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Demand Characteristics of The Newly Proposed Kuwait Metro

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ABSTRACT

Traffic models are of foremost importance in the planning of any transportation infrastructure. This importance lies in the ability to predict future behaviour of users and, therefore, the demand on each link of the network. In order to properly study the demand patterns and characteristics of the city of Kuwait, a detailed modelling of these phenomena is required. The purpose of this modelling is to create a useful tool, with which to objectively evaluate the alternatives proposed in this paper research. Future demand on the proposed public transport network had been forecasted based on the transportation model developed by Atkins for Colin Buchanan & Partners in the framework of the 3rd Kuwait Masterplan Review. This model, built on a SATURN platform, was translated to a CUBE environment. This step involved reproducing both the data (networks and demand), then also the model algorithms, and checking the output results after running the model on this new platform matched those obtained by Buchanan. That initial model, built for a 2003 base year, was then updated to the current situation, where both road and public transport networks were concerned. The current road network was checked, and amended or completed when necessary, as well as the public transport services.

Keywords: Demand; Kuwait; Metro; railways; transportation; networks.

1. INTRODUCTION

Population in general has seen a very enormous growth in the twentieth century (UN statistics 2010; 2013). As a result, urban population had moved for areas that are away from cities (United Nations, 2009). Because of the massive urban development, many challenges showed up such as high density over limited space and the outsized increase in number of vehicles (Aljoufie 2014; Global Mass Transit 2015; Pojani and Stead 2015). Population is considered an indicator of travel demand (Javid et al., 2013). Sperling and Gordon (2009) stated that the number of vehicles is expected to reach two billions globally in the coming two decades. This increase will cause several problems such as traffic jams, air pollution, and highway accidents (WHO 2004; Santos et al., 2010a). Using cars by riders for road trips is harmful to rural areas. The infrastructure design is usually not able to cope up with the huge numbers of cars (Jaarsma et al., 2009). Meanwhile, the growing numbers of vehicles cause noise pollution (Gray et al., 2001). Also, parked vehicles are a kind of visual pollution (Tolley, 1996). The overall amount of automobile kilometres travelled had increased from 48 billion in 1980 to 84 billion in 2011 (FOD Mobiliteit en Vervoer, 2013). The huge increase in traffic associated with more peak periods had caused a heavy congestion and extensive time losses (Redmond and Mokhtarian, 2001; Sultana, 2002). Encouraging people to use the public transport is very important (Benenson et al., 2010; Boon, 2003; Mavoa et al., 2012). Moreover, public transport is good for health in some ways like walking to the stations or cycling (Rojas-Rueda et al., 2012). So as to convince people to utilize public transport, travel time is a vital unequivocal factor (Beirão and Sarsfield Cabral, 2007; Kwok and Yeh, 2004; Redman et al., 2013). Public transportation networks are dependent of their uses. For example, the distance of the trip and time required are less than other automobiles. Also, the tracks used for public transport are less congested as compared to cars using normal roads (Owen and Levinson, 2015). Likewise, these public networks like buses and railways had been assembled and enhanced in numerous urban communities to augment access and support travel ridership (Cervero, 2004). In general, the greater part of the transportation problems rises when vehicles do not fulfill the request of urban mobility (Global Mass Transit, 2015). Many researches had been done to determine certain transport related issues in urban regions (Rodrigue et al., 2013; Doi and Kii, 2012; Pan, 2012). The process of re-arranging streets, transport frameworks, and railways can help in controlling the use of land to accomplish more reasonable mobility (Rodrigue et al., 2013; Pojani and Stead, 2015; Litman, 2017). Finally, cities would incredibly benefit from reducing the problems related to transportation. This can be achieved through executing techniques and strategies adopted worldwide that match city-particular needs (Zavitsas et al., 2010).

2. DESCRIPTION OF THE INITIAL SATURN MODEL. TRANSLATION TO CUBE

2.1 Networks

The model developed in the frame of the 3rd Kuwait Master Plan Review included an extremely detailed road network, as well as highly comprehensive Public Transport network. Both networks included all necessary data for a correct demand modelling. Where the road network is concerned, link lengths, number of lanes, free-flow speed, hourly capacity, and delay-flow functions are also included as shown in Table 1. The public transport service attributes included routes, stops and headways, and fares. Additional data were also taken in account such as parking fares at selected facilities. Both of these networks were successfully translated to CUBE, with some minor adjustments due to software requirements, as zoning system, among others. Figure 1 shows the base year road network in CUBE and the base year public network in CUBE.

Table 1. Flow Delay Functions.

	Road Type								
Index	**Type**	**Speed**	**Lanes**	**Frontage**	**Junction**	**F.F. Speed**	**Speed @ Capacity**	**Capacity/ Lane**	**Power**
1	Dual	120				96	70	2000	4.64
2	Dual	100				95	70	2000	3.04
3	Dual	80	3+			76	55	1850	4.34
4	Dual	80	2			68	50	1650	3.33
5	Dual	45		Primary		62	30	1450	2.89
6	Dual	45		Secondary		47	30	850	2.68
7	Dual	45	2	Shopping		49	30	1000	3.84
8	Single	45				42	25	1000	1
9	Dual	80			Rbt	63	52	1150	5.83
10	Dual	45			Rbt	56	41	1150	2.68
11	Dual	45			Rbt	45	25	8550	3.59
12	Dual	45			Rbt	46	30	1000	2.53
13	Dual	120			Signals	96(+27s)	70(+57s)	2000*	4.64
14	Dual	100			Signals	95(+27s)	70(+57s)	2000*	3.04
15	Dual	80	3+		Signals	76(+27s)	55(+57s)	1850*	4.34
16	Dual	80	2		Signals	68(+27s)	50(+57s)	1650*	3.33
17	Dual	45		Primary	Signals	62(+27s)	30(+57s)	1450*	2.89

18	Dual	45		Secondary	Signals	47(+27s)	30(+57s)	850*	2.68
19	Dual	45	2	Shopping	Signals	49(+27s)	30(+57s)	1000*	3.84
20	Single	45			Signals	42(+27s)	25(+57s)	1000*	1
21	Short Traffic Signal Approach				Signals	30(+27s)	30(+57s)	*	1
22	Traffic Signal Exit Link					30	0	0	0
23	On-/Off-Ramps					68	50	1650	3.33
24	Filter Lane		1			50	50	1000	0
25	Filter Lane		2			55	55	1000	0
26	U-turn					33	30	850	1
27	Roundabout Circulating Link					22	0	0	0
99	Bus/Zone					30	0	0	0

*Signals are given the smaller value of the link capacity or (850 x the number of entry lanes)

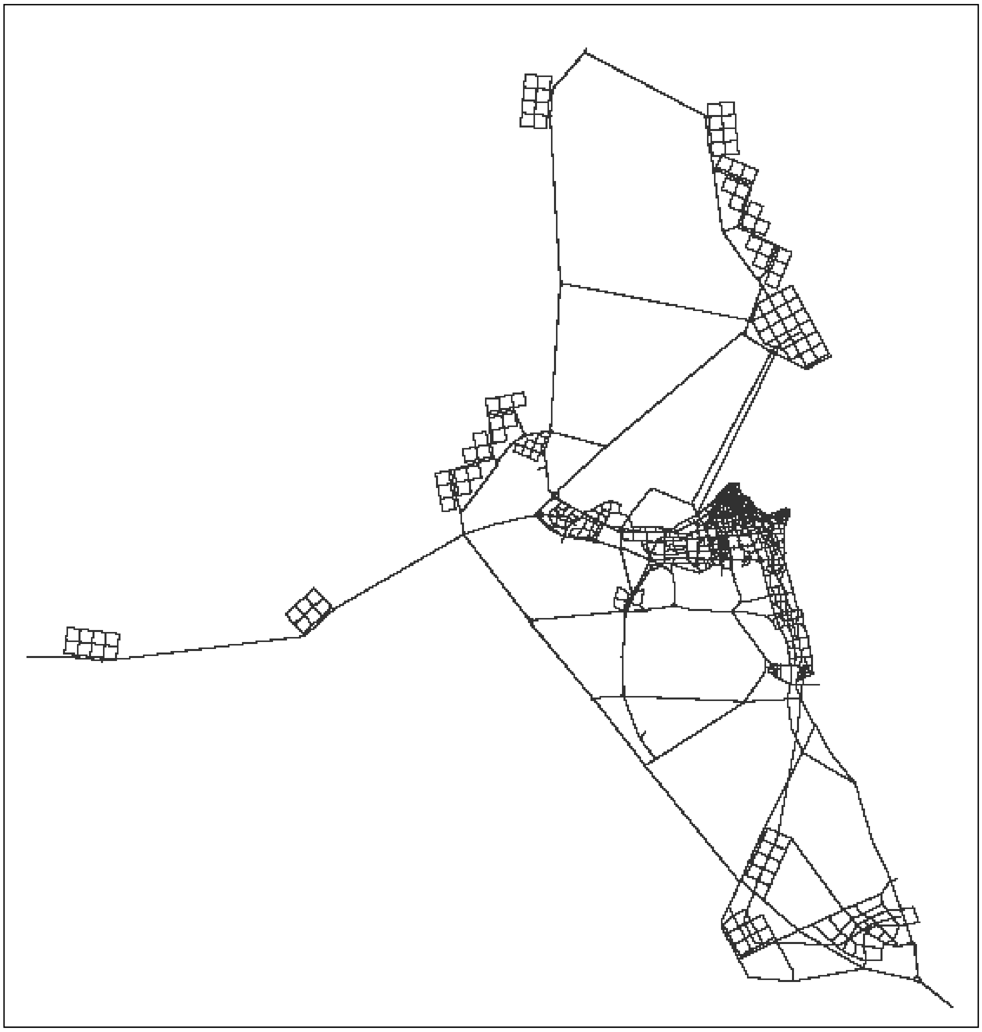


Figure 1. Base Year Road Network in CUBE – (A) General View

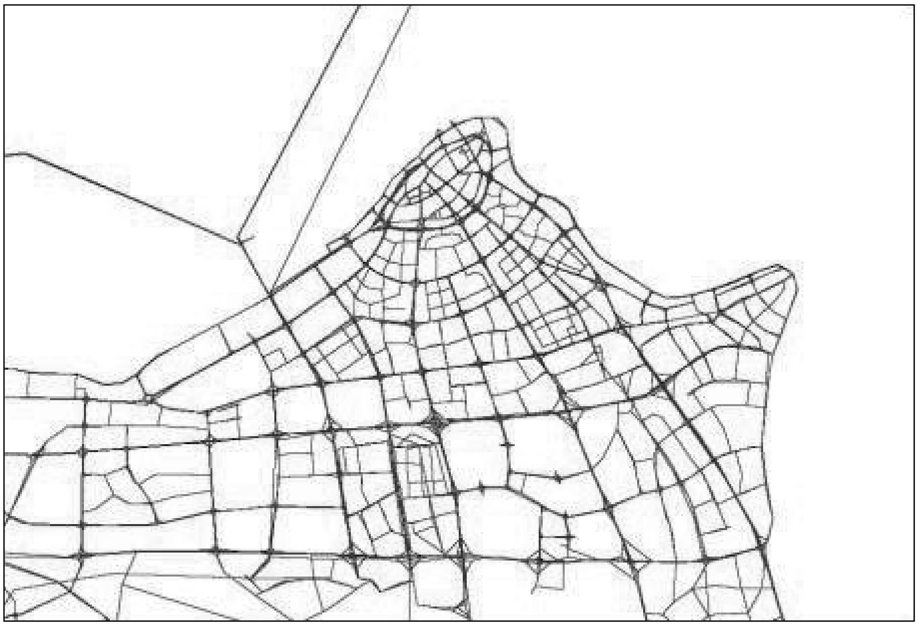


Figure 1. Base Year Road Network in CUBE – (B) City Detail

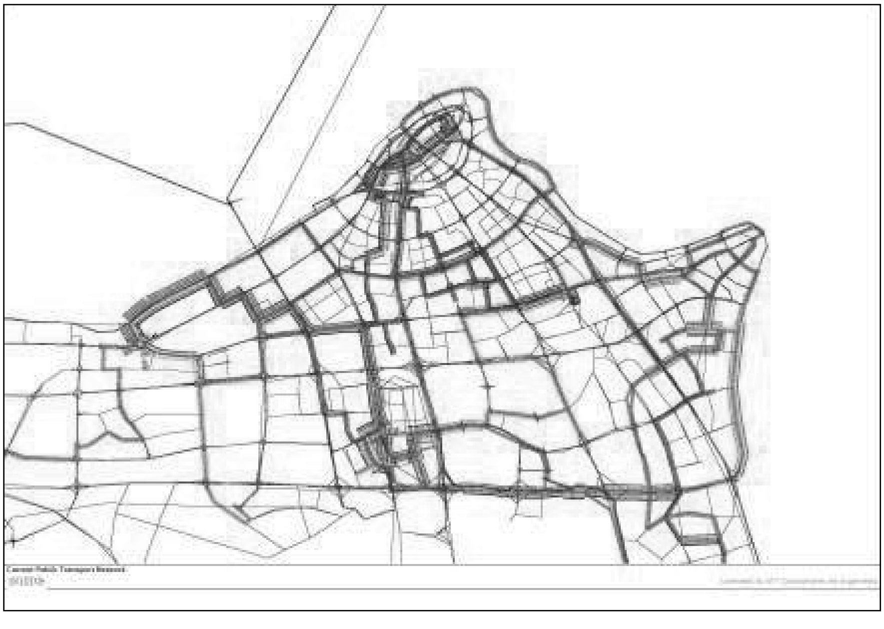


Figure 1. (C) Base Year Public Network in CUBE

2.2 Zoning System

The zoning system includes 495 zones, part of which is shown in Table 2 (Sectors 1, 2, and 3 and part of sector 4). This system was kept in CUBE, though centroids were renumbered to comply with CUBE requirements (correlative zone numbers). This zoning system covers both existing urban areas and future/ongoing urban developments (New Towns). Figure 2 shows the zoning areas.

Table 2. Zoning System SATURN/CUBE Numbering.

Sector	Governorate	Neighbourhood	Saturn Zone	CUBE Zone	Sector	Governorate	Neighbourhood	Saturn Zone	CUBE Zone
1	Capital	Dasman	11	1	3	Capital	Faiha	133	51
1	Capital	Sharq	12	2	3	Capital	Faiha	134	52
1	Capital	Sharq	13	3	3	Capital	Faiha	135	53
1	Capital	Sharq	14	4	3	Capital	Abdullah as-Salem	136	54
1	Capital	Sharq	15	5	3	Capital	Abdullah as-Salem	137	55
1	Capital	Sharq	16	6	3	Hawalli	Maidan Hawalli	141	56
1	Capital	Dasman	17	7	3	Hawalli	Maidan Hawalli	142	57
1	Capital	Dasman	18	8	3	Hawalli	Maidan Hawalli	143	58
1	Capital	Sharq	19	9	3	Hawalli	Sha'ab	144	59
1	Capital	Dasman	21	10	3	Hawalli	Sha'ab	145	60
1	Capital	Bneid al-Qar	22	11	3	Hawalli	Hawalli	151	61
1	Capital	Mircab	23	12	3	Hawalli	Hawalli	152	62
1	Capital	Mircab	24	13	3	Hawalli	Hawalli	153	63
1	Capital	Mircab	25	14	3	Hawalli	Hawalli	154	64
1	Capital	Dasman	26	15	3	Hawalli	Hawalli	155	65
2	Capital	Mircab	30	16	3	Hawalli	Hawalli	156	66
2	Capital	Mircab	31	17	3	Hawalli	Hawalli	157	67
2	Capital	Mircab	32	18	3	Hawalli	Hawalli	158	68
2	Capital	Mircab	33	19	3	Hawalli	Hawalli	159	69
2	Capital	Qiblah	34	20	3	Hawalli	Hawalli	161	70
2	Capital	Qiblah	35	21	3	Hawalli	Hawalli	162	71
2	Capital	Qiblah	36	22	3	Hawalli	Hawalli	163	72
2	Capital	Qiblah	37	23	3	Hawalli	Hawalli	164	73
2	Capital	Qiblah	38	24	3	Hawalli	Hawalli	165	74
2	Capital	Mircab	39	25	3	Hawalli	Hawalli	166	75
2	Capital	Qiblah	41	26	3	Hawalli	Hawalli	167	76
2	Capital	Qiblah	42	27	3	Hawalli	Hawalli	168	77
2	Capital	Qiblah	43	28	3	Capital	Rawdah	171	78
2	Capital	Qiblah	44	29	3	Capital	Rawdah	172	79
2	Capital	Qiblah	45	30	3	Capital	Rawdah	173	80
2	Capital	Qiblah	46	31	3	Capital	Rawdah	174	81
2	Capital	Qiblah	47	32	3	Capital	Rawdah	175	82
2	Capital	Qiblah	48	33	3	Capital	'idailiyah	176	83
2	Capital	Qiblah	49	34	3	Capital	'idailiyah	177	84
3	Capital	Da'iya	111	35	3	Capital	'idailiyah	178	85
3	Capital	Da'iya	112	36	3	Capital	'idailiyah	179	86
3	Capital	Da'iya	113	37	4	Capital	Keifan	211	87
3	Capital	Da'iya	114	38	4	Capital	Keifan	212	88
3	Capital	Dasma	115	39	4	Capital	Keifan	213	89
3	Capital	Dasma	116	40	4	Capital	Keifan	214	90
3	Capital	Bneid al-Qar	117	41	4	Capital	Keifan	215	91
3	Capital	Bneid al-Qar	118	42	4	Capital	Khaldiyah	221	92
3	Capital	Qadisiyah	121	43	4	Capital	Khaldiyah	222	93
3	Capital	Qadisiyah	122	44	4	Capital	Khaldiyah	223	94
3	Capital	Qadisiyah	123	45	4	Capital	Shuwaikh Ind.	231	95
3	Capital	Mansouriyah	124	46	4	Capital	Shuwaikh Ind.	232	96
3	Capital	Mansouriyah	125	47	4	Capital	Shuwaikh Ind.	233	97
3	Capital	Mansouriyah	126	48	4	Capital	Shuwaikh Ind.	234	98
3	Capital	Nuzhah	131	49	4	Capital	Shuwaikh Ind.	235	99
3	Capital	Nuzhah	132	50	4	Capital	Shuwaikh Res.	236	100

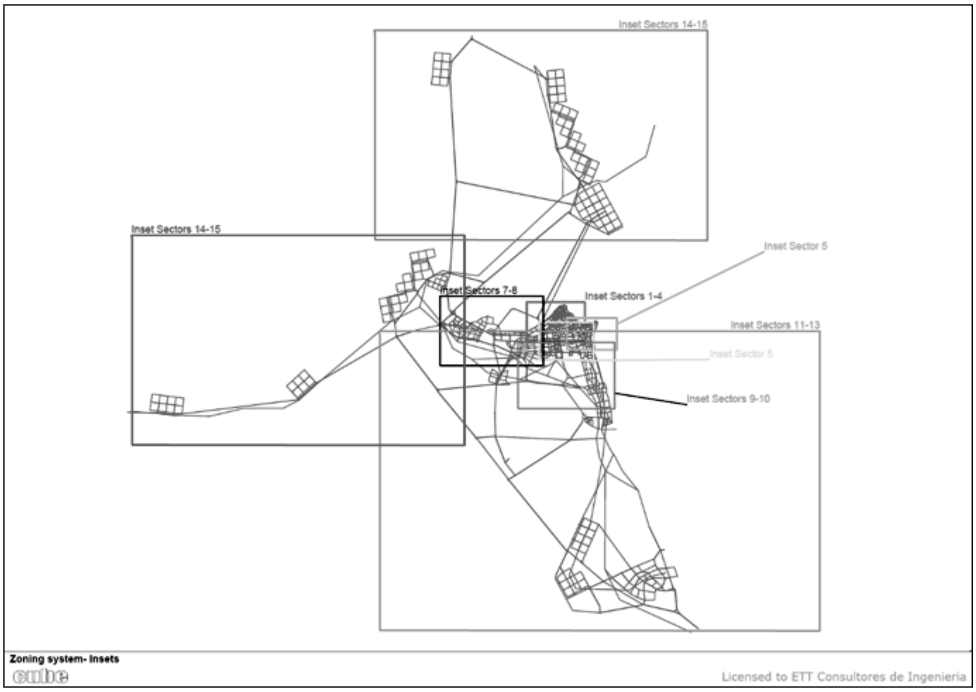


Figure 2. (A) Zoning System – General View and Sectorial Insets

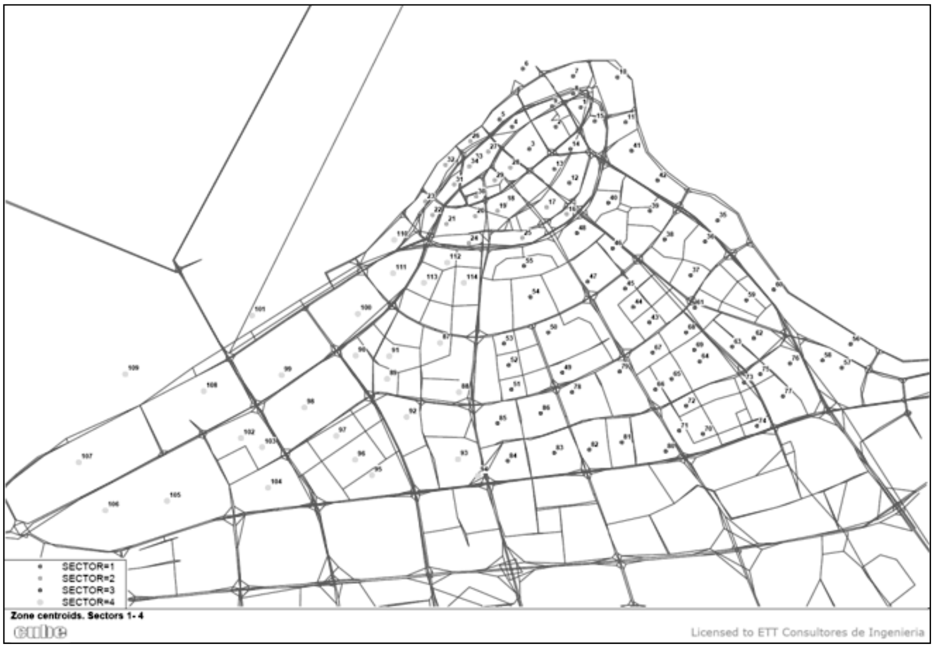


Figure 2. (B) Zoning System – Sectors 1-4

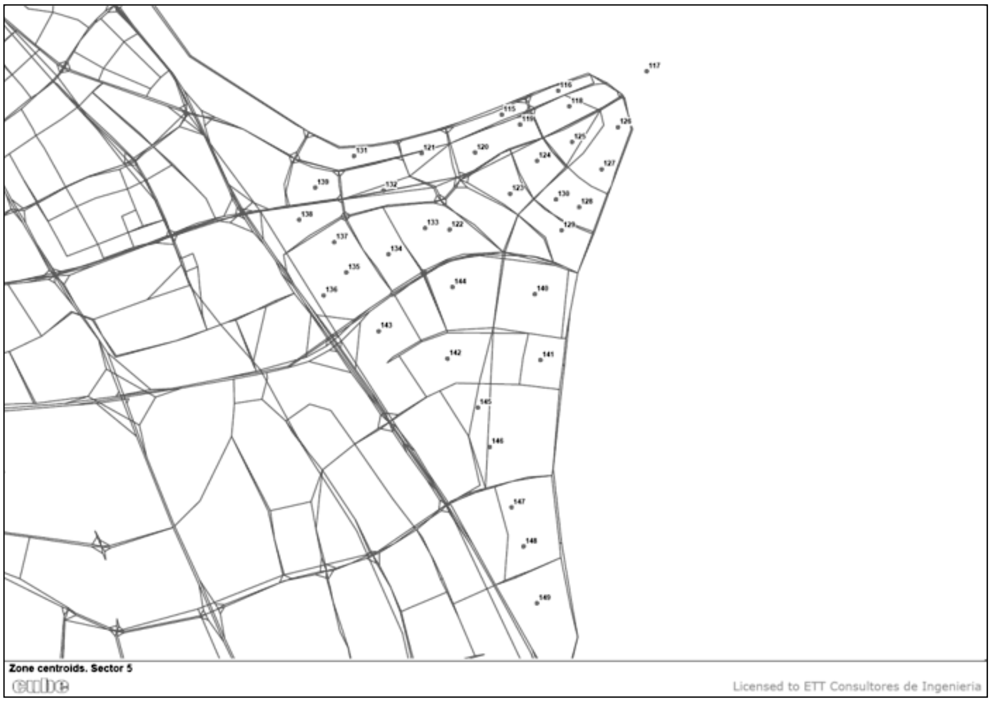


Figure 2. (C) Zoning System – Sector 5

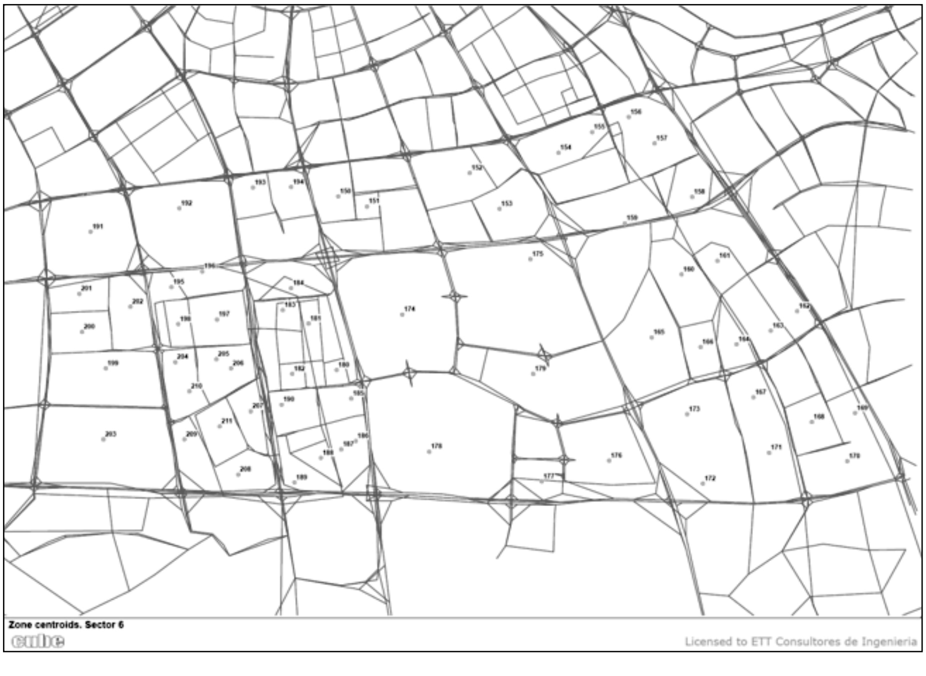


Figure 2. (D) Zoning System – Sector 6

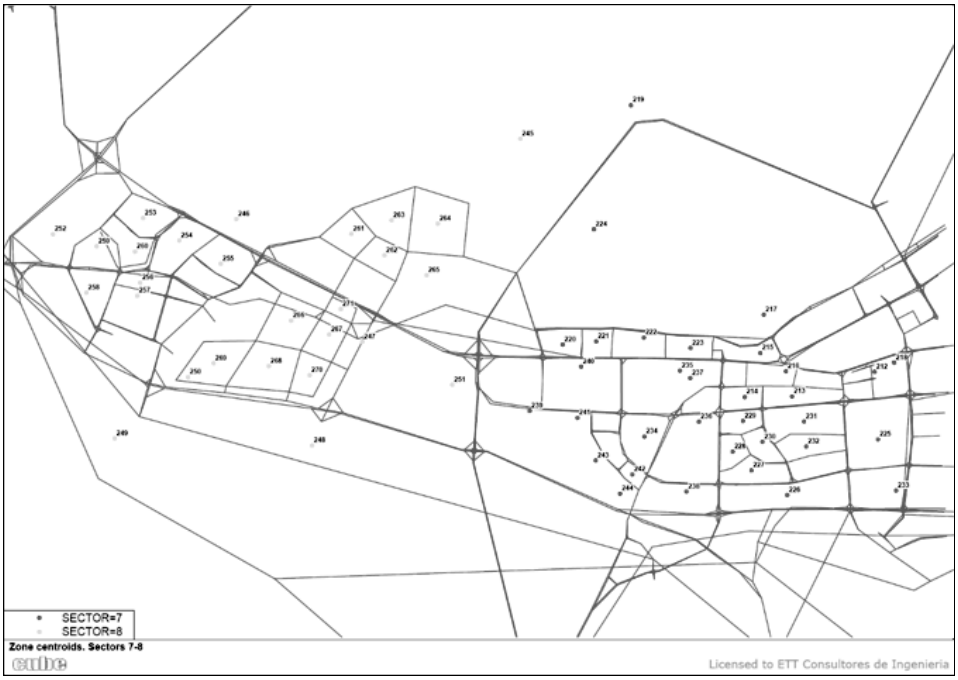


Figure 2. (E) Zoning System – Sector 7-8

Figure 2. (F) Zoning System – Sector 9-10

Figure 2. (G) Zoning System – Sector 11-13

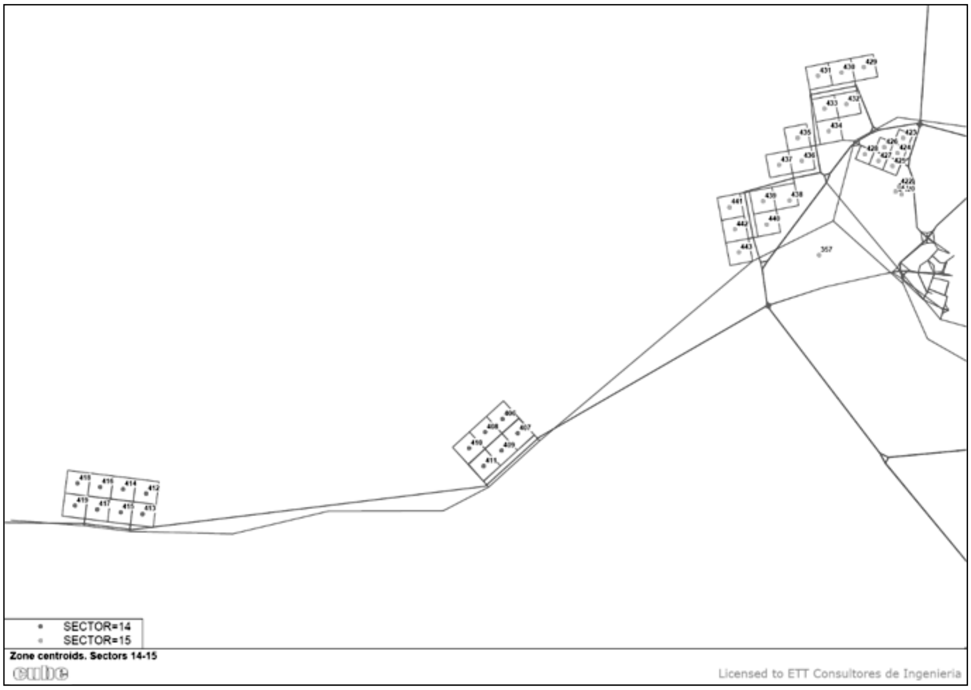


Figure 2. (H) Zoning System – Sector 14-15

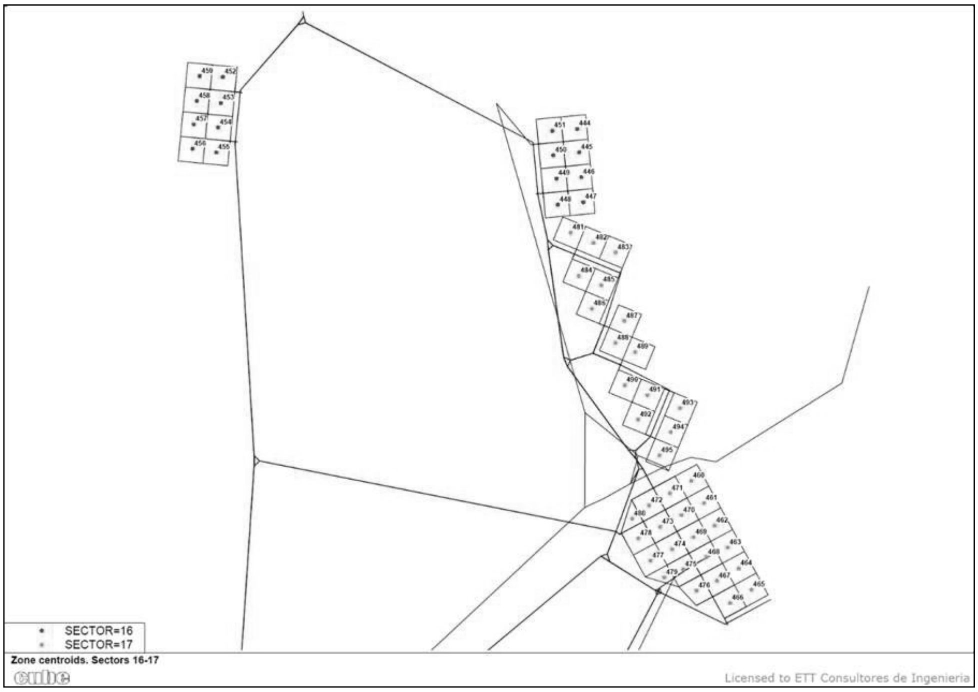


Figure 2. (I) Zoning System – Sector 16-17

2.3 Demand Data

The base year 2003 demand data, that is, matrices for both private vehicle and bus trips, used in the 3rd KMPR model, were derived form 1995 matrices, updated with 2003 count data.

The data used in building the model included the following:

1. Surveying of over than 50000 residents of 6334 households throughout the Metropolitan Area of Kuwait.
2. Surveying of almost 3000 employees and their employers at establishments close to the alignment of the proposed transit system.
3. Manual and automatic traffic counts at almost 500 locations throughout the Metropolitan area
4. Measurements of travel time and traffic speed on over than 300 km of roads of different types on 9 routes in the Metropolitan Area.
5. Observations of junction operation, capacity, delays, and queuing behaviour at 27 separate locations.
6. Measurements of traffic signal timings and phasing at 62 junctions.
7. An inventory of road network characteristics on every important road link and junction throughout the Metropolitan area.
8. Bus passenger counts at every major stop on every route operated by KPTC scheduled services.

These data were validated and analysed using different software such as SPSS: household and establishment interview data analysis; trip end modelling, RIAS, and ROADWAY (trip matrix Building and Validation): roadside interview data analysis; trip matrix building, SATURN: private vehicle network building; matrix building and assignment, MOTORS: public transport network building; matrix estimation and assignment, LOTUS: trip end modelling and trip rate calibration, TRADVV: trip distribution and modal split and ALOGIT: disaggregate model investigations.

2.4 Model Structure

The 3rd KMPR model followed broadly a traditional four-step sequence: Trip generation, Trip distribution, Modal Split, and Assignment. Figure 3 shows the 3rd KMPR model structure. The main particularity of the model structure for the 3rd Kuwait Master Plan rests on the fact that 2 of the standard 4 steps involved in demand modelling (distribution and modal split) were merged into one single process. Based on planning variables (population, employment, schooling, etc.), trip production and attraction were calculated for each zone in the model, disaggregated by nationality. Next, and based on these output trips and travel costs (time, distance, PT, and parking fares), trip distribution and modal split were run simultaneously, by applying previously calibrated mathematical algorithms. This procedure outputted sets of trip matrices (origin-destination) disaggregated by travel mode (Car/PT). Ultimately, these were assigned to their respective networks. Considering that no updated origin-destination data (from new surveys) were available to recalibrate a different approach, the same model structure was implemented in the CUBE model framework.

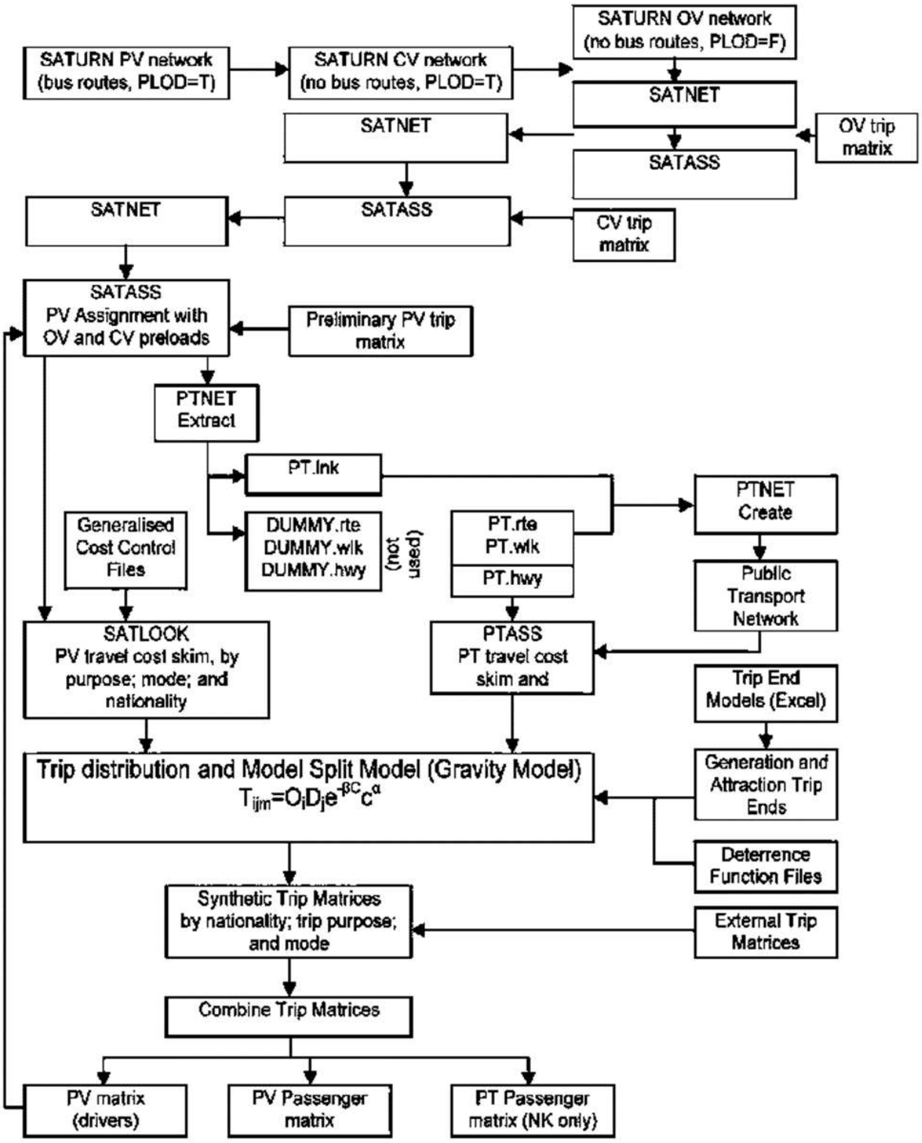


Figure 3. 3rd KMPR model structure.

2.5 Trip Generation

Trip ends were calculated based on currently available planning data. Each zone had been assigned a pre-determined trip rate based on the average car-ownership and population for a zone. The trip rates are per household and were derived from the 1987 Corridors Study, which undertook a large programme of household interviews. Trip rates had been increased by 3% per annum to account for a general increase in trip-making. Trips were calculated for:

1. home-based work;
2. home-based education;
3. home-based other, and;
4. non-home-based,

for both Kuwaitis and non-Kuwaitis.

The trip purpose determines the appropriate trip rate for the four trip categories. For home-based work, the trip rate depends on the number of working people per home, whilst the remaining three trip types, home based education, home based other, and non-home based, are based on the number of students per household. Trip rates are referenced by an index, based upon the matrix sector, number of automobiles per household and number of employees per household. The total number of home-based work, home-based education, and home-based other trips was calculated as the number of households multiplied by the appropriate trip rate for each purpose. Non-home-based trips were calculated as the number of school and work places multiplied by the appropriate non-home-based trip rate. Employer's business trips were calculated as the sum of trip ends of the four other purposes divided by 23. The origin of this assumption is unclear - employer's business was not specified as a purpose in 1987 and there are no references to this in the 3KMP models. Nevertheless, the assumption has been retained as there is insufficient information on which to base any changes.

2.6 Trip Distribution and Modal Split

The trip distribution and modal split are both undertaken in the same mathematical process. The process is essentially a gravity model calculated by equation 1:

$$T_{ijm} = a_i O_i b_j D_j F(C_{ijm}) \quad \text{(1)}$$

Where; i is the origin zone;

j is the destination zone;

m is the mode number;

is the number of trips from zone i to zone j for mode m;

a_i is the balancing factor for row i;

b_j is the balancing factor for column j;

O_i is the number of trips from zone i, and;

D_j is the number of trips to zone j.

F(Cijm) is the gravity function,

which in this case is a "Tanner" as in equation 2:

$$F(C) = e^{\beta C} C^{\alpha} K \quad \text{(2)}$$

α, β, and K are constants specified for each mode, nationality and trip purpose and for different areas of the matrix. These values are the same as those used in the original 1987 study and were calculated based on an extensive series of household interviews.

There are five trip purposes: Home-based work; Home based education; Home based other; Non-home based; Employers business.

3. TRANSPORT MODEL UPDATE AND ANALYSIS

Once the base 3rd KMPR model was fully implemented in CUBE, a thorough updating of all data (networks, matrices, etc.) was run through.

3.1 Network Development

The imported network was checked out carefully to check its integrity. Besides that, an updating process was needed so as to have all the new changes represented along with the more detailed available network. This updating process involved a careful binding of the previous model links with the adequate links from GIS cartography of street centrelines. Figure 4 shows the GIS details at both the country level and the urban level while Figure 5 shows a comparison between 3KMPR and GIS cartography.

Figure 4. GIS detailed street centrelines – (A) Country level

Figure 4. GIS detailed street centrelines – (B) Urban level

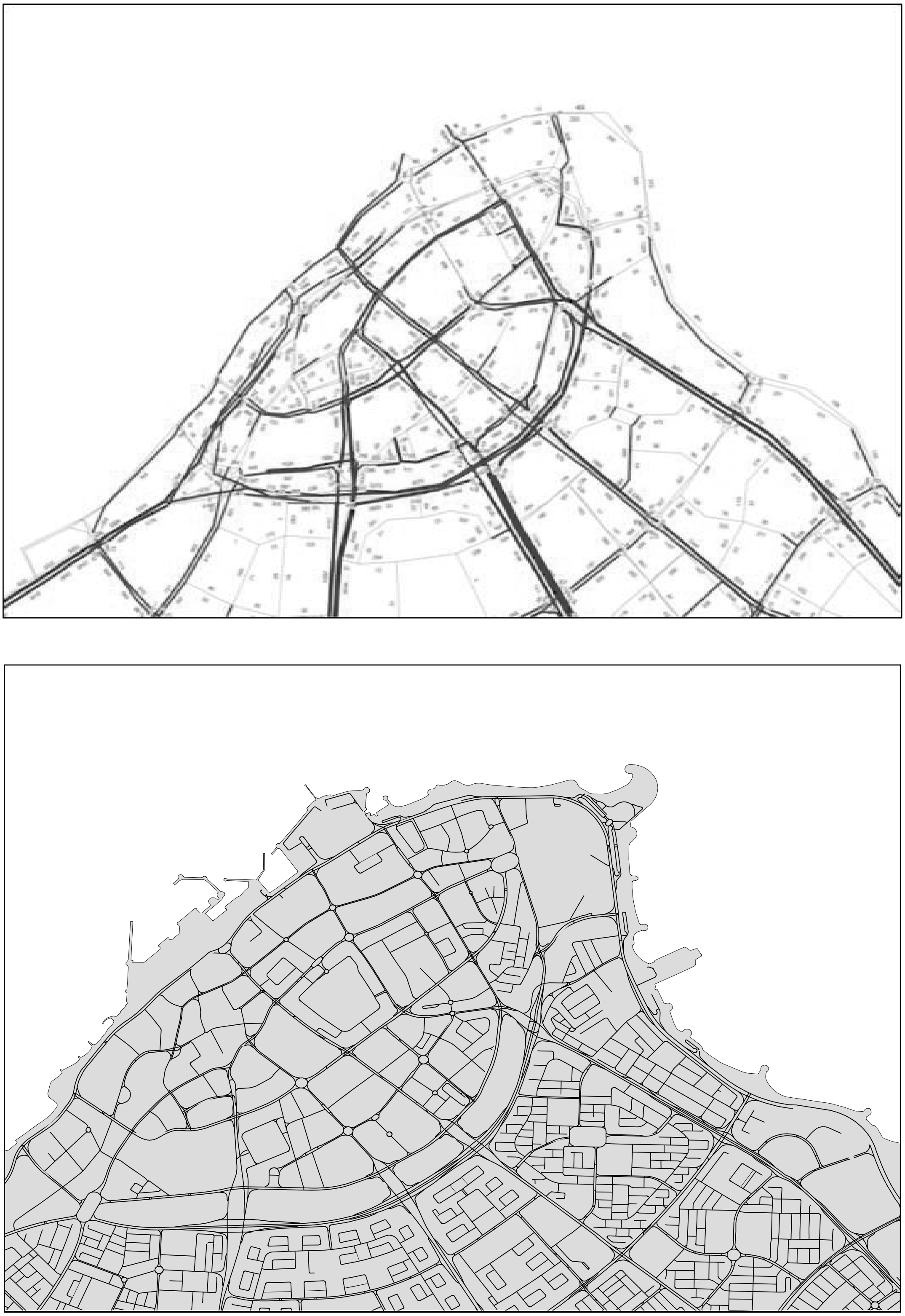


Figure 5. 3KMPR and GIS cartography comparison

3.2 Trip Matrices

Trip matrices for year 2003 were updated to 2005, based on the latest traffic counts available, as well as passenger counts on bus lines, and also on the latest population figures for 2005 as shown in Table 3.

Table 3. Year 2005 Traffic Count.

LOC	Location	Direction	September		October		November		December	
			AM Peak	PM Peak	AM Peak	PM Peak	AM Peak	PM Peak	AM Peak	PM Peak
1	4th Ring Road (Between Audiliya & Qurtuba)	Going To Airport Rd	5065	5671	5074	4625	4996	5565	5432	5738
1	4th Ring Road (Between Audiliya & Qurtuba)	Going To Damascus St.	6071	5243	5336	5695	6099	5138	6037	5736
2	Ghazali Expressway (Before Jahra Road)	Going To Shuwaikh	3269	1489	3450	2016	3635	7072	3697	3422
2	Ghazali Expressway (Before Jahra Road)	Going 4th RR	2252	2532	1979	2431	1873	2716	3722	3558
3	4th Ring Road (Between Ghazali & M.Bin Al Qassim	Going To M.Bin Al Qassim St.	5061	4579			5124	4791	4969	4500
3	4th Ring Road (Between Ghazali & M.Bin Al Qassim	Going To Ghazali St.	5350	5234			5513	5736	5448	5599
4	1st Ring Road \ Riyadh St. (Under the Bridge)	Going To Dasman	2147	3041	2274	3100	2187	3021	3284	3348
4	1st Ring Road \ Riyadh St. (Under the Bridge)	Going To Sheraton	2602	1807	2714	2218	2886	1910	3590	3504
5	6th Ring Road (Opposite Dajeej Area)	Going Jahra			8166	8144	8196	7593	7937	7300
5	6th Ring Road (Opposite Dajeej Area)	Going Messila			6098	6925	6351	6090	6163	6333
6	5th Ring Road (Between Damascuse & Maghreb St.)	Going Salmiya	6193	5229	6106	5108	6298	5017	6463	5163
6	5th Ring Road (Between Damascuse & Maghreb St.)	Going Jahra	4225	5132	4140	5344	5513	5736	3508	5172
7	Jamal Abdul Nasser (Opposite Kuwait)	Coming From City	3115	3097	3319	3479	4995	4717	4830	4824
7	Jamal Abdul Nasser (Opposite Kuwait)	Going to City	3403	3431	3486	4268	4088	5514	4084	5616
8	Riyadh Street (Between khaldiya & Audiliya)	Going 4th RR	6445	7350	6046	7249	7189	7430	6862	7610
8	Riyadh Street (Between khaldiya & Audiliya)	Going 3rd RR	7696	6624	7868	7497	7925	7145	8110	6662
9	Cairo Street (Between 3rd Ring Road & Beirut St.)	Going Salmiya	2337	2599	2369	2777	3284	3422	3494	3348
9	Cairo Street (Between 3rd Ring Road & Beirut St.)	Going 3rd Cairo	1437	1005	1405	1673	3722	3558	3590	3604
10	Maghreb Motorway (Between 4th R.R. & Beirut)	Going To 4th RR \ Maghreb	4151	7141			4803	7260	4112	7569
10	Maghreb Motorway (Between 4th R.R. & Beirut)	Going Beirut St.	7012	6459			7158	6653	7329	6422
11	Arabian Gulf St. (Opposite Sultan Center)	Going to Qatar	3092	2181	3226	2331	3801	2476	3822	2579
11	Arabian Gulf St. (Opposite Sultan Center)	Going to Amr Ben Alaas	2200	2568	2582	2907	2389	2701	2053	2649

3.3 Expansion Development

For the future years, the matrices would have to represent the new expansion developments, already included in the transport planning of the city of Kuwait. In order to achieve this, new zones could be added to the matrix that will accommodate the resulting new trips. The demand model to be used for generating and attracting trips will be based on the same correlation estimated in the prior step.

3.4 Demand Variables

As stated before, the model should be based on the available socio-economic variables, which are the ones used in the 3KMPR model. In the previous model (3KMPR), generation requirements, by zone of residence included: Population by nationality; Employed population by nationality; Population in education by nationality; Number of households by nationality; Non-Kuwaitis living in Kuwaiti households; Employed non-Kuwaitis living in Kuwaiti households; Non-Kuwaiti servants living in Kuwaiti households; Non-Kuwaitis in education living in Kuwaiti households; Car ownership by nationality.

Attraction requirements included:

1. Number of jobs in each zone;

2. Number of school places in each zone.

As it can be clearly seen, there are enough socio-economic variables on which to base the spatial correlation of the generations/attractions model. As an abstract, these variables are represented in the next diagrams aggregated in the following four categories: Total population as shown in figure 6, Density of population as shown in figure 7, Total number of work places as shown in figure 8 and Total number of school places as shown in figure 9.

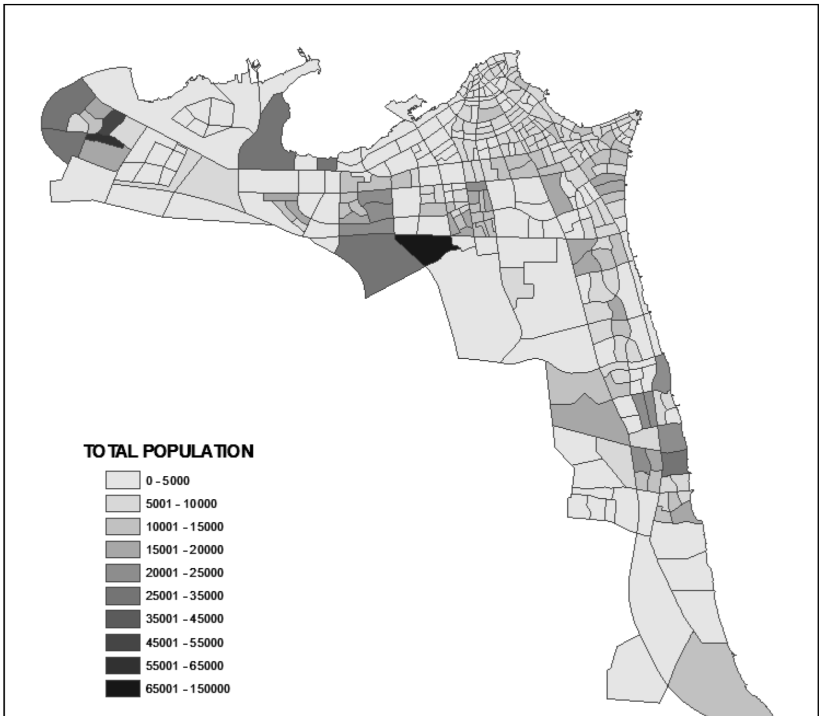


Figure 6. Total Population.

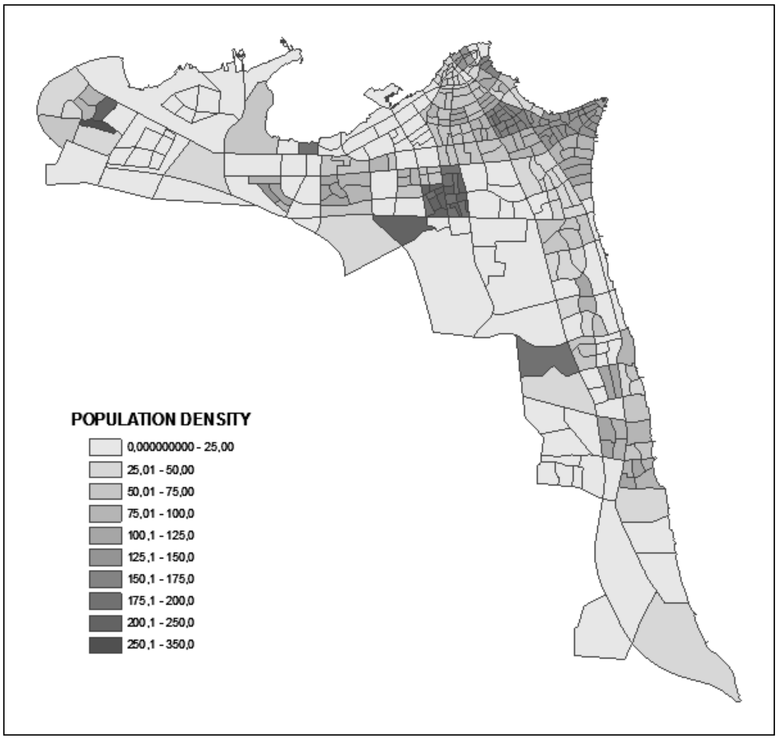


Figure 7. Population Density.

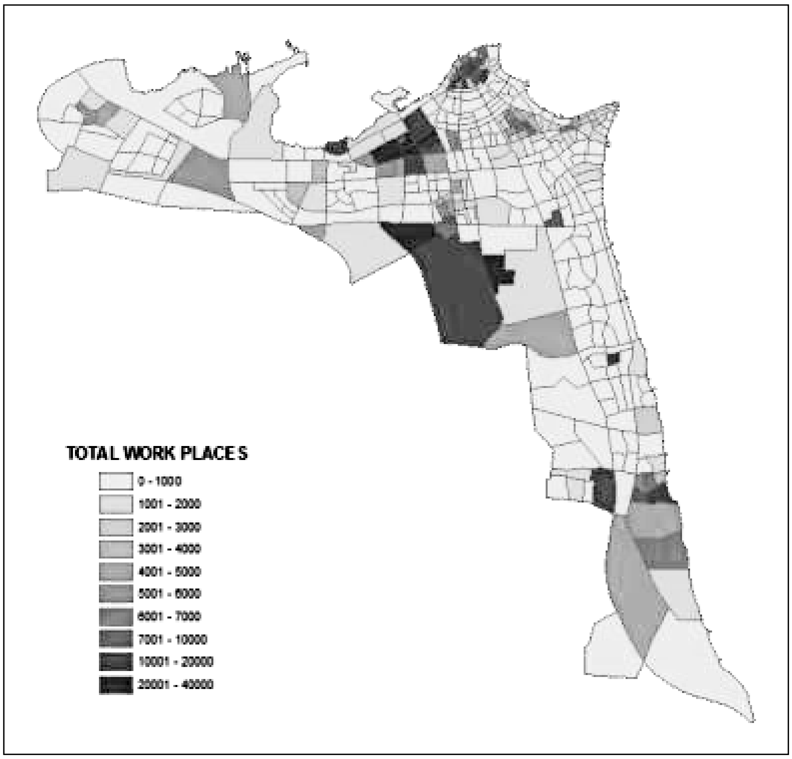


Figure 8. Total Number of Work Places.

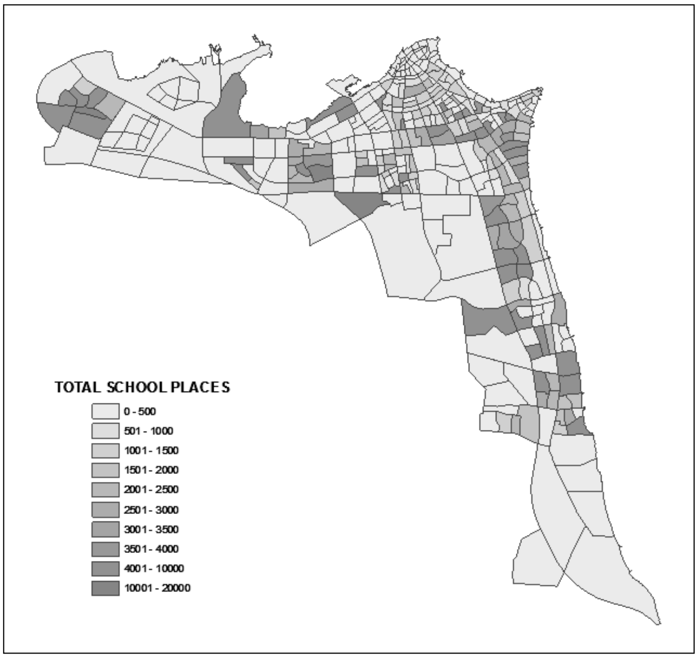


Figure 9. Total Number of School Places.

3.5 Model Analysis

Apart from this land-use data, other interesting aspects that could be extracted from the previous model are shown in the next four diagrams. These diagrams show the subgroup of the assigned trips that pass through a particular section (shown as a black traversal line). This process is called "skimming" the network trips. As can be seen, the network is quite balanced, without a clear focalization in the centre area. Figure 10 shows the corridor accessibility assignment for each direction.

Figure 10. Corridor Accessibility Assignment – (A) Eastern Corridor

Figure 10. Corridor Accessibility Assignment – (B) South-Eastern Corridor

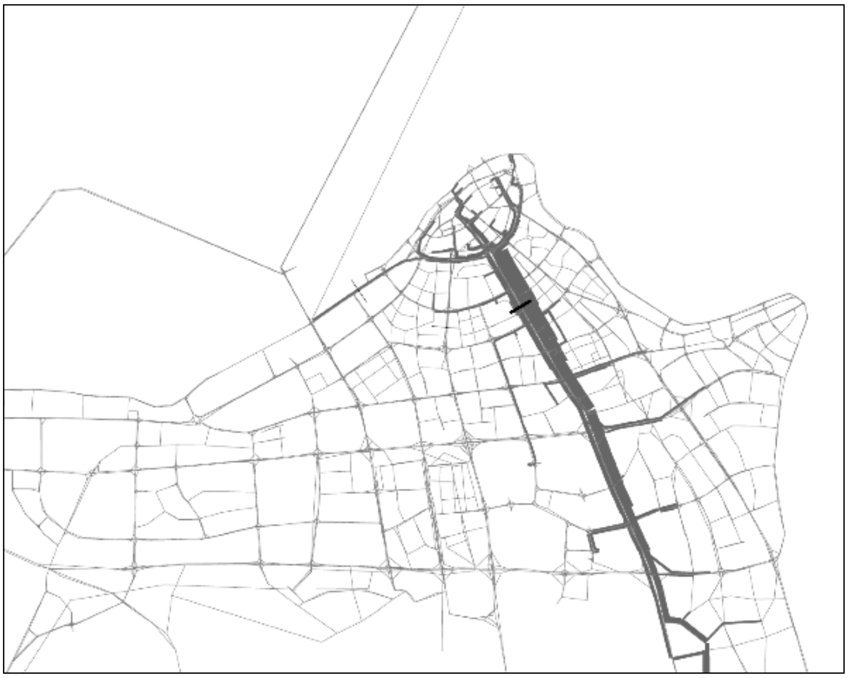


Figure 10. Corridor Accessibility Assignment – (C) South-Western Corridor

Figure 10. Corridor Accessibility Assignment – (D) Western Corridor

Another analysis that could be undertaken is a non-restrained assignment, in order to identify the natural corridors used in a free-flow situation. Unfortunately, the resulting assignment is more or less similar to the calibrated network and quite distributed (without clear corridors), so it could not be used as an aiding tool for the planning of the corridors. Figure 11 shows this assignment in different scales.

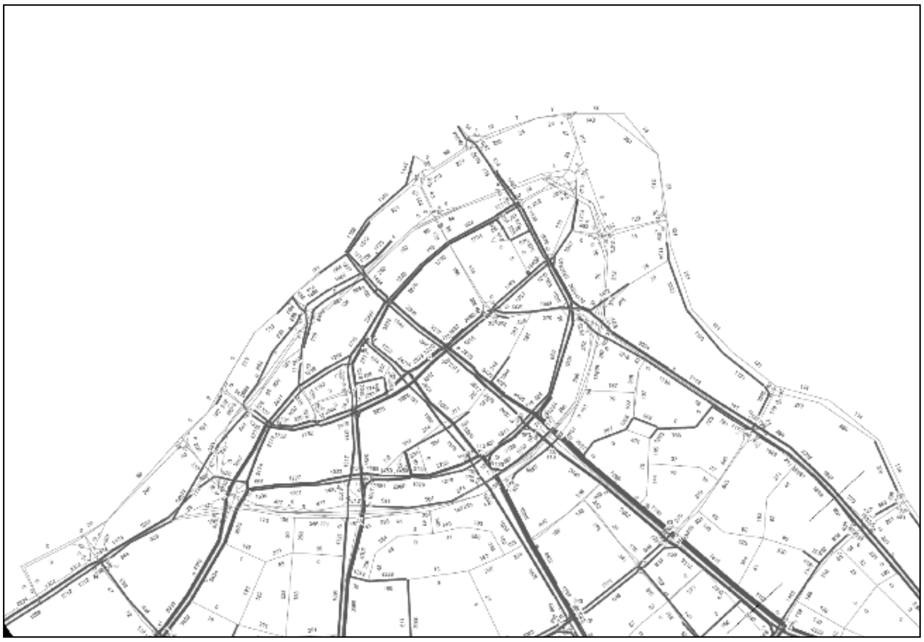


Figure 11. (A) Free Flow Assignment.

Figure 11. (B) Free Flow Assignment.

Lastly, a pair of desire lines diagrams is shown in the following figure. These diagrams show the main (over 10 trips for public traffic and over 50 trips for private traffic) mobility patterns during the AM peak hour. The complete net of desire lines is too dense to display, that was the reason for trimming it up.

The Transport Desire Lines during AM Peak Hour are shown in figure 12.

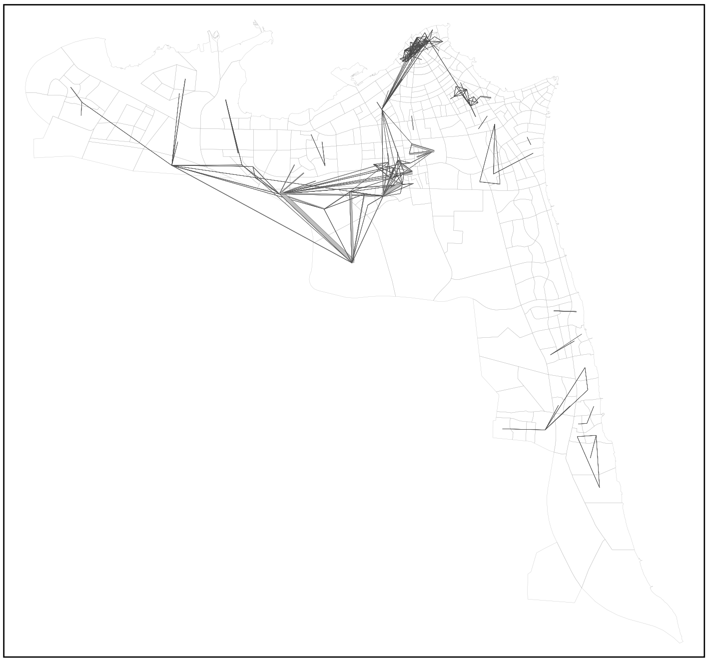


Figure 12. (A) SW Public Transport Desire Lines (Over 10 Trips during AM Peak Hour)

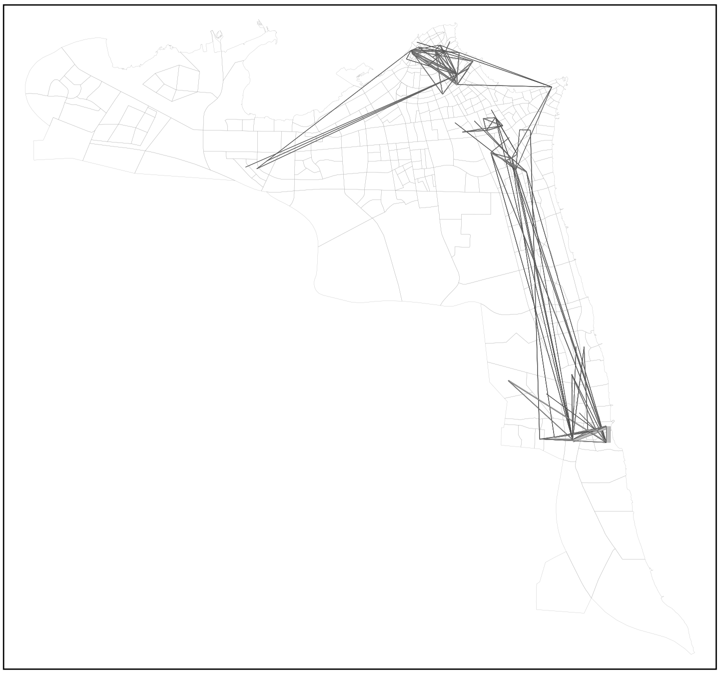


Figure 12. (B) SE Public Transport Desire Lines (Over 10 Trips during AM Peak Hour)

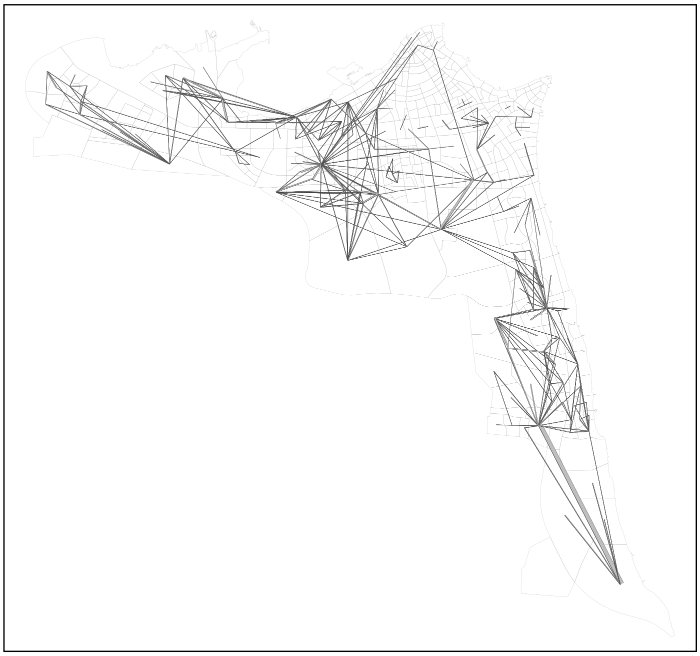


Figure 12. (C) Private Transport Desire Lines (Over 100 Trips During AM Peak Hour)

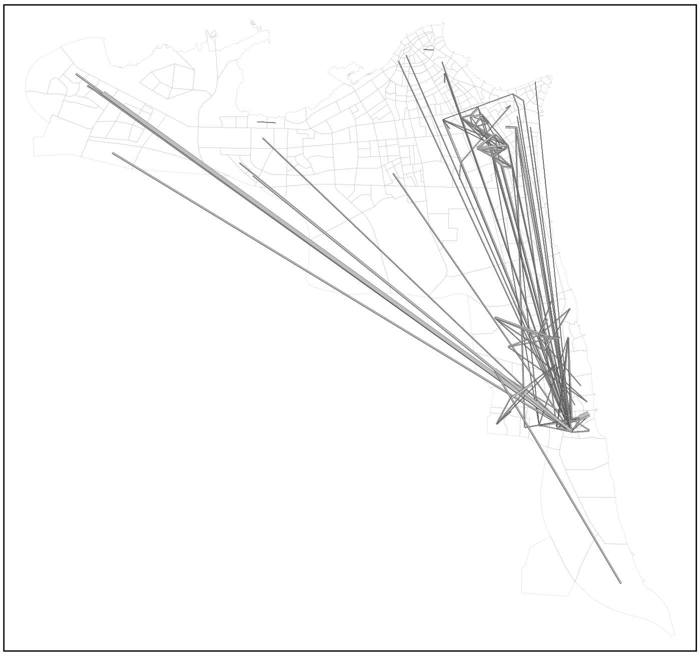


Figure 12. (D) Fahaheel-Ahmadi Private Transport Desire Lines (Over 50 Trips During AM Peak Hour)

3.6 Modal Split Model

The main difference introduced in the current study relates to how the different nationality groups are treated. While the Buchanan study did calculate and list variables and parameters (Value of time, deterrence functions, etc.) for both Kuwaitis and non-Kuwaiti, the former were excluded from the modal split process, based on the assumed reluctance of this demand group to use public transport. This study revises this assumption and believes that high-quality public transport services may, though presumably moderately, be attractive enough to capture some Kuwaiti travel demand. This was implemented by simply allowing Kuwaitis to use the PT system, and entering the modal split process, by applying the parameters calculated by Buchanan for this demand group.

4. PROPOSED METROPOLITAN NETWORK

Once the base year model was updated and validated, Future PT networks were built by adding to the current network the proposed Rapid Transit & Railroad lines. Additionally, park-and-ride facilities were incorporated into the network at terminal nodes, and at main mode or line transfer nodes. Figure 13 shows the proposed metropolitan network for three-line stations and for park and ride facilities.

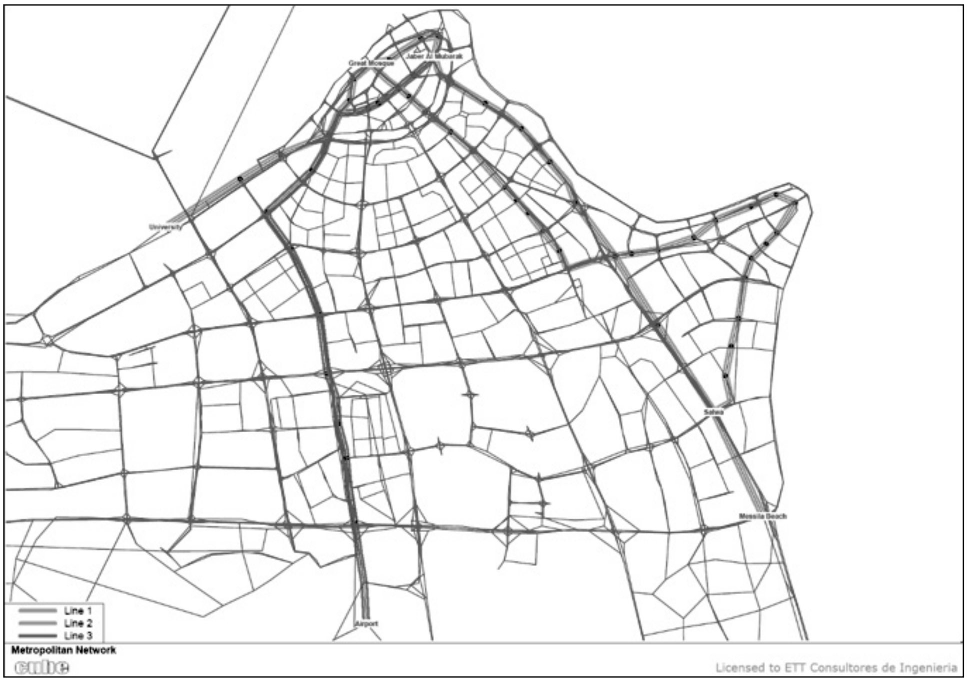


Figure 13. (A) Proposed Metropolitan Network

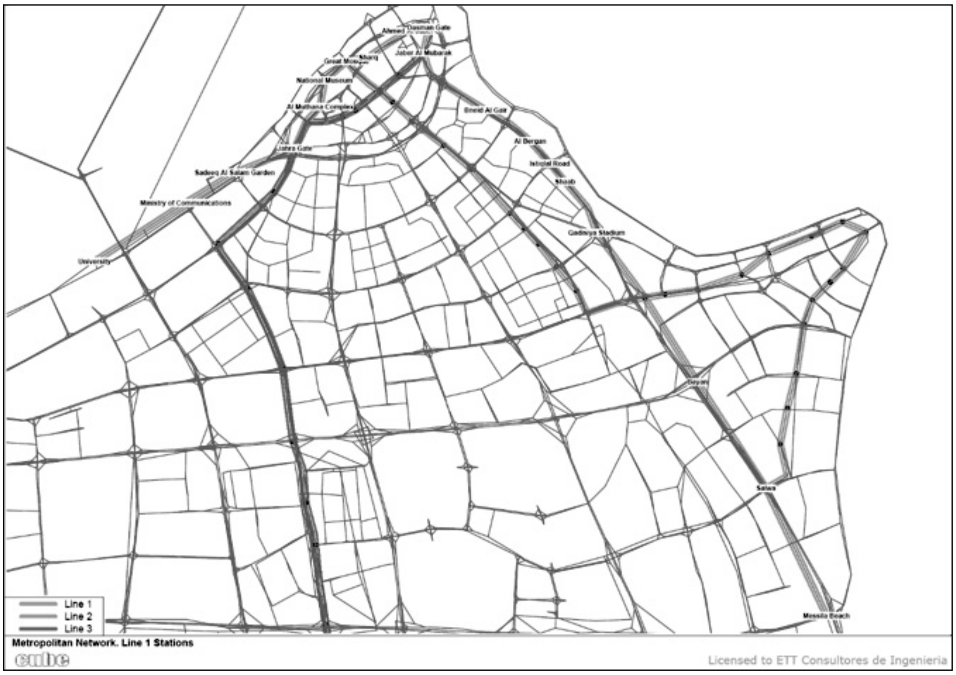


Figure 13. (B) Line 1 Stations

Figure 13. (C) Line 2 Stations

Figure 13. (D) Line 3 Stations

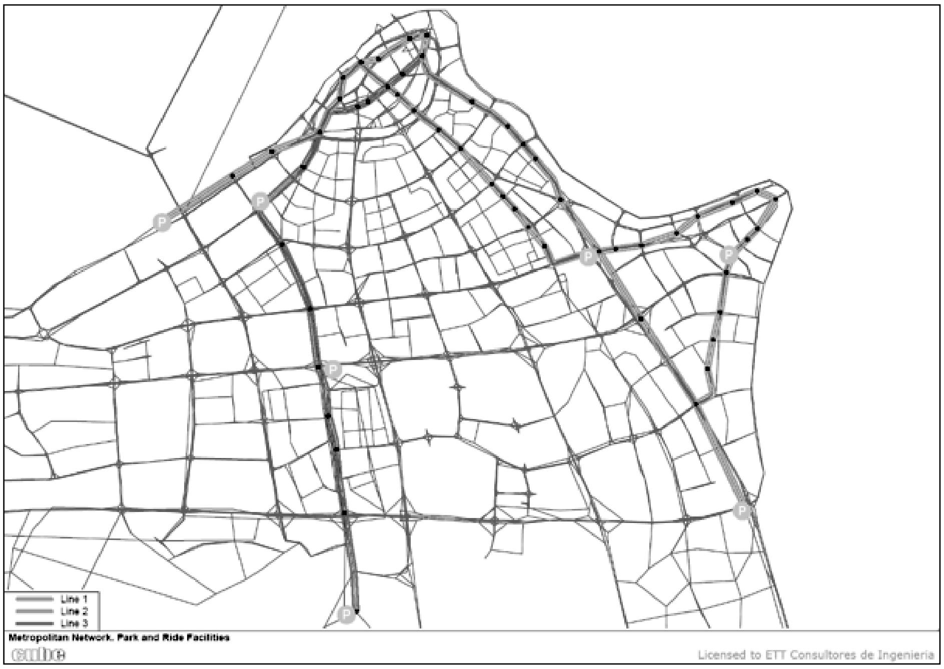


Figure 13. (E) Park and Ride Facilities

Passenger flows on the new Public Transport network were obtained by five methods. First, the initial private transport matrices (car), derived from household and road-side interview surveys, were loaded on the road network, in order to calculate travel costs (time) for this mode, and also, by applying adequate coefficients, for bus lines. Second, travel costs were then calculated for the existent bus lines, and for the proposed Rapid Transit & Railroad lines. The former was derived from travel times on the road network and from frequency data, while the latter were based on fixed timetables. Third, these two sets of data, complemented with PT and parking fares, along with trip ends (total demand produced/attracted by each transportation zone, and for each demand group) were inputted to the distribution/ modal split model. Fourth, resulting private transport (car) matrices and PT matrices were then reloaded on each respective network. This procedure was applied iteratively, travel costs being recalculated at each iteration, until equilibrium was reached. Fifth, final PT matrices were loaded on the proposed PT network, and boardings/alightings and flows for each PT line were outputted. These steps were run for both AM and PM peak periods.

5. ASSIGNMENT RESULTS

5.1 Daily Demand

Tables 4, 5, 6, 7, 8, and 9 and figures 14, 15, 16, 17, 18, and 19 show daily boardings, alightings, and loads for each direction of each of the 3 lines.

Table 4. Daily Demand – Line 1 – Direction University / Messila Beach.

Station Number	Station Name	ON	OFF	VOL
41	University	4,324	0	4,324
40	Ministry of Communications	12	2	4,334
39	Sadeeq Al Salam Garden	86	0	4,420
29	Jahra Gate	4,715	1,602	7,533
28	Al Muthana Complex	2,607	865	9,274
27	National Museum	3,063	2,774	9,563
26	Great Mosque	1,754	3,091	8,226
25	Sharq	1,333	2,194	7,364
24	Ahmed Al Jaber	1,823	2,809	6,379
23	Dasman Gate	279	371	6,288
22	Jaber Al Mubarak	2,364	1,954	6,698
21	Bneid Al Gair	49	204	6,543
20	Al Bergan	98	175	6,466
19	Istiqlal Road	31	66	6,430
18	Shaab	135	153	6,412
17	Qadisiya Stadium	525	509	6,428
16	Mubarak Al Kabeer Hospital	1,010	4,315	3,123
42	Bayan	61	462	2,721
1	Salwa	1,198	1,126	2,792
77	Messila Beach	0	2,792	0
	Total	**25,465**	**25,465**	

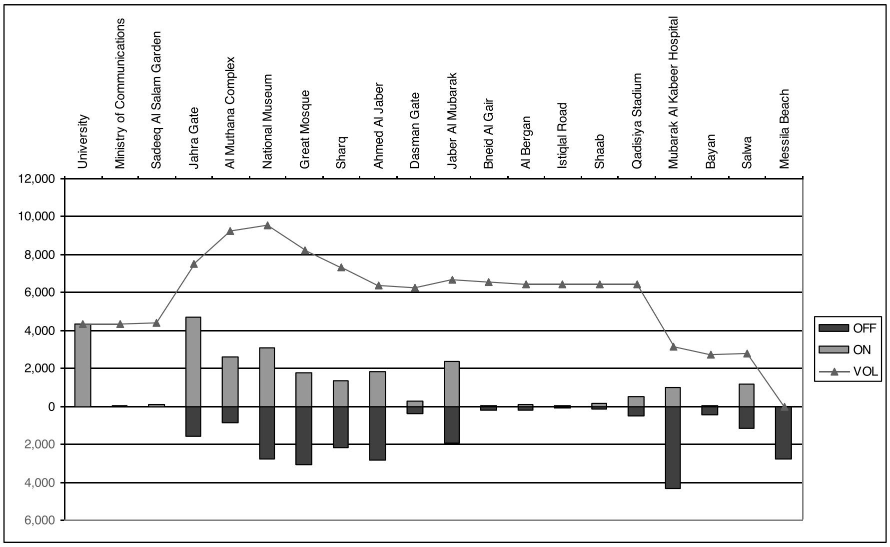


Figure 14. Daily Demand – Line 1 – Direction University / Messila Beach.

Table 5. Daily Demand – Line 1 – Messila Beach / University.

Station Number	Station Name	ON	OFF	VOL
77	Messila Beach	3,078	0	3,078
1	Salwa	1,285	1,383	2,980
42	Bayan	453	54	3,379
16	Mubarak Al Kabeer Hospital	3,526	1,008	5,897
17	Qadisiya Stadium	320	641	5,576
18	Shaab	151	143	5,583
19	Istiqlal Road	67	32	5,618
20	Al Bergan	175	97	5,696
21	Bneid Al Gair	203	48	5,852
22	Jaber Al Mubarak	2,804	2,218	6,438
23	Dasman Gate	378	308	6,508
24	Ahmed Al Jaber	2,382	1,628	7,262
25	Sharq	1,734	958	8,039
26	Great Mosque	2,984	1,635	9,387
27	National Museum	2,871	3,291	8,967
28	Al Muthana Complex	1,101	2,849	7,219
29	Jahra Gate	2,097	4,478	4,838
39	Sadeeq Al Salam Garden	0	117	4,721
40	Ministry of Communications	2	11	4,712
41	University	0	4,712	0
	Total	**25,612**	**25,612**	

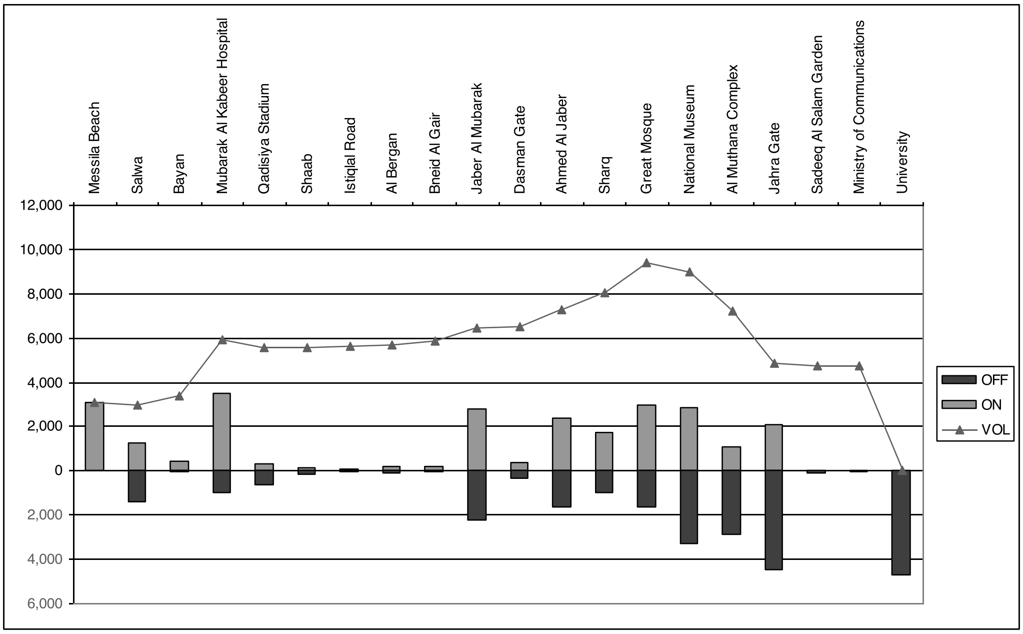


Figure 15. Daily Demand – Line 1 – Messila Beach / University.

Table 6. Daily Demand – Line 2 – Great Mosque / Salwa.

Station Number	Station Name	ON	OFF	VOL
26	Great Mosque	4,898	0	4,898
53	Sawaber	5,489	1,975	8,412
51	Awfaq Complex	433	656	8,188
50	Cairo	340	1,072	7,457
49	Arabi	22	32	7,447
48	Qadisiya Street	55	82	7,419
47	Bin Khaldun	860	638	7,642
46	Bin Rushd	671	945	7,367
45	Al Mohalab Mall	276	287	7,357
44	Tunis	1,051	252	8,156
43	Al Bahar Mall	2,076	4,247	5,984
16	Mubarak Al Kabeer Hospital	962	3,183	3,762
15	Hardun Al Rashid	119	413	3,468
14	Amman	260	592	3,136
13	Salmiya Hospital	406	1,117	2,425
12	Marina Mall	94	161	2,358
11	Amr Bin Al Assa	127	155	2,330
10	Salem Al Mubarak	223	494	2,059
9	Scientific Center	120	220	1,958
8	Khansa Street	111	150	1,919
7	Qatar Street	24	112	1,830
6	Salmiya Park	255	543	1,543
5	Hassan Al Banna	43	742	844
4	Nasr Al Mubarak	29	139	734
3	Al Masjed Al Aqssa	140	102	772
2	Al Montanabi	133	26	879
1	Salwa	0	879	0
	Total	**19,216**	**19,217**	

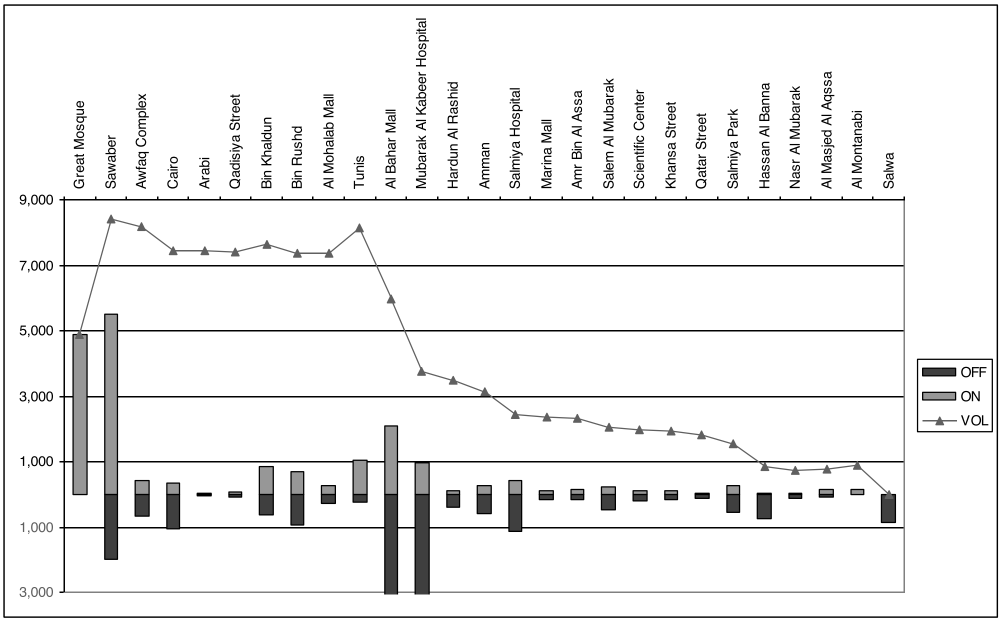


Figure 16. Daily Demand – Line 2 – Great Mosque / Salwa.

Table 7. Daily Demand – Line 2 – Salwa / Great Mosque.

Station Number	Station Name	ON	OFF	VOL
1	Salwa	1,471	0	993
2	Al Montanabi	150	202	958
3	Al Masjed Al Aqssa	448	386	999
4	Nasr Al Mubarak	38	227	872
5	Hassan Al Banna	660	43	1,289
6	Salmiya Park	727	362	1,535
7	Qatar Street	88	23	1,579
8	Khansa Street	165	125	1,605
9	Scientific Center	255	113	1,701
10	Salem Al Mubarak	542	211	1,925
11	Amr Bin Al Assa	198	99	1,991
12	Marina Mall	257	98	2,099
13	Salmiya Hospital	961	381	2,490
14	Amman	600	274	2,710
15	Hardun Al Rashid	401	115	2,903
16	Mubarak Al Kabeer Hospital	3,605	792	4,801
43	Al Bahar Mall	4,210	2,578	5,902
44	Tunis	394	829	5,609
45	Al Mohalab Mall	296	290	5,613
46	Bin Rushd	788	551	5,773
47	Bin Khaldun	653	898	5,607
48	Qadisiya Street	80	46	5,630
49	Arabi	32	23	5,636
50	Cairo	1,074	343	6,129
51	Awfaq Complex	720	479	6,292
53	Sawaber	2,272	6,028	3,758
26	Great Mosque	0	5,571	0
	Total	**21,086**	**21,087**	

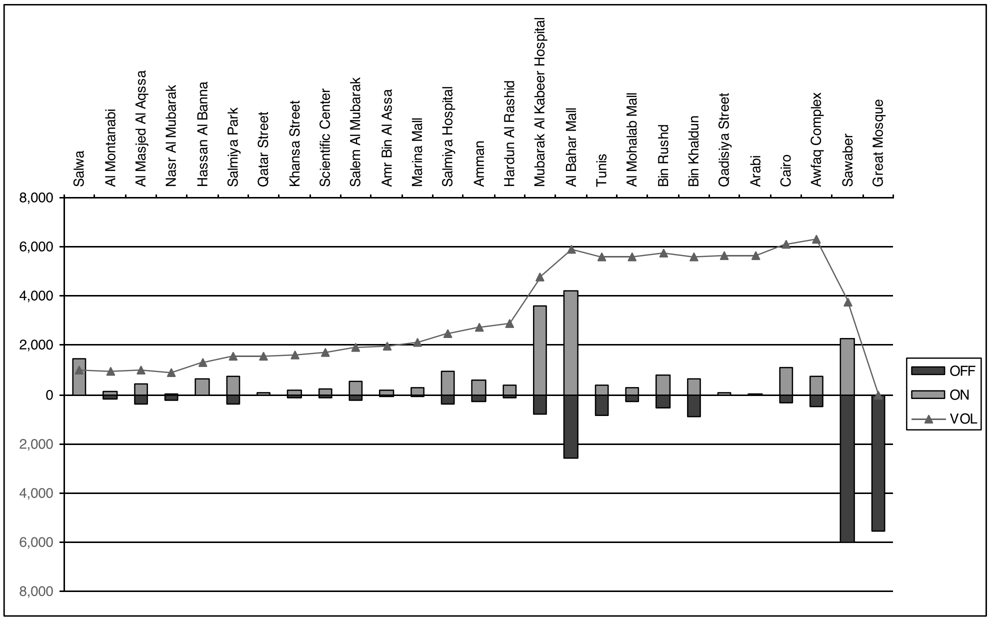


Figure 17. Daily Demand – Line 2 – Salwa / Great Mosque.

Table 8. Daily Demand – Line 3 – Jaber Al Mubarak / Airport.

Station Number	Station Name	ON	OFF	VOL
22	Jaber Al Mubarak	4,614	0	4,614
52	Chamber of Commerce	3,741	809	7,546
53	Sawaber	5,558	1,140	11,963
54	Central Bus Station	808	677	12,094
55	Liberation Tower	3,846	4,615	11,325
29	Jahra Gate	2,979	4,386	9,918
30	Jahra Road Park	46	265	9,700
31	Shuwaik Industrial	2,024	855	10,869
32	Keefan College	17	34	10,852
33	Friday Market	232	228	10,856
34	5th Ring Road	7,707	6,839	11,724
35	Muscat Street	79	282	11,521
36	South Kheitan	908	6,785	5,644
37	6th Ring Road	318	1,915	4,048
38	Airport	0	4,048	0
	Total	**32,878**	**32,878**	

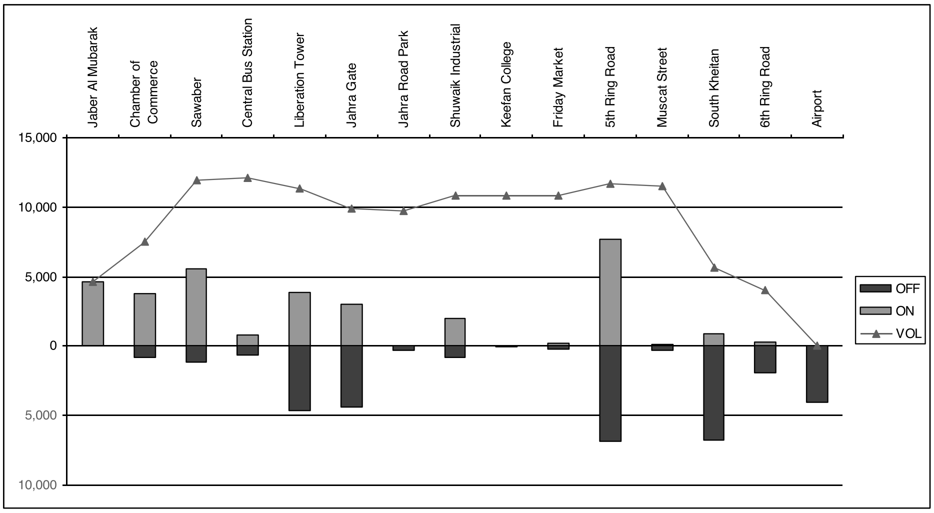


Figure 18. Daily Demand – Line 3 – Jaber Al Mubarak / Airport.

Table 9. Daily Demand – Line 3 – Airport / Jaber Al Mubarak.

Station Number	Station Name	ON	OFF	VOL
38	Airport	4,585	0	3,106
37	6th Ring Road	1,754	323	4,074
36	South Kheitan	7,059	938	8,220
35	Muscat Street	279	75	8,358
34	5th Ring Road	5,726	8,388	6,555
33	Friday Market	235	234	6,555
32	Keefan College	34	17	6,566
31	Shuwaik Industrial	1,134	121	7,252
30	Jahra Road Park	267	49	7,400
29	Jahra Gate	4,798	3,789	8,083
55	Liberation Tower	4,326	4,057	8,266
54	Central Bus Station	688	687	8,266
53	Sawaber	1,561	5,005	5,933
52	Chamber of Commerce	977	4,129	3,798
22	Jaber Al Mubarak	0	5,608	0
	Total	**33,422**	**33,422**	

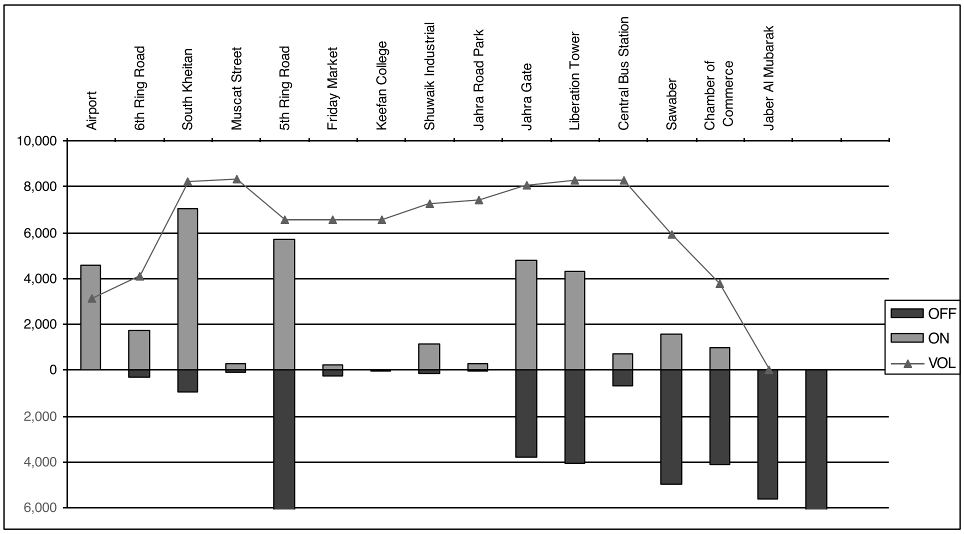


Figure 19. Daily Demand – Line 3 – Airport / Jaber Al Mubarak.

5.2 AM Peak Hour Demand

Figure 20 shows the peak hour demand in AM for each direction of each of the 3 lines.

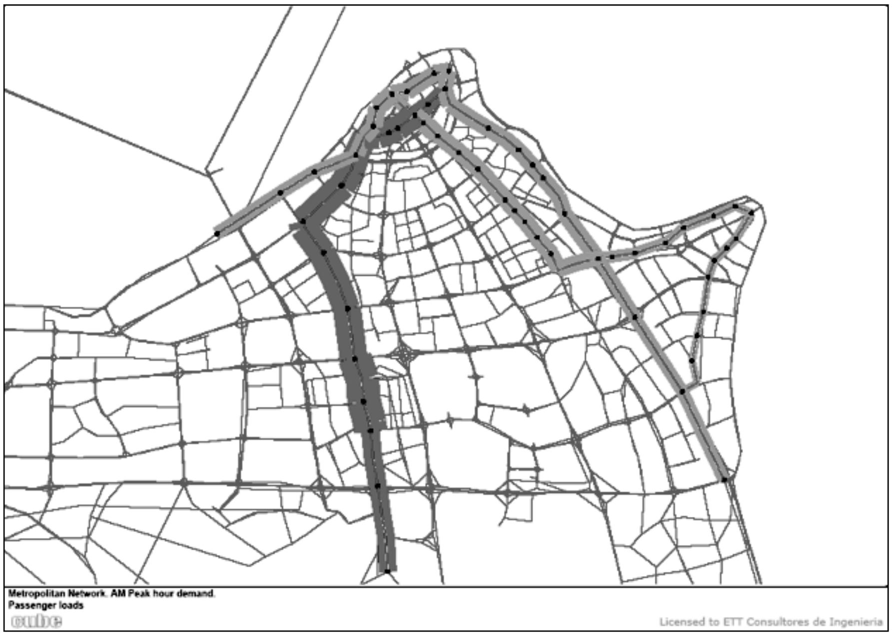
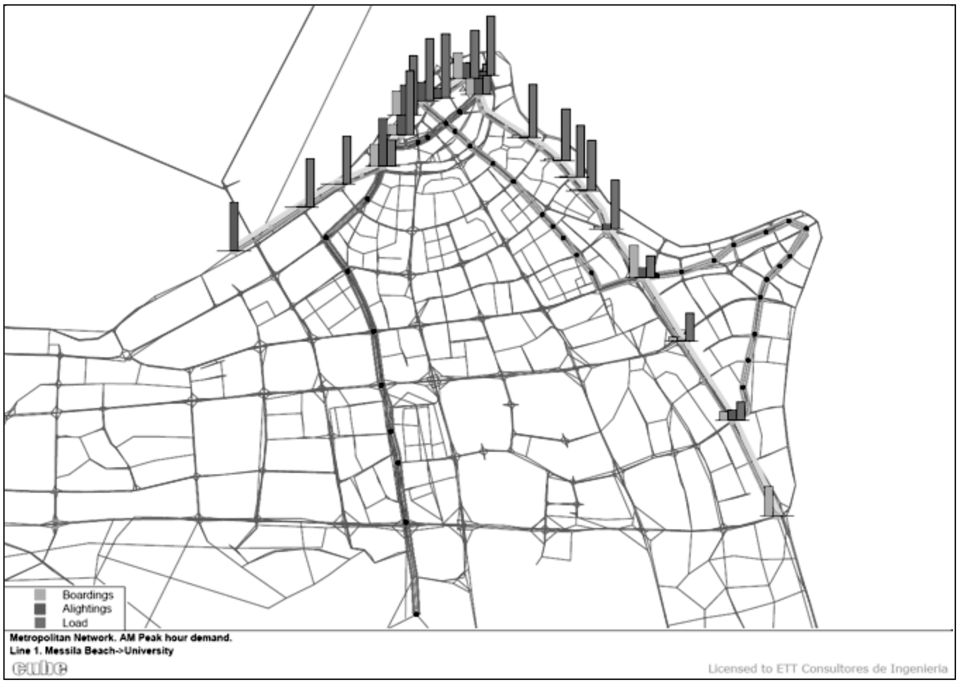


Figure 20. AM Peak Hour Demand



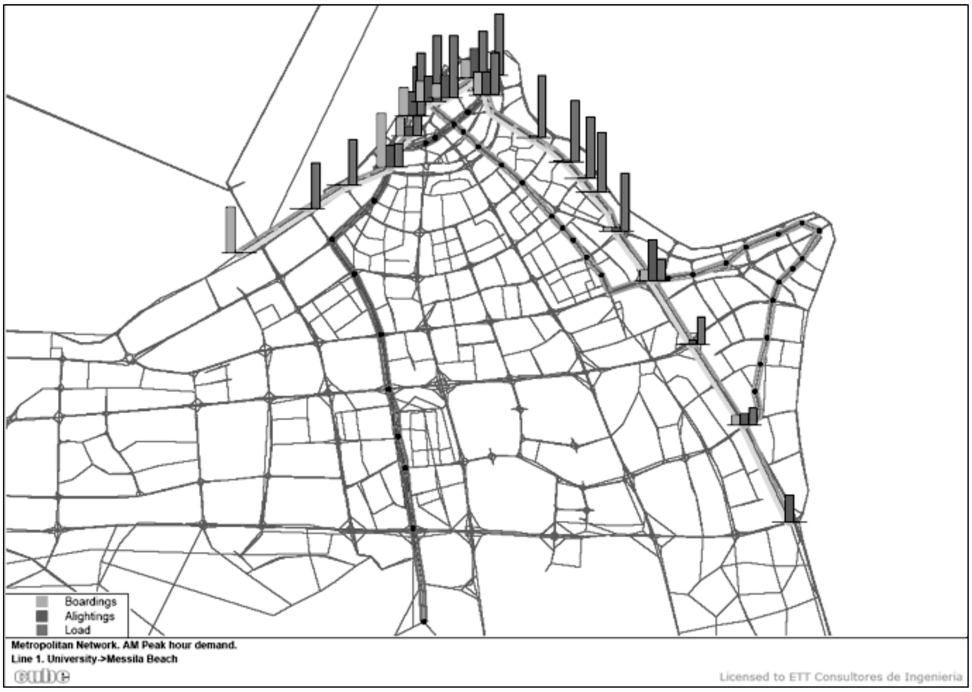


Figure 20. AM Peak Hour Demand (Line 1)

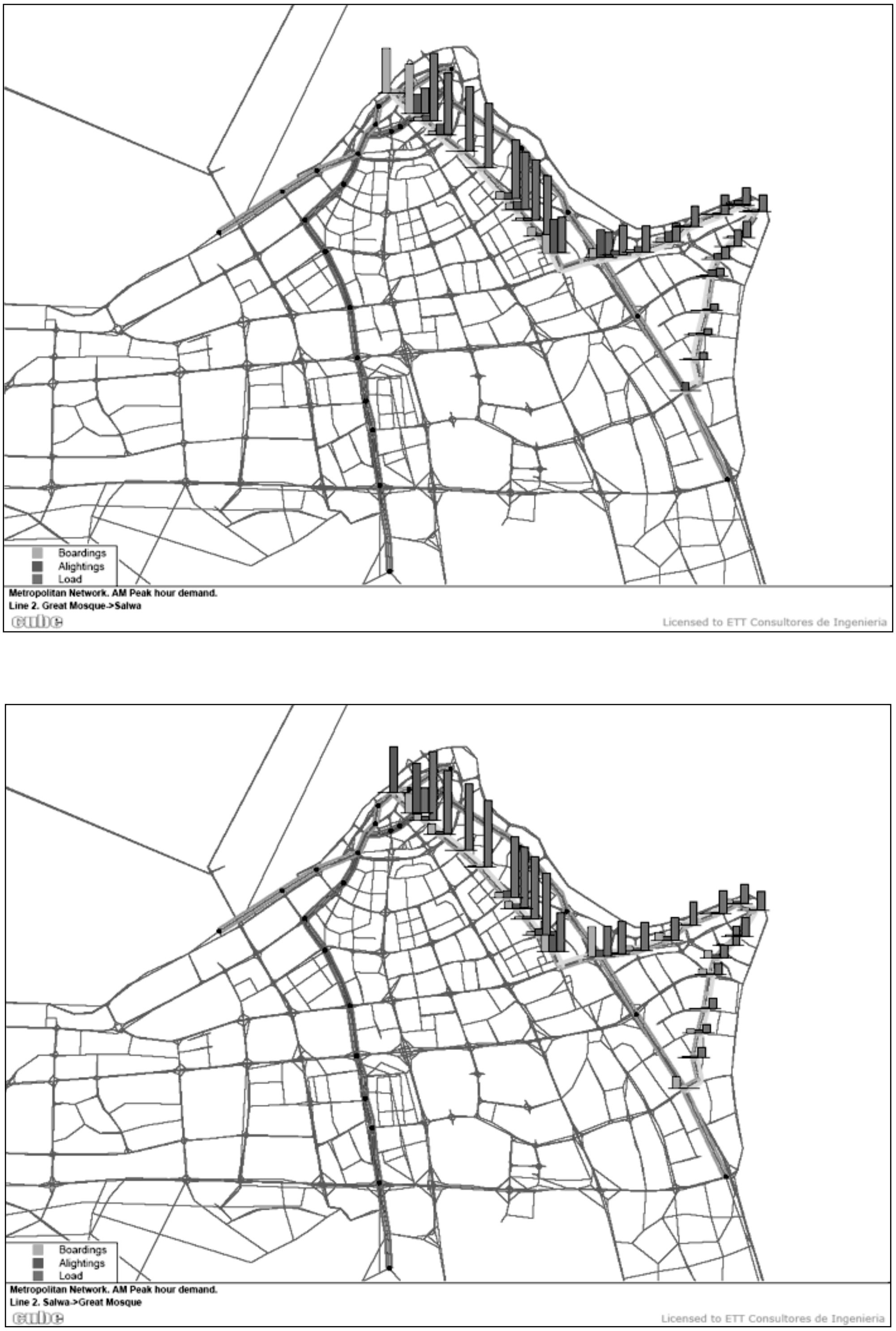


Figure 20. AM Peak Hour Demand (Line 2)

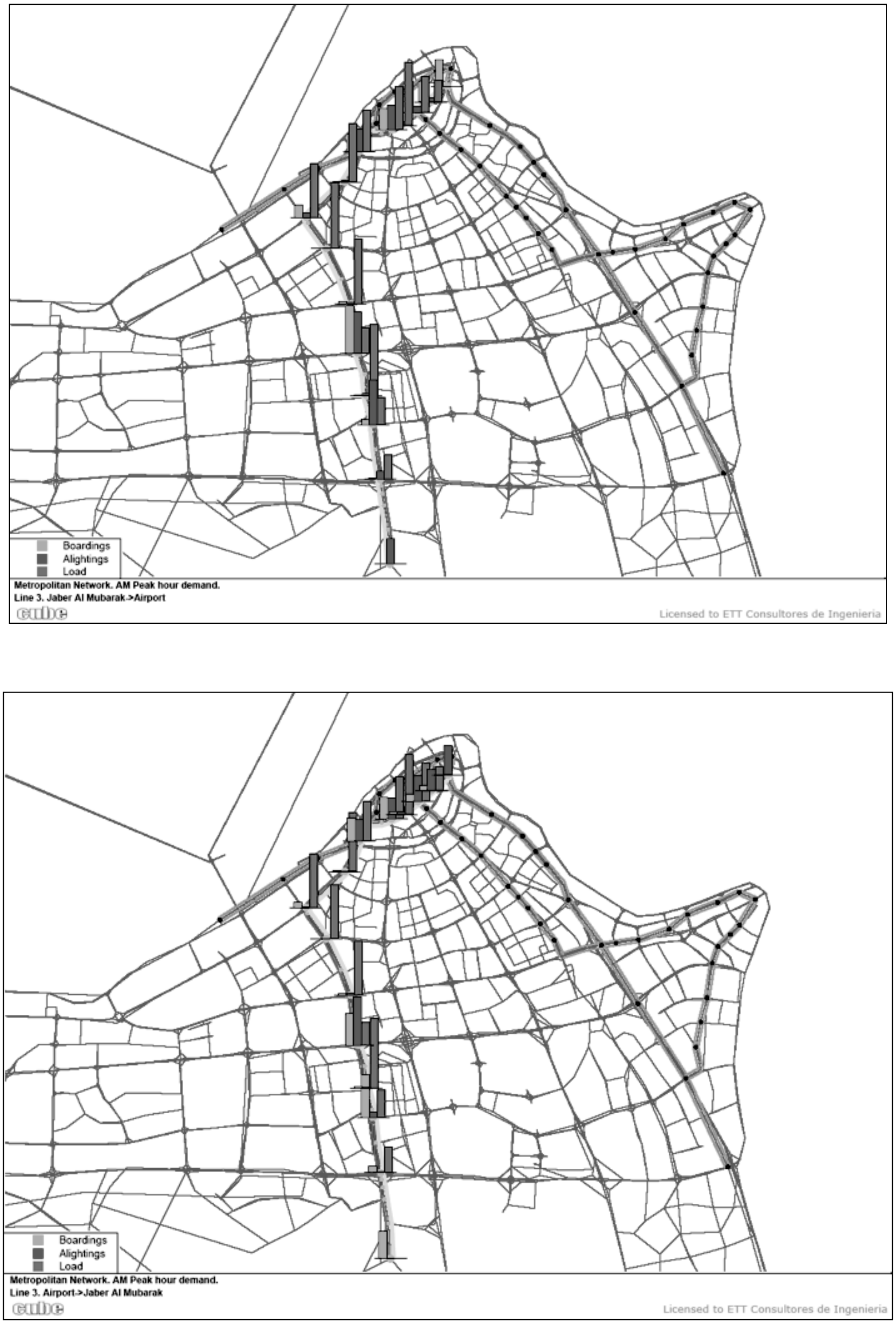


Figure 20. AM Peak Hour Demand (Line 3)

5.3 PM Peak Hour Demand

Figure 21 shows the peak hour demand in PM for each direction of each of the 3 lines.

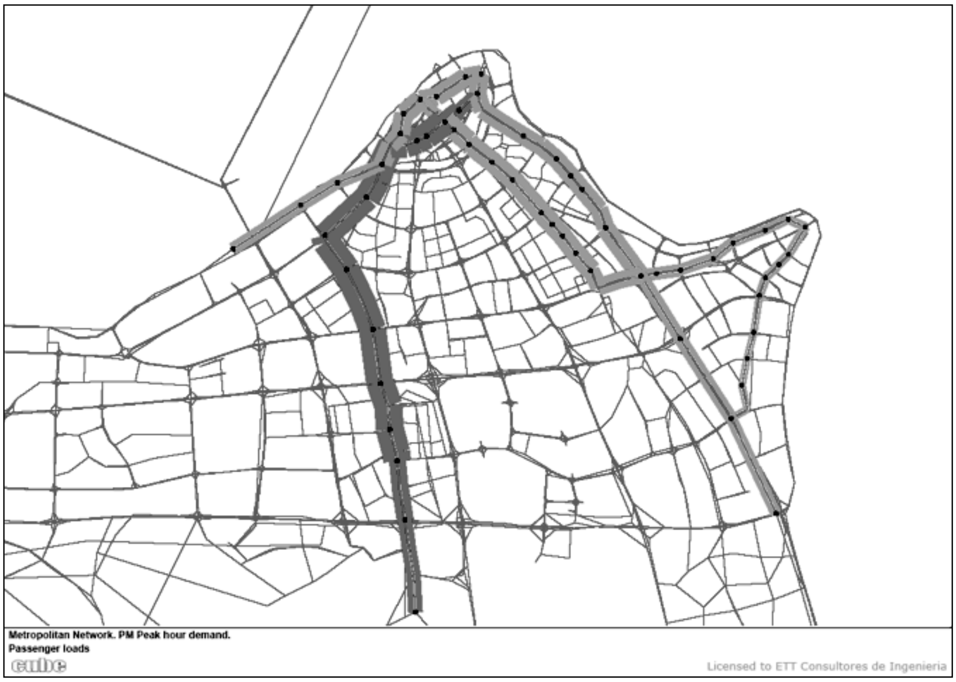
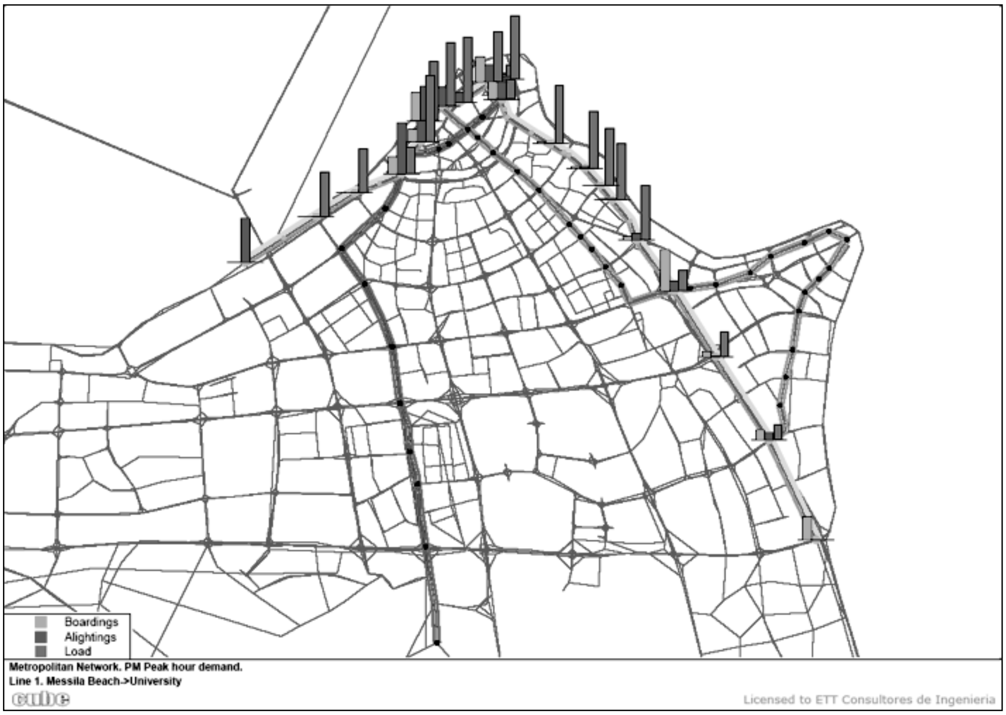


Figure 21. PM Peak Hour Demand



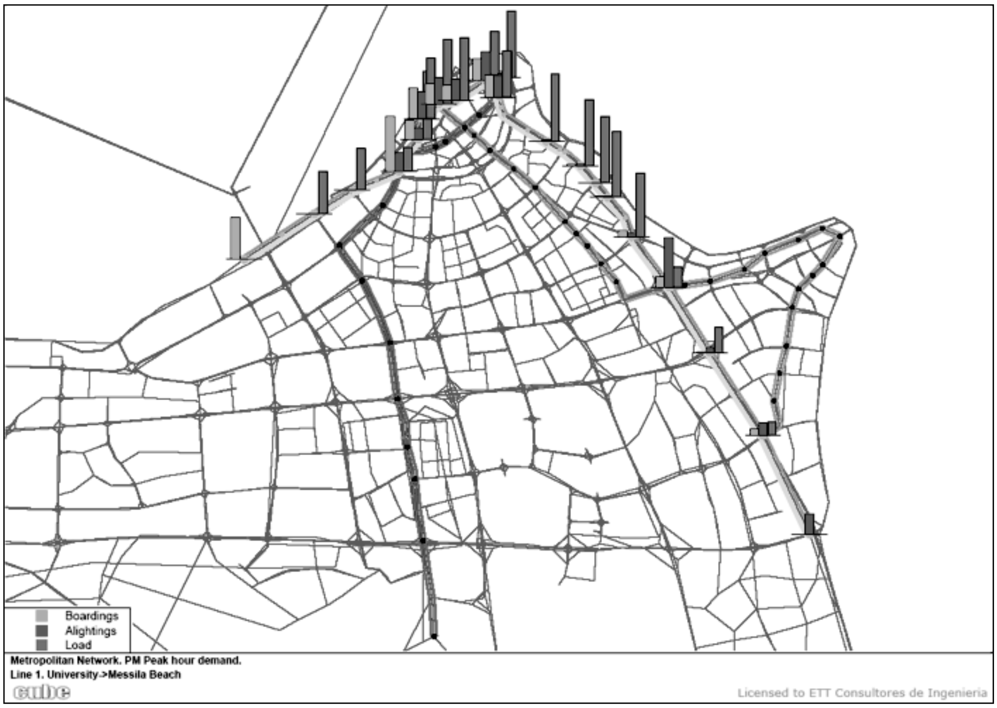
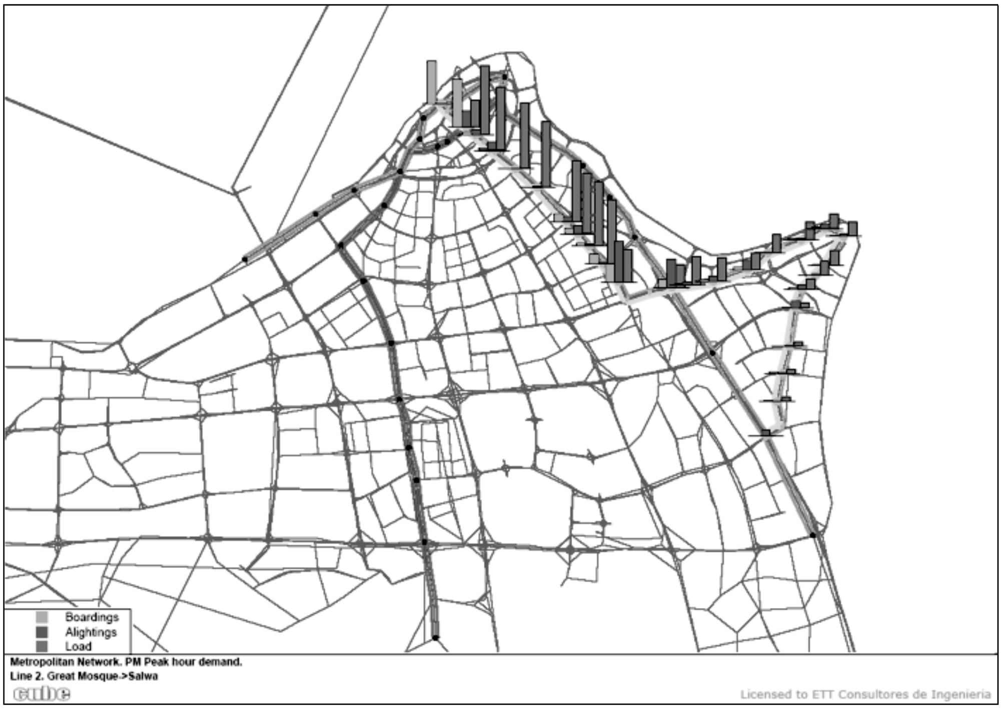


Figure 21. PM Peak Hour Demand (Line 1)



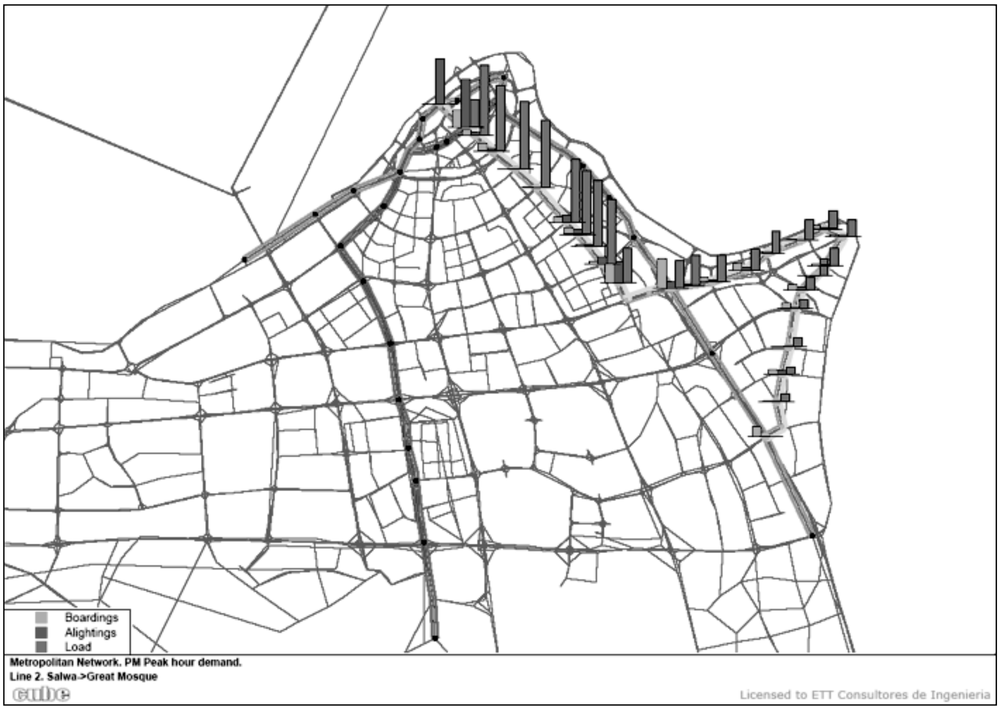
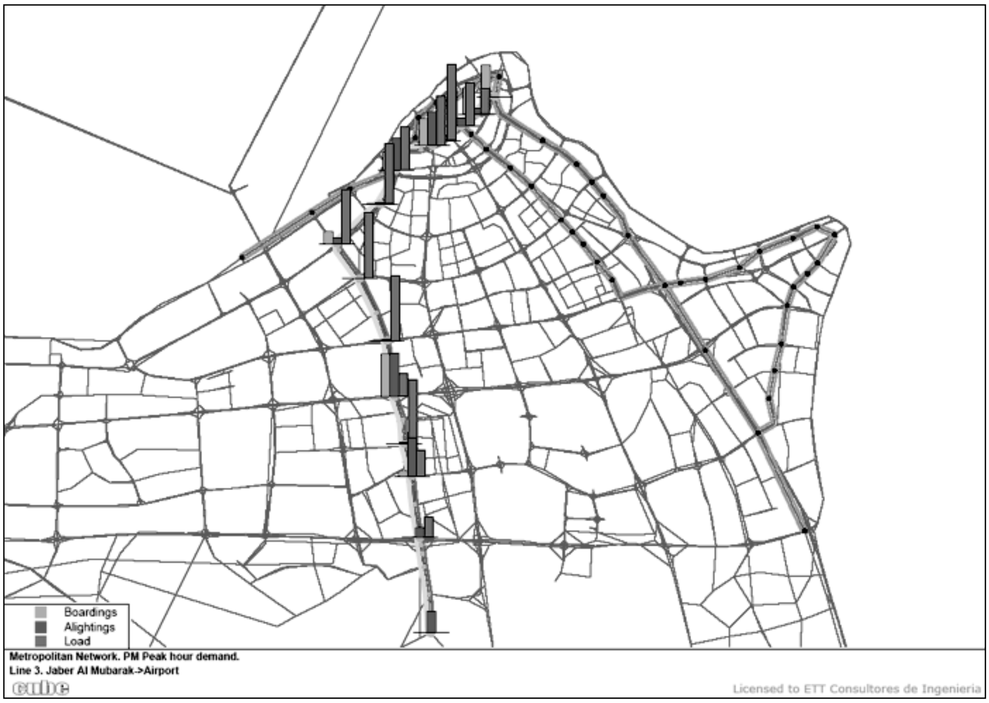


Figure 21. PM Peak Hour Demand (Line 2)



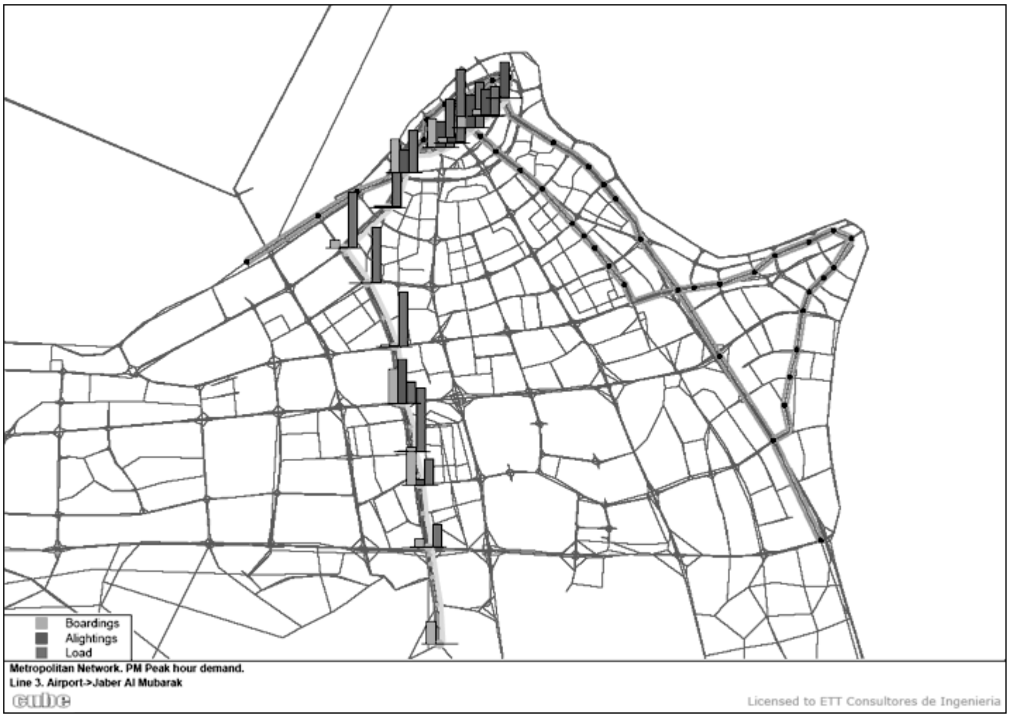


Figure 21. PM Peak Hour Demand (Line 3)

6. CONCLUSIONS

Railway transport is considered a significant part of passenger facilities for long-distance transportation in several metropolitan areas. Urban metro traffic begun as naturally well-disposed transportation mode with high conveying limit and low discharges. With all of the enormous increase in population and trips especially in peak periods, streets became more crowded and congested. Metro is required to reduce the traffic jam on streets. Metro could be underground or on some special lanes. This solution required full detailed study about many parameters such as total population, population density in some areas, distribution of work, and residential places and about markets and educational facilities. The timing schedule and costing for metro users also should be considered.

In order to properly study the demand patterns and characteristics of the city of Kuwait, a detailed modelling of these phenomena was required. The purpose of this modelling was to create a useful tool, with which to objectively evaluate the alternatives proposed in this paper research. Future demand on the proposed public transport network had been forecasted based on the transportation model developed by Atkins for Colin Buchanan & Partners in the framework of the 3rd Kuwait Masterplan Review. This model, built on a SATURN platform, was translated to a CUBE environment. This step involved reproducing both the data (networks and demand), then also the model algorithms, and checking the output results after running the model on this new platform matched those obtained by Buchanan. That initial model, built for a 2003 base year, was then updated to the current situation, where both road and public transport networks were concerned.

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خصائص الطلب على مترو الكويت المقترح حديثاً

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الخلاصة

نماذج المرور لها أهمية قصوى في تخطيط أي بنية تحتية للنقل. وتكمُن هذه الأهمية في القدرة على التنبؤ بسلوك المستخدمين في المستقبل؛ وبالتالي، الطلب على كل وصلة من الشبكة. من أجل دراسة أنماط وخصائص الطلب في مدينة الكويت بشكل صحيح، يتطلب ذلك نمذجة مُفصلة لهذه الظواهر. والغرض من هذه النمذجة هو إنشاء أداة مفيدة يمكن من خلالها تقييم البدائل المُقترحة بموضوعية في هذا البحث. تم التنبؤ بالطلب المستقبلي على شبكة النقل العام المُقترحة بناءً على نموذج النقل الذي طورته شركة أتكينز لصالح كولين بوكانان وشركاه في إطار مراجعة الخطة الرئيسية الثالثة لدولة الكويت. تمت ترجمة هذا النموذج المبني على منصة SATURN إلى بيئة CUBE. وتضمنت هذه الخطوة إعادة إنتاج كل من بيانات (الشبكات والطلب) ومن ثم خوارزميات النموذج، وتم التحقق من نتائج المخرجات بعد تشغيل النموذج على هذه المنصة الجديدة والتي تطابق النتائج التي حصلنا عليها من Buchanan. تم تحديث هذا النموذج الأولي الذي تم بناؤه لعام 2003، وفقاً للوضع الحالي، حيث يتعلق الأمر بشبكات الطرق والنقل العام. وتم فحص شبكة الطرق الحالية وتعديلها أو استكمالها، إذا لزم، وكذلك خدمات النقل العام.