Qatar 2050 قطر
الخطة الشاملة للنقل
Transportation Master Plan

وزارة المواصلات
MINISTRY OF TRANSPORT

TRANSPORTATION MASTER PLAN FOR QATAR

Strategic Transportation Model

BOOK ONE: The Summary

December 2020

نقل متكامل ومستدام للجميع
INTEGRATED & SUSTAINABLE TRANSPORT FOR ALL

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بالنسبة إلى التغييرات أو الإصدارات المستقبلية، ستقوم الوزارة بتوفيرها ويمكن الحصول عليها من خلال الاتصال بالإدارة المخولة في الوزارة. وعليه يتوجب على المستخدم التحقق بشكل متواصل بأن لديهم أحدث إصدار من هذا التقرير.

ملاحظة: ستقوم وزارة المواصلات بمواصلة تحديث وتعديل هذا التقرير مع الأخذ بعين الاعتبار النظريات الجديدة وأحدث الأساليب التكنولوجية والمواضيع المُستجدة التي تتعلق بتخطيط وتحليل وتصميم أنظمة النقل والمرور.

إن وزارة المواصلات والاتصالات تشجع المستخدم على تقديم الملاحظات والاقتراحات والتعليقات وردود الأفعال وذلك من خلال قنوات الاتصال الخاصة بالوزارة حيث سوف يتم مراجعة هذه الملاحظات والاقتراحات ومن ثم تقييمها وإمكانية إدراجها ضمن الإصدار القادم من التقرير.

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ABBREVIATIONS

Abbreviations

ABM	Activity Based Model
ACT	Access Time
AM	Ante Meridiem (Before Noon)
ATC	Automatic Traffic Counts
BPR	Bureau of Public Roads
BRT	Bus Rapid transit
CBD	Central Business District
CEMDAP	Comprehensive Econometric Micro-simulator for Daily Activity-travel Patterns
CEMSELTS	Comprehensive Econometric Micro-simulator of Socioeconomics, Land Use and Transportation Systems
EGT	Egress Time
GB	Giga Bytes
HGV	Heavy Goods Vehicles
HHI	Household Interview
HIS	Households Interview Survey
IPF	Iterative Proportional Fitting
ITS	Intelligent Transport System
IVT	In-Vehicle Time
JRT	Journey Time
LGV	Light Goods Vehicles
LTPD	Land Transport Planning Department
MCC	Manual Classified Counts
MD	Mid-Day (Noon)

MDPS	Municipality of Development, Planning and Statistics
MME	Ministry of Municipality and Environment
MMUP	Ministry of Municipality and Urban Planning
MOTC	Ministry of Transport and Communications
MSA	Method of Successive Averages
NTR	Number of Transfers
O-D	Origin–Destination
OP	Origin-Parking trip
OVT	Off-Vehicle Time
P	Parking
Park & Ride	Park and Ride
PD	Parking-Destination trip
PM	Post Meridiem (After Noon)
PopGen	Population Generation
PrT	Private Transport
PT	Public Transport
PUMS	Public Use Microdata Sample
PuT/PT	Public Transport
QABM	Qatar Activity Based Transport Model
QAR	Qatari Riyal
QBROS	Qatar Bus Routes Operation Study
QSTM	Qatar Strategic Transport Model
RAM	Random Access Memory
ROW	Right-of-Way

ABBREVIATIONS

RSI	Roadside Interviews
SRMSE	Standard Root Mean Square Error
TAZ	Traffic Analysis Zone
TMC	Turn Movements Counts
TMPQ	Transportation Master Plan for Qatar
TOR	Terms of Reference
TWT	Transfer Waiting Time
UPDA	Urban Planning & Development Authority of Qatar.
VBS	Visual Basic Script
VDF	Volume-Delay Function
WebTAG	Transport Analysis Guidance available on the web
WKT	Walking Time

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GLOSSARY

Glossary

Access Time	In the model representation, the time spent to travel from a TAZ centroid along a connector to the road network.
BPR function	A cost function introduced by the US Bureau of Public Roads that is used to estimate the link travel time as a function of the saturation degree.
Calibration	Technique aimed at reducing the difference between modeled and observed data.
Connections	Routes with detailed departure and arrival times.
Convergence	An equilibrium or balanced position between two interrelated model outputs. A converged assignment is one where the assigned flows and the resulting travel costs are consistent.
Convergence Criteria	The values of measures of convergence by which it is accepted that an adequate level of convergence or equilibrium has been reached.
CT-RAMP	A set of models developed in the USA that share the Coordinated Travel - Regional Activity Modeling design and software platform to represent intra-household interactions.
DaySim	A software that simulates a day of activity and travel for each person in each household of a synthetic population distributed throughout a given geographical area.
Egress Time	In the model representation, the time spent to travel from the road network along a connector to a TAZ centroid.
GDA	Greater Doha Area.
Headway-Based Assignment	A model that assigns passengers to the first transit line that arrives from an optimal set of lines.
Highway Assignment Model	A model which assigns car and goods vehicle trips to routes through a highway network.
In-Vehicle Time	Time spent in path legs using PT service.
Journey Time	Time spent for all phases of a trip.
KML	Keyhole Markup Language (KML).
KMZ file	A KMZ file stores map locations viewable in Google Earth.
Level-of-Service (LOS)	A quantitative or qualitative measure of the effectiveness of transport infrastructure.

Link Types	Links with same properties are classified in VISUM as Link Types. These are used to assign standard link attributes that define traffic related properties of links.
LTPD 2016	Release of the QSTM supplied as model version MOTC- LTPD Base Year Model 2016.
Micro-Simulation Model	A dynamic model that simulates individual driver decisions and vehicle trajectories on the network.
Mowasalat	A public company for bus lines transport management in Qatar.
Number Transfers	Total number of transfers per trip.
Off-Vehicle time	Sum of the Walking time, the Egress time and the Access time.
Origin Wait Time	Time spent waiting for the first boarding.
Park 'n' Ride	Commuter car parking area at public transport stops and stations for accessing public transport services. Generally, also accommodates passenger drop-off zones.
Pedestrian	Number of PT passenger trips without PT ride.
Perceived Journey Time	Time resulting from the weighted components of the Journey time and further components.
PTrips Linked >2	Number of PT passenger trips with more than 2 transfers.
PTrips Linked 0	Number of PT passenger trips without transfers.
PTrips Linked 1	Number of PT passenger trips with 1 transfer.
PTrips Linked 2	Number of PT passenger trips with 2 transfers.
QRail	A State-owned railway company, responsible for rail transport in Qatar.
QSTM 1.0	Release of the QSTM supplied as model version UpdatedQSTM-Sep2013-CON-VISUM13.
QSTM 2.0	Release of the QSTM supplied as model version QSTM 2.0_Expressway model Ashghal updates.
QSTM 2.0b	Release of the QSTM supplied as model version QSTM 2.0_Visum15.
Route choice	The differentiation of alternative routes on the basis of travel time or generalized cost.
Timetable-Based Assignment	Assignment method based on a detailed timetable for public transport services.
TModel	A cost function that models the average delay at a road junction depending on the overall traffic volumes.

Total Num Transfers	Total number of transfers of all PT trips.
Transfer Wait Time	Time spent waiting during transfer, without transfer walk times of PT trips.
Validation	The comparison of modeled and observed data.
Validation Acceptability	The acceptable proportion of instances where the validation criteria are met.
Validation Criteria	The difference between modeled and observed data by which it is determined that the modeled volumes are valid.
VISEM	Disaggregated Behavior oriented demand model (Activity Chain Based).
VISEVA	Demand modeling system for urban and regional commercial transport.
VISUM	Software for traffic analyses and transportation forecasts.
Volume Delay Function (VDF)	In traffic assignment models, VDF is used to express travel time travel time along a link (or through a node) as a function of traffic volume.
Walk Time	Time spent walking.

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SECTION - 01

BACKGROUND

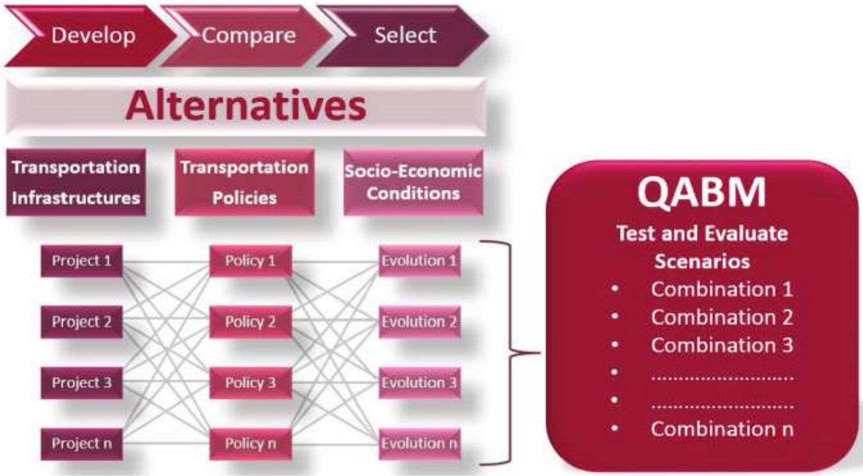
1. Background

The Qatar Activity-Based Model

1.1. Developing a Strategic Transport Master Plan

Transport plays a crucial role in the economic vitality and the long-term development of a country, with most people using the transport network daily. An effective, efficient transport network is a fundamental part of everyday life; connecting homes, businesses, jobs, health and education facilities and leisure opportunities. A transport network that is fit for purpose, reliable, less congested, with strong connections is thus the backbone of a resilient economy and for creating job opportunities.

Operating a transport network affects the environment, health and society, often resulting in conflicting-demands on the transport system. When developing a strategic transport master plan, such as the TMPQ, all these various demands come into play. Therefore, a strategic transport master plan has to manage the demands in a way that is opertationally safe, economically efficient, environmentally sustainable, and societally equitable.



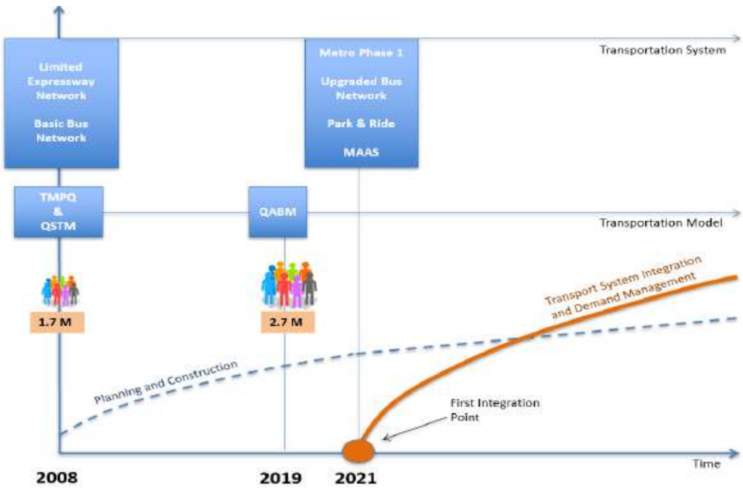
To do so, alternatives reflecting different infrastrucure, sevices, and land-use, are commonly proposed. The search for the best alternative from a potentially large pool of possible solutions, requires predicting the travel demand, and assessing the impacts or the perfromance of the transport system for each possible alternative, through the use of a transport model.

A transport model is essentially a mathematical representation of the transport supply system (for example, roads, bus services), one the one hand, and mobility needs or the travel demand (such as the need to go to work, to school, to shop, to deliver goods, etc.), on the other hand. The supply and the demand are tied up together through a user behavioural and a policy decision-making relationship, the outcome of which determines which route to take for travelling on the road network, what time to travel, which transport mode to use, what bus to take. More importantly, it determines how all these decisions taken collectively by the travellers an decision makers impact the transport network.

1.2. Why QABM

Over the past two decades, Qatar has seen phenomenal growth in all areas of its economy and society, while making many fundamental steps for better quality of life for its population and increasing its global recognition. This rapid development lead to population expansion and evolution that have by far exceeded expectations.

Thanks to its thriving economy in industry, housing, retail, tourism, education, sports, science, and technology, this development is expected to continue to increase at a rapid pace, which comes with its own set of impacts and challenges – transportation being one of them.



The development of QABM is a key component of the Transport Master Plan for Qatar. It will guide the process of setting out transportation policies to take transport forward to support the accelerating growth of Qatar and deliver the Qatar National Vision 2030, while providing safe and sustainable transport networks for the resident population and visitors. Such an order instils a requirement for a model which is based on sound principles of travelers' behavior, which is accurate, robust, and which can forecast the impacts of various policy measures.

Qatar is home to an extremely diverse population whose needs are constantly evolving. Personal, professional, and social factors all play a key role in each individual's activities and decisions on a daily basis. Hence, a responsive transportation model is needed to simulate these activities and forecast the mobility needs of citizens, residents and visitors.

1.3. QABM Features

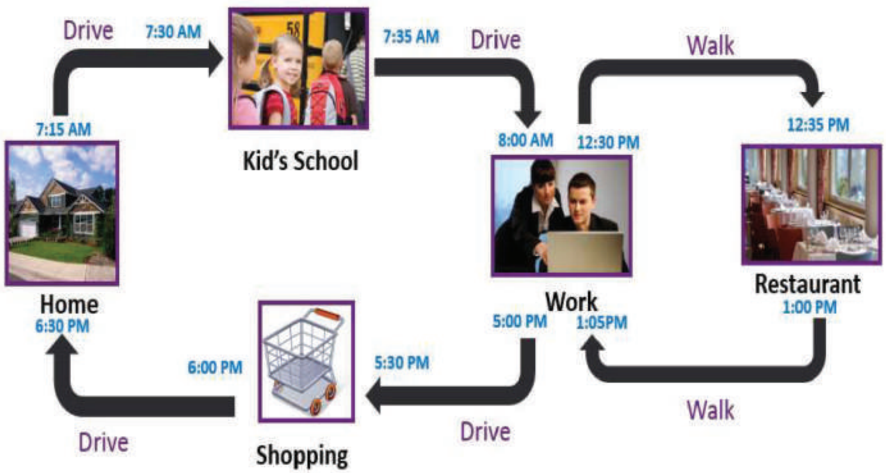
QABM is different than other traditional transport models. Many of the commonly used transportation models are trip-based models. These are inherently founded on the fundamental unit of travel being the "trip" which is made by a traveler from an origin to a destination for a particular purpose by a particular mode of transport (e.g. private car).

Trip-based models have many limitations. Most notably, they assume that trips made by travellers are independent. For instance, if a person chooses to travel to work by metro rather than by car, then for the return trip the car would not be available – trip-based models have it as available, when the likelihood of this is almost nil.

In contrast, QABM goes beyond the concept of "trip" by embracing instead the notion of an activity as being the fundamental unit of travel, where travel demand is considered to be derived from people's daily activity patterns; that is, when, where, how long, and with whom, to complete these activities.

QABM is an activity-based model. It treats trips as being inter-dependent, and decisions made about one trip affect others. This modeling structure results in a more detailed representation of how travelers may respond to policy alternatives, pricing mechanisms, as well as land-use and socioeconomic changes when compared to the trip-based classical models.

Transportation Activity Based Models are at the forefront of travel forecasting models. Because every day and every journey is different, QABM addresses the dynamic needs and journey patterns of people's everyday activities, forecasting transportation patterns across all modes of travel, including private vehicles, public transport, cycling, and even walking.



QABM can, for example, simulate the conditioned choices within a household that determine which adult member escorts children to school before going to work. Since the members of a household usually have different activities and destinations, the trip tours and possibly the modal choices are affected if, for instance, the household owns only one vehicle

QABM can also provide a more sophisticated assessment of the impacts due to different mobility policies, such as congestion pricing and parking fares, by taking account of:

1. The mobility choices of each person;
2. The interrelations that determine the daily mobility choices of each household member;
3. The long-term mobility choices of each household member through the implementation of a Comprehensive Econometric Micro Simulator of Socioeconomics, Land Use and Transportation Systems (CEMSELTS);
4. The impacts of Park & Ride use and parking fares on the spatial distribution of activity opportunities; and
5. The crowding effects on the level of public transport use, which is currently not a significant problem in Qatar but may become so in the future with the new Metro system.

1.4. Major Efforts and Deliverables

The QABM development started from the review of existing documents, models and conditions, through to data analysis review, models development, reporting and training. The overall project and QABM development took two years and a half to complete and had an extensive program of tasks to deliver.

The project activities covered two stages, with nine main tasks in total. These are outlined in Table 1.1.

Table 1.1: Stages and Tasks for QABM Development.

STAGE A	STAGE B
Task 4.1-Undertake Review of Existing and current Documents in the state of Qatar	**Task 5.1-Model Upgrade, development and update**
Task 4.2-Undertake Literature Review of International Best Practices	**Task 5.2-Base Year Modeling**
Task 4.3-Collect Stakeholder Input	**Task 5.3-Calibration and Validation**
Task 4.4-Transport Assessment Framework	**Task 5.4-Horizon Year Modeling**
	Task 5.5-Development of Network and Policy Scenarios

QABM incorporates a detailed representation of the transport network for the entire State of Qatar. This comprises of 183,000 road and public transport links and services, and 65,000 road junctions.

The effort made in developing QABM included:

- More than 80 specialists and experts who strenuously worked on this project.
- Collaborating with world-renowned Universities on Activity-based modeling: La Sapienza and Roma Tre Universities (Italy), Santa Barbara California, Texas, and Arizona in United States of America (USA).
- More than 200 technical meetings
- Setting up more than 143,000 files to generate the input data for QABM, resulting in more than 170,000 files produced as Output
- Preparing 2,000 pages of final reports together with a user manual
- Analyzing more than 14 different surveys across the State of Qatar of the types listed in
- Table 1.2 for extracting the data needed for setting up QABM

Table 1.2: Surveys Carried out for the Development of QABM.

Type of Survey	Completed	Type of Survey	Completed
Automatic Traffic Counts	424	Household Interviews	10,082
Automatic Traffic Counts	76	Household Interviews	2,146
Turning Movement Counts	500	Laborer Interviews	1,044
Manual Classified Counts	100	Stated Preference Surveys	3,123
Travel Time Surveys	75	Roadside Interviews	18,599
Pedestrian and Cyclist Counts	25	Parking Interviews	1,148
Pedestrian and Cyclist Interviews	1,233	Hotel Visitors Surveys	1,067
Public transport Surveys	1,589	Air Passenger Interviews	1,174

The outcomes of the various project activities have been illustrated in Technical Notes, Reports and Manuals, the content of which can be summarized as follows:

- Acquisition and review of existing documents and international best practices
- Data collection and analysis
- Specification, calibration and validation of the supply and demand QABM models
- Simulation of the current transport systems (Base Year) and five Future Scenarios (Horizon Years) according to proposed transport projects and socio-demographic evolutions
- Investigation of alternative policy options.

In addition to the above, tools and software developed along with present and future scenarios implemented in the transport model have been delivered with their corresponding data and routines. Further, a special Graphical User Interface (GUI) has been developed to provide a user-friendly interface for QABM and customize the model runs.

Table 1.3 outlines the main deliverables of the project.

Table 1.3: QABM Project Main Deliverables

<table>
<tr><th>STAGE A - Final Reports</th><th>STAGE B - Final Reports</th></tr>
<tr><td>Review of Existing and Current Documents in Qatar Report</td><td>Model Upgrade, Development and Update Report</td></tr>
<tr><td>Undertake Literature review of International Best Practices Report</td><td>Base Year Modelling Report</td></tr>
<tr><td>Stakeholder Inputs (including summary of Data Review and workshops) Report</td><td>Model Calibration and Validation Report</td></tr>
<tr><td rowspan="2">Model Based Performance Indicators Report</td><td>Horizon Year Modelling Report</td></tr>
<tr><td>QABM Sensitivity Tests Report</td></tr>
<tr><th colspan="2">Project Main Deliverables</th></tr>
<tr><td colspan="2">Executive Summary Report</td></tr>
<tr><td colspan="2">Integrated QABM Models - Base Year and Horizon Years (2025, 2030, 2035 and 2050)</td></tr>
<tr><td colspan="2">QABM User Manual</td></tr>
<tr><td colspan="2">GIS Linkage</td></tr>
<tr><td colspan="2">GIS Visualization Tool</td></tr>
<tr><td colspan="2">Digital Library</td></tr>
<tr><td colspan="2">Training Manual</td></tr>
</table>

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SECTION - 02

MODELING BASIS AND DATA INPUT


Pahlwan
Saad Ismail Al Jassim
The Old Pearl Diver

2. Modeling Basis and Data Input

Available and Collected Data and Documentation

2.1. Existing and Current Documents in Qatar

During Stage A of the project, a thorough review of all pertinent current and existing documentation, data, guidelines, and studies developed by the various government departments and agencies has been carried out. The main goals of this review were to:

- Establish a good understanding of the existing background documents.
- Highlight the main findings of the reviewed documents that are relevant to the development of QABM; and
- Ultimately, identify and conceptualize what and how to utilize existing documents and data in the QABM development.

Table 2.1 lists the reviewed Existing and Current Documents in Qatar. 64 documents were studied in total.

Table 2.1: List of Reviewed Documents

No.	Reference Document	No.	Reference Document
1	Qatar National Vision for 2030 (QNV)	21	Review of Major Development Report
2	National Development Strategy (and other strategies)	22	Review of Parking Design Discussion Paper
3	Review of Guidelines and Procedures for Transport Studies	23	Practice for Designing Parking Facilities
4	Qatar Highway Design Manual (QHDM)	24	Review and Expansion of Pedestrian Network
5	Review Of 'Towards Advanced Public Transport Investment with Multi-leveled Economic Assessment' Paper	25	Pedestrian Facilities Guideline
6	QIBAP Financial Modeling	26	Review and Critique Bicycle Network Plan
7	National Road Safety Strategy	27	Qatar Traffic Control Manual (QTCM), MOTC
8	Intelligent Transportation Systems (ITS) Strategy	28	Review of Existing and Future Capacity of Population and Employment Land Use Scenario 'Ultimate Capacity'
9	Review of Current Land Use and Development, Transport and Land Use Context in Qatar	29	Scenario Development Report
10	Review of Traffic Engineering Current Issues and Discussion of Potential Short-Term Solutions	30	Evaluation and Testing Criteria for Scenarios
11	Review of Traffic Data Collection and Analysis Report	31	Specification and Development of the Transportation Model
12	Existing Road Network Data	32	Review of Model Calibration and Validation Report (Base Year 2006)
13	Local Factors and Traffic Analyses Parameters	33	Model Implementation Report (VISUM)
14	Review of Traffic Data Management System	34	Short Term Solutions – Scope of Work & Priority Schemes
15	Traffic Data Management System (TDMS) Recommendation Report	35	Appraisal and Recommendation of Short-Term Solutions (VISSIM -Modeling)
16	Current Development Control and Impact Assessment in Qatar	36	Transportation Impacts and Benefits

No.	Reference Document	No.	Reference Document
17	Review of Guide to Conducting Tis In Qatar	37	Review of Economic Evaluation of Preferred Scenarios
18	Review of Existing Functional Road Network Hierarchy	38	Current Conditions & Safety Related Policies
19	Review of Functional Road Network Hierarchy – Classification Criteria	39	Road Safety Strategy Plan for Qatar (RSSPQ)
20	Review of Guide to Planning Roads in Qatar	40	Review of Current ITS Initiatives Worldwide
41	Potential Modifications to Utility Corridors within the R.O.W. of Roads and Highways in Qatar	53	Review of ITS Policy Plan
42	Truck Route Network and Truck Operating Policies - Existing Conditions and Related Issues	54	Review of Travel Demand Management in Qatar
43	Truck Route Network Development Policies Paper	55	Coordination Mechanisms for Government Agencies – Current Coordination Issues
44	Policies for the Movement of Goods	56	Coordination Mechanisms for Government Agencies – Recommendations
45	Review of Weigh in Motion	57	Transportation Implementation Plans
46	Review of Existing Public Transport Network	58	Transportation Implementation Plan Strategy Assessment
47	Public Transport Objectives for Qatar	59	Assessment of the Development of A-Ring Road and Al Muntazah Street
48	Review of Public Transport Network for Qatar	60	Al Khor Master Plan
49	Review of Existing Parking Conditions and Literature Review	61	Al Wakra Master Plan
50	Review of Future Parking Needs	62	Draft Qatar National Development Framework (QNDF)
51	Review of Existing Parking Condition	63	Municipal Spatial Development Plans (MSDP) (as available)
52	Review of Parking Policies strategy & Action Plan	64	Review of Guide to Conducting TIS In Qatar - SEA Environment Report Final

The above documents were grouped into five distinct modules:

- Main planning documents, current studies, and project.
- Traffic data collection and analysis.
- Transportation/Traffic modelling.
- Policy development; and
- Transportation implementation

To standardize and simplify both the review process and the review outcome, a 'review template' was developed. The template was designed to facilitate the achievement of the goals outlined above. The main headings of the review template include the following:

1. **Summary** of the reviewed data/documents and background information. This section provides detailed information about:
   a. Study author / developer
   b. Study methodology and resources utilized
   c. When, where, and why the study was conducted

2. **Main Findings and Use in QABM**. This section contains detailed information regarding the main findings of the study and how it would be utilized in the development of QABM.

3. **Conclusions and Recommendations**. This section answers the following questions:
   a. Does the information contained in the reviewed document require any update?
   b. What actions are required, and by whom, to bridge any identified gaps in the information and/or knowledge?
   c. What lessons are learnt from the document review?

The detailed review of each document listed Table 2.1 can be found in the *Review of Existing and Current Documents in Qatar Report*. The summary and main recommendations stemming out of the overall review insofar as model development is concerned are as follows:

1. **Data Format and Update.** Formats for input and output data of a transport model are a crucial issue if updating and sharing of data among stakeholders is to be efficient. In the future, as the demands for transport model update become more frequent and progressively automated, it is expected that the relevance of databases in relation to people and goods mobility, land use features, and the environment will rapidly increase.

   Many advanced methods that exploit Big Data are available for several purposes, including both in transport planning and mobility management, such as, mobility analysis and traffic predictions. To take full advantage of these opportunities, it is recommended that formats and specifications of data are standardized so that the rules for data collection, coding, updating and processing are defined and applied in future uses.

2. **Advances in Transport Modelling Data Gathering.** Rapid advances in automatic data collection technologies and a continuous progress in developing effective methods for Big Data analysis suggest having a parallel activity of progressive update and enhancement of the transport model. This could be an added value for ABM, where the whole chain of personal activities information can benefit also through the continuous collection of time-space and crowding data of every kind of public site, such as shops, offices, museums, etc. This approach will be equally useful for the setting out of transport supply models. As much real-time data collection of vehicles and persons in mobility is widespread as more it will enable modelers to develop and

update high-definition traffic models. Such high-definition and frequently updated models will be able to simulate temporary and local changes more accurately in the transport system. Thus, these models can be applied to study special events, and gatherings with a large number of people, as well as the planning and management of these events and resolving the hard transportation problems commonly faced.

3. **Model Update and Upgrade.** The review of the existing QSTM model has effectively informed the development of QABM, particularly in relation to data input and output and what QSTM model components can be utilized in QSTM to maximize on the extensive investment made in QSTM. The review highlighted the need as well for both tools to have a common coding mechanism for the model input, and similarly for the model output, so that the output form each model can be fed into a single transport assessment framework for the evaluation of the impacts of transport strategies and scenarios. The review additionally established that there is a substantially rich set of planning data which are implemented in QSTM and which can be used in the development of QABM.

4. **Sensitivity Testing.** This is an important step of a transport model development. It essentially aims at examining the model response as well as its robustness to changes in policy and auto pricing measures, for example, different fuel prices, and parking charge, and how these impact other modes of travel. For the development QABM, the review analyzed the various policy options that are feasible to implement and categorized these, in addition to the pricing measures, by whether they are hard or soft measures.

2.2. International Best Practices

A review of International Best Practices has been conducted with the aim of identifying significant characteristics applicable to the State of Qatar. After a preliminary review of nineteen (19) transportation master plans and their corresponding transport models, the review zoomed in on five international transportation master plans which have been selected as benchmarks. These are Abu Dhabi in UAE, Philadelphia and Chicago in the USA, Auckland in New Zealand, and Rome in Italy. The review of the master plans of these cities provided a comprehensive understanding of the numerous aspects and application of the transport models, while focusing on ABM, parking, Park & Ride, and crowding as components of the overall model, including as well the way these components are interlinked with the overall model.

The detailed review of the five best practices is documented in the *Undertake Literature Review of International Best Practices Report*, and cover:

1. Plans, policies, regulations, and measures
2. Modeling details
3. Applicability to the State of Qatar and for updating QABM.

The main findings applicable to the development of QABM are related to the best practices of transport modeling, their unusual features, as well as the management strategies adopted or applied in those cities. Such information provided appropriate solutions, and model development strategies for making QABM sensitive to simulating the impacts of changes in the transport supply and demand model.

Table 2.2 shows a summary of the five reviewed best practices. The selection of practices was based on the type of model implemented, for both the demand and the supply sides, the number and type of spatial units, the drafted transport plans, and the software used for performing the traffic assignment step, which allocates routes to travelers within the transport model.

Table 2.2: Comparison of the Attributes of the Case Studies

Location	Population	Models	Spatial Units	Software	Transport Plans
Qatar	2,169,000	ABM, Parking Park & Ride, Public Transport Crowding	Zones (1839)	VISUM	Master Plan
Abu Dhabi	2,800,000 (1,200,000)	Abu Dhabi Enhanced Model	Zones (1900)	CUBE	Master Plan
Auckland	1,400,000	Four-step demand model. MMA P&R, PT Fares, boarding and transfer attributes.	Zones (512)	EMME	Regional Land Transport Program 2015-2025, Integrated Transport Program (2012-2041), Regional Public Transport Plan 2013, Parking Strategy
Chicago	10,000,000 (2,800,000)	CT-RAMP1 ABM model, ABM-DTA integration approach	Zones - Microzones (1,944 internal + 17 external)	EMME / DYNA SMART	Traffic, Transit & Pedestrian
Philadelphia	6,000,000 (1,500,000)	ABM DAYSIM version: Household - Person	Microzone (3399)	VISUM	Master Plan
Rome	4,000,000 (2,875,000)	Land-Use and transport interactions demand model STIT. MMA. P&R	Zones (1331 internal + 8 external)	TransCAD	General Urban Traffic Plan, Air Quality Improvement Plan, Strategic Plan for Sustainable Mobility, Municipality Road Safety Plan, Rome Cycle Plan

The review activity highlighted the following aspects which guided the development of QABM and application of the model:

1. ***ABM Use and its Application.*** One of the most important innovation in transport modelling is the application of ABM; therefore, two of the chosen case studies use ABM. The Philadelphia ABM is implemented in DAYSIM (as a day activity choice simulation model) and VISUM (as a traffic assignment simulation model). The latter is the tool adopted for QABM. A focus in the review considered the size of the study area and the population in order to establish the feasibility of applying ABM to Qatar and ensure that model simulation run times are not prohibitive. This was confirmed in the more or less similar number of zones in Chicago, with Philadelphia ABM having a larger number of zones, while both models are able to simulate much bigger population than Qatar.
2. ***Parking and Park & Ride.*** An additional topic for QABM is the incorporation of parking model in the overall model. Parking and Park & Ride models have been found to be implemented in Rome and Auckland models. Moreover, in Rome model, parking search time is considered as a determining factor in the choice of parking location - the higher the search time, the less likely the car park will be used (during certain times of the day). In Chicago, parking is considered in the Central Business District and a distinction is made between off-street and on-street parking by the application of different classes of users. This is highly relevant to Qatar where free on-street parking is widely available.
3. ***Area Wide Modeling.*** The ABM of Chicago is based on the CT-RAMP as a day activity choice simulation model. The traffic assignment is carried out using EMME software for the wider area, while the dynamic traffic simulation DYNASMART tool is employed for detailed modelling in congested areas. The model has a very detailed public transportation network and accounts for crowding effects, both on-board and at the stops. These features form a major component in QABM.

4. ***Integration with Geographical Information Systems (GIS).*** In Rome, an interesting feature is concerned with the integration with the GIS. This feature permits the analysis and managing of a huge amount of data in a user-friendly manner by creating thematic maps and overlapping different kinds of information.
5. ***Management Strategies.*** The review of the master plans revealed that usually management strategies are not limited to one single measure but are characterized by multimodality and various actions. This best practice has been found to be mostly the case in the City of Auckland.
6. ***Public Transport Modeling.*** The analysis carried out highlighted the need of high-quality modeling for all the aspects of the PT system to catch the demand needs. Abu Dhabi has been used as best practice amongst the Gulf countries. The model is based on the typical trip made by representative individuals and households, with distribution, mode choice and assignment improved in the ADEM's last version. The strategies focus on providing a new public transport hierarchy with cycle routes and facilities and high-quality passenger interchanges/stations to reach a high-quality passenger experience. Chicago best practice has the explicit representation of the crowding conditions in the assignment phase. Rome and Auckland are using fares at zonal level in public transport assignment. In the QABM the fares are integrated in the model as well as the crowding conditions.
7. ***Data Requirements and Model Calibration.*** The review has determined that a) all ABM developments involved the need for a large set of data and very detailed information about the population and their travel behavior; and b) calibrating an ABM is different than a traditional four-stage model in that each model component must be individually calibrated to guarantee the integrity of the whole model.

Following the results of the best practices review a Strength, Weakness, Opportunities and Threats (SWOT) analysis of QABM was carried out. This is summarized in Table 2.3.

Table 2.3: SWOT Analysis of the Methodological Approach for QABM.

Strength	Opportunities
• ABM • Park and Park&Ride models	• Detailed and realistic representation of PT (crowding model, fares, etc.) • Multimodal comprehensive policies
Weaknesses	**Threats**
• Requires a huge amount of data • Requires detailed information about population	• Rapid population expansion • Importance of avoiding excessive details

2.3. Surveys and Input data for QABM

The development of QABM used a variety of information from many different sources. These can be grouped as follows:

- Field surveys, and
- Public Agencies.

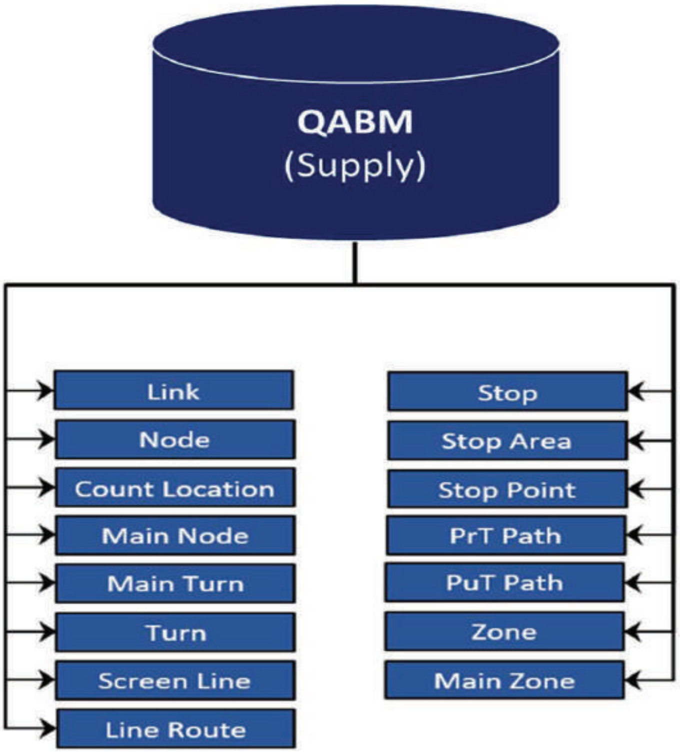


Figure 2.1: Supply Model Data Structure

The data collected constitute the basis for developing the supply and demand models for QABM. Figure 2.1 shows the main elements of the supply models of QABM for which specific data have been collected, analysed and implemented, while Figure 2.2 illustrates the information which have been incorporated in the demand models of QABM.

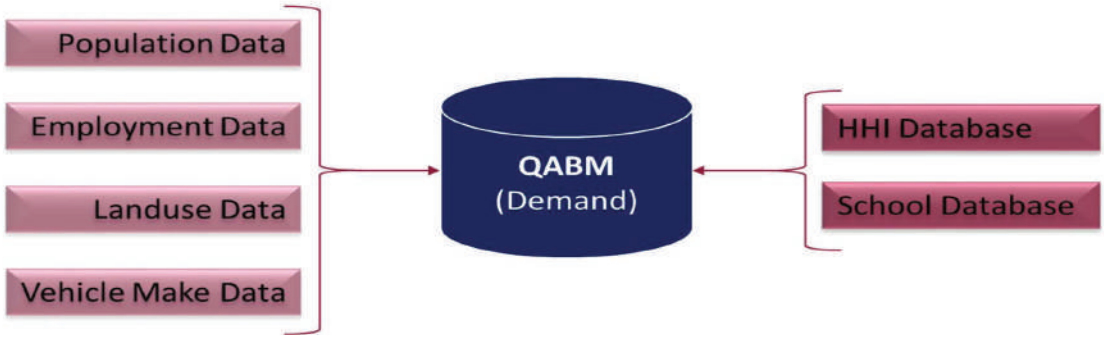


Figure 2.2: Demand Model Data Structure

The *Review of Received Surveys for Model Upgrade, Development and Update Report* details the data received in the course of QABM development for building the network supply and travel demand models

The next sections give a summary description of collected data as well as the source.

2.3.1. Road Network

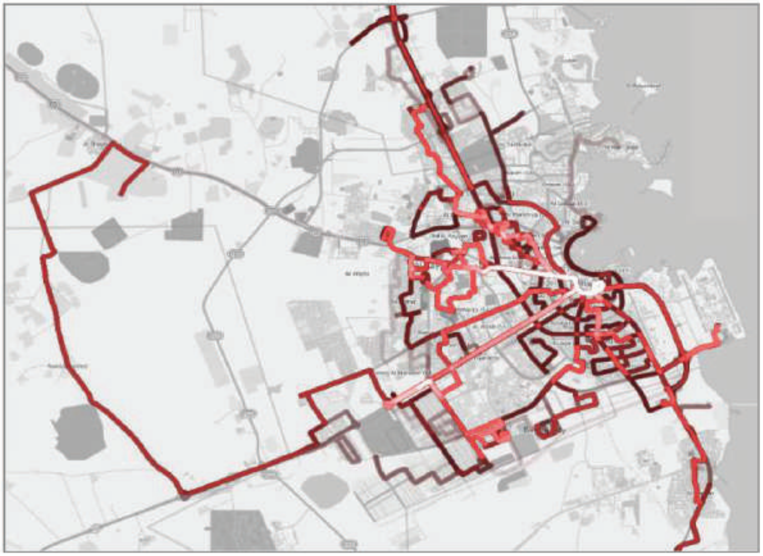
For building the road network model, Ashghal have provided most of the basic information, including posted speed, road alignments, and signalized intersections, for both the existing and future road projects.

The data supplied by Ashghal were complemented by Google Earth analysis and site visits to identify and verify special cases, such as, the opening of a new road or traffic diversions.

For calibrating and validation QABM, traffic survey data were utilized.

2.3.2. Public Transport Network

Mowasalat have been the main source for the Public Transport Bus Network Model. They have provided detailed information on the existing service, including timetables, stop points and bus stations. In addition, Mowasalat provided the ticketing and AVL data, which was employed in calibrating and validating the Public Transport model.



For implementing rail and metro in QABM, the needed data were gathered from QRail. This data included information as well on the Metro Projects and Lusail LRT Project.

Other information related to public transport systems were derived from the Local Master Plans and previous transport models made available to the QABM project.

2.3.3. Household Interviews

Survey Interviews with Household members (HHI) were conducted in 2018 in order to collect the necessary input data for the Activity Based Model. The data made available from the surveys are summarized in the Figure 2-3.

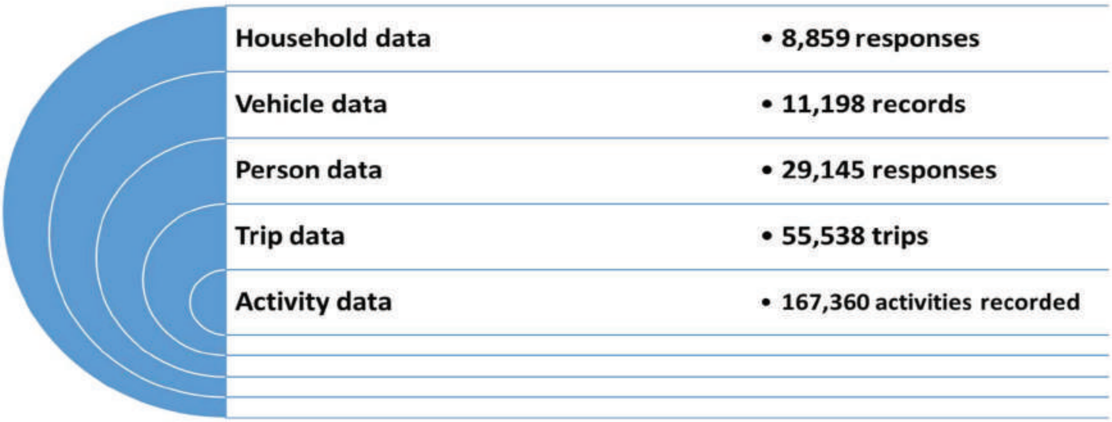


Figure 2.3: Data from Surveys

Table 2.4 gives an overview of the trip rates derived from the surveys on a weekday and weekend for both Doha and Non-Doha regions.

Table 2.4: Trips Results from HHI

Doha - Weekday	Non-Doha Weekday
Average number of trips per person: 2.29 ▪ **Workers: 2.95** ▪ **Non-Workers: 1.05** **Zero trip makers: 27%** **Private vehicle trips: 77%** ▪ **47% SOV**	**Average number of trips per person: 2.27** ▪ **Workers: 2.91** ▪ **Non-Workers: 1.35** **Zero trip makers: 32%** **Private vehicle trips: 82%** ▪ **44% SOV**
Doha - Weekend	**Non-Doha Weekend**
Average number of trips per person: 1.84 ▪ **Workers: 2.12** ▪ **Non-Workers: 1.29** **Zero trip makers: 36%** **Private vehicle trips: 78%** ▪ **26% SOV**	**Average number of trips per person: 2.05** ▪ **Workers: 2.47** ▪ **Non-Workers: 1.44** **Zero trip makers: 39%** **Private vehicle trips: 83%** ▪ **27% SOV**

2.3.4. Traffic Surveys

Traffic surveys were conducted in 2018 on specific road segments, at certain junctions, and along selected routes.

The location of the survey sites were defined by applying a specific methodology that maximized (at the same time) the coverage area of the surveys, the representativeness of the different types of roads and junctions, and their relevance with respect to intercepting the most of the origin and destination trips. Figure 2.4 depicts the location of the traffic survey sites which cover all the Municipalities in Qatar.

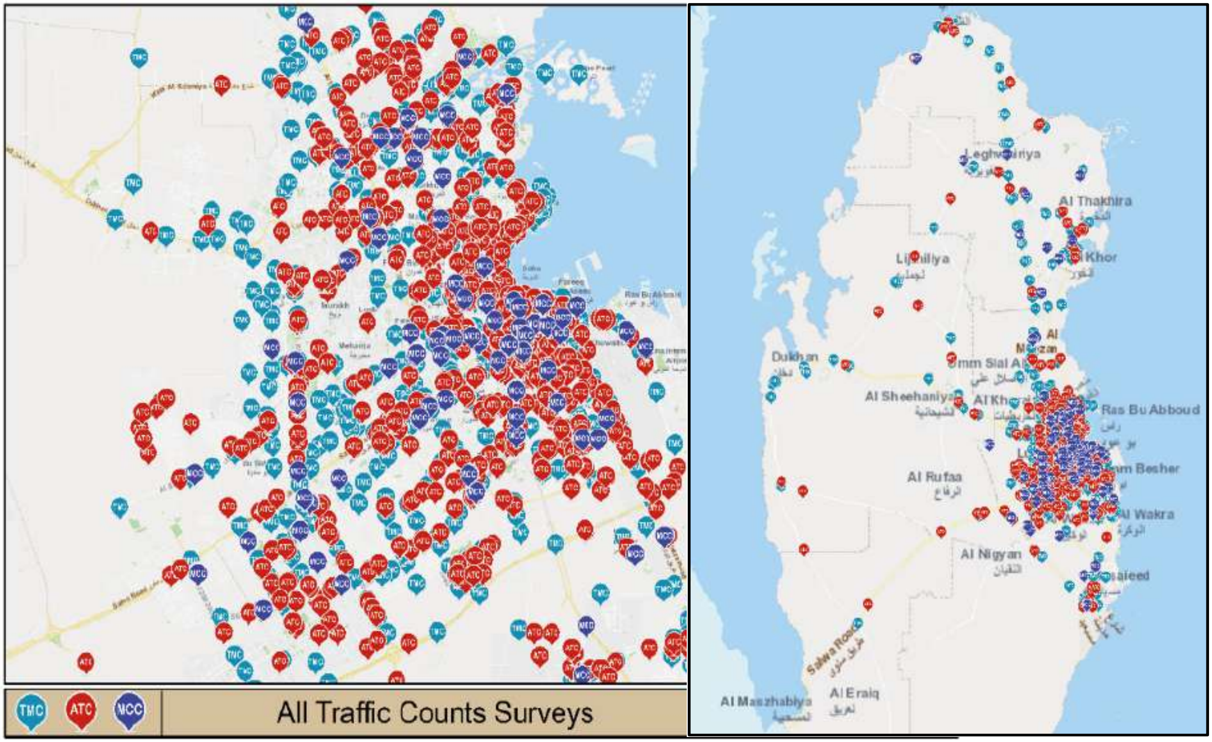


Figure 2.4: Location of Traffic Surveys

SECTION - 03

DEMAND MODEL

3. Demand Model

Modeling Mobility Based on People's Mobility

3.1. Demand Model Overview

The Qatar Activity Based Model (QABM) is based on the Simulator of Activities, Greenhouse Emissions, Networks, and Travel (SimAGENT) developed for Southern California with modifications from lessons learned in the New York Metropolitan Council (NYMTC). The SimAGENT model system was designed to support the California State Senate Bill 375 that explicitly calls for major metropolitan areas in California to meet ambitious greenhouse gas (GHG) emission reduction targets within the next several years.

The Qatar Activity Based Model is designed to address a wide range of mobility policies, yet customized to reflect the Qatar context. Differences in size compared to other countries do not lead to model simplification, and QABM has been designed for a complex multimodal and diverse planning context, with multiple stakeholders and decision makers in different jurisdictions. The new activity-based microsimulation model system is developed to address precisely this diversity among persons and contexts, and it is expected to be used as one of the main modeling tools for Qatar's planning activities.

The modeling framework approach, initially developed for Los Angeles and then implemented in QABM, is now also applied in the Metropolitan Area of New York. This approach is considered one of the 'state of the art' Activity-Based Models. The report *Demand Models Configuration and Modeling Report* provides more detailed information.

QABM is one step further ahead compared to other models because it includes the integration with traffic assignment using automated feedback instead of manual iterations as they are in the original model. QABM also includes a dynamic parking demand model, taking advantage of the detailed time of day destination choice (stops) and activity duration at each stop of ABM. The other unique particularity is the integrated interaction between private and public transport.

3.2. Demand Model Structure

The overall model structure is presented in Figure 3.1 in a cascading schematic form. The set of blocks on the left-hand side represents groups of models that are designed for the first year (baseline) of the simulation that for this application is Year 2018.

Each block of the figure represents a group of techniques and statistical models, many of which are developed to address policy actions aiming to replicate the resident population activity and travel decision making. In essence, the set of models on the left side of Figure 3.1:

- Recreates the resident population and the attributes for each person.
- Configure a daily schedule and
- Ultimately, assigns traffic to the network and computes parking.

In the middle of Figure 3.1, there are the growth forecast and land-use regional economy components that produce changes in time and space. Note that, the agent and environment evolution represent changes in the socio-demographic changes over space and time. This also converts travel times and spatial distribution of economic activity and residential locations into accessibility indicators that drive the travel behavior.

The right side of Figure 3.1 is a repetition of the daily activity and travel pattern models for the simulation of the horizon years.

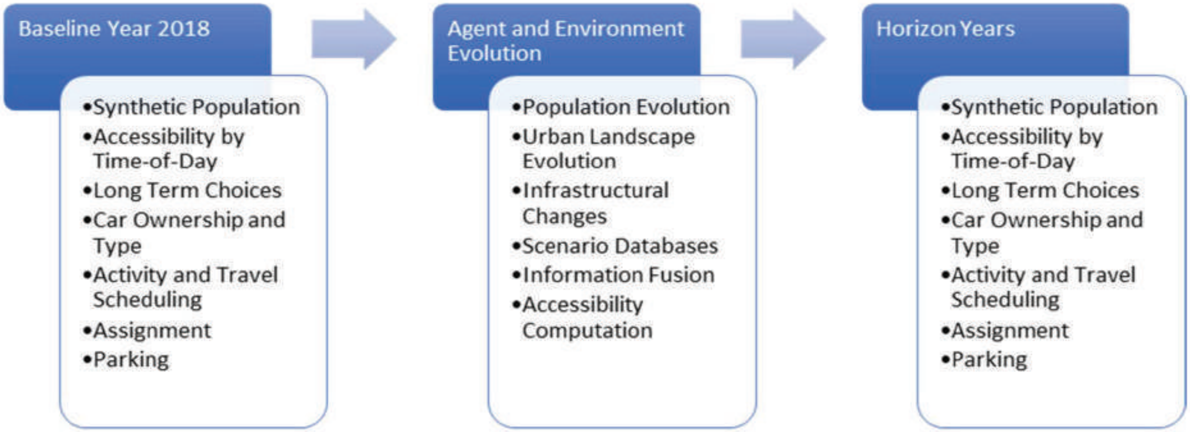


Figure 3.1: Schematic Representation of QABM Blocks

This way, a variety of policies can be assessed at the microscopic level tracking all decisions simulated by the model. For example, land use policies of increasing density and land use mix can be reflected in shifting of the spatial distribution of economic activity, location decisions, car ownership and use, activity participation and destination choices, including decisions in activity participation and in traveling alone or with others.

3.3. QABM Design Specifications

There are four major components in QABM each of which is designed to handle specific tasks.

First, PopGen is the model system used to recreate the synthetic population (household and person characteristics) of Qatar.

Second, CEMSELTS is the component used to give additional socioeconomic and demographic attributes for each person in the synthetic population with a view to developing a rich set of input data for the activity-based microsimulation model system.

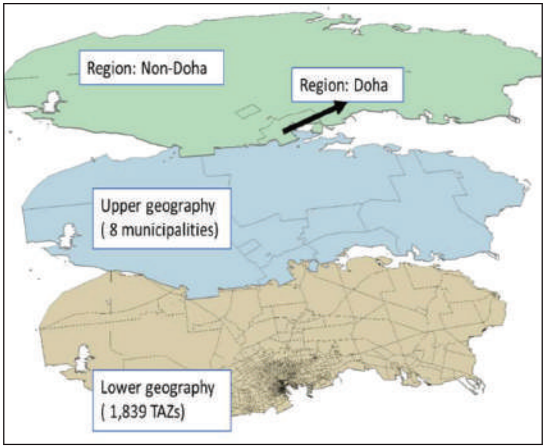
Third, the Comprehensive Econometric Micro-simulator for Daily Activity-travel Patterns "CEMDAP" tailored for Qatar, is the component used to give at each person a daily activity and travel schedule.

CEMSELTS uses imputed data for school attainment and personal/household income. It also appends (transfers) person and household characteristics from the survey data. To avoid major spatial biases, work and school locations observed in the survey data are replaced by predictions using discrete choice models. The complete set of CEMSELTS and CEMDAP models are econometrically estimated so that they can also be used in any future upgrading or updating.

Lastly, the output from CEMDAP is aggregated at zonal level to build O-D trip tables (by travel mode, user class, and time of travel), which are then loaded along with other O-D trip tables into the transportation network by using VISUM.

3.4. Population Synthesis

In QABM, the process starts with an application of the model (PopGen) that synthetically generates/recreates the entire resident population, person-by-person and household-by-household, in Qatar. The input to this software and block of methods are the spatial organization of the simulated area in the form of zone-specific univariate distributions of resident person and household characteristics provided by Qatar Census data. As the population is recreated on a person-by-person and household-by-household basis, these distributions are used as the control totals for each spatial unit of analysis (1,839 TAZ in this version of the model system) in an iterative algorithm that starts from a multivariate set of relationships (in essence a cross-tabulation) among the person and household variables used as seed information.



Based on the population census data received during this project, various control variables have been considered. The description related to the preparation of each control variable is explained next:

Household Level Marginals: The household level control variables prepared are the total number of households, housing unit type, and household size distribution.

Person Level Marginals: The preparation of the person-level variables includes gender, age, nationality, and the total population in the household. Please note that all the person level control variables provide the distribution for a person in the household.

The seed information comes from a household and laborer survey in Qatar. For future years, these distributions are Qatar forecasts based.

Table 3.1 and Table 3.2 provide the comparison between synthetic population and base year marginal data by municipality. The univariate and bivariate comparisons are provided for household, person, and laborer level control variables.

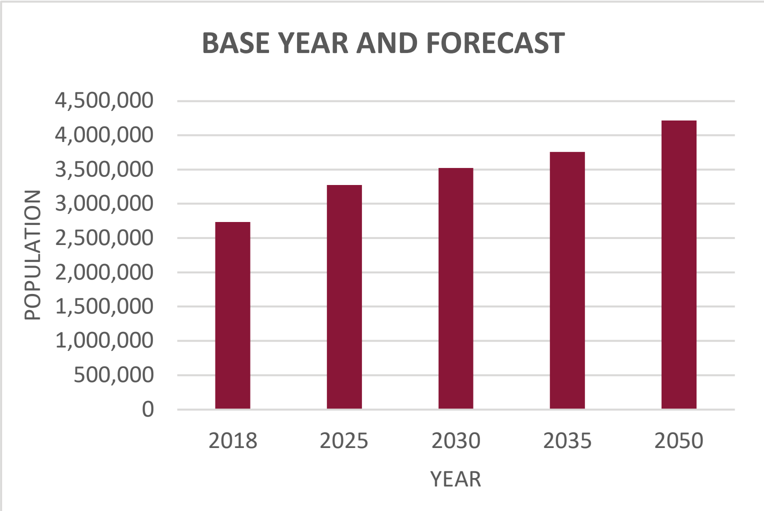


Table 3.1: Comparison between Region Marginal and Synthetic Population at Municipalities

Municipalities	Characteristics	Region Marginal	Synthetic Population	Difference
Doha	Total Households	109,831	109,840	0%
	Total HH Population in	426,964	425,066	0%
	Total Labor Population	660,355	660,354	0%
Al Rayyan	Total Households	70,799	70,796	0%
	Total HH Population	407,420	404,724	1%
	Total Labor Population	281,061	281,051	0%
Al Wakra	Total Households	19,682	19,687	0%
	Total HH Population	89,898	88,184	2%
	Total Labor Population	249,985	249,988	0%
Umm Slal	Total Households	7,914	7,914	0%
	Total HH Population	57,369	55,385	3%
	Total Labor Population	45,878	45,877	0%
Al Dayeen	Total Households	5,490	5,489	0%
	Total HH Population	34,173	33,897	1%
	Total Labor Population	27,635	27,638	0%
Al Khor and Al Thakhira	Total Households	8,677	8,678	0%
	Total HH Population	38,543	38,577	0%
	Total Labor Population	191,081	191,080	0%

Municipalities	Characteristics	Region Marginal	Synthetic Population	Difference
Al Shamal	Total Households	897	896	0%
	Total HH Population	4,664	4,663	0%
	Total Labor Population	5,332	5,333	0%
Al Sheehaniya	Total Households	5,646	5,644	0%
	Total HH Population	27,406	27,065	1%
	Total Labor Population	185,782	185,784	0%

Table 3.2: Comparison between Region Marginal and Synthetic Population

Characteristics	Region Marginal	Synthetic Population	Difference
Total Persons in Household	1,086,437	1,077,561	+0.8%
Total Laborers	1,647,109	1,647,105	0.0%
Total Population	2,733,546	2,724,666	+0.3%
Total Households	228,936	228,944	0.0%

3.5. Accessibility by Time of Day

To represent employment opportunities and the spatial-temporal distribution of activity participation opportunities, opportunity-based accessibility indicators are computed at the level of the TAZ. Accordingly, the model represents the ease (or difficulty) of reaching different types of industries (representing the opportunities for activity participation) from each of these TAZs within travel times of 0-10 minutes, 10-20 minutes, and 20-50 minutes and for travel distances of 0-2km, 2-5 km, and 5-20km). Thus, the model creates geographic “buffers” within which activities and opportunities that can be reached are counted.

The types of industries span a wide spectrum from construction to retail and government services. Different accessibility values are obtained for peak and off-peak periods capturing different roadway conditions, as illustrated in Figure 3.2. Also, procedures to capture patterns of opening and closing of businesses during the day were created by allowing within each period above to also have different opening and closing hours of each industry type.

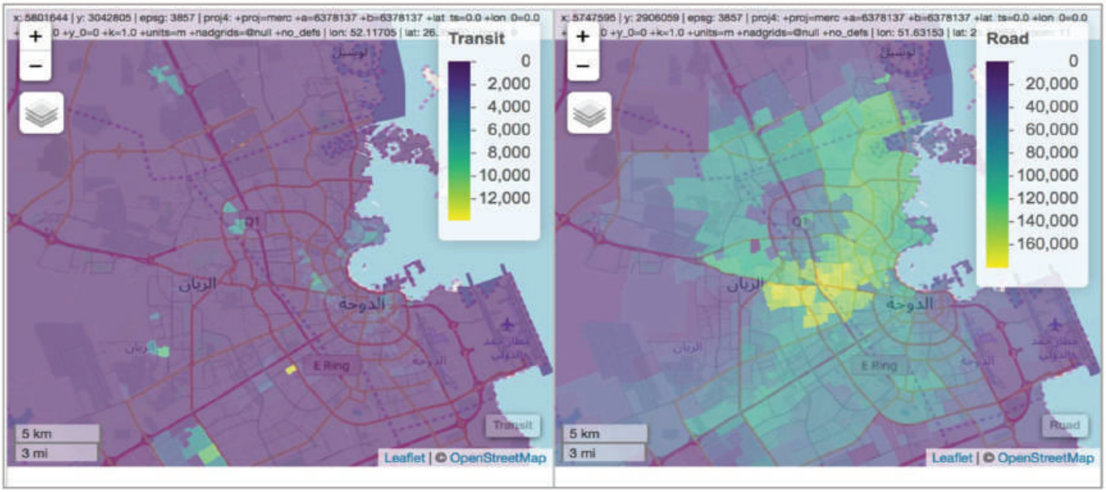


Figure 3.2: Traffic Analysis Zone - Accessibility Maps for the AM, 20-min Buffer for Services

The resident population with its detailed characteristics and a selection of indicators of the accessibility they enjoy are the inputs for the next block. Accessibility indicators are used in many of the behavioral models of the baseline year. Then, for subsequent simulation years, they are modified when the spatial distribution of economic activities changes, and they are also modified based on travel times that may change based on network flow reflecting delays on roads links and at junctions.

3.6. Estimating Long-Term Activities and Mobility Choices

The synthetic population that is obtained from PopGen includes many demographic and socio-economic attributes for each household and persons within the household. However, many of the socio-economic choice phenomena are not explicitly modeled as a function of other demographic attributes within PopGen, thus creating a system where long and medium-term choice decisions are not sensitive to household and person demographic characteristics.

The block of models is designed to estimate long-term activities and mobility choices is called the Comprehensive Econometric Micro-simulator of Socioeconomics, Land Use and Transportation Systems "CEMSELTS". In CEMSELTS, each person and household created in PopGen, and located in each zone of the study region, is given additional characteristics.

For example, for college students, a college destination choice model is used to assign a college TAZ. Workers are identified utilizing a labor force participation model that is a function of age, gender, education, and presence of children in the household. Employed persons are then assigned (in a probabilistic way) to their type of industry, work location, weekly work duration, and work flexibility. Every individual is also assigned a driver's license depending on age, gender, and race. Using these characteristics, household income is computed as a function of the person and household characteristics. This is followed by a residential tenure model (own or rent) and a housing type model to assign each household to a single-family detached, single-family attached, apartment, or other types of residence.

One of the inhibitors in building car ownership, car type and make/model is the existence of many possible alternatives in this choice setting that includes many combinations of available alternatives. The solution here is to use the random utility Multiple Discrete-Continues Extreme Value (MDCEV) model, which is capable of modeling multiple vehicle holdings, body types, fuel types, age, and use simultaneously. The model estimated for Qatar includes vintage and size of the cars owned by households. The model includes as explanatory variables household composition and wealth indicators.

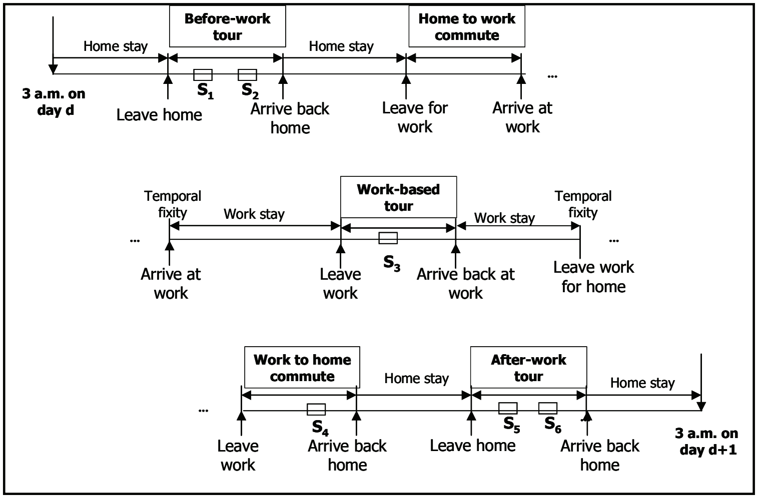
In the developed simulation cascade illustrated in Figure 3.1, the model system produces the spatial distribution of all the residents by different social and demographic levels (including ethnicity) as well as employment and school locations assigned to each person. In addition, each household is assigned to a housing type. This resembles a complete Census of the resident population and can be done at any level of spatial aggregation for which information is available. One could also draw samples from this population or proceed to the next step using 100% of the simulated residents. This is particularly convenient and useful in testing different policy scenarios. It is also possible to focus on a specific subarea (e.g., a city) and perform more detailed analysis and modeling while keeping the rest of the region as an evolving background. The next set of models simulates the life of persons in a day.

3.7. Estimating Daily Activities and Mobility Choices

For each synthetically generated household and person within each household, daily activity and travel patterns are created in this block of models. To do so, a new modified version of the Comprehensive Econometric Micro-simulator of Daily Activity-travel Patterns (CEMDAP) and customized to Qatar is used as the modeling engine that simulates activity-travel patterns of all individuals in the region for 24 hours along a continuous time axis. This model block creates synthetic schedules in two steps:

1. **The generation step** in which work and school activity participation and timing decisions are created, children's travel needs are estimated and an allocation of escort responsibilities to parents takes place when the available data allow this allocation, and independent and joint activity participation decisions are modeled.

2. **Application of the scheduling of activities** that produces the sequence of activities, with the departure and arrival times, activity duration(s), mode for each trip, and determination of the location of each activity.



The models in this way create for each person in a household a complete description of the Activities at the locations and the Movements among locations over space and time. These Activities and Movements are congruent with the Movements of the rest of the household. Therefore, for each person, information is available about the type of activity, when, where, how long, with whom, in what sequence, and interrelationships with other persons and locations in the engagement pattern. In the generation step, working and student adults are first passed through models that predict if they will work or go to school in the simulated day. Then, models assign start and end times for their work and school activity. Conditional on these start and end times, a household level model is then used to simulate combinations of joint and solo activities for all persons.

This provides an intra-household consistent schedule of activities and makes the entire simulation feasible because its formulation decreases the number of alternatives to simulate.

Joint and solo activity durations are predicted for shopping, maintenance, social, entertainment, visiting active recreation, eating out, and others. In addition, durations for work-related and other serving passengers are also modeled. Activities are then arranged in tours (complete sequence of stops and trips starting and ending at the same location) and the modes used are predicted accordingly.

Figure 3.3 provides an example in which there are two adults that go to work and a child going to school independently. In the evening they all go out for dinner. The trips, stops, activity types, activity start and ends times, modes are all determined by the simulation that includes persons in households and laborers. Simulation of policy causes changes in destinations, activities alone and with others, durations, and modes creating "realistic" behavioral changes.

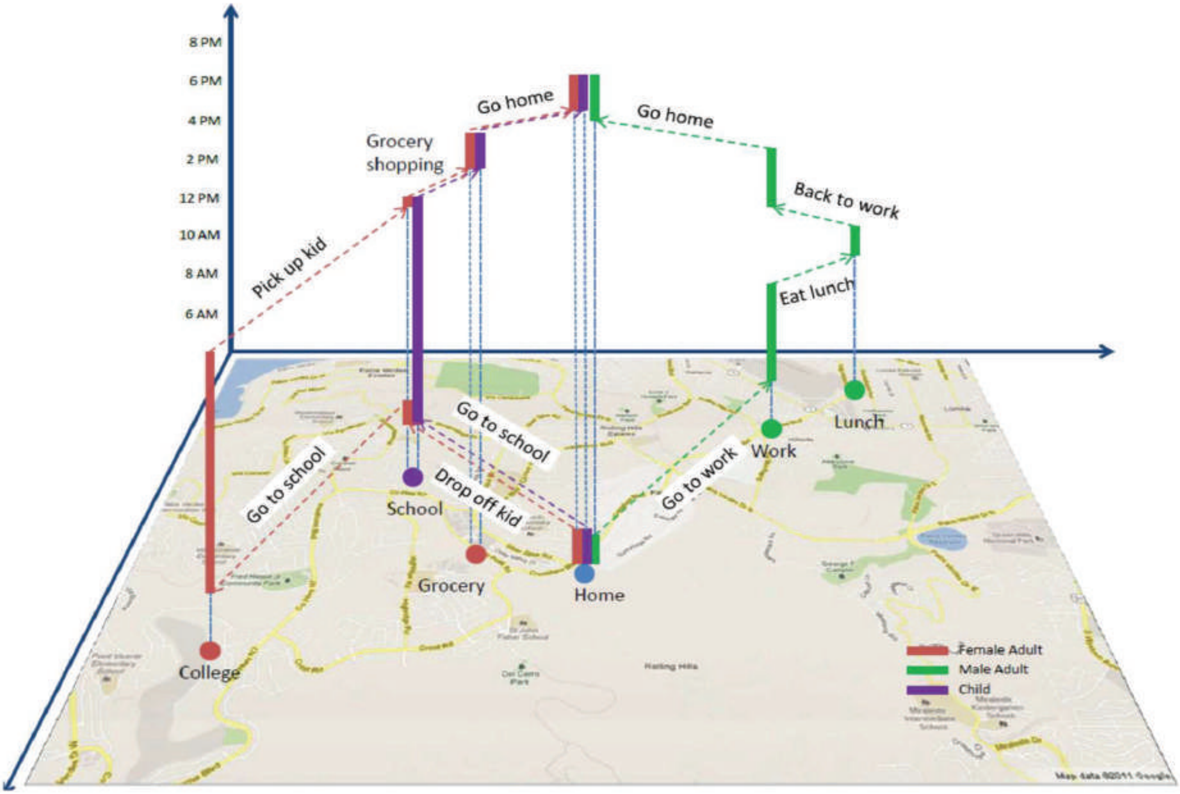


Figure 3.3: Example of a Daily Three-Person Household Schedule

3.8. Data Input

The core data used by many of the QABM components are from the survey interviews with household members (HHI), which is explained in Section 2.3.3. HHI collected household activity-travel, specifically information on:

1. Household-level characteristics (e.g., household location, household structure, income, vehicle ownership, bicycle ownership, housing characteristics, and house ownership)
2. Individual-level characteristics (e.g., age, gender, race, ethnicity, education, student status and school location, employment status, employment location, work hours, and the ownership of driving license), and
3. Information of the travel undertaken by individuals, which includes how, why, when, and where they traveled.

Time use and activity surveys also collected additional information on the activities participated by individuals such as timing, and duration of in-home, at work, and at other place activities. Many household travel surveys also include information about the fleet of household vehicles owned, including the make, model, year of manufacture, and additional information about each vehicle and related transactions.

Surrounding these core data elements are land use and infrastructure data that include information on the spatial residential characteristics of households, employment locations, school and activity opportunity locations, and transportation network data that includes highway network (roadway functional class, distance, direction, number of lanes, hourly capacity, posted speed limit, and so forth) and transit network data (routes followed by buses and trains, the frequency of service, travel speeds, distance, and travel time among nodes in the network).

TRANSPORTATION MASTER PLAN FOR QATAR
STRATEGIC TRANSPORTATION MODEL

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SECTION - 04

SUPPLY MODEL

4. Supply Model

Updating and Upgrading Transport Network Models

4.1 Supply Model Overview

QABM has a strong formal structure for the transport network supply models. The transport networks are coded by including the roads, bus lines and metro services that have been realized or are planned. In addition, the capability of the supply models to reproduce the real phenomenon was developed through detailed modelling, exploiting the data emerging from the extensive surveys which we carried out. A summary of the coded network supply features implemented in QABM is presented in Table 4.1.

The network coding has a highly detailed representation of the road junctions, which includes - in a unique form - all available turning maneuvers. Through this representation, each traffic light was coded with signal settings. The *Supply Models Configuration and Modelling Report* provides more detailed information.

Intermodal connections were also introduced in QABM by implementing new parking and park and ride models, and so is a new crowding model to consider possible congestion effects that may occur in future scenarios when the metro network is completed and demand has ramped up.

Table 4.1: Summary of Coded Supply Features in QABM

Feature	Numbers
Links	182,502
Nodes	64,769
Turns	553,328
Main Nodes	1,344
Main Turns	76,694
Count Locations	1,242

4.2. Zoning System

The TAZ system has been developed to be compliant with the enhanced capabilities of the model. QABM utilizes huge datasets related to the population such as composition, socio-economic characteristics, etc. Since these data are collected from different sources and are usually classified by administrative boundaries, the TAZ system is compliant with all these boundaries.

There are currently various administrative zoning systems being used by different authorities in the State of Qatar. In a descending order of their spatial resolution, these are Municipalities, Planning Zones, Districts and Census Blocks. Most of these administrative zones have been subject to modifications due to the implementation of many projects and developments. Major changes were observed in the Census Block boundaries from Year 2010 to Year 2015. Accordingly, the new zone system has been developed as the aggregation of Census Blocks, thereby placing TAZ between Census Blocks and District Boundaries in the overall hierarchy of the Administrative Zones.

The TAZ system ensures consistency with administrative boundaries, new mega projects, future primary road network, and metro transit lines. QABM also includes the location of new Park & Ride sites and representation of external generators. The final zoning system of the QABM includes 1,839 TAZs.

Figure 4.1 and Figure 4.2 show the changes made to the zone boundaries to ensure that the zone are compatible with the Census Blocks and the planning zones.

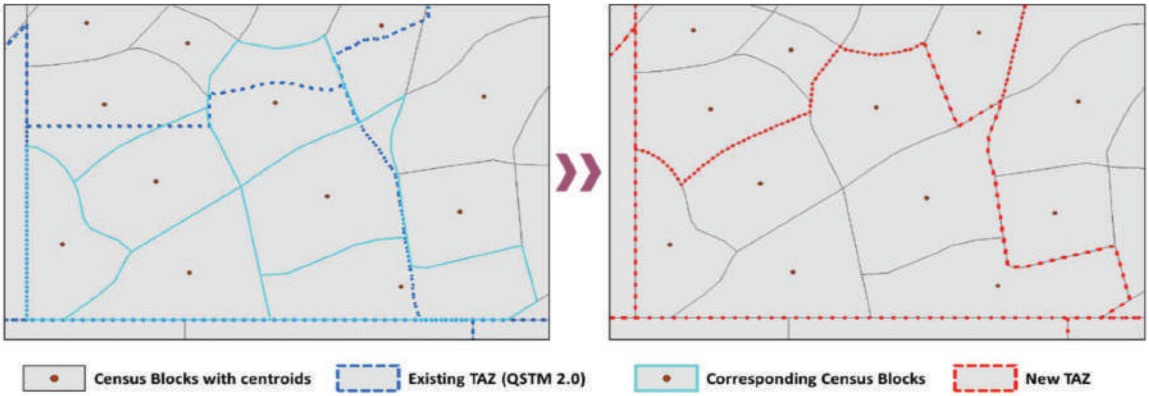


Figure 4.1: Adjusting the TAZ Boundary to be Compatible with Census Blocks

Figure 4.2: Zoning System is Compliant with the Planning Zones

The TAZs in QABM have been classified according to their location in each municipality, as Figure 4.3 illustrates.

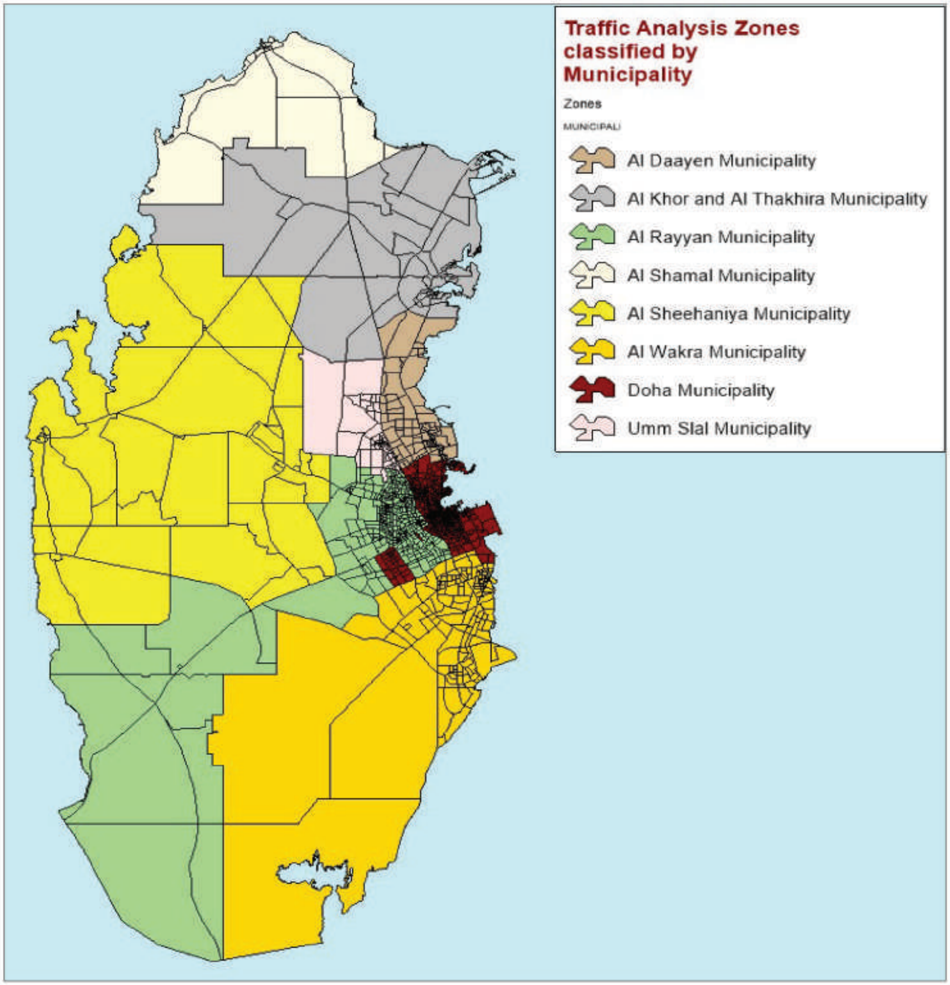


Figure 4.3: Zone Classification According to Municipality

4.3. Road Network Model

The road network model development started from the collected data and engulfed numerous steps. These are illustrated in the next sections. Topology validation and the road hierarchy update required, as aforementioned, the undertaking of some site visits and analysis of many sources of information, including GIS data and Google Earth, as the schematic flowchart in Figure 4.4 explains.

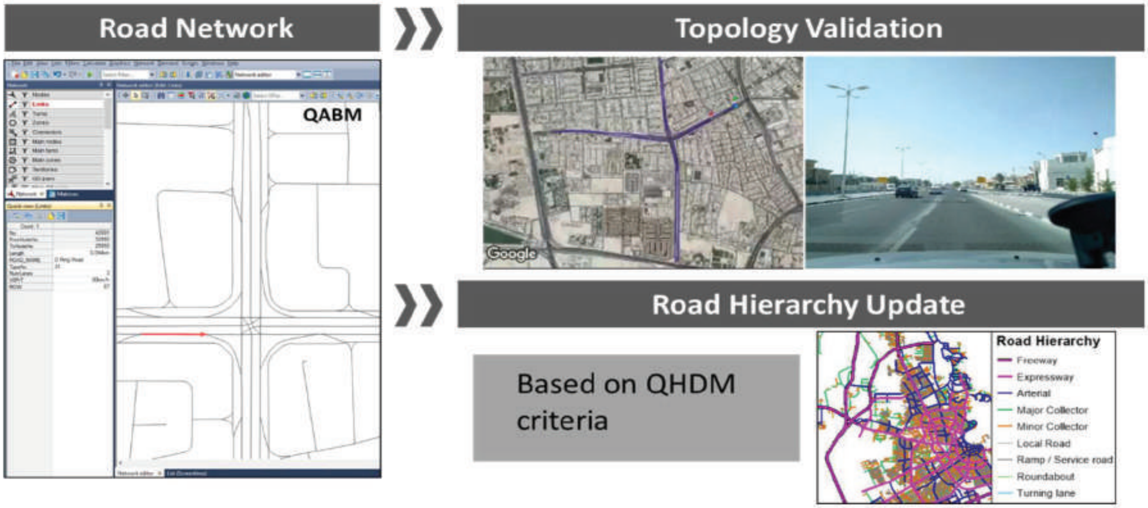


Figure 4.4: Topology Validation and Hierarchy Update

4.3.1. Road Network Coding

1. **Network Coverage.** The road transport network model covers the whole State of Qatar. Several road network models were built:

- One representing the existing – Base Year road network
- Others representing future conditions – Horizon Year Road Networks

Each horizon year road network model includes all the improvements foreseen - committed and planned - for the specific horizon year to establish the corresponding realistic Scenario.
The evolution of the road network from the base year of 2018 to the ultimate horizon year of 2050 is displayed in the Figure 4.5.

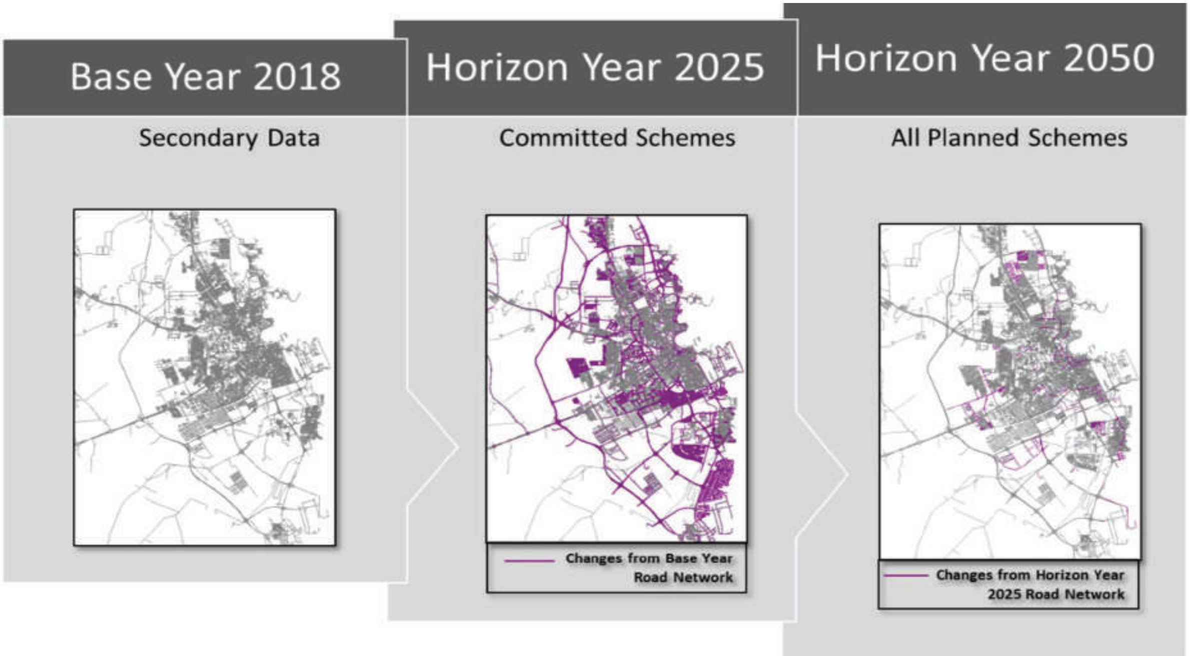


Figure 4.5: Road Network Model Evolution

The road network mirrors the road hierarchy that defines the road functionalities, which are broadly classified into Freeway, Expressway, Arterial, Major Collector, Minor Collector and Local Streets.

The road network has been coded in every details in order to capture even the smallest interactions between conflicting turning movements at junctions, between buses and general traffic, and between pedestrian and bicycle flows and other traffic.

The network graph topology implementation required a careful representation of centroids and zonal connectors to ensure that the loading of traffic on the road network is as realistic as possible. Figure 4.6 gives on an example of density of the road network and how this is connected to the local areas.

Walk and bike paths have been coded along the road network by introducing new a transport system and specific link codes. This coding method enables an accurate representation of barriers, pedestrian crossings at signalized junctions and the existence of pedestrian footbridges.

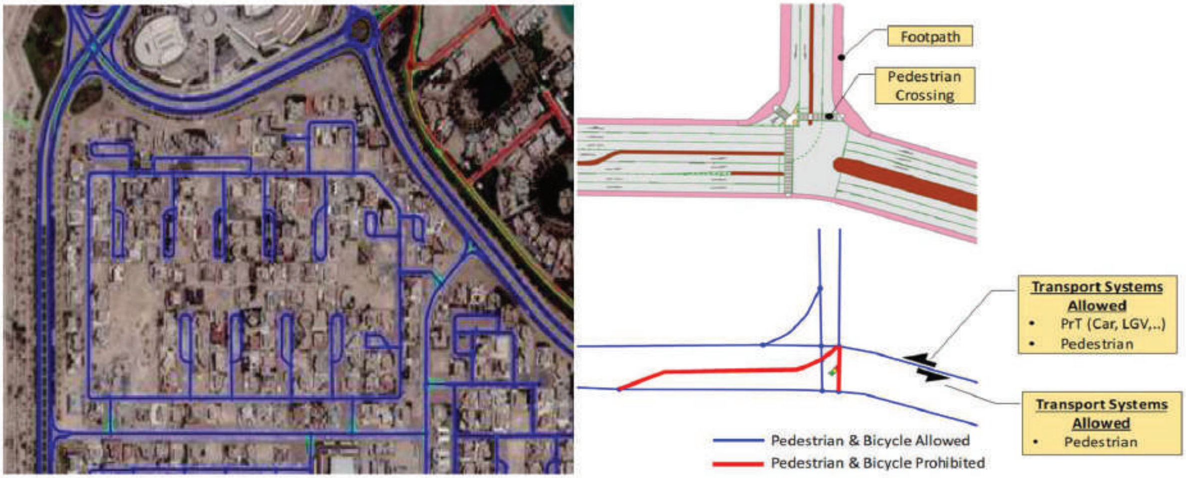


Figure 4.6: Level of Detail of the Road Network Graph

2. **Road Hierarchy.** The **r**oad hierarchy has been updated to be compliant with the criteria defined in the Qatar Highway Design Manual. The new hierarchy ensures a closer correspondence between the physical characteristics of the roads and modeling requirements. The adjustment of the road hierarchy was based on the application of the following criteria:

    - Area Type (Urban/ Rural)
    - Number of Lanes
    - Posted Speed
    - Right of Way
    - Frontage Land-use

The process for updating road hierarchy in the road network was carried out in two steps.

The first step included an audit of the existing road hierarchy implemented in QSTM - from which the road network in QABM was developed - in order to confirm the consistency between rural and urban classification, as set out in QHDM.

In the second step, a more elaborate, analytical approach was followed. Initially, the identified road corridor sections, based on homogeneity and corresponding information related to the above criteria (rural versus urban), were categorized in a database format. Then, the existing hierarchy for each corridor section were verified with the ranges specified in QHDM, while applying predominant values of the road hierarchy.

Figure 4.7 displays the road network hierarchy implemented in QABM.

Figure 4.7: Road Hierarchy in Qatar - National level (left) and Greater Doha (right)

4.3.2. Private Transport Model Specifications

1. **Transport Demand Segments.** The Transport Demand is divided into the following segments:
    - Car High-Income level
    - Car Medium Income level
    - Car Low Income level

- Company Bus
- Taxi
- Light Goods Vehicles
- Heavy Goods Vehicles Restricted
- Heavy Goods Vehicles Permitted

All these demand segments are represented in Origin-Destination matrices which are assigned to the road network. Public transport bus services are built into the road network layer so that bus travel speeds are kept synchronized with the speed of other vehicles (cars, heavy goods vehicles, etc.).

Thresholds for the Value of Time (VoT), which forms one of several components of the generalized travel cost experienced by travelers, have been defined based on income levels derived by Household Interviews analysis, as follows:

- Low Income: less than 10 QAR/h
- High Income: more than 26 QAR/h.

The other components of the generalized traffic cost include distance-related costs (e.g. fuel), parking charge, and road use charge (if applicable).

2. **Road Link Attributes.** In the road network model, each road link has several functional attributes. These are:

   - Capacity
   - Free flow speed (speed limit)
   - Minimum speed

- Number of lanes
- Permitted types of vehicles which can traverse the link
- Permitted maximum speed of evert transport system that can use the link
- Transport system specific speed for the calculation of bus run times from the link lengths

A specific attribute has been introduced in QABM that specifies the speed of Public Transport in either shared or protected lanes depending on the car speed.

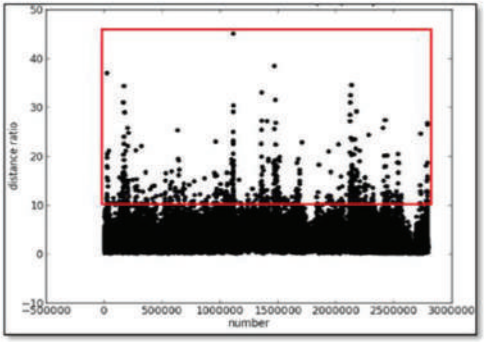
Road links having the same values of the functional attributes are classified within the same link type. Up to 100 link types are allowed in the software used. These link types serve as network classifiers and make it possible to assign type-specific standard values for the above defined attributes.

3. **Vehicle Classes.** The vehicle classes that can be permitted on each element of the network are defined as follows:

- Private Car
- Company Bus
- Public Transport
- Light Goods Vehicles
- Heavy Goods Vehicles Restricted to certain areas and zones
- Heavy Goods Vehicles Permitted to certain areas and zones
- Pedestrians

4.3.3. Road Network Error Checking

The setting up of a large, detailed and complex road network model such as the one encompassing the whole of Qatar is an arduous task and is naturally prone to coding errors. To avoid such coding errors are not carried forward, a careful and a thorough review of the road network was launched. This was assisted as well by the building of an automated error checking procedure that considers every element of the road network model for ensuring correctness of coding, reasonability of values, and connectivity with the rest of the road network.



Type Number	Control Type	Number of Nodes
0 or 1	None	21,606
31	Priority Control	8,453
38	Merging	3,416
51	Uncontrolled	22,916
99	Part of Main Node	8,060
	Total	64,451

The automated error-checking procedure outputs a frequency distribution analysis which can be utilized for spotting anomalies, such as an unrealistic link speed or a capacity value, in addition to checking bus routes and as to whether they double back on themselves, for instance. The errors identified by the checking procedure can then be verified by the user of the model who will judge whether they are genuine errors or acceptable from a coding perspective.

More details on the error-checking procedure are available in the *Supply Model Configuration and Modelling Report*.

4.4. The Public Transport Network Model

4.4.1. Features of the Implemented Public Transport Model

The public transport (PT) model implemented in QABM has the following features:

1. **Public Transport Network Coding and Implementation.** This covered the implementation of all PT services currently operating in Qatar in the base year model, all planned PT services in the future year, together with all the connectors and transfer links between the various PT services, including those between metro and buses.
   The evolution of the public transport network from the base year of 2018 to the ultimate horizon year of 2050 is displayed in the Figure 4.8.

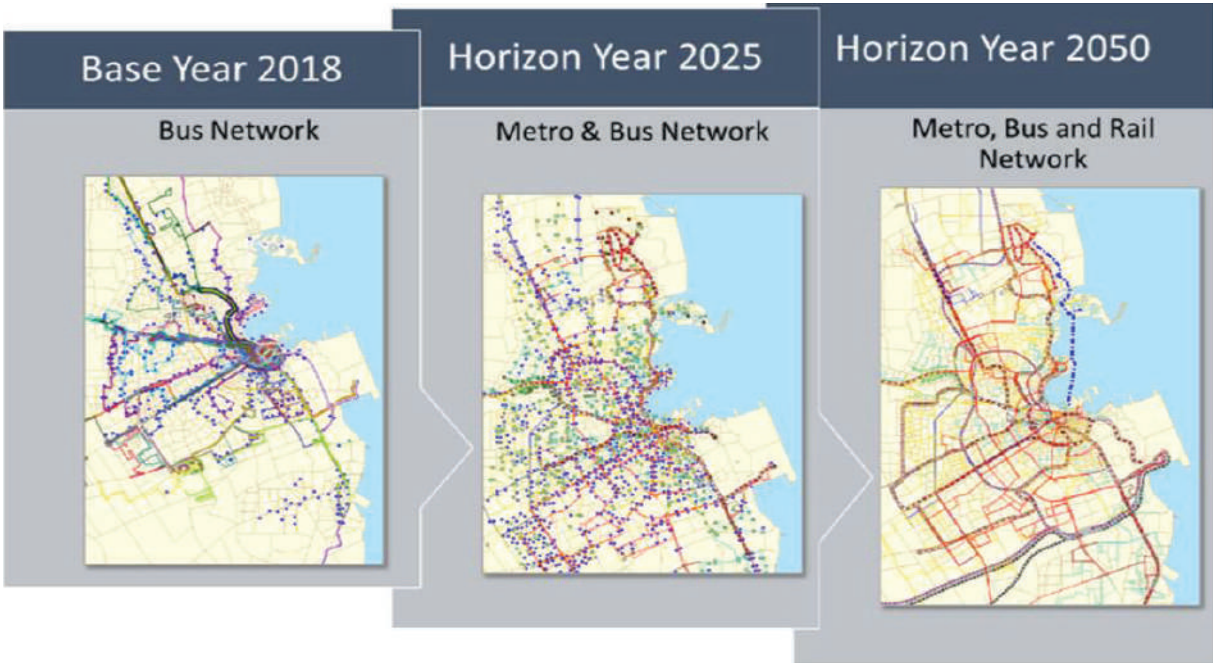


Figure 4.8: Public Transport Network Model Evolution

2. **Public Transport Network Assignment.** For the public transport assignment, both the timetable-based and headway-based assignment were followed. The timetable-based assignment is used for the Base Year model due to the low frequency of services, while the headway-based assignment is implemented for the Horizon Years when Metro, LRT and bus services become more frequent.

3. **Transit Crowding Modeling.** Crowding can have a somewhat large impact on PT services in the form of discomfort, additional delays, and in some cases lack of space for boarding a particular the PT service; thus, resulting in additional delays from having to wait for the next service. To account for these various elements of a PT trip, a crowding model has been implemented in QABM.

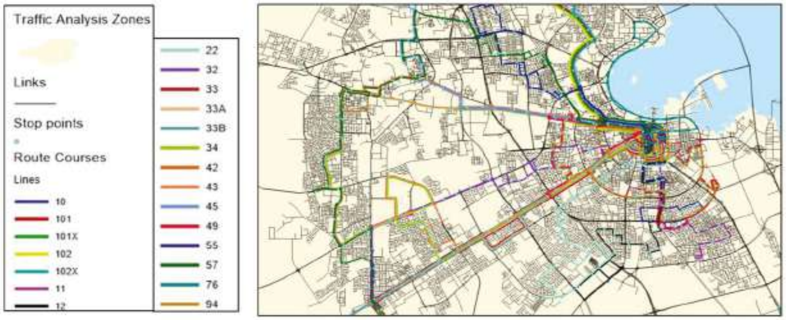
4. **Fare System Representation.** The fare system implemented in QABM shadows that of the existing card-payment system in the base year, which is basically distance-based. In the horizon year models, the fare system has been implemented and developed according to the information available in the Qatar Bus Routes Operation Study "QBROS" fare system. This is as follows:
    - A multi-modal ticket that allows users having free transfer among bus, Metro and LRT lines within the Greater Doha area.
    - A single-mode ticket for LRT with a flat fare of QAR 3.00.
    - A distance-based ticket for trips where only bus is used, similar to the current fare for the bus network.
    - A zone-based ticket for water trips, with free transfers between the bus and water services.

5. **Interaction between Private and Public Transport Supply.** It essential that bus travel times are representative of the travel times on the road network where they share a common space. Accordingly, public transport bus services have been built into the road network layer in QABM so that bus travel speeds can be kept synchronized with the speed of other vehicles (cars, heavy goods vehicles, etc.). To fully account for this, a special procedure which updates the bus travel times in the PT model, based on the travel times experienced in the road network, has been implemented in QABM.

The main features characterizing the public transport model updates and upgrades are summarized in Table 4.2.

Table 4.2: Public Transport Model Updates and Upgrades

UPDATES	UPGRADES
Existing bus network updated to February – March 2018	Crowding Model
Detailed Timetables	Interaction between Private and Public Transport Supply
Qatar Bus Route Optimization Study included in the Model implementation	Fare System
Existing and future Rail Network input data updated to April – May 2018	
Education City and Msheireb Tram System coded as built	



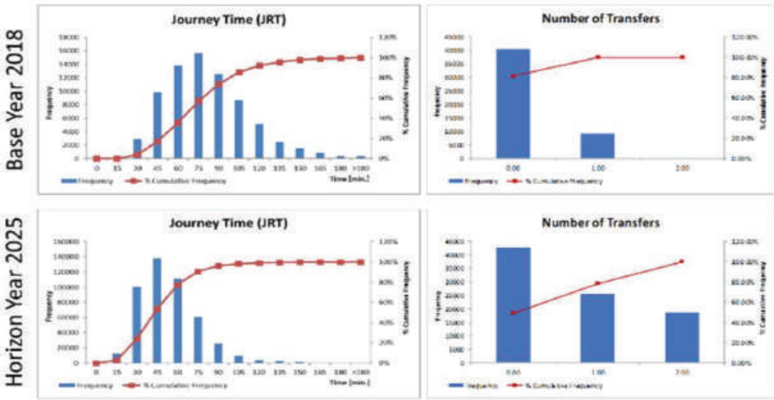
4.4.2. Public Transport Network Error Checking

In line with the error checking procedure developed for the road network, a similar error checking procedure was built for the public transport network. The error checking procedure applied to verify the PT network supply model in QABM performs the following checks:

- Consistency of the VISUM PT network
- Public transport routes and alignments
- Public transport services
- Network skimming

The *consistency checks* verify the connection of all the zones to the PT network, the links, the PT vehicles, connectivity between the stops forming a stop area or a PT interchange, the vehicle journey sections and the trip chains.

Checks on the *public transport routes and alignments* are performed through a visual examination of the network, comparing the data provided with those resulting from model implementation.



Checks on *Public transport services* comprise inspecting public transport travel times, speed and line length. These checks are summarized in frequency distributions.

Network skims are the result of determining the value of indicators (such as the travel times, costs and distances) between each zones pair for which a PT service is available. The PT skimming procedure contains a set of rules which have been set out for maximum and minimum thresholds to be applied (e.g. minimum public transport in-vehicle time) for identifying possible errors.

4.4.3. Calibration of the Public Transport Model Parameters

PT travel times have been calibrated by using the ridership data of public bus services operated by Mowasalat. This data refer to boarding and alighting passengers at stops from 1 November 2017 to 8 May 2018 (i.e. 189 days) and consist of 5,236,000 records. Using the boarding time element of such data, it is possible to compute the travel time of the vehicle journey items between two stops, as the difference between the boarding times at the two stops. The adopted methodology for the calibration process aims at defining a set of model parameters able to reproduce the three peak periods (AM, MD, PM) of a typical workday.

The calibration of the model parameters has been carried out for both timetable-based assignment and headway-based assignment. Observed data for boarding passengers at stops were used for the calibration, whilst alighting data were used for the validation. During the calibration, such values are compared with the “simulated” ones obtained by using the base-year PT model. The PT model assignment performs the interaction between the demand and the supply to obtain boarding and alighting passengers at stops, which vary according to the tentative values of the coefficients within the calibration procedure.

The calibration process is made up of PT assignments using coefficients which vary iteration-by-iteration, aiming to minimize an objective function which is defined as a linear combination of the sum of weighted squares of the difference between simulated and observed data, in each of the peak periods (AM, MD, PM).

Since the calibration is done by using aggregated data (passenger counts at stops), the calibration process used the Goodness-of-Fit statistics, such as, the Mean Absolute Error (MAE), Root Mean Squared Error (RMSE) and the Determination Coefficient (R^2). The results are reported in Table 4.3, where the error statistics have been calculated for both the initial (starting values) and the optimal set of coefficients. All statistics show improvements from the initial conditions at the start of the optimization process; thus, demonstrating the quality of the calibration process.

Table 4.3: Timetable-based calibration – Goodness of Fit (GoF) statistics

Goodness-of-Fit statistics	Timetable-Based Assignment		Headway-Based Assignment	
	Initial Value	Optimal Value	Initial Value	Optimal Value
MAE	2.94	2.70	2.94	2.70
RMSE	14.70	11.58	14.70	11.58
R^2	0.81	0.89	0.81	0.89

4.5. The Parking Model

The parking model in QABM embodies a two-level approach:

- The first level is a disaggregated parking model that is built within QABM, since QABM explicitly emulates parking behavior.
- The second level is within the network model which incorporates a capacity restraint mechanism in the parking choice model.

The second level of the model is called a "network-based parking model," whose role is to distribute the parking demand among the different available alternatives on the basis of the cost utility (or, more precisely, cost dis-utility) describing the parking choice of each user class for each parking type.

Due to the need to differentiate between the various behaviors in the parking choice process, the "network-based parking model" operates by distinguishing between the following:

- Parking Type: According to Qatar Parking Master Plan "QPMP", the following parking types are considered: 1) On-street free; 2) Off-street free; 3) On-street charged; 4) Off-street charged.
- User classes (Qatari/Non-Qatari) and income segmentation (low, medium and high income) have been included implicitly in the model adopting the Value of Time (VOT), thus allowing the possibility of examining alternative charging strategies in future scenarios.

The “network-based parking model” works at the zone level (TAZ). For each destination zone, a set of alternative TAZs for parking are selected, thus generating what can be described as the Catchment Area (CA) related to that specific destination. The Catchment Area concerning a specific destination TAZ is composed of all the TAZs satisfying a maximum walking distance, set at 400 meters. The cost utility for determining the choice of parking location includes, for each time interval, the available parking alternatives in the Catchment Area related to the parking destination. The parking search time in each zone and parking type is a function of the parking occupancy level. This function yields higher values for the search time for more capacitated car parks.

The Value of Time (VOT) adopted for the cost utility computation reflects the opportunity cost of time spent traveling versus time that could otherwise be spent performing other activities. This is customarily expressed as a fraction of the household income.

The main output of the “network-based parking model” is parking occupancy in each TAZ for each time interval and parking type, as Figure 4.9 visualizes. More details about the VOT are provided in the *Demand Models Configuration and Modelling Report*.

The parking choice model is applied to each person (person list from QABM/CEMDAP) following a disaggregated approach. The algorithm tracks any single trip and user and computes the parking choice probability in the specific time interval according to Logit model formulation. Thus, it can be considered as a microsimulation model analyzing each trip, where all the trips are ordered by their time of arrival to the desired parking zone and type. The probabilities of alternative TAZs parking are equal to zero until there is capacity available in the parking destination zone (for the considered parking type). If capacity of the car park is reached, then the parking choice model computes the probabilities of parking in alternative TAZs.

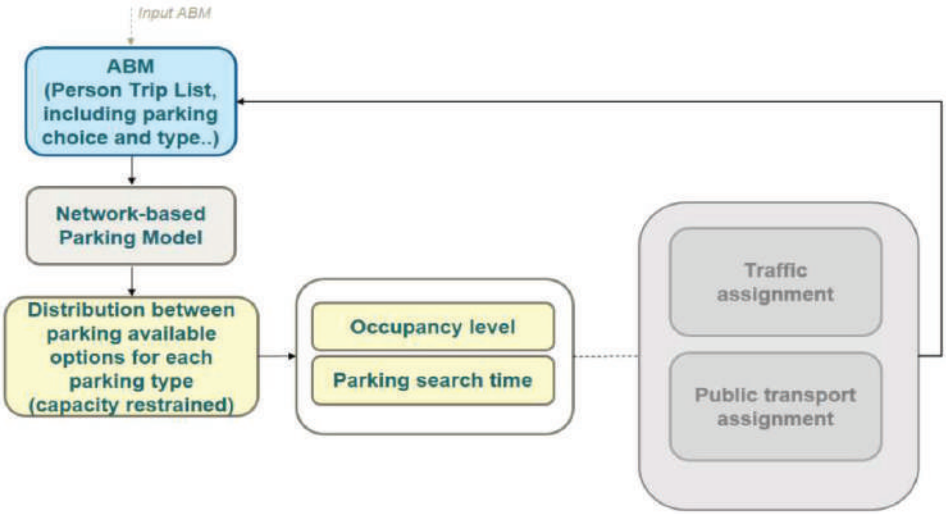


Figure 4.9: Output of parking model and QABM-road network model integration.

The parking choice model is probabilistic, but the final choice is AON (All or Nothing), through the adoption of a Roulette Wheel; thus, it is not possible to split one user between different parks.

In addition to the loading phase, the parking choice model includes the unloading component of each car park by each user, taking account of the parking time duration or when the user activity time has expired. Figure 4.10 shows the residual capacity at nighttime for on-street (a) and off-street (b) within Doha.

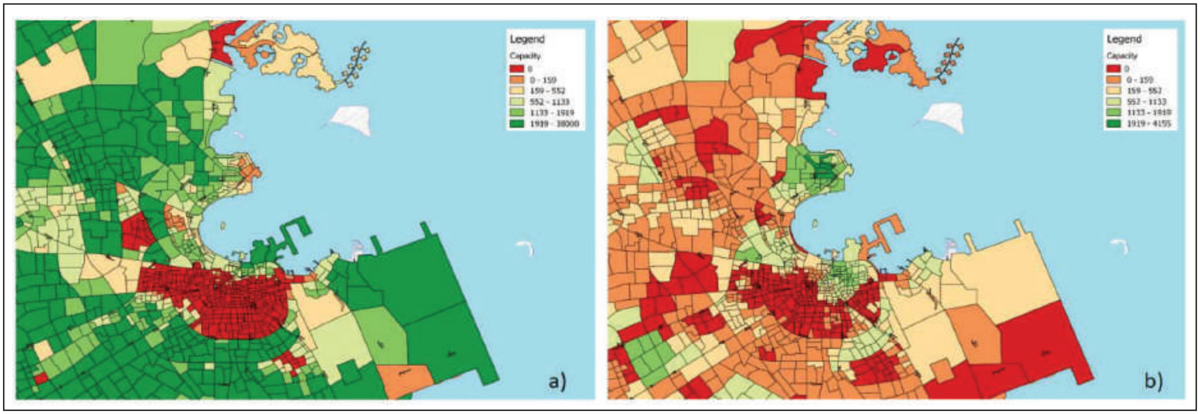


Figure 4.10: Residual Night Time Capacity of on Street (a) and off-Street Parking (b) in Doha

4.5.1. Calibration of the Parking Model Parameters

Due to the lack of sufficient information during the development stage of QABM to calibrate the parking model, the values of the parameters of the random utility model parking model and the value of time have been determined from the technical literature where such a model has been successfully implemented.

4.6. The Park & Ride Model

Accurate modeling of Park & Ride is fundamental for representing the mixed mode choices of the transport network users. Park & Ride is required for Qatar for the evaluation of future scenarios, involving different types of public transport alternatives. QABM has been empowered by such a model.

The Park & Ride model (P&R) in QABM allows the simulation of individual trips that combine the private mode for the first component of their journey and parking at the Park & Ride site, and subsequently use public transport for the second component of their journey. This QABM feature does not only enable the assessment of the benefits of introducing Park & Ride services from the reduction of car trips - and accordingly reduced congestion - but also the evaluation of alternative scenarios in terms of location, dimension and fare systems of the Park & Ride sites.

The Park & Ride model that has been implemented in QABM has many similarities with that of the parking model described above, except for that the car park is at an intermediate location within the road network, rather than at the destination point, and that the available car park at a TAZ are the Park & Ride sites themselves.

The QABM Park & Ride model - referred to below as the “network-based Park & Ride model” - is fed by the Park & Ride demand that is determined by the higher tier model (CEMDAP). The “network-based Park & Ride model” simulates the loading process of the Park & Ride sites and modifies the Park & Ride site selection when the parking occupancy is close to capacity. In that sense, it considers parking search time as being a function of the parking occupancy level of the Park & Ride site.

In a similar fashion to that of the "network-based parking model," the "network based Park & Ride model" works at the zone level; that is, each Park & Ride site is represented by a TAZ.

On the other hand, whereas the definition the Catchment Area in the "network based parking model" is based on the preset walking distance value of 400m, in the "network based Park & Ride model," the set of alternative Park & Ride sites for each OD pair are defined using a number of rules. These rules are presented below. They mainly serve the purpose of both limiting the number of Park & Ride alternatives for each traveler and avoiding the choice of unrealistic Park & Ride sites.

The output of the "network-based Park & Ride model," as Figure 4.11 displays, comprise:

- The parking occupancy in each Park & Ride site "P" for each time interval "t". The occupancy level is provided as a skim matrix (for each TAZ representing a Park & Ride site).
- Updated O-P private demand matrix and updated P-D transit demand matrix, due to the use of Park & Ride site P.

The same disaggregate approach that is applied in the "network-based parking model," is followed for loading and unloading each Park & Ride site, and so is the choice of a Park & Ride site that is made on the same principles of utility formulation. The utility in the Park & Ride model differs though and is calculated as is expressed as the sum of VOT car travel time from the origin to the Park & Ride site, parking search time in the Park & Ride site, initial waiting time by public transport from the Park & Ride site to the final destination, onboard travel time by public transport from the Park & Ride site to the final destination, plus the parking cost and/or PT fare.

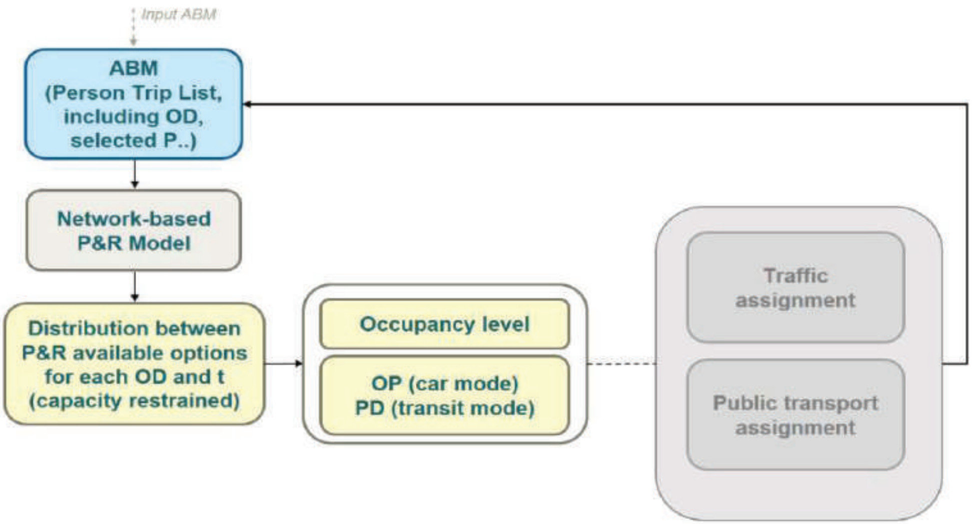


Figure 4.11: Output of Park & Ride model and QABM-supply model integration

4.6.1. Park & Ride Sites

Eleven Park & Ride sites have been identified in QABM. Table 4.4 presents the Park & Ride sites which have been integrated into QABM, and Figure 4.12 shows the location of these Park & Ride sites.

Table 4.4: List of Park & Ride Sites Represented in QABM

Site No.	Location / Site Name
1	Al Wakra
2	Matar Al Qadeem
3	Sports City
4	Al Messila
5	Al Riffa
6	Education City
7	Katara
8	Legtaifiya
9	Lusail
10	Al Qassar
11	Equestrian Club

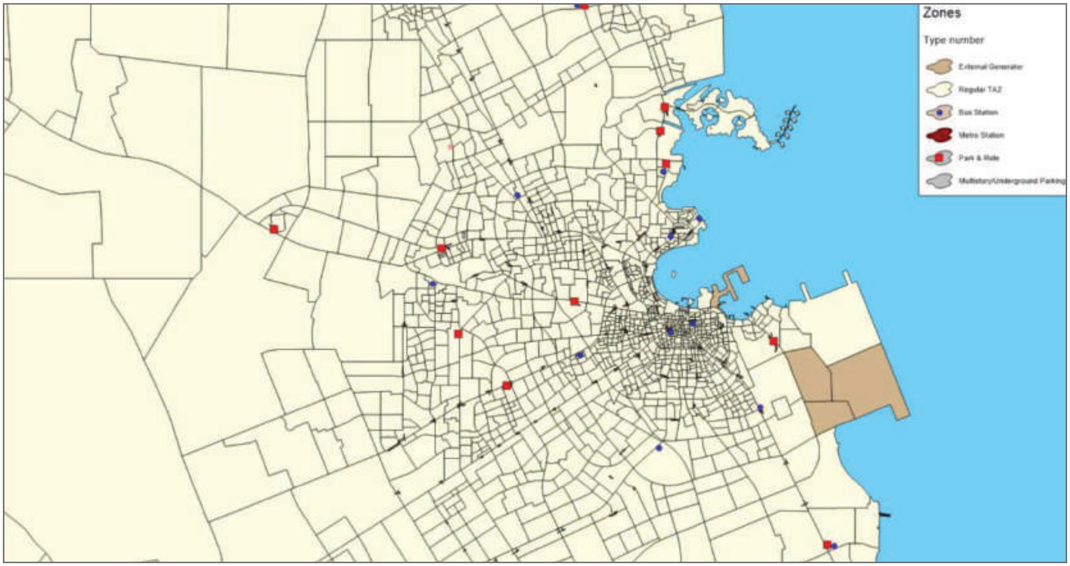


Figure 4.12: Location of the Park & Ride Sites Incorporated into QABM

4.6.2. Calibration of the Park & Ride Model Parameters

In setting up and calibrating the Park & Ride model a number of rules had to be made on what qualifies as being a trip which can be made by Park & Ride, or more specifically, which trips fall within the definition of the Catchment Area of each OD (CAOD). These rules are as follows:

1. Short distance trips are not considered by the Park & Ride model if the total trip length is below 3 km
2. If the distance between the starting zone O and the Park & Ride site is lower than the maximum walking distance (400 meters being the recommended value, as in the parking model), the site is not included in CAOD

3. For consideration of accessibility to the destination, a Park & Ride site belongs to the CAOD if the travel time between the last transit stop and the final destination is lower than 11.5 minutes by bus, or lower than the maximum walking distance
4. The relative time/length of the first and second leg of the trip of that of the overall trip time/length:
    a. A threshold α = 0.71, representing the ratio obtained by dividing the time/length of the first leg of the trip (measured from the starting zone O to the Park & Ride site) by that of the whole trip time/length (measured from the starting zone O to the destination D), is used to rule as to whether a trip can be part of CAOD of the site. Only Park & Ride sites for an OD trip resulting in a ratio that is less < 0.71 are considered as being part of the CAOD
    b. A threshold β = 1.07, representing the ratio obtained by dividing the time/length of the second leg of the trip (measured from the Park & Ride site to destination D) by that of the whole trip time/length (measured from the starting zone O to the destination D by the car mode where drivers usually choose a different, more direct route than that taken by Park & Ride), is used to rule as to whether a trip can be part of CAOD of the site. Only Park & Ride sites for an OD trip resulting in a ratio less < 1.07 are considered as being part of the CAOD

For the calibration, the maximum walking distance threshold was derived from interviews. The value of the thresholds α and β were taken from the technical literature. More details can be found in the *Demand Models Configuration and Modelling Report*.

For the VOT value, the same assumptions made for the parking model were adopted also for the Park & Ride model. The weights of initial waiting time and on-board travel time have been set to 1.5 and 6, respectively.

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SECTION - 05

INTEGRATED QABM

5. Integrated QABM

Model and software to simulate interactions between Demand and Supply

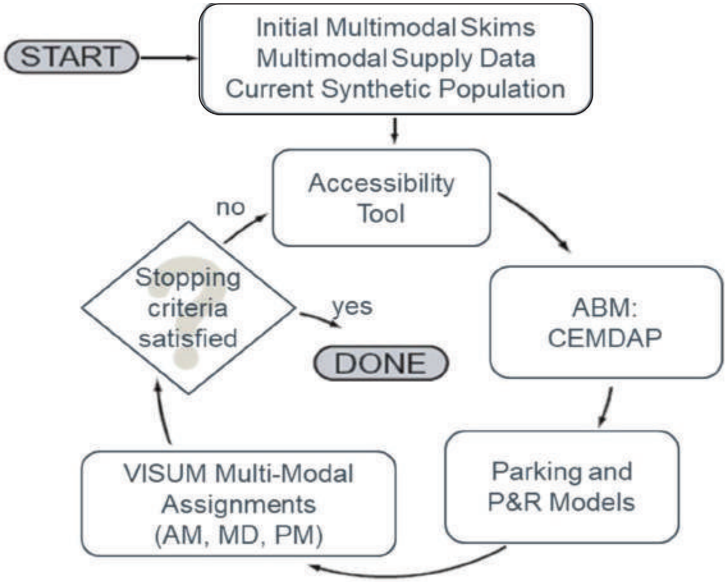
5.1. Features of the Integrated Model

QABM is one of only few transport models where integration between an Activity-Based Model and a commercial traffic assignment tool (VISUM) is applied in practice.

The demand, although essentially determined by land-use features and socio-economic characteristics of the population, is nevertheless affected by the performance of the transport system. Equally, the demand, once loaded onto the supply networks, affects the performance of the transport network, as determined by the assignment process. QABM takes full account of the mutual interaction between the demand and the supply sub-systems through a Graphical User Interface (GUI) which has been specifically developed to automate the integration procedure.

The procedure adopted for integrating ABM (representing the travel demand) with the traffic assignment (representing the supply) is presented in Figure 5.1. This procedure is fully explained in the *Integrated Demand & Supply Model Report*.

The procedure starts with an initial estimation of the supply network performance. The performance values, along with the output of PopGen and CEMSELTS (as higher tier models which sit outside the integrated procedure) are used to feed the Accessibility Tool, as shown in Figure 5.1. Then, the integration loop is commenced.



The output from the Accessibility Tool forms an input into CEMDAP, whose output is passed onto the Parking and Park & Ride Models.

Afterwards, the multi-modal traffic assignment process is carried out for each peak period (AM, MD, PM) separately in VISUM. Traffic volumes and network performance values are computed.

Executing further iterations between the demand and supply depends on whether the termination criteria are met. The termination criteria are based on the comparison of the performance values between two consecutive iterations: if the performance values between the consecutive iterations are sufficiently close to each other, then the integration process is terminated; otherwise, the loop is iterated.

5.2. Convergence Properties of the Integrated Model

Due to its structure, the integrated QABM poses two levels of convergence problems:

- Convergence of the internal loop and the algorithms used in the multi-modal traffic assignment models.
- Convergence of the external loop corresponding to the interaction between demand and supply

For the convergence of the internal loop, the traffic assignment model implemented in VISUM generally complies with the mathematical requirements that assure the existence of a solution, and it is just a matter of time before the algorithm converges. Hence, the runtime depends on the computer's processing speed. However, there are cases where convergence cannot be guaranteed due the interaction between the conflicting movements at intersections, such as at priority junctions, and the computational time required to achieve the convergence varies according to the threshold adopted for the assignment models.

To speed up convergence of the traffic assignment, the integrated loop has been configured in such a manner which allows for the traffic assignment run to be restarted from the results of the previous iteration. A set of tests were carried out to evaluate the efficiency of the traffic assignment convergence with this configuration. It was found that after four external iterations, the internal iterations become sufficiently stable and the traffic assignment problem converges with no more than 7 internal iterations.

To assess the convergence properties of the external loop, the O-D trip matrices and the travel times of two successive iterations are compared. Extensive testing of the developed procedure by applying this to the base and future year models has shown that the external loop converges after 5 external iterations.

The stopping criteria of the external loop comprise:

a. Comparing the absolute difference of the peak hour travel times of two successive iterations against a pre-specified threshold. This threshold can be defined by the user. The default value is 120 seconds.
b. Setting the maximum number of iterations. This can be defined by the user. The default value is 5.

5.3. The Overall QABM Procedure

The flowchart shown in Figure 5.2 provides a graphical representation of the modules and the functional interactions among them that constitute the overall procedure of QABM.

In the flowchart, the various colored boxes have the following meaning. Dark blue boxes represent the various modules making up the overall QABM procedure. The input data are signified by grey boxes, while the output data are represented in green boxes. Each module or blue box receives a set of input data and yields a set of output data required by another module. The red lines illustrate how the various modules are interlinked.

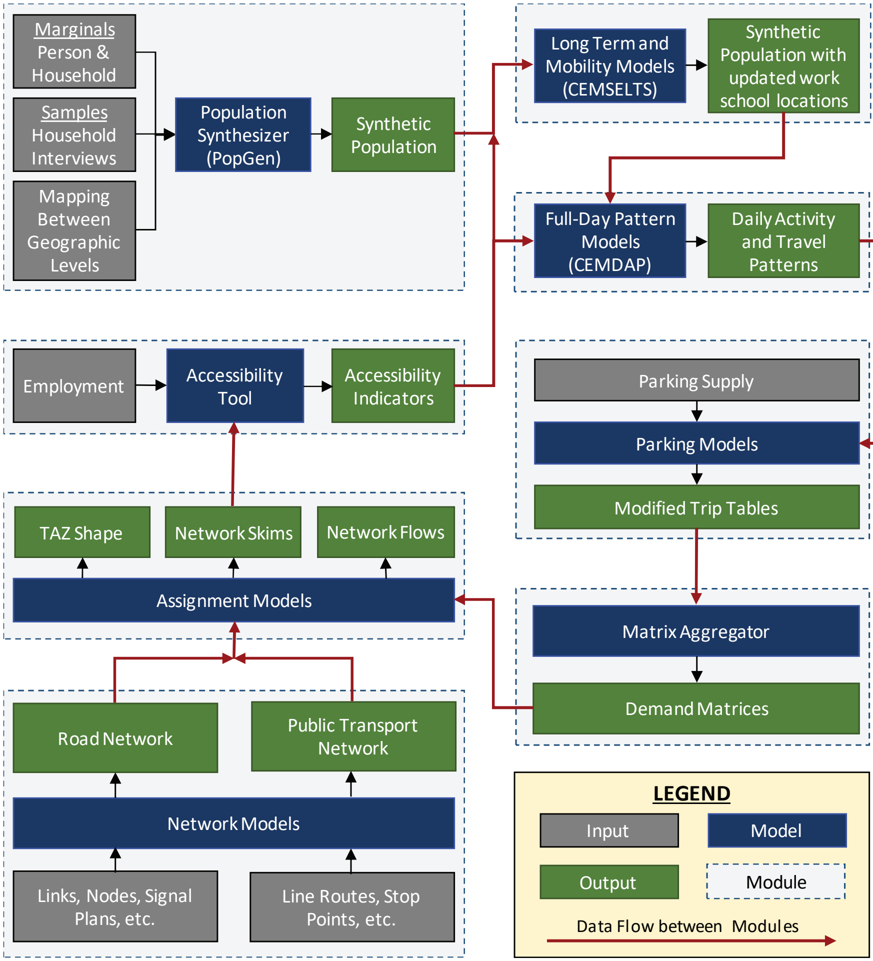


Figure 5.2: The Overall QABM Procedure

The modules making up the overall QABM procedure comprise:

- PopGen and CEMSELT (these two modules fall outside the integrated loop shown in Figure 5.2)
- Accessibility Tool
- CEMDAP as a full-day choice model
- Parking Model
- Park & Ride Model
- Matrix Aggregator which converts person whole day travel into peak hour flows
- VISUM as a traffic assignment tool which as well implements, runs and controls the integration loop, based on instructions set out by the GUI.

5.4. Runtime Estimates

From initial tests carried out on the Base Year model, the computational time for each loop of the integrated model was about 42 hours.

However, after taking advantage of distributed computation features available within the software, the computational time was reduced to less than four hours per iteration on a computer workstation.

The used workstation has the following configuration:

- 2 x Intel Xeon Gold 5118 2.3Ghz, 3.2Ghz Turbo, 12Core, 10.4GT/s2 UPI, 16MB Cache, HT (105W) DDR4-2400
- 192 GB (12x16GB) DDR4 2666Mhz RDIMM ECC
- M2 2TB SSD
- NVIDIA Quadro P1000 4GB Graphics

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SECTION - 06

BASE YEAR MODEL CALIBRATION AND VALIDATION

6. Base Year Model Calibration and Validation

Replaying the Present as Reference Scenario

Calibration of the base year model consists in estimating model parameters that best fit the observed values of the output variables. Validation, on the other hand, aims at assessing the outcome of a calibrated model when compared to an independent set of observed data. Accordingly, two different sets of data which were collected in 2018 have been used respectively for calibration and validation of the base year model, which is thus a 2018 model by virtue of the year when the surveys were carried out.

The calibration and validation process of the whole model is articulated as shown in Figure 6.1. During the calibration and validation phases, statistics related to simulated and observed values have been computed and compared against expected tolerances.

Calibrating and validating an activity-based transport model such as QABM does not necessarily imply that every available data should be split into two sets, one for calibration and another validation. This is commonly the approach that is followed and recommended in the literature for calibrating and validating a traffic assignment model. For QABM, the process is wholly different, as the demand is derived from the population. This cannot be altered; otherwise, the model would not be representative of the population it is attempting to replicate. Instead, for calibrating and validating QABM, the available data obtained from the surveys and various other sources were divided into two sets, each containing a different type of data, one set for estimating/calibrating the models whose output is fed into the day choice models, and another set - of a different type and content - for validating the supply models, as described next:

- Household Interviews for calibrating the Activity-Based Demand Model, more specifically, CEMSELST and PopGen
- Automated traffic counts (ATC), turning movement counts (TMC) and travel time surveys for validating the road network supply mode
- Ticket counts and boarding/alighting passenger surveys for calibrating the parameters of the transit network supply model calibration.

Currently, CEMDAP, reflects day choice parameters which have been transferred from the SCAG (Southern California) model, after customizing this to Qatar conditions to account to cases where there is a marked difference between Qatar and California. For example, government employees in Qatar finish work mostly at 2.00PM, whereas in the USA, the work end time is commonly at 5.00PM. Similarly, school timings have a different start and finish time in Qatar than in the USA.

Next, calibration and validation of QABM is discussed. For a much wider discussion on the subject, the following reports can be referred to:

- *Demand Models Configuration and Modelling Report*
- *Supply Models Configuration and Modelling Report*
- *Calibration and Validation Report*

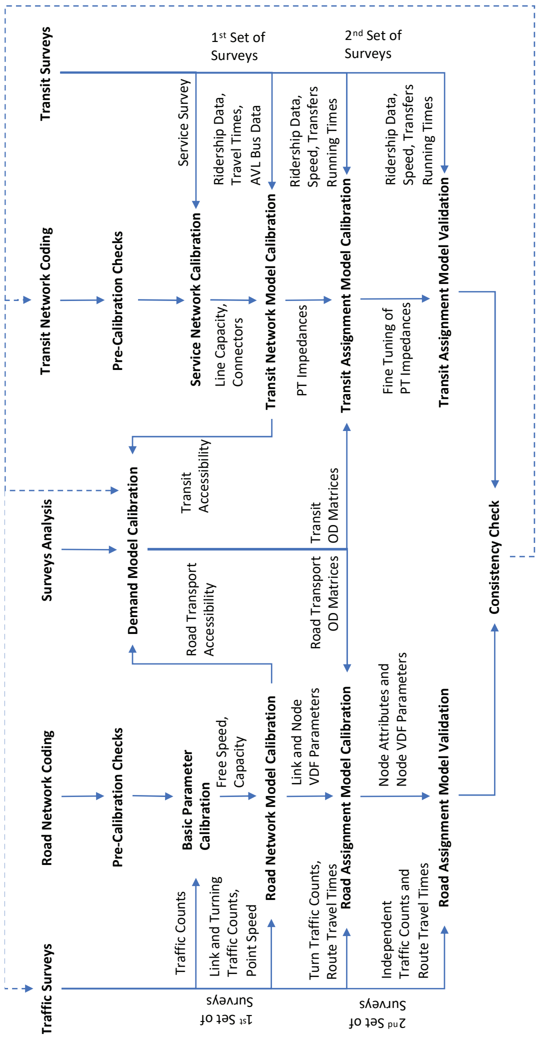


Figure 6.1: QABM Calibration and Validation Process

6.1. Model Calibration

Several components of the overall QABM had to be calibrated before these are applied and made to work together. These are:

- The demand models comprising PopGen and the long-term CEMSELTS models
- Parameters of the road network assignment model
- Parameters of the public transport network assignment model

6.1.1. Demand Model Calibration

The calibration of the demand model of QABM was realized by utilizing the seed data obtained from the HHI surveys to synthesize the whole population of Qatar, and associate socio-economic attributes for each household and individual by engaging the long-term estimation models which were fitted to additional information in the seed data, as described in Section 3. The output of the demand model was then compared against the observed data to establish how good the models were at replicating reality. Various comparisons were made, foremost amongst which are:

- The average activity duration in percentage terms for each activity purpose
- The simulated daily activity pattern by time of day
- Number of tours, number of trips, average tour duration and average trip durations, by workers and non-workers and by their schedule
- Proportions of number of trips, trip duration and distance by mode
- Proportions of number of tours, tour duration and distance by mode.

Figure 6.3 and Figure 6.4, are two examples of the kind of output which was utilized to judge the accuracy of the demand model.

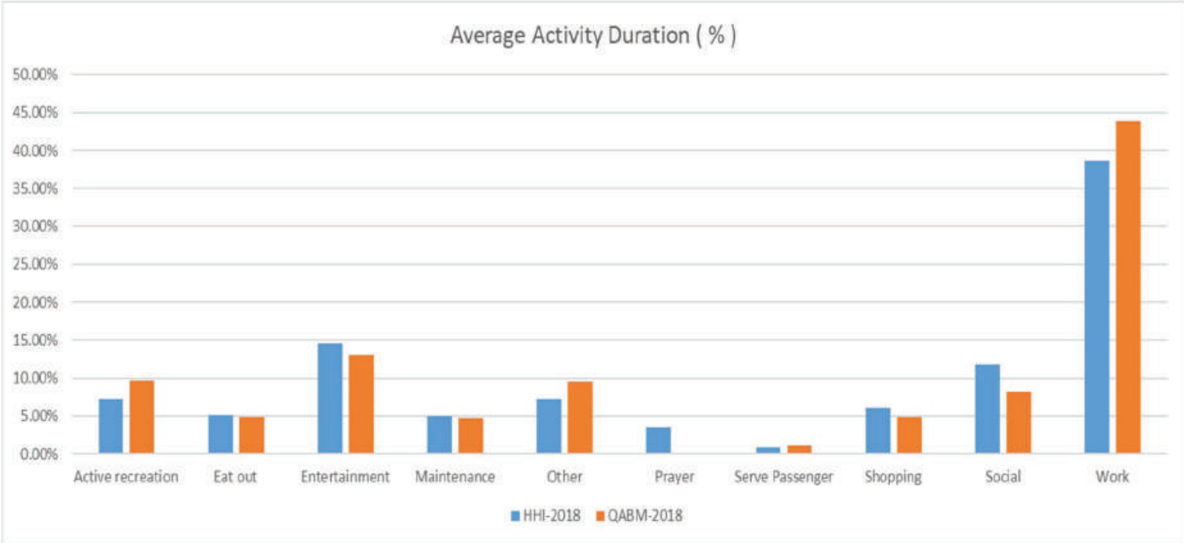


Figure 6.2: Activity Duration by Purpose Comparison - HHI vs. QABM

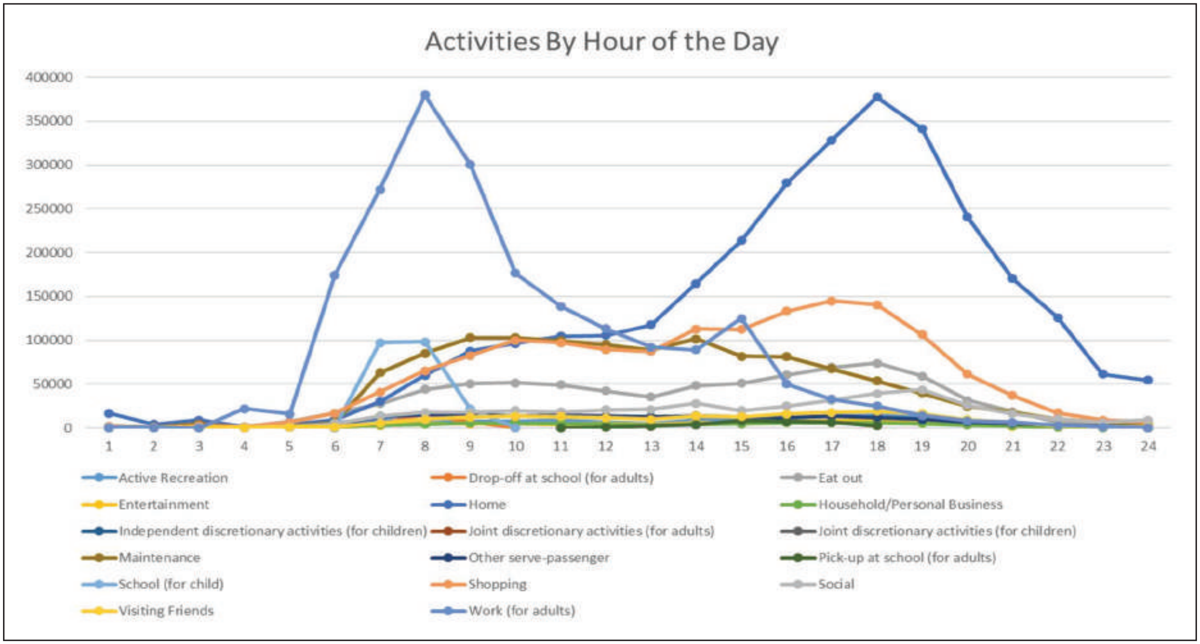


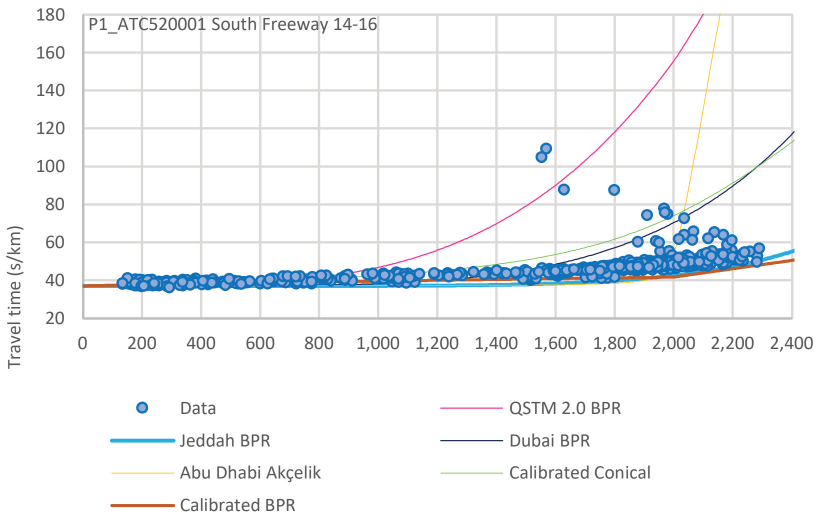
Figure 6.3: Activity Purpose by Hour of the Day - QABM 2018.

6.1.2. Calibration of the Road Link and Junction Parameters

The performance of any element of the road transport network is modeled through a mathematical relationship which relates the delays and travel time to traffic volumes, or what is called as a Volume-Delay Function (VDF). The more traffic is present on a road link, the higher will be the delays and travel time needed to traverse the link. The same principles apply as well to junctions.

VDF differ between road link and junction types and hierarchy. The Volume-Delay Function used for any type of road link or junction has been carefully calibrated against data which were collected as part of the traffic surveys as described in Section 2.3.4.

The values of the VDF parameters obtained by calibrating those functions for various road types are reported in Table 6.1. Link Type numbers are associated with every function type, as required in VISUM.



For road junctions, different types of node and turn-delay functions have been defined. At signalized junctions, the turn delays have been explicitly related to the actual timings of the traffic lights. At all junctions, since the delays depend on the traffic volume, an optimization method has been developed to calibrate the multivariable Volume-Delay Functions for the road nodes. This exploits the travel time surveys conducted on pre-defined routes and optimizes the values of the function coefficients to provide the best approximation of the travel times on all the surveyed routes.

Both calibration methods for the link and node Volume-Delay Functions have been implemented in specific software routines that makes it easy to redo the calibration if more traffic data are made available.

Table 6.1: Parameters of the Link Volume-Delay Functions

Hierarchy	Speed (Kmph)	Link Type Number	Function Type	Parameters
Freeway	100, 120	From 2 to 12	BPR3	a=0.44, b=3.00, c=1.00, d=0.03
	80	From 13 to 17	BPR3	a=0.44, b=3.00, c=1.00, d=0.03
Expressway	100, 120	From 18 to 27	BPR3	a=1.00, b=2.60, c=1.00, d=0.05
	80	From 28 to 32	BPR3	a=1.00, b=4.20, c=1.00, d=0.05
Arterial	100, 120	From 34 to 38	BPR	a=1.20, b=2.40, c=1.00
	80	From 39 to 42	BPR	a=1.20, b=2.40, c=1.00
	50	From 43 to 46	BPR	a=1.20, b=2.40, c=1.00
Major Collector	50	From 48 to 56	BPR	a=1.40, b=2.20, c=1.00
Minor Collector	40	From 57 to 60	BPR	a=1.40, b=2.20, c=1.00
Local Street	30	From 61 to 63	BPR	a=1.75, b=2.40, c=1.00

6.1.3. Calibration of the Public Transport Network Assignment Model Parameters

The PT supply for the Base Year Model consists of Mowasalat bus network updated to March 2018 (52 lines, 94 line-routes and 1,532 stop points).

The following data which were furnished by Mowasalat have been used for calibrating the parameters of the public transport assignment model:

- GPS Data 01-05to08-5.csv
- Ridership disaggregated data.csv
- Card_Usage_by_Bus_Report.zip (received 6th of September)

The results of the calibration of the PT assignment model parameters are depicted in Table 6.2.

Table 6.2: Calibration of the PT Assignment Model - Set of Optimal Coefficients

Attribute	Timetable-based Coefficient	Headway-based Coefficient
In-Vehicle Time	1.00	1.00
Access Time	6.00	6.00
Egress Time	6.00	6.00
Walk Time	6.00	6.00
Transfer Wait Time	1.40	1.40
Number of Transfers	5 min	5 min
Origin Wait Time	2.50	2.50
Perceived Journey Time	1.00	1.00
Fare	1.71	1.71
DeltaT (early)	1.40	1.40
DeltaT (late)	2.00	2.00

6.2. Model Validation

Similar to the model calibration, a number of components of the overall QABM had to be validated. These are:

- The output of the demand models
- The results of the road network assignment model
- The output of the public transport network assignment model

6.2.1. Validation of the Demand Model (QABM)

Validation of the Base Year 2018 demand model was conducted by comparing the output from the Integrated QABM Base Year against the HHI data. The validation was made with respect to the following:

- Household patterns, including HH by auto-ownership, number of drivers, and HH income;
- Personal activity patterns, such as activity participation by person type, and trip length frequency distributions by activity type; and
- Mobility demand patterns, for example, travel time by activity Type, tour modal share by activity type and auto-ownership, frequency of joint trips, VKT by person type, and intra-zonal trips for All Activity Types.

The validation results have shown a relatively good correspondence between observations and estimated values. Figure 6.5 and Figure 6.6 are two examples of the kind of validation output utilized to verify the demand model. These two examples demonstrate how close the model output in (relation to the tour mode and the frequency of the intermediate stops of the tours) is to the observed HHI data.

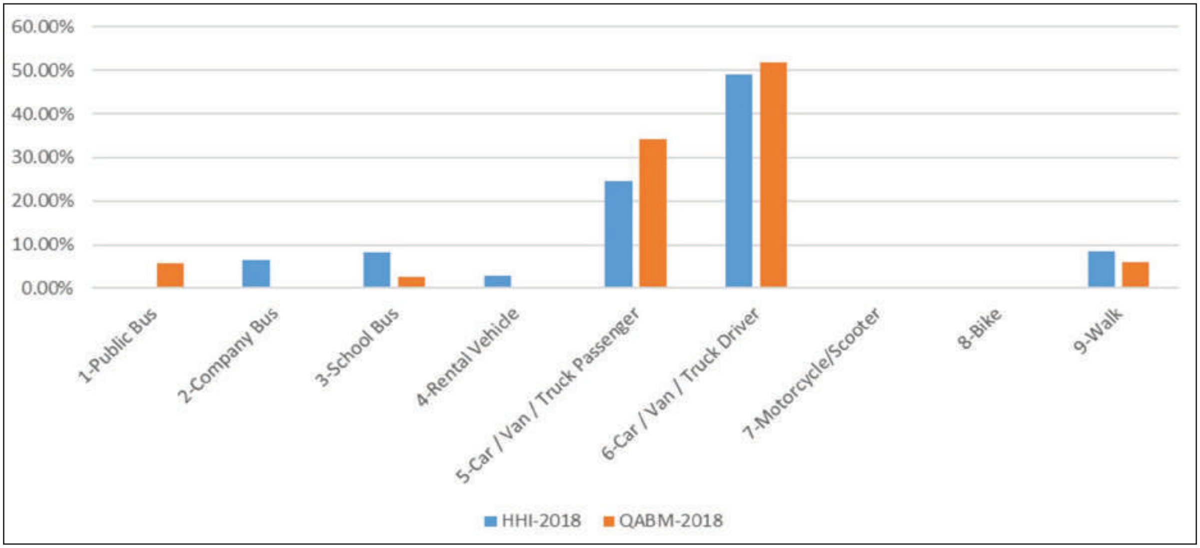


Figure 6.4: Tour Mode Share Comparison - HHI vs. QABM

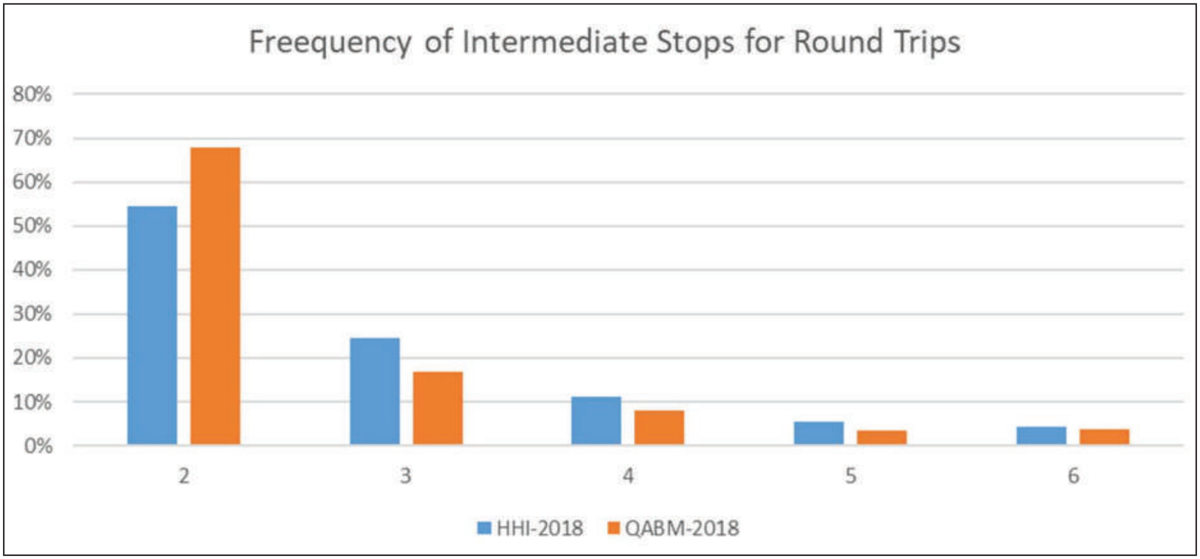


Figure 6.5: Intermediate Stops Frequency of Round Trips - HHI and QABM Comparison

6.2.2. Validation of the Road Network Model

The road network validation focused mainly on making a comparison between modelled link flows and journey travel times against observed values. The comparison was reported for screen lines and for individual counts, and by fitting regression lines to the modelled and observed flows. The results of the regression analysis and journey time comparisons are summarized as follows:

1. **Simulated versus observed volumes on links.** The Goodness-of-Fit statistic indicators yielded a good correlation, ranging between 0.59 and 0.61. Slope of the regression line is equal to 1.0 for AM period, 0.76 for the MD period, and 1.28 for the PM. The y-intercept value was found to be always close to 0.00.
2. **Simulated versus observed volumes at the main turns.** The Goodness-of-Fit statistic showed that the modelled turn volumes are reasonably close to the observed volumes. The Coefficient of Determination ranged between 0.59 and 0.61.
3. **Simulated versus observed volumes across screen lines**. The screen lines delineate different geographical sectors of the study area, as represented in Figure 6.7. The goodness-of-fit for radial screen lines was found to be acceptable in the AM and PM periods, with the Mean Absolute Error (MAE) equal to 9% in the AM peak, and 13% in the PM peak. For the concentric screen lines, MAE is considered satisfactory too, for it equaled to 21% in the AM peak, and 28% in the PM peak. However, for the MD peak, the comparison yielded quite a high value for the MAE, equal to 42%. This has been attributed to the low volume of modelled car users going through the concentric screen lines in the Mid-Day period as compared to the observed flows, and to the possibility that a significant portion of car users was not reported in the household surveys.
4. **Estimated versus observed journey travel times**. The Mean Absolute Error of the journey travel time of each peak was about 17-20%, which is within the acceptable range of the coefficient of variation of the data; that is around 16-18%. The Coefficient of Determination ranged from 0.72 to 0.75. However, factors that were found to degrade the results of the validation of journey times are anomalous observed travel times on some routes, as Figure 6.7 highlights in black.

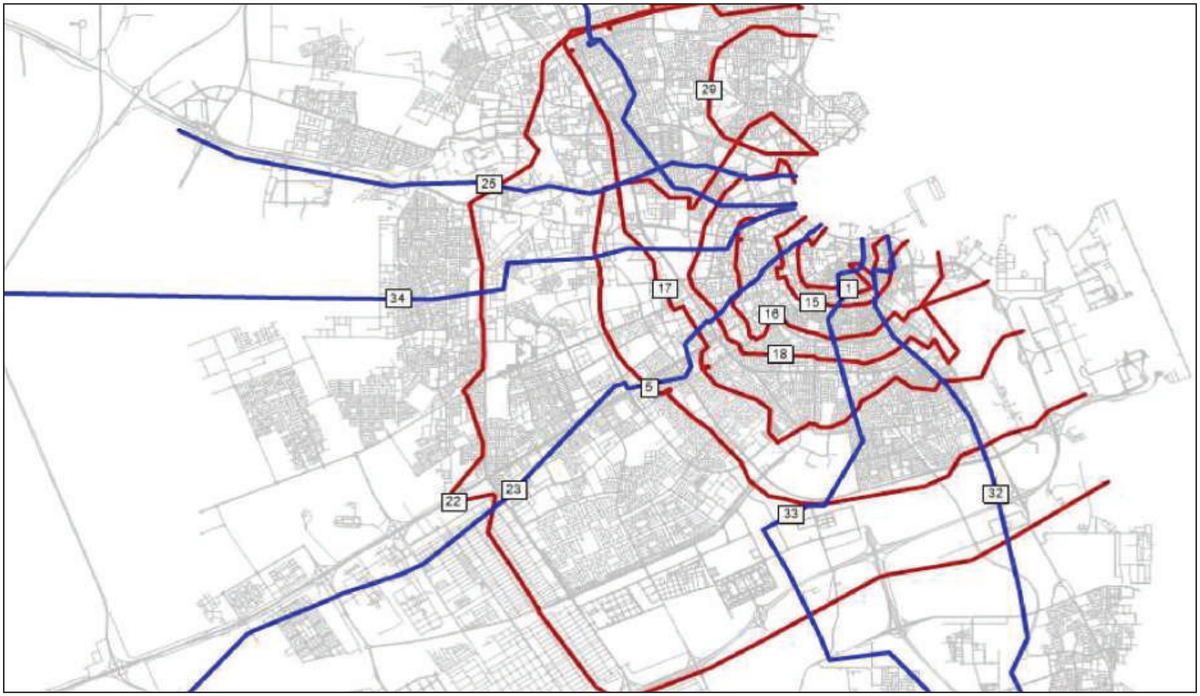
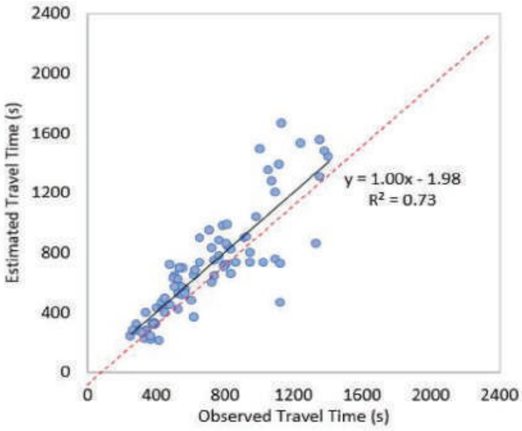


Figure 6.6: Concentric (Red) and Radial (Blue) Screen Lines for Validation



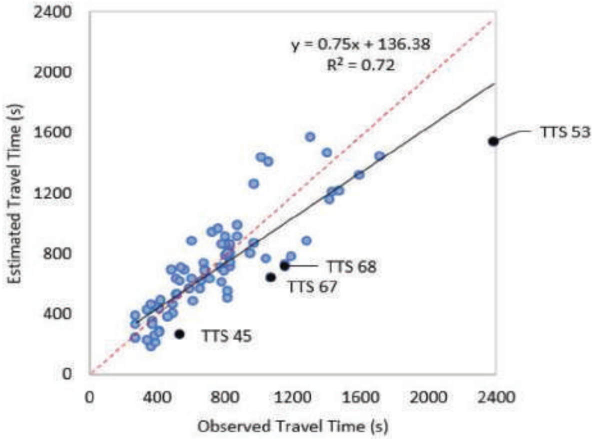


Figure 6.7: Observed vs. Estimated Travel Times - AM (left), PM (right) and Anomalous Conditions (Black)

6.2.3. Validation of the Public Transport Network Model

In the calibration of the public transport network model, observed boarding passengers based on ticketing data were used to determine the coefficient for access time, in-vehicle time, egress time, wait transfer time, etc., as described in Section 6.1.3, and then the Goodness-of-Fit statistics between the modelled alighting passengers and those observed were worked out to establish initially how well the model is calibrated against ticketing data. For validating the PT assignment model, following a complete QABM run, the Goodness-of-Fit statistics calculated between the modelled alighting passengers and the observed values were compared against those statistics which were initially obtained in the calibration stage.

Table 6.3 reports how favorable the comparison between the statistics is, for both timetable-based and headway-based assignment, considering in addition that the simulated alighting passengers are also influenced by path choice when multiple alternatives are available for the same O-D pair.

Table 6.3: Public Transport Assignment Model Validation – Goodness-of-Fit Statistics

Goodness-of-Fit statistics	Timetable-Based Assignment		Headway-Based Assignment	
	Calibration Value	Validation Value	Calibration Value	Validation Value
MAE	2.70	2.71	2.94	2.95
RMSE	11.58	6.25	14.45	8.11
R^2	0.89	0.85	0.81	0.77

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SECTION - 07

BASELINE HORIZON YEARS MODELS

7. Baseline Horizon Years Models

Modeling Future Mobility in Business-as-Usual Scenario

7.1. Definition of Baseline Future Years

The baseline horizon year models describe the transport system in future years, with the assumptions that all planned schemes of the transport system and land use are implemented, and that the socio-economic characteristics of the present population are largely maintained, as further explained in the *Horizon Years Modeling Report*. The horizon years considered for analysis and simulation are: 2025, 2030, 2035, and 2050.

7.2. Planning Data for Baseline Future Years

The planning data required as input into QABM (aggregated at TAZ level) include the following set of variables:

- Population totals, household population and labor population:
  - Household Marginals: total households, households by size, households by residence type
  - Person Marginals: total population, persons by gender, persons age by categories, and persons by Qatari and non-Qatari categories
- Employment Marginals: total employment, employment by sectors.

For QABM Models, the required population categories are population living in households and population living in collective housings (laborers or singles).

7.2.1. Population

The adopted total population forecasts are provided by TMPQ. These are based on the future land use plan (QNMP). The total population forecasted for 2035 and 2050 are 3,570,000 and 4,210,000, respectively.

TAZ wise, the total population have been split into household population and laborers using the base year proportions.

The approach followed in evolving the baseline population is summarized as follows:

1. Basic information about total population forecasts for the horizon years were received from MDPS and adopted in QABM.
2. Existing transport model (QSTM 2.0) projections, defined for the ultimate year 2031, were adapted for the 2050 ultimate horizon year in QABM. The land use interface of QSTM 2.0 has been used since the total population for the ultimate year 2031 in QSTM and that of 2050 in QABM are very similar. Some adjustments were necessary though to determine the population by TAZ for the horizon years 2025, 2030, 2035, and 2050.
3. The TAZ system adopted in QABM differs from that implemented QSTM 2.0. Therefore, both zoning systems were correlated, and an area-based proportioning was adopted to convert QSTM 2.0 information into QABM baseline population.

Following this approach, Figure 7.1 shows the total population forecasts, split into households and laborers, as well as the trend over the horizon years by employment category.

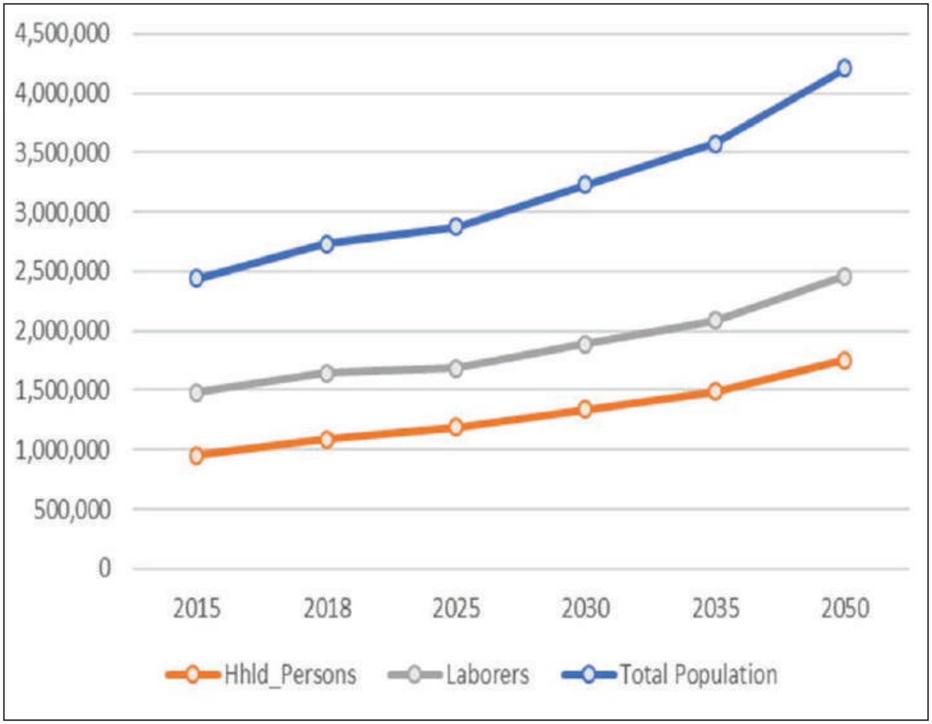


Figure 7.1: Trend of Population in the Future Horizon Years

7.2.2. Employment

The approach that has been adopted to evolve the baseline employment in QSTM for the horizon year is largely similar to the one that has been followed to evolve the total population in QABM.

The approach is summarized as follows:

1. Basic information about employment forecasts for the horizon years were received from MDPS and adopted in QABM. Further refinements had to be carried out for the final values.
2. Existing Transport Model (QSTM 2.0) projections, defined as the ultimate year 2031, were adapted for the 2050 ultimate year in QABM. The land use interface of QSTM 2.0 has been used in QABM since the total employment for the ultimate year 2031 in QSTM and that of 2050 in QABM are very much similar. Some adjustments were necessary however to determine the employment by TAZ for each horizon year.
3. The TAZ system adopted in QABM differs from that implemented in QSTM 2.0. Therefore, both zoning systems were correlated, and an area-based proportioning was adopted to convert QSTM 2.0 information into QABM baseline employment.
4. The employment types were categorized into five groups as per the classification of the Planning and Statistics Authority (PSA, Formerly MDPS):
   a. Mining including hydrocarbons;
   b. Manufacturing including agriculture;
   c. Buildings and construction;
   d. Traded-financial services, transport and communications, and
   e. Non-traded-social services, government services, household services, plus utilities.

   Categories a, b, and c were retained as is. Categories d and e were aggregated ('d+e') and further categorized into three categories: Leisure & Retail, Services and Others. Base year employment proportions were used to subdivide the combined 'd+e' values into Leisure & Retail (37% of 'd+e'), Services (27% of 'd+e') and Others (37% of 'd+e') categories.

On the basis of the above approach, Figure 7.2 gives the employment forecasts and the trend over the horizon years by employment category.

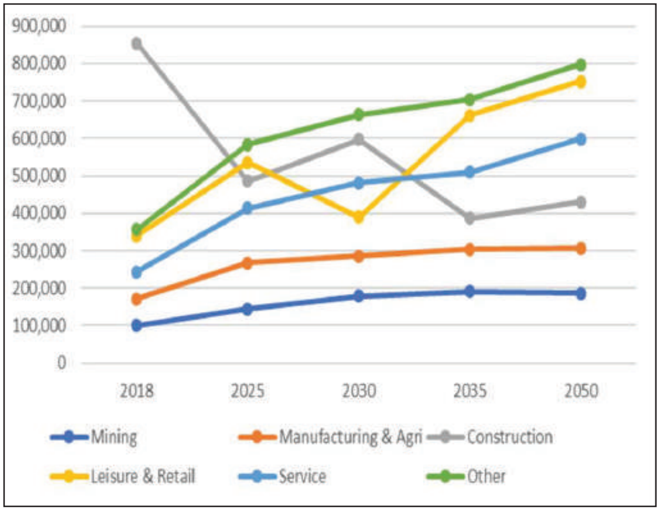


Figure 7.2: Trend of Employment in the Future Horizon Years

7.3. Demand Forecast

7.3.1. Year 2025

The demand for transport in 2025 is about 845,000 trips in the AM peak, 630,000 trips in MD peak, and 825,000 in PM peak. Compared with the Base Year scenario, the demand increases by about 12%, 15% and 14% respectively in the AM, MD and PM peak periods respectively. The modal share of PT is about 11% in the AM peak, 9% in the MD peak, and 9% in the PM peak. These shares are in line with expectations following the opening of the metro lines. Figure 7.2 shows the trend of forecast demand and the share of the public transport.

7.3.2. Year 2030

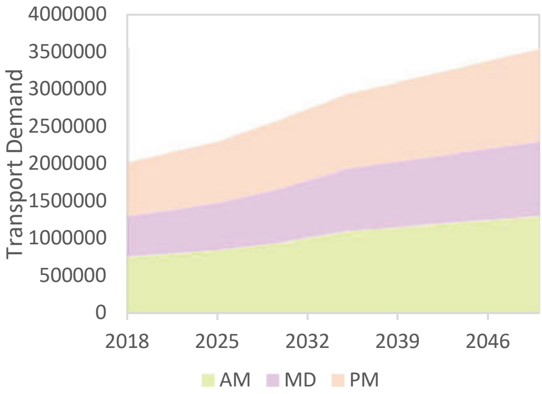
The demand for transport in 2030 is approximately 950,000 trips in the AM, 725,000 trips in the MD peak, and 930,000 in PM. The increases are nearly 13%, 15% and 13% over those of the Horizon Year 2025. The modal share of PT remains similar to that of the Horizon Year 2025.

7.3.3. Year 2035

In 2035, the demand for transport continues to grow, by about 15% compared to 2030, to reach around 1,100,000 trips in the AM peak, 835,000 trips in the MD peak, and 1,000,000 in the PM peak. Modal share of public transport is predicted to rise to about 14% in the AM, 10% in the MD peak, and 12% in the PM peak, mainly due to the introduction of more metro lines by 2035.

7.3.4. Year 2050

In the ultimate year, the demand for transport reaches about 1,300,000 trips in the AM peak, 1,000,000 trips in the MD peak, and almost 1,245,000 in the PM peak. In this period, the increase of private transport is expected to be higher than that of public transport. Modal shares of PT are forecast to be approximately 12% in the AM peak, 9% in the MD peak, and 10% in the PM peak.



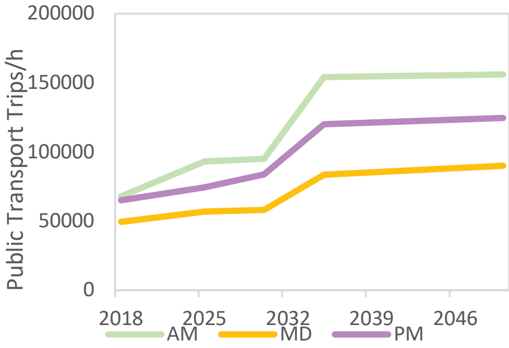


Figure 7.3: Trend of Predicted Demand - Total Transport (left) and Public Transport (right)

7.4. Supply Models

7.4.1. Road Network Model

The Base Year Model has been used as the starting point for building the Horizon Year Road Network Models. Data regarding proposed/ongoing expressway projects - totaling 48 projects - and their schedule of implementation has been received from Ashghal and used to determine the list of projects for each horizon year.

According to Ashghal's implementation plan, about 30 Expressway Projects are programmed to be completed by 2022, and thus these were considered in the Horizon Year 2025. Then, a quantitative assessment procedure has been applied to select the most effective projects to relief traffic congestion from the remaining 18 uncommitted or "deferred" schemes. Based on this procedure, seven expressway projects have been identified for implementation as part of the baseline scenario for Horizon Year 2035.

In addition to the Expressway Project, the proposed projects under Local Roads and Drainage Program (LRDP) by Ashghal were also coded. Since no implementation plan has been provided by Ashghal for the LRDP projects, assumptions had to be formulated for the list of projects to be coded in the Horizon Year 2025 Model and identify the projects to be deferred beyond HY-2025. For Horizon Year 2035, LRDP projects have been selected based on the quantitative assessment approach referred to in the previous section.

For the ultimate Horizon Year 2050 Model, all remaining projects from Ashghal and LRDP were included in the model.

Figure 7.3 provides a graphical representation of the how the length of the road network, by different road types, will grow over the years. Notably, the length of the road network will increase from the current length of about 27,000 km, coded in the Base Year 2018, to around 32,000 km in 2025, 34,000 km in 2035, and 35,000 km in 2050.

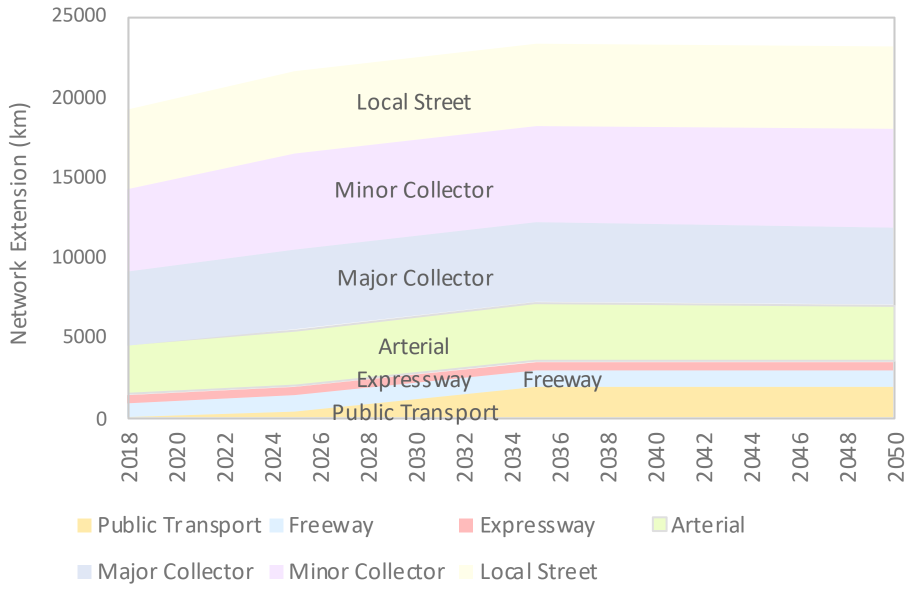


Figure 7.4: Evolution of Road Network from Base to Horizon Years

7.4.2. Public Transport Model

The Public Transport Network Models of the Horizon Year 2025 and 2030 include the 3-Line Metro network (Phase 1), 4 Lines of the Lusail LRT network, Tram Lines (People Mover Network), and the streetcar system of the Heart of Doha.

In addition to the above, the Horizon Year 2035 scenario includes the development of the long distance and national rail network, which along with the Metro network will constitute the backbone of public transport network. The following secondary transport systems have been also implemented in the Horizon Year 2035:

- The Automated People Mover in West Bay area
- The Water Taxi Service, connecting Doha Port – West Bay – The Pearl – Lusail Marina – Lusail.

The same Public Transport scenario is assumed in the Horizon Year 2050.

Metro network and the Lusail LRT network both have been coded respectively according to Phase 2c and Phase 2 related projects collected by QRail, which include the 4th Line for the Metro.

Figure 7.5 represents the Public Transport Network in Horizon Year 2025/2030 in Greater Doha and Figure 7.6 represents the Public Transport Network in the whole of Qatar in Horizon Year 2035/2050.

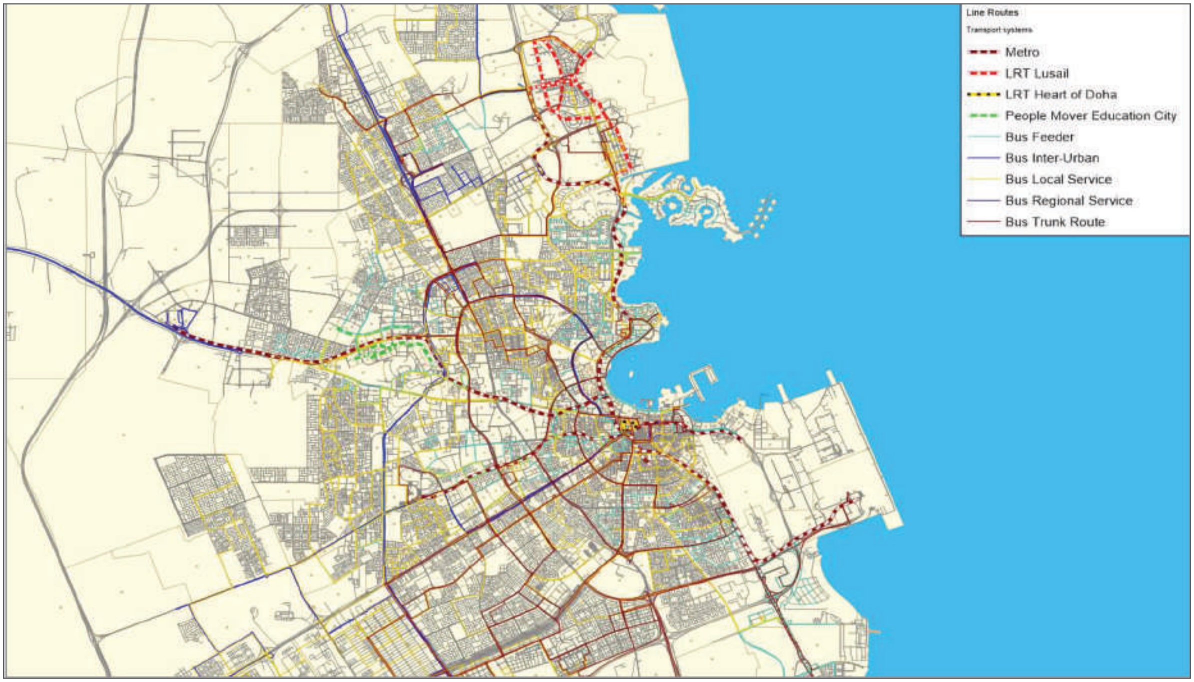


Figure 7.5: Public Transport Networks in Horizon Year 2025/2030

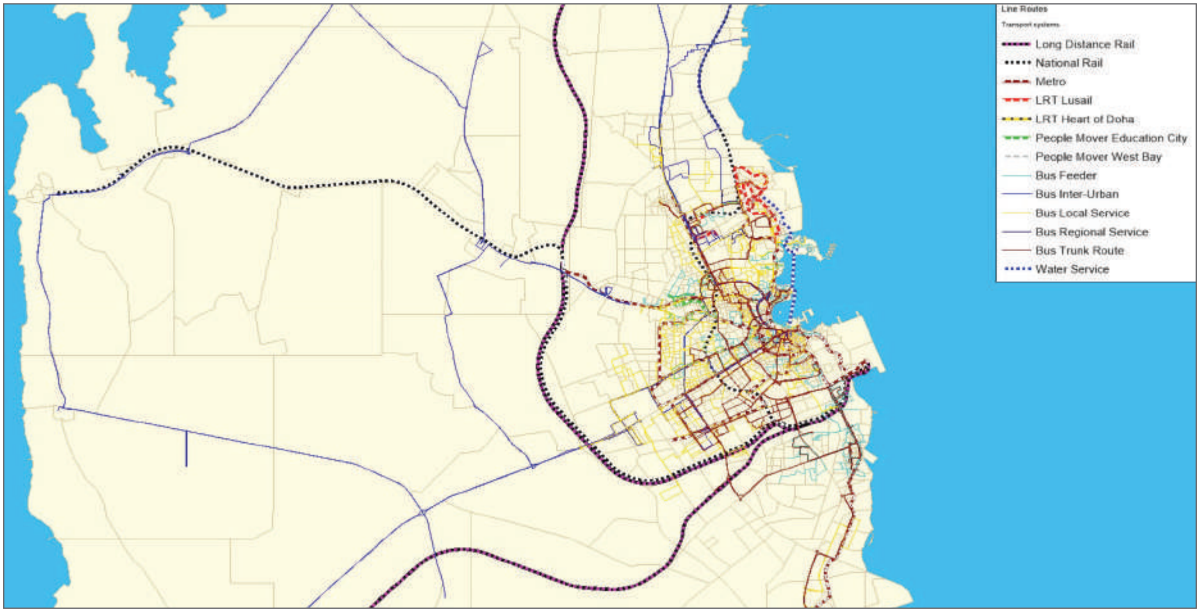


Figure 7.6: Public Transport Network in Horizon Year 2035/2050

7.5. Transport System Performance in Horizon Years

QABM produces a wide range of results, including, for example, the type of activities by persons, number of stops, performance of the transport system in terms of travel times, distance travelled, and congestion levels which are computed by the traffic assignment model.

The results of the performance of the transport systems in the horizon years are summarized as follows.

7.5.1. Private Transport Network

Due to the changes in both the demand and the transport supply system, traffic congestion on the road network is expected to ease in the future years, with the highest reduction anticipated in 2025 when three Metro lines, 4 BRT lines and the tram network will be fully operating. As shown in Figure 7.7, the total traveled distance by car in the AM peak will decrease from 3.9 million vehicle-km in the Base Year to about 3.3 million in 2025 (-15%), then it will increase slightly to 3.7 million in the years 2030 and 2035 (-4%).

For the ultimate year 2050, when the transport system is supposed to be unchanged and the population is still on a rising trend, the total travel distance will grow to 4.7 million vehicle-km, exceeding the current value by 18%.

Because of the extension and the enhanced performance of the road network, as well as because of the non-proportional relationship between traffic and congestion, the total travel time and the time traveled in congested conditions decreases more than the total traveled distance. In 2025, the total car travel time in the AM peak is predicted to decrease from the current value of 100,000 vehicle-hour (29% of which is in congestion) to about 60,000 vehicle-hour (16% will be in congestion), and to about 67,000 (17% will be in congestion) in 2030 and 2035. In the ultimate year, the total travel time spent on the network (despite the increase in travel distance) will still be lower than the Base Year and will reach the value of 87,000 vehicle-hour (21% of which will be in congestion).

Very similar trends are observed for the other components of the road network traffic (including, Company Buses and Light and Heavy-Duty Vehicles), as well as for the MD and PM peak periods.

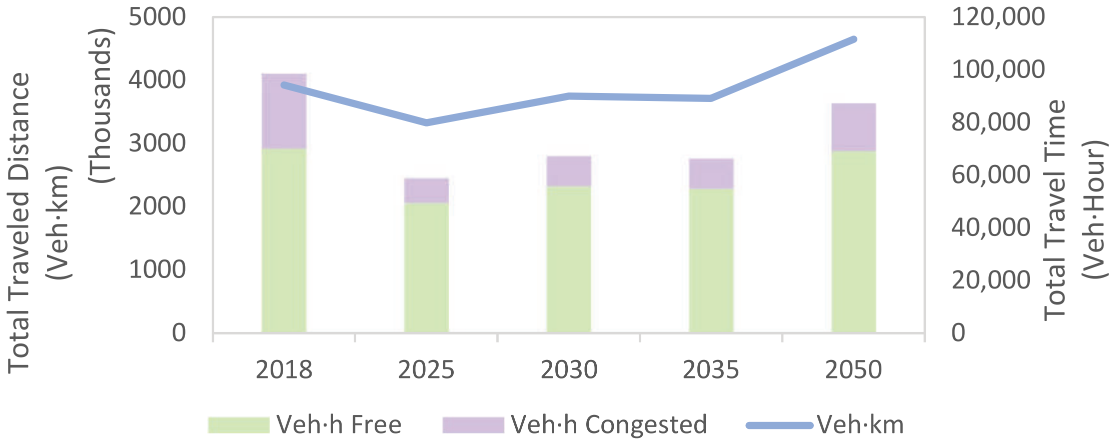


Figure 7.7: Total Car Traveled Distance and Total Travel Time in the AM Peak

7.5.2. Public Transport Network

The Qatar Public Transport Network will be more extensive in 2025, when the three Metro lines, the Lusail LRT and tram network will be operating, as highlighted in Figure 7.8. The patronage is expected to increase by about 25 times compared with the Base Year. In the morning peak hour, about 53,000 passengers will access the public transport network and will travel for a total of about 30,000 hours, covering 830,000 km, with 96,000 total transfers from one line to another.

The high number of transfers highlights the effectiveness of the feeder bus network, which forms an integrated transport supply with the metro network. These numbers vary slightly in 2030, but further increases in 2035 scenario are predicted, due to introducing the fourth Metro line and the national long-distance railway lines. In the AM peak, the number of first-boarding passengers on the day will reach 100,000 and the total distance travelled will be 1.6 million Passenger*Km, with about 140,000 transfers. The total time spent on the PT network will increase to nearly 50,000 Passenger-Hour.

Finally, in the Ultimate Scenario a fraction of the demand is expected to shift onto the private mode of transport. Public transport services will experience a reduction in performance, with about 80,000 first boarding passengers, 100,000 transfers, 1.4 million passenger-km, and 38,000 passenger-hour.

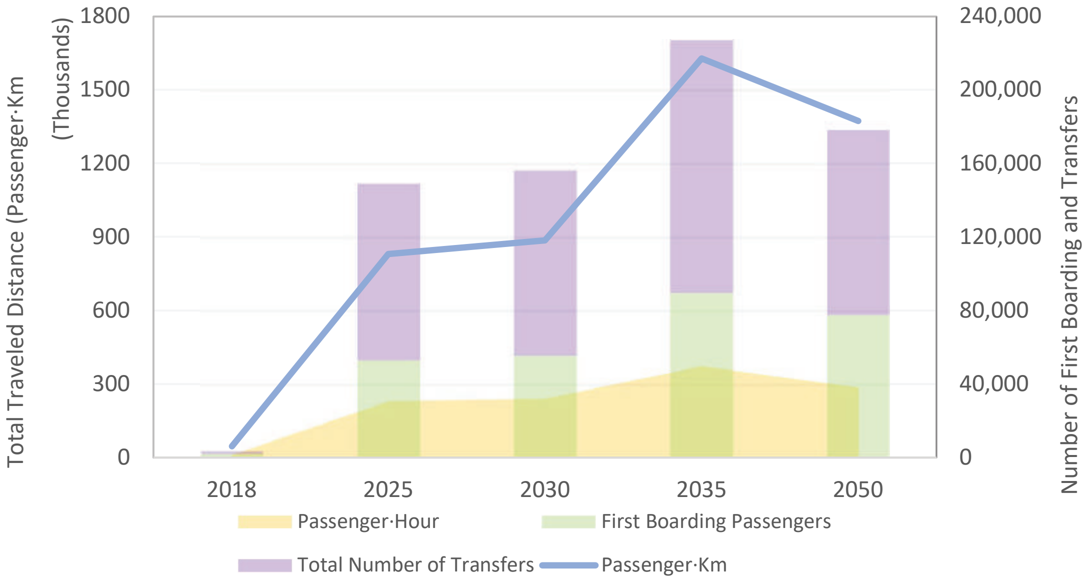


Figure 7.8: Passengers Traveled Distance, Total Boardings and Transfers on Public Transport - AM Period

SECTION - 08

QABM SENSITIVITY TO TRANSPORT POLICIES

8. QABM Sensitivity to Transport Policies

Modeling Opportunities for Investigating Alternative Projects and Policies

8.1. Policy Option Analysis

The goal of the policy option analysis is to investigate what kind of possible alternatives can be potentially introduced and proposed for further evaluations in the strategic transport planning process relative to the Baseline Scenarios. In fact, the Baseline Year Scenarios are concerned with the projects that are ongoing or are already planned. Policy option testing investigates the expected impact of possible alternative policies.

At this stage, the level of implemented details is preliminary, and has a two-fold goal:

- Assess the capability of the model to reproduce the effects of the changes assumed on the transport supply
- Gain a preliminary estimate of the possible impacts

Policy options on fuel cost, congestion pricing, public transport tariffs, and parking fares have been studied, starting from the analysis of some of the relevant international best practices, and then by employing a preliminary analysis that confirmed the sensitivity of QABM to the implemented changes.

Furthermore, a Stress Test Scenario has been implemented by assuming a mobility demand level forecasted for HY 2035 and the supply networks planned for the HY 2025. This allows recognizing the most critical elements of the transport network and identifying possible measures to reduce the congestion level.

More information on policy option testing is documented in the *QABM Sensitivity Tests Report*.

8.2. Policy Option Strategies

In this context, a strategy is meant to comprise a set of mechanisms by which, for example, the objective of total emissions reduction from road traffic can be attained. Six strategies have been explored: reduction of several trips, reduction of trip distance, modal transfer, load factor increases, better vehicle flows, and better vehicles. The strategies and mechanisms for transport policy options implementation are explained in Table 8.1.

To test the sensitivity of QABM to the transport policy options, a framework for the process was developed utilizing the steps illustrated in Figure 8.1.

Table 8.1: Strategies and Mechanisms for Transport Policy Options Implementation

Strategy	Enabling Mechanisms
Trip Reduction	Substituting trips: • Physical to virtual (tele-activity) • Physical to physical (e.g. passenger to freight in home delivery) • Linking trips (trip chaining and multi-purpose trips)
Distance Reduction	• Switching destination
Modal Transfer	• Reducing car use and switching mode towards collective and non-motorized modes
Load Factor Increase	• Increasing load factor for individual, collective and goods vehicles
Better Vehicle Flows	• Re-distributing flows on network links by switching travel time or travel route • Increasing capacity of links and junctions
Better Vehicles	• Introducing and spreading technological innovation • Improving maintenance

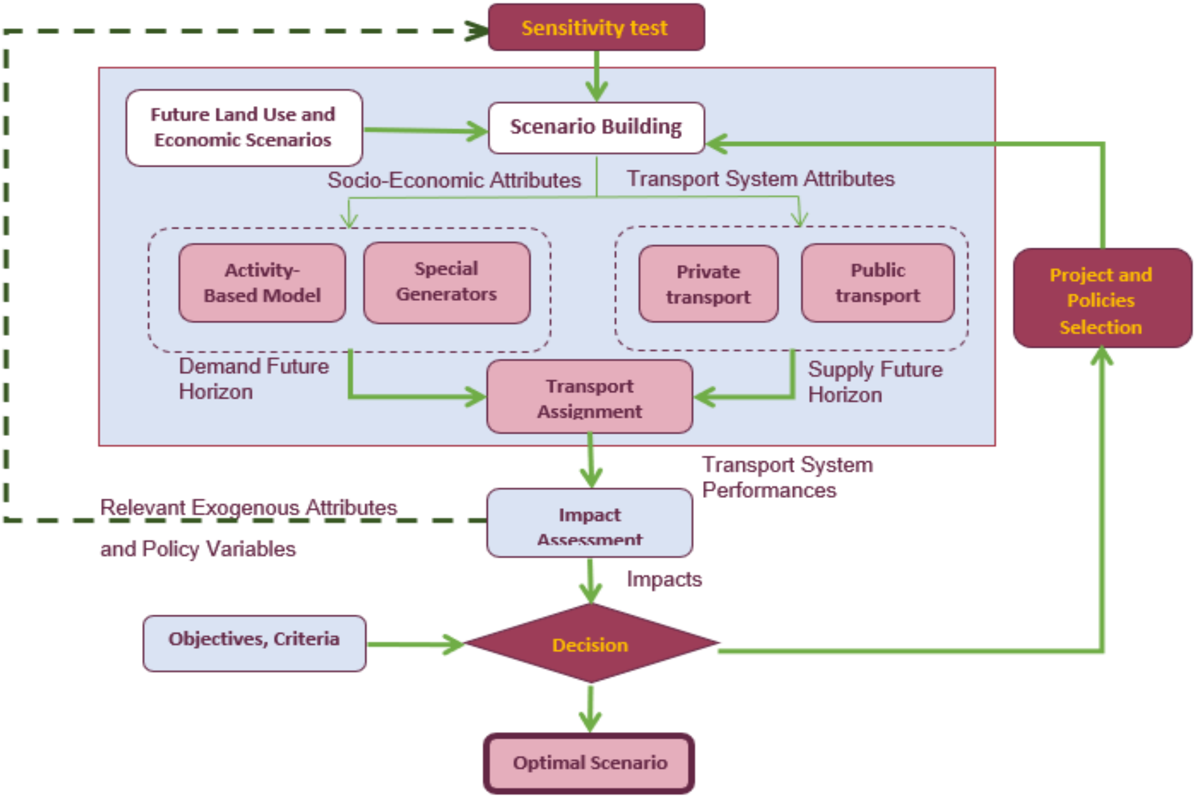


Figure 8.1: Modelling Framework and Policies Selection.

8.3. Sensitivity Analysis Results

The sensitivity analysis aims to demonstrate that the structure of the QABM can sensibly react to changes in travel time and transport costs; that is, the model outputs change if travel time or transport cost change.

8.3.1. Fuel Cost

Increasing the cost of gasoline from 1.55 QAR/liter (base year gasoline cost) up to 2.325 QAR/liter would result in a reduction of 3.3% of car traffic and will have a negligible effect on public transport patronage.

8.3.1. Congestion Pricing

Introduction of road tolls was simulated in two selected areas within the C-Ring and around the West Bay, for two different levels of charge, based on international best practice review. These levels are 10 QAR/entry and 43 QAR/entry. Test results confirmed that the model is sensitive to the introduction of toll, although only limited reductions of road use and slight increase in public transport patronage were estimated.

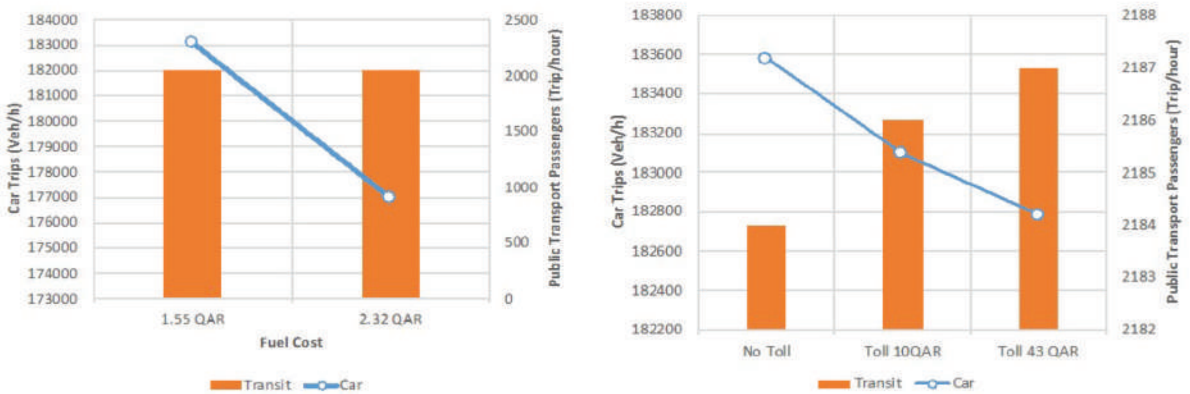


Figure 8.2: Trend of Predicted Demand - Total Transport (left) and Public Transport (right)

8.3.3. Parking Fare

For evaluating the sensitivity of the parking model two different pricing policies were tested, a parking fare of 11 QAR/h and another fare of 43 QAR/h in all the parking lots (both on-street and off-street) existing in the two selected areas within C-Ring and around the West Bay. For the morning peak, the lower parking fare produces a reduction of cars attraction of nearly 5.6% and a decrease in car park occupancy of about 3.6%. This is mainly due to relocation of parking to nearby places and to modal shifts, when possible.

The higher parking fare reduces car attractions by 14.3%, while car park occupancy reduces by only 1.4%, due to the increasing cumulative effects of parking choices in the previous hours in the AM Peak. These variations are amplified in the PM peak, with greater reductions with both the lower fare scenario (9.1% for car attractions and 7.7% for park car occupancy) and the higher fare scenario (27% for cars attraction and 14.3% for park occupancy).

8.4. Investigating Network Development Opportunities - Stress Scenario

8.4.1. Stress-Test Scenario

Developing alternative strategies and scenarios with respect to the Baseline future years is a challenging process that involves the choice criteria defined in the decision process. Such a process will be fully carried out and finalized during the development of the Qatar Strategic Master Plan.

Analyses of Baseline Years scenario focus on the average conditions in the peak periods. However, small random variations of demand could induce significant increases in congestion levels.

To properly consider the impacts of such random changes, the analysis of alternative strategies was carried out by introducing a Stress-Test Scenario having the supply network of Horizon Year 2025 and a demand level of Horizon Year 2035.

The results of this QABM-tested scenario are summarized in Figure 8.3 which shows the corresponding changes in modal share for the AM peak period. Most notably:

- Car Traffic increases from 250,000 veh/h to 300,000 veh/h (that is, around 20%)
- Public Transport increases from around 2,200 passengers/hour up to about 56,500 passengers/hour (that is, an increase of about 26 times thanks to the introduction of new metro system).

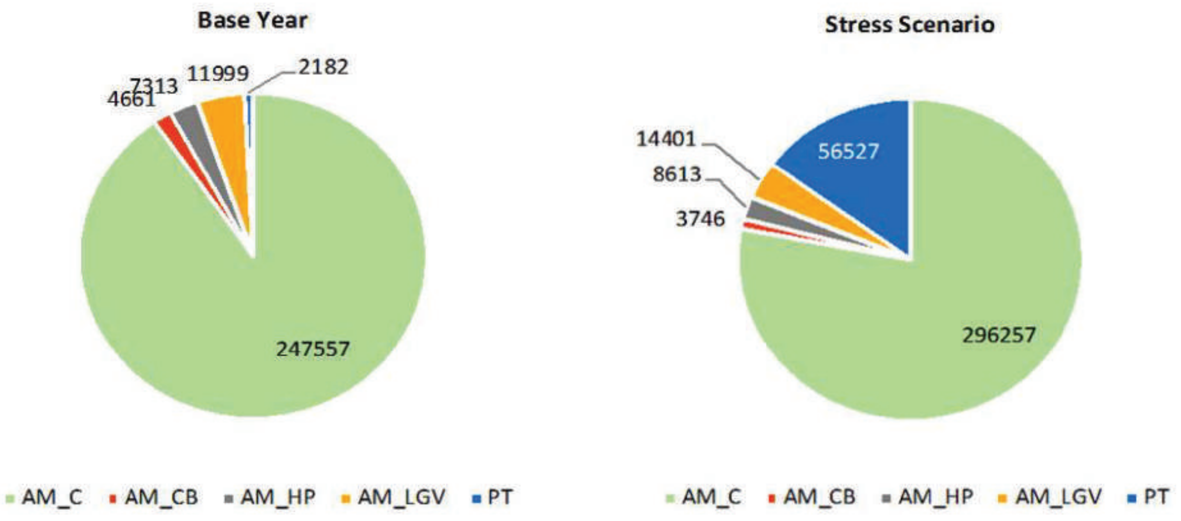


Figure 8.3: AM Transport Modal Share - Base Year (left) and Stress-Test Scenario

8.4.2. Road Network

The results of road network simulation highlighted that the level of congestion with the Stress-Test Scenario is higher than the Baseline Year 2025, and significantly lower than the Base Year. The highest concentration of heavily congested junctions occurs in the central area of Doha. Heavy congestion is also observed on Al Jamiaa Street near West Bay Lagoon. Local oversaturated conditions are also predicted on Salwa Road, Al Waab Road and near the Old Airport.

From the analysis of the Stress-Test Scenario, it follows that access to the central area Doha will experience critical delays, even after the implementation of the measures planned in 2025. Since the central area of Doha is well served by public transport services, congestion pricing could be deemed necessary to reduce the demand level and alleviate congestion. For example, congestion pricing and parking charges in the area bound by the C-Ring could be applied.

Introducing road tolls on the most congested corridors around Doha (Doha Expressway and Al Rayyan Road) could also positively contribute to reducing traffic on selected corridors and congestion in the central area of Doha.

8.4.3. Public Transport

In the AM peak, according to the Street Scenario, the increase of about 52,000 PT users will cause congestion along 27 bus lines. These congested bus lines can be grouped into those affected by extensive congestion and those affected by congestion on a limited part of their route/journey.

The set of lines affected by extensive congestion mainly consists of PT lines connecting Doha with other Qatar cities. The set of lines affected by congestion on a limited part of their routes are those that in the AM peak connect the main generation and attraction zones to the metro sub-network. This suggests that feeder and distribution lines will suffer from such a stress scenario.

This type of over-saturation problem can be solved with simple operation management and by increasing the line frequency and/or vehicle capacity.

8.5. Land Use Development Strategies

The approach adopted for developing alternative land-use strategies is applied to the ultimate year of 2050 (Baseline Scenario HY 2050). The following steps provide the details regarding the approach adopted to evaluate the Baseline Scenario HY 2050 and come up with land-use strategies.

1. Step-1: Evaluate the performance of the supply network of the Baseline Scenario HY 2050in order to identify the congested corridors on the road network.
2. Step-2: Identify the predominant O-D pairs along the congested corridors.
3. Step-3: Analyze the proportions of activity types for these predominant O-D trips experiencing congestion along these corridors so as to identify the major activities making these trips.
4. Step-4: Adjust the input planning data from the Origin TAZs or to the Destination TAZs, or both, based on identified activities.

Figure 8.4 shows the volume-capacity ratio along links of the Baseline Scenario HY 2050 in the AM peak hour. From this volume-capacity figure, it can be observed that the sections of Doha Expressway corridor highlighted in orange have volume-capacity ratios between 0.85 to 1.20.

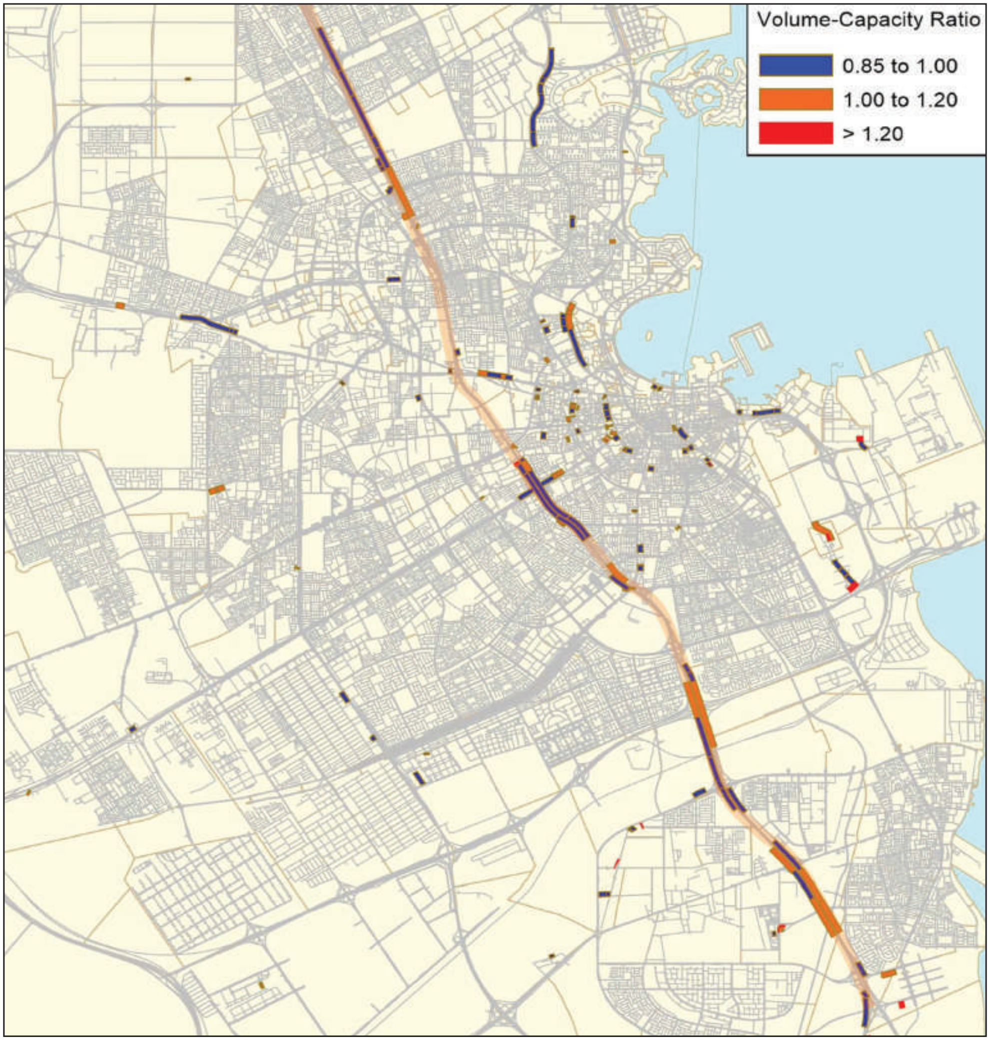


Figure 8.4: Volume-Capacity Ratio of the Baseline Scenario HY 2050 in the AM Peak

Figure 8.5 shows the flow bandwidths for cars along the congested corridor identified above. The desire lines between the major O-D pairs (20 pairs) are shown in the same figure on the right. From the desire lines it is clear that the majority of trips are between Al Wakra and areas in the north of Doha, such as Lusail, Al Daayen, Umm Salal Ali, etc. Also, it is clear that there are origin trips that are more concentrated from few TAZs/areas within Al Wakra than from other areas, whereas the destination trips are observed to be more distributed among the various TAZs in Doha North.

Furthermore, the activities between these OD pairs have been assessed using the output data from CEMDAP and the results are as follows: Work 58%, School 32%, Shopping/Social 7%, Others 4%.

As the predominant number of trips are composed of Work (58%) and School (32%) activities, providing additional school locations and increasing employment opportunities in Al Wakra will provide better accessibility within the area for work and school activities and will thus reduce trips along the congested corridor.

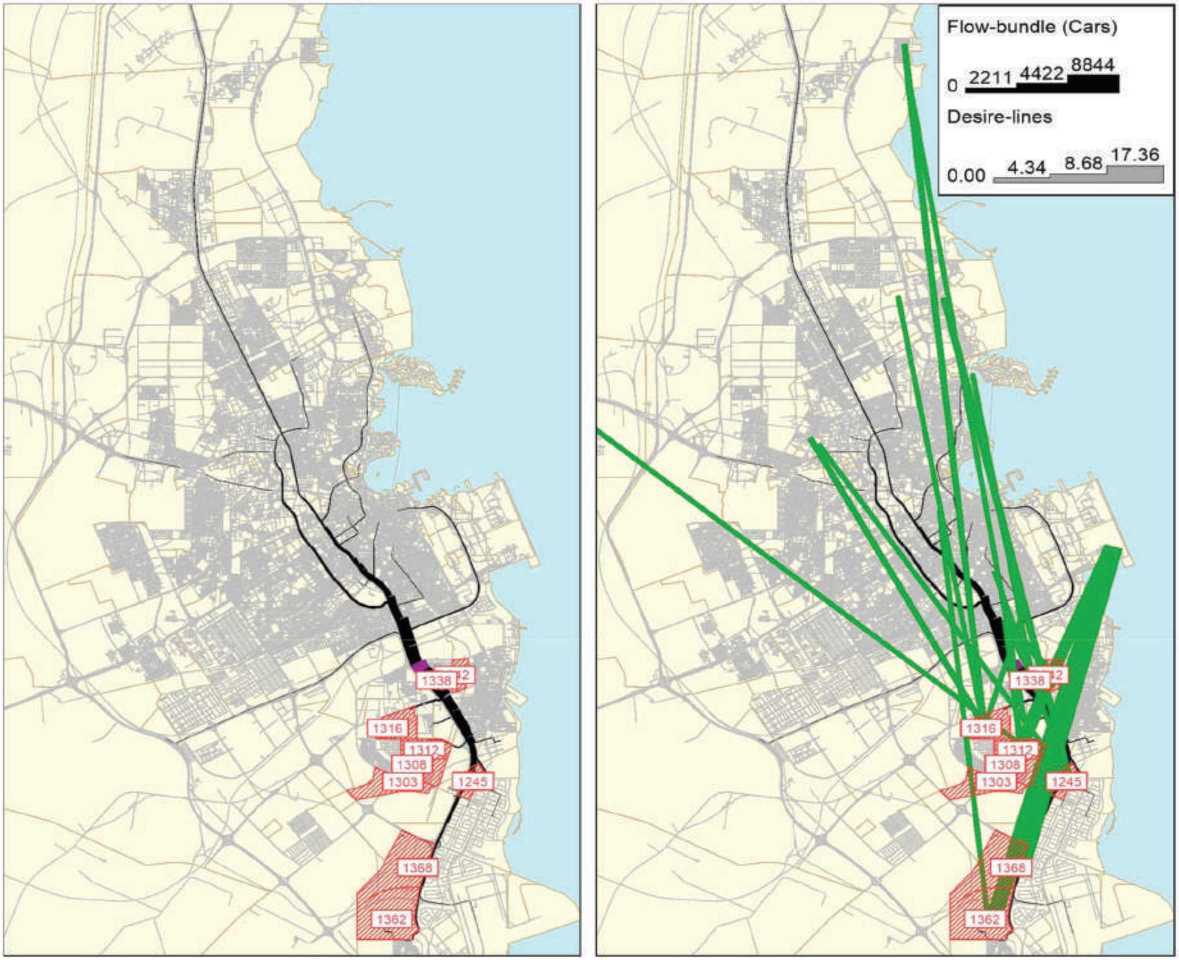


Figure 8.5: Flow-bundle and Predominant Desire-lines along Doha Expressway Corridor

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SECTION - 09

QABM SOFTWARE

9. QABM Software

How to Run the QABM

9.1. Description

QABM is provided with a Graphical User Interface (GUI) that is designed to help the user in configuring a simulation year. The QABM's GUI allows the user to prepare the desired VISUM version file by defining:

1. The folder containing ABM and Skim Inputs
2. Models to simulate
3. Output folder

Once the VISUM version is prepared, the QABM GUI generates the procedure that will run the QABM Integrated process.

The procedure which launches the QABM GUI is shown in Figure 9.1.

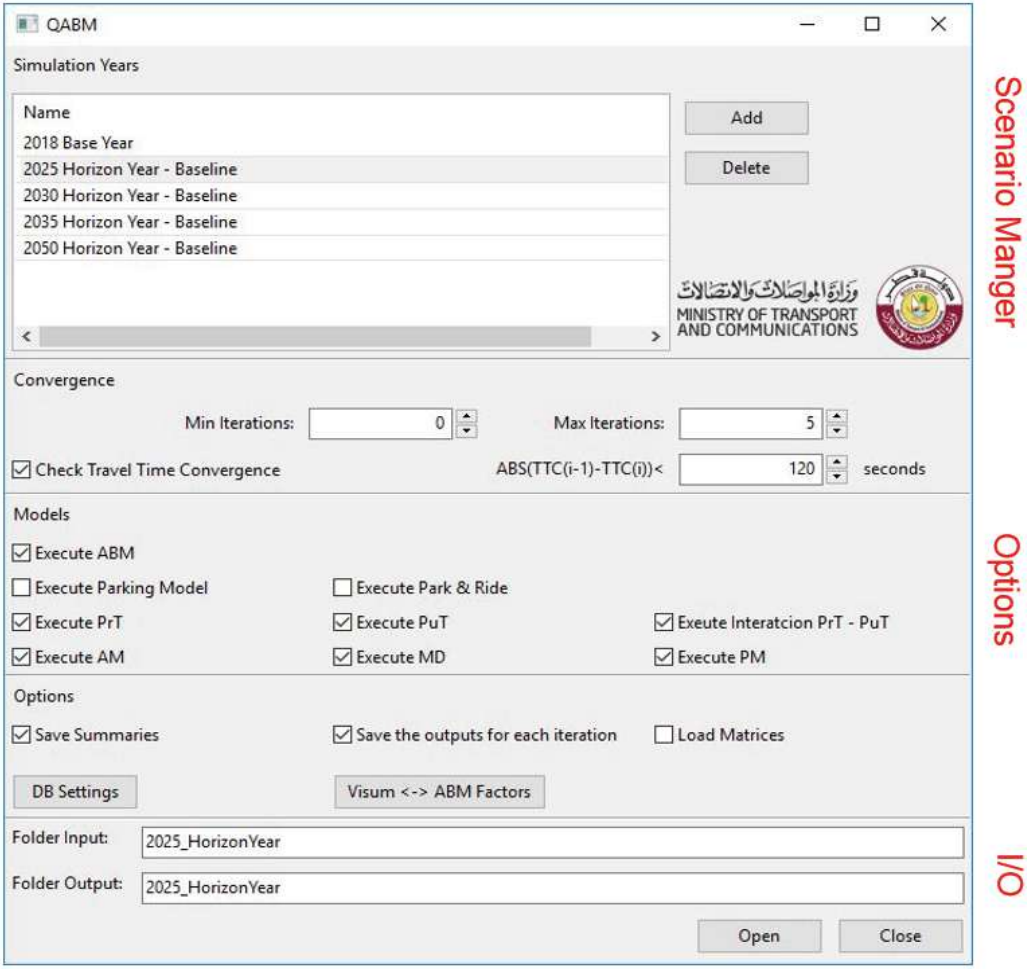

Figure 9.1: QABM Graphical User Interface

9.2. Features

The GUI has three main components:

1. **Scenario Manager.** This component shows a list of all simulated years loaded within QABM. The user can choose the simulation year from the list to perform or add other simulation years from the input folder.
2. **Options**. In the Options area, the user can customize the model behavior. The following options can be selected: Sub-model of QABM, Peak Periods, and a set of convergence parameters. Furthermore, the database settings to store socio-economic and land use variables can be configured through this component.
3. **Input/Output (I/O)**. In the I/O part, the GUI shows the input and the output folders used by QABM. By combining the simulation year with different input folders, it is possible to create new scenarios mixing different supply and demand.

9.3. Simulation Procedure

After defining the run parameters mentioned in the above three components, the GUI runs the routine that pre-processes the input data and prepares the version for the VISUM package. Then, the user can control and manage the simulation process through the VISUM's buult-in procedure window (Figure 9.2), where the scripts that compose QABM are shown together with the necessary subroutines for data import and export.

Furthermore, a separate script is available to simulate trips of the users originated by Special Generators like ports, airport, and hotels, which are not represented in the Activity Based Model.

Count: 25	Execution	Active	Procedure	Reference object(s)	Variant/file	Comment
1	▷	☒	Group Init	2 - 6		Init
2		☒	Run script		CheckParameter.py	Check folders, files and db cor
3		☒	Edit attribute	Network - Iteration Number		ITERATION_NUMBER=0
4		☒	Calculate PrT skim matrix	P P		Calculate Pedestrian Skims
5		☒	Combination of matrices and vectors	Matrix([CODE] = "Walk_DIS"):=Mat		Save Pedestrian Distance
6		☒	Combination of matrices and vectors	Matrix([CODE] = "Walk_T"):=Matrı		Save Pedestrian Trips
7		☒	Group Start Loop	8		Start Loop
8		☒	Edit attribute	Network - Iteration Number		ITERATION_NUMBER += 1
9		☒	Group Accessibility	10 - 11		Accessibility
10		☒	Run script		Visum2ACC.py	Export Data from Visum to Ac
11		☒	Run script		LaunchAccessibility.py	Launch Accessibility Tool
12		☒	Group Demand & Parking Model	13 - 18		Demand & Parking Model
13		☒	Run script		Visum2ABM.py	Export data from Visum to AB
14		☒	Run script		LaunchCemdap.py	Launch CEMDAP
15		☒	Run script		ABM2Trips.py	Extract CEMDAP output
16		☒	Run script		LaunchParking.py	Launch Parking Model
17		☒	Run script		Trips2Mat.py	Import trips to VISUM
18		☒	Run script		SpecialGenerators.py	Special Generators
19		☒	Group Parallel Assignment	20		Parallel Assignment
20		☒	Run script		LaunchAssignments.py	PrT: AM,MD,PM PuT: AM,MD,I
21		☒	Group Convergence & Save	22 - 25		Convergence & Save
22		☒	Run script		Summaries.py	Calculate the Summaries
23		☒	Run script		Convergence.py	Evaluate the convergence ma
24		☒	Run script		SaveVersion.py	Save files ver
25		☒	Go to the procedure	Procedure 7		Iterations: [0-5)

Figure 9.2: QABM Integration Procedure

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SECTION - 10

GIS LINKAGE

10. GIS Linkage

To conduct a transportation assessment during the transportation planning and designing stages, Key Performance Indicators (KPIs), such as traffic volumes, travel times and congestion levels by travel mode, are applied.

QABM has been configured to output such Key Performance Indicators (KPIs). These are then displayed on a computer screen through a GIS tool which has been specifically developed to work with QABM.

The tool has been designed to overcome the common challenges which arise when data sharing and accessibility to the data by the transportation professionals and stakeholders are needed. The tool uses an enterprise level technology which host the QABM data and share it with the stakeholders through a GIS Linkage to provide a centralized Geodatabase and an easy to use mechanism to access the data.

The GIS Linkage includes the following main operations:

1. Extract the data from QABM version files and store it in a centralized Geodatabase.
2. Publish the data over a standard web services protocols using ESRI ArcGIS Enterprise.
3. Visualize the data on an interactive web application.

The developed GIS Linkage system includes the following main components, which are illustrated in (Figure 10.1):

1. QABM Data Integration Tool.
2. QABM Geodatabase.
3. ArcGIS Enterprise.
4. QABM Visualization Tool.

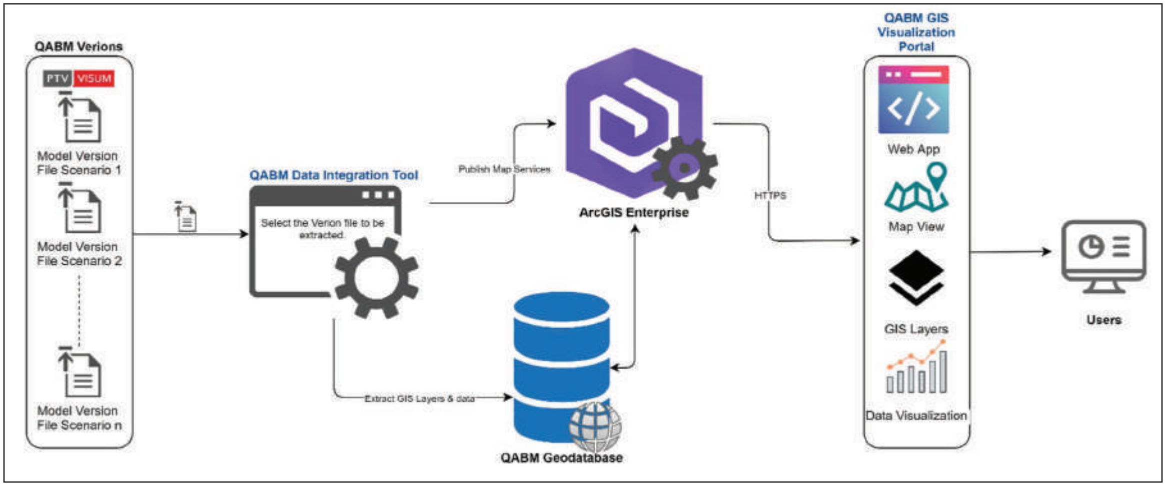

Figure 10.1: GIS Linkage System Diagram

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SECTION - 11

CONCLUSION AND RECOMMENDATIONS

11. Conclusion and Recommendations

The Qatar Activity Based Model (QABM) covers the whole State of Qatar and incorporates all currently operational land transport systems. It is the first strategic transport model in the Gulf implementing an Activity Based Model (ABM). Indeed, QABM is the first model having a comprehensive integrated ABM.

QABM has been born out of a huge effort that stretched over 2.5 years, and involved:

1. Collecting and analysing a large set of data;
2. Poring over a wide literature related to the latest advances in activity-based modelling;
3. Conducting a thorough review of international best practices, while focusing on the feasibility of applying ABM to Qatar and establishing what lessons can be learnt from such similar model developments elsewhere;
4. Building the model and developing the scripts and software applications which are needed to realize the model;
5. Calibrating and validating the base year model;
6. Testing the model by assessing its sensitivity to various trasnport policy measures;
7. Enabling the model to assess the performance of the future transport systems and guide the transport planning process; and
8. Devloping a GIS interface which can easily allow the user to view the model outcome of option testing on the screen to identify, for instance, road congestion hot spots, location of limitedpublic transport services, or which public trasnport services are overloaded.

The model has gone through a rigorous checking procedure to ensure that all of its various components are well integrated, and the model output is sensitive to transport policy measures, as per the expected norm.

However, similar to the development of any country-wide, complex strategic transport model, there will always be a scope for further model enhancements and refinements, particularly as the model is further applied in evaluating scenarios and policies, and as more up-to-date data (e.g. census data) are made available. One of the biggest tasks in developing QABM was the data collection, and each collected information had to be utilized to the most possible, to get the best out of it. When there was a lack of data, many potential alternatives were explore. Rational assumptions were made when there were no alternatives. One example is the case with CEMDAP, where the parameters of the model had to be borrowed from SCAG (Sothern California). This model has been customized to Qatar, but additional efforts can be expended to make the model more specific to Qatar.

Other areas which can also be considered in model enhancement and updates is the runtime. ABMs consider the daily activities at the individual's level. This consideration consequently requires long computational time. Therefore powerful computers can be utilized to reduce the runtime. Currently, the model takes between 15-24 hours to complete a full scenario. It is believed, however, this matter will be resolved in the near future, as more powerful computers that can dramatically reduce the run time will emerge. A possible solution to overcome the runtime issue is the use of a supercomputer. This has the potential of testing several alternatives within a few hours or less.

At the end of the QABM development, there can many takeaway recommendations. Foremost amongst them though is: maintain, update and always upgrade QABM. Activity-based modelling is an area that has rapidly been advancing over the last years. Insofar as the development of QABM is concerned, this is only the beginning; the basic structure of the model, the tools, the scripts, etc. have all been built. Nonetheless, these tools and scripts can be further built upon in the future.

وزارة المواصلات
MINISTRY OF TRANSPORT

P.O. Box 24455 ص.ب.
Doha, Qatar الدوحة, قطر
T +974 4045 1111 ت
motc.gov.qa

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