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Application of Transportation Models for Analysing Future Intercity and Intracity Travel Patterns in Kuwait

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Abstract**—**In order to meet the increasing demand for housing care for Kuwaiti citizens, the government authorities in Kuwait are undertaking a series of projects in the form of new large cities, outside the current urban area. Al Mutlaa City located to the north-west of the Kuwait Metropolitan Area is one such project out of the 15 planned new cities. The city accommodates a wide variety of residential developments, employment opportunities, commercial, recreational, health care and institutional uses. This paper examines the application of comprehensive transportation demand modeling works undertaken in VISUM platform to understand the future intracity and intercity travel distribution patterns in Kuwait. The scope of models developed varied in levels of detail: strategic model update, sub-area models representing future demand of Al Mutlaa City, sub-area models built to estimate the demand in the residential neighborhoods of the city. This paper aims at offering model update framework that facilitates easy integration between sub-area models and strategic national models for unified traffic forecasts. This paper presents the transportation demand modeling results utilized in informing the planning of multi-modal transportation system for Al Mutlaa City. This paper also presents the household survey data collection efforts undertaken using GPS devices (first time in Kuwait) and notebook computer based digital survey forms for interviewing representative sample of citizens and residents. The survey results formed the basis of estimating trip generation rates and trip distribution coefficients used in the strategic base year model calibration and validation process.

Keywords**—**GPS based household surveys, transportation infrastructure, origin-destination trip matrices, traffic forecasts, transportation demand modeling, travel behavior patterns.

I. Introduction

STATE of Kuwait has experienced rapid economic growth over the past several decades, a trend that is expected to continue well into the future. The current population is 4 million approximately and is expected to reach 6 million by 2030. The expected increase in national population and the in-flux of immigrant workers attributed to the economic boom have resulted in severe traffic congestion in many parts of Kuwait. At the same time, it is unlikely that this population will increase in the urban area further due to the acute strain on the infrastructure. In order to achieve better population distribution in Kuwait in future and to alleviate the current overcrowding in the current metropolitan area, as many as 15 self-sustaining new cities are being developed outside the current urban area. Some of these cities are already in construction stage.

Al Mutlaa City is an upcoming self-sustaining city with 370,000 inhabitants circa that occupies an area of just over 100 sq.km comprising of 12 residential neighborhoods for Kuwaitis and investment housing for expatriates. The city offers a range of land uses including commercial core, two district centers, city center with a mixed use core (for expatriates) and ministries district, youth and sports center, educational facilities, employment centers, health care facilities and recreational facilities. The city is located approximately 38 km in the west-northwest direction of Kuwait City (Central Business District) [11].

Kuwait's National Transportation Model is a key analysis tool used for taking crucial investment decisions related to the expansion of urban areas and development of transportation infrastructure in Kuwait. Travel patterns are often dynamic in nature for any urbanized area, more so in a rapidly developing nation like Kuwait.

This paper explores the application of National Transportation Model as a tool for analysing the future intercity and intracity travel patterns in Kuwait as well as to inform the planning of transportation infrastructure for Al Mutlaa City. Fig. 1 depicts the current urban area and the upcoming cities.

II. Transportation Modeling Summary

National Transportation Models (NTM) for Kuwait is a comprehensive strategic multi-modal transportation model developed in PTV Group's VISUM platform owned by the Kuwait Municipality. The NTM nationwide transportation model is capable of supporting the conventional four-stage multimodal models and is fully GIS compatible. The modeling steps comprise of trip generation, trip distribution, mode choice and trip assignment. The national base models have been calibrated and validated for 2014 and the forecast models represent demand for year 2030.

The peak periods in model are as follows:

- Morning (AM) Peak Hour: 07:15 to 08:15
- Afternoon (AN) Peak Hour: 13:00 to 14:00
- Evening (PM) Peak Hour: 17:00 to 18:00

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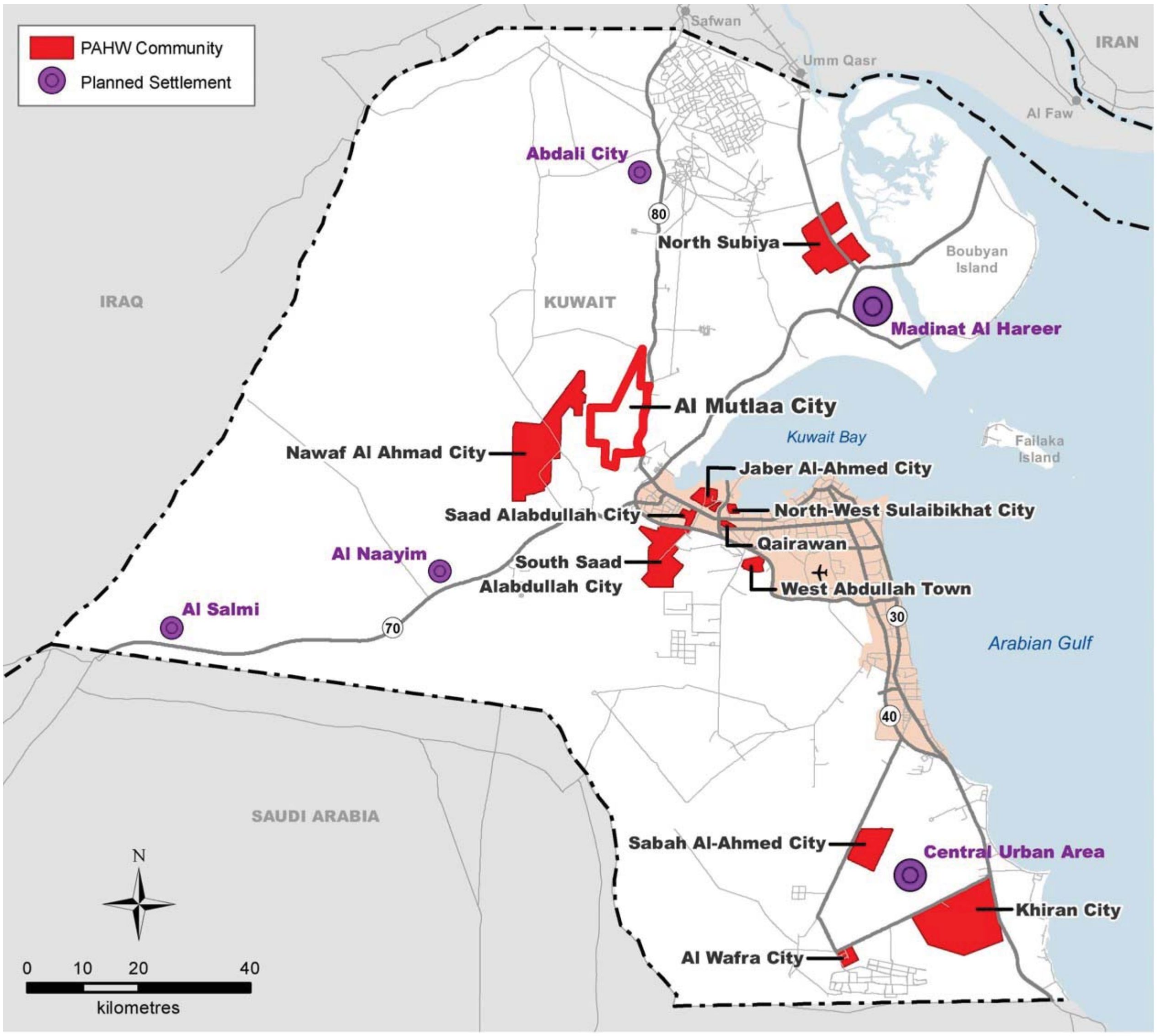

Fig. 1 Kuwait Urban Area and New Cities

The demand segments [1], [10] estimated for each of the Kuwaiti and expatriate population groups included the following:

- Home-based Work;
- Home-based School;
- Home-based University;
- Home-based Shopping;
- Home-based Social;
- Home-based Recreation;
- Non Home-based

Transport Modes included:

- Private Transport: Car, Goods vehicles (light, medium, and heavy goods vehicles)
- Public Transport: Bus, Metro, BRT

The latest version of transportation model data sets was used as a platform to develop sub-area models for Al Mutlaa City to maintain consistency of the results with the strategic models. These models were developed representing three weekday peaks consistent with the nationwide model peaks.

In order to understand travel behavior patterns in the future given the brisk economic growth potential, three types of transportation models were developed with varying levels of detail:

- Sub-area models for Al Mutlaa City with disaggregate zone system for estimating intracity trips
- Update of strategic nationwide model for estimating intercity trips as well as trips from / to current metropolitan area
- Sub-area models for residential areas within Al Mutlaa City for assessing block level traffic demand

Fig. 2 illustrates the transportation model development and update framework.

Sub-area models have been built by cordoning-off the model coverage area from the strategic model for detailed assessment of demand and travel behavior in the base year. Traffic Analysis Zone (TAZ) structure and transportation network modifications were carried out within the sub-area to enhance the model. The four-step transportation planning procedures [6] were executed within the sub-area models. The resulting trips were distributed and assigned to obtain base year highway origin-destination (O-D) trip matrices. These trip demand matrices were then calibrated and validated using *Tflowfuzzy* technique in VISUM by comparing the link traffic flows against observed traffic count data [5], [2].

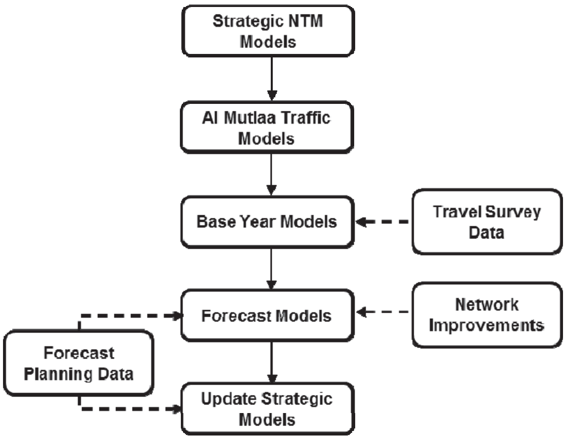

Fig. 2 Transportation Model Development Framework

III. Travel Surveys Using GPS Technology

Household surveys constitute a major activity in the base year model development process. The primary objective of the household survey was to obtain travel diaries for a sample of all major person types living in Kuwait, for calculating trip rates and trip distribution coefficients. In this context, a person type belonging to a specific demographic group is defined with respect to variables associated with travel behavior, where travel behavior is measured in terms of frequency, time, mode, purpose etc. of travel, and the variables include demographic group and other socio-economic variables. The demand segments in the model constitute the person types belonging to each demographic group.

The key element of survey program was undertaking household surveys using GPS technology for first time in Kuwait. These surveys were carried out using GPS devices and notebook based electronic survey forms by interviewing representative sample of citizens and expatriates using the stratified random sampling technique [3].

IV. Scope of GPS Based Household Surveys and Data Analysis

The household surveys were undertaken in 2014, with 206 households surveyed on normal days using Blumax GPS loggers. The survey recorded trips by all modes, including walk trips of at least 200 meters of all the adult members of the household. The analysis presented is based on motorized modes only and so excludes walk and cycle trips. The travel survey diaries relate to people age 16 and over.

The survey questionnaire constituted three main modules viz., household information, personal information and travel diary [4]. The household information module gathered details such as family size, car ownership, dwelling type etc. The questionnaire also gathered personal information like gender, demographic group, age and occupation for each individual family member. The travel diary module collected details of trips performed by the respondent and the family members during the previous working day.

A. Survey Execution

First, initial contact was normally made by visiting selected household and seeking to provide an overview to an adult who is a responsible member of the household to explain the nature of survey. The privacy was clearly explained that all data will be treated confidentially and will not pass any names or household addresses to any other organization or person. The names and home addresses were entirely deleted from all datasets records once the other information obtained in the survey have been extracted. Survey lasts for 15-20 minutes in the initial meeting, and a second visit after two or three days; a third visit may be needed if some household members are not present at the second visit.

The trip details and trip purpose for the trips retrieved from GPS devices were collected during the second visit. This is time-consuming activity to undertake these surveys using GPS technology, as it requires multiple visits to the household to obtain comprehensive information from each family member. An internet based File Transfer Protocol (FTP) portal was setup so the surveyor can upload the data to centralized database. The data was downloaded from the server to carry out the data cleanups and detailed statistical analysis.

The trips per person were summarized on each record for each of the demographic groups and for each of the trip purposes. The survey data was compiled with data from previous household surveys to provide a broader and representative sample. The parameters and results obtained from the surveys were checked for accuracies before using in model estimation process. The survey data was also compared and collated with data from past surveys before using in strategic model estimation process. Fig. 3 illustrates the survey execution plan.

B. Demographic Groups

The Arab expatriates constituted the largest group followed by Asian expatriates in the surveyed sample. Having the largest samples in these two groups is adequate as they form the largest expatriate populations and are likely to be more diverse in travel behavior than Kuwaitis (largely due to a very wide range of income levels among the expatriate groups). Western expatriates form only a small percentage of the population in Kuwait (around 1%) and therefore the small size of the sample is not a major concern. The trip generation rates and trip length data were calculated using the survey data for each of the demographic group and applied in the model discretely for each of the demand segment. Fig. 4 illustrates the cross section of the surveyed sample.

Fig. 5 shows the family size of the interviewed households. The family size of the Kuwaiti household seemed to be high generally constituting of a large villa house.

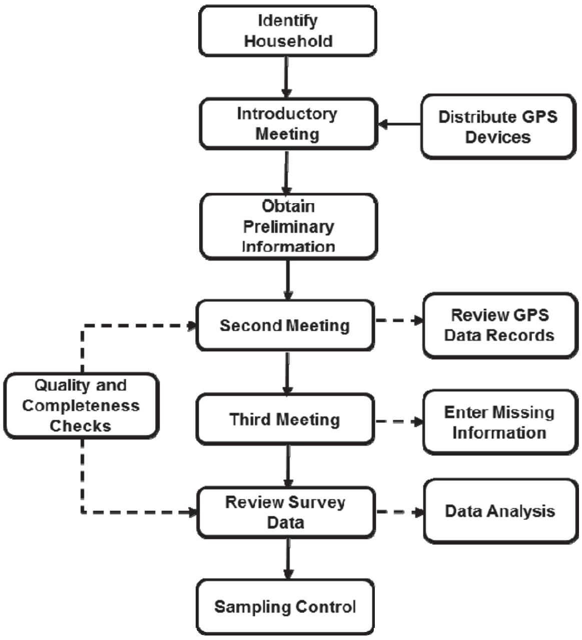

Fig. 3 Household Survey Execution Plan

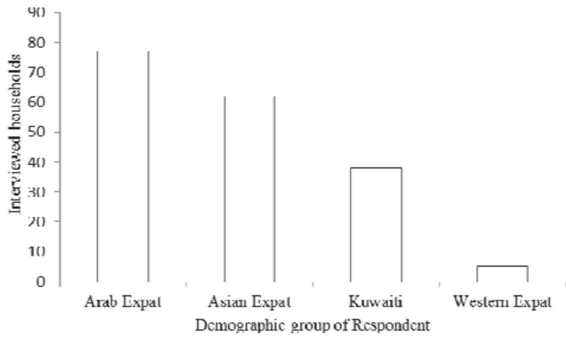

Fig. 4 Sample Cross-Section - Demographic groups

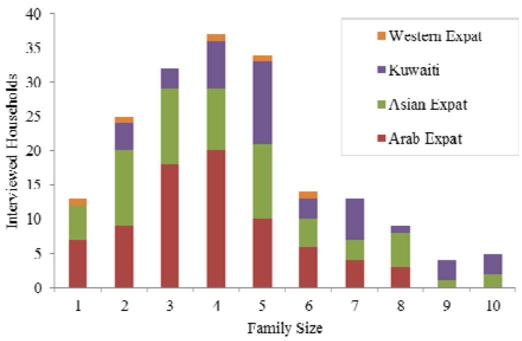

Fig. 5 Family Size of Demographic groups

C. Challenges in GPS Based Household Surveys

Some of the practical difficulties encountered in execution of GPS based household surveys included:

- Poor signal reception in certain areas resulting in missing information;
- Possibility of survey program getting prolonged as multiple visits to household may be required to obtain all relevant information
- Data cleanups [4] are required after downloading trip data from GPS loggers prior to detailed analysis;
- Survey response rates are low; due to apprehensions about privacy as this type of surveys are implemented for the first time in Kuwait;
- Challenges in survey management including labeling and managing devices, configuration of GPS devices, survey personnel and sampling control;
- High budgetary requirements including procurement of devices, computers, survey equipment and accessories.

D. Advantages of GPS Based Household Surveys

Even though, there are certain practical difficulties in execution and application, the GPS based household surveys provide more accurate information than the traditional travel diary interviews [8]. As the new technologies are emerging rapidly, enhanced GPS devices coupled with mobile applications can be used in transportation data collection to overcome some of these issues and improve quality further.

The key advantages in GPS based household surveys included:

- Use of GPS loggers ensure continuous and accurate representation of trips by time of day eliminating the underreporting of trips [9]
- The exact time and location of each trip is recorded that aids in estimating consistent and realistic trip length distribution
- Allows incessant tracking of chained trips (series of trips with one or more intermediate destinations) throughout the day thereby providing better understanding of Non-home based trips
- Trip records data are collated from each of the family member which ensures comprehensive info from all family members
- The survey records are directly saved to electronic database facilitating automation in statistical data analysis [4].

The sample sizes used in the study were relatively small as the GPS based surveys were carried out for the first time in Kuwait. The enlarged sample sizes are recommended taking into consideration the lessons learned from the survey efforts for further enhancing the quality of data.

V. Planning Data – Al Mutlaa City

The master plan envisages a total population of approximately 370,000 and the land-uses include villas, commercial establishments, mosques, educational establishments, services and other support facilities [11]. The year 2030 planning data is summarized in Table I and the city master plan is illustrated in Fig. 6.

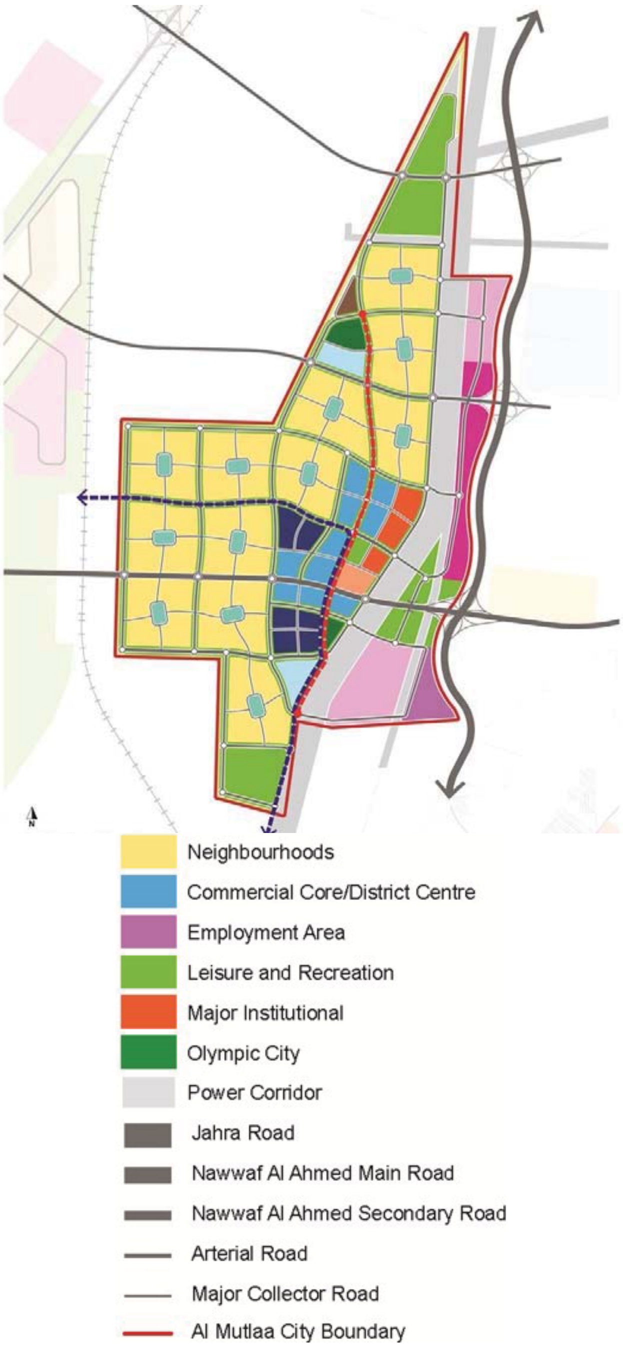

Fig. 6 Al Mutlaa City Master Plan

TABLE I
PLANNING DATA – AL MUTLAA CITY

Attribute	Kuwaitis	Expatriates	Total
Population	218,900	150,500	369,400
Dwelling Units	30,400	35,000	65,400
Employees	70,900	112,000	182,900
Work Places	85,600	146,200	231,800

VI. TRANSPORTATION MODELING FOR AL MUTLAA CITY

The primary purpose of the transportation models was to provide a tool for evaluating the transportation system of Al Mutlaa City. The models acted as a decision making tool by providing input into the infrastructure design process in the form of traffic flows and levels of service. The forecast strategic model data sets in conjunction with validated base year models formed basis for the developing forecast models. The transportation model components are outlined below [5].

A. Trip Generation

In this step, the trip generation rates were applied on respective socio-economic variables followed by a procedure to balance trip productions and attractions for each demand segment. The variables used in the trip generation included population, employees, work places, resident students and enrollment (school and university), retail floor area and recreational floor area of each TAZ in the city.

B. Trip Distribution and Modal Split

The sub-area models associated with Al Mutlaa City were executed with disaggregated zone structure initially and were then introduced into the strategic model to carry out the trip distribution process in the nationwide model. Due to the varying characteristics of these evolving cities, analysing the trip distribution and mode choice patterns has been complex and models were executed in iterative manner to achieve reasonableness in results. The trip interactions were estimated using the gravity model technique [10] for the intracity zones as well as cordon zones (representing urban area and other future cities) within the traditional four-stage transportation planning model. The survey data was used to calibrate utility function parameters of gravity model in VISUM. The generalized form of utility equation [1] is given in (1):

$$f(U_{ij})=a*e^{c*U_{ij}} \quad (1)$$

where U_{ij} – Value of the utility between zone i and zone j; *a, c* – Estimated parameter values of the utility function.

Mode choice models were utilized to allocate trips determined by trip distribution models between competing private and public transport modes available to trip maker to satisfy the zone-to-zone trip movements. The mode choice model has a logit form, in which the choice between travel alternatives depends upon an exponential function of generalized cost or disutility. The primary inputs are trip demand matrices and cost matrices, where cost implies various components of generalized cost.

The principal model components: distribution and mode choice are two logit models, placed in a hierarchical model, in an order determined by the relative sensitivities of the choice parameters. The two components were executed within a loop, which is repeated until model convergence is achieved. The output consists of converged variable demand trip matrices by purpose and segment, and reports and statistics detailing the process. The output also includes the assignments of the trip matrices to the relevant modes of the transportation network.

The public transport mode share was estimated as 10%, 12% and 16% in AM, AN, and PM peak hours respectively. Fig. 7 illustrates the framework of updating forecast models.

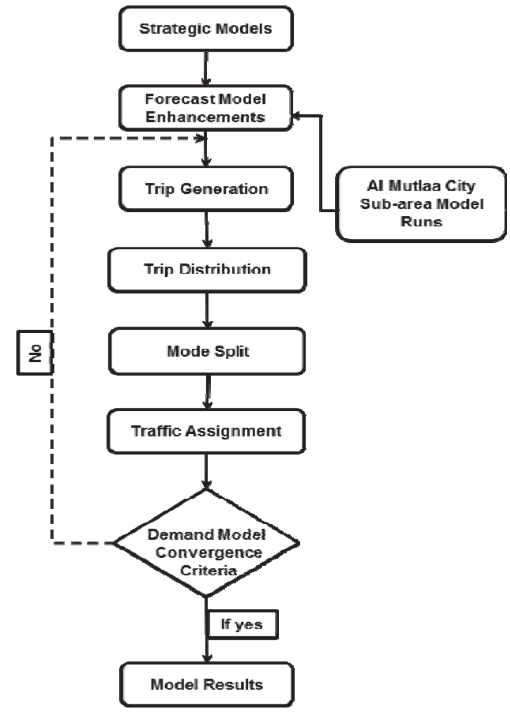

Fig. 7 Forecast Model Update Framework

C. Trip Assignment

The user equilibrium procedure in VISUM was used to assign private vehicle trips to the highway network in each of the three peak periods. The user equilibrium process assigns trips on the network such that all used links between each O-D pair will have equal impedance. Every road user selects his route in such a way that the impedance on all alternative routes is the same and switching to a different route would increase personal travel time [2]. Within the city, the traffic flows are heavy i.e., in excess of 4,000 vehicles per hour (vph) in each direction along the east-west road that leads to the adjacent future city Nawaf Al Ahmed City main road and up to 3,000 vph along the north-south central arterial spine in all peak periods.

Figs. 8-10 illustrate the traffic flows along main road network in each of the peak hours.

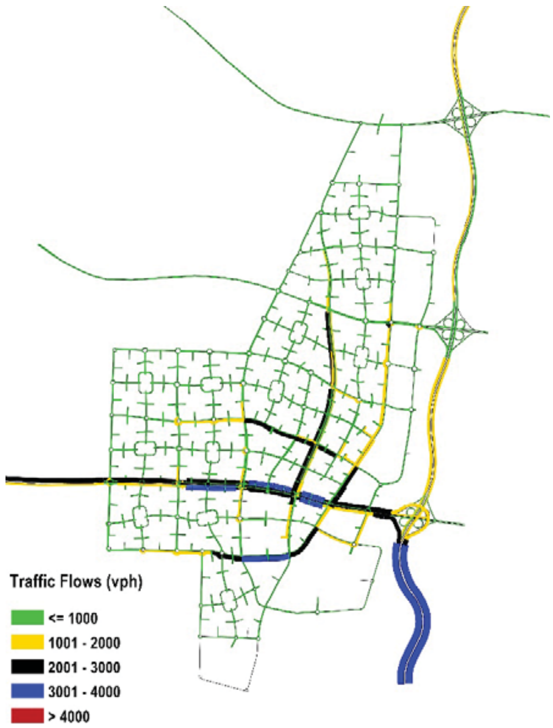

Fig. 8 Al Mutlaa City Traffic Flows – 2030 AM Peak Hour

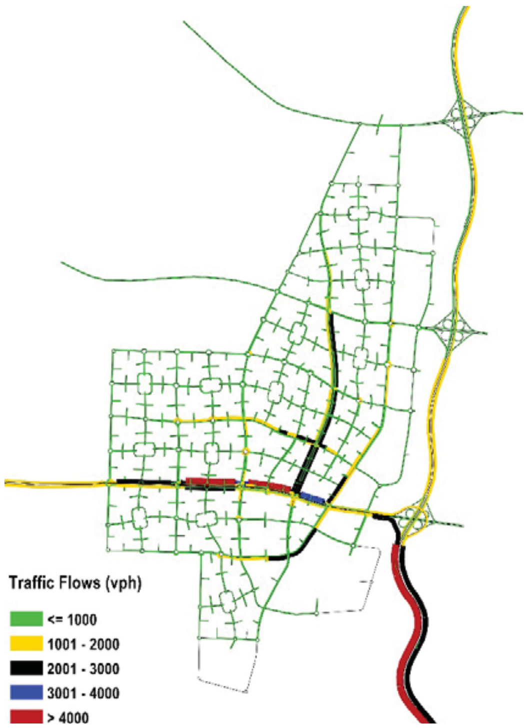

Fig. 9 Al Mutlaa City Traffic Flows – 2030 AN Peak Hour

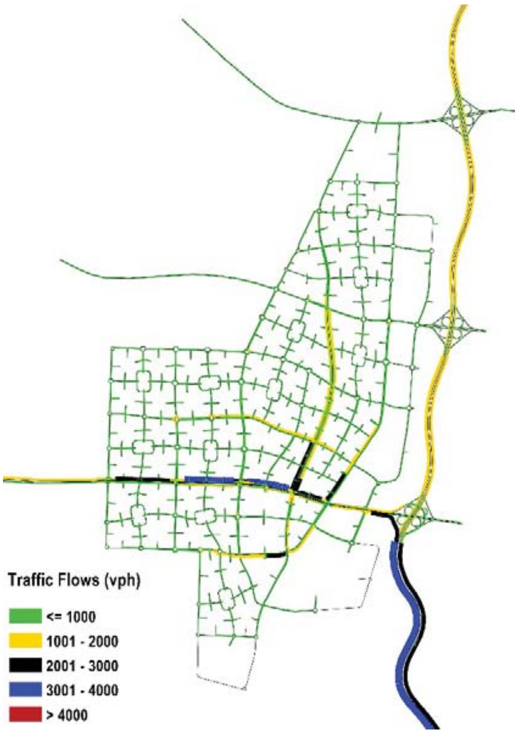

Fig. 10 Al Mutlaa City Traffic Flows – 2030 PM Peak Hour

TABLE II
SECTOR O-D TRIP MATRIX – AM PEAK

AM O-D	Nawaf Al Ahmed	Al Mutlaa	Jahra	Urban Area	Totals
Nawaf Al Ahmed	24,636	749	2,049	2,075	29,508
Al Mutlaa	1,515	33,644	1,203	1,525	37,888
Jahra	3,215	1,954	44,746	15,181	65,096
Urban Area	535	350	16,815	1,988	19,688
Totals	29,901	36,698	64,814	20,768	

TABLE III
SECTOR O-D TRIP MATRIX – AN PEAK

AN O-D	Nawaf Al Ahmed	Al Mutlaa	Jahra	Urban Area	Totals
Nawaf Al Ahmed	28,962	732	1,587	1,463	32,743
Al Mutlaa	1,026	26,576	819	1,735	30,156
Jahra	975	716	43,535	13,558	58,785
Urban Area	734	432	14,589	1,138	16,892
Totals	31,696	28,456	60,530	17,894	

TABLE IV
SECTOR O-D TRIP MATRIX – PM PEAK

PM O-D	Nawaf Al Ahmed	Al Mutlaa	Jahra	Urban Area	Totals
Nawaf Al Ahmed	21,962	321	847	756	23,886
Al Mutlaa	1,633	24,663	1,603	1,000	28,898
Jahra	608	615	29,254	13,850	44,328
Urban Area	1,040	655	15,486	2,902	20,083
Totals	25,243	26,253	47,190	18,508	

VII. TRIP INTERACTIONS

Al Mutlaa City being a regional trip generator and trips from the city are expected to be distributed all over Kuwait. The distribution of trips by purpose generated is based on available routing towards the strategic road network, and the location of major urban areas near the development site. As discussed earlier, the exponential form of gravity model function was used for distributing trips within the sub-area model. Home Based trips for work and school purposes were doubly constrained. Home Based trips for shopping, social and recreational purposes were constrained to productions (i.e. the home end). Non Home-Based trips were constrained to origins. Tables II-IV summarize the private vehicle Origin-Destination (O-D) sector-to-sector trip matrices (vehicles per hour) in each of the peak hours.

The sector O-D trip matrices indicate that significantly high proportion of intracity trips (i.e., originating trips are destined to zones within the Al Mutlaa City) consistent with the self-sustaining nature of the city. The intracity trips within Al Mutlaa City are estimated at 89% in AM peak, 88% in afternoon peak, and 85% in PM peaks respectively. A similar trip pattern has been observed for the adjacent future city Nawaf Al Ahmed. The trip proportions between the Al Mutlaa City and Urban Area were estimated as 7%, 9%, and 9% in each of the 3 peak periods. The transportation model results are deemed fit for planning purposes.

VIII. PUBLIC TRANSPORTATION PLAN

Public transportation plan has been proposed to cater the needs of the Al Mutlaa City residents offering connectivity within the city as well as integration with the proposed regional metro system.

The proposed public transport plan consists of following services:

- Bus Rapid Transit (BRT) routes
- Regular Bus routes (supplemented with bus feeder services)

BRT service supported with bus services would be optimum public transport system for residents of Al Mutlaa City [11]. Fig. 11 presents the proposed public transportation system.

IX. TRANSPORTATION MODELING FOR RESIDENTIAL NEIGHBORHOODS

Residential neighborhoods in Al Mutlaa City provide housing, schools, mosques, health care facilities, retail shopping, community facilities, and green space for gathering, playing, and relaxing for Kuwaiti inhabitants. In total, there are 12 neighborhood residential areas in Al Mutlaa City [11]. Fig. 12 illustrates the three types of neighborhood designs proposed for the residential areas viz., Octagonal, Rectilinear and Offset Rectilinear concepts.

Development of sub-area transportation model for neighborhoods is the process of cordoning off the residential area from the Al Mutlaa sub-area model (set out in previous section) for detailed assessment of demand and traffic behavior of internal roads within the residential area. The model coverage area included the residential area bounded by the surrounding main road network and the external zones.

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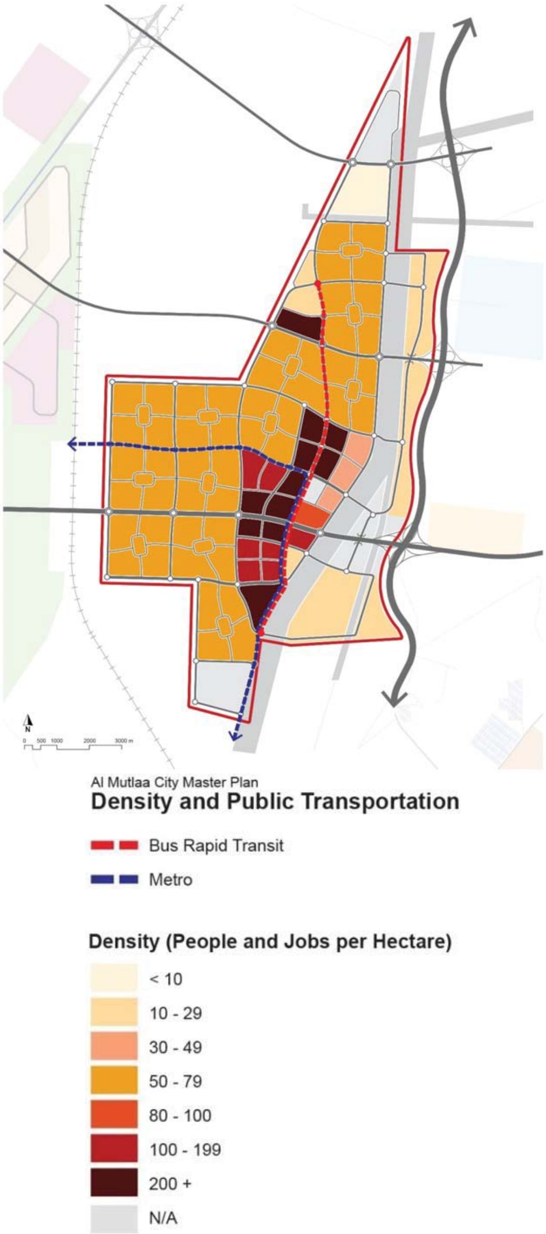

Fig. 11 Public Transportation Plan – Al Mutlaa City

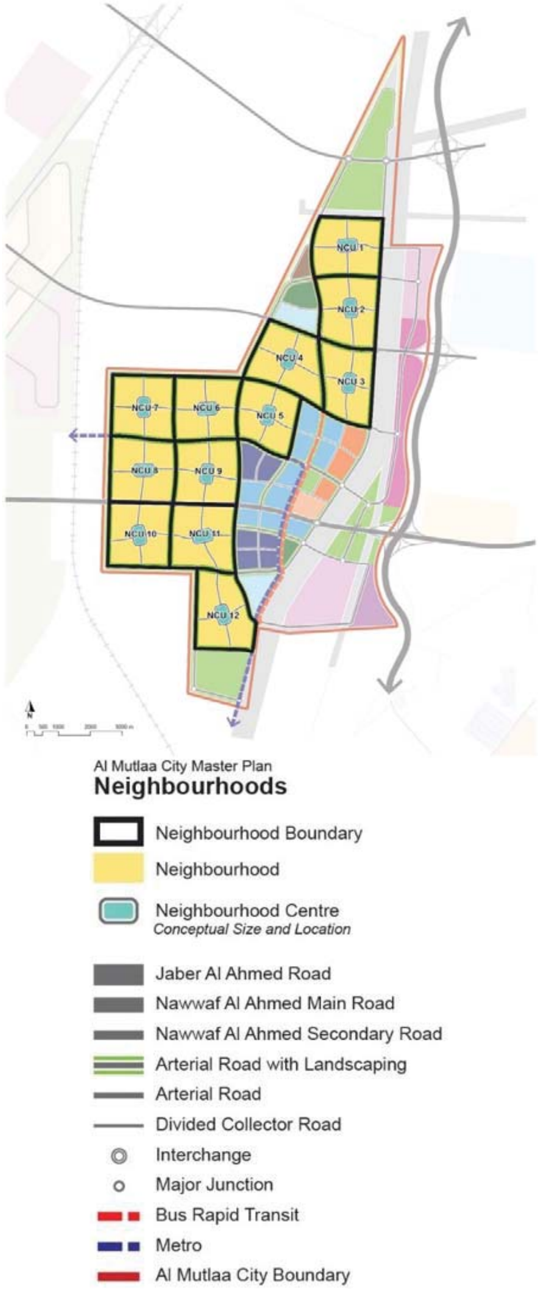

Fig. 12 Residential Neighborhoods – Al Mutlaa City

A. Octagonal Residential Area

The octagonal residential area in Al Mutlaa City envisages 2,435 dwelling units approximately which is expected to support a population of 21,000 and it includes villas, commercial establishments, services and other support facilities.

The procedures of standard four-step transportation demand model were executed similar to the sub-area models built for Al Mutlaa City. The model results including traffic flows were extracted to study the impact of infrastructure changes and transportation system requirements within the residential area. The traffic flows along the residential area network indicate highest traffic volumes along the peripheral road of the residential area (in excess of 1,200 vehicles per hour) in all peaks. Figs. 13-15 illustrate traffic flows in octagonal residential area in each peak period.

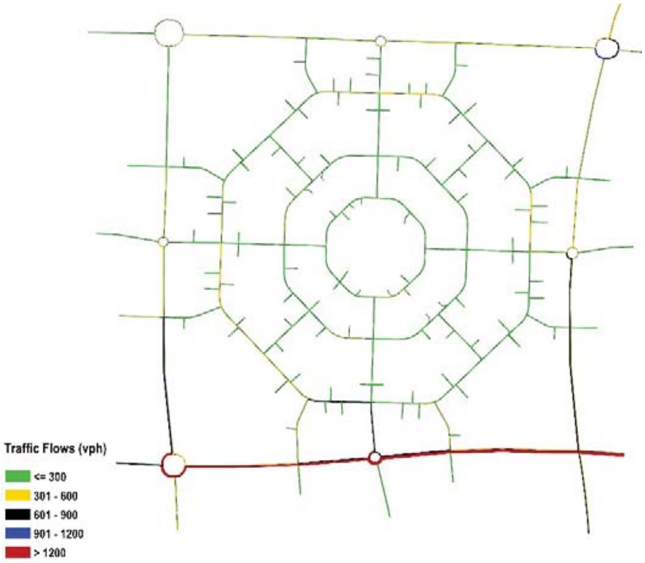

Fig. 13 2030 AM Peak Traffic Flows – Octagonal Residential Area

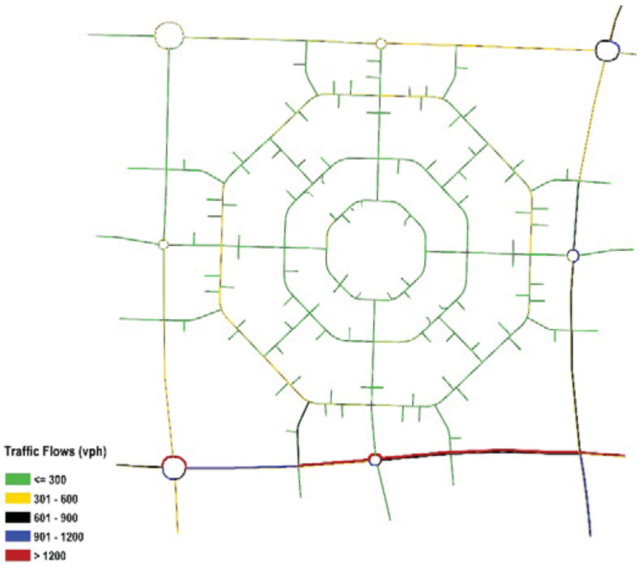

Fig. 14 2030 AN Peak Traffic Flows – Octagonal Residential Area

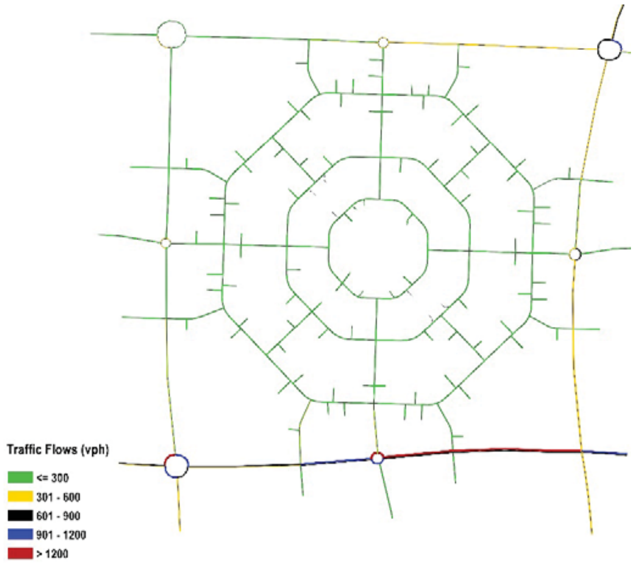

Fig. 15 2030 PM Peak Traffic Flows – Octagonal Residential Area

B. Rectilinear Residential Area

The rectilinear residential area in Al Mutlaa City envisages 2,544 dwelling units approximately which is expected to support a population of 22,000 and land-uses are identical to other residential areas in the city.

The traffic flows along the residential area network indicate highest traffic volumes along the peripheral road of the residential area (in excess of 1,200 vehicles per hour) in all peaks. Figs. 16-18 illustrate the traffic flows in rectilinear residential area in each peak period.

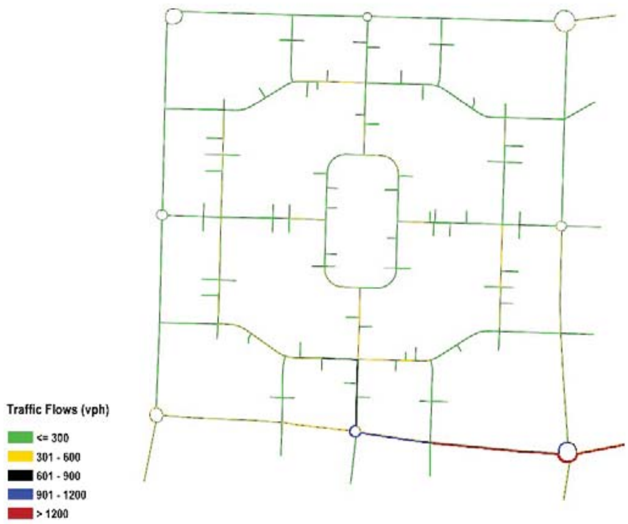

Fig. 16 2030 AM Peak Traffic Flows – Rectilinear Residential Area

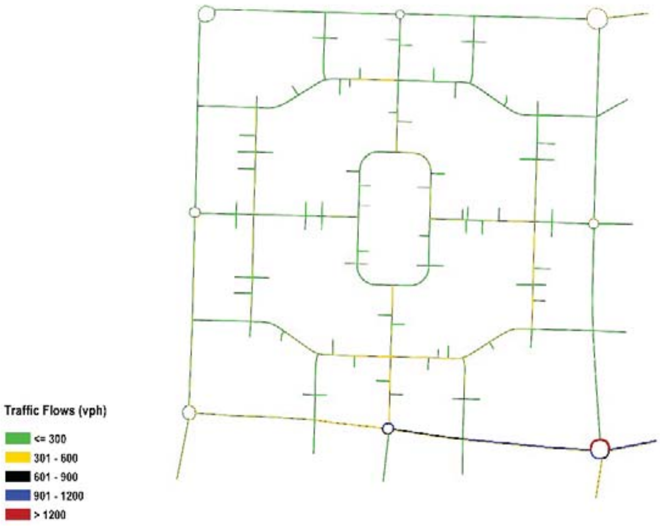

Fig. 17 2030 AN Peak Traffic Flows – Rectilinear Residential Area

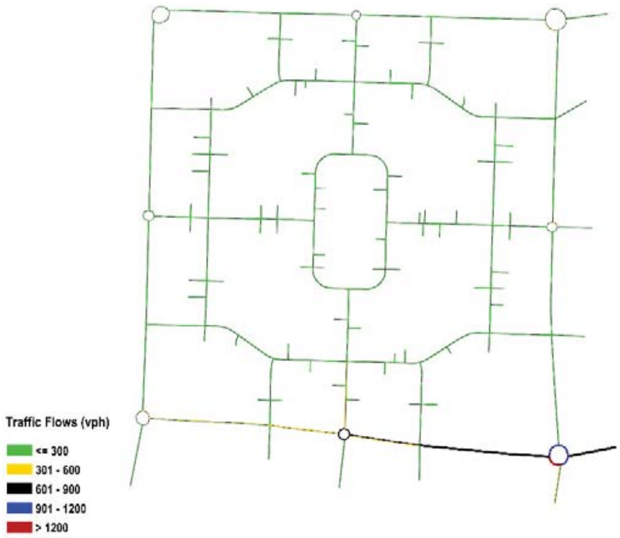

Fig. 18 2030 PM Peak Traffic Flows – Rectilinear Residential Area

C. Offset Rectilinear Residential Area

The offset rectilinear residential area in Al Mutlaa City envisages 2,410 dwelling units approximately which is expected to support a population of 20,969 and land-uses are identical to other residential areas in the city.

The traffic flows along the residential area network indicate highest traffic volumes along the peripheral road of the residential area (in excess of 1,200 vehicles per hour) in all peaks. Figs. 19-21 illustrate the traffic flows in offset rectilinear residential area in each peak period.

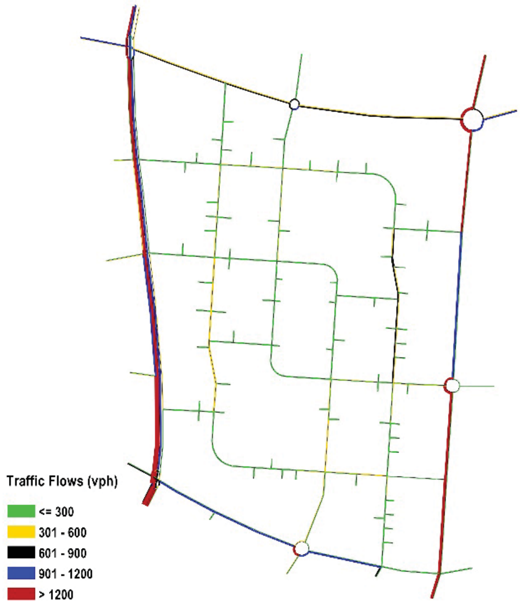

Fig. 19 2030 AM Peak Traffic Flows – Offset Rectilinear Residential Area

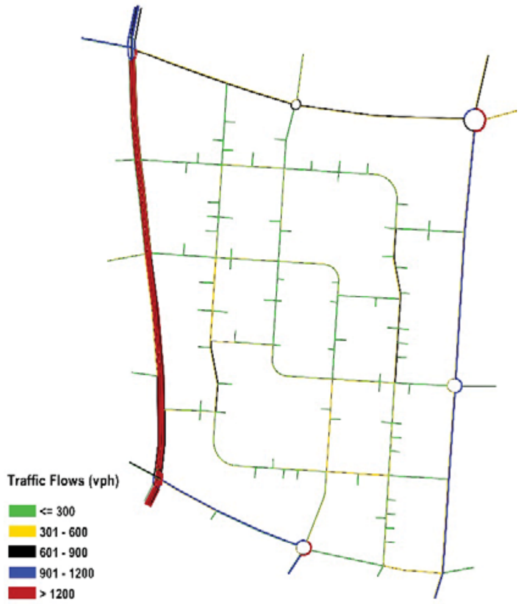

Fig. 20 2030 AN Peak Traffic Flows – Offset Rectilinear Residential Area

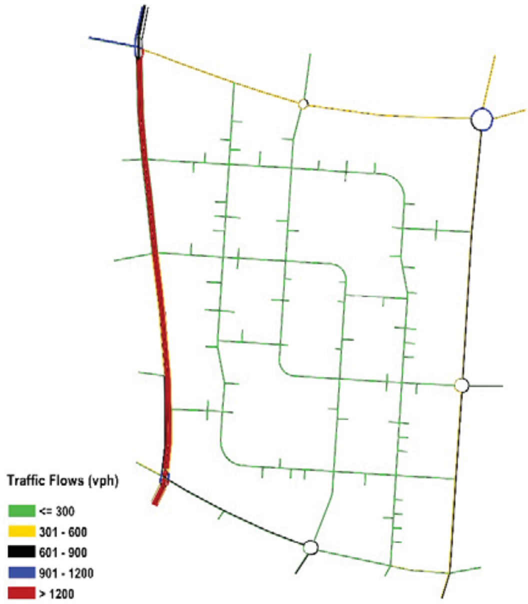

Fig. 21 2030 PM Peak Traffic Flows – Offset Rectilinear Residential Area

The transportation model results aided in planning of the internal road network including junction types within the residential neighborhoods.

X. Conclusion

This paper documents the efforts to apply the conventional four-stage transportation demand modeling principles to understand the future travel behavior of residents within the urban area and upcoming cities in Kuwait. Three types of multi-modal transportation models with varying levels of detail were developed and utilized to propose road network as well as public transport network for Al Mutlaa City. The model results aided in understanding the trip behavior patterns in the horizon year. The transportation model results will support the decision makers in planning sustainable transportation infrastructure improvements in Kuwait in the horizon year 2030. The strategic model update framework was discussed which whilst providing unified forecasts also facilitates ease of integration with sub-area models related to upcoming cities in Kuwait.

The paper presented the role of GPS technology in household surveys [7] and model estimation process. The challenges and practical difficulties in carrying out GPS-based surveys in Kuwait have been discussed which can be taken into account when planning for future surveys. The paper outlines the key advantages of using travel data collected from GPS devices.

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