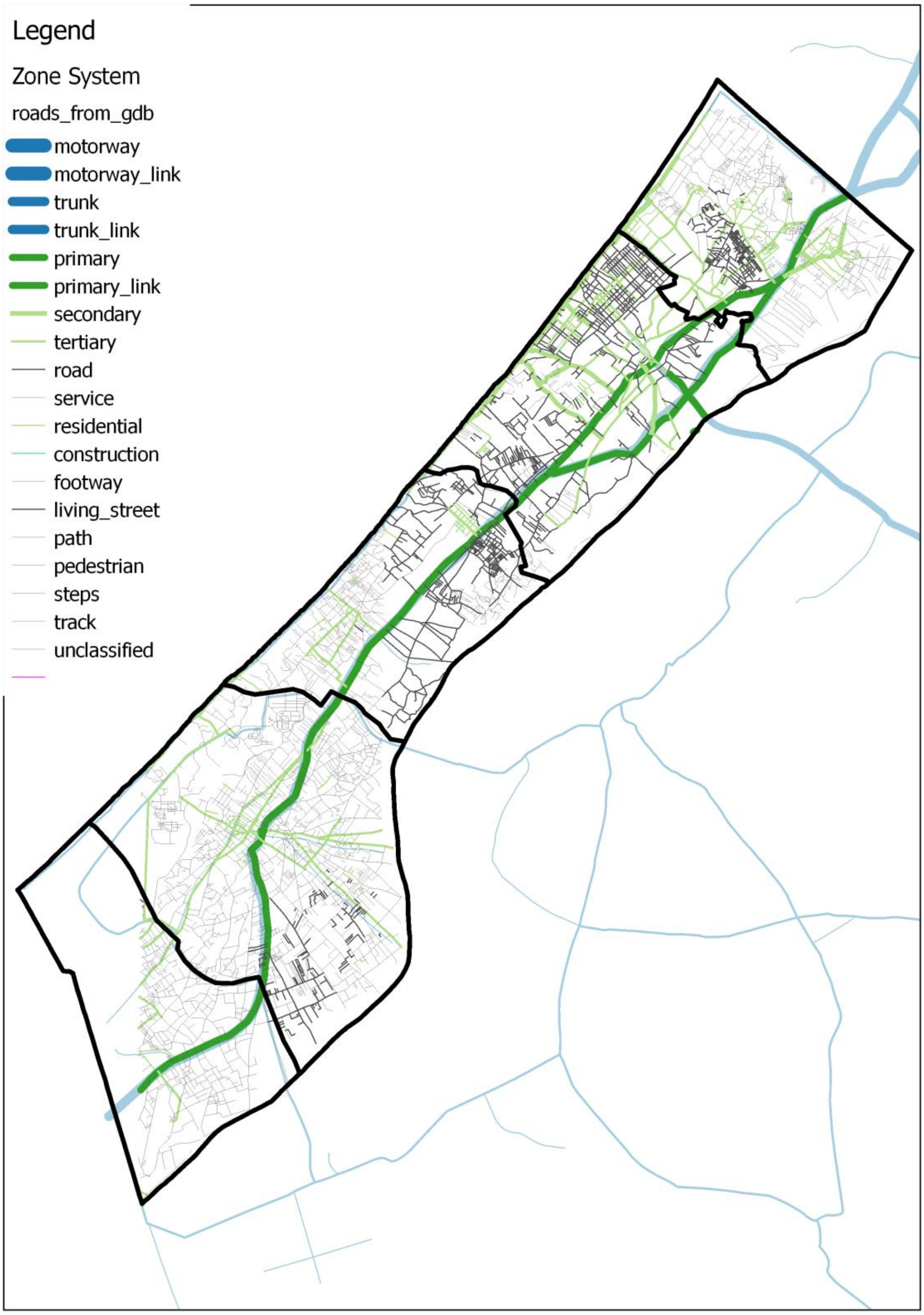
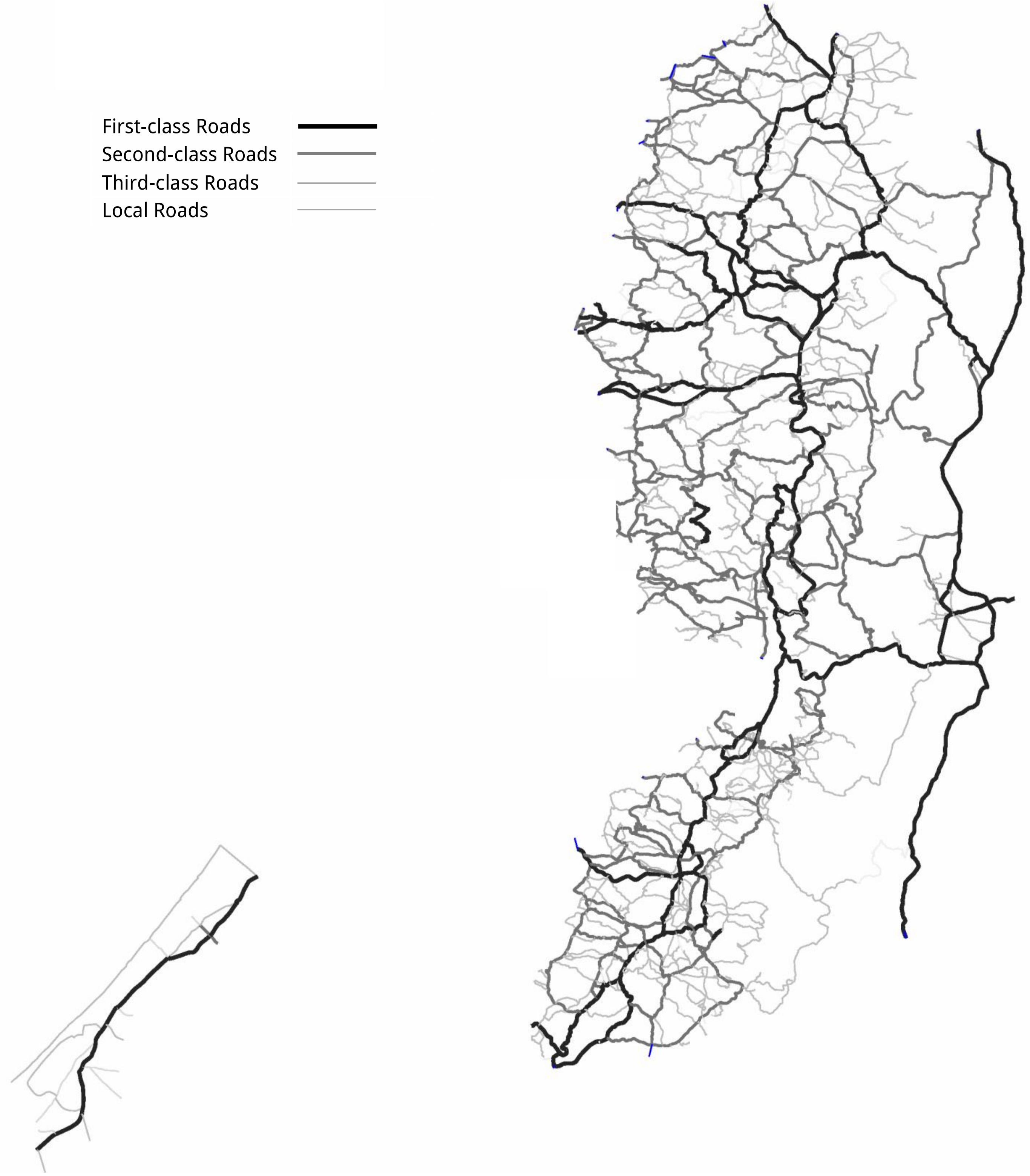


Figure 12. Modelled Road Network, Base Year 2015



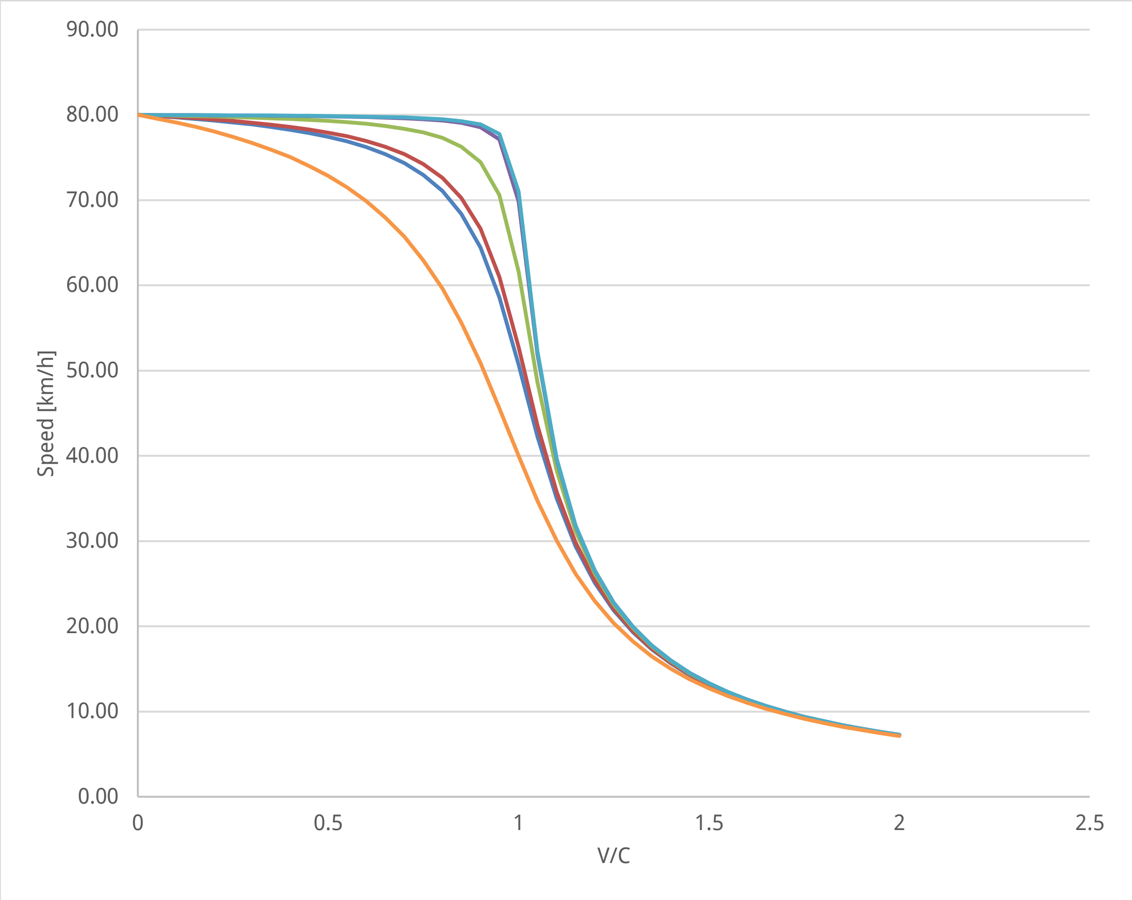
In the following, the main attributes of the road network are described:

- A = starting node
- B = ending node
- SPEEDLIMIT = speed limit in km/h
- LANES = number of lanes
- LINKTYPE = road category
    - first class road
    - second class road
    - third class road
    - others

- T0 = free flow travel time in minutes
- CHECKPOINT = identify a checkpoint section
- GEOPOLITIC = jurisdiction
    - Area A: Full Palestinian Control : Y+W+G plates
    - Area B: Joint Control: Y+W+G plates
    - Area C: Israeli Control: Y Plates
    - Area D: Israel: Y Plates
    - Area E: Gaza Strip: Y+W+G plates
- DISTANCE = length in km
- CAPACITY = link capacity in veh/4h

The travel time on the links will depend on the traffic, so specific speed-flow curves linktype based has been applied, as the shown in the following sample picture, where each curve is related to the same linktype but the shape varies on the basis of the capacity:

Figure 13. Speed Flow Curves



Public Transport Network

The public transport network in the base year consists on a network of buses. The overall public transport modelled network, representative of the Modeling Period, comprises 110 routes.
The entire set of supply/service attributes included into the PTM to adequately describe the public transport network are listed below

- NAME – Route Name for each direction
- MODE – 1-9 (bus, BRT, rail systems)
- OPERATOR – operators' names
- ONEWAY – routes with different paths per direction
- HEADWAY – headway
- VEHICLETYPE – (bus, coach, etc.)
- CRUSHCAP – total capacity of the vehicle

The fare system is cumulative on the basis of distance, considering 0.2 Shekel for the bus and 0.36 Shekel for both the BRT and Railways.

6. Trip Generation

The trip generation stage of the four-stage transport model is used to predict the total number of trips generated by one TAZ and attracted to another TAZ within the study area. A trip (or journey) represents the one-way movement from a point of origin to a point of destination. This modelling stage is in particular concerned with person trips, whereas the analysis and production of freight trips has followed a separated analytical process.
The trip productions and attractions were calculated by the calibration of a linear regression, calibrated on the basis of the trip ends data available from the expanded OD matrix (See Expansion of OD Trips Chapter). The goal of the linear regression method is to estimate the coefficients to be associated to the demographic and land use data in order to calculate the TAZs' trip productions and attractions. Given a data set $\{y_i, x_{i1}, x_{i3}, \dots, x_{in}\}$, where $i = 1, \dots, n$ statistical units, a linear regression model assumes that the relationship between the dependent variable y_i and the p-vector of regressors x is linear. This relationship is modeled through a disturbance term or error variable ε_i, an unobserved random variable that adds noise to the linear relationship between the dependent variable and regressors. Thus the model takes the following form:

$$\boldsymbol{y_i = \beta_1 x_{i1} + \cdots + \beta_p x_{ip} + \varepsilon_i}$$

In order to provide estimates for the β parameters, the Ordinary Least Squares (OLS) is the chosen estimator because it is the most common and simplest method, widely used in different applications. Although the data from the OD surveys provide information about the purpose of the trips (see **Errore. L'origine riferimento non è stata trovata.**), separating trip generation based on different purposes did not provide significant results, as the survey was conducted during the PM peak hour and several information about the purpose are misreported by the respondents. The model will then concentrate on the total trips reported and expanded during the OD observed matrix expansion process.

Trip Generation

The Trip Generation parameters were estimated by using the observed matrix (See Expansion of OD Trips Chapter) trip ends as dependent variables. The following table reports the results of the final specification, obtained after several test of combination of the different variables:

Tab 8. Trip Generation Coefficients

Variable	Value	t-stat	p-value
(Intercept)	-2.13E+02	-1.362	0.17461
M00_14	-7.06E-01	-3.662	0.000313
HH06	-1.42E+01	-6.221	2.40E-09
APT	2.56E+00	6.147	3.57E-09
HABITATION	3.02E+00	6.937	4.24E-11
HABWORK	-9.10E+00	-4.017	8.06E-05
ESTABS	5.84E+00	8.052	4.77E-14
INDUSTRIAL	5.05E-03	3.669	0.000304
PUBLICBLDG	-7.41E-03	-3.69	0.000282

- M00_14 = male population from 0 to 14 years' old
- HH06 = number of families of 6 components
- APT = number of apartments
- HABITATION = number of habitations
- HABWORK = number of apartments
- ESTABS = number of establishments
- INDUSTRIAL = sqm of industrial areas
- PUBLICBLDG = sqm of public buildings

The calibration results are reported in the following:

- Residual standard error: 1550 on 224 degrees of freedom
- Multiple R-squared: 0.8361, Adjusted R-squared: 0.8302
- F-statistic: 142.8 on 8 and 224 DF, p-value: < 2.2e-16

Trip Attraction

The Trip Attraction parameters were estimated by using the observed matrix (See Expansion of OD Trips Chapter) trip ends as dependent variables. The following table reports the results of the final specification, obtained after several test of combination of the different variables:

Tab 9. Trip Attraction Coefficients

Variable	Value	t-stat	p-value
(Intercept)	-12.5793	-0.109	0.913607
M15_64	0.762617	5.168	5.25E-07
HH04	16.00929	4.964	1.37E-06
HH05	-14.5457	-5.061	8.71E-07
HH07	-8.27001	-3.744	0.000231
HABWORK	-9.81459	-5.403	1.68E-07
ESTABS	6.411003	8.876	2.31E-16
TOURISM	0.005919	4.638	5.98E-06
INDUSTRIAL	0.006956	5.663	4.56E-08
PUBLICBLDG	-0.01215	-5.968	9.34E-09

- M15_64 = male people from 15 to 64 years' old
- HH04 = number of families of 4 components
- HH05 = number of families of 5 components
- HH07 = number of families of 7 components
- HABWORK = number of apartments
- ESTABS = number of establishments
- TOURISM = sqm of tourism facilities
- INDUSTRIAL = sqm of industrial areas
- PUBLICBLDG = sqm of public buildings

The calibration results are reported in the following:

- Residual standard error: 1418 on 223 degrees of freedom
- Multiple R-squared: 0.8668, Adjusted R-squared: 0.8615
- F-statistic: 161.3 on 9 and 223 DF, p-value: < 2.2e-16

The trips generated in the Base Year 2015 are 317,388, while the trips attracted are 292,756.
Specific growth factor rates are provided by the economic analysis to update the dataset to the corresponding phase.

International Passengers

The economic analysis (For more details refer to Economic Model and Travel Demand Analysis Chapter of the Report) provided data about international passengers, already in a O/D form and ready to be implemented in the modal choice step.
Specific growth factor rates are provided by the economic analysis to update the dataset to the corresponding phase.

Demand Forecasting

The travel demand projections are based on evidence standards. A person usually makes 2.5 trips per day. By applying this factor to the forecasted population, the results are the total population daily trips. From the traffic survey has been proved that the PM peak hour factor is 28% (4-hour peak), assumed to be constant during the years. The PTM, however, is reproducing not the overall mobility, but only the inter-city trips, so not including the intra-zonal trips. At the Base Year 2015, the intercity trips are the 9.22% of the total daily trips. This percentage is assumed to growth in the years according to a logarithmic distribution, from which the reference percentage is extracted for each forecasting scenario. By applying this methodology to the forecasted population, it has been possible to calculate growth factors on a year base to be applied to the overall travel demand in each forecasting scenario. The following table reports the growth factors for each reference year:

Tab 10. Travel Demand Growth Factors

Year	Value
2015	1.000
2019	1.215
2025	1.491
2032	1.789
2038	2.065
2045	2.418

7. Matrix Estimation

The observed expanded matrix (See Expansion of OD Trips Chapter) is representative of the surveyed OD relations, but due to the sampling procedure it could be biased by missing or excessive relations between the different ODs. In order to build a matrix representative of the mobility patterns in the whole territory of Gaza and West Bank, a matrix estimation process is performed.
The matrix estimation is an iterative process that updates the prior matrices on the basis of the observed data (traffic counts, See Traffic Survey Chapter) and the route choice in the network. The matrix estimation process from traffic counts is a commonly used procedure in transport planning when reliable and consistent data on observed choices are available.
The matrix estimation process works with:

- A prior matrix;
- Trip ends (from the trip generation/attraction step);
- Traffic counts (from the survey);
- Simulated flows (from traffic assignment).

The estimation process has been applied to all the vehicle categories for which a sufficient number of traffic counts is available: Private Car, Taxi, Motorcycle, Collective Taxi, Light Commercial Vehicles, Heavy Commercial Vehicles.
Each input data of the matrix estimation process needs to be associated with an appropriate statistical confidence level that represents the “weight” and the reliability of the data.
Once the car matrix estimation process is over, it provides an updated matrix that is then assigned to the network in order to update the simulated flows. The estimated matrix is compared with the prior matrix that will be adjusted on the basis of the comparison, and then the matrix estimation process starts again. The iterative process ends when a convergence is reached, namely when the differences between the results of the current iteration and the previous are negligible.
The matrices estimated during the matrix estimation process will be the reference matrix for the calibration of the whole Base Year 2015 model.

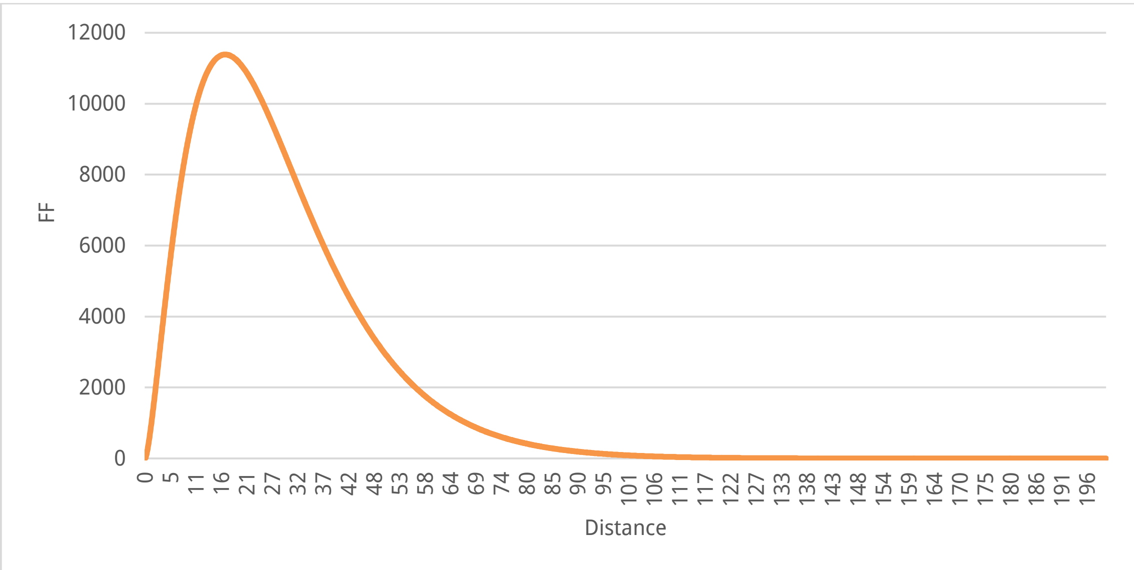
8. Trip Distribution

The trip distribution is the analytical stage that follows the trip generation stage; as generation and attraction provide a quantification of trip making across the study area. The trip distribution stage is concerned with the definition of the most likely patterns of trip making, in terms of expected structure of all trip relations among different TAZs.
The trip distribution stores the trips made from an Origin to a Destination during a particular time period, that in the case the PTM is the PM peak hour; it is also called an Origin Destination (O-D) matrix, that represents the structure of the origin-destination trips for all the purposes considered (See Trip Generation Chapter).
The trip distribution model works by combining activity system attributes (indirectly through the generations and attractions), network attributes (typically generalized transport costs per mode of transport) and friction factor curves, representative of the users' behavior.
The best known and most used of trip distribution models is the gravity model, originally generated from an analogy with Newton's gravitational law. These models estimate trips for each cell in the matrix without directly using the observed trip pattern; therefore, they are sometimes called synthetic as opposed to growth-factor models. The model was further generalized by assuming that the effect of distance or 'separation' could be modelled better by a decreasing function, to be specified, of the distance or travel cost between the zones. This can be written as:

$$\boldsymbol{T_{ij} = \alpha O_i D_j f(c_{ij})}$$

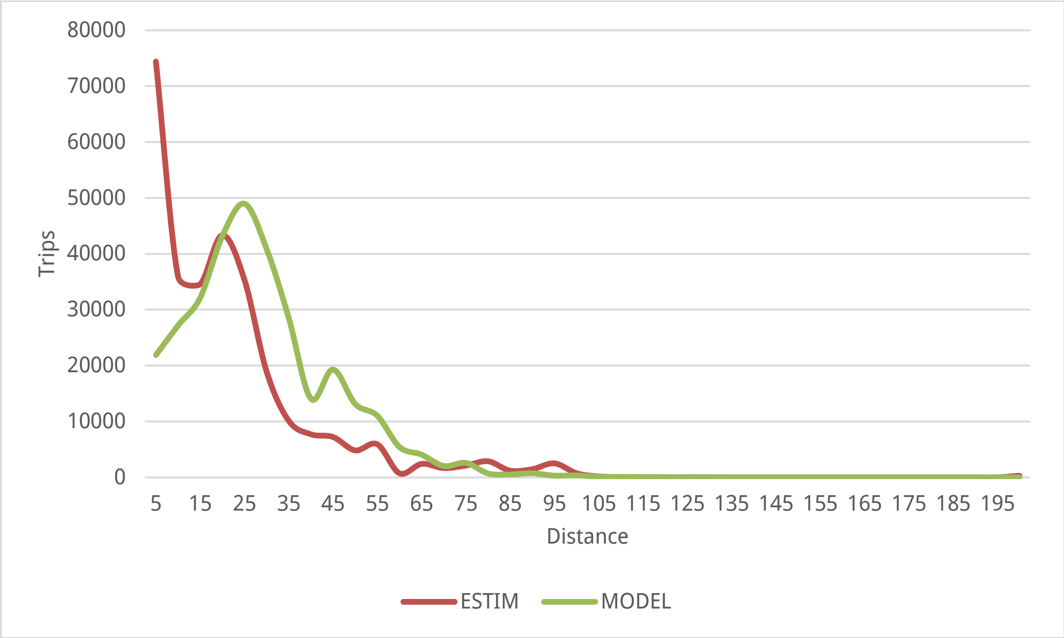
where T_{ij} are the trips between the origin i and the destination j $O_i D_j$ are the total trip ends, α is a parameter to be calibrated and $f(c_{ij}) = c_{ij}^n \mathrm{e}^{-\beta c_{ij}}$ is a generalized function of the travel costs with one or more parameters for calibration.
In the case of the PTM, a gamma distribution for $\alpha f(c_{ij})$ (FF, friction factors curve) was calibrated, with $\alpha = 750$, $n = 1.5$, $\beta = 0.09$ and c is the travel distance. The calibrated friction factors curve is shown in the following graph:

Figure 14. Friction Factors Curve



Through an iterative process that updates the costs in the network with respect of the modal split and traffic assignment results, the Base Year 2015 trip distribution parameters have been calibrated by comparing the trip length distribution (TLD) with the one of the estimated matrices, in order to verify the goodness of fit and the calibration of the model parameters. The following picture show the comparison between the resulting TLD and the one of the estimated matrices.

Figure 15. TLD comparison



The trip distribution model estimates, for the Base Year 2015, a total passenger trips of 317,388. The figure shows how the modeled TLD shape fits with the estimated one, with exception of the first part, representative of trips shorter than 15 km. In order to fix this discrepancy, the matrices (after being processed in the modal choice step) are corrected by factors calculated based on the estimated results, as reported at the Traffic Assignment – Data Preparation.

9. Freight

No data about freights was available to perform a specific trip generation/attraction process. In this case, the adopted approach was to estimated LCV and HCV matrices from observed traffic counts (See Matrix Estimation Chapter)
From the economic analysis (For more details refer to Economic Model and Travel Demand Analysis Chapter of the Report) data about import and exports are added to the estimated freight matrices
These matrices will directly be used in the traffic assignment step.
Specific growth factor rates are provided by the economic analysis to update the dataset to the corresponding phase.

10. Modal Choice

The factors influencing mode choice can be primarily related to the following main aspects: a) characteristics of the traveler, b) characteristics of the journey and c) characteristics of the transport facility and public transport availability/effectiveness.
To represent the attractiveness of the alternatives the concept of utility (which is a convenient theoretical construct defined as what the individual seeks to maximize) is used. Alternatives, per se, do not produce utility: this is derived from their characteristics (Lancaster 1966[1]) and those of the individual; for example, the observable utility is usually defined as a linear combination of variables like travel time, walking time, fares, etc.[2]. To predict if an alternative will be chosen, according to the model, the value of its utility must be contrasted with those of alternative options and transformed into a probability value between 0 and 1. For this a variety of mathematical transformations exist which are typically characterized for having an S-shaped plot. The modal split stage of the PTM has been developed and structured on the basis of the Discrete Multinomial Logit Model (MNL) in relation to the following four main modes: private traffic, bus, taxi, collective taxi. The general formula of the MNL is:

$$\boldsymbol{P_{iq} = \frac{e^{\beta V_{iq}}}{\sum_{A_j \in A(q)} e^{\beta V_{jq}}}}$$

where V_{iq} is the linear utility function, β are parameters to be estimated, i is the current alternative, q is the user, A is the set of available alternatives.
By calibrating the MNL, the probability of choosing each alternative is calculated and then the β parameters are estimated. The utility function is then integrated in the Absolute Logit model and the trip matrices for each mode are forecasted. The final set of O/D matrices per mode will be assigned to the multimodal network and subsequently validated.
Multinomial Logit
Several test were performed in order to identify the best model specification. The final utility functions are specified as:

$$\boldsymbol{V_{car} = \beta_1 \cdot COST_{car}}$$

$$\boldsymbol{V_{taxi} = \beta_2 \cdot COST_{taxi} + ASC_{taxi}}$$

$$\boldsymbol{V_{ctx} = \beta_3 \cdot COST_{ctx} + ASC_{ctx}}$$

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[1] Lancaster, K.J. (1966) A new approach to consumer theory. Journal of Political Economy 14, 132–157.
[2] de Dios Ortuzar, J., Willumsen, L.G. (2011) Modelling Transport - 4th Edition, John Wiley & Sons, Incorporated

$$V_{bus} = \beta_4 \cdot TIME_{bus} + WTIME_{bus}$$

where $COST$ is the generalized cost of transport, $TIME$ is the travel time, $WTIME$ is the waiting time at transit stops and ASC are alternative's specific constants. The data used for the matrix calibration are the estimated matrices (See Freight Chapter), that represent the actual choices of the users. The following table reports the model results and calibration statistics.

Tab 11. Modal choice calibration parameters

Variable	Estimate	t-stat
$COST_{car}$	-0.0175	-2.3700
$COST_{taxi}$	-0.0061	-3.6400
$COST_{ctx}$	-0.0060	-3.0700
$TIME_{bus}$	-0.0097	-1.6200
$WTIME_{bus}$	-0.4320	-12.6600
ASC_{taxi}	-0.6410	-5.9500
ASC_{ctx}	-1.0500	-9.0800

The final log likelihood is -1594.568, while the rho-square is 0.217.

Absolute Logit

The parameters estimated during the MNL model calibration are used to calculate the utility functions in the aggregate demand model that, starting from the all passengers and international passengers matrices calculated, respectively, in the trip distribution step and in the economic analysis (see the related main section of the report), provides different O/D matrices for each of the considered modes. As the calibration is based on the estimated matrices, as representative of the actual travel patterns, in the following the comparison results are reported.

Tab 12. Modal split

	Estimated	Modeled	Mod. Passengers Trip
CAR	59%	57%	186,590
TX	21%	21%	60,731
CTX	16%	16%	50,396
BUS	4%	6%	19,661

The following pictures show the calibration results for each mode, on the basis of the trip ends (TE) and O/D specific.

Figure 16. Modal choice calibration, Car by trip ends

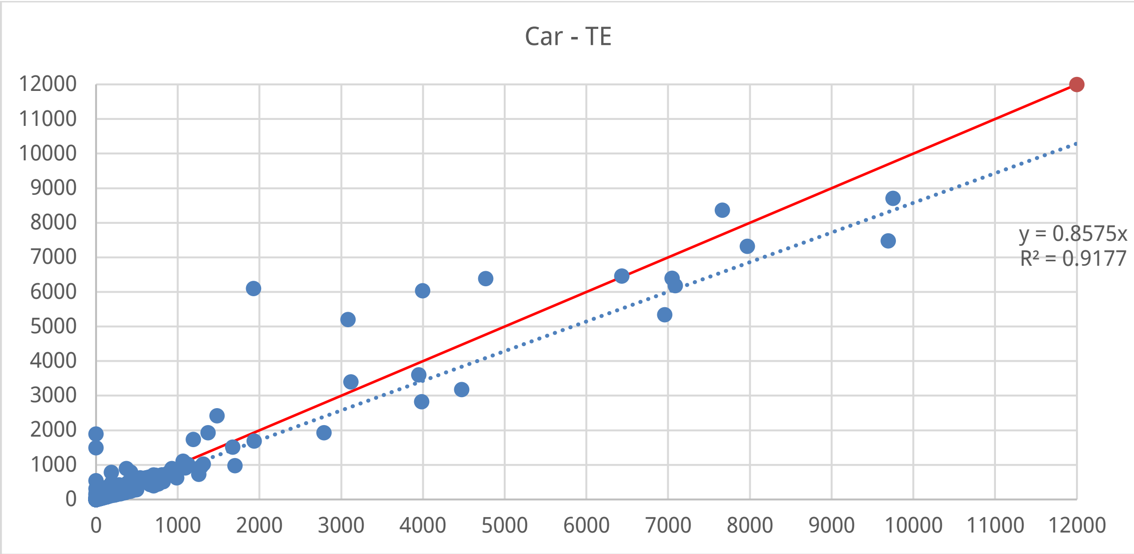


Figure 17. Modal choice calibration, Car by O/D

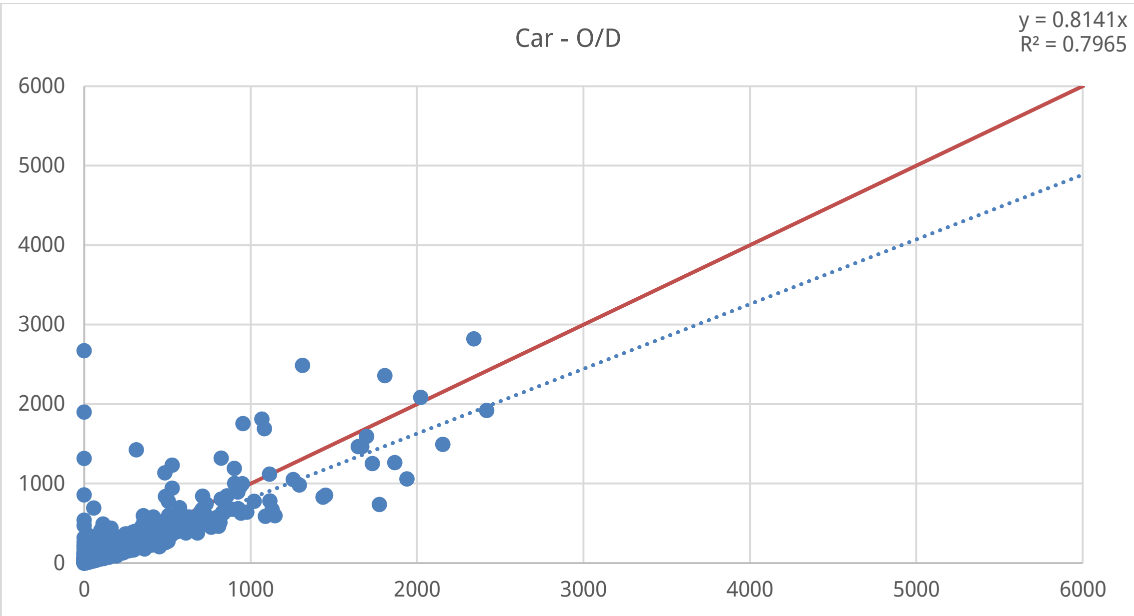


Figure 18. Modal choice calibration, Taxi by trip ends

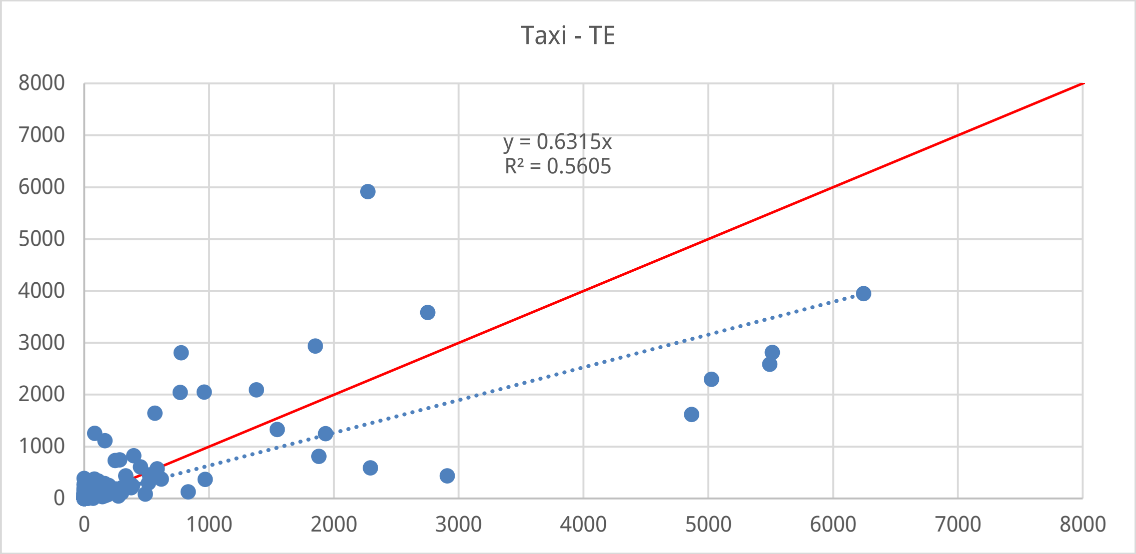


Figure 19. Modal choice calibration, Taxi by O/D

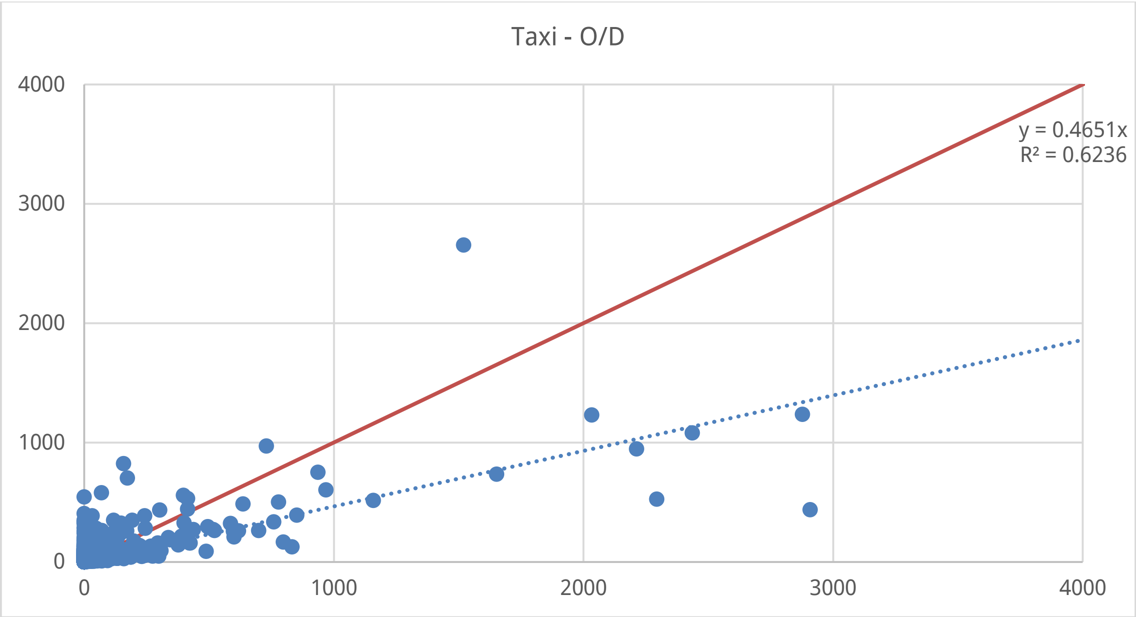


Figure 20. Modal choice calibration, Collective Taxi by trip ends

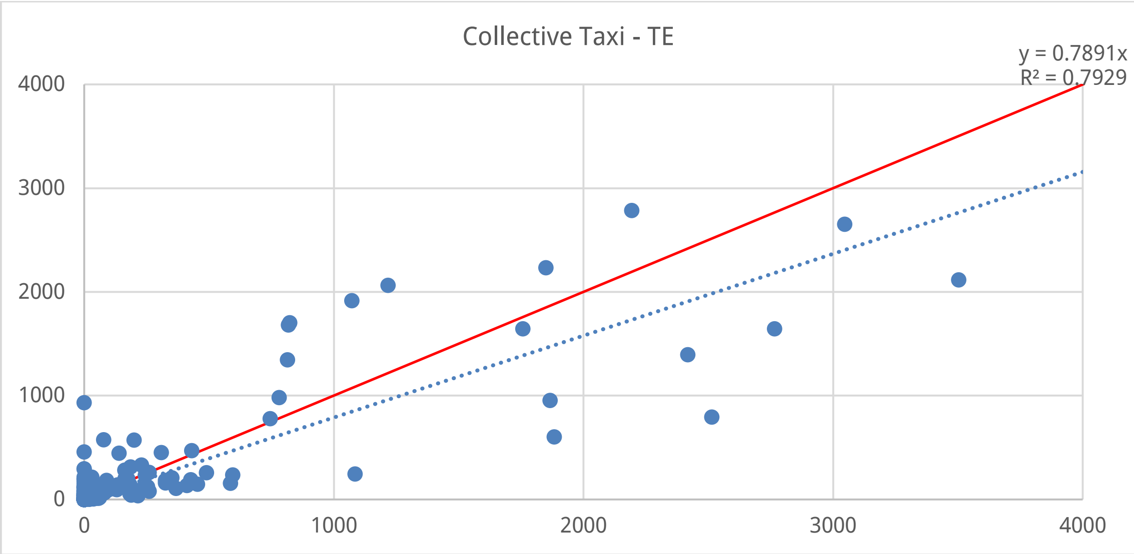


Figure 21. Modal choice calibration, Collective Taxi by O/D

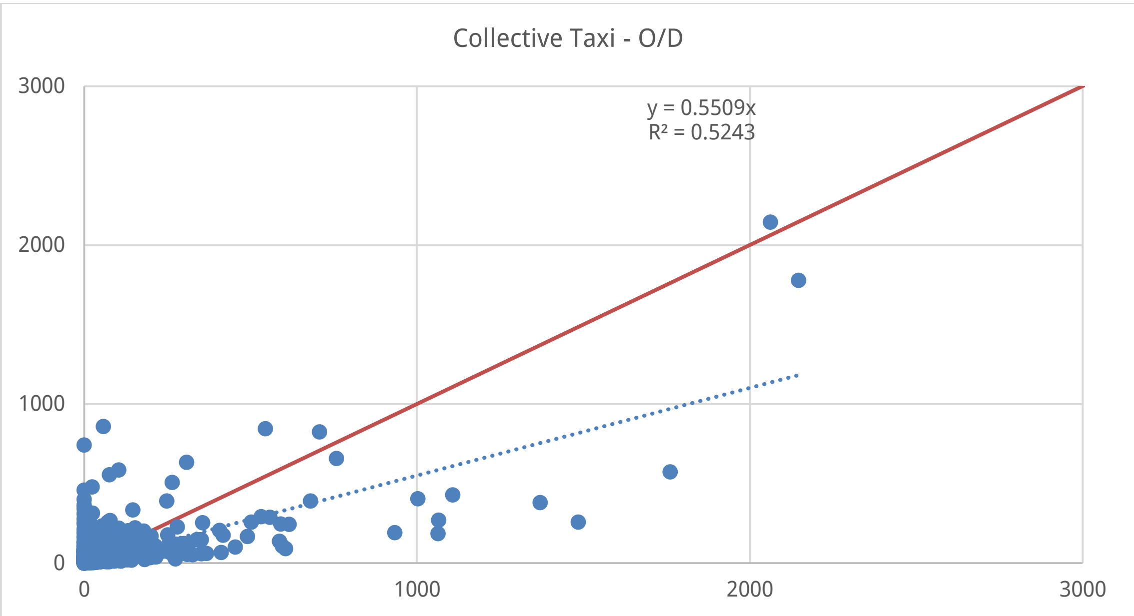


Figure 22. Modal choice calibration, Bus by trip ends

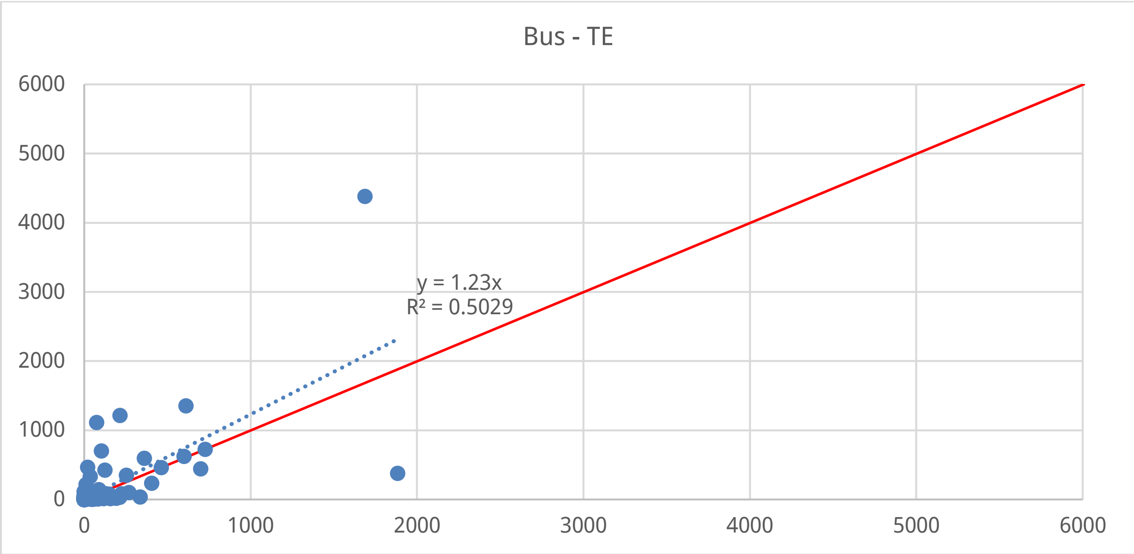
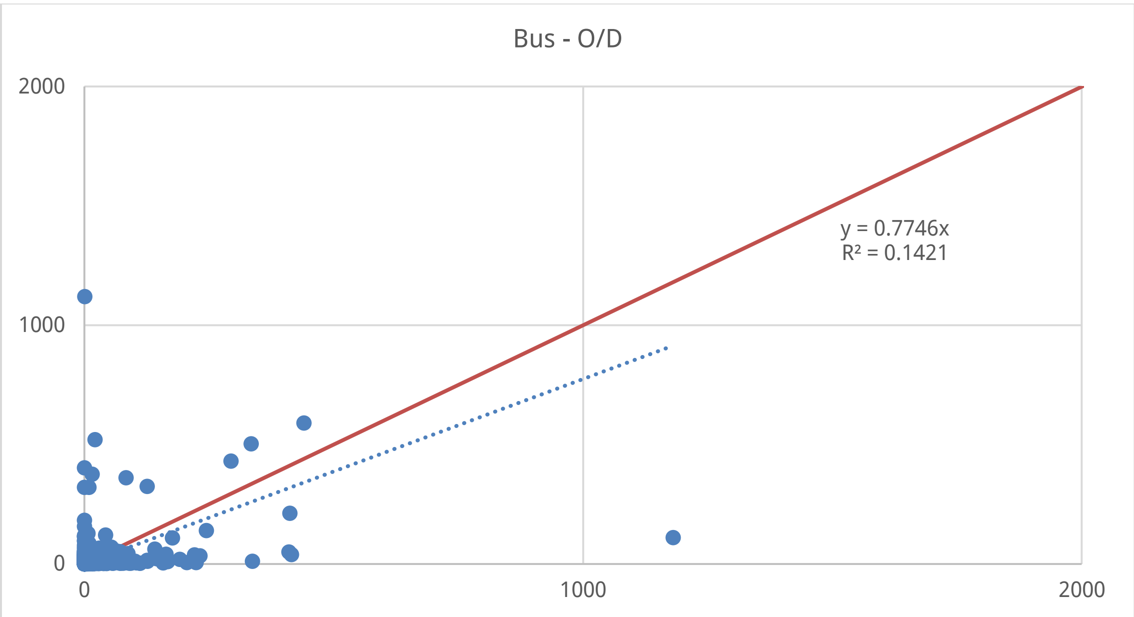


Figure 23. Modal choice calibration, Bus by O/D



11. Traffic Assignment

When all preceding demand model stages have been developed, the estimated travel demand O/D matrices are assigned to the multimodal network. The assignment stage is an iterative process that loads the number of trips for each O/D pair (per mode of transport) across the network after evaluating the final travel cost for each O/D pair and through each reasonable path between each O/D pair in the congested situation *(Route Choice).* The iterative process used in traffic assignment stage allows the continuous updating process of the generalized costs per O/D pair and mode of transport, producing the calibration parameters to reach the equilibrium condition.

Data Preparation

Matrices provided from the modal choice step are processed in order to apply correction factors to avoid biased relations. The correction factors are calculated on the basis of the estimated matrices (Refer to Matrix Estimation Chapter) and are applied to all modes: car, taxi, collective taxi, bus, LCV, HCV. Vehicle occupancy factors (Refer to Traffic Survey Chapter) are applied in order to convert the passenger data (car, taxi, collective taxi) into vehicles. As motorcycle trips represent part of the used modes, they are assumed to be part of the private-car trips, calculated (according to the surveys) as the 8.65% of the private car trips. The matrices resulting from the data preparation step are used in the traffic assignment model.

Private Traffic

The private traffic matrices are assigned to the network according to a set of rules on how to identify desirable routes i.e. fastest, lowest generalized cost) to connect origin to destination and then a systematic way of allocating O-D trips to these routes to reflect actual observed traffic patterns (model validation).
The basic premise in assignment is the assumption of a rational traveler, i.e. a traveler would choose the route which offers the least perceived (and anticipated) individual costs. A number of factors are thought to influence the choice of route when driving between two points; these include: journey time, distance, monetary cost (fuel and others), congestion and queues, type of maneuvers required, type of road, etc.
Once all the required parameters and functions are defined, an equilibrium assignment is performed.
The "Method of Successive Averages" (MSA) is used. It is an iterative assignment algorithm where the “current” flow on a link is calculated as a linear combination of the current flow on the previous iteration and an auxiliary flow resulting from an ‘all-or-nothing’ assignment in the present iteration. The algorithm can be described by the following steps (Ortùzar and Willumsen, 2011)[3]:
Select a suitable initial set of current link costs, usually free-flow travel times. Initialize all flows $V_a = 0$; make n = 0.
Build the set of minimum cost trees with the current costs; make n = n + 1.
Load the whole of the matrix T all-or-nothing to these trees obtaining a set of auxiliary flows F_a.
Calculate the current flows as:

$$\boldsymbol{V_a^n = (1-\phi)V_a^{n-1} + \phi F_a}$$

with $0 \le \phi \le 1$
Calculate a new set of current link costs based on the flows $\boldsymbol{V_a^n}$. If the flows (or current link costs) have not changed significantly in two consecutive iterations, stop; otherwise proceed to step 2. Another, less good but quite common, criterion for stopping is simply to fix the maximum number of iterations.

[3] de Dios Ortuzar, J., Willumsen, L.G. (2011) Modelling Transport - 4th Edition, John Wiley & Sons, Incorporated

Iterative assignment algorithms differ in the method used to give a value to φ. A simple rule is to make it constant, for example φ = 0.5. A much better approach due to Smock (1962), is to make φ = 1/n.
If the network is "well behaved," and the appropriate processes are included, eventually a state of equilibrium is reached. That state is reached when further adjustments in the link costs used for routing, will not produce significant differences in the system as a whole. In theory, equilibrium is reached when there is no ability for individual i-j (read: origin-destination) path costs to improve, without causing degradation in other parts of the network.
The basic measure of equilibrium is total system user cost, and in most situations, cost involves some measure of time and monetary cost; further, monetary cost is often deemed proportional to travel distance. The majority of traffic assignment programs allow the user to allocate weights to travel time and distance in order to represent drivers' perceptions of these two factors. The weighted sum of these two values then becomes a generalized cost used to estimate route choice.

Public Transport

The public transport matrices are assigned to the network using an algorithm, which assigns the passengers to the best path calculated between the selected OD. The PT travel times are calculated based on the private traffic congested travel time.
The PT assignment module automatically calculates the pedestrian links between zones and transit stops, with a walking speed of 4 km/h. The best route is then calculated accounting all the different factors affecting a PT trip: walking times, waiting time, transfer time, fares and on-board time.
The public transport module can account of different modes (bus of different sizes, BRT, light rail, heavy rail, etc.), each one characterized by the specific fare system.

Calibration

The calibration of the Base Year 2015 model is an iterative process, which loops from the trip distribution step to the traffic assignment step till the differences of the results of the two last iterations don't change more than a threshold. In the following paragraphs are reported the calibration outcomes related to the traffic assignment step, where the traffic volumes on the network are compared to the traffic counts (Refer to Traffic Survey Chapter). In general, considered the all the factors and the available data, the model satisfies the calibration standards and it is well calibrated.

Macroscopic Indicators

The Typical Strategic Macroscopic Calibration Criteria are described in the following:

- **R^2:** The model's validation process is based on the principle of comparing modelled with observed flows on a number of significant screen lines, by plotting observed versus modelled flows and adjusting the best-possible straight line (trend line) to them. The corresponding R^2 (the closer to 1 the better) parameter, as well as slope and intercept are used as validation reference. The closer the slope is to 1 the better (adequate confidence is for $R^2 > 0.85$) and the closer the intercept is to zero the better. Moreover, the "cloud" of points and the parameters above will help identify any bias in the results.
- **Root Mean Squared Error (RMSE):** The RMSE is a frequently used measure of the differences between value (sample and population values) predicted by a model or an estimator and the values actually observed. The RMSE represents the sample standard deviation of the differences between predicted values and observed values. These individual differences are called residuals when the calculations are performed over the data sample that was used for estimation, and are called prediction errors when computed out-of-sample. The RMSE serves to aggregate the magnitudes of the errors in predictions for various times into a single measure of predictive power. RMSE is a good measure of accuracy, but only to compare forecasting errors of different

models for a particular variable and not between variables, as it is scale-dependent. The upper bound to consider a model well estimated is considered at RMSE=30%.

- **Mean Absolute Percentage Error (MAPE):** is a measure of accuracy of a method for constructing fitted time series values in statistics, specifically in trend estimation. It usually expresses accuracy as a percentage. The upper threshold to consider a model well estimated is considered at MAPE=20%.

In the following are calibration results are reported for each vehicle category:

All vehicles

R2 - Coefficient of determination - Value = 0.82
MAPE - Mean absolute percentage error - Value = 14.6%
RMSE - Root-mean-square error - Value = 46.7%

Private cars + taxi

R2 - Coefficient of determination - Value = 0.78
MAPE - Mean absolute percentage error - Value = 13.8%
RMSE - Root-mean-square error - Value = 53.7%

Collective Taxi

R2 - Coefficient of determination - Value = 0.70
MAPE - Mean absolute percentage error - Value = 35.4%
RMSE - Root-mean-square error - Value = 90.7%

Public Transport

R2 - Coefficient of determination - Value = 0.89
MAPE - Mean absolute percentage error - Value = 23.3%
RMSE - Root-mean-square error - Value = 49.9%

Motorcycles

R2 - Coefficient of determination - Value = 0.98
MAPE - Mean absolute percentage error - Value = 24.1%
RMSE - Root-mean-square error - Value = 32.8%

Light Commercial Vehicles

R2 - Coefficient of determination - Value = 0.97
MAPE - Mean absolute percentage error - Value = 8.4%
RMSE - Root-mean-square error - Value = 26.5%

Heavy Commercial Vehicles

R2 - Coefficient of determination - Value = 0.82
MAPE - Mean absolute percentage error - Value = 16.7%
RMSE - Root-mean-square error - Value = 56.0%

Microscopic Indicators

The Microscopic Calibration Criteria used for the Base Year 2015 is the GEH (Geoffrey E. Havers). The mathematical form is an empirical formula that has proven useful for a variety of traffic analysis purposes:

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}}$$

Where M is the traffic volume from the traffic model and C is the traffic count. The GEH is a very restrictive parameter and it is usually applied for microscale models.

Report GEH - Traffic Count Section - Total Vehicles

Percentage of Sections with GEH<5 = 74.10 %
Percentage of Sections with GEH=5-10 = 7.19 %
Percentage of Sections with GEH>10 = 18.71 %

Report GEH - Traffic Count Section – CARTXs

Percentage of Sections with GEH<5 = 76.26 %
Percentage of Sections with GEH=5-10 = 5.76 %
Percentage of Sections with GEH>10 = 17.99 %

Report GEH - Traffic Count Section – CTXs

Percentage of Sections with GEH<5 = 67.63 %
Percentage of Sections with GEH=5-10 = 15.83 %
Percentage of Sections with GEH>10 = 16.55 %

Report GEH - Traffic Count Section – MCYs

Percentage of Sections with GEH<5 = 84.17 %
Percentage of Sections with GEH=5-10 = 15.83 %
Percentage of Sections with GEH>10 = 0 %

Report GEH - Traffic Count Section – LCVs

Percentage of Sections with GEH<5 = 90.65 %
Percentage of Sections with GEH=5-10 = 4.32 %
Percentage of Sections with GEH>10 = 5.04 %

Report GEH - Traffic Count Section – HCVs

Percentage of Sections with GEH<5 = 86.33 %
Percentage of Sections with GEH=5-10 = 10.79 %
Percentage of Sections with GEH>10 = 2.88 %