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1- Introduction

This study, (***The Enhancement of Traffic Performance On Streets and Roads in Kingdom of Saudi Arabia)***, aims at preparing integrated guidelines and instructions which constitute clear work methodologies, to enable city municipalities in the Kingdom of Saudi Arabia to carry out evaluation and improvement of traffic conditions. This study is organized according to the following main points:

- A statistical study to evaluate vehicle parking in the cities. This includes the comparison of parking demand with parking supply. In addition to engineering evaluation of parking lots, a methodology for evaluating parking as to their suitability with respect to parking demand is envisaged.
- A study of inner-city intersection evaluation models.
- A statistical study to evaluate traffic safety requirements of streets and roads and preparing traffic safety standards inside cities.
- Preparing a study on the fulfillment of needs for people with special needs' requirements.
- A study to present and analyze traffic safety techniques with a view to technology transfer from advanced countries and improving existing practices.

In addition to the final detailed report, the methodologies resulting from this study were presented in this summarized guidance upon the ministry's request to provide a simplified clear work guide which assists municipality engineers to perform traffic evaluation processes which include:

- Vehicle parking evaluation inside the cities as to parking supply sufficiency for parking demand together with engineering evaluation of those parking lots.
- Traffic performance evaluation of urban intersections.
- Evaluation of most important traffic safety requirements inside cities.

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2- Parking Evaluation Methodology

2.1 Introduction

Parking areas are considered among the most basic land uses in cities whereas parking availability is a primary issue for vehicle users. This applies to business, commercial activity, industrial, residential and entertainment areas.

Problems of parking can be noticed at all types of areas and activities which contain a concentration of human activity such as city centers, large shopping centers, stadiums, hospitals, and it is generally noticeable that parking problems escalate with the increasing city size.

City centers suffer from their inability to provide adequate areas for parking, due to the large volume of human activities and consequently large traffic volumes attracted to a relatively limited area. Another matter that increases the importance of providing parking spaces in city centers is that those centers usually represent the end of work trips which play an important role in transportation planning processes due to their impact on the economy, community, congestion problems and air pollution. In addition, work trips are more sensitive to cost and public transportation alternatives in comparison with shopping trips. This is why consideration has been given to parking spaces in city centers all over the world on one hand and seeking alternatives to reduce dependence on private vehicles on the other, to control the growing problems of parking in city centers.

Dependence in residential area is mainly on roadside parking. Despite the considerable capacity provided by roads and streets for parking, roadside parking is not sufficient to accommodate all vehicles particularly in populated large cities with the increase of private vehicles' ownership and dependency on private cars as the main mode of transportation. In view of the above and for providing parking requirements which represent a basic factor in prevailing transportation systems, the need for organizing and monitoring parking demand and supply is essential for evaluating the performance of parking facilities, and laying future plans, and seeking strategies to encourage transportation alternatives for private vehicles. Parking evaluation methodology deals, in detail, with the following:

- Data collection required for the evaluation process
- Evaluation of the traffic condition of the parking, including:
    - Parking durations
    - Parking occupancy

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- Parking turnover.
- Parking capacity compatible to mean parking period

- Engineering Evaluation of Parking lots

2.2 Summary of Parking Analysis' Results

Within the scope of the study, comparison has been made between parking demand in Riyadh and nine other cities with parking supply. The study has concluded the following general results:

- Parking demand is less than parking supply (capacity) for most of sites handled by the study. In other words, the parking areas which were studied accommodate the number of vehicles which are parked for a period compliant with the average calculated parking periods; exceed the number of vehicles which use the parking at each site of the study. This is applicable for most of the parking sites, but in most cases does not apply to onstreet parking.
- The rates of occupancy varied for each type of parking at each site. This is also applicable for the remaining variables used in the evaluation such as parking durations and parking turnover. Despite the adequacy of the number of the total parking spaces in a parking lot, the distribution of this demand between various parking types has not been proportionate with the number of available parking for each type; since it was found that surface parking attracts the majority of parking vehicles at the site. This makes surface parking suffers from high occupancy rates and parking turnover as compared with underground parking which remains semi-empty despite good engineering design and high level of parking demand in surface parking.
- The problem is not that parking supply is not enough for meeting parking demand, but in the way of using parking spaces by the drivers and their tendency to stop as near as possible to the served establishment' gates, in addition to some problems related to parking management. Parking management may use the methods of encouraging or forcing drivers to use currently unused parking (particularly during peak periods) through procedures that include total or partial restrictions of using the parking, which include determining periods of parking and imposing parking charges.
- On-street parking suffers from high parking demand due to the geographic extension on one hand, and the concentration of serviced landuses on the other hand, compared with the few number of onstreet parking spaces available. Therefore, a very high rate of occupancy has been noticed in onstreet parking that considerably exceeds its capacity. This is due to the illegal parking which takes space from adjacent streets and consequently decreases their capacity and increase the possibility of accidents. This highlights the need to investigate ways of

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increasing the number of parking spaces on one hand and cooperating with traffic police to prevent illegal parking on the other.

- A major part of parking demand studied was of short parking durations (≤10 minutes). Those vehicles which load and unload passengers (whether taxis or vehicles that acts as taxis) enter off-street parking without actually using parking spaces. They occupy space on the routes causing obstruction to other vehicles from one hand and give the impression that there is congestion in the parking lot on the other (this erroneous impression discourages some drivers from searching for an empty parking space). Therefore, it is very important to prepare special routes for these vehicles together with a number of temporary parking spaces near the gates (proportionate with the served establishment and the rate of these vehicles) so that their movement does not conflict with the movement of the vehicles searching for empty parking spaces. This shall provide fast and safe flow of these vehicles and extra route space for the remaining vehicles searching for empty parking spaces.
- The necessity for ensuring the importance of considering the engineering requirements in designing and organizing parking, particularly off-street parking facilities and planning roadside parking to insure safe and efficient parking operations.

It is paramount to stress the importance of transportation policies and strategies and their effects on all aspects of transportation. Parking is not an exemption, but it is considered as a major transportation element, especially at the beginning and end of all car dependant trips.

Generally, the transportation policies and strategies currently applied in the Kingdom of Saudi Arabia are still fully dependent on using private vehicles as a main mode of transportation. This creates a growing need for parking at the ends of all types of trips and which leads to an increasing need for vehicle parking particularly with the increasing vehicle ownership rates. Therefore, the solutions which may be provided are short term solutions which may not suffice the increasing parking demand.

The international experience has proved, the solution lies in supporting and encouraging public transportation sectors by establishing diversified public transportation services which should be developed of high standard so that they represent an attractive competitor rival for private vehicles. Similarly there should be restriction on the usage of private vehicles by financial and legal procedures to limit high dependency on them.

This may be done by adopting transportation policies in the Kingdom that are allocating funds for constructing public transportation infrastructure instead of constructing more highways, bridges and parking particularly in cities.

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The parking evaluation methodology is divided into methodologies for evaluating parking traffic conditions and geometric conditions. Each part includes a detail description of data collection suitable for intended analysis due to the effect of data collection on the results of the evaluation process. A brief definition of some terms related to parking is given as under:

2.3 Basic definitions

Parking lots: These are vehicle temporary storing stations and they form a main part of the overall transportation system.

Parking demand: It is the required number of parking spaces to be provided to serve a type or a number of types of parking users within the conditions affecting parking demand (including parking charges if any).

Parking space: An area adequate for parking of one vehicle including a sufficient space for opening doors; it is connected with an adjacent route and does not include a maneuvering space.

Routes: Pathways within the off-street parking area used for vehicles movement and maneuver inside the parking area to enter and exit parking spaces.

Parking is divided into:

a- On-street parking: These are the roadside parking spaces which may be used by vehicles for parking parallel, perpendicular, or angular to the sidewalk depending on certain factors including width of the adjacent road and volume of traffic on it. Roadside parking may be:

- Unrestricted (available for use at any time and without any fee)
- Restricted (available for certain times, or for a specified charge or both)

b- Off-street parking: These are areas adjacent to roads which are designated and organized as parking lots. Entrance to or exist from them is done by gates which link them to adjacent roads. They consist of parking spaces that are perpendicular, parallel or angular, and they may have:

- Surface parking (on the ground surface)
- Parking Garage: That can be
    - At ground
    - Underground
    - Multi-storied structure

The parking evaluation methodology is explained in the following section.

2.4 Data Collection

Distinction is made between data collection that is required for parking traffic or geometric evaluation.

2.4.1 Data Collection for Parking Traffic Evaluation

It is possible to organize data collection stages required for traffic analyses of parking according to the following steps:

1- Counting Available Parking Spaces

Manually count the number of available parking spaces in the studied site for each type of parking (onstreet, surface, or garages). In case there are no marking for parking spaces, then the number of parking spaces could be obtained by dividing the existing lengths / areas for parking by the minimum dimensions allowed for parking indicated in the Parking Specifications published by the Ministry (6.5 meters for parallel parking and 2.5 for perpendicular parking. This length is variable for diagonal parking according to its angle).

2- Determining Counting Time and Period by Experimental Counts

Generally, data collection is an expensive activity. This is particularly correct for collecting parking data, because it requires the efforts of trained enumerators for long working hours, and in absence of an automatic device to collect such data since it is difficult to depend on recording entering and exiting vehicle registration plates using video cameras.

Therefore, in order to obtain reliable data, and reduce the efforts of data collection process, and minimize its time period and cost, the survey duration is determined such that it must cover the peak hours and peak days of parking demand. This is ensured through experimental counts for a number of entering and exiting vehicles (in periodical intervals of half an hour for every hour, and for a duration that covers the expected parking peak), to determine daily and weekly peak time, and in order to carry out the detailed traffic count at weekly peak (in the day and time in which parking demand at the study site is the highest).

After that it is possible to specify time period for carrying out counting. The period and timing of the count depend mainly on the nature of the served landuse and the concentration of human activities. Governmental agencies, for example, are mostly crowded in the morning. Therefore parking counts are conducted for the entire working hours. While for residential areas and markets, evening peak is prominent. The counting period is generally determined on the basis of the experimental counts

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so that it may cover the peak period completely, and it is good to coordinate with the owners and users of the parking to determine these peaks. After determining timing and duration of parking count, the field work is performed.

3- Performing Traffic Count for Subject Parking Spaces

The count is performed according to the following steps:

- Immediately before commencing detailed traffic counts at a given site, information of registration plates of existing vehicles must be recorded using the form shown in Exhibit-1 attached in the Appendix. Those vehicles shall be considered later as entered at the start of the count.
- Gates are numbered (or blocks, in the case of onstreet parking) or any parking access to differentiate between them.
- Detailed traffic count is performed by using the FORM (shown in Exhibit-1 in the Appendix) by the trained enumerators.
- If the subject parking location is off-street, the enumerators are distributed in the parking area so that each one of them records the registration plate of all entering or exiting vehicles together with time at their specified location.

In case the gate was designated for both entering and exiting, it is advisable that a person be appointed to record entering vehicles data and another person to record exiting vehicles data.

In the processes of data collection, data entry and analyses, consideration shall be given to separate the data of each type of parking (surface, garages, onstreet) through the use of separate data collection form. This is done by distributing the enumerators in a manner that ensures obtaining entering/exiting vehicle data for each type of parking separately so that it becomes possible to analyze each type of parking individually and accurately to identify the utilization of each type of parking.

- In case of on-street parking (no gates) a number of adjacent parking spaces are allocated (10 to 15 parking spaces, or it is possible to divide the area into blocks compatible with the building blocks at the study site) to each enumerator so that he may monitor them and record the data of each vehicle that enter / leave the parking area.
- At the end of counting period, data of the remaining vehicles are immediately recorded using the form shown in Figure-1 attached in the appendix. These shall be considered as exited cars at the end of the count.

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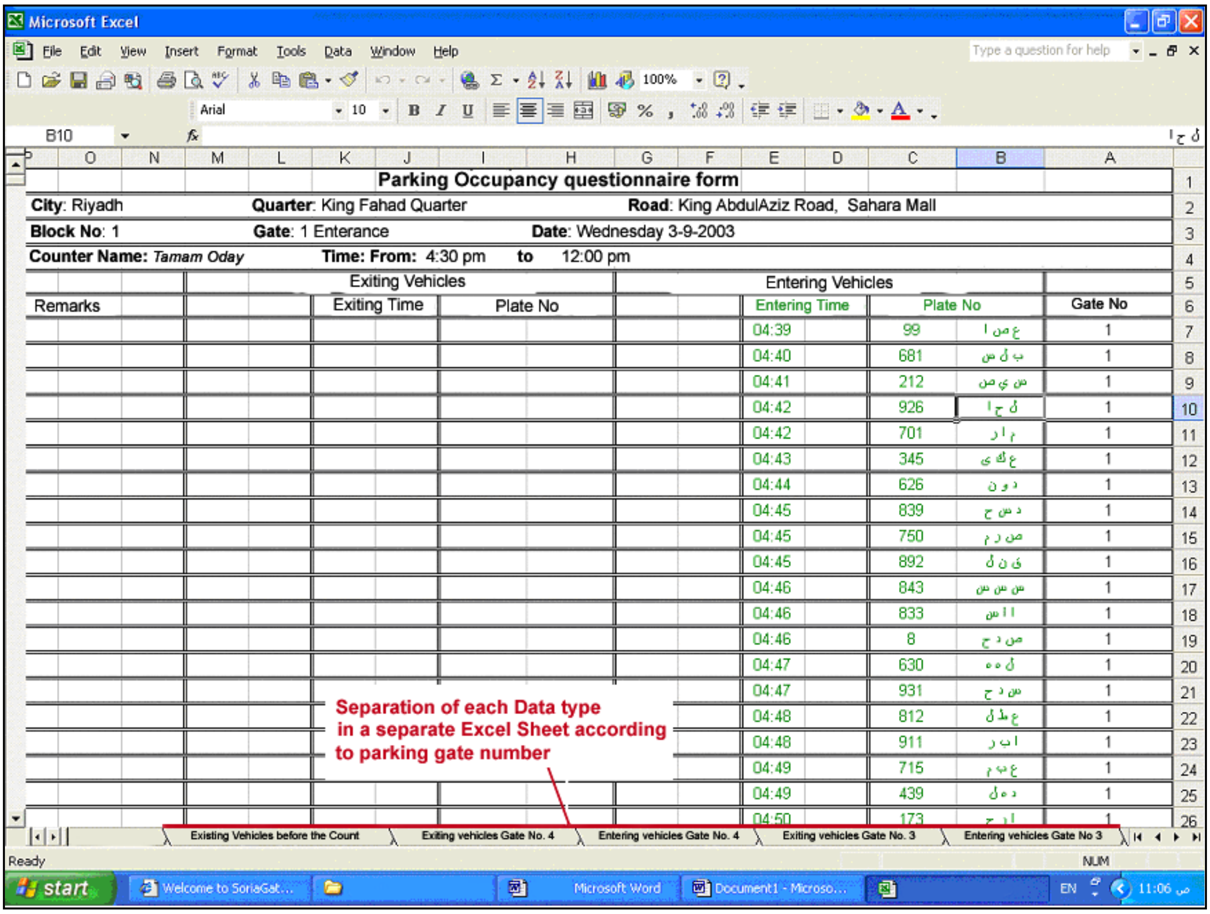


Figure-1: An Example of Data Separation for Each Type of Parking

2.4.2 Data Collection required for Parking Area Geometric Evaluation

Data required for geometric analysis of parking are collected using the FORM shown as Exhibit-2 attached in the appendix. The technical specifications included in this form are derived from the Parking Technical Specifications issued by the Ministry of Municipal and Rural Affairs.

Besides that, an engineering sketch for each type of parking should be prepared to illustrate the geometric details, which include:

- Shape and dimensions of parking spaces.
- Gates width, method of using them and their relation with streets around the parking areas.
- Routes dimensions and method of using them.
- Location of traffic signs, humps, concrete barriers…. (if any).
- Number and specifications of people with special needs' parking spaces if any, and the continuity of their paths from parking to the building' gates.
- Distance of gates of off-street parking from the nearest intersection and in the case of onstreet parking the distance of the start and end of parking spaces from the nearest intersection.

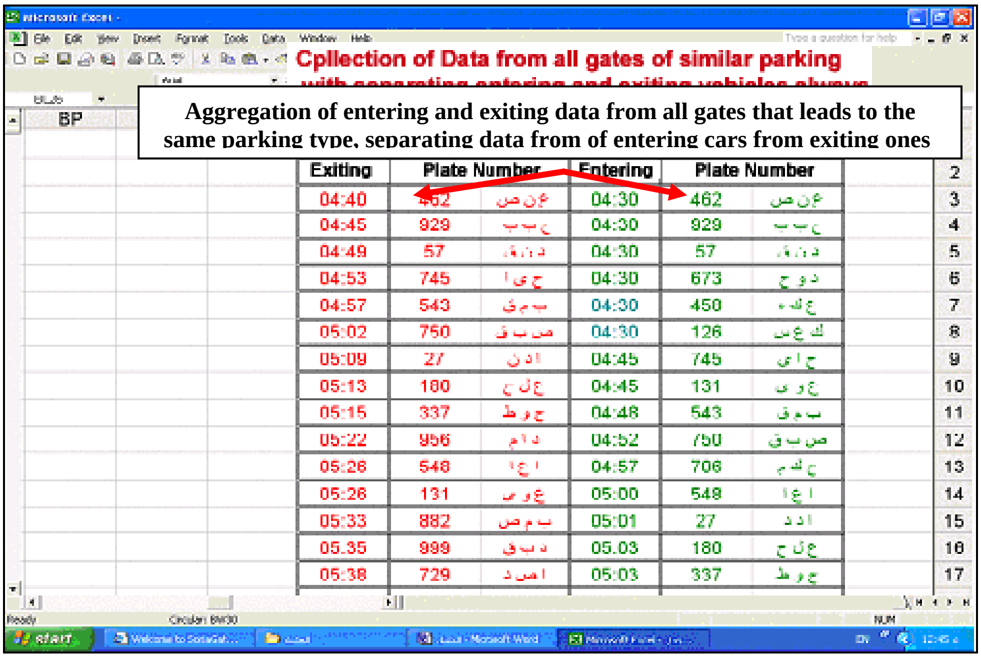
- Recording of various obstruction types, lighting conditions, relationship of off-road parking with the adjacent streets and buildings.

The data collected is then analyzed to evaluate the traffic and geometric conditions of the subject parking area.

2.5 Parking Traffic Evaluation Methodology

After traffic data is collected by using the form designed for this purpose, this data is processed by using Excel worksheet. MS Excel provides the facilities of relatively easy data processing and displaying. Entering data is done by using a digital form of Exhibit-1, which was used to collect parking traffic data. After entering the data of each gate separately (in a separate Excel worksheet as shown in Figure-1 above) in the case of off-street parking, the data is aggregated in one table (for each type of parking) considering:

- Separation between entering and exiting vehicles (each type has a side of the table as is the case in the form (Exhibit-1 in the Appendix).
- Separation between data of each parking type, i.e. this aggregation is applied on the data of the gates which lead to one type of parking (surface or garage or road-side parking) so that it becomes possible to analyze each type of parking individually to accurately identify parking pattern for each type of parking. In the case of roadside parking, all parking spaces located in each block are analyzed individually as a block (separately from other blocks) in order to obtain a detailed understanding of the relationship between parking pattern and the nearest serviced building (refer Figure -2).



Exiting	Plate Number		Entering	Plate Number		
04:40	462	ع ن ص	04:30	462	ع ن ص	3
04:45	929	ح ب ب	04:30	929	ح ب ب	4
04:49	57	د ن ة	04:30	57	د ن ة	5
04:53	745	ح ى ا	04:30	673	د و ح	6
04:57	543	ب م ق	04:30	450	ع ك ه	7
05:02	750	ص ب ق	04:30	126	ك ع س	8
05:09	27	ا د ن	04:45	745	ح ا ى	9
05:13	180	ع ل ح	04:45	131	ع و ى	10
05:15	337	ح و ط	04:48	543	ب م ق	11
05:22	956	د ا م	04:52	750	ص ب ق	12
05:26	548	ا ع ا	04:57	706	ح ك م	13
05:26	131	ع و س	05:00	548	ا ع ا	14
05:33	882	ب م ص	05:01	27	ا د د	15
05.35	999	د ب ق	05.03	180	ع ل ح	16
05:38	729	ا ص د	05:03	337	ح و ط	17

Figure-2: Aggregation of Entering and Exiting Data for the Same Parking Type

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A traffic analysis process for each parking type (or each block in case of on-street parking) is then undertaken as given below:

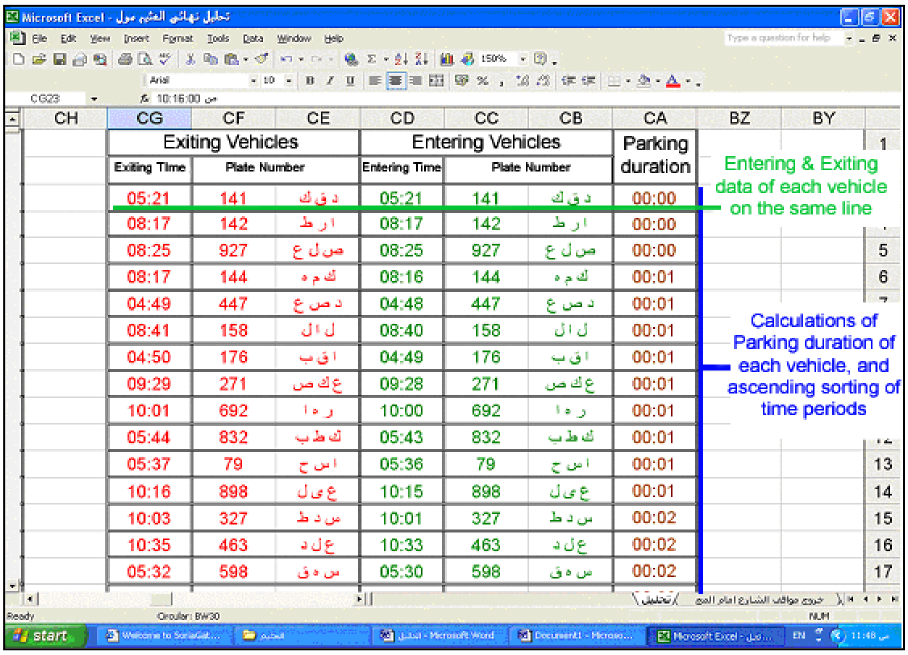
2.5.1 Analysis of Parking Durations

It is the period for which each vehicle is parked at a certain parking space. The mean parking duration is the amount of time that all vehicles are parked in the parking area during survey duration.

The nature of served landuse plays a major role in determining parking patterns. For example, employees' parking duration is long, while costumer parking duration varies. Data is processed to obtain parking duration for each vehicle by using the following steps:

1- Data arrangement and sorting such that entering data of each vehicle and its exiting data are on the same line (entering and exiting times in addition to identical data of registration plates) using Sort command. Then parking duration for each vehicle is automatically computed by subtracting entering time from exiting time (to be able to do that, entering and exiting times should be entered to Excel in a time format (for example 04:30) in separate columns, in order to enable the software to identify them as times, and consequently treat them as times not as numbers).

2- Arrangement of this data table in an ascending order according to the parking duration is shown in Figure-3.



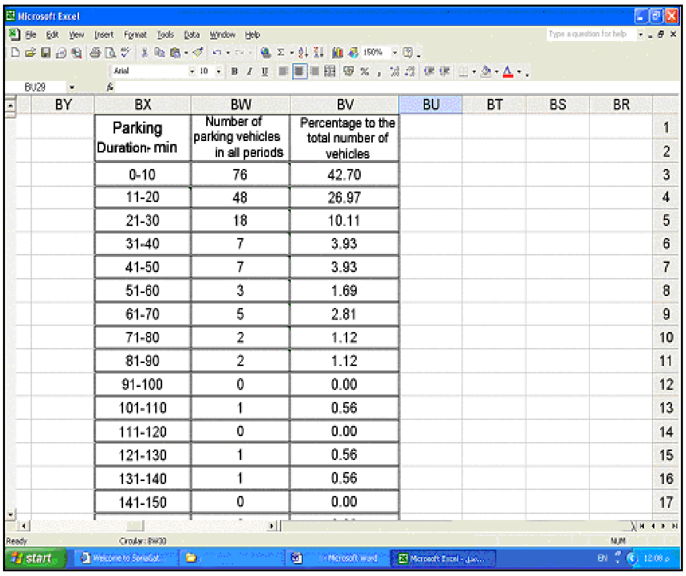
Exiting Vehicles			Entering Vehicles			Parking duration
Exiting Time	Plate Number		Entering Time	Plate Number		
05:21	141	د ق ك	05:21	141	د ق ك	00:00
08:17	142	ا ر ط	08:17	142	ا ر ط	00:00
08:25	927	ص ل ع	08:25	927	ص ل ع	00:00
08:17	144	ك م ه	08:16	144	ك م ه	00:01
04:49	447	د ص ع	04:48	447	د ص ع	00:01
08:41	158	ل ا ل	08:40	158	ل ا ل	00:01
04:50	176	ا ق ب	04:49	176	ا ق ب	00:01
09:29	271	ع ك ص	09:28	271	ع ك ص	00:01
10:01	692	ر ه ا	10:00	692	ر ه ا	00:01
05:44	832	ك ط ب	05:43	832	ك ط ب	00:01
05:37	79	ا س ح	05:36	79	ا س ح	00:01
10:16	898	ع ى ل	10:15	898	ع ى ل	00:01
10:03	327	س د ط	10:01	327	س د ط	00:02
10:35	463	ع ل د	10:33	463	ع ل د	00:02
05:32	598	س ه ق	05:30	598	س ه ق	00:02

Figure-3: Organizing and Sorting of Data for Each Parking Type to Calculate Parking Durations

3- After that, these parking durations are classified according to progressive time ranges of 10 minutes (0-10, 11-20, 21-30,…), then the number of vehicles for each time duration category is recorded together with the percentiles from the total number of parked vehicles (for each parking type, Figure-4).

Results of this step are represented in two graph charts, the first is for the number of parked vehicles for each time range (Figure-5) and the other is for the percentage of vehicles in each time range from the total number of parked vehicles during the count (Figure-6).

Also mean parking duration, parking periods' standard deviation and other statistical standards that describe parking durations' data are calculated automatically through Excel worksheets. This analysis enables us to evaluate parking patterns and the impact of parking periods on parking capacity during the count period in the subject site.



Parking Duration- min	Number of parking vehicles in all periods	Percentage to the total number of vehicles
0-10	76	42.70
11-20	48	26.97
21-30	18	10.11
31-40	7	3.93
41-50	7	3.93
51-60	3	1.69
61-70	5	2.81
71-80	2	1.12
81-90	2	1.12
91-100	0	0.00
101-110	1	0.56
111-120	0	0.00
121-130	1	0.56
131-140	1	0.56
141-150	0	0.00

Figure-4: Parking Durations and Vehicles Percentages per Each Time Range, for Each Type of Parking

Vehicles which are parked for less than 10 minutes in a parking are those which load and unload passengers without occupying a parking space, while parking for less than 30 minutes is considered as a short term parking. Medium duration parking is for periods between 30 to 60 minutes, and long duration parking is for periods which exceed 60 minutes.

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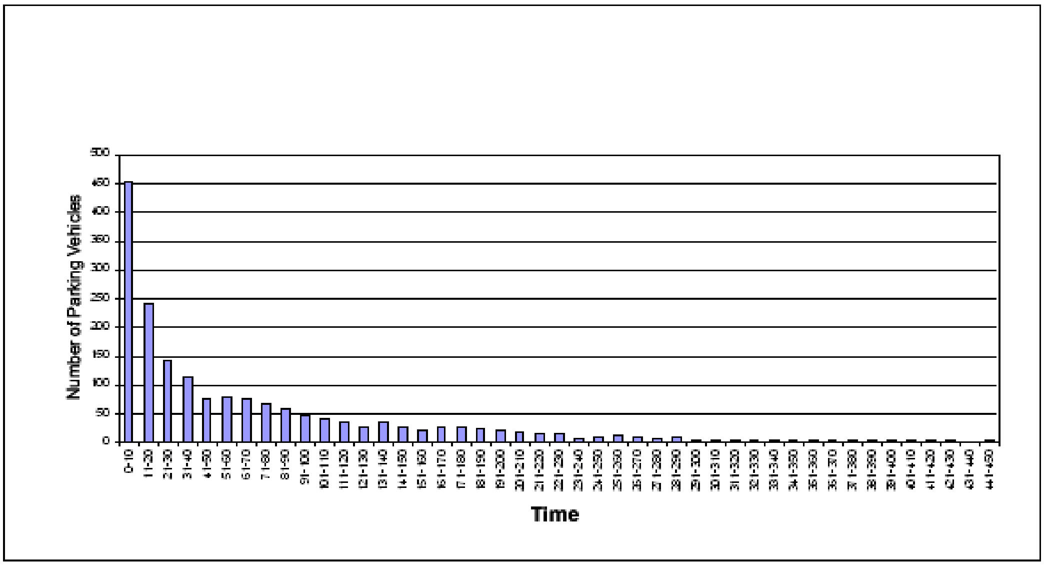

Figure-5: An Example of a Graphic Chart Showing the Number of Parked Vehicles in Each Time Range in One Type of Parking

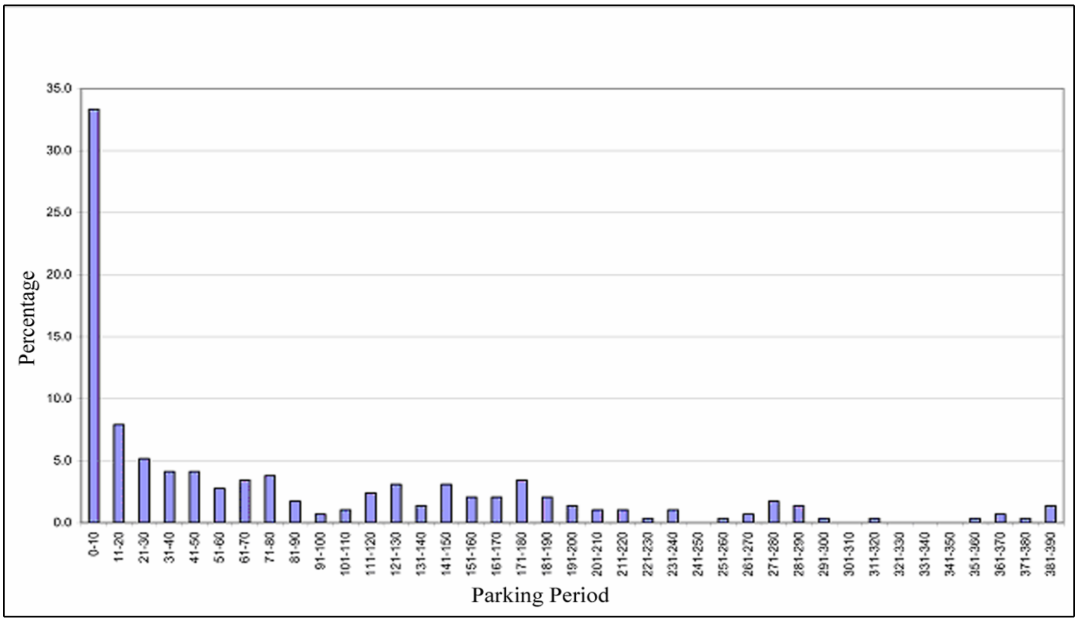

Figure-6: A graphic Chart Showing the Percentage of Vehicles in Each Time Range From the Total Number of Parked Vehicles, in one Type of Parking

2.5.2 Parking Occupancy Computation

The parking durations' tables arranged in an ascending order depending on parking durations, (from the table produced in step 2 in parking duration count, Figure -3) are used to undertake the following:

1- Omission of vehicles with less than 5 minutes parking periods, since these vehicles do not occupy parking spaces, but load or unload passengers (the vehicles which

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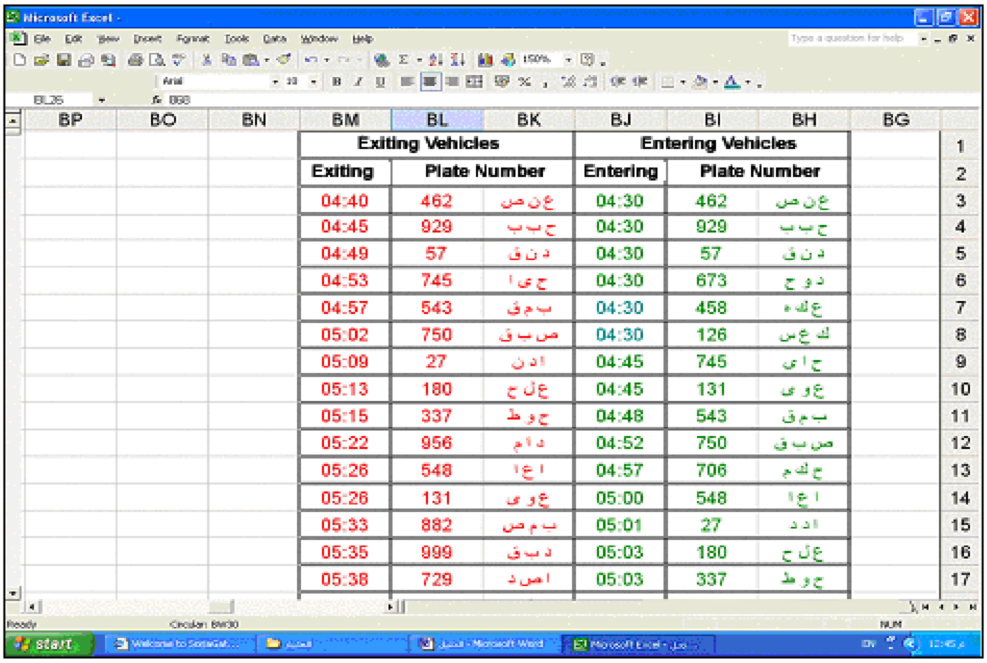
stop for less than 10 minutes period were not totally omitted to insure that results handle the greatest parking demand possible for the site).

2- In this step, processing of entering vehicles data and sorting them in an ascending order on the basis of entry time is undertaken, and the same also applies to exiting vehicles on the basis of exiting time (for data of each type of parking) as shown in Figure-7.



Exiting Vehicles			Entering Vehicles		
Exiting	Plate Number		Entering	Plate Number	
04:40	462	ع ن ص	04:30	462	ع ن ص
04:45	929	ح ب ب	04:30	929	ح ب ب
04:49	57	د ن ق	04:30	57	د ن ق
04:53	745	ح ى ا	04:30	673	د و ح
04:57	543	ب م ق	04:30	458	ع ك ه
05:02	750	ص ب ق	04:30	126	ك ع س
05:09	27	ا د ن	04:45	745	ح ا ى
05:13	180	ع ل ح	04:45	131	ع و ى
05:15	337	ح و ط	04:48	543	ب م ق
05:22	956	د ا م	04:52	750	ص ب ق
05:26	548	ا ع ا	04:57	706	ح ك م
05:26	131	ع و ى	05:00	548	ا ع ا
05:33	882	ب م ص	05:01	27	ا د د
05:35	999	د ب ق	05:03	180	ع ل ح
05:38	729	ا ص د	05:03	337	ح و ط

Figure-7: Sorting Entry Data in an Ascending Order on the Basis of Entry Time, then Exit Data on the Basis of Exiting Time, for each Type of Parking

3- Dividing the counting period into equal periods of 10 minutes, starting from the time the count starts, and ends with the count ending time. Each 10 minute period is represented by the mid-period time.

4- Computation of the number of vehicles entered and vehicles exited during each time period.

5- In this way, net parked vehicles are computed in each time period in the subject parking area for each 10 minutes period by subtracting the number of exiting vehicles from the number of entering vehicles during each time period.

6- Accumulatively adding the net numbers of parked vehicles (the accumulative number of parked vehicles in each period equals the net number of parked vehicles within that time period plus the total net numbers of parked vehicles in previous periods). It shall be noticed that the first value of this accumulative total is not zero, but it equals to the number of vehicles existed in the subject parking spaces before the start of the count (i.e. those vehicles are considered as if they entered at the start of counting) plus the number of vehicles which actually

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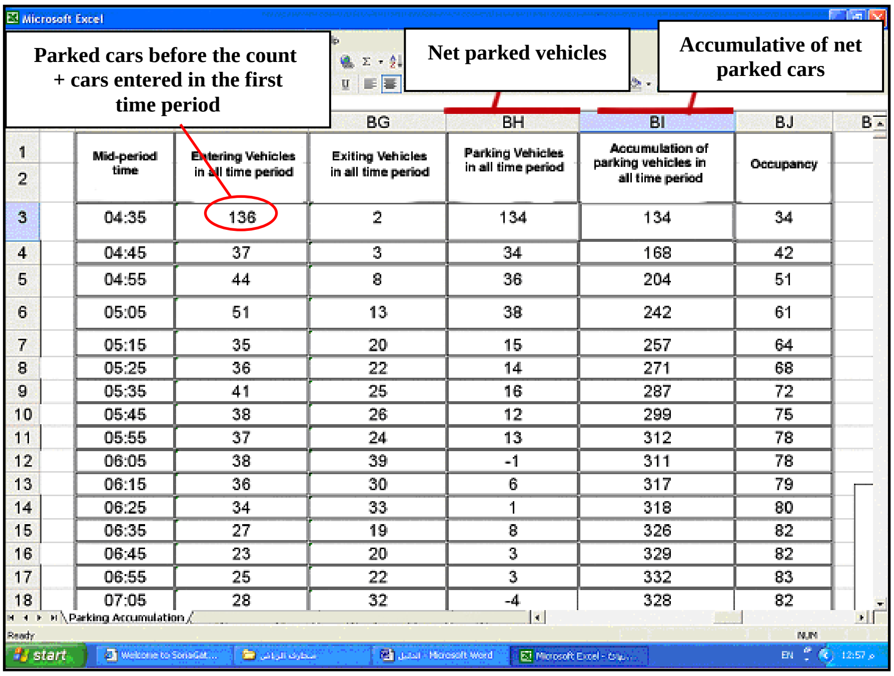
entered the parking in the first time period minus cars that exited in the same period (first one), (Figure-8). Also, the number of vehicles remaining in the parking after the counting period ends are considered as existed at the end of the count (added to the last value of vehicles exiting from parking as the number of vehicles which remained in parking after the end of the count) so the final value of occupancy is zero.

7- Occupancy for each time period is calculated by dividing the accumulative total for each time period over the available parking spaces (for each type of parking). The output is transferred into a percentage by multiplying by 100. The Occupancy results are graphically presented as percentages during each time period (Figure-9).



	Mid-period time	Entering Vehicles in all time period	Exiting Vehicles in all time period	Parking Vehicles in all time period	Accumulation of parking vehicles in all time period	Occupancy
3	04:35	136	2	134	134	34
4	04:45	37	3	34	168	42
5	04:55	44	8	36	204	51
6	05:05	51	13	38	242	61
7	05:15	35	20	15	257	64
8	05:25	36	22	14	271	68
9	05:35	41	25	16	287	72
10	05:45	38	26	12	299	75
11	05:55	37	24	13	312	78
12	06:05	38	39	-1	311	78
13	06:15	36	30	6	317	79
14	06:25	34	33	1	318	80
15	06:35	27	19	8	326	82
16	06:45	23	20	3	329	82
17	06:55	25	22	3	332	83
18	07:05	28	32	-4	328	82

Figure-8: Occupancy Calculation Table for Each Type of Parking

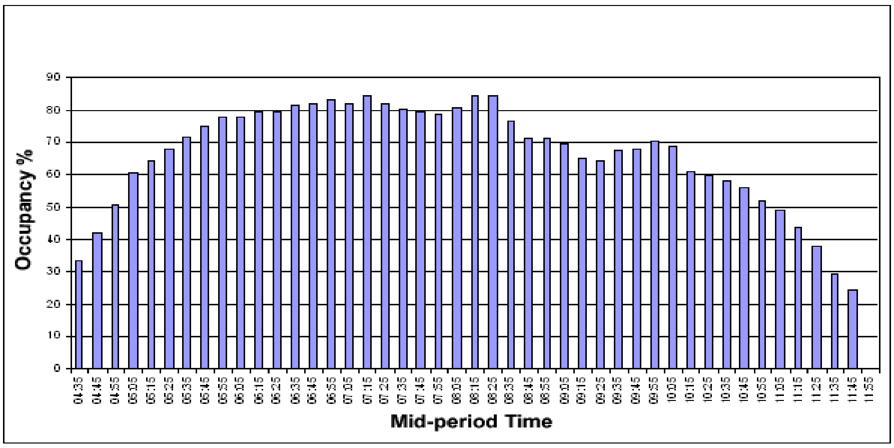


Figure-9: An example of Occupancy Rates for each Time Period, for one Type of Parking

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Occupancy is the percentage of the number of occupied parking spaces from the total available parking spaces in the subject parking area (for one type of parking). Maximum Occupancy value and timing of this value enable us to determine the maximum demand for parking at subject parking area and timing of this parking, which gives a more clear understanding of the parking usage.

Maximum allowed occupancy percentage is 90% (depending on the Effective Supply principle), which expresses that the parking has reached its maximum capacity. This is called the effective supply of parking. A 10% reduction is made in the parking capacity in consideration to the erroneous impression of parking users when the parking is congested, whereas no much effort is practiced by drivers in the process of seeking a space for parking their vehicles assuming that all parking spaces are occupied even if there are some empty parking spaces away from gates.

When the parking occupancy exceeds 90%, demand is assumed to be greater than the number of available parking spaces (supply). In this situation the possibility of increasing parking capacity shall be studied by making some modifications in the geometric conditions while maintaining parking specifications imposed by the Ministry for all parking elements, or by increasing the number of parking spaces available by allocating more off-street parking lots or on-street parking in the area.

The average occupancy value and the standard deviation of occupancy data and other statistical standards which describe parking occupancy data are computed by using Excel sheets.

2.5.3 Parking Turnover

Parking turnover is the number of different vehicles which are parked in one parking space during certain time period. Parking turnover is equal to the total number of different vehicles parked during the count period divided by the number of available parking spaces (for each type of parking).

Parking turnover for commercial centers' parking lots is generally higher than that for other landuses. Parking turnover usually varies from 1.1 to 1.2 for employees parking, while in shopping centers it may vary from 3 to 11 per day. In this way, one parking space serves one or two vehicles per day in the case of employees parking while it may serve 3 to 11 vehicles per day in markets.

This factor gives an idea about the frequency of one parking space usage by knowing the average number of times in which each parking space is used.

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2.5.4 Parking Capacity Compatible with Mean Parking Duration

It is the number of different vehicles which can park during the count time for a period equals to the mean parking duration in subject parking. It is calculated using the following equation:

Number of vehicles that can park in a parking = number of parking spaces x count period x *f* /mean parking duration.

Where *f* is the correction factor of the time loss during entering and exiting the parking, and it ranges from 0.85 to 0.95.

It gives an idea about parking capacity under current operational conditions for a time period equals to the count period.

This capacity, which is compatible with the mean parking duration, is compared with the total number of vehicles using the parking to verify whether parking demand exceeds parking capacity (Parking Supply) which reflect conditions and mechanism of its usage (considering mean parking duration in calculating this capacity).

If subject parking includes two or three types of parking, each type is separately evaluated by calculating parking durations, occupancy and other traffic factors. The final values of average parking durations, maximum occupancy, etc are calculated for the whole parking by taking the arithmetic averages of compatible values of these rates from the results of analysis of each type of parking.

2.6 Parking Geometric Condition Evaluation

Parking design is not limited to providing the maximum utilization of available space but also consider providing the parking process with the least number of maneuvers. In addition to safety considerations in the process of vehicle entering and exiting the parking area, provision of safe passage of pedestrians to the serviced landuses for all parking users is also considered. Geometric design principles of parking include the following:

- Provision of safe entry of vehicles to parking by providing deceleration lanes on highways, or service roads.
- Construction of entry/exit gates with dimensions compatible with the size of parking area and traffic volume using the gates.
- Provision of space required for maneuvering and parking within the parking lot.
- Provision of adequate parking space for vehicle to park with opened doors.
- Provision of safe access for pedestrians from/to serviced landuse.
- Provision of required space for vehicles to seek exits in off road parking.

- Provision of safe exit from off road parking to highways by providing acceleration lanes or service roads.

The approved reference for evaluating the geometric condition of parking are the Parking Technical specifications presented by the Ministry of Municipal and Rural Affairs. The geometric conditions of parking are compared with the minimum limits indicated in these specifications, which include:

- Minimum dimensions for perpendicular parking spaces are 2.5 meters width and 5.5 meters length.
- Minimum dimensions for parallel parking spaces are 2.5 meters width and 6.5 meters length.
- Minimum distance for gates is (in the case of on-street parking, the beginning and the end of parking spaces) 6 meters from secondary street intersections and 15 meters from main street intersections.
- Minimum limit for entry or exit gate width is 3.5 meters (7.5 meters with a separating island 0.5 meters width).
- Minimum limit for the width of one way route inside the off-street parking is 4.5 meters (two way 7.5 meters).
- At least 5% of the total area of parking (not less than 2 parking spaces) should be specified for people with special needs (disabled persons), specifications of these parking spaces and the continuity of their path to the gates of the serviced landuse are given in the specifications.

In case of off-street parking, a special lane is proposed for vehicles which stop for less than 10 minutes if the percentage of these cars exceeds 15% of total vehicles using the parking. In addition to that, a number of parking spaces are designed near the serviced landuse gates, so that these vehicles can load and unload people quickly without an obstruction for other cars that are looking for parking spaces. Construction of speed humps, marking pedestrian crossings and suitable lighting are basic issues in medium and large size off-street parking, to ensure the safety of pedestrians and other parking users.

Detailed geometric analysis for parking aims at evaluating the geometric condition and obtaining accurate information about parking spaces for on-street and off-street parking areas (surface parking or garages), and includes the following:

- Sufficiency of parking spaces after calculating parking maximum occupancy rate.
- Geometric condition of entrances including their dimensions, site and guidance signs.
- Routes for users and its dimensions.
- Parking spaces as to their types, dimensions, number, and requirements for people with special needs.

- Proposing special routes and parking spaces on the basis of the rate of vehicles which stop for less than 10 minutes.
- Distribution of guidance signs and walkways inside off-street parking.
- The geometric condition of garages including entry / exit gates and their other geometric conditions (grade, ramps, course surface ..)
- Type of control system in the parking lot if any (time restrictions or parking charges etc.)
- Taxis operation standards, if any
- Sight distance at intersections (in case the parking is adjacent to a main intersection).

The collected data is analyzed and compared with the Technical Specifications for Parking issued by the Ministry of Municipal and Rural Affairs. The proposed improvements are presented on a detailed sketch of the subject parking. Figure-10 shows an example for the resulting sketch.

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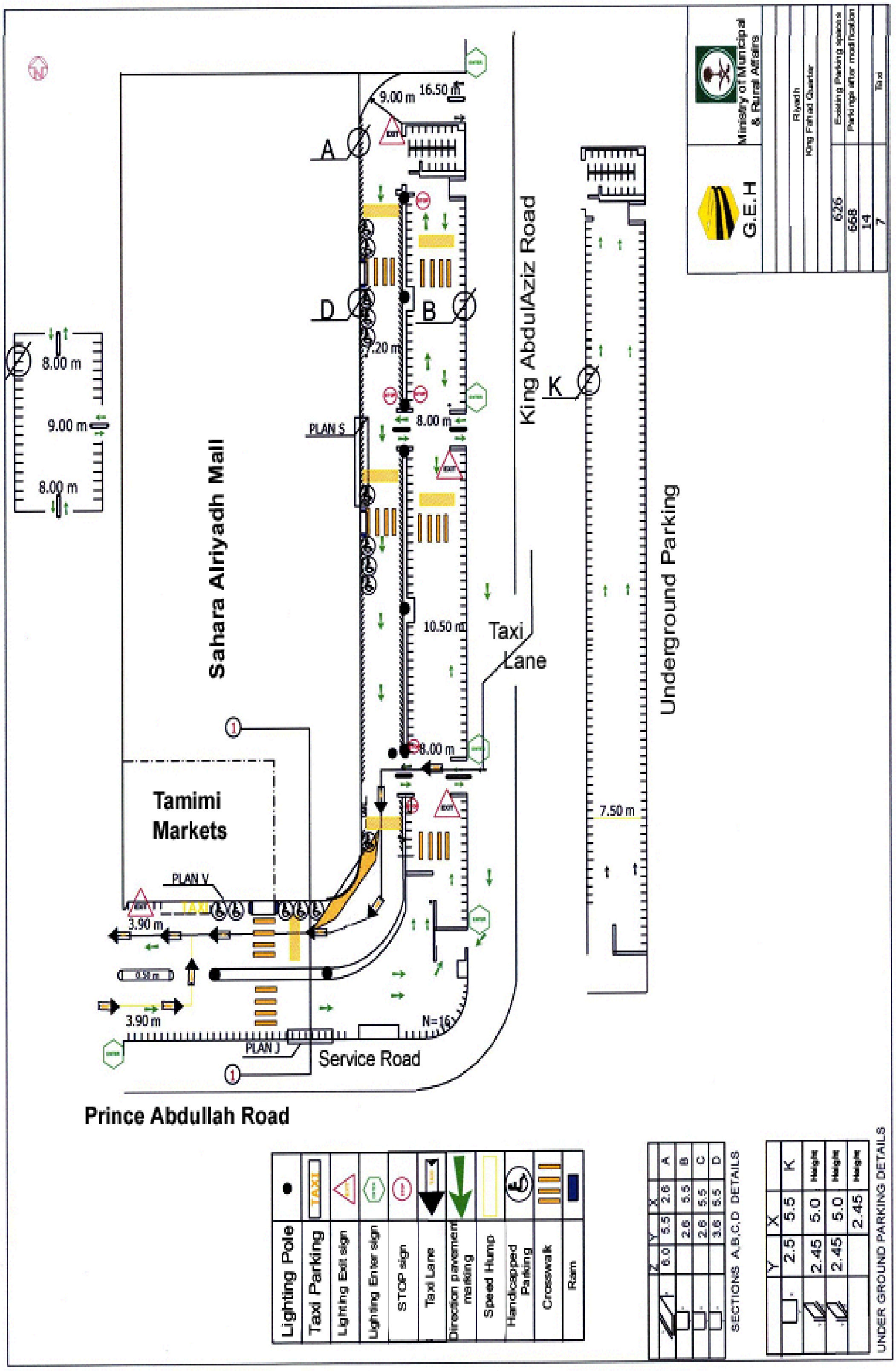

Figure-10: An Engineering Sketch for Off-street Parking Presenting a Number of Improvements

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3- Intersections Traffic Performance' Evaluation Methodology

3.1 Introduction

Road intersections are considered to be critical sites in any road system, since they represent a test for the success of available road system management on one hand, and for determining the road system capacity as a whole on the other hand.

Although intersections represent a small part of the road system as to their geographic extension, they have a great impact on this system. Since intersections with lower capacity than the road segment will be jammed and result in what is called "bottle neck", which will adversely affect the general performance of the road network by increasing delay times, travel times, and consequently reduce service levels over the whole system.

Intersections have special importance in urban areas due to many factors such as heavy morning and evening traffic volumes related to work trips and strong traffic volume imbalance on urban roads during peak times. In addition, there are also problems associated with spatial separation in urban intersections.

Therefore it is very important to evaluate urban area intersections on scientific basis, which enable us to make an accurate identification of problematic areas, and consequently take the possible measures to improve the performance of those intersections as far as possible. Intersections are classified into three categories:

- At-grade un-signalized intersections.
- At-grade signalized intersections.
- Grade separated interchanges.

The focus of this study is on at-grade signalized intersections. Within the scope of this study, traffic performance evaluation has been made for some intersections in cities included in the study. It was found that the current traffic conditions at most of the subject intersections witness low levels of service due to high delay times. This is due to high traffic volumes at the intersections, the lack of coordination between adjacent intersections, the weakness of the road system' management as a whole, the absence of comprehensive studies at city level to organize and manage transportation sector as a whole and to study transport-related issues.

Thus, most of the traffic studies are limited to the treatments for individual cases without a comprehensive strategic view that guides transportation planning and trouble shooting. Before handling the traffic evaluation methodology of urban intersections, it is essential to present a brief theoretical review on the most important aspects related conceptions and definitions.

3.2 Theoretical Review

3.2.1 Definitions

Cycle Length: Total time of traffic signal to complete a full cycle passing through all phases.

Phase: A portion of the cycle length that grants the right of passing for a group of movements at the same time during a specific period.

Change Interval: It is the yellow plus all red times that provides discharging all movements after the green of certain phase before starting green for the next conflicting movements or pedestrians.

Green Time: Phase time in which the signal is green (G).

Lost Time: This is the time in which the intersection is inactivated or effectively used by any movement. It occurs during change interval between phases (evacuation time) and during the beginning of each phase (delay time during take off).

Effective Green Time: It is the time during which certain phase is effectively used by certain movement of traffic. It is normally taken as green time plus the change interval minus the lost time.

Lane Group: Lanes in each approach can be divided into groups of lanes which contain lanes designated for turning movements (right or left), lanes for combined straight movements and turning movements or only straight movements. Every lane group moves together within the same phase.

3.2.2 Traffic Signal Types

1- **Pre-timed Signals:** In which green, change interval, and red times alternate in a periodical and fixed cycle and their values are pre-determined.

2- **Semi-actuated Signals:** Give green time continuously for the main road except when a demand for green time is made on the minor road by special detectors placed on it.

3- **Fully-actuated Signals:** All traffic signal phases are controlled by detectors placed on all approaches.

4- **Central computer-controlled Signal:** In which the signal programs are coordinated with the nearby signals according to a central controlled program depending on data obtained from the detectors spread on road network.

This study deals with pre-timed traffic signals. It is possible to follow the same methodology with other signal types after collecting the required data. If the signals

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are fully or partially actuated it is possible to collect field measures for various signal cycles and use the average value to perform the evaluation.

3.2.3 Capacity

It is the maximum number of vehicles which may pass certain intersection under the prevailing traffic and road conditions during a time period of one hour. The capacity is calculated for each lane group (lanes designated for through, right, left or combined movements), for each approach, and then for the intersection as a whole. The capacity of the intersection is affected by the following factors:

- **Intersection geometric conditions, including:**
  - Nature of area (city center, other areas)
  - Number of lanes on each approach
  - Lane width
  - Grade of each approach
  - Existence of lanes designated for turning left or right
  - Length of storage bays, and
  - Vehicles parking conditions.

- **Intersection Traffic Conditions, including:**
  - Directional traffic volumes
  - Ideal saturation flow
  - Peak Hour Factor (PHF)
  - Heavy vehicles percentage in the traffic flow
  - Conflicting pedestrian volumes
  - Public transportation stops at intersections
  - Form of vehicle arrival at intersection
  - Rate of vehicles which arrive during green time, and
  - Speed.

- **Traffic Signal Conditions, including:**
  - Cycle length
  - Green time
  - Yellow change interval
  - All red time
  - Type of the signal (pre-time or traffic actuated)
  - Pedestrians push buttons
  - Minimum pedestrian's green interval
  - Phase sequence, and
  - Analysis period

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3.2.4 Level of Service

The level of Service depends on the criterion of the average delay time of the signalized intersection resulting from vehicles stopped during red phase of traffic signals. It is calculated for each lane group, approach and for the intersection as a whole. Level of service is the basic evaluation standard internationally used for signalized intersections. There are several levels of service with the following progression:

Service level	Equivalent delay time average (Sec./vehicle)
A	≤ 10
B	>10 – 20
C	> 20 – 35
D	> 35 – 55
E	> 55 – 80
F	> 80

Source: HCM 2000

3.2.5 Theoretical Basis of Intersection Performance Evaluation Methodology

The Highway Capacity Manual (HCM) 2000 is considered as the first and most widespread reference in studies related to intersection traffic performance evaluation and the most comprehensive and integrated manual as related to various traffic subjects. It was developed gradually in USA, and was adopted by many countries throughout the world as an approved guide for the design and evaluation of traffic aspects of roads and streets.

Basically, HCM uses the following formula in the process of analyzing traffic performance of signalized intersections to calculate the adjusted flow:

$$S = S_o . N. f_w . f_{hv} . f_g . f_p . f_{bb} . f_a . f_{lu} . f_{lt} . f_{rt} . f_{lpb} . f_{rpb}$$

Whereas:

- S: Adjusted flow
- S_o: Ideal saturation flow
- N: Number of lanes
- f_w: Lane width adjustment factor
- f_{hv}: Heavy vehicle adjustment factor
- f_g: Grade adjustment factor
- f_p: Parking adjustment factor
- f_{bb}: Bus stop adjustment factor
- f_{lu}: Lane utilization adjustment factor
- f_a: Area type adjustment factor
- f_{lt}: Left turn adjustment factor

f_{rt}: Right turn adjustment factor
f_{lpb}: Pedestrian left turn adjustment factor, and
f_{rpb}: Pedestrian right turn adjustment factor

HCM 2000 derives the values of the above adjustment factors from special tables and equations depending on the intersection's geometry and traffic conditions together with traffic signal conditions. After that, capacity and the ratio of traffic volume to capacity are calculated to obtain loading rate for each lane group, then delay times and levels of service are calculated for each group of lanes, approach and finally for the intersection as a whole. Figure-11 shows the theoretical methodology applied in the evaluation of signalized intersections performance according to HCM 2000.

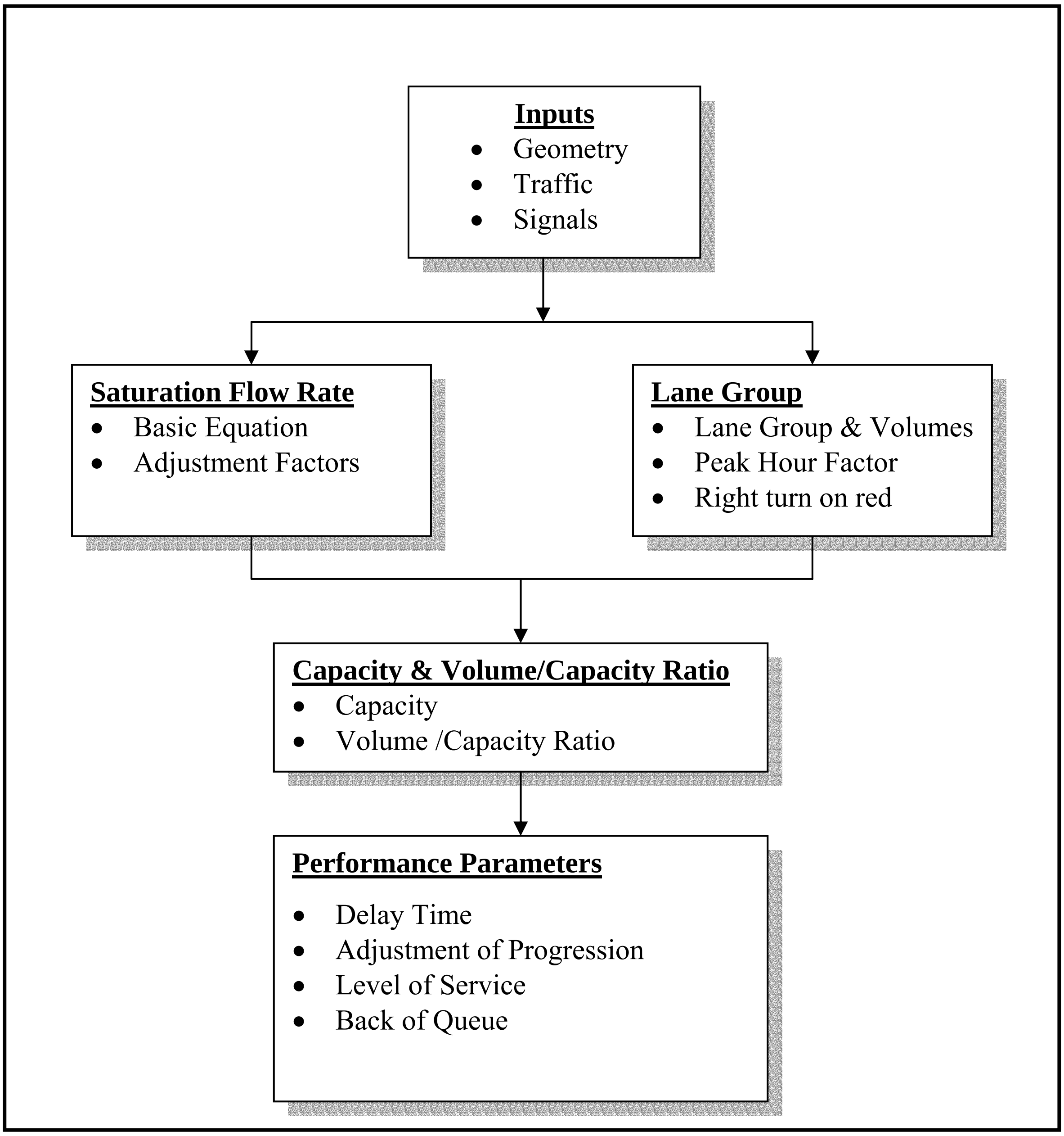

Figure-11: HCM Traffic Performance Evaluation Methodology for Signalized Intersections

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3.3 Traffic Performance Evaluation Methodology for Signalized Intersections

There are various software which implement the evaluation methodology applied in HCM. These software differ from each other in adopting some research results related to one of the aspects handled by HCM to be closer to the field values of delay times or to enhance the program performance in the direction of certain type of studies or to perform advanced functions. Therefore, there are differences which might be marginal or major in the results of these software arising from the amendments incorporated in equations and factors used in calculating the adjusted flow and delay times for the purpose of developing the calculation methodology for those factors on one hand and to designate the software for certain type of traffic analysis, or even amending it so that it may contain factors which reflect local traffic conditions of certain country.

HCM, Sidra, and Synchro-5 are some of most popular software used for signalized intersections**.** This study chooses one of the software in order to establish a methodology for evaluating intersections' traffic performance. These software need validation, calibration, and adjustment of some of their parameters before approving any of them as an official analysis and evaluation tool. Validation and calibration ensure that local traffic conditions are reflected in the calculations made by the software.

Synchro-5 software has been chosen in this study. It is a software package that evaluates the current traffic performance of intersections and proposes traffic solutions on the basis of adjustments suggested by either the software or the user. These adjustments include changes in signal programs, phase sequence and/or traffic designation on lanes.

This program has been chosen because it is characterized, besides being widely used as a tool for evaluating intersections traffic performance, by its easiness. It allows the analyst to enter inputs through friendly interfaces. It includes analysis processes depending on various methods, and gives clear and quick output reports. In addition to that it provides the opportunity of performing simulation processes for the existing situation and solution alternatives.

The software allows adjusting traffic and signal conditions without changing the geometric conditions of the intersection. The software does not provide solutions which depend on spatial separation between different conflicting flows of traffic in the intersection such as the construction of a bridge or tunnel. Decisions about solutions are made by the traffic engineer who carries out the analysis according to factors which will be mentioned later.

The traffic performance evaluation process depends on calculating Level of Service (LOS) on the basis of delay time calculation for each group of lanes, approaches, then the intersection as a whole.

3.3.1 Synchro-5 Data Entry Windows

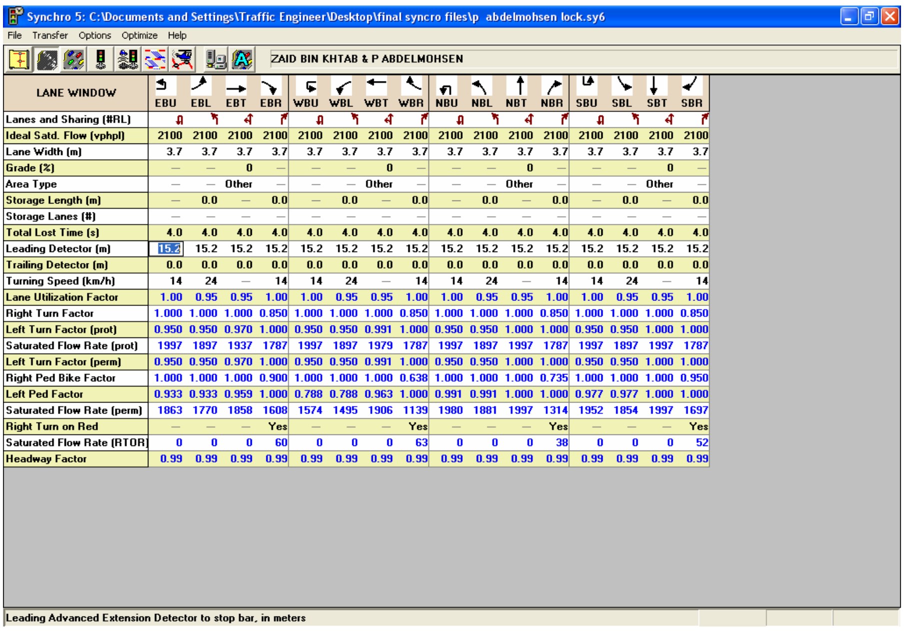
Data which is required by the software to perform the evaluation are entered through a number of windows. Each data type is entered in a separate window. These data include:

3.3.1.1 Geometric Inputs

These include:

- Number of lanes for each lane group
- Lane width
- Grade of each approach
- Area type
- length and number of storage bays
- Link distance
- Link speed, and
- Travel lanes

The geometric data are obtained through direct inspection and measurements at site or by taking measurements from location maps with accepted accuracy. Figure-12 shows an example of the geometric inputs' entry window.



LANE WINDOW	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBU	NBL	NBT	NBR	SBU	SBL	SBT	SBR
Lanes and Sharing (#RL)																
Ideal Satd. Flow (vphpl)	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100
Lane Width (m)	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Grade (%)	—	—	0	—	—	—	0	—	—	—	0	—	—	—	0	—
Area Type	—	—	Other	—	—	—	Other	—	—	—	Other	—	—	—	Other	—
Storage Length (m)	—	0.0	—	0.0	—	0.0	—	0.0	—	0.0	—	0.0	—	0.0	—	0.0
Storage Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total Lost Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Leading Detector (m)	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
Trailing Detector (m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turning Speed (km/h)	14	24	—	14	14	24	—	14	14	24	—	14	14	24	—	14
Lane Utilization Factor	1.00	0.95	0.95	1.00	1.00	0.95	0.95	1.00	1.00	0.95	0.95	1.00	1.00	0.95	0.95	1.00
Right Turn Factor	1.000	1.000	1.000	0.850	1.000	1.000	1.000	0.850	1.000	1.000	1.000	0.850	1.000	1.000	1.000	0.850
Left Turn Factor (prot)	0.950	0.950	0.970	1.000	0.950	0.950	0.991	1.000	0.950	0.950	1.000	1.000	0.950	0.950	1.000	1.000
Saturated Flow Rate (prot)	1997	1897	1937	1787	1997	1897	1979	1787	1997	1897	1997	1787	1997	1897	1997	1787
Left Turn Factor (perm)	0.950	0.950	0.970	1.000	0.950	0.950	0.991	1.000	0.950	0.950	1.000	1.000	0.950	0.950	1.000	1.000
Right Ped Bike Factor	1.000	1.000	1.000	0.900	1.000	1.000	1.000	0.638	1.000	1.000	1.000	0.735	1.000	1.000	1.000	0.950
Left Ped Factor	0.933	0.933	0.959	1.000	0.788	0.788	0.963	1.000	0.991	0.991	1.000	1.000	0.977	0.977	1.000	1.000
Saturated Flow Rate (perm)	1863	1770	1858	1608	1574	1495	1906	1139	1980	1881	1997	1314	1952	1854	1997	1697
Right Turn on Red	—	—	—	Yes	—	—	—	Yes	—	—	—	Yes	—	—	—	Yes
Saturated Flow Rate (RTOR)	0	0	0	60	0	0	0	63	0	0	0	38	0	0	0	52
Headway Factor	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Figure-12: An Example of the Geometric Inputs Entry Window

3.3.1.2 Traffic Inputs

These inputs include:

- Ideal saturation flow rate
- Directional traffic volumes
- Conflicting pedestrians
- Peak Hour Factor
- Adjusted flow
- Traffic growth factor
- Heavy vehicles percentage in the traffic flow
- Bus blockage percentage in the traffic flow, and
- Adjacent parking lane and number of required maneuvers

Traffic data are obtained by direct traffic counting or video recording during peak periods which occur for work trips in the morning when people go to work and evening when they return. Also, this applies for night time congestion related to shopping trips. Traffic data are obtained by automatic counter if available.

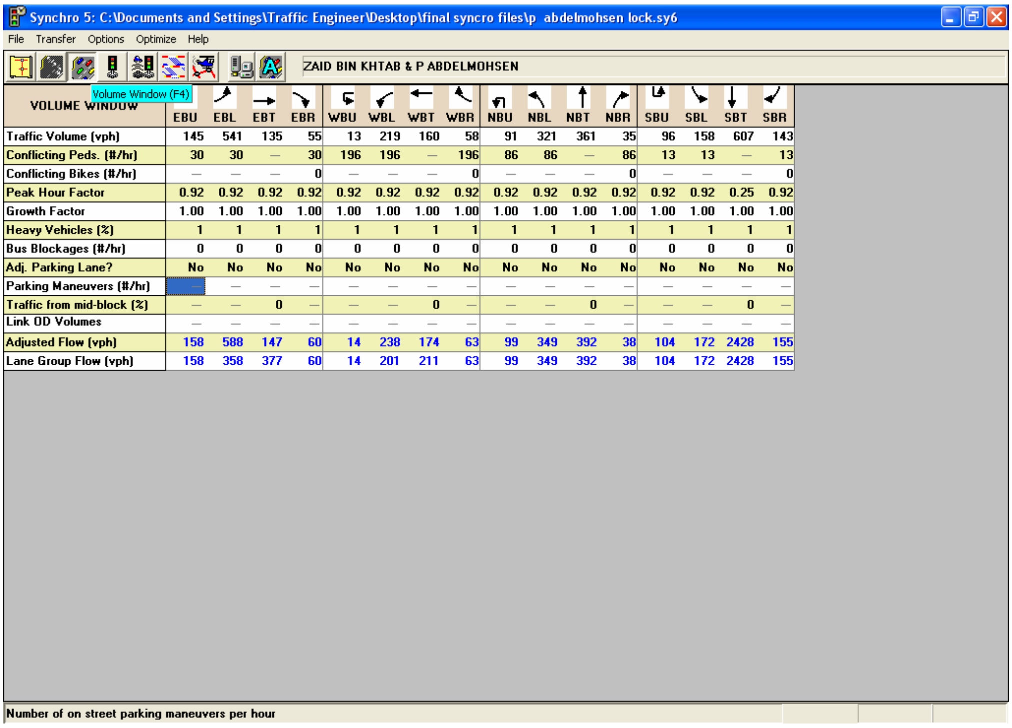
After the video recording is finished, a manual count is performed for vehicles passing through each approach for every 15 minutes using recorded films. After that the peak hour of the intersection as a whole is determined. This peak hour is the hour during which the maximum number of vehicles crosses the intersection from all approaches (to determine the greatest traffic volumes on all approaches).

After determining the intersection peak time a manual classified count is carried out using the recorded films to obtain directional traffic volumes, the rate of heavy vehicles and buses during the peak hour (their ratio to the total traffic volume for each group of lanes). Pedestrian volume counting is carried out by manual counting in the hour that coincides with peak hour on the subject intersection. Figure-13 shows an example of traffic inputs' entry window.

3.3.1.3 Signal and Phase Inputs

These inputs are related to cycle length, time separation, controllers, and detectors. They include:

- Phase Templates
- Controller type
- Cycle length
- Traffic volumes



VOLUME WINDOW	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBU	NBL	NBT	NBR	SBU	SBL	SBT	SBR
Traffic Volume (vph)	145	541	135	55	13	219	160	58	91	321	361	35	96	158	607	143
Conflicting Peds. (#/hr)	30	30	—	30	196	196	—	196	86	86	—	86	13	13	—	13
Conflicting Bikes (#/hr)	—	—	—	0	—	—	—	0	—	—	—	0	—	—	—	0
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.25	0.92
Growth Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Heavy Vehicles (%)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Adj. Parking Lane?	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Parking Maneuvers (#/hr)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Traffic from mid-block (%)	—	—	0	—	—	—	0	—	—	—	0	—	—	—	0	—
Link OD Volumes	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Adjusted Flow (vph)	158	588	147	60	14	238	174	63	99	349	392	38	104	172	2428	155
Lane Group Flow (vph)	158	358	377	60	14	201	211	63	99	349	392	38	104	172	2428	155

Figure-13: An Example of the Traffic Inputs Entry Window

- Turn type
- Total split time
- Yellow time
- All-Red Time, and
- Pedestrian phase

Traffic signal timings are measured by normal stop watch. The remaining traffic data such as pedestrian volume, number of maneuver movements for parking vehicle and designation of lane groups are directly collected from the site (during the peak time). Figure-14 shows an example of Traffic signals input window.

Synchro-5 can carry out an actual simulation of the site through operating SimTraffic program which comprises a part of Synchro-5 software, such that the former uses the inputs of the later and performs a simulation that assists the engineer in evaluating the solution visually on the computer. Figure-15 shows an example of SimTraffic simulation animation process.

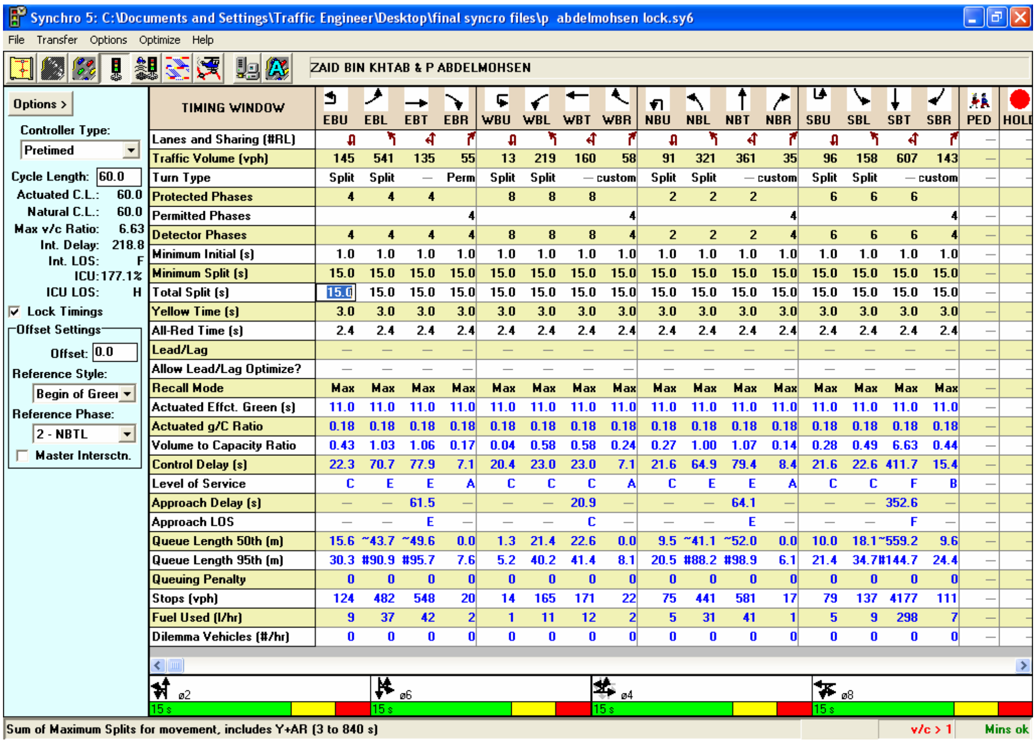


Figure-14: An Example of Traffic Signals Input Window

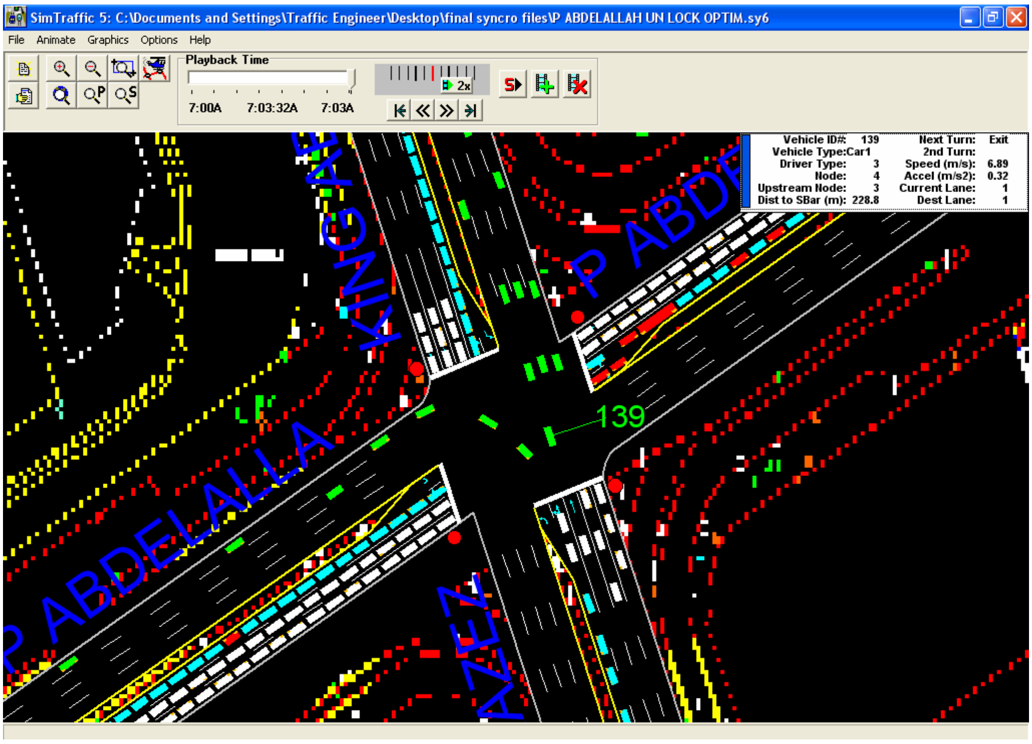


Figure-15: A sample of Intersection Simulation Animation by SimTraffic

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3.3.2 Traffic Performance Evaluation

Synchro-5 uses the data entered to calculate delay times and determine levels of services that are required to evaluate intersection performance.

The internationally approved standard for evaluating intersection performance which the study has applied is the intersection level of service on the basis of the average control delay time of vehicles crossing the intersection.

Each level of service corresponds to a range of average delay time for each vehicle that uses the intersection, as shown in the following table:

Level of Service	Corresponding delay time average (sec./vehicle)
A	≤ 10
B	> 10-20
C	> 20-35
D	> 35-55
E	> 55-80
F	> 80

The aim of improving intersection performance is to raise the level of service to at least level of service D (preferably C) since levels E and F express long delay times associated with long vehicle queues and very low speeds of vehicle interfered with a lot of stops.

The software performs traffic performance evaluation for intersections through three levels of evaluations:

1- Traffic performance evaluation for each lane group: By calculating average delay times and determining level of service for each lane group.

2- Traffic performance evaluation for each approach: Calculation of average delay times and determining level of service for each approach.

3- Traffic performance evaluation of the whole intersection: Calculation of average delay times and determining the level of service for the intersection as a whole.

This process enables the analyst to perform his analysis at many levels starting from the total evaluation of service level of the intersection as a whole, to reach the accurate identification of delay positions on the intersection on the level of lane groups, and consequently directing the solution alternatives towards the lanes or

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approaches which suffer from high delay times without wasting efforts by focusing on lane groups which have low delays.

3.3.3 Alternatives Evaluation

Determining the level of service for an intersection is not a difficult task if the required inputs are available for running the software package used in the evaluation. But the difficulty is in identifying suitable solutions which are capable of improving the performance of the subject intersection.

This can be done by choosing the most effective solutions on the worst approaches (or even the worst lane groups) according to the level of service. Some solutions may raise the service level on some lane groups without affecting the total level of service on the intersection as a whole which proves their meager effectiveness due to their unsuitability or as a result of high traffic volumes on more than one approach in the intersection.

The solution alternatives suggestion is a process which requires an engineering sense from the traffic engineer, so he shall be capable of understanding the intersection conditions and comprehend the problems on it logically. He shall accurately identify problematic zones in the intersection on one hand, and fully comprehend the effects of each of the solution alternatives on areas adjacent to the intersection and types of land uses on the other hand. In other words, when the analyst is suggesting solutions, he shall consider the mutual and varied effects between the intersection and the surrounding areas and activities without separating the intersection from the environment directly surrounding it.

Generally, it is possible to classify the possible solutions to improve the traffic performance of intersections into simple low-cost solutions, and complex high-cost solutions.

The software deals with simple traffic solutions according to ready scenarios provided by the software or solutions suggested by the analyst. The analyst can experiment with a wide range of traffic solution alternatives and evaluate their effectiveness in improving the traffic performance of the subject intersection such as:

- **Optimization of Phase Times**: In case the phase times were not proportionate with their traffic volumes, cycle can be kept fixed and time is redistributed among phases.
- **Adjustment of Cycle Length:** In case of increased traffic volumes in one or more approaches on a traffic signal with a short cycle, in such case the cycle length is increased and the phases are re-distributed in proportion with traffic volumes.

- **Changing Phase Intervals Sequence:** When the sequence of phases differs between morning peak and evening peak to give priority for green times in the traffic signal for approaches with higher traffic volumes which alternate in times of morning and evening peaks on one hand, and on the other, to consider coordination with adjacent intersections, if any (coordination between adjacent intersections - green wave- to pass greater traffic volumes). The wave differs according to the difference of direction and peak times.
- **Proposing New Phases to Serve Certain Turn Movement with relatively High Traffic Volume:** In case one of the turning movements is of a relatively high directional traffic volume without exclusive phase, in this case an exclusive phase shall be allocated for this turning movement proportionate with the directional traffic volume on it (mostly a left turn).
- **Redistribution of lane groups in conformity with directional traffic volumes:** Designating traffic lanes suitably with directional traffic volumes facilitates discharging of movements with higher directional traffic volumes, because this reduces interruption of remaining traffic movements and facilitates the process of designating phases.
- **Channelization:** Placing ground delineators or directional islands which help in guiding drivers and decreasing confusion when they cross the intersection and consequently reducing conflicts between drivers of various traffic movements.
- **Addition of storage lanes for some turning movements without the need to confiscate lands adjacent to the intersection:** Allows additional capacity to accommodate the turning movement. Also, it enables this movement to share in the green time for a non-conflicting phase on another approach. This means quick discharging of this movement and consequently lesser delay times.
- **Updating traffic control devices:** Depending on more advanced systems in operating traffic signals which allow more flexibility in the distribution of priorities and more adaptation with the daily changes of traffic volumes using the intersections.
- **Coordination between intersections:** Linking adjacent intersections or those lying on the same axis with each other by using the green wave principle or linking their traffic signals with modern control systems which allow for effective coordination between those intersections such that they ensure reduction of delay times and consequently improve the level of service of the subject corridor (this is done through a comprehensive study for corridor that contains a number of intersections).

In case, simple traffic solutions do not succeed and are not effective in improving traffic performance of the intersection, measures of improvement shall be diverted to complex solutions which require constructional work. The software does not handle these kinds of solutions. They include:

- Expanding the intersection by confiscating adjacent property.
- Grade separation between conflicting movements by constructing bridges or tunnels.

These solutions are applied at the intersections with high traffic volumes on all approaches of the intersection, which suffer from increased delay times and reduced levels of service. This situation results in a difficulty in time separation between all conflicting movements. These complex solutions need special feasibility studies.

It is not possible to lay down a decisive methodology for acquiring solution for a specific intersection since such a process is greatly affected by many factors which interfere in the solution selection process. Those factors include the following:

- The present situation of traffic and signal conditions. Traffic properties and present signals have a role in suggesting simple alternative solutions.
- Alternative solution costs may play a major role in applying one simple solution although this solution does not improve traffic performance in the same level as the complex solutions.
- Intersection site plays an important role in selecting solutions. If the intersection is inside a city, in which simple solutions were of no use in improving performance, then it is possible to think of widening the intersection or constructing a bridge or tunnel to provide crossing of some high traffic volume movements. But during this we shall think carefully in the possibility (and cost) of expropriating land properties adjacent to the intersection on the purpose of executing the project. Also, the impact of such project on adjacent areas plus types of land uses with infrastructure projects should be considered, due to the major effect of transportation on the neighboring human populations and activities.
- Some solutions may be difficult to execute particularly those which require a change in the engineering situation of the intersection due to technical reasons. Those obstructions might be the presence of a highly concentrated and sensitive infrastructure in the area (water supply lines, electric power extensions or communication lines, high tension wires, presence of some sensitive structures near the intersection).
- The existence of certain transportation or traffic policy adopted by the authorities who manage transportation and traffic that automatically omit some suitable solutions. For example, being unconvinced with roundabouts, or two level separation, or even policies on the country level which encourages alternative types of transportation which do not depend on private vehicles. Also the lack of funding of bridges and tunnels construction projects to solve traffic problems, and transfer funds for constructing modern public transportation infrastructure or promotion for environment - friendly transportation programs.

In conclusion, it is necessary, when proposing solutions to improve the traffic performance of certain intersection, to refrain from isolating it from all its surrounding conditions. Also, to present solutions with consideration to various technical effects and applied policies through accurate detail studies for the condition of each intersection.

Synchro-5 can be used to evaluate simple traffic solutions only, since this type of software, does not handle complex constructional solutions.

4- Traffic Safety Improvement Methodology in Urban Areas

4.1 Introduction

There is a prevalent triangular relationship in the field of traffic safety, which includes the road user, the road itself and the vehicles. This relationship is a traffic accident producer even if the effect of each of the three factors differs. There is no doubt that the role of roads in the occurrence of accidents has not been studied deeply enough in the kingdom due to poor recording of traffic accident statistics, and lack of technical experience in investigating accidents.

However, specialized studies and international experience always confirm the role of the road in accident occurrence to the extent that the most famous road design manual AASHTO, 2001 emphasizes the conception of "Forgiving Highways" confirming the role of road engineers in making the road environment forgiving to the mistakes of drivers such that traffic safety specifications are incorporated in all engineering elements of the road. Those elements either assist the driver in avoiding the accident or at least reduce the severity of collision.

For example, clear vision of fixed objects in the roadside reduces the risk of colliding with a fixed object and consequently the danger of accident. Breakable signs, service and advertisement posts in the roadsides reduce the damage arising from colliding with them if the driver loses control on his vehicle. Adequate sight distance at the intersection which is not signalized or controlled by a stop sign gives the driver ample time to avoid colliding with conflicting vehicles.

There are many geometric arrangements for traffic safety improvement and their scopes may be classified as:

- **Roads engineering design:** Road geometric elements such as sight distance, road widths, shoulder width etc.
- **Geometric design of road sides:** Side protection, keeping the area free from fixed objects such as trees, sign post specifications, and walkways.
- **Design of traffic control devices:** Traffic signals and their operation, traffic signs including their location and clarity, warning and alarm by distinct signs.

It is worth mentioning that determination of the problem may require quantitative analysis for speeds, signal times etc, besides field visual inspection. Also, treatment requirements neither are necessarily ready solutions nor come as one integrated methodology but they are a set of guidelines and standards which can be customized. The solutions may be in the form of detailed engineering studies according to nature of the specific problem and its complexity due to the variety of factors affecting traffic safety in urban areas.

Due to the proportionate relationship of over speeding and running red signal violations with about 45% of the total accidents that occur in the kingdom (i.e. about half the accidents), that represent a motivation for those working in roads engineering to take those factors into consideration. The engineering procedures to counter speed and signal crossing are possible and have achieved significant successes at different parts of the world and there are useful professional applications and practices in this field.

From the above, the traffic safety methodology will provide guidance on the engineering side for the geometric design of roads and roadsides, traffic control devices such as signs, ground markers etc. in the form of guidelines that is due to the difficulty in collecting the variety of subjects related to traffic safety in one methodology.

4.2 Suggested Guidelines

4.2.1 Signs Engineering Guidelines

During field survey for the study, variations have been noticed in signs whether traffic or advertising in their sizes, elevation from the ground, and installation sites which calls for setting out guidelines for engineering standards that provide uniformity for these elements.

When installing a traffic sign the engineer shall focus on the sign dimensions and installation site as specified in the Manual on Uniform Traffic Control Devices 2002 (MUTCD, 2002). Following are the basic specifications and guidelines for installing the signs.

4.2.1.1 Signs Installation Guidelines

- It is not possible to determine a unified place for sign installation location but the sign plate edge shall not be less than 60 cm from the road edge (30 cm is an accepted case, if it is not possible to achieve the 60 cm distance particularly with the existence of pedestrian pathway as shown in Figure-16).
- If there is no sidewalk the sign shall be far from the road edge (pavement limit) by 1.8 meter and shall be of "breakaway" base or protected by a side barrier or shock absorber.

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4.2.1.2 Writing and Diagram Guidelines

- Follow the colors that traffic regulations have stipulated.
- When text is written on the sign the rate of the letter size is 25 mm high for each 12 m reading distance and this applies to various Arabic letters used in the Kingdom.

4.2.1.3 Signs Frame

Standard: If not specified, the frame color shall be of the same color of writing prevalent in the Kingdom.

Guidance: Dark colored frame is used with light colored sign background and vice versa. If the sign size is 750 mm, the frame width shall be from 13 to 19 mm and far from the sign plate edge by 13 mm. In signs more than 1800 x 3000 mm the frame width shall be 50 mm and it may reach 75 mm and the sign angles shall be circular except stop sign.

4.2.1.4 Sign Dimension Guidelines

- The engineer shall apply traffic regulations or the adopted specifications in determining standard dimensions of signs.
- Increasing the sign dimensions more than specified by the standards is possible for drawing attention providing that the increase is gradual by150 mm.
- When writing instructions on the sign, the rate and proportion on which the letter size is based is 25 mm of letter height for each 12 meters reading distance, and follows the Arabic handwriting version applied in the Kingdom.

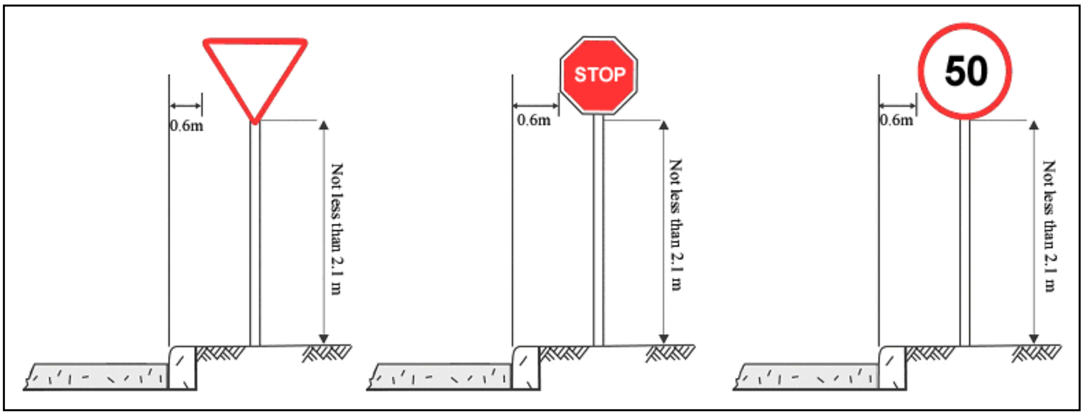

Figure-16: Traffic Sign Location

4.2.1.5 Advertisement Signs and Trees

Advertising signs are widespread near roads and when installed on sidewalks they shall follow the engineering standards and guidelines of traffic signs as indicated previously. But it has been noticed at both study areas, that advertisement signs are installed randomly at intersections near signal posts and on median opening sidewalks and that these signs may be a veil for vision due to their high elevation and width. Therefore, we lay down the following guides:

Guidance: The height of advertisement signs and trees shall not exceed, at intersections and median openings, 0.5 meter so that they may obstruct the vision with a minimum distance from the intersection of 150 m if they were installed in median islands, and 25 m if the installation was on sidewalks. Also their width shall be according to standard sign dimensions.

Guidance: In case a sidewalk exists and there is a distance of 1 meter between the pedestrian path and sidewalk edge it is possible to have this distance for trees, traffic signals, advertising and fire hydrant but by a distance not less than 60 cm from the road edge.

Guidance: The separating area (buffer zone) is considered a service area for various signs or landscaping and at the same time a protection for pedestrians Figure-17.

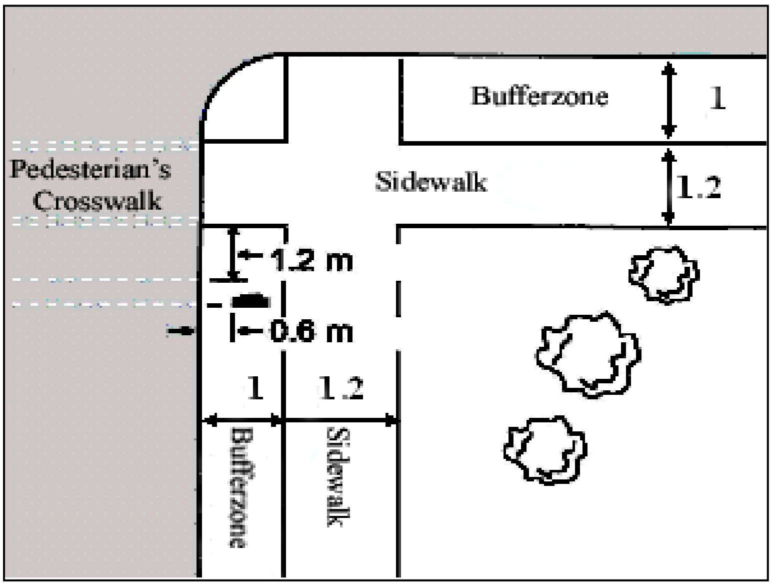

Figure-17: Pedestrian Footpath and Buffer-Zone

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4.2.2 Mid-Block Crosswalks

Mid-block crosswalks are considered of great importance for the safety of pedestrian movement (Figure-18). The design of the crosswalk varies according to many considerations, the most important of which is the speed limit on the road since the crosswalk is not safe for speeds of 70 km/h and over. For such speeds, the engineer shall resort to pedestrian bridges or under passes considering the justifications which are based on pedestrian volumes and land uses serviced by the path. In all cases, when selecting the location of crosswalks between intersections, the engineer shall consider the shortest and safest path which pedestrians can follow to the crossing point so that it becomes attractive to pedestrians instead of crossing randomly.

4.2.2.1 Guidelines

- The width of the crosswalk shall not be less than 1.8 m.
- The crosswalk can be painted with a reflective color to improve the driver's view of the crosswalk at night, and the width of lines shall be from 30 to 60 cm.
- There should be a warning sign of fluorescent yellow-green reflection at a distance of 50 to 100 m before the crosswalk (Figure-18).
- No crosswalk shall be made on roads with speeds of 70 km/h and over.

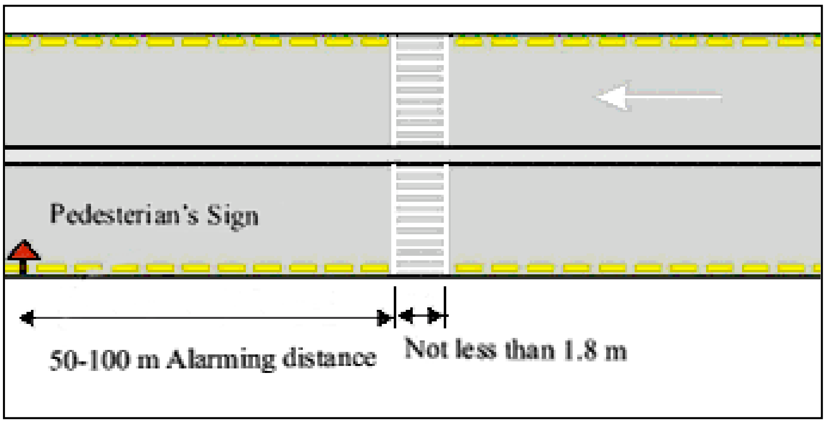

Figure-18: Mid-Block Crosswalk

4.2.3 Directional Signs

Although they are installed on links, they serve turning movements on the following intersection. These signs provide early guide to the driver towards the lane suitable for the turning before he reaches the intersection. Somebody may say these signs are not important since they are neglected / overlooked by the drivers, but we should put into consideration that the traffic engineer shall provide all the standard road requirements according to the engineering standards specified by the applied professional references and leave the matter of the driver's adherence to the authorities enforcing traffic regulations on the road.

4.2.3.1 Guidelines

- Pavement marking such as arrows and writings shall be of white color, and with dimensions as shown in Figure-19.
- The letter height in ground writings shall be at least 1.8 m.

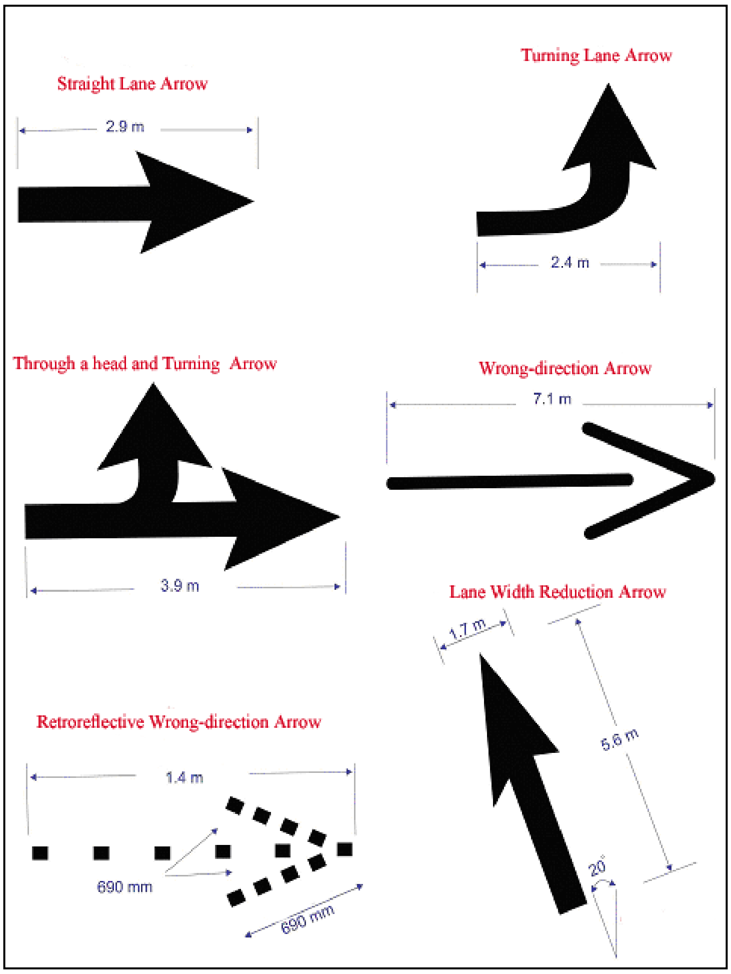

Figure-19: Pavement Arrow Dimensions

4.2.4 Pedestrian Crosswalk Lines

Pedestrian crosswalk lines guide the pedestrians during crossing the road, they identify the path they should walk through and they are spread at signalized intersections. In addition, these lines are considered a warning and reminding tools for the drivers that there is a pedestrian crossing. The standard (*criterion*) of pedestrian lines and their engineering guidelines together with an illustration diagram are given below.

4.2.4.1 Criterion

Pedestrian lines should be of white color with a line width that should not be less than 150 mm and not more than 600 mm. The frequently used three types of crosswalk lines are shown in Figure-20.

4.2.4.2 Guidelines

There are certain guidelines to be followed while designing the crosswalks, these are:

- Crosswalk width shall not be less than 1.8 m.
- Pedestrian lines shall extend from the edge of the pavement to the other edge (from sidewalk to sidewalk) to avoid pedestrian walking outside the crosswalk, as shown in Figure-20.

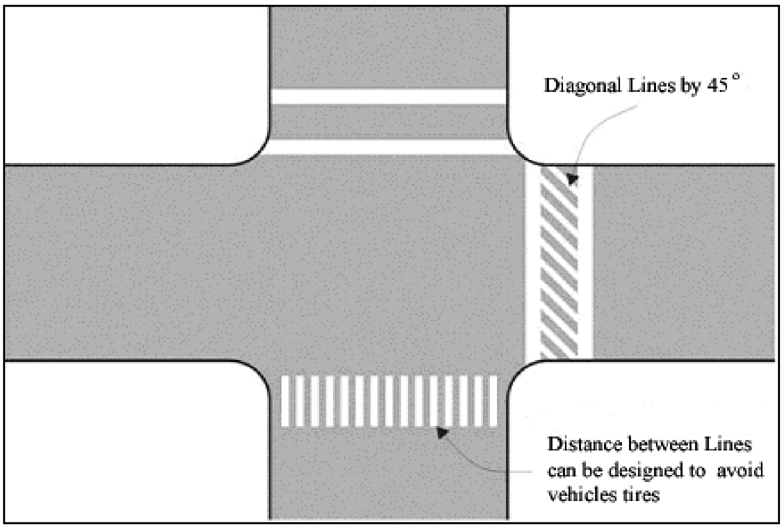

Figure-20: Crosswalk Line Types

- Provision of crosswalks is not limited only to intersections but also at mid blocks where pedestrians cross or any other place used as crossing by the pedestrians.
- It is possible to use only the two parallel lines of the crosswalk (without diagonal lines with 45) at sites with low pedestrian volumes which is not considered as a main crosswalk, to save money and reduce maintenance.
- If the perpendicular or diagonal lines were used in the crosswalk their width shall be 300 to 600 mm with a separation distance of 300 to 600 mm.

4.2.5 Pedestrian Routes and Sidewalks

Sidewalks are for the use of pedestrians. Sidewalks should have sufficient capacity to accommodate the pedestrians and allow them to move easily, comfortably and safely by separating their movement from vehicles. This study has found that the heights of sidewalks are variable and are not according to clear standards. This variation creates many problems which reduce the benefits from using them at traffic signs and cause inconvenience for the movement of people with special needs particularly wheelchairs, as they do not provide easy outflow of pedestrian movement.

4.2.5.1 Guidelines

- The 1 meter wide separation area is for signs and fire hydrants and serves as protection area to separate pedestrian walkways and roads so that pedestrians feel safer.
- The 1.2 m wide Pedestrian route is adequate for passing two parallel persons with sufficient distance between them and shall be kept completely free from any obstructions for the pedestrians and it is preferable to have 1.5 m to serve people with special needs. In commercial areas width of pedestrian sidewalk shall not be less than 2.4 m.
- If there is a projection for the commercial store fronts, at least 0.5 m is added to the sidewalk width.
- It is absolutely prohibited for existence of any projecting objects from building walls overlooking sidewalks which pedestrians may collide with during their movement except when the objects are higher than the sidewalk surface by 2 meters minimum.
- Shop and house doors overlooking pedestrian sidewalks shall not narrow the width of the sidewalk during their opening.
- The smoothness and fineness of the footpath shall be considered providing that this help the wheelchair to move with ease.
- If the pedestrian footpath at the intersection is congested with pedestrians, the engineer shall design the intersection angle such that prospective pedestrians do not close the footpath.
- The footpath and separating area depend on the type of the road and available area for the sidewalk and the above measurements are considered as minimum limits which the engineer may apply.
- In residential areas it is recommended that the sidewalk width shall be from 1.2 to 2.4 m with a separation distance of 0.6 m. It is possible to be satisfied with a sidewalk at one side of the road but it is always preferable to be at both sides.
- The sidewalk height shall not be less than 10 cm (Figure-21).

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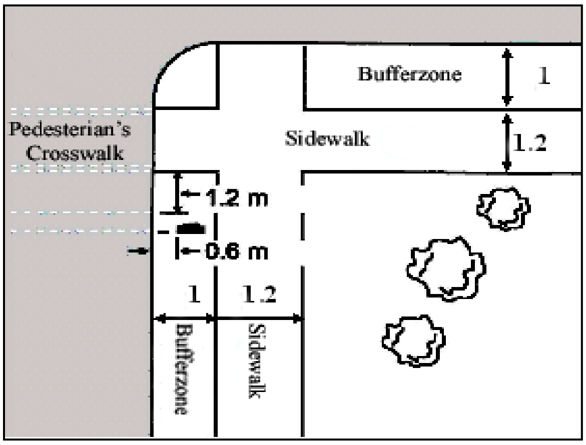

Figure-21: Footpath and Buffer-Zone

4.2.6 Pedestrian Curb Ramps

If pedestrian paths were available on the sidewalk there should be curb ramps at the sidewalk corners to facilitate pedestrian's crossing of the road, particularly those with wheelchairs. The design of ramps depends on many factors, most important of which are the footpath width, sidewalk angle radius, sidewalk height and width, existence of water drainage, and road width. Figure-22 shows different forms of ramps (a ramp for a mid block crossing) with the following specifications.

4.2.6.1 Guidelines

- Ramp width shall not be less than 90 cm with a maximum grade of about 8% for the ramp entrance; a distance of 0.6 m shall be designated as coarse surface so that pedestrians feel the beginning of the ramp.
- The ramp end shall be linked with the road surface without an elevation that may block the wheelchair from entering the ramp or expose it to frontal turnover in case the ramp end edge was elevated above the road surface.
- The point of contact of the ramp end with road surface shall prevent collection of water and wastes which might obstruct the wheelchair.
- In case there is a median island an opening in its midst shall be provided through it for pedestrian and wheelchair crossing as shown in Figure-23.

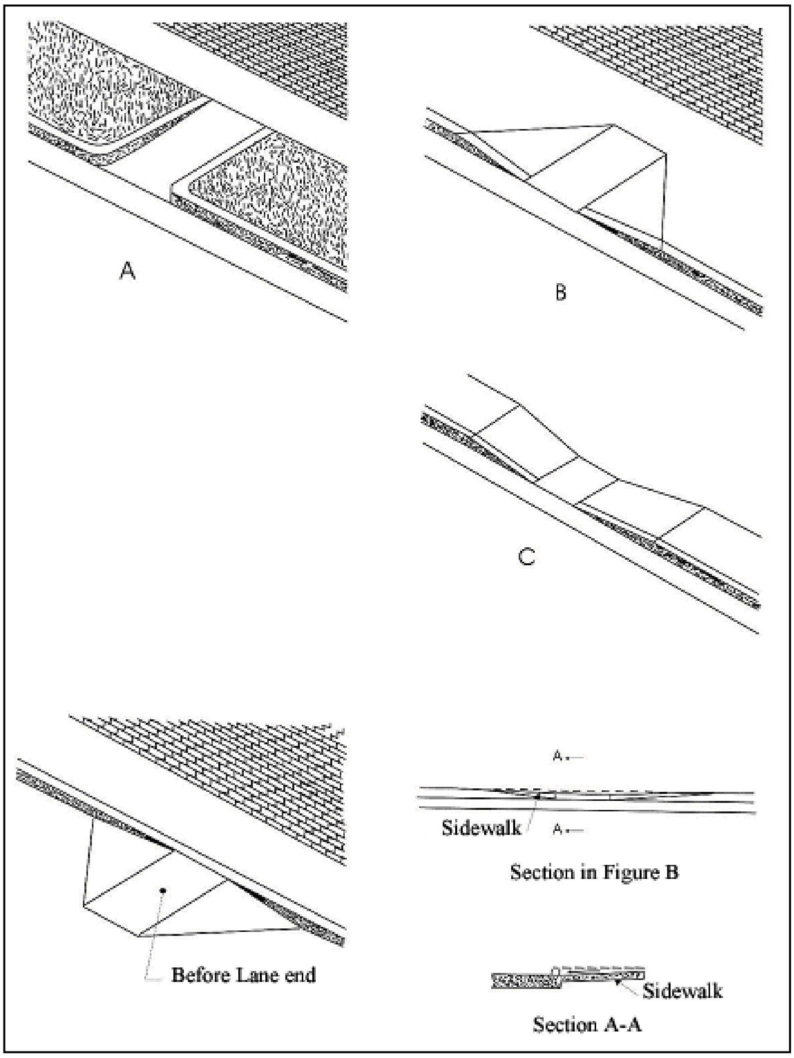

Figure-22: Types of Sidewalk Ramps

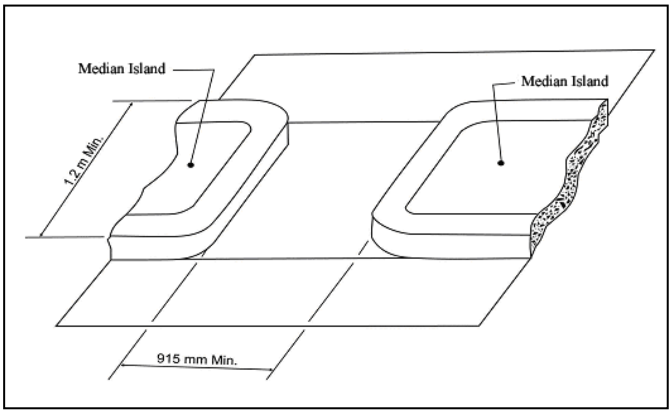

Figure-23: Openings at Mid-Islands

4.2.6.2 Pedestrian Ramp and Access to Pedestrian Pushbuttons

Sometimes due to the weak demand for a transverse footpath, the engineer places pedestrian push buttons. These push buttons shall be subject to engineering specifications linked with pedestrian ramp as shown in Figure-24.

4.2.6.3 Guidelines

- The pedestrian pushbuttons shall be at a distance not less than 3 m from each other as shown in Figure-24.
- Pedestrian pushbutton height shall be about 1.1 m from the footpath surface.

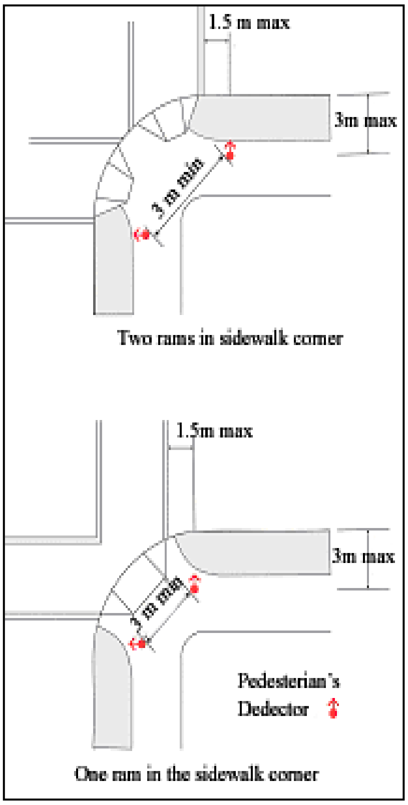

Figure-24: People with Special Needs' Ramp at the Intersections' Corner

4.2.7 Stop Line

Stop line is used to specify the place at which the vehicle shall stop. Stop line should be located before pedestrian lines to prevent overlapping of vehicles with pedestrians, as shown in Figure-25 and Figure-26.

4.2.7.1 Criterion

Stop line shall be of white color and 300 to 600 mm wide.

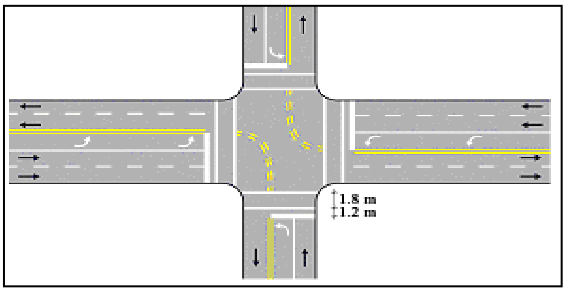

Figure-25: Stop Line and the Relation with Pedestrian Crosswalk

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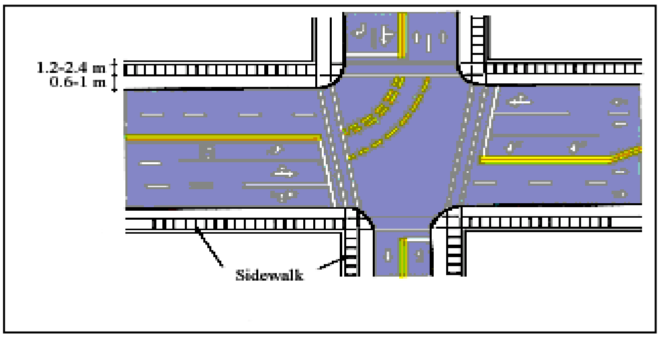

Figure-26: The Extension of Crosswalks to Pedestrian Footpath

4.2.7.2 Guidelines

- Stop line shall be far from pedestrian crosswalk line (to the rear) by 1.2 m and parallel to it.
- In some sites it is not required to have pedestrian crosswalk lines in an intersection, but that does not mean to omit stop line which shall be far from the intersected road edge by a distance of 1.2 m. It is possible that it may be far from the road edge by more than this distance and with maximum limit of 9 m if the engineering design of the intersection required that.

4.2.8 On-Street Parking near Intersections

At some of the study intersections, randomness of parking spaces was noticed. Vehicles park very close to the intersection corners which obstruct turning movements and make those corners potential sites for accidents. It was found that the engineering treatment for that was not feasible, which calls for re-designing the intersection corners to prevent parking. This can be done either by projecting the sidewalks to the outside or through ground signs showing prohibition of parking near "no stop" signs.

From the engineering point of view, the last side parking near the intersection shall be at a distance of not less than 8.4 m from the footpath as shown in Figure-27, while the first parking shall be after the intersection exit at a distance of 20 m from the intersected road.

4.2.8.1 Guideline

- Ground lines for side parking shall be white.

4.2.8.2 Criterion

- The first side parking shall be before the intersected road at a distance of 8.4 m from the sidewalk and parking width shall not be less than 2.4 m and its length varies from 6 to 6.5 m.
- Parallel parking is more preferred than the angular parking particularly near intersections, to lessen the effect of overlapping with traffic flow on the road.
- On main roads, where there is commercial activity, it is advisable that the parking width shall be from 3 to 3.6 m to be used by freight vehicles (fast loading and unloading).
- On main roads it is always preferable that the parking width shall be from 3 to 3.6 m for the possibility of using the parking space as an additional lane for traffic movement during peak periods through preventing parking during those periods, and it shall be considered that the intersection angle design shall comply with that.
- On internal streets of residential areas the parking spaces width may be 2.1 m.

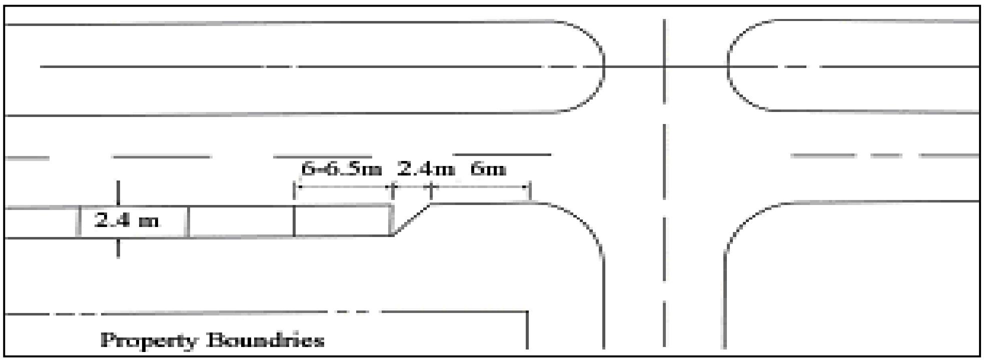

Figure-27: Roadside Parking near Intersection

4.2.9 Speed Humps

Speed humps are considered one of the traffic calming measures in traffic engineering. In the field visits, it was noticed that there are humps for the purpose of decreasing speed but they were not designed based on engineering specifications, which may adversely affect traffic flow. Therefore, it is vital to set out engineering standards for the selection of the hump site and design.

4.2.9.1 Guidelines

Speed humps shall be applied taking into account the following:

1- Engineering Study

The hump construction shall be undertaken when there is requirement of traffic safety and operation at the subject site. This requirement shall be discovered after confirming that no other possible alternatives are available since the hump has negative effect mostly on vehicles which cross it and residents living near it. Speed humps cause noise and environmental pollution due to changing driving speed imposed by the hump. Also, existence of the hump, especially when repeated, may motivate drivers to divert to other alternative roads particularly residential roads, leading to adverse consequences on traffic safety and environment.

2- Road Classification

Humps are constructed only on local streets according to AASHTO. Local streets are defined as streets which focus on and mainly serve access to adjacent residential land uses. Humps are not provided for through traffic (high speed).

3- Road Width and Number of Lanes

Engineering experience recommend that humps construction shall be limited to two lane roads of which the total road width is about 12 m (or greater but with only two lanes), providing that the road surface is good and allows water drainage.

4- Road Grade

When providing the hump it is recommended that the road grade shall not exceed 8%, and when the grade is greater other precautions shall be made to insure that the vehicle does not approach the hump in high speed. In case of rainy season or flowing water, a special analysis is required to determine hump installation warrant.

5- Vertical and Horizontal Curves

The engineer shall refrain from constructing humps within sharp horizontal and vertical curves due to the effect of that on dynamic forces affecting the vehicle when crossing the hump. Also, constructing hump shall be avoided at turns of a radius less than 100 m (radius from road centerline) because such turns ensures low speeds required to maneuver the turn. Humps can be used, if necessary on tangent to the curves.

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6- Sight Distance

Humps are constructed when minimum stopping sight distance is available as shown in the table below, and the engineer shall use the 85^{th} percentile speed for this purpose.

Minimum Stopping Sight Distance

85^{th} percentile speed (km/h)	Minimum required sight distance (m)
30	50
40	65
50	85
60	110
70	140
80	165
90	195
100	220

7- Speed

Humps are constructed on roads with speed of 50 km/h or less, and care shall be taken when the prevailing speed is more than 70 km/h.

8- Traffic Volumes

Engineering experiments have not shown a significant effect on traffic volume due to constructing humps. The applications on sites in which traffic volumes varied, in the average, from some hundreds to 10,000 vehicle/day have not required a particular specification for this purpose, but it is important to refer to the importance of studying each site individually to justify hump construction.

9- Traffic Safety

When humps are constructed to prevent vehicle or pedestrian accidents, the causes of these accidents shall be determined to ensure that construction of the hump shall help in eliminating them. This is because the hump may become a factor in increasing the number of accidents instead of reducing them.

10- Traffic Flow Composition

Construction of humps shall be avoided if heavy vehicle (such as buses) rate is more than 5% except when there is another alternative road that they can use. A consideration shall be given when designing the hump to bicycles and motorcycle.

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11- Emergency Vehicles

If the road is heavily used by emergency vehicles such as ambulances and fire fighting vehicles, no construction of humps shall take place on it. Also, if the road was the route of public buses this shall be considered in designing the hump.

12- Frequency

When a group of consecutive speed humps are to be installed, it is recommended that distances between them shall be in the range of 60 to 225 m.

13- Traffic Control

Construction of speed humps shall be associated with traffic control devices to warn drivers about their existence such as using signs and ground markers and flash signals. The hump warning sign is linked with its site and it is possible to install the sign at the hump site or before the hump (for example on a 50 km/h road, the sign is installed 35 m before the hump). It is preferable to paint the hump so that it becomes clear for the driver in the absence of hump signs, or paint two yellow lines (paint or ceramic) before the hump separated by 1 m. Also it is possible, according to the importance of the location, to install an additional sign under the hump warning sign on the same pole indicating the required speed.

14- Water Drainage Considerations

The engineer shall consider water drainage when constructing the hump such that the later does not interrupt water drainage. Also, he shall avoid constructing the hump on drainage openings or close to them, or near fire hydrants. It is very important to watch out for treating both ends of the hump for preventing interruption of water flow and bicycles. The treatment should not encourage drivers to cross along the hump edge. Therefore, it is important that the hump extends from edge to edge of the road (even through shoulder).

15- Cross-Section Design

The elliptical shape as shown in Figure-28 is considered more widespread in designing hump cross section with a height of 10 cm (it can be 7.5 cm if the heavy vehicles rate is high).

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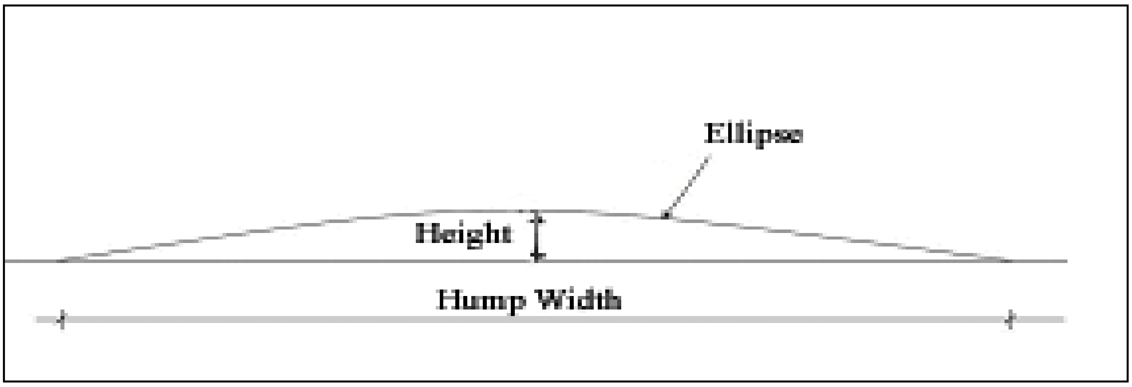

Figure-28: Cross-Section in Elliptical Shaped Hump

The hump can also take the leveled surface shape as shown in Figure-29.

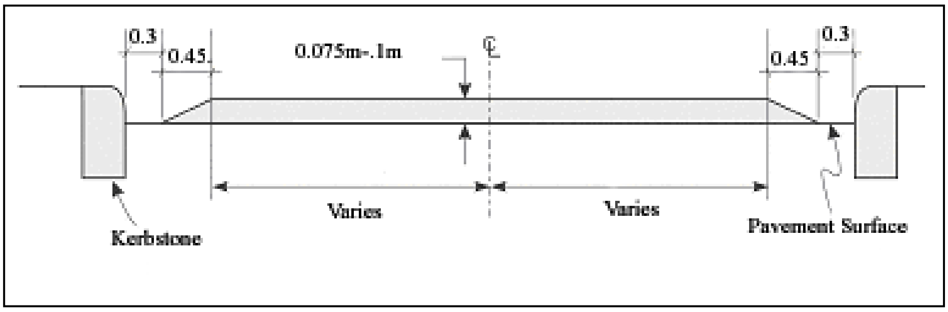

Figure-29: Cross-Section of Leveled Surface Hump

4.2.10 Hazardous Sites Analysis

4.2.10.1 Guidelines

Follow the following steps**:**

1- Determine accident analysis period. It is recommended to be 3 years, and if this is not possible, at least one year.

2- Collect accident reports recorded from the subject site during the above analysis period.

3- Summarize accident data in the form shown in Figure-30 and ensure the provision of the following information for each accident:

- Accident location.
- Weather conditions.
- Accident time and date.

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- Road surface condition.
- Accident type.
- Accident reason.
- Accident severity (property damages, injuries, deaths).
- Accident sketch.

	First Year	**Second Year**	**Third Year**	**Total**	**% of total**
	Number	**Number**	**Number**	**Number**	
Type Of Accident					
Left turn					
Rear end					
Angular					
Side					
Pedestrian run over					
Front end					
Linked with side road					
Fixed object					
Other					
Road Condition					
Wet					
Dry					
Lighting Condition					
Day					
Sunrise or Sunset					
Night					
Accident Severity					
Death					
Injuries					
Property damage only					
Total Accidents (injuries)					

Figure-30: A sample of Accident Data Summary Form

4- Prepare the collision diagram with the names of streets.

5- Interpret each accident type on the collision diagram according to Figure-31.

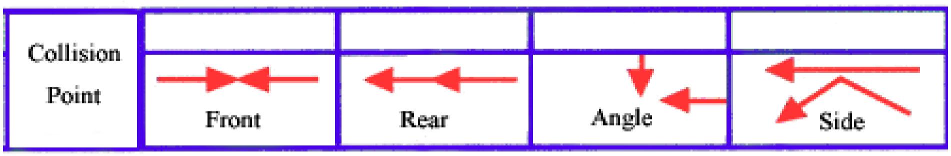

Figure-31: Accident Types

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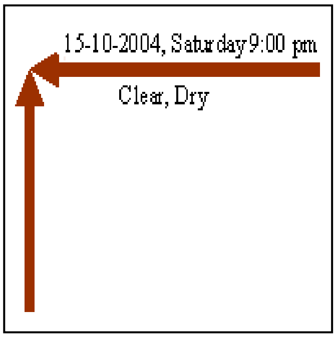
6- Transfer data of each accident on the arrow specifying the type. These data are: time of the accident, its date and day, weather conditions, road surface condition, the following figure shows an example for an angular collision:



7- Determine the prevailing types of accidents and their locations in the subject site, if any.

8- In case the prevailing type is determined, consult Figure-32 to choose the suitable measures of treatment.

Figure - 32: Treatment Countermeasures of Prevailing Accident Types at the Investigated Site

Accident type	Possible reasons	Treatment countermeasures
Angular collision at a signalized intersection	Poor vision of signal	- Installation of an early alert sign for the signal. - Decrease speed limit if it is justified by the speed study. - Remove any visual obstruction. - Replace lenses with larger ones (12 inches). - Change signal site and it may need overhead signals. - Add linkage and coordination with adjacent signals.
	Imposed traffic signal timing	- Adjust yellow timing. - Increase all red timing. - Change control system. - Install detectors. - Add linkage and coordination with adjacent signals.
	Poor vision	- Install warning signs. - Install stop signs. - Install yield signs. - Remove vision obstructions. - Install traffic signals. - Improve lighting conditions in intersection. - Channelization
Angular collision at un-signalized intersection	High volumes of traffic at intersection.	-Install traffic signal.

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	High speed on intersection approaches.	-Lower speed limit. - Installation of rumble strips.
Rear-end collision at signalized intersection.	Unsuitable signal timing.	- Re-evaluate yellow time.
Rear-end collision at un-signalized intersection.	Pedestrian crossing	-Install or improve vision of pedestrian crosswalks. - Transfer crosswalks to another site.
	Driver is not aware of intersection existence	-Install warning sign.
	Road skidding surface	-Add warning sign with (wet and skid surface). - Reduce speed limit. - Improve water drainage system. - Groove pavement layer. - Overlay pavement layer.
	High turning volume	- Increase sidewalk radii - Add left and right winding lanes.

4.2.11 Choosing the Speed Limit

The 85^{th} percentile speed is the most common standard among traffic engineers to determine the speed limit on the road. Concerning this matter, the following guides could be used:

- Choosing a suitable location for the speed measurement points, so that speed is not affected by intersections, sharp curves etc. Measurements also must be taken outside peak hours.
- Sample size is determined according to the standard speed study procedures shown in traffic engineering references. In Riyadh, and according to previous studies and at statistical inference level of 5 %, a 150 sample size will be enough.
- From the speed observations, the 85^{th} percentile speed could be calculated by:

85^{th} percentile speed = Speed Average + 1.4 (Standard Deviation of Speed)

Speed Average and Standard Deviation could be obtained from previous studies (from similar highway type with similar conditions), or by measuring a small sample. The speed could be approximated to the nearest ten-fold, and in all cases the determined speed must comply with the speed limit determined by the traffic department.

5- Conclusions

This study has handled three main subjects:

- Comparing parking demand with parking supply to build an evaluation methodology of parking sites.
- Evaluation of pre-timed signalized intersections traffic performance, and the mechanism of finding suitable solutions.
- Methodologies of surveying and evaluating the most important traffic safety aspects within urban areas.

The methodologies were proposed as a result of data collection and analyses at the selected study areas.

The study focused on Riyadh city in addition to nine other cities to find out the variations due to the local conditions affecting the traffic conditions of these cities.

The study concluded that the most common parking patterns in Saudi Arabia are short-period parking patterns. The problems of parking are not related to short of parking supply, but are generally related to poor parking managements. So, there should be a review of parking policies and management. On-street parking suffers from a high parking demand which exceeds its capacity due to high dependence on private cars which are the main mode of transport.

Concerning traffic performance, it was found that most of the signalized intersections were evaluated as over-loaded with high traffic volumes. This made it difficult for these intersections to operate with acceptable levels of service. Simple and low-cost solutions (without spatial separations) were able to reduce delay times to some extent but not to improve levels of service.

There are many deficiencies related to traffic safety requirements within these cities. Standards and specifications for installing and designing traffic and road elements (which have huge impacts on traffic safety) were not taken into account, despite the availability of such standards and the adaptation of them by the concerned authorities.

This study did not deal with the traffic planning and its effects on the traffic and transportation sector, despite its considerable effect on the whole transportation system. Because of the increasing growth of private cars and the dependency on them as the main mode of transport make all small-scaled treatments ineffective.

The major method of solving transportation problems, from the planning point of view, is by the reduction of traffic volumes (mainly private cars), or at least curtail the

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continued growth, and that is by reducing private car ownership rates, or by reducing number of private cars trips (especially work trips) through the encouragement of public transport.

A strategic planning process must be formulated on city-levels, to produce effective plans, policies and strategies of transportation which are effective on short, medium and long terms basis in treating transportation problems or at least reducing their aggravation.

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Appendices

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Exhibit-1: Parking Traffic Data Collection' Questionnaire Form

PARKING OCCUPANCY SURVEY			
City: Area:	Street:	Building Name:	No. of Gates / Blocks
Gate No.		Date	
Name of Surveyor:		Time of Survey: From Till	
Exiting Cars		Entering Cars	
Registration Plate	Time of Exit	Registration Plate	Time of Entry

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Exhibit-2: Parking Geometric Data Collection' Form

Parking Geometric Survey Form

City: **Region:** **Name of served establishment:**

Parking types:

☐ On street parking ☐ Surface ☐ Garages

Specifications	Site information and field comments	Technical specification
On street Parking		
Distance between the nearest intersection and the first parking space in road side parking		Not less than 6 m for minor intersection, and 15 m for major one.
Minimum length of parallel parking		6.5 m
Minimum width of the road adjacent to the parallel parking		5.5 m
Minimum distance between angular parking roadside space and the nearest intersection		9 m at the start of parking row and 12 m at the end
Surface Parking		
Entrances and Exits of surface parking	Far from intersection Close to intersection	
Entrances and Exits	- There is service road - There is no service road • There are accelerating and decelerating lanes • There are no accelerating and decelerating lanes	
Width of Entrances and Exits	Entrances Exits Entrances and Exits	Not less than 3.5 m Not less than 3.5 m Not less than 7.5 m with 0.5 m separation island
Length of vertical parking		5.5 m
Width of vertical parking		2.5 m
Concrete barriers	Exist Does not exist	
Dimension of concrete barrier	Length Width Height Distance from the sidewalk edge	1.8 m 0.2 m 0.15 m 0.76 m
Angular parking	Exist Does not exist	
Angle of diagonal parking		
Diagonal length for Angular parking		Minimum compatible distance
Diagonal parking width		Minimum compatible

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		distance
Perpendicular length of diagonal parking		Minimum compatible distance
Routes		
One way route width		4.5 m
Two ways route width		7.5 m
One way curve width		3.5 m
Two way curve width		7.00 m
Skid prevention		Course surface Small series of humps
Speed calming humps inside parking at walkway sites		
Noticing Enter/Exit signs and guidance light signals inside parking		
Garages		
Garages	Exists Does not exist	
Entrance and exits dimensions	Entrance width Exit width Both Entrance/Exit	3.5 m 3.5 m 7.5 m
Entrance/Exit site comments		Far from intersection and roads
Comment on vision clarity when exiting		
Net height	Height inside garages Entrance gate height Exit gate height	2.5 m 2.5 m 2.5 m
Noticing existence of a sign specifying allowed height at gate		Shall be flexible and suspended from top only
People with special needs' Parking		
People with special needs parking	Exist Does not exist	
People with special needs parking number	People with special needs parking length People with special needs parking width	
Specification of those parking	Length Width	5.5 m 3.6 m
Noticing distance to lift		
Noticing distance to entrance (continuity of sidewalk to reach entrance or using ramps)		
Existence of disabled signs	Ground signs	

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	Suspended signs	
Noticing of existing curb ramp to the People with special needs' parking		

Note: The traffic analyst must visit the site and prepare a Condition Diagram, and the following form. Also he must observe driver's behavior and attitudes during peak accident period according to the traffic accident records.

Exhibit-3: Visual Survey Field Report Form

Site: Day: Date: Time: Visual:	**Indicate if the problem exists**
First: Site Nature:	
1- Vision obstruction for control devices at site or near it?	....
2- Vision obstructions interrupting conflicting traffic?	....
3- Existence of legal parking obstructing vision?	....
4- Traffic signs are not suitable in terms of number, size, message, site, reflection, vision?	....
5- Traffic signals are not suitable in terms of number, size, message, site, reflection?	....
6- Ground markers are not suitable in terms of number, size, message, reflection, vision?	....
7- Separation Islands do not make:	....
a- Reduction of conflict areas?	....
b- Designation of traffic route?	....
c- Separation of traffic flows?	....
8- Not adequate radius of intersection angles?	....
9- Sharp slope of one intersection approach?	....
10- Not adequate routes and intersection width?	....
11- Not good pavement surface?	....
12- Road sides include fixed objects?	....
13- Not suitable Side road sites?	....
14- Not suitable sites and designs of crossway?	....
15- Bad lighting?	....
16- Advertising signs interrupt driver's vision?	....
Second: Operational Visual Surveys:	**Put sign if the problem exists**
1- Drivers response to traffic control devices is not suitable?	
2- Repeated violations which breach control devices?	....
3- High speeds due to site conditions?	....
4- Vehicles change routes suddenly?	....
5- Certain traffic movements cause hazards:	....
a- Vehicles turning left?	....
b- Vehicles going ahead?	....
c- Vehicles turning right?	....
6- Maneuvers of parking vehicles cause hazards?	....
7- Entering or exiting from side road cause hazards?	....
8- Traffic congestion and delay cause hazards?	....
9- Pedestrians in the site cause traffic confusion or conflict?	....
Comments and description of each problem that was identified in the review list: The above identified problems become clear during discussing relevant points during describing them whereas they shall be handled in detail according to their importance.	

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