CHAPTER 7:

OPTIMAL ROUTE SELECTION

7.1 Natural Conditions in the Study Area

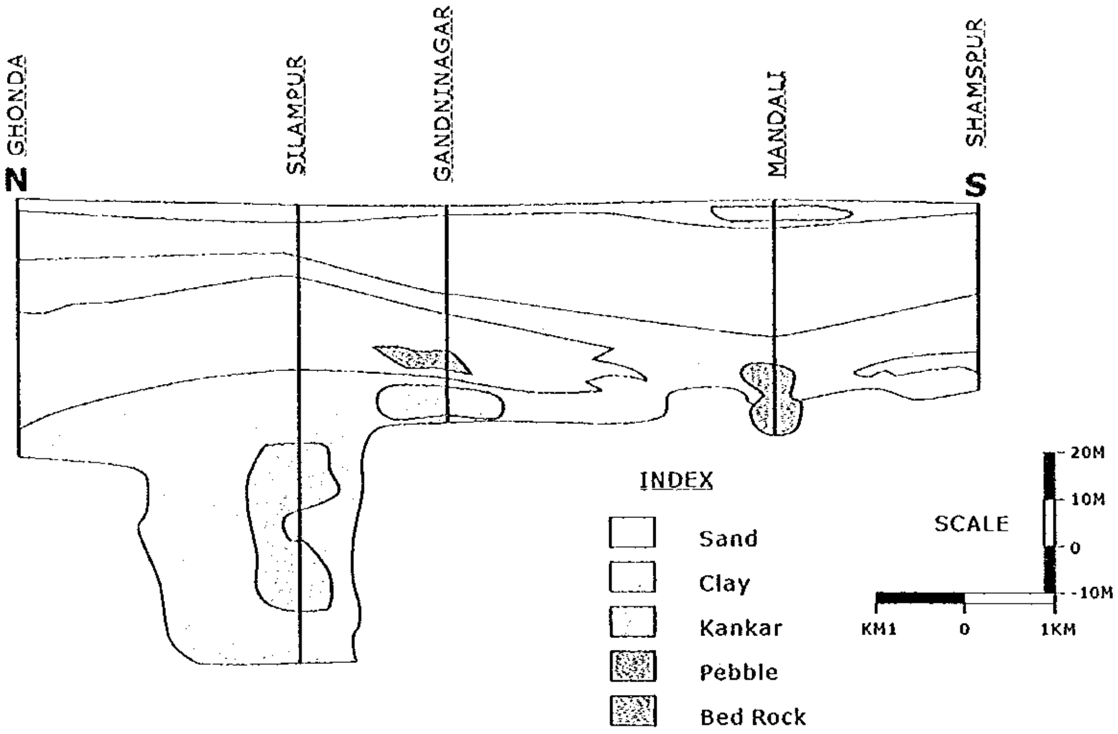
7.1.1 Topography and Geology

The Study Area is located at northern and eastern part of the National Capital Region (NCR). The NCR covers an area of 30,242 km^2 extending into three states namely Haryana, Rajasthan and Uttar Pradesh in addition to the Delhi Union Territory.

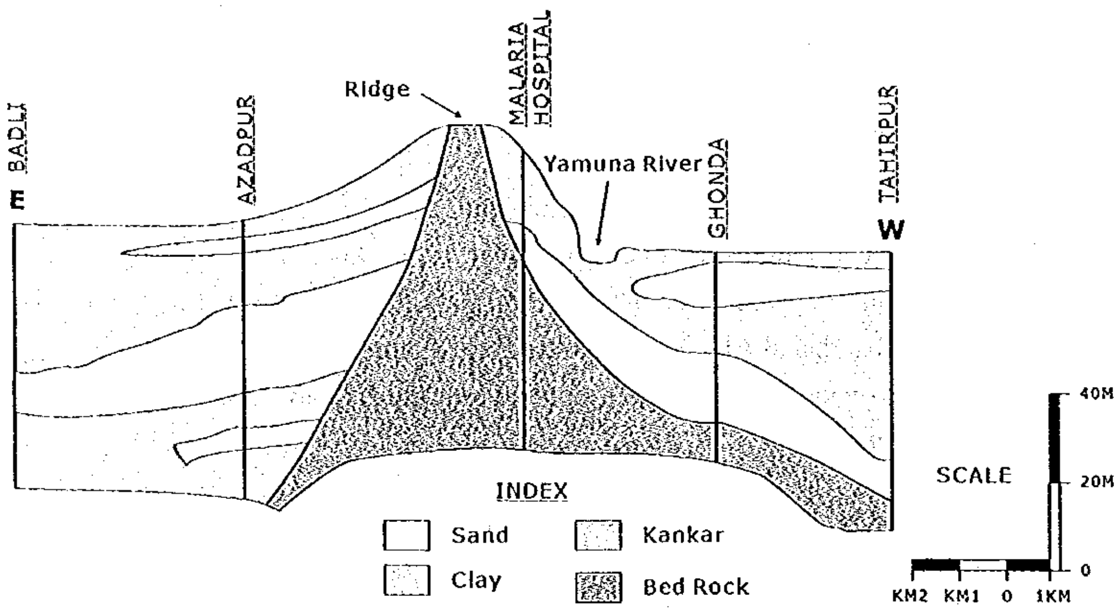
Topographically the NCR has two major sub-units. The alluvial plains whose monotony is intercepted by isolated hillock or fairly continuous ridges of hard rock and sand dunes not more than 50 m in height from the plain lands which constitute the NCR terrain around Delhi, Haryana and U.P. Sand dunes are prominent in Haryana and Rajasthan parts and hard rock ridges bending NE to SW are seen in the south and south-west of NCR covering good parts of Alwar district and Delhi.

The geological set-up of the area is constituted by two major groups of rocks separated by a single conformity. The top formation is Quaternary Alluvium consisting of unconsolidated sediments. The base formation is consolidated hard rock belonging to the Ajabgarh and Alwar series of the Delhi-Supra Group rocks of the Pre-Cambrain, which are included by post Delhi intrusives such as quartz veins, pegmatities, grenilis and amphibobits.

Soil in the NCR generally consists of alluvial deposits in the Gangetic plains. The sub-surface geological section showing sub-surface correlation in Delhi are shown in Figure 7.1.1. These are illustrated by two sections of the sub-surface strata drawn in a N-S direction along Ghonda-Samspur and E-W direction along Badli-Tahirpur showing correlation of the various sand and clay beds prevalent in Delhi.



SUBSURFACE GEOLOGICAL SECTION SHOWING SUB-SURFACE CORRELATION N-S



SUBSURFACE GEOLOGICAL SECTION SHOWING SUB-SURFACE CORRELATION E-W

Figure 7.1.1: Sub-Surface Geological Sections

7.1.2 Climate and Hydrometeorology

The NCR is climatologically an integral part of the following meteorological sub-divisions defined by Indian Meteorological Department (IMD):

(a) West UP Plains
(b) Haryana, Delhi and U.T. Chandigarh
(c) East Rajasthan

Rainfall, altitude and topography determine the climatic classification of a region. Based on the 'State Climatological Summaries' issued by IMD (1991), the NCR is divided into the following two types of climate:

(a) Subtropical monsoon (mild winter, dry winter and hot summer) climate region comprises of (i) Meerut, (ii) Ghaziabad, (iii) Bulandshahr, and (iv) Panipat districts.

(b) Tropical Steppe, semi-arid and hot summer climate region comprises of (i) Sonipat, (ii) NCT Delhi, (iii) Rohtak, (iv) Gurgaon, (v) Faridabad, (vi) Rewari and (vii) Alwar districts.

The whole region of West UP hill Districts and Himachal Pradesh constitute the upper catchments of Rivers Yamuna and Ganga, and they experience the same climate. The whole upper basins of Ganga and Yamuna receive copious rainfall causing floods in the NCR and adjoining regions.

The network of ordinary and self-recording raingauge stations in and around the NCR satisfies the normal limit of density as per guidelines of World Meteorological Organization and the IMD. The available normal rainfall of 1901-1950 of the IMD concerning the NCR and adjoining areas have been further updated up to 1990 after collection and analysis of rainfall data, and the same have been utilized for various hydrometeorological studies.

The annual normal rainfall of NCR is 61 cm. 79 % is contributed by monsoon rainfall, and the rest is by that of other seasons. The coefficient of variation of annual and monsoon rainfall varies from 25 % to 40 %. In post-monsoon and winter season the coefficient of variation of rainfall is comparatively higher.

In the NCR and adjoining areas it has been observed that May and June are the hottest months and January the coldest. Relative humidity is generally high in August and low in May. Strong surface winds persist in May and June and light winds during winter months. Extreme dryness and cold winter are experienced during certain periods of the year. Fairly comfortable climate is due to reduced day temperature during July to September.

The hydrometeorological aspects gave the severe rainstorms to Yamuna and Ganga sub-basins affecting NCR during the years 1924, 1947, 1978 and 1988 including associated synoptic situations. Monthly normal rainfall of September at available raingauge stations in the upper river catchment is 18 cm, and the average maximum daily rainfall intensity was 12 cm in the upper catchment during the above severe storms period.

The meteorological data of the study area are shown in Appendix 8.1.1 as follows:

- Mean daily temperature
- Maximum and minimum daily temperature
- Mean maximum and mean minimum temperature
- Seasonal and annual rainfall
- Normal rainfall comparison of 50 years
- Related humidity
- Mean maximum and minimum relative humidity
- Mean wind speed

7.1.3 Hydrological survey

The purpose of the hydrological survey was to obtain basic engineering data for river-crossing. The first purpose was to obtain basic information for selecting the river-crossing points (the optimum route selection) of Yamuna and Hindan Rivers. The second purpose was to obtain detail data for deciding the river-crossing height at the selected crossing points of the two major rivers.

To obtain the basic information for selecting the river-crossing points the cross sections survey was conducted and the past flood records were collected. The design high flood level (HFL) and discharge volume were computed to decide the river-crossing height.

The cross section survey and collection of the past flood records were carried out in March 1999. The calculation of HFL was carried out in July 1999.

(1) Cross sections survey

The cross sections survey was implemented at the northern and southern sections along the proposed alternative routes of the K-G Expressway over Yamuna and Hindan Rivers. The survey lengths are shown in Table 7.1.1.

Table 7.1.1 Cross Sections Survey Length

Name of river	Location	Survey length
Yamuna River	Northern section	3.5 km
	Southern section	2.5 km
Hindan River	Northern section	2.0 km
	Southern section	2.0 km

Source: JICA Study Team

The results are shown on the drawings in Appendix 7.2.

(2) Past flood records

The past flood records were investigated for high flood levels and discharge volumes at the 2 stations (Mawi and Delhi Railway Bridge) for Yamuna River and 1 station (Okhla Barrage) for Hindan River. The locations of these stations are shown in Table 8.1.2.

Table 7.1.2 Hydrological Observation Stations

River	Observation station	Location	Catchment area (km2)
Yamuna River	Mawi	85 km up stream of proposed southern section	15,622
	Delhi Railway Bridge	10.5 km down stream of proposed southern section	18,552
Hindan River	Okhla Barrage	25 km down stream of proposed southern section	-

Source: Central Water Commission

The major flood records for Yamuna River in 1978, 1988 and 1995 at above stations are shown in Table 7.1.3.

Table 7.1.3 Major Flood Records of Yamuna River

Station	Mawi		Station	Delhi railway bridge	
Date	Peak level (elevation)	Discharge (m3/sec)	Date	Peak level (elevation)	Discharge (m3/sec)
04 Sep. 1978	232.00	11,137	06 Sep. 1978	207.49	6,824
26 Sep. 1988	232.45	14,386	26 Sep. 1988	206.92	5,642
26 Sep. 1995	232.16	6,386	26 Sep. 1995	206.93	7,028

Source: Central Water Commission

The major flood record of Hindan River in 1967, 1978, 1988 and 1993 at above station are shown in Table 7.1.4.

Table 7.1.4 Major flood records of Hindan River

Station	Okhla Barrage	
Date	Peak level (elevation)	Discharge (m3/sec)
30 Aug. 1967	203.57	1,653
05 Sep. 1978	202.65	3,684
05 Aug. 1988	201.60	1,090
22 July 1993	202.00	1,290

Source: Central Water Commission

The past flood data were obtained from the Master Plan of Flood Management and/or Flood Damage Report. The liable flood area in the study area is the right side area of Yamuna River along K-G Expressway.

(3) Design high flood level

For the optimal route, the design high flood level (HFL) and discharge volume are calculated at 3 locations for Yamuna River. These locations are Mawi, Delhi Railway Bridge and the selected river-crossing point on the optimal route. The calculation term were of 50 year and 100 year return periods. The results of the calculation are shown in Table 7.1.5.

Table 7.1.5 Design HFL of Yamuna River

Location	50 year return period		100 year return period		Catchment area (km2)
	Discharge (m3/sec)	HFL50 (elevation)	Discharge (m3/sec)	HFL100 (elevation)	
Mawi	10,220	232.67	12,660	232.93	15,622
Delhi railway bridge	12,217	207.00	15,684	207.26	18,662
Selected bridge point	11,400	216.98	14,400	217.24	17,500

Source: JICA Study Team

The design high flood level (HFL) and discharge volume were calculated at the location of the river-crossing point. The calculation terms were of 50 year and 100 year return periods. The results of these are shown in Table 7.1.6.

Table 7.1.6 Design HFL of Hindon River

Location	50 year return period		100 year return period		Catchment area (km2)
	Discharge (m3/sec)	HFL (elevation)	Discharge (m3/sec)	HFL (elevation)	
Hindon Cut	4,925	-	6,760	-	15,622
NH-24 bridge	4,250	-	-	-	-
Selected bridge point	3,572	208.33	4,900	208.82	3,572

Source: JICA Study Team

After completion of the bridge construction across Yamuna River, the design affluxed HFL at the point will be effected by the bridge length. The bridge length is proposed to be 600 m, the design affluxed HFL and the discharge volume are re-calculated for 50 year and 100 year return periods. The results of these re-calculation are shown in Table 7.1.7.

As same as Yamuna River, the design affluxed HFL at the point of Hindan River will be effected by the bridge length. The bridge length is proposed to be 200 m or 240 m, the design affluxed HFL and discharge volume were re-calculated for 50 year and 100 year return periods. The results of the re-calculation are shown in Table 7.1.8.

Table 7.1.7 Affluxed HFL of Yamuna bridge

Bridge length (m)	50 year return period			100 year return period		
	Discharge (m3/sec)	HFL (elevation)	Velocity of flow (m/sec)	Discharge (m3/sec)	HFL (elevation)	Velocity of flow (m/sec)
Before construction	11,400	216.98		14,400	217.24	
600 m	11,401	218.89	2.768	12,792	219.45	2.897

Source: JICA Study Team

Table 7.1.8 Affluxed HFL on Hindon bridge

Bridge length (m)	50 year return period			100 year return period		
	Discharge (m3/sec)	HFL (elevation)	Velocity of flow (m/sec)	Discharge (m3/sec)	HFL (elevation)	Velocity of flow (m/sec)
Before construction	3,572	208.33	-	4,900	208.82	-
200 m	3,575	210.45	3.449	4,915	211.90	3.913
240 m	-	-	-	4,917	210.26	3.585

Source: JICA Study Team

7.2 Control Factors in Route Selection

7.2.1 Basic Data for Route Study

The most important data for route study is a topographic map. Current topographical maps are available to a scale of 1:50,000 and 1:25,000 in the study area. The maps of 1:50,000 has a reasonable accuracy in terms of topography, however, for the study area these maps are surveyed around 1970 to 1977, and considered to be very old for geographic information including expansion of urban area and villages, land use changes, new roads and other transportation alignments. The maps of 1:25,000 are based on more recent survey, which were carried out mostly in 1990 to 1991. These 1:25,000 maps, however, cover only half of the study area, mostly Delhi and its vicinity only.

Generally in such a situation, aerial photos, photo mosaic and their mapping data are useful information for route study. In India, however, aerial photo is one of the most strictly classified information in view of national defense for both an access to already available photos and a permission for new taking.

Under these circumstances, the Study Team decided to use the topographic maps to a scale of 1:50,000 as a main source for alternative route selection. The required new information which is not included in the maps has been collected by the study team members by site investigation, interviews with State PWDs, and the result of the social survey. In fact, a lot of changes are observed in Delhi and its adjacent vicinity, however, the social survey and site investigation found that the study area as a whole do not have a drastic change from the available mapping information indicated in 1:50,000 maps in terms of urbanization and locations of control points. It is considered, therefore, that the investigated data together with the topographic maps will reflect the present geographic conditions with a reasonable accuracy for carrying out the route study. The result was ensured by a satellite image which was obtained before the study team left Delhi at the end of the first working period in India.

7.2.2 Interchange Locations

Location of JUNCTION (i.e. expressway-to-expressway interchanging facility; JCT) and INTERCHANGE (i.e. expressway-to-artery (at-grade) interchanging facility; IC) is one of the major governing factors in selecting the expressway routes. Since K-G and G-M Expressways are not isolated expressway sections but a part of 'NCR Expressway Network', (1) a Junction for the connection of K-G and G-M

Expressways at north of Ghaziabad, and the terminal interchange locations of (2) Kundli (NH01), (3) Ghaziabad(NH24) and (4) Meerut (SH14) are considered as given conditions in the study.

The locations of other intermediate interchanges are studied in view of:

(i) interchange intervals,
(ii) connection to major arterial highways, and
(iii) locations of urban area, regional centers and other major traffic generators.

For K-G Expressway it is considered appropriate to locate an interchange on State Highway 57 near Khekra. In addition to its access to SH57, this location gives an access to the town of Khekra (1996 Population = 41,000), one of major urban areas in this area, and Tronica Industrial City along SH57, a large-scale industrial city under construction. For G-M Expressway it is considered appropriate to locate an interchange at Modinagar (1996 Population = 143,000) in view of the size of the city, and its industrial aspect.

As a summary, the interchange locations and the intervals are shown in Figure 8.2.1. Since Ghaziabad North JCT will not have a service for connection to at-grade arterial road, the interchange intervals for Khekra - Ghaziabad will be 34.4 km, and the same for Modinagar - Ghaziabad will be 23.3 km. Although the interval of 34.4 km between Khekra and Ghaziabad is considered a little too long, an additional interchange will not be necessary in this area since there is no major urban area nor major access highways at present. The additional interchange can be planned in the future when a major urban development or new radial highway is planned in this area.

7.2.3 Major Control Points

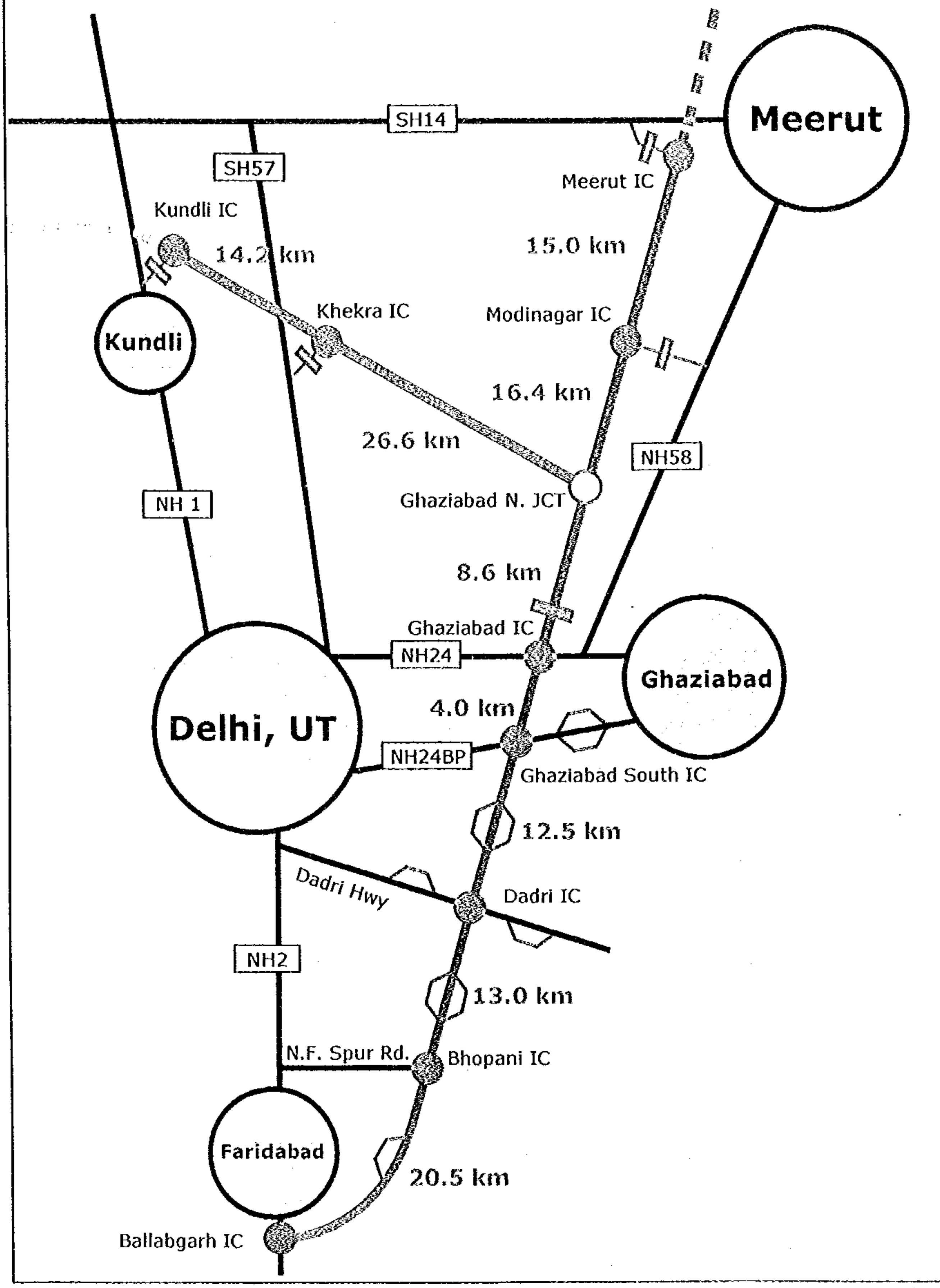
(1) Topography, Geology and River System

The study area is basically in plain terrain at the altitude of 200m - 225 m. As is shown in Figure 7.1.1, the east side of Yamuna River is forming a ridge, which is roughly 10 m higher than the west side. K-G Expressway will cross over two major rivers of Yamuna and Hindan. Particularly, since Yamuna River has a more flooding history, the river crossing point was carefully studied.

(2) Village Communities, Religious Points and Public Buildings

Village communities are interspersed throughout the study area. A division of the communities should be avoided as much as possible. The result of the social survey

Figure 7.2.1: Interchange Locations for G-M, K-G & FNG Expressways



shows that religious buildings of Hindu temples, Islamic mosques and graveyards are mostly located within the communities, and they can be mostly avoided by keeping away from village communities. It is also identified that most of public buildings of schools and hospitals are within the communities. Many villages have State Tube Wells (STW) constructed by the State Governments for a water resource. These are also an important public facilities to be avoided as much as possible.

(3) Main Power Lines and Substations

Crossing main power lines are sometimes unavoidable. FNG Expressway alignment will cross a main power line at the location of Ghaziabad IC on NH24, which must be relocated at the time of construction. When main power lines run in parallel with expressway alignment, it is important to avoid unnecessary crossings wherever possible. This is particularly critical in the case of G-M Expressway. A few main power lines run along NH58 at its west side, which will run closely in parallel with the proposed expressway alignment. Several major substations are also located along these power lines. These locations are also carefully avoided in the route study.

(4) Industrial Plants and Agricultural Plantations

Industrial plants are located in some of the urban areas in the study area. For land acquisition difficulty in terms of cost and negotiation, these must be avoided as much as possible. Many brick factories are observed all over the study area, the number of which are so many that it seems difficult to avoid all of them. There are, however, several concentrated brick factory areas, and these concentrated areas are to be avoided as much as possible. Agricultural plantations are observed in many part of the study area because of its rich land characteristics. Particularly, a large scale mango plantation around the town of Rataul located between Yamuna and Hindan Rivers are considered as a major control point.

7.3 Alternative Routes and Engineering Comparison

7.3.1 Basic Policies for Route Selection

Since K-G and G-M Expressways are not an independent highway stretch but form a part of 'NCR Expressway Network', the alignment study must be carried out based on the relationship with other part of the network. The west terminal location of K-G Expressway at Kundli on National Highway No. 1, from which it will extend to Peripheral Expressway in future, is proposed by Haryama PWD based on the previous analysis. The south-east terminal location at Ghaziabad on National Highway No. 24

is already fixed by FNG Expressway study. Although the terminal location at Meerut has not been fixed and has a flexibility for the interchange location, it has very limited options due to its access conditions and urban planning constraints.

Under these circumstances the freedom of setting alternative routes are limited. the topographical conditions in the study area are homogeneous, which tends to make alignment alternatives quite homogeneous in terms of length and construction cost. Though a preliminary cost analysis is made for comparison, it is predicted that construction cost is not a critical element to select the optimum route, particularly for G-M Expressway.

The identification of alignment alternatives and optimum route selection process, therefore, should consider more social and environmental aspects of the alignment alternatives. Particularly, how to avoid major control points will be an important issue in the process of optimum route selection. It is also important to predict the difficulty in right-of-way acquisition since it is a general tendency that right-of-way acquisition is a major controlling factor in project implementation schedule in India, as well as in many other countries.

7.3.2 Description of Alternative Routes

In view of the described policies, the alternatives for alignment were identified. Three alternatives for each of K-G and G-M Expressways have been established for comparison in the route study as shown in Figure 7.3.1. A brief description of each route for each project is presented below.

(1) Kundli - Ghaziabad Expressway

Route No.1

This alternative is based on the preliminary alignment proposed by U.P. PWD. After separated at Ghaziabad North JCT, it will pass around the town of Rataul and its large mango plantation areas at the northern side, also passes the town of Khekra at the northern side. The river crossing points both at Yamina and Hindan Rivers are selected to have as close as a right angle against the river flow. It also avoids a recent (past 30 year) meandering area of Yamuna which is located to the west of Khekra. The alignment is able to achieve larger radii of curves through the way.

Route No. 2

This alternative tries to pass around Rataul, the mango plantation area, and Khekra at their southern side. It also tries to cross Yamuna and Hindan Rivers with as close as a right angle. Since it avoids the meandering point of Yamuna at its southern side, the alignment will change the direction to north at the west side of Yamuna River to approach the Kundli IC location. A major advantage of this alternative is that it is closer to Tronica Industrial City from Khekra IC on SH57. Although its alignment has smaller radii of curves compared with Route No. 1, the radii are all more than 2,000 m, which are 3 times larger than the regulated minimum radius, and will not be a problem in horizontal alignment. Its disadvantages are: a) it must pass through concentrated brick factory areas at the south of Khekra, and b) it passes through the west side of Yamuna where future urbanization, as an expansion of Delhi, is expected, and c) it must pass over a major irrigation canal, Drain No. 8, which flows into Yamuna from the west side.

Route No. 3

This alternative tries to follow the alignment of Route No. 2, and shift to Route No.1 between Rataul and Khekra in order to avoid the disadvantages of Route No. 2 mentioned above. However, it also looses the advantage of closer access to Tronica Industrial City. An advantage is that the alignment is closer to Delhi in the Hindan River area, so that it will have a better access to Delhi when future development of this area proceeds with an additional interchange.

(2) Ghaziabad - Meerut Expressway

The identified alternatives for throughway are three, however, the two alternative locations for Meerut IC give two alternatives to each throughway route. The throughway alternatives are described as Route 1, 2 and 3, and the Meerut IC location alternatives are additionally described as Route 1-1 and 1-2, and so on. This makes the total number of alternatives to be six for G-M Expressway as in Figure 8.3.1.

Meerut IC Alternatives (Route 1-1 and 1-2)

Aside from the discussion of the throughway alternatives, two alternatives were identified for the location of Meerut IC on SH14. The original location was 1 km west of the intersection between NH58 bypass and SH14, which is planned to avoid the congestion of the bypass intersection, and yet tries to minimize the access length to Meerut urban center (Route 1-2). This route however will be a rivalry route with the proposed Meerut Circumferential Road planned under the Meerut City Master Plan.

The second alternative location is proposed to conform the interchange location and the last 4 km section to the proposed Meerut Circumferential Road (Route 1-1). It is considered more appropriate to conform to the master plan, though the interchange location itself is relatively distant from Meerut urban center with this alternative.

Route No. 1 (1-1 and 1-2)

Like K-G Expressway, this alternative is based on the preliminary alignment proposed by U.P. PWD. This alternative tries to minimize its influence to the existing ribbon development along NH58 by keeping a certain distance from the NH58. As a result, it achieves a smooth alignment with larger radii of curves all through the corridor.

Since the section near Ghaziabad cannot avoid passing through a new town area near the intersection between NH24 and NH58, the curve should adopt a smaller radius of 1,500 m, which is the smallest horizontal curve throughout the alignment. This section is common to all of the alternative routes.

Route No. 2 (2-1 and 2-2)

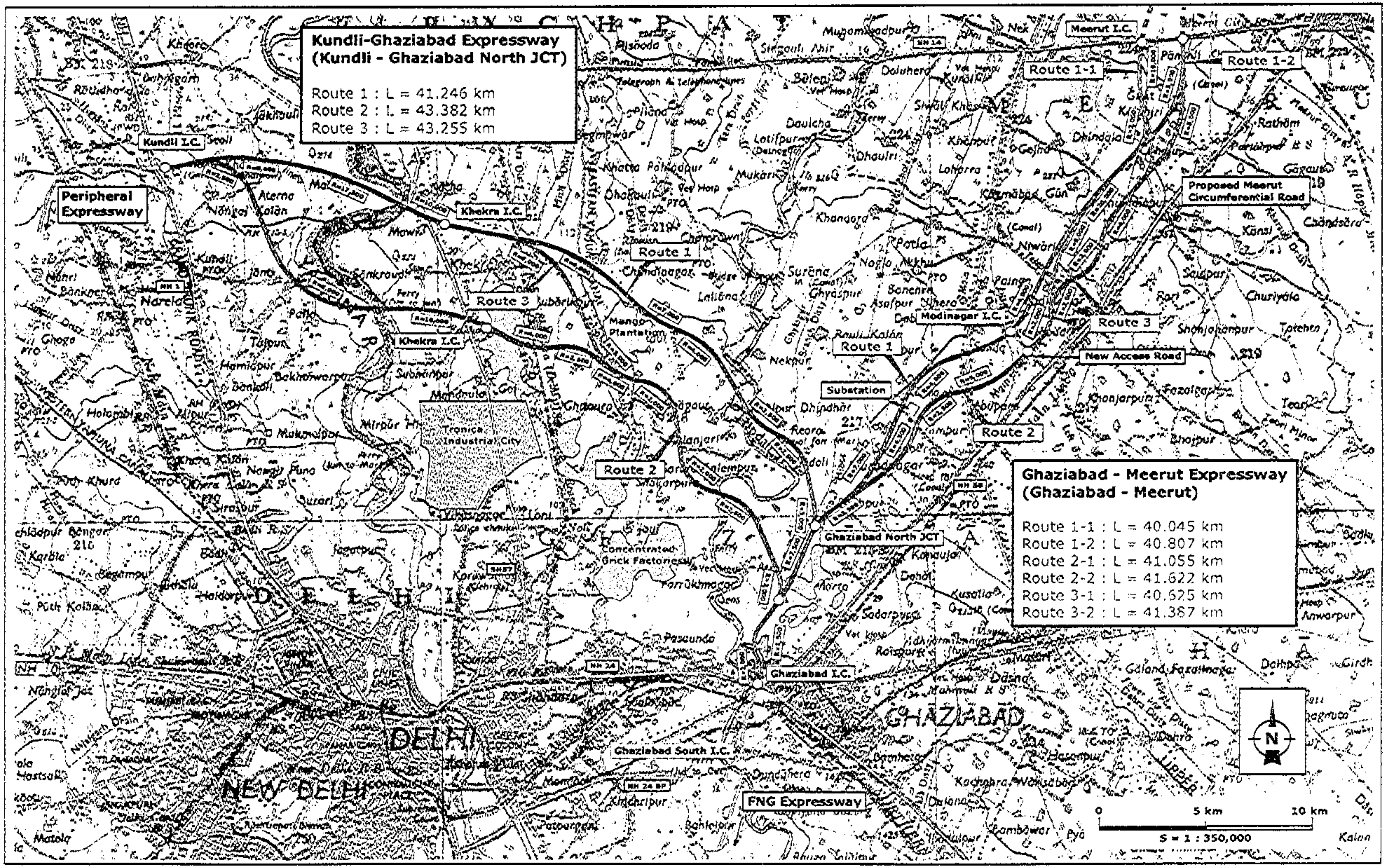
This alternative is identified in order to minimize an access length from Modinagar IC to NH58. The best existing candidate as the access road between NH58 and Modinagar IC is the existing road section between Modinagar urban center and Niwari. However, this road is not appropriate as the expressway access, since it is already very busy with local traffic, market activities and non-motorized vehicles. It is, therefore, highly recommended that a new access road be provided for Modinagar IC. This alternative is able to achieve less access road length by shifting the alignment closer to NH58 as a whole. For achieving it, however, the alignment has to pass through more urbanized areas near NH58, and as a result it requires to adopt more winding alignment. Although the smallest radii of curves is 2,000 m on this alignment it is still much larger than the regulated minimum.

The section between Ghaziabad IC and Ghaziabad North JCT has a very little room for setting alternatives because the area has been already occupied with many industrial, residential and agricultural activities, particularly concentrated brick factories. This section, therefore, has a common alignment to Route 1.

Route No. 3 (3-1 and 3-2)

This alternative tries to take an advantage of Route 2 for Modinagar IC access, and yet

Figure 7.3.1: Alternative Routes for Kundli-Ghaziabad Expressway and Ghaziabad-Meerut Expressway



to avoid smaller curves between Modinagar IC and Meerut IC by shifting the alignment from Route 2 to Route 1.

7.3.3 Optimum Route from Engineering Viewpoints

Although the final decision on optimum route selection will depend on the result of preliminary economic analysis, the features of each alternative are mostly identified through the analysis of the first stage study period. The following is a summary of the alternative route comparison, and proposals for the optimum route for each expressway segment from engineering viewpoints. The final conclusion on optimum route selection will be based on the traffic demand forecast and basic economic and financial analysis which will be carried out with the economic and financial analysis.

A summary of the following analysis is shown in Table 7.3.1 (1) for K-G Expressway, and Table 7.3.1 (2) for G-M Expressway.

(1) K-G Expressway

The geometric aspects show that Route 1 is better than the other alternatives. The alignment of Route 1 has larger horizontal curves and less number of curves. The vertical alignment was not compared among the alternative routes, however, they are mostly homogeneous except a small difference in elevation at immediate west bank of Hindan River. The location of whole expressway stretch is also in favor of Route 1 since Route 2 urges a steep change of direction at the west side of Yamuna River.

The major difference in construction features are the total length and an additional major bridge on Route 2 for Drain No. 8 at west side of Yamuna River. This contributes to the cost increase of Route 2.

All of the alternative routes are intended to avoid crossing communities as a major consideration for the route search, and which contributes to no major community divides. Route 2, however, cannot avoid some of the major brick factory concentration at the south of Khekra.

In the socio-economic aspects, the accessibility to Tronica Industrial City is a major obligatory factor. Route 2 has a shorter access to the future industrial complex than Route 1 by 3 to 5 km, which may make a difference in future traffic generation. Although the area between Khekra IC and Ghaziabad North JCT, particularly at the west bank of Hindan River, is an undeveloped area without any state highways, there is a possibility of development in the future when the city of Delhi expands. Route 2 will be considered to contribute more to the development of this area because of its location closer to NH24 and the east vicinity of Delhi. However, this will not give an immediate benefit to the expressway.

By the analysis of these overall factors, **Route No.1** is recommended as an optimum route for K-G Expressway.

(2) G-M Expressway

The total difference in kilometrage as well as elements of the alignment are not significant among the alternatives for G-M Expressway. The smallest radius appears near Ghaziabad IC to conform to the development of the new town in this area, which is a common section for all of the expressway segments. Construction features also have no significant differences among the alternatives.

The difference appears in the environmental aspects and interchange access convenience for the urban area of Modinagar. Route 2 has an advantage of shorter access road. This will contribute to the benefit in total travel distance as well as construction cost saving, if the access road is constructed in the Expressway project. However, Route 2 must have more curves to avoid many communities as it is shifted closer to the urban area of Modinagar. The alignment of Route 2 tries to follow the proposed NH58 bypass in the master plan of Modinagar to minimize its adverse effect to the urban planning, however, the expressway does not have a function of local services, and it can be an impedance to the future urban expansion.

From these analysis, **Route 1** is recommended as an optimum route for G-M Expressway.

For Meerut IC location, **Route 1-1** is considered more favorable than Route 1-2 due to its conformity to the city master plan of Meerut. It is not considered reasonable to construct an arterial highway and expressway in parallel. It is also better for future extension of this expressway to form the proposed circumferential road of itself.

Table 7.3.1(1): Comparison of Alternative Routes (1)

Kundli - Ghaziabad Expressway (Kundli - Ghaziabad North JCT)

Description	Unit	Route 1	Route 2	Route 3
A. Geometric Aspects				
1. Total Length	km	41.2	43.4	43.3
2. Number of Horizontal Curves	each	9	10	9
3. Smallest Radius	m	2,500	2,000	2,000
B. Construction Features				
1. Number of Facilities Crossed				
National/State Highways	each	2	2	2
District Roads	each	1	1	1
Railway Lines	each	1	1	1
Major Rivers and Canals	each	2	3	2
Minor Canals and Distributaries	each	6	6	6
2. Construction Works				
Earthwork Section	km	40.1	42.3	42.3
Bridge Section	km	1.1	1.1	1.0
Long Span Bridges	m	800	900	800
Other Bridges	m	258	248	238
Box Culverts	no.	9	11	15
3. Construction Cost Index		100	112	107
C. Environmental Impacts				
1. Communities Crossed	each	---	---	---
2. Brick Factory Areas Crossed	km	---	1.2	---
D. Socio-economic Aspects				
1. Service to Tronica Industrial City		Fair	Good	Fair
2. Contribution to Future Development		Fair	Good	Good
Comparison (Ranking)				
Geometry		1	3	2
Construction		1	3	2
TOTAL RANKING		1	3	2

Source: JICA Study Team

Table 7.3.1(2): Comparison of Alternative Routes (2)

Ghaziabad - Meerut Expressway (Ghaziabad IC - Meerut IC)

Description	Unit	Route 1-1	Route 2-1	Route 3-1
A. Geometric Aspects				
1. Total Length	km	40.0	41.1	40.6
2. Number of Horizontal Curves	each	10	13	12
3. Smallest Radius	m	1,500	1,500	1,500
B. Construction Features				
1. Number of Facilities Crossed				
National/State Highways	each	2	2	2
District Roads	each	3	3	3
Railway Lines	each	---	---	---
Major Rivers and Canals	each	1	1	1
Minor Canals and Distributaries	each	8	10	8
2. Construction Works				
Earthwork Section	km	39.7	40.8	40.3
Bridge Section	km	0.3	0.3	0.3
Long Span Bridges	m	100	100	100
Other Bridges	m	190	230	200
Box Culverts	no.	8	14	12
3. Construction Cost Index		100	102	101
C. Environmental Impacts				
1. Communities Crossed	km	0.9	1.4	1.4
2. Brick Factory Areas Crossed	km	0.5	0.5	0.5
D. Socio-economic Aspects				
1. Accessibility to Modinagar		Fair	Good	Good
2. Contribution to Future Development		Good	Poor	Fair
Comparison (Ranking)				
Geometry		1	3	2
Construction		1	3	2
TOTAL RANKING		1	3	2

Meerut IC Location	Route 1-1, 2-1, 3-1	Route 1-2, 2-2, 3-2
Conformity to City Master Plan	O	×
Accessibility to City Center	△	O
Total Cost Effectiveness	O	△
TOTAL RANKING FOR MEERUT IC	O	△

Source: JICA Study Team

7.3.4 Preliminary Economic Comparison

Kundli -- Ghaziabad route is characterized as a part of the ring road of Delhi Metropolitan Area. Ghaziabad - Meerut route tends to radiate to the northern direction. Those two routes of expressway are analyzed as one expressway network to select optimum route in this chapter.

There are nine alternatives by combing three routes of Kundle-Ghazabad and three routes of Ghaziabad - Meerut as shown in Table 7.3.2. Figure 7.3.2 shows the route location and distance of each section of route alternatives.

Table 7.3.2: Alternatives and Distance for Analysis of Route Priority

Alternatives	K-G Route		G-M Route	K-G Route	G-M Route	Total
Alternative 1	K-G Route 1	+	G-M Route 1	41.25	40.05	81.29
Alternative 2	K-G Route 1	+	G-M Route 2	41.25	41.06	82.30
Alternative 3	K-G Route 1	+	G-M Route 3	41.25	40.63	81.87
Alternative 4	K-G Route 2	+	G-M Route 1	43.38	40.05	83.43
Alternative 5	K-G Route 2	+	G-M Route 2	43.38	41.06	84.44
Alternative 6	K-G Route 2	+	G-M Route 3	43.38	40.63	84.01
Alternative 7	K-G Route 3	+	G-M Route 1	43.26	40.05	83.30
Alternative 8	K-G Route 3	+	G-M Route 2	43.26	41.06	84.31
Alternative 9	K-G Route 3	+	G-M Route 3	43.26	40.63	83.88

Based on the preliminary estimate of project costs, traffic demand and benefits, this section aims to select an optimum route from these nine alternatives. Derived economic indicators such as Economic Internal Rate of Return (EIRR), Benefit Cost Ratio (B/C), and Net Present Value (NPV) are summarized indicatively in Table 7.3.3 to identify the priority plan among the alternative routes.

Table 7.3.3: Indicative Priority Order Among Alternative Plans

Economic Indicator	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9
Internal Rate of Return (IRR)	100	97	98	97	94	96	97	94	96
Benefit Cost Ratio (B/C)	100	95	97	94	89	91	94	89	91
Net Present Value (NPV at 12 %)	100	89	94	92	81	86	91	79	84
Priority Order	1	4	2	5	9	6	3	8	7

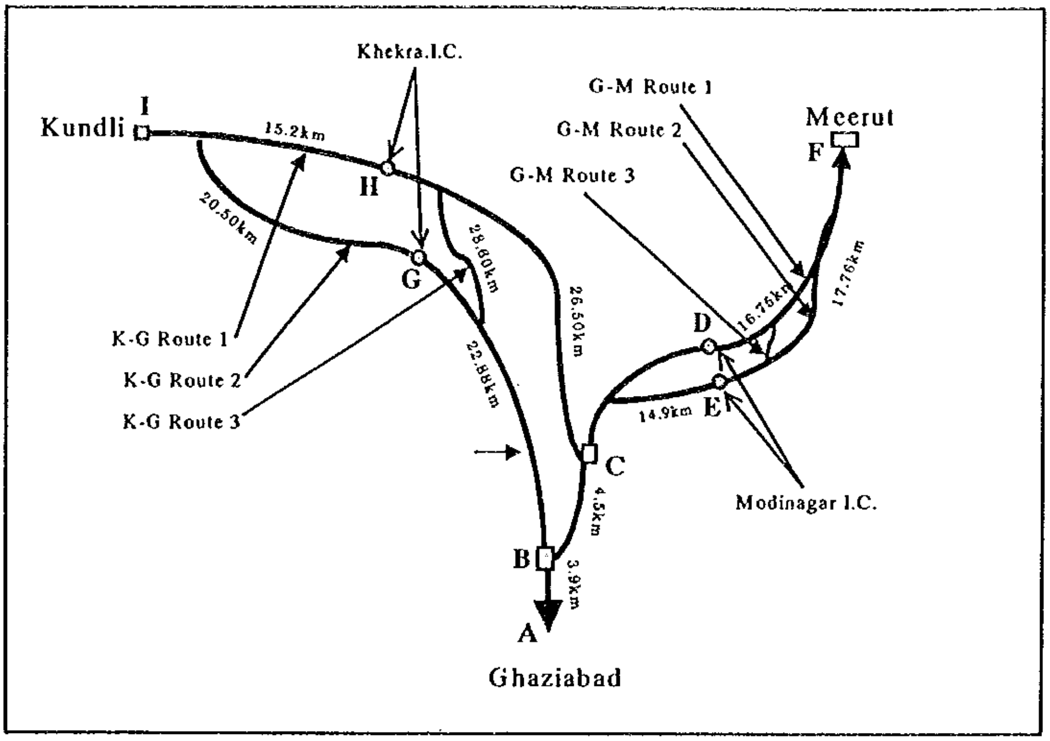


Figure 7.3.2: Alternative Routes of Project Expressway

7.4 Comprehensive Evaluation of Alternative Routes

The alternative routes were compared and evaluated from engineering, environmental and regional development aspects as shown in Table 7.4.1. As the consequence, Route 1 and Route 1-1 were selected as the priority routes for K-G Expressway and G-M Exressway, respectively.

Table 7.4.1: Comparison of Alternative Routes

Description	Kuundli-Ghaziabad Expressway			Ghaziabad-Meerut Expressway		
	Route 1	Route 2	Route 3	Route 1-1	Route 2-1	Route 3-1
Geometry	1	3	2	1	3	2
Construction	1	3	2	1	3	2
Environmental Impact	1	2	1	1	2	2
Regional Development	2	1	2	1	2	1
Total Ranking	1	3	2	1	3	2

The results of the economic analysis shows that Alternative 1 (Route 1 for K-G Expressway and Route 1-1 for G-M Expressway) is the most feasible. Hence, Alternative 1 was finally selected as the optimum route.

Regarding the extension of G-M Expressway, it is recommended, as the result of economic comparison, that the extension be open to traffic after year 2013.

CHAPTER 8:

TRAFFIC DEMAND ANALYSIS

8.1 Overview

This chapter presents the development of the methodology to analyse the impact of the KG-GM expressway system on the existing transport network. The transport model for this study will produce estimates of usage of the proposed expressways. This study methodology is not designed for the detailed analysis of the road network within the National Capital Territory of Delhi (NCTD).

The modeling procedure considers the network within the NCTD as an impedance to travel. As this impedance to travel increases in value, more traffic is shifted to the bypass roads. The expressway under study provides an alternative to the congestion of NCTD whilst also providing an expressway connection between Meerut and Ghaziabad.

This Chapter of the report is divided into three further sections namely: -

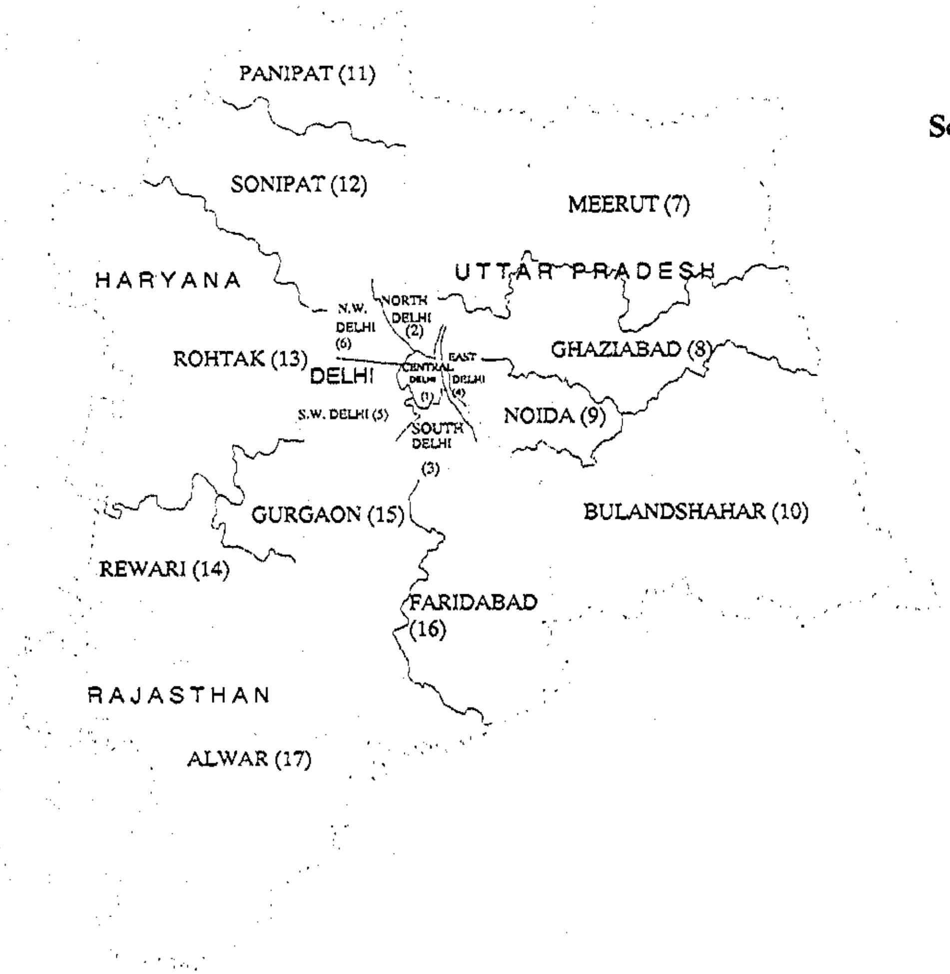
- Socio-Economic Data;
- Transport Model Development,
- Future Traffic Volume Projections; and
- Scenario Analysis

8.2 Socio-Economic Data

Zonal population, employment opportunities and per capita income projections have been prepared for the study area i.e. the National Capital Region (NCR). The methodology used in the preparation of this data is discussed in Chapter 5.

For the purpose of presentation the study area was divided into 17 sectors. These sectors are shown in Figure 8.2.1 and the population, employment and per capita income associated with these sectors are presented in Tables 8.2.1, 8.2.2 and 8.2.3 respectively.

Figure 8.2.1 Sectors in the National Capital Region of India



Sector	Sector Name	State
1.	Central Delhi	Delhi
2.	North Delhi	Delhi
3.	South Delhi	Delhi
4.	East Delhi	Delhi
5.	S.W. Delhi	Delhi
6.	N.W. Delhi	Delhi
7.	Meerut	U.P.
8.	Ghaziabad	U.P.
9.	Noida	U.P.
10.	Bulandshahar	U.P.
11.	Panipat	Haryana
12.	Sonipat	Haryana
13.	Rohtak	Haryana
14.	Rewari	Haryana
15.	Gurgaon	Haryana
16.	Faridabad	Haryana
17.	Alwar	Rajasthan

.... NCR Boundary
-.-.---- Interstate Boundary

Table 8.2.1 Population Projection by Sector (Million of People)

Sector	Sector Name	1999	2006	2016	2021
1	Central Delhi	2.81	3.08	3.25	3.28
2	North Delhi	1.11	1.53	1.99	2.14
3	South Delhi	1.89	2.39	2.86	2.99
4	East Delhi	2.09	2.63	3.10	3.21
5	S.W.Delhi	2.86	3.73	4.74	5.12
6	N.W. Delhi	2.49	3.58	4.67	4.96
7	Meerut	4.02	4.56	5.30	5.63
8	Ghaziabad	2.76	3.66	5.20	5.99
9	Noida	0.90	1.39	2.14	2.53
10	Bulandshahar	3.14	3.36	3.69	3.86
11	Panipat	1.01	1.23	1.56	1.73
12	Sonipat	1.30	1.56	1.96	2.16
13	Rohtak	1.82	2.19	2.77	3.05
14	Rewari	0.77	0.95	1.22	1.36
15	Gurgaon	1.41	1.71	2.18	2.42
16	Faridabad	2.04	2.79	3.96	4.52
17	Alwar	1.81	2.35	3.18	3.58
Total		34.22	42.68	53.76	58.52

Source: JICA Study Team

Table 8.2.2:Employment Opportunities Projection by Sector (Million of People)

Sector	Sector Name	1999	2006	2016	2021
1	Central Delhi	1.58	1.77	2.03	2.12
2	North Delhi	0.39	0.55	0.68	0.71
3	South Delhi	0.55	0.78	1.04	1.10
4	East Delhi	0.51	0.89	1.27	1.35
5	S.W.Delhi	0.76	1.30	1.80	1.90
6	N.W. Delhi	0.85	1.32	1.68	1.77
7	Meerut	0.58	0.75	1.03	1.17
8	Ghaziabad	0.50	0.76	1.23	1.50
9	Noida	0.20	0.35	0.57	0.70
10	Bulandshahar	0.23	0.25	0.29	0.30
11	Panipat	0.14	0.19	0.27	0.31
12	Sonipat	0.18	0.24	0.35	0.42
13	Rohtak	0.24	0.31	0.42	0.48
14	Rewari	0.09	0.12	0.18	0.21
15	Gurgaon	0.19	0.25	0.35	0.40
16	Faridabad	0.42	0.68	1.17	1.44
17	Alwar	0.17	0.24	0.39	0.47
	Total	7.58	10.74	14.74	16.35

Source: JICA Study Team

Table 8.2.3 Monthly Per Capita Income ('99 Rupees)

Sector	Sector Name	1999	2006	2016	2021
1	Central Delhi	2,535	2,999	4,129	4,955
2	North Delhi	2,477	2,973	4,087	4,836
3	South Delhi	2,397	2,861	3,927	4,679
4	East Delhi	2,350	2,903	4,065	4,856
5	S.W. Delhi	2,300	2,749	3,787	4,477
6	N.W. Delhi	2,266	2,727	3,728	4,425
7	Meerut	657	724	829	881
8	Ghaziabad	726	802	900	944
9	Noida	840	912	981	1,041
10	Bulandshahr	462	471	485	491
11	Panipat	1,531	1,593	1,727	1,816
12	Sonipat	1,471	1,552	1,724	1,832
13	Rohtak	1,388	1,423	1,510	1,572
14	Rewari	1,175	1,226	1,340	1,413
15	Gurgaon	1,356	1,402	1,506	1,576
16	Faridabad	1,601	1,833	2,211	2,412
17	Alwar	766	852	961	1,042

Source: JICA Study Team

These tables show that between 1999 and 2006, the overall population of NCR grows at 3.2% per annum. Whilst the per capita income increases at 3.1% per annum in the sectors of NCTD adjacent to Uttar Pradesh. Within the sector of Ghaziabad the population grows at 4.1% per annum between 1999 and 2006. Beyond 2006 the population growth slows to 2.1% per annum. However, the per capita income in East Delhi continues to grow rapidly, for example beyond 2006 the growth rate is 3.5% per annum.

A growth rate of 3.5% per annum implies that over 20 years, the variable will double if this growth is sustained over time. These high growth rates in per capita income and population have a compounding impact on the growth in traffic.

Within the transport modeling framework the other important economic parameters are the perceived vehicle operating cost and the perceived value of time.

These parameters are used in the traffic assignment procedure. This procedure assigns motorcycles and other vehicles to the network separately. This is discussed further later in this chapter.

The perceived vehicle operating costs are directly related to fuel costs; whilst the value of time was derived for cars and motor cycle.

In the preparation of the final report it is possible to test the sensitivity of estimated expressway volume to these values. In the future the value of time generally increases in the same proportion to household income.

Between 1999 and 2006, household income and per capita income will increase in a similar proportion. Beyond 2006, household size is expected to decrease. The impact of this is uncertain. The value of time is held constant beyond 2006.

8.3 Development of Transport Model

8.3.1 History of Recent Transport Models

The three most relevant recent transport studies undertaken in the last 5 years for this project are namely:

- Delhi-Noida Toll Bridge Project (Kamsax,1993);
- Transport Sector Plan and Investment Strategy-2011 National Capital Region for NCRPB in 1994;and
- Proposed Faridabad-Noida-Ghaziabad Expressway prepared for the Asian Development Bank and the Ministry of Surface Transport, March,1995

In the case of the first document, which is a reference for the other projects, NCRPB was not able to provide a copy of the report to the project team for review within an appropriate timeframe.

(1) Transport Sector Plan and Investment Strategy-2011

For the Transport Sector Plan (TSP), a four-stage transport model was developed using the transport planning software package, TRANPLAN. The study area was the NCR with 46 traffic zones within the NCTD and a further 63 zones in the remainder of the NCR.

The first phase in the model development, for person trips is a combined trip generation and modal split model. The person trip generation equation for non-walk trips in 1994 trips is given below:

Per Capita Trip Rate=0.5301*Ln(1994 Per Capita Income)-2.7688

The trip attractions were distributed on the basis of the labour force estimates, whilst the modal split was applied directly to the trip generation, no consideration was given to modal access or network characteristics. The overall modal split in favour of public transport was approximately 70%. Anecdotal evidence suggests that this has changed little since 1994.

The trip distribution in this model is based on a classical gravity model, for completeness the friction factor equation associated with the gravity model for all non-walk trip purposes is given below:

Friction Factor = 10000/(Travel Time in Minutes)^0.30702

Road networks were developed for the future years of 2001 and 2011. The traffic network assignment was developed on the basis of all or nothing travel time with a "constrained approach".

The detailed estimation methodology associated with the production of the commercial vehicle trip tables is documented in an Appendix. It was unable to obtain a copy of this appendix to the project team within an appropriate timeframe.

(2) Proposed Faridabad-Noida-Ghaziabad (FNG) Expressway Final Report

The traffic zoning system for this transport model was developed from the zoning system used in the Delhi Noida Toll Bridge Study (DNB).

The zonal trip productions by vehicle type are directly estimated from zonal demographic characteristics. In this case only the two parameters of population and employment opportunities are used in the estimation of trip ends. There is thus no link to economic growth. For the process of estimating the trip generation equations, the city is divided into nine geographic zones namely:

- South East Delhi;
- Central Delhi;
- South West Delhi;
- North East Delhi;
- East Delhi, Noida and Greater Noida;
- Faridabad;
- Ghaziabad;
- West Delhi; and
- Fringe Zones.

A trip generation equation is developed for each geographical region. In the TSP, total person trip generation is developed, whereas this approach is to directly estimate vehicle trip ends from socio-economic data.

A gravity model is then developed for distribution between the traffic zones. This type of model does not make any allowance for modal split. In the future the number of vehicles on the road grows only as a result of increases in population and employment. Bus traffic on the roads is developed in the future using a fratar model.

There is also an on going transport project by the Rail India Technical and Economic Services (RITES) to develop a detailed four-step transport model for the NCR. The development schedule of this project for RITES is apparently similar to the schedule for this project. Unfortunately NCRPB has not been able to schedule a meeting with RITES.

8.3.2 Outline of the Transport Model

The unavailability of existing transport modelling data implies that the project team will develop a model framework from our own surveys and the documented equations in the reports that have been made available to the study team.

The transport model for the analysis of the KG and GM expressway includes the four elements of a traditional transport model namely:

- Trip generation;
- Trip distribution;
- Modal Split ; and
- Traffic Assignment

In most places this model would be developed from an existing transport database. However in this instance a comprehensive transport database does not yet exist in Delhi. The structure of a typical transport database is presented in Figure 8.3.1. During this study the team relied heavily on existing data sources in the model development phase as well as results from surveys, conducted for this study.

The model flowchart is shown in Figure 8.3.2. The modal split model segment is included in the trip generation as there is a large proportion of the tripmakers who are captive to public transport mode i.e. trip makers from these households have no access to private transport. The overall model development will closely follow procedures
developed during the "Transport Sector Plan and Investment Strategy – 2011". However in the development of commercial vehicle model the approach draws on the FNG model.

The external vehicle trip tables will be developed from the recently conducted roadside interview surveys. These data together with the recently completed traffic counts will form the basis for the model calibration.

(1) Traffic Zone System

The study area in this case, the National Capital Region is divided into manageable areas for the purpose of development of the transport model. These geographical areas are referred to as traffic zones. The greater the number of zones, the smaller they can be to cover the study area. However, the larger the number of zones, the more detail is required for the development of planning data. In reality the number of zones is often determined by existing regional boundaries.

In the case of the NCTD, this is determined by the existing zoning system for Delhi, which consists of 46 zones as developed for the TSP (see Figure 8.3.3). Outside the Delhi urban area the zone boundaries have been devised to follow district or tehsil boundaries. Tehsils in close proximity to the alignment of the GM and KM expressways have been split into two. Each urban centre within the NCR has also been allocated to an individual traffic zone. In total the NCR has been divided into 97 zones (see Figure 8.3.4).

The locality description of the traffic zones outside the NCTD is described in Table 8.3.1.

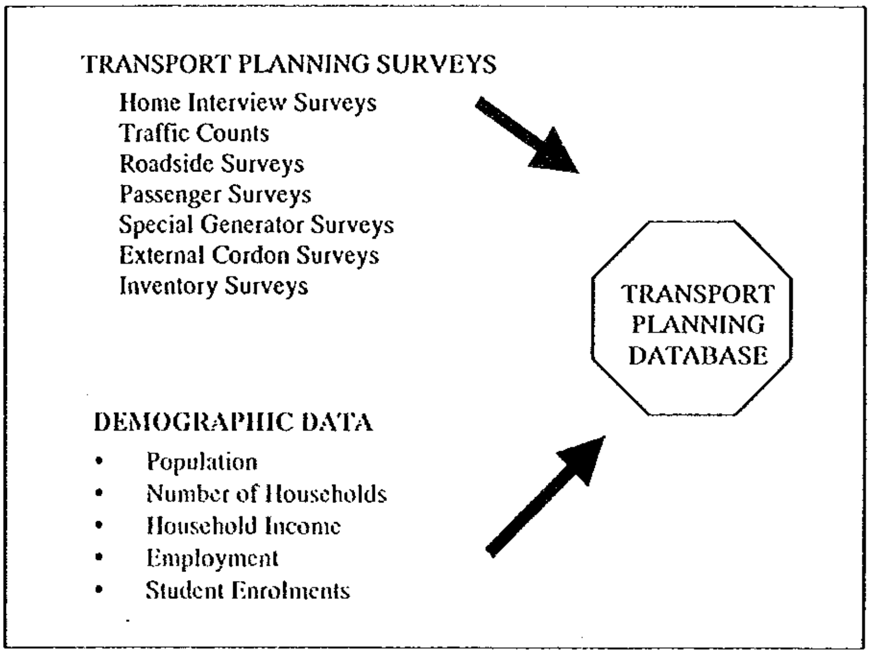


Fig 8.3.1 The Urban Transport Database

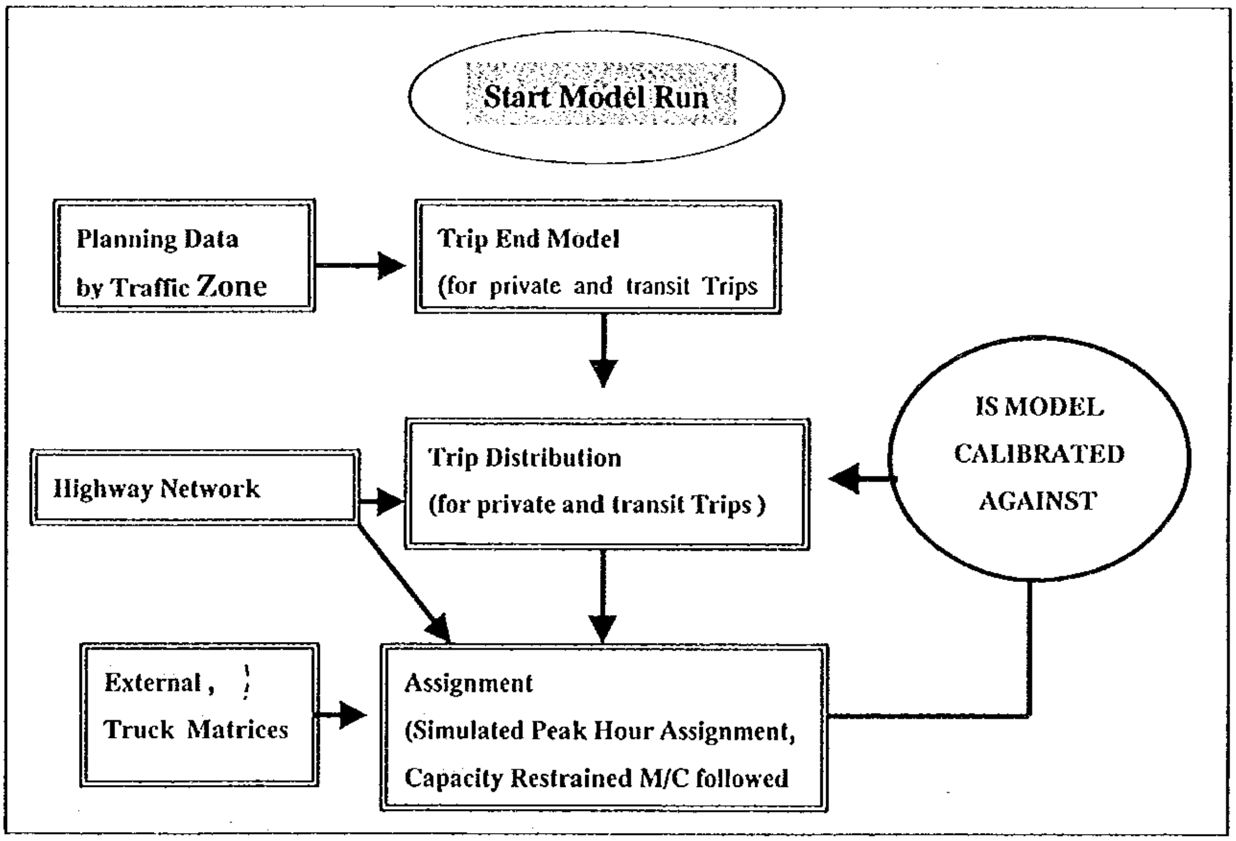


Fig 8.3.2 Model Flowchart

(2) Road Network

As discussed briefly in the earlier sections, this project is only interested in the estimation of traffic flows on the two proposed expressways. The modal split will be estimated at the trip generation stage only. For this reason there is no need to develop a public transport network.

The modelled road network for the base year is depicted in Figure 8.3.5 for the NCTD and in Figure 8.3.6 for the remainder of the NCR. Inventory data has been already collected for the network outside the NCTD. The following inventory data is available for the region namely:

- Road cross-section;
- Type of Street Lighting;
- Land Use either side of Road Reserve;
- Road Encroachment; and
- Road Surface Quality.

Inventory data within NCTD was taken from TSP.

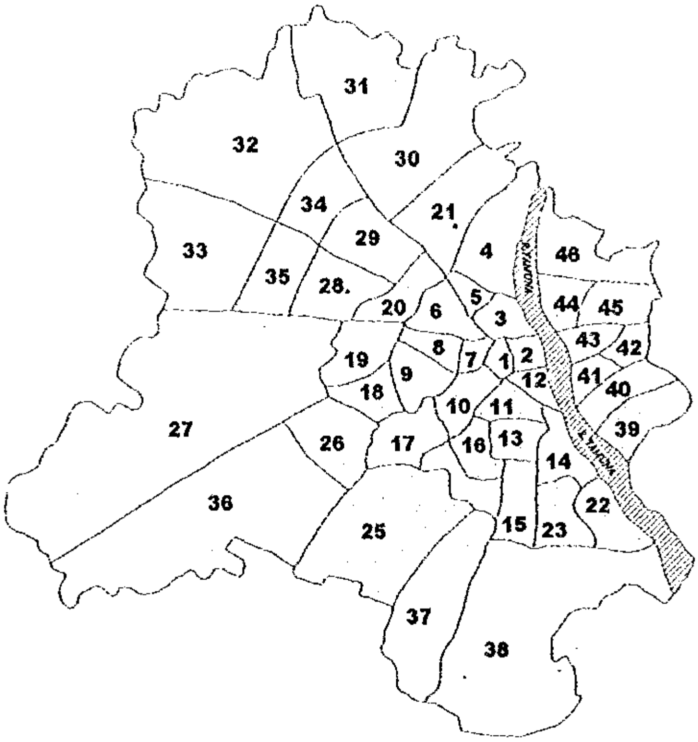


Figure 8.3.3 Zoning System Within National Capital Territory of Delhi

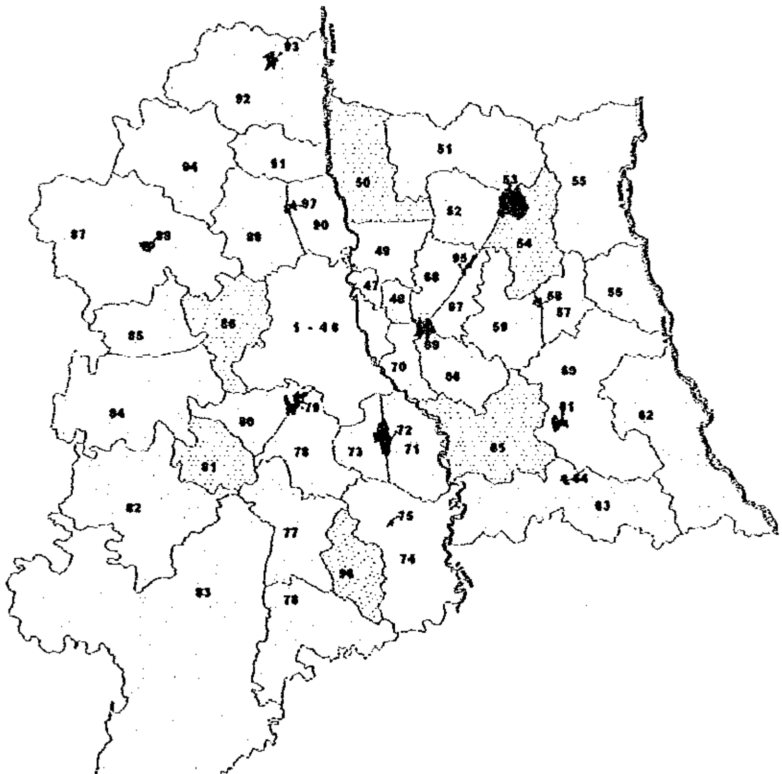


Figure 8.3.4 Zoning System Outside National Capital Territory of Delhi

Table 8.3.1(1) Description of Traffic Zones

Zone Number	Description
1-46	Delhi (same as Previous CIDA study)
47	Loni (West of Railway to Baraut includes new town of Taronica)
48	Shakapura - North of Ghaziabad Railway Line)
49	Baghpat
50	Baraut
51	Saradhana
52	Meerut-Rural Region east of Railway Line
53	Meerut- Urban Center
54	Meerut-Rural Region west of Railway Line
55	Mawana
56	GarhMuktesar
57	Hapur-Rural Region west of Railway Line
58	Hapur
59	Hapur-Rural Region east of Railway Line
60	Bulandshahar-Rural
61	Bulandshahar-Urban
62	Anupshahar
63	Khurja-Rural
64	Khurja-Urban
65	Sikandrabad
66	Dadri
67	Modinagar-Rural region west of Railway Line
68	Modinagar-Rural region east of Railway Line
69	Ghaziabad-Urban
70	Noida
71	Faridabad-Rural region east of the Railway Line
72	Faridabad-Urban
73	Faridabad-Rural region west of the Railway Line
74	Palwal-Rural
75	Palwal-Urban
76	Ferozepur Jhirka
77	Nuh

(contd.)

Table 8.3.1(2) Description of Traffic Zones

Zone Number	Description
78	Sohna-Rural Gurgaon east of the Railway Line
79	Gurgaon-Urban
80	Gurgaon-Rural west of the Railway Line
81	Pataudi
82	Rewari
83	Rajasthan
84	Jhajjar (South of road to Bahadurgarh
85	Jhajjar (North of road to Bahadurgarh
86	Bahadurgarh
87	Rohtak-Rural
88	Rohtak-Urban
89	Sonipat-Rural west of Railway line
90	Sonipat-Rural East of Railway line
91	Ganaur
92	Panipat-Rural
93	Panipat-Urban
94	Gohana
95	Modinagar-Urban
96	Hathin
97	Sonipat-Urban
External Zones	
98	West India (Gujarat and Maharashtra)
99	Eastern, Southern and Central India
100	UP (South Central) (Aligarh, Etah, Firozabad, Baduan, Mainpuri, Farrukhabad, Kanpur Rural, Kanpur Central, Allahbad, Fatehpur, Mirzapur, Sonbhadra)
101	Rest of UP
102	UP(North-East I)(Muzzafarnagar, Saharnpur, Haridwar, Dehradun, Tehri, Gharwal, Uttarkashi, Chamoli, Uttarkashi)
103	UP (North-East)(Pitthoragarh, Almora, Nainital, Rampur)
104	North India (North Punjab, Jammu & Kashmir and Himachal Pradesh
105	West Haryana, South Punjab and North Rajasthan (Sirsa, Fatehabad, Hisar, Mahendragarh, Bhiwani, Mansa, Firozpir, Bhatinda, Faridkot, Ganganagar, Hanumangarh, Bikaner, Churu, Jhunjhunu)

8.3.3 Trip Generation/Modal Split – Person Trips

The trip generation equation for non-walk trips internal to the study area was taken from TSP. These generation equations are sensitive to population and the per capita income and are time dependent. The depend variable is the per capita income stated in 1994 Rupees.

Trips Per Capita = a*Log$_{natural}$ (Per Capita Income)+b

The equation co-efficients are presented in Table 8.3.2. The inflation rates used to deflate the '99 Per Capita Incomes for zones within NCR are 10.7%, 9.1% and 8.2% for NCTD, Haryana and the remainder of the study area respectively.

Table 8.3.2 Trip Generation Equation Co-efficient

Year	a	b
1999	0.43	2.0
2001	0.40	1.7
2006	0.375	1.45
2011	0.35	1.2

Source: Transport Sector Plan & Investment Strategy, 2011

In 1999 the application of the above generation equations yield a total of 27.5 million person trips. This includes all non- walk trips for all purposes. For primary employment, it is assumed that the non-walk trips are effectively local, internal to the traffic zone. For the study area the estimate of these trips is 4.5 million, as determined from a primary employment force of three million.

Secondly, this analysis is essentially not concerned with non-motorised and rail person trips. The proportion of these trips has been estimated by the study team from surveys undertaken during the TSP.

The remainder of the trips, some 17 million are then split into private and public road transport. These modal split proportions are derived from the analysis by TSP. It is reasonable to include the modal split in the trip generation phase as it is assumed that a large number of the public transport trip makers are captive to that mode without access to the private mode of transport. These modal split is tabulated by sector in Table 8.3.3

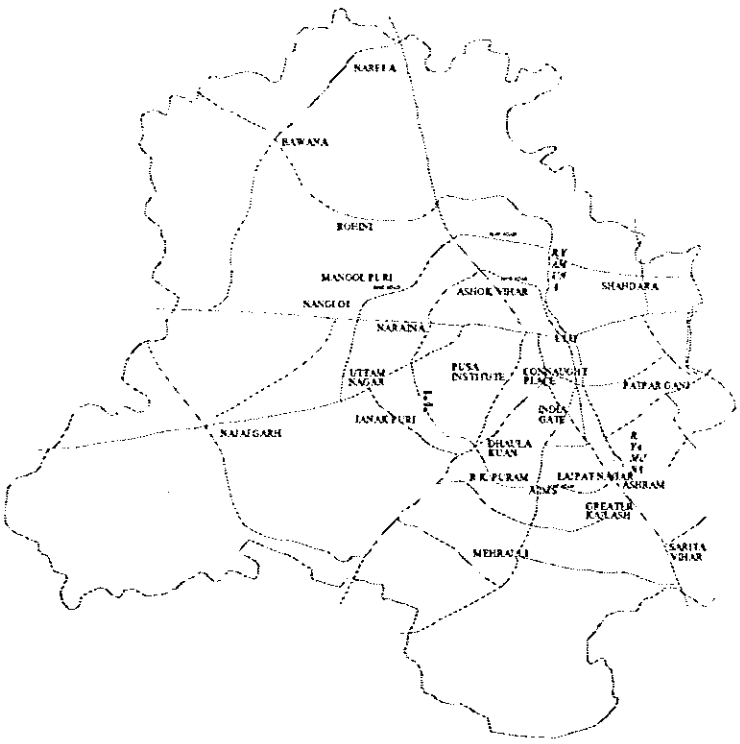


Figure 8.3.5 Road Network Within National Capital Territory of Delhi

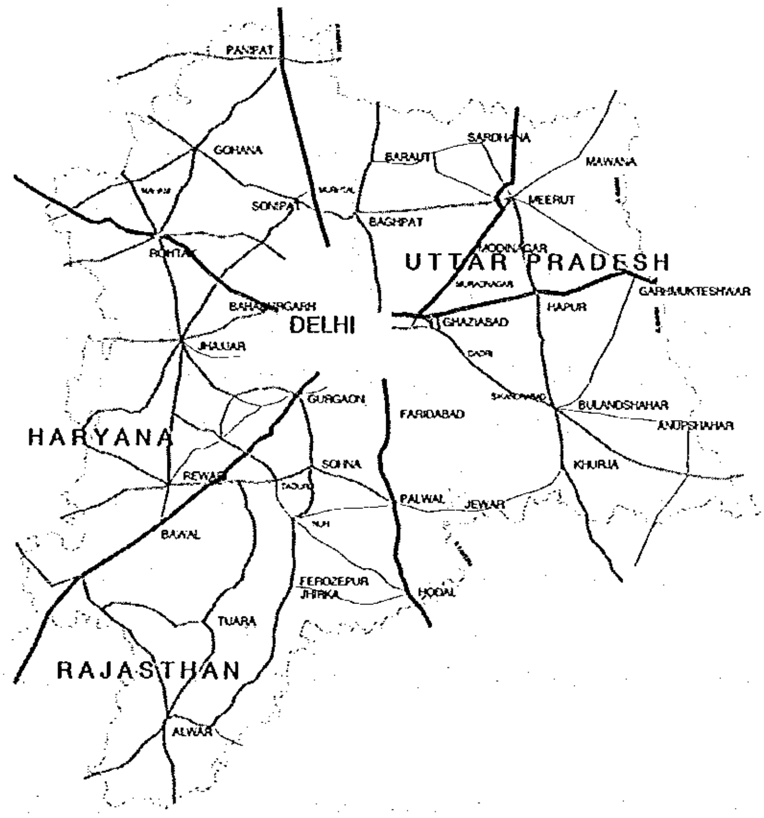


Figure 8.3.6 Road Network Outside National Capital Territory of Delhi

The trip attractions were distributed in proportion to employment. Regionally this is approximately 30% of all trips.

Table 8.3.3 Percentage Modal Split By Sector within NCR

Sector	Private Vehicle	Public	Total
1	39.3	60.7	100.0
2	30.5	69.5	100.0
3	37.1	62.9	100.0
4	36.9	63.1	100.0
5	30.8	69.2	100.0
6	29.0	71.0	100.0
7	28.7	71.3	100.0
8	46.9	53.1	100.0
9	92.8	7.2	100.0
10	46.6	53.4	100.0
11	25.0	75.0	100.0
12	44.3	55.7	100.0
13	42.1	57.9	100.0
14	21.4	78.6	100.0
15	63.2	36.8	100.0
16	52.5	47.5	100.0
17	35.4	64.6	100.0
Overall	38.2	61.8	100.0

Source: Transport Sector Plan & Investment Strategy 2011 and the JICA Study Team

In 1999 the overall trip rate per capita is 0.49 trips per person for the whole of NCR and 0.82 trips per person within the NCTD. There is a significant difference between the trip rates in NCTD and the rest of the region. This is a reflection of the significant differences in income level.

8.3.4 Trip Distribution

The trip generation procedure yields public and private mechanized non rail person trips. There is no distinction between trip purposes. From the roadside interview surveys, it was observed that more than 50% of the trips are work related.

The trip distribution equation is taken from TSP. The friction factors associated with the gravity model take the following form:

Friction Factor = 10,000*(Travel Time)$^{0.3072}$

This equation was then used in the generation of the gravity model formulation.

8.3.5 Development of External Trip Table and Partial Truck Traffic Trip Table

Trucks that would use the proposed expressways or other ring expressways were sampled in the roadside surveys undertaken for this project. An observed truck travel matrix, is developed from these relevant to the KG-GM and other ring expressways.

During the FNG project, trip generation equations were devised for trucks within the NCTD as a function of employment and population within NCTD a set of productions and attractions are estimated for the model run years. These are then used to develop growth factors for future years. Outside the NCTD changes in employment and population are used to directly generate a set of growth factors. These together with the growth factors within NCTD input in the development of the future trip table. The growth factors are applied to the observed base year truck matrix.

In the case of the external matrix, an observed external matrix is derived from the observed data. The growth factors for the external matrix are developed from the regional growth in economic activity as presented in chapter 5 of this report.

8.3.6 Development of Passenger Car Unit (PCU) Trip Tables

The earlier stage of the model development has thus produced the following trip tables:

Person Trip Table (Private Vehicle Mode);
Person Trip Table (Public Transport – Road Based);
External Trip Table; and
Truck Trip Table;

These trip tables are then combined into a PCU matrix. The vehicle occupancy factors are used in the combination of trip matrixes to produce a PCU trip table for two wheelers and other vehicles.

8.3.7 Calibration and Traffic Assignment

The vehicle assignment is an Iterative All or Nothing Equilibrium traffic assignment model. The traffic assignment was undertaken for a representative peak hour. This assumes a peak hour factor of eight percent. An equilibrium assignment approach used was based on generalized cost. Generalized cost is a function of travel time, travel distance and toll. All three variables are converted into units of cost by the application of the perceived value of time and perceived vehicle operating cost. The traffic assignment has 15 iterations in two steps with the two wheelers assigned initially to the network, followed by the remaining vehicles. This procedure is necessary as in the future the two wheelers are effectively assigned to a separate network, a network without expressways. For future years the two wheelers are not allowed access to the expressway system. The associated speed flow curves are given in Figure 8.3.7. The associated speed flow are presented for 7 road types namely:

Curve1 - Roads with One Way Capacity less than 1,000 PUC per hour;
Curve2 – Two way two lane not divided;
Curve 3 – Two way multilane not divided;
Curve 4 – Two way, two lane divided;
Curve 5 – Two way, Multilane divided;
Curve 6 – Expressway Ramps; and
Curve 7 – Expressway;

After each set of assignments iterations, the results are fed back into the gravity model until the Vehicle Kilometers of Travel (VKT) and Vehicle Hours of Travel (VHT) remain stable (see Table 8.3.5).

Table 8.3.4 Traffic Assignment Results

Variable	Set1	Set2	Set3
VKT (Million)	4.7150	4.462	4.4568
VHT (Million)	0.2159	0.2043	0.2033

Source: JICA Study Team

When the model was stable, a comparison was undertaken for three screen lines against the observed traffic counts. This comparison is shown in Table 8.3.5. All the screen lines show a variation which is less than 10%. The locations of the traffic count screen lines are shown in Figure 8.3.8.

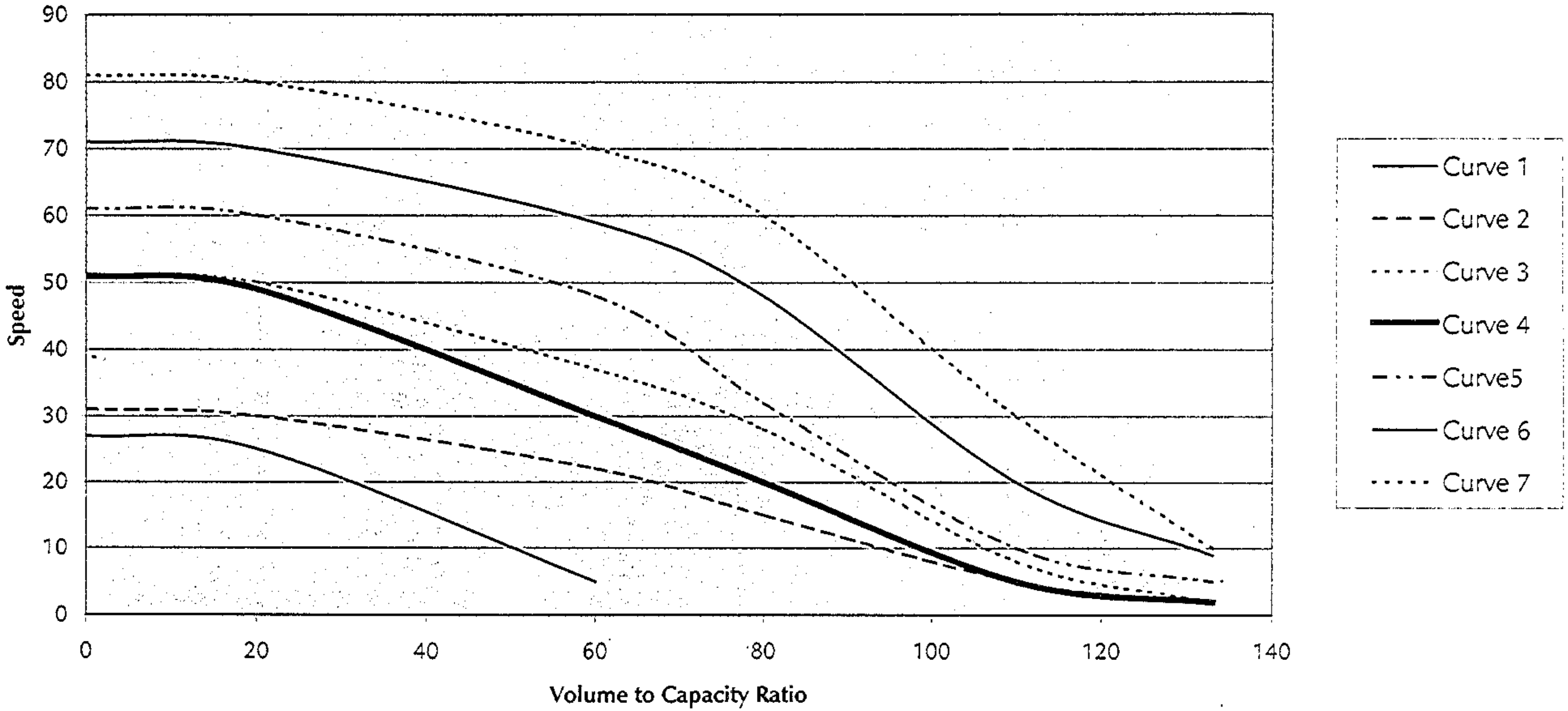


Figure 8.3.7 Speed Flow Curves

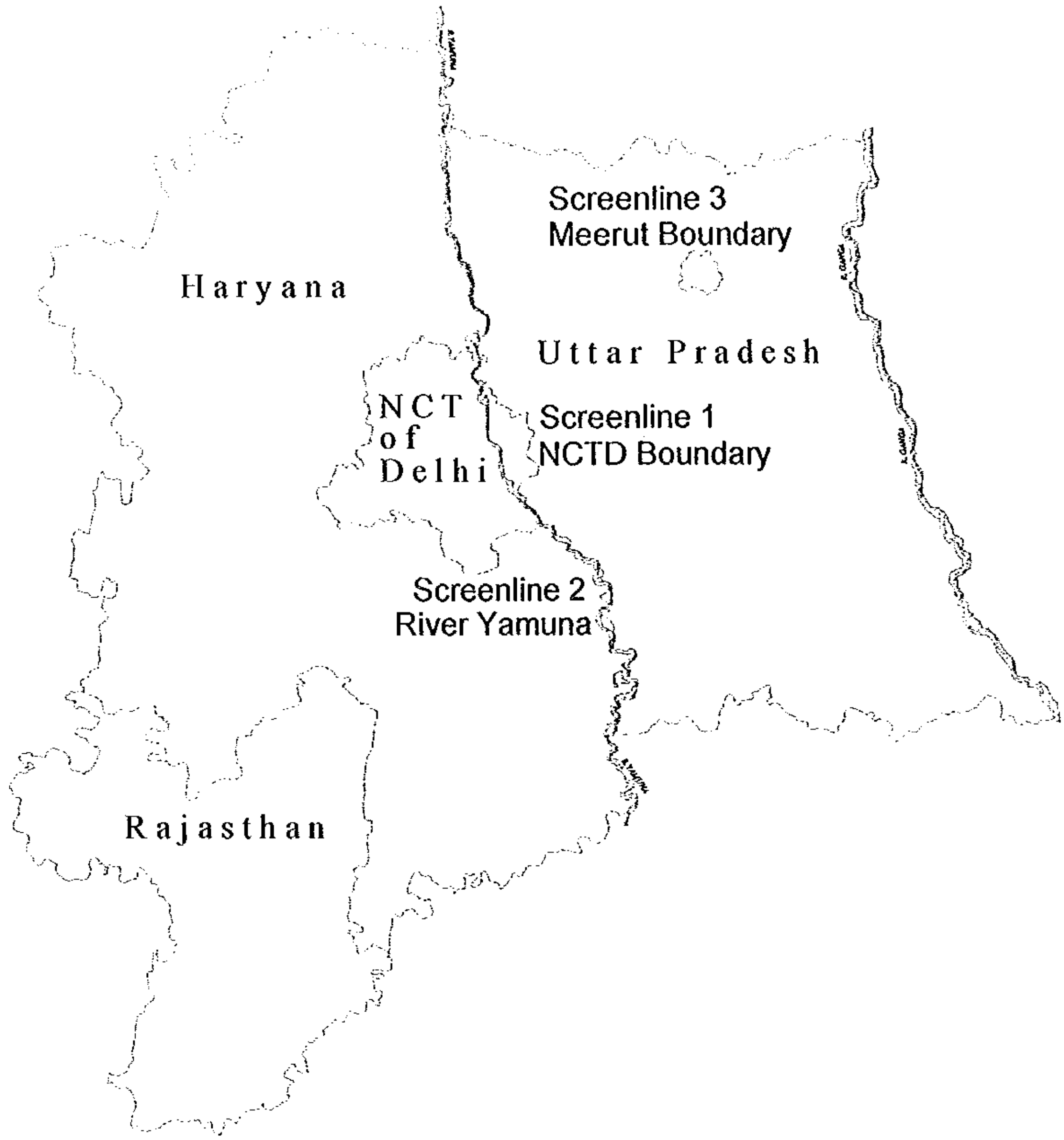


Figure 8.3.8: Location of Traffic Count Screenlines

Table 8.3.5 Daily Screen Line Comparison in PCU for Motorised Vehicles

Yamuna Screen Line	Observed	Estimated	% Difference
External (boundary of NCTD)	295,600	302,900	2.5
River	434,000	397,000	-8.5
Vicinity of Meerut	59,700	64,100	7.4

Source: JICA Study Team

In addition a comparison was made between individual link counts and the estimation of motorised traffic. The Mean Absolute Difference Ratio was used for this comparison. The relationship is defined below:

$$MAD \sim Ratio = \sum \left| \frac{Estimate - Count}{Count} \right| \frac{1}{n}$$

where n is the number of observations

Over all the observed traffic counts, this yielded a value of 0.17. Any value less than 0.30 is normally considered good.

The observed network speed in the morning peak hour varies from 20kph on the Outer Ring Road to a high of 35kph on National Highway Route 10 (see Chapter 4). The synthetic peak hour in the model, simulates an average speed of 22kph on the network with NCR. A slightly higher average speed of 26.5kph is simulated within NCTD. This average speed includes roads other than those for which observed travel time is available.

On for example the Ring Road, the observed speed varies from 19-24kph throughout the day, whilst the simulated synthetic speed is 25kph.

Overall the base year calibration reflects the observed data thus implying the calibration of all model parameters.

8.3.8 Traffic Diversion to Project Expressway

When new toll expressways are added into the network in the future year analysis, traffic is diverted to these new links. The cost of travel on these links not only includes vehicle operating cost and travel time cost but also the actual toll of the expressway. As will be seen in Section 8.4.2, when the toll is high, there is less diversion than when the toll is low.

The transport model was devised for the purpose of estimating the diversion of traffic to the expressway. The "User Opinion (Willingness to Pay) Survey" assisted in the confirmation of the model results and eventually, the verification of the estimated diversion model.

A simple diversion curve was not used in this analysis. In fact the expressway is part of complex urban network. Traffic is diverted during the iterative assignment procedure until the urban network has achieved equilibrium. Under the equilibrium condition of the network traffic arranges itself in the congested urban network such that all used routes between each origin and destination traffic zone pair have equal and minimum costs while all unused routes have greater or equal costs. In the transport modeling literature this is referred to as Wardrop's equilibrium principle.

During each iteration of the assignment model (for the Delhi model there are 15 iterations) traffic is assigned to a route according to the cost of travel. The traffic on each route will reduce the available capacity and thus the speed of that route prior to the next assignment iteration. This procedure is repeated until the achievement of equilibrium of the road network.

In the User Opinion Survey, responses suggested that for a time saving of 50%, 50% divert to the toll road for a 20 Rupees toll. The results from the transport model also suggest that travel time on KG-GM will reduce by 50% the journey time between Meerut and Ghaziabad (See Table 4.5.13). These results are thus similar to the response from the User Opinion Survey.

8.4 Estimation of Future Traffic on Project Expressway

8.4.1 Network Configurations

Between now and 2006, the proposed opening year of the KG and GM expressways, several planned major road infrastructure projects are scheduled for completion. It is expected that major projects such as the Noida Toll Bridge and the Faridabad-Noida-Ghaziabad (FNG) expressway would also be operational. Hence these have been included in the base network. Some network changes are also likely to occur within NCTD like the construction of flyovers over Ring Road and other important arterial roads. These changes will increase the capacity of network within NCTD. Therefore the capacity of the traffic assignment network is increased to reflect this additional road capacity.

By the year 2011, the transport network plan as proposed in the Regional Plan 2001 prepared by NCRPB is scheduled for implementation and consequently this plan has been reviewed in the preparation of future year networks. This plan includes the following major road infrastructure proposals namely :

- Peripheral Expressway: This expressway will follow the southern and western boundary of Delhi. It will start from Kundli (terminal point of KG Expressway) with interchange connections with NH2 at Kundli, NH 10 at Tikri Border, NH8 at Kapashera Border and finally terminate at Faridabad linking to the terminal point of the FNG Expressway;
- Delhi Sonipat Panipat Expressway(DSP) : This expressway is in the planning stage. It will commence at Panipat. It is expected to have interchanges at Murthal, Bhalgarh and Kundli;
- Delhi Noida Khurja Aligarh Expressway(DNK) : This expressway is also in the planning stage. It is proposed on entirely new alignment parallel to the existing Main Railway Line from Delhi to Aligarh; and
- Strengthening and widening (4-laning) of the Existing roads within NCR including the upgrading of the Ring Road .

The first phase of the Mass Rapid Transit System (MRTS) is expected to be operational in 2006 (see Figure 8.4.1). It should however, be noted that the MRTS Phase 1 is not expected to have a significant impact on the proposed expressways.

The network assumptions for each year used in the development of the various transport scenarios are given in Table 8.4.1 whilst the alignment of the expressways is shown in Figure 8.4.1. In the case of the KG GM expressway, the Meerut extension is included in the networks beyond 2006.

Table 8.4.1: Major Road Network Assumptions

Project name	Year		
	2006	2016	2026
Noida Toll Bridge	✓	✓	✓
FNG Expressway	✓	✓	✓
Peripheral Expressway	×	✓	✓
Delhi Sonipat Panipat Expressway(DSP)	×	✓	✓
Strengthening and widening of Roads within NCR	✓	✓	✓
Delhi Noida Khurja Aligarh Expressway(DNK)	×	×	✓

In the scenario testing discussed in detail in the next section, the sensitivity of the traffic is tested with respect to the FNG expressway. The other network sensitivity is in respect of the individual segments of the system namely the KG or the GM segment.

8.4.2 Optimum Toll Rate

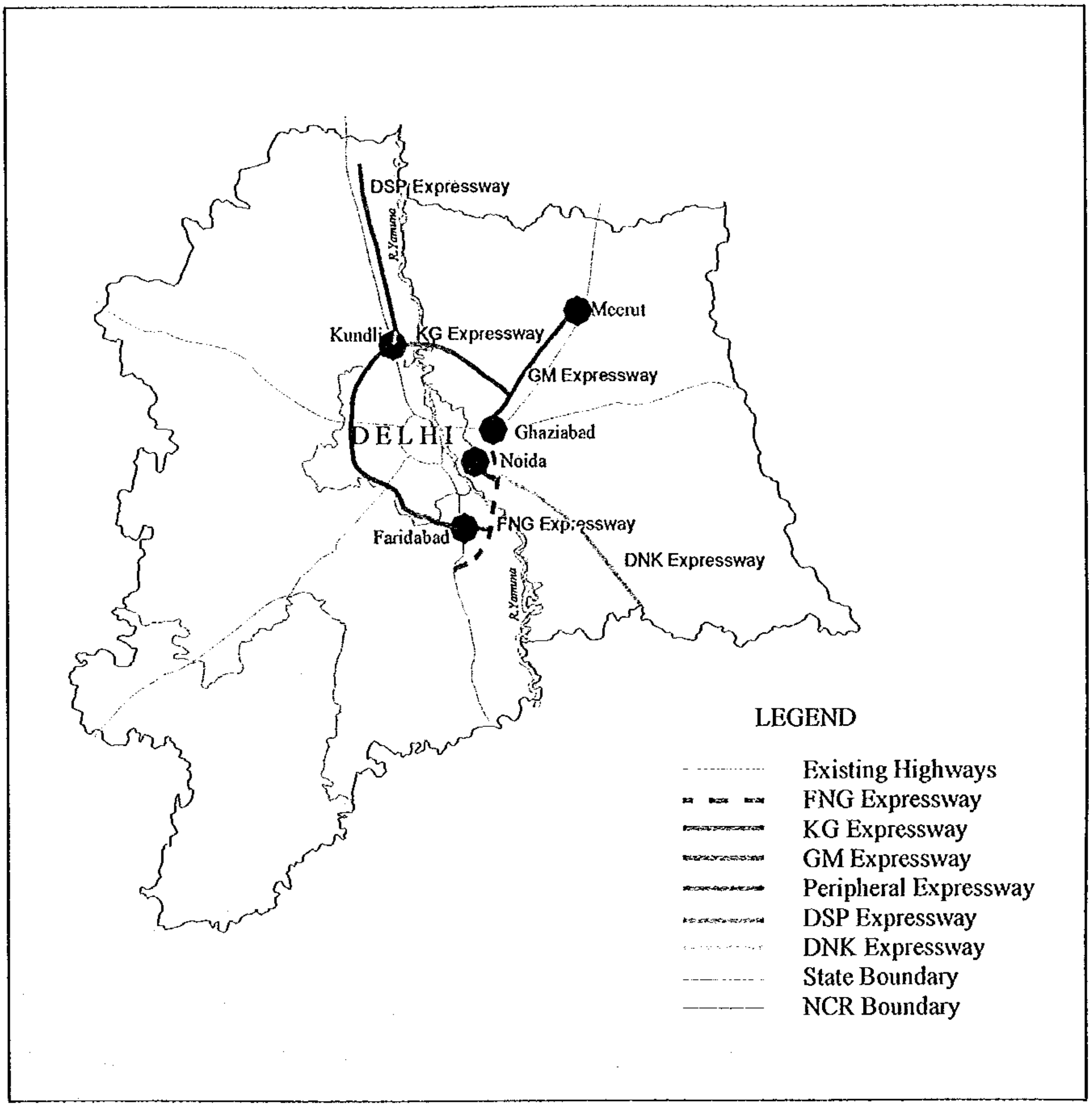
The sensitivity of the combined KG and GM system to various toll levels was analysed for five toll levels over 20 years. Every expressway in the network has the same toll for a specified scenario. For example if a toll is specified at 1.5 Rs per pcu-km, then this toll level is applied to every expressway in the system as defined in Section 8.4.1.

These results are tabulated in Table 8.4.2 for various tolls and shown pictorially in Figures 8.4.2 and 8.4.3.

Table 8.4.2: Daily Revenue('99 Thousand Rupees) as a Function of Time and Toll

Year	Toll (Rupees per pcu-km)				
	0	0.5	1.0	1.5	2.0
2006	0	1,638	2,672	2,998	2,437
2016	0	2,542	4,570	6,044	7,100
2026	0	3,915	7,177	9,870	12,040

Figure 8.4.1 Proposed Expressways within NCR



The daily revenue is shown more precisely for 2006 in Figure 8.4.4. This opening year is the most important to maximise the revenue and the figure clearly shows that revenue is maximised in 2006 at the toll level of 1.5 Rs per pcu-km.

The toll level of 1.5 Rs per pcu-km maximizes the toll revenue in 2006 and it continues to produce higher revenue then the toll level of 2.0 Rs per pcu-km until 2010(see Figure 8.4.2). Thus, the toll level to maximize the revenue varies over time. This will hence provide a basis to increase the toll level in the future, though it has to meet such criteria that the toll rate should be determined within the benefit of expressway users. The increase of toll rate will be estimated not only from revenue maximization but also from real increase of productivity in the transport sector or total economy, say by using a growth rate of income level.

As discussed in Chapter 11, Economic Analysis of the project, the toll level of 1.5 Rs per pcu-km only accounts for 32 % of the total user benefit but affords to maximize the toll revenue during the important initial operation period. Hence, this toll level should be adopted as the toll rate at the threshold of the expressway operation, and it should remain unchanged as far as the 1999 constant price is applied for the revenue calculation. An increase in toll rate will have to be discussed in the financial analysis at current price.

As expected the traffic volume on the KG GM expressway will decrease as the toll level increases, these results are tabulated in Table 8.4.3 and presented in Figure 8.4.5. Detailed results for these cases is presented as Scenario A to O in Appendix 4.

Table 8.4.3: Daily Entrance Traffic(pcu) on KG GM Expressway as a Function of Time and Toll

Year	Toll (Rupees per pcu-km)				
	0	0.5	1.0	1.5	2.0
2006	91,100	79,400	66,800	51,400	34,500
2016	134,00	124,600	115,00	106,600	94,000
2026	198,900	186,800	176,100	163,200	152,300

Figure 8.4.2: Daily Revenue as a function of Time

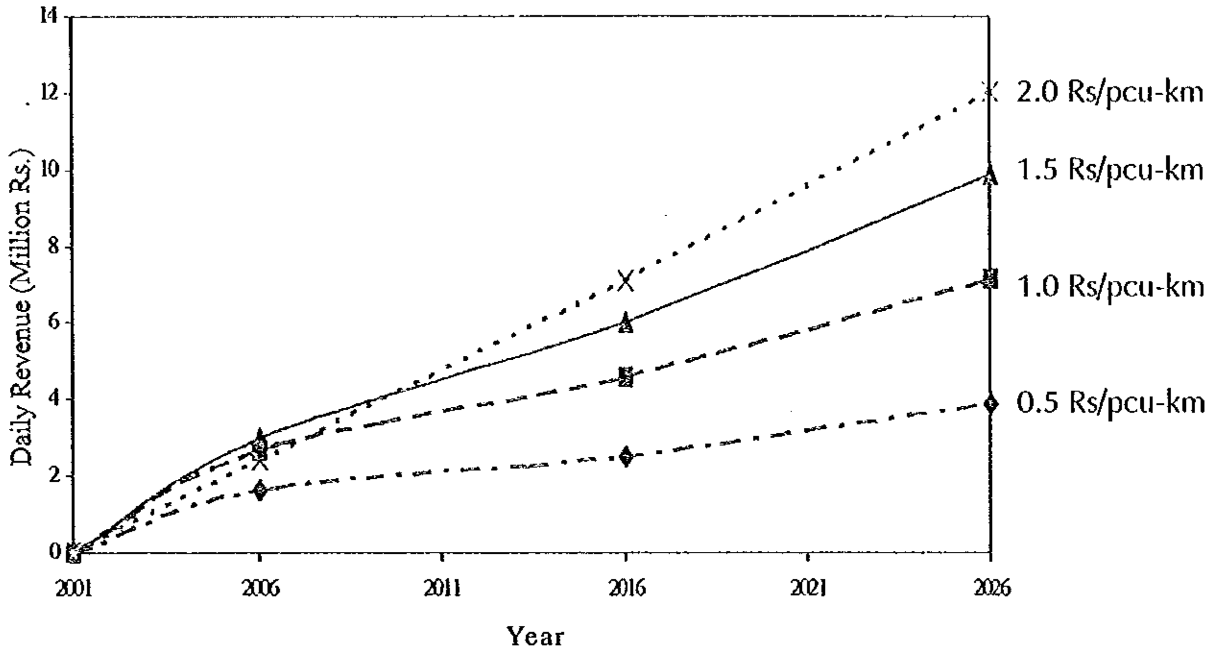


Figure 8.4.3: Daily Revenue as a function of Toll Rates

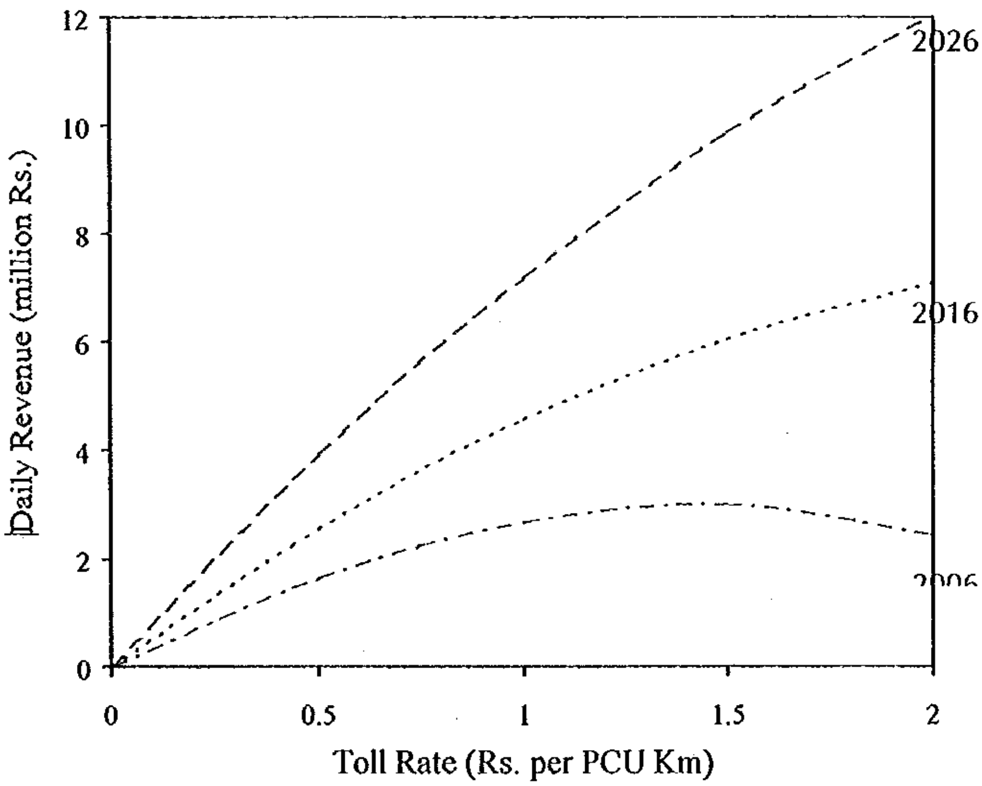


Figure 8.4.4: Toll Revenue Vs Toll Rate (KG GM Expressway) in 2006

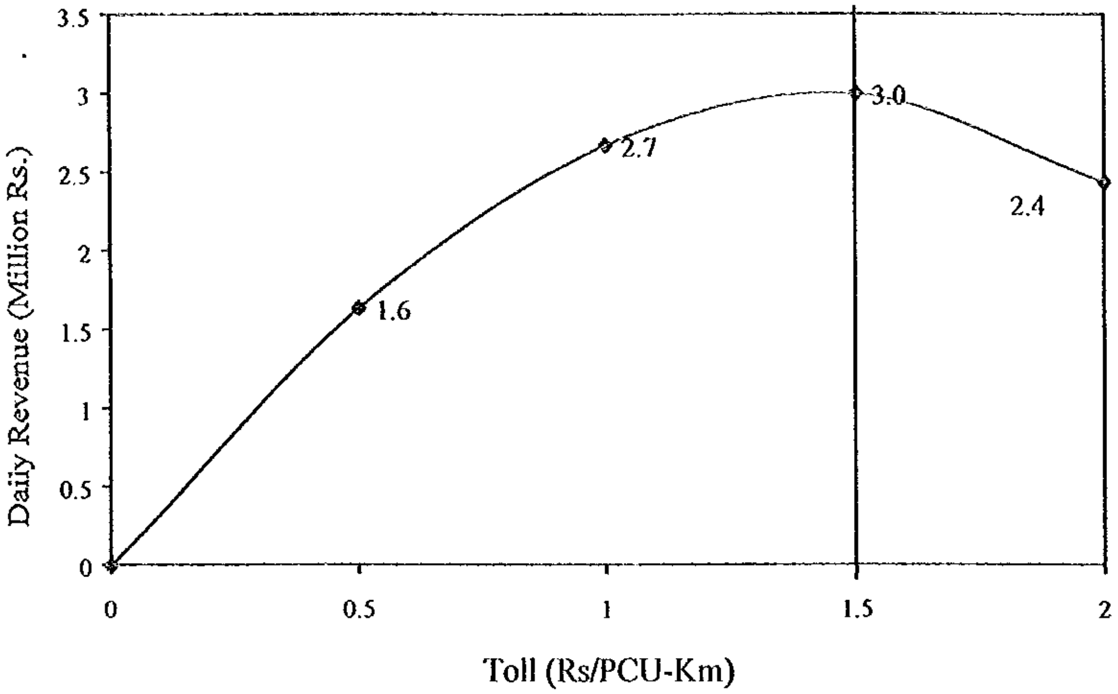
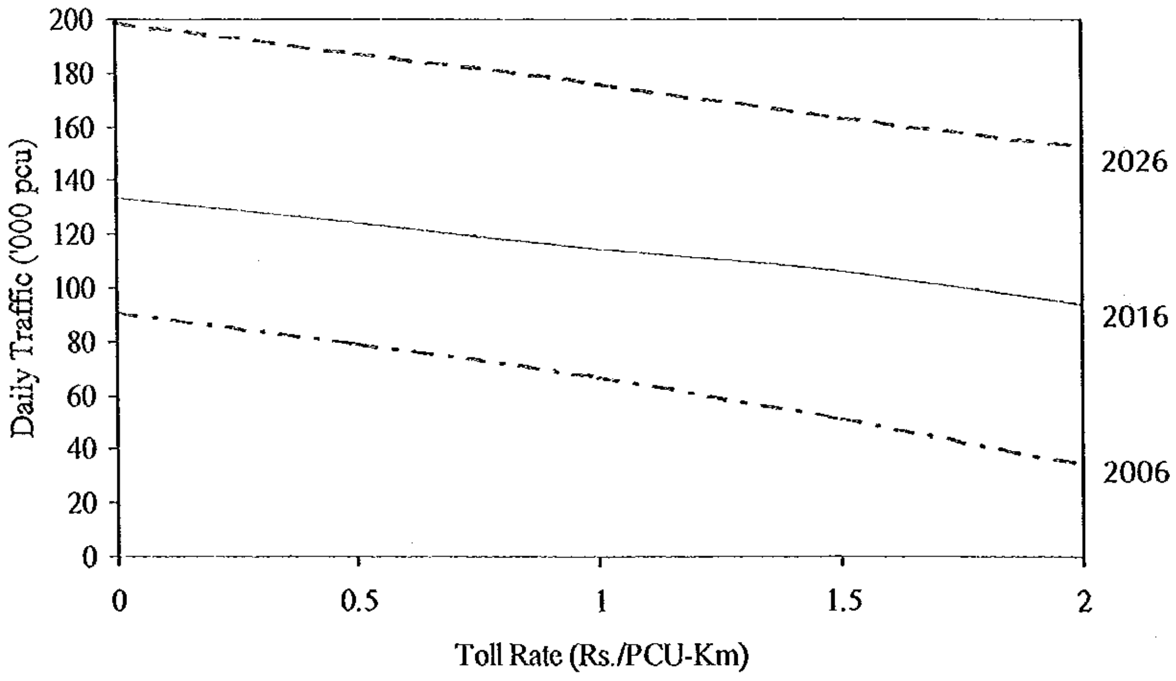


Figure 8.4.5: Daily Entrance Traffic as a function of Toll Rate



8.4.3 Assigned Traffic Volumes on Project Expressway

Between 1999 and the opening year 2006, the expected growth rate in private person trips is at a rate of 6% per annum. This is as a direct result of the high growth in population and per capita income (see section 8.2).

Between 1999 and 2021 the average per capita trip rate within NCR grows from 0.49 to 0.73 trips per person for mechanized trips excluding rail. The total growth trips is given in Table 8.4.4.

Table 8.4.4: Growth in Trips for NCR

Year	Private Person Trips (million persons)	Externals Plus Trucks (thousand PCU)
1999	16.8	313.3
2006	25.4	382.5
2016	34.9	494.2
2021	42.7	560.1

Note: Private Person Trips is all motorised person trips excluding rail.
Source: JICA Study Team

Based on the estimated transport models discussed in Sections 8.3 and 8.4 above, assigned traffic volumes on the project expressway were estimated as shown in Table 8.4.5.

Table 8.4.5: Estimated Traffic Volumes on Project Expressway

	2006 [1)]	2016 [2)]	2021 [2)]	2026 [2)]
K-G Expressway				(pcu/day)
Kundli IC – Khekra IC	41,200	67,000	87,400	112,800
Khekra IC – JUNCTION	30,900	52,900	76,100	98,100
G-M Expressway				(pcu/day)
Meerut IC – Modinagar IC	24,300	40,400	56,700	75,200
Modinagar IC – JUNCTION	27,700	50,700	75,500	101,300
JUNCTION – GhaziabadIC	43,100	74,400	102,600	132,300

Note: 1) with FNG Expressway
2) with FNG, Peripheral and G-M Expressway Meerut Extension
Source: JICA Study Team

8.5 Scenario Analysis

8.5.1 Overview

A testing program was developed with the intention to determine the optimum economic and financial combination of the two legs of the KG GM expressway in combination with the FNG expressway. Other major new road infrastructure projects discussed in the earlier section were not varied between the scenario tests.

Besides finding an optimum network the objective of the testing program was to develop an optimum toll level strategy as discussed previously in Section 8.4.2. The results from each transport scenario test were used as input into the economic and financial analysis. Over all some 50 scenarios were tested in this study. The detail results of the most important are documented in Appendix 4. The testing procedure is shown in the Flowchart in Figure 8.5.1.

The results from the transport model are input directly into the financial analysis. However for the economic analysis the transport model output in units of pcu (passenger car unit) is split into four vehicle types namely motorcycle, car, bus and truck. These vehicle categories are adopted so that the vehicle operating cost savings can be estimated by vehicle type. This breakdown varies over time and is a function of the vehicle trip length and the growth in vehicle ownership.

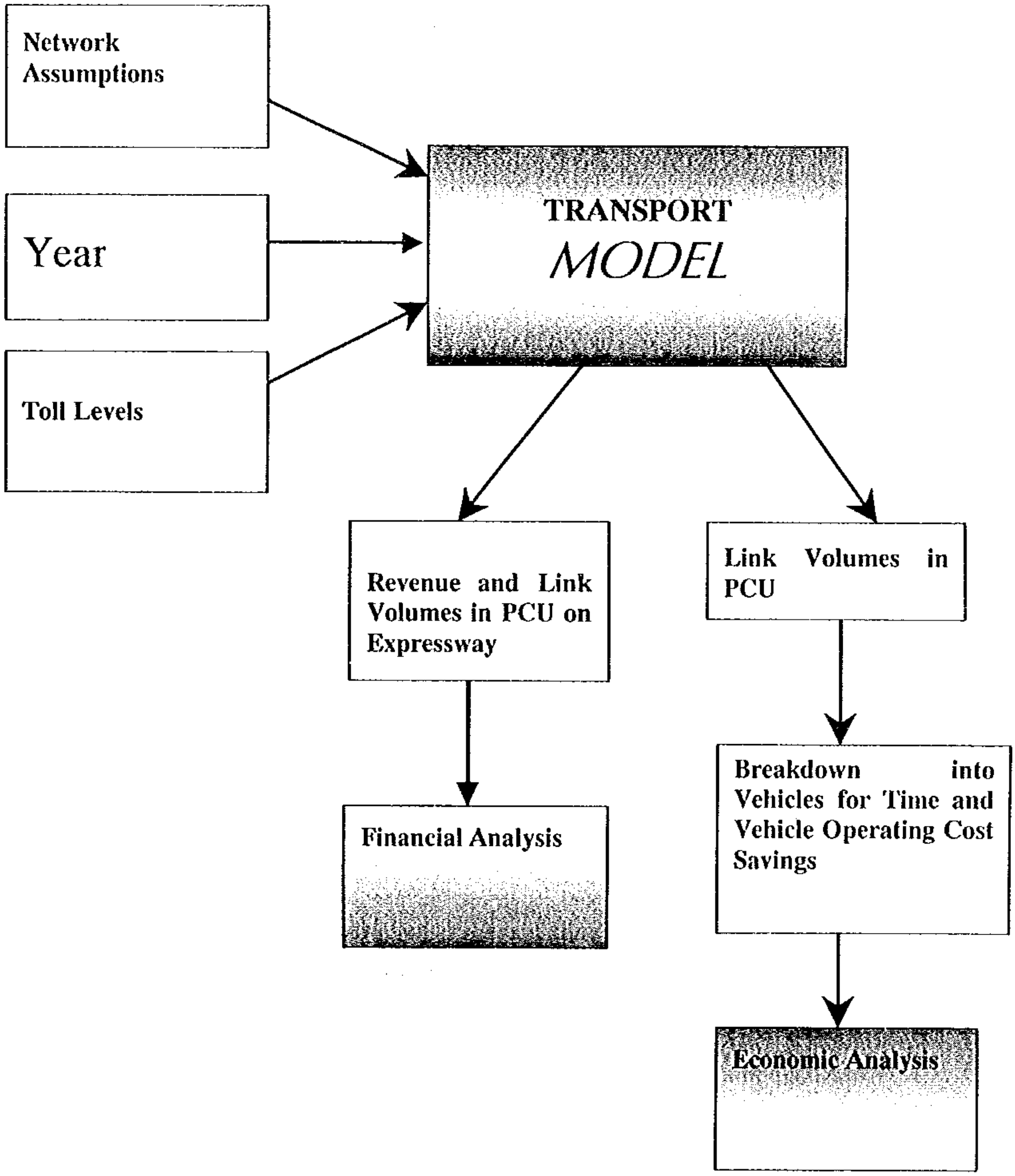
8.5.2 Traffic Assignment Results for Economic and Financial Analysis

In the case of the economic analysis, these various scenarios discussed above were compared with the scenario in which there is no expressway. The results are presented in detail as Scenarios P, Q and R in Appendix 4. In the economic evaluation the input into the analysis is the change in vehicle hours and vehicle kilometres of travel. This is prepared for 21 link classifications.

These link classifications include the three expressways composing the Ring Expressway i.e. the FNG, KG GM, and Peripheral expressway, the remaining expressways, national and state highways and other major roads. The highways and other roads are subdivided into five groups, which are a function of the lane configuration. The toll specified in the detailed results in Appendix 4 is applied equally to all expressways.

For the economic analysis an estimation of user benefit is determined from the transport model. For cases where the expressway is included in a network, the trips using the expressway are identified. These same trips are then assigned to a network without the expressway. It is thus possible to estimate the benefits to a user and hence an appropriate toll level. This is discussed further in the economic analysis.

Figure 8.5.1: Scenario Testing for KG GM Expressway



8.5.3 Sensitivity Test on Network Configuration

As a result of the economic and financial analysis the recommended toll level is 1.5 Rs per pcu-km. The network configuration sensitivity is tested at this level. The base network for each year is as described in Section 8.4.1. The sensitivity tests are undertaken for each leg of the KG GM expressway and the FNG expressway. The results are presented in Table 8.5.1 and the detailed results are documented as Scenario S to AA in Appendix 8.

Table 8.5.1: Daily Entrance Traffic(pcu) on KG GM Expressway as a Function of Network Configuration for the Toll of 1.5 Rs per pcu-km.

Network Configuration	Year		
	2006	2016	2026
Base ~~~ KG + GM + FNG	51,400	106,600	163,200
KG Only + FNG	33,600	62,400	111,800
GM Only + FNG	20,700	47,500	66,200
KG + GM, No FNG	50,700	102,700	164,300

The results clearly show that there is a significant decrease in overall expressway traffic if only one leg of the expressway is built. The construction of only the KG leg will result in significant higher traffic levels than only the construction of the GM level. The impact of the FNG on traffic levels seems to be marginal. There are the following implications:

(1) When the FNG exists the traffic on Ghaziabad IC - Junction consists of FNG traffic (35 %) and Ghaziabad IC traffic (65 %).

(2) When the FNG does not exist:

(a) Ghaziabad IC traffic increases about 10,000 pcu/day from 23,400 pcu/day to 33,500 pcu/day.

(b) the traffic between Ghaziabad and Kundli - Khekra - Meerut decreases by 2,800 pcu/day from 26,300 pcu/day to 23,500 pcu/day.

(c) the traffic between Kundli and Khekra - Modinagar - Meeriut increases by 1,200 pcu/day from 14,400 pcu/day to 15,600 pcu/day.

CHAPTER 9:

PRELIMINARY ENGINEERING DESIGN AND CONSTRUCTION PLANNING

9.1 Design Policy

Since expressway is a road facility to provide a highest level of service for road users, the alignment design should achieve sufficient safety and comfort with reasonably economical cost. The alignment should also conform to its topography, social and environmental necessity.

The horizontal curves should be as large as possible conforming to the topography, particularly for the highway sections having a consecutive high embankment sections to secure an appropriate sight distance for driving. The alignment of an expressway should have a continuous and smooth characteristics, and this should be achieved by an appropriate combination of circular curves, straight lines and transition curves.

Although the straight lines are the best alignment in terms of distance between an origin and a destination, it has been a worldwide acceptance that a long simple straight alignment for expressways should be avoided. The Japanese Expressway Design Manual published by Japan Highway Public Corporation, for example, empirically recommends that the length of straight alignment be less than 20 times of the design speed, which will be 2,400 m in case of 120 km/hr. This is because a long simple straight line often has a difficulty to conform to its topography, and the drivers on the expressway have a tendency to loose their driving caution.

This does not mean straight alignment should be avoided at all times. It means in fact that a combination of straight lines and small curves are not a smooth continuous expressway alignment. In the case of K-G and G-M Expressways, the topography is basically flat, however, it is already unreasonable to apply a long simple straight horizontal alignment due to the location of many control points.

The horizontal alignment policy, therefore, is to provide large curves to conform to the topography and to avoid control points to have a smooth visual continuation as a principle, and straight lines will be used when their application is appropriate.

9.2 Design Standards

9.2.1 Geometric Design Standard

The following Indian Road Congress (IRC) design guidelines are the present geometric design standards in India.

A. IRC:73-1980 Geometric Design Standards for Rural (Non-Urban) Highways
B. IRC:86-1983 Geometric Design Standards for Urban Roads in Plains

These standards, however, regulate design standards up to the design speed of 100 km/hr, and do not cover expressways for 120 km/hr design speed. The Ministry of Surface Transport (MOST), therefore, is now conducting a study for expressway design standards, which focuses particularly on the design speed of 120 km/hr. Currently the following reports are available, and obtained from the MOST.

C. Guidelines for Expressway Design Standards in India; Interim Report
Technical Report No. 2: Design Standards, December 1996
Technical Report No. 3: Interchanges and Toll Plazas, March 1997

Under the circumstances these guidelines will be used to the maximum extent when applicable to the Project. Further items not covered in the above guidelines are referred to other foreign standards whenever applicable. These reference foreign standards will be mainly as follows:

D. AASHTO: A Policy on Geometric Design of Highways and Streets
E. Japan Highway Public Corporation: Expressway Design Manual

A summary of geometric design standard is shown in Table 9.2.3. The major features for the standard are discussed in the following sections.

(1) Geometric Design Standard for Throughway

Design Speed

A 120 km/hr design speed is applied to the design of K-G and G-M Expressways since they will be in plain terrain, and their function will be inter-urban expressway which provides high-speed and high-capacity services with full access control. This design speed is the same as that applied to the Faridabad-NOIDA-Ghaziabad (FNG)

Expressway on which a feasibility study was completed in March 1995.

Cross Section Elements

The lane width will be 3.75 m, which is the same as in FNG Expressway intended to keep the desirable lateral clearance of 0.5 m at each side of a vehicle having a maximum width of 2.7 m referred to the revised Motor Vehicle Act of 1988.

A 3.0 m wide outer shoulder and a 0.7 m wide inner shoulder will be adopted. The outer shoulder will consist of a 0.5 m wide edge strip and a 2.5 m wide paved shoulder. The inner shoulder will be an edge strip only. A median width excluding edge strip will be 4.5 m and with a concrete safety barrier.

Horizontal Alignment

The minimum radius of curves is given by the following equation:

$R = V^2 / (127 * (e_{max} + f_{max}))$

Where, R = Minimum radius of curve (m)

V = Design speed (120 km/hr)

e_{max} = Maximum superelevation (0.06)

f_{max} = Maximum side friction factor (0.100 recommended in Guideline-C)

From the given conditions, the minimum radius of curve for 120 km/hr design speed is to be 710 m.

A maximum superelevation of 6.0 % will be adopted in accordance with Guideline-C. This value is considered reasonable since the vehicle types likely to dominate on the expressways are trucks and multi-axle vehicles, and the operational speed will be expected to fall well below the design speed in a high volume operation.

The superelevation (e) in response to a radius of curvature (R) is derived from the related table of Guideline-C. This is shown in Table 9.2.1 on the mathematical correlation between e and 1/R.

Table 9.2.1: Relation between e and R for 120 km/hr

Radius of Curves (R)	Superelevation (e)
R ≦ 1,000 m	6 %
1,000 m < R ≦ 1,400 m	5 %
1,400 m < R ≦ 1,900 m	4 %
1,900 m < R ≦ 2,700 m	3 %
2,700 m < R	2 %

Source: Computed by JICA Study Team based on Guideline-C

The superelevation runoff for 120 km/hr design speed is 0.38 % (1/263) in accordance with Guideline-C.

The minimum radius of curves, the minimum length of curves, the minimum radius of normal crown without superelevation, the minimum transition length, the minimum radius without transition curves are all computed in accordance with Guideline-C, and presented in Table 9.2.4.

Vertical Alignment

The normal maximum grade for 120 km/hr design speed in plain terrain should be 2.0 % in Guideline-C. Although the Project is planned in the plain terrain, a number of bridges and box culverts will be necessary for crossing facilities. Considering the necessity of minimizing the height of embankment for reducing the construction cost for non-flood area, the absolute maximum grade and length are recommended to be 3 % and 500 m respectively for shortening the stretches for grade separation. The minimum grade should be 0.3 % for drainage in accordance with Guideline-C.

(2) Geometric Design Standard for Interchange Ramps

Design Speed of Ramps

There are two types of interchanging facilities; the junction (JCT) for joining an expressway to another expressway, and the interchange (IC) with a function of joining an expressway to at-grade arterial roads. The type of ramps applicable to junctions and interchanges are as follows:

- Junction: Direct connector, Semi-direct connector including outer connector
- Interchange: Semi-direct connector including outer connector and loop

The design speed of the above ramps when the design speed of the throughway is 120 km/hr will be as follows in accordance with Guideline-C:

Direct Connector:	80 km/hr
Semi-direct Connector:	60 km/hr
Loop:	50 km/hr

However, these values will be adopted only for the ramps from/to the expressway lanes, and the interchange ramps from/to the at-grade arterial roads are to be as follows in accordance with IRC: 92-1985 Guidelines for the Design of Interchanges in Urban Areas:

Semi-direct Connector:	40 km/hr
Loop:	30 km/hr

Cross Section Elements

The lane configuration will be in two cases, which are a) one lane - one way operation with no provision for passing a stalled vehicle on the lane, and b) two lane - two way operation. The lane width for these cases will be as follows:

a) one lane - one way operation: 4.50 m for one lane
b) two lane - two way operation: 7.75 m for two lanes

A 2.0 m wide outer shoulder and a 0.7 m wide inner shoulder will be adopted. The outer shoulder will consist of a 0.5 m wide edge strip and a 1.5 m wide paved shoulder. The inner shoulder will be an edge strip only. These values will satisfy the requirement (0.6 to 1.2 m) in Guideline-C. The edge strip is the same width as the throughway.

Since there are no rules mentioned for median width on rampways in Guideline-C, a 1.0 m wide median with kerbstones is recommended for the following reasons:

- It can substitute for concrete barriers
- The stretch is relatively short where this median is provided
- This is a typical ramp median width by international standards

Horizontal Alignment

The minimum radius of curves for each design speed of ramps are as follows:

R = 280 m for 80 km/hr (f = 0.125)
R = 150 m for 60 km/hr (f = 0.140)
R = 100 m for 50 km/hr (f = 0.150)
R = 60 m for 40 km/hr (f = 0.150)
R = 30 m for 30 km/hr (f = 0.150)

The maximum superelevation is to be 6.0 % as same as in the throughway design standard. Since the relation between superelevation and radius of curves are not presented in Guideline-C, the relation between e: superelevation and R: radius of curvature for each design speed is derived from Guideline-D (AASHTO), and shown in Table 9.2.2. The values for the design speed of 40 km/hr or less will be based on Guideline-A.

Table 9.2.2: Relation between 'e' and 'R' for Ramps

Design Speed = 80 km/hr		Design Speed = 60 km/hr		Design Speed = 50 km/hr	
Radius of Curves (R)	e	Radius of Curves (R)	e	Radius of Curves (R)	e
R ≦ 360 m	6 %	R ≦ 200 m	6 %	R ≦ 140 m	6 %
360 m < R ≦ 560 m	5 %	200 m < R ≦ 320 m	5 %	140 m < R ≦ 220 m	5 %
560 m < R ≦ 850 m	4 %	320 m < R ≦ 500 m	4 %	220 m < R ≦ 360 m	4 %
850 m < R ≦ 1,300 m	3 %	500 m < R ≦ 800 m	3 %	360 m < R ≦ 580 m	3 %
1,300 m < R	2 %	800 m < R	2 %	580 m < R	2 %

Source: Computed by JICA Study Team based on Guideline-C

The superelevation runoff for each design speed will be as follows:

0.51 % (= 1/196) for 80 km/hr
0.60 % (= 1/167) for 60 km/hr
0.65 % (= 1/154) for 50 km/hr
0.70 % (= 1/142) for 40 km/hr or less

Vertical Alignment

The maximum grade for direct connections and semi-direct connections at a junction applies to the throughway standard, the absolute minimum value is recommended to be 3.0 %. The maximum grade for semi-direct connections and loops at an interchange is recommended to be 4.0 % considering the situation that the ramps will carry a number of heavy commercial vehicles.

Table 9.2.3: Recommended Geometric Design Standard for Expressway

Design Elements		Unit	Throughway	Rampway: Direct connection	Rampway: Semi-direct connection	Rampway: Loop
Terrain			Plain	Plain	Plain	Plain
Design Speed		km/hr	120	80	60	50
Cross - Section	Right of Way	m	100	Nil	Nil	Nil
	Road Width (both sides fill)	m	37.4	-	-	-
	No. of Crriageway and Lane	No.	2 * 3 (2)	3 (2)	1 (2)	1 (2)
	Carriageway Width	m	3.75	3.75	4.45 (7.75)	4.45 (7.75)
	Outer Edge Strip	m	0.5	0.5	0.5	0.5
	Inner Edge Strip	m	0.7	0.7	0.7	0.7
	Outer Paved Shoulder Width	m	2.5	2.5	1.5	1.5
	InnerPaved Shoulder Width	m	Nil	Nil	Nil	Nil
	Median Width	m	12.0 (4.5)	Nil	Nil	Nil
	Outer Verge (Earth Shoulder)	m	1.5	1.5	1.5	1.5
	Crossfall					
	Carriageway	%	2.5	2.5	2.5	2.5
	Outer Shoulder Paved	%	2.5	2.5	2.5	2.5
	Outer Shoulder Earthen (Min.)	%	3.0	3.0	3.0	3.0
	Inner Shoulder Paved	%	2.5	2.5	2.5	2.5
Sight Distance	Stopping Sight Distance	m	250	115	80	60
	Passing Sight Distance	m	Nil	Nil	Nil	Nil
Horizontal Alignment	Max. Surperelevation	%	6.0	6.0	6.0	6.0
	Relation Radius - Superelevation		Table 9.2.1	Table 9.2.2	Table 9.2.2	Table 9.2.2
	Max. Rate of Superelevation Run-off	-	1 / 263	1 / 196	1 / 166	1 /142
	Min. Radii of Horizontal Curve	m	710	280	150	100
	Min.Length of Curve	m	240	160 (160)	110 (110)	90 (100)
	Min. Radii without Surperelevation	m	7,000	3,500	2,000	1,300
	Min. Transition Length	m	120	80 (80)	55 (55)	45 (50)
	Min. Radii without Transition Curve	m	4,000	2,000	1,000	700
	Extra Width at Min. Radii	m	Nil	Nil	Nil (0.50)	Nil (0.75)
Vertical Alignment	Max. Grade	%	2.0	2.0	4.0	4.0
	Absolute Max. Grade	%	3.0	3.0	Nil	Nil
	Max. Length with Limiting Grade	m	500	500	Nil	Nil
	Min. Gradient	%	0.3	0.3	0.3	0.3
	Summit Vertical Curve Length	m	L>S : L=NS^2 / 404, L<S : L=2S - 404 / N			
	Valley Vertical Curve Length	m	L>S : L=NS^2 / (120 + 3.5S), L<S : L=2S - (120+3.5S) / N			
	Min. Vertical Curve Length	m	100	70	50	40

Notes : 1. The values in brackets indicate for initial stage in phase construction.

: 2. The values in bracket are for substantially large traffic volume.

9.2.2 Bridge Design Standard

The following Indian design guidelines are the present structure design standards in India.

A. Design Method:	IS:456-1987 Code of Practice for Plain and Reinforced Concrete
B. Material Strength	
B-1 Concrete Structure:	IRC:21-1987 Standard Specifications and Code of Practice for Road Bridges, Section III-Cement Concrete (Plain and Reinforced) (Second Revision)
B-2 Prestressed Concrete:	IRC:18-1985 Design Criteria for Prestressed Concrete Road Bridges (Post-tensioned Concrete) (Second Revision)
C. Live Load	IRC:6-1966 Standard Specifications & Code of Practice for Road Bridges, Section II - Loads and Stresses (Third Revision)
D. Horizontal Seismic Force:	IRC: 6-1966
E. Reference Standards:	AASHTO Standards and Specifications Japan Road Association Specifications for Highway Bridges

(1) Materials and Strength

Concrete

The requirements for σ_{28} will be based on the specified cylinder test.

Table 9.2.4: Concrete Types

Structural Type	Compressive Strength σ_{28}	Designation (IS: 456)
PC Post-tension	350 km/cm^2	M44
Slab and Lateral	300 km/cm^2	M40
Abutment and Pier	240 km/cm^2	M30
Caisson	240 km/cm^2	M30
Bored Pile	300 km/cm^2	M40

Source: IS456-1987

Steel Bar

The tensile stress should not be less than the values in Table 9.2.5. Fe415 is specified in IS1786-1985, Indian Code.

Table 9.2.5: Types of Reinforcement

Designation	Tensile Stress Not less than	AASHTO Code Equivalent
Fe 415 (SD30)	45 km/mm^2	GRADE 60
(SD24)	39 km/mm^2	GRADE 40

Note: Designation in ( ) is the names from the Japanese Code.

Source: IRC:21-1985

PC Cable

PC cable for I or T beam for span length of 20 - 40 m should have the types and strength specified in Table 9.2.6.

Table 9.2.6: PC Cable Types

Cable System	Consistence	Tension Stress (tf)	Remarks
Multi Strand	12-T12.4	195.6	For Beams
	12-T12.7	224.4	
PC Bar	Φ 21.8 mm	54.8	For Lateral

Source: IRC:18-1985

(2) Loading

Dead Load

The following weights are to be used for computation of the dead load.

Table 9.2.7: Dead Loads

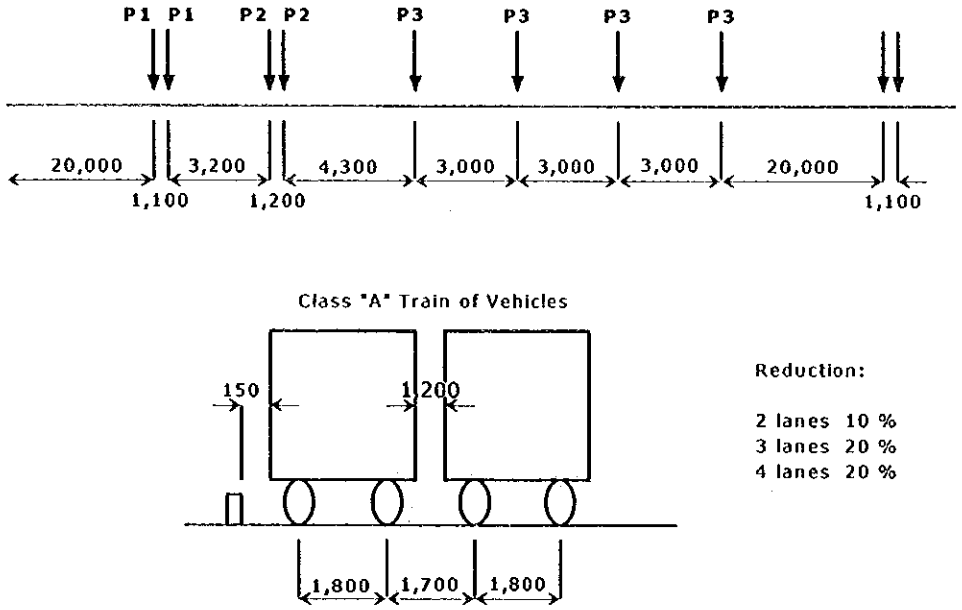
Materials	Weight (kmf/m^3)	Materials	Weight (kmf/m^3)
Steel or Cast Iron	7,850	Plain Concrete	2,350
Cast Iron	7,250	Cement Mortar	2,150
Reinforced Concrete	2,500	Asphalt Concrete	2,300

Source: IRC: 6-1966

Live Load

The present design load for bridge structures can be derived from IRC: 6-1966. As an example, IRC Class "A" loading is shown as in Figure 9.2.1.

Figure 9.2.1: Class "A" Loading by IRC



The standard for design loading will be based on IRC6: 1966, however, the loading will be cross checked with the present and expected future loading conditions particularly on expressways.

Seismic Force

The horizontal seismic forces for resistance are computed by the following equation:

$$Feq = \alpha \cdot \beta \cdot \gamma \cdot G$$

where,

Feq: Seismic force to be resisted
α: Horizontal seismic coefficient depending on location
β: A coefficient depending on the soil foundation system
γ: A coefficient depending on the importance of the bridge
G: Dead Load

An application of bridge conditions on the expressway will give the following result:

$$Feq = 0.05 \times 1.2 \times 1.5 \times G = 0.09G \fallingdotseq 0.1G$$

0.05: Zone No. IV
1.2: As type II and Well foundation
1.5: As important Bridge

Therefore, 0.1G will be adopted for seismic force.

9.2.3 Pavement Design Standard

The current Indian pavement standards are as follows:

A. IRC:37-1984 Guidelines for the Design of Flexible Pavements
B. IRC:58-1988 Guidelines for the Design of Rigid Pavements

However, these Indian pavement standards are in the process of revision in the Ministry of Surface Transport mainly for accommodating increasing heavier vehicle loads, and currently not available. Also, for the purpose of the feasibility study, it is important to design the pavement structure based on the life cycle cost analysis for the analysis period of up to 30 years. A reference will be made, therefore, to the following design guideline since it has many indications for life cycle analysis of pavement systems:

C. AASHTO Guide for Design of Pavement Structures

9.2.4 Design Standards for Other Facilities

For particular expressway facilities of interchanges, rest areas, toll gates, toll plazas, etc., the following guidelines will be referred to:

A. Guidelines for Expressway Design Standards of India; Interim Report
B. Japan Highway Public Corporation Expressway Design Manual.

A reference will be also made to other on-going expressway projects in India, whenever the information is available.

9.3 Toll Levy System and Interchange Type

9.3.1 Basic Conditions

Kendli - Ghaziabad (K-G) Expressway will ultimately form a part of the outer circumferential expressway network of Delhi together with the proposed FNG Expressway and Peripheral Expressway. Ghaziabad - Meerut (G-M) Expressway will form a radial Expressway extended from the circumferential expressway network. This means that either of these two expressways cannot be operated in an isolated system, and a total network view for the entire "NCR Expressway System" will be indispensable for discussing their toll levy system.

The toll levy system will be substantially different whether it will allow the exchange of collected tolls among the different investors/operators who will operate each segment of the expressway network. If each investor should establish their own system without any exchange or cooperation of toll collection with other investors, the most foreseeable result would be the establishment of throughway toll plazas at every boundary of the projected expressway segments. This is what actually happens globally among expressway projects implemented by multi private investors.

The NCR Expressway System will be no exception. A reference should be made to Figure 8.2.1 (pp.8-7), which shows a schematic illustration of a toll levy system for G-M, K-G Expressways and FNG Expressway in together. The toll levy system for FNG Expressway is assumed to be the proposed system by the feasibility study report of FNG Expressway[1]. Figure 8.2.1 shows a recommended interchange types with no toll plazas at Kundli and Meerut boundaries, however, if K-G and G-M Expressways adopt the boundary toll plaza system, there will be five full throughway toll plazas and one half throughway toll plaza in this expressway network. This means if a driver is to travel from Faridabad to Meerut or Kundli, for example, he has to pass through at least four throughway toll plazas during his 70 km travel. This will be even five if he will take FNG Expressway from NH2 Interchange at the south of Faridabad. It is not difficult to imagine what would happen when the Peripheral Expressway comes along.

The major problem is that the throughway toll plazas will create the biggest traffic bottlenecks on expressway network, particularly when the roadway gets congested. That will seriously reduce the travel time, which will seriously decrease the user benefit. Even when the expressway traffic volume is less and the delays at throughway toll plazas are minimal, it can never be a user-friendly tollway operation if the users (customers!) must stop frequently to pay tolls at toll plazas. The toll levy system, therefore, should try to minimize the number of throughway toll plazas as few as possible including an option of 'full-closed system,' which enables toll collections at the interchange access toll gates only, so that no throughway toll plazas will be necessary.

9.3.2 Toll Levy System Study

The possible alternative systems are discussed as follows with a policy of how to minimize the number of throughway toll plazas. The Ghaziabad I.C. - Ghaziabad North JCT section is assumed to belong to K-G Expressway from the network viewpoint. The following analysis will remain basically the same whichever project will take up this common section. These alternatives are shown in Figure 9.3.1.

[1] Proposed Faridabad-NOIDA-Ghaziabad Expressway Final Report; ADB, March 1995

(1) Proportional Toll System with Three Main Toll Plazas (Alternative 1)

The most common system would be to furnish toll plazas at each boundary of tollway projects. This will basically eliminate exchange of collected money with FNG Expressway and Peripheral Expressway. To discriminate K-G and G-M Expressways, however, the toll must be collected at the entering gate, which will be checked at the exit gate, rather than issuing ticket at the entrance and collecting the toll at the exit. This is shown in Alternative 1 Table in Figure 9.3.1. It is because the ticketing-collection system always necessitates exchange of collected tolls between K-G and G-M.

Even in this system, however, exchange of collected tolls cannot be completely eliminated when a driver travels more than the distance he paid at the entrance. If a driver enters from Kundli IC paying a toll for Khekra IC and travels to Meerut IC, for example, he has to pay a toll (A) for Khekra IC -Ghaziabad North JCT section in addition to a toll (B) for Ghaziabad North JCT to Meerut IC section. This (A) toll should be collected by Meerut Toll Plaza, but the money belongs to K-G Expressway. This problem will remain the same even if the Meerut Toll Plaza is moved to near Ghaziabad North JCT. The only way to avoid it is to furnish another toll plaza near the Junction in addition to Meerut Toll Plaza. This, however, is considered to be too many toll plazas in terms of cost and user convenience.

In this alternative every interchange pair traffic has to stop for two times during their travel on K-G and G-M system. There will be three throughway toll plazas and two intermediate interchange toll gates in this case.

(2) Flat Toll System with Two Main Toll Plazas (Alternative 2)

This is an alternative trying to minimize the number of throughway toll plazas by adopting flat toll system. Flat toll here means the toll price for Ghaziabad IC and Khekra IC will be the same as that for Ghaziabad IC and Kundli IC, as well as Ghaziabad North JCT - Modinagar IC and JCT - Meerut IC. The advantage of this alternative is that it will need only one throughway toll plaza for the dominant through traffic, which means the interchange pairs of Ghaziabad - Meerut and Ghaziabad - Kundli. On the contrary, it is a disadvantage for minor interchange pairs. For example, a driver entering from Khekra IC and exiting from Modinagar IC must pass through two throughway toll plazas and two access toll gates of each interchange. The collected tolls at Muradnagar Toll Plaza has to be distributed to K-G Expressway because it includes the toll for drivers coming from Ghaziabad IC.

There will be two throughway toll plazas and two intermediate interchange toll gates.

(3) Consolidated Toll System with No Toll Plazas (Alternative 3)

This is the full closed system to be able to control all of the interchange pairs by ticketing at entrance and collecting tolls at exit. There will be no throughway toll plazas, which means much less cost, and greater traffic advantage compared with other alternatives. The each investor, however, should cooperate one another to correctly distribute the collected tolls.

This is an ideal toll levy system because of no need for throughway toll plazas. It is also a user-friendly system since the driver does not have to stop at throughway toll gates, and he does not have to declare (pay for) where he is going. Possibility of future traffic congestion on the Expressway network is drastically reduced unless it reaches saturated conditions.

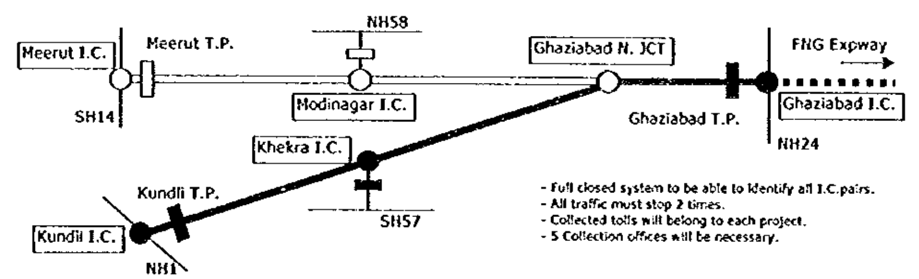
It needs a strong policy and leadership of the responsible government agency for the total expressway projects to realize this system, since every investor/operator should follow this system and cooperate. It is, however, not difficult to identify the amount of collected tolls to be exchanged among the investors with a centralized computer system, because among the tickets an interchange has issued, it can easily detect which interchange they exited. If other alternatives can not completely eliminate the exchange of collected tolls, this alternative would be even better since it can automatically disclose all the interchange pairs by a centralized computer system.

To make this alternative possible facility designs for the entire expressway network must be based on this system as a prerequisite condition, particularly for interchange design. Since all the traffic will be checked at interchange access toll gates, full or partial cloverleaf type will not be appropriate for concentrated toll gate location. FNG Expressway is planned to have partial cloverleaf type for most of its interchanges, and it is necessary to revise them for adopting this alternative.

The study team strongly recommends that the consolidated toll system: alternative 3 be adopted because it is critically important when the total expressway network system will be realized.

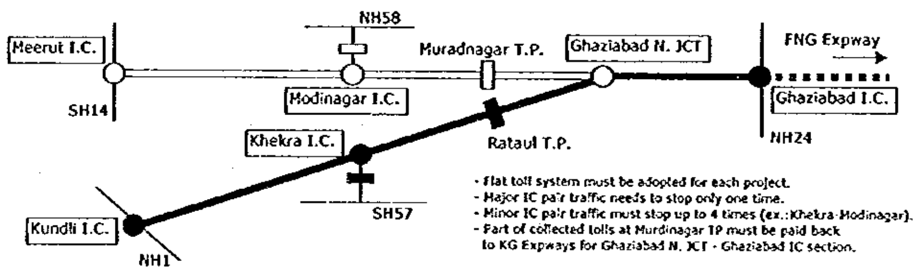
Alternative 1 : Proportional Toll System

Origin			Destination: Kundli	Khekra	Gaziabad	Modinagar	Meerut
Origin	Kundli	Pay Check/Pay		Kundli TP Khekra IC	Kundli TP Ghaziabad TP	Kundli TP Modinagar IC	Kundli TP Meerut TP
Origin	Khekra	Pay Check/Pay	Khekra IC Kundli TP		Khekra IC Ghaziabad TP	Khekra IC Modinagar IC	Khekra IC Meerut TP
Origin	Ghaziabad	Pay Check/Pay	Ghaziabad TP Kundli TP	Ghaziabad TP Khekra IC		Ghaziabad TP Modinagar IC	Ghaziabad TP Meerut TP
Origin	Modinagar	Pay Check/Pay	Modinagar IC Kundli TP	Modinagar IC Khekra IC	Modinagar IC Ghaziabad TP		Modinagar IC Meerut TP
Origin	Meerut	Pay Check/Pay	Meerut TP Kundli TP	Meerut TP Khekra IC	Meerut TP Ghaziabad TP	Meerut TP Modinagar IC	



Alternative 2 : Flat Toll System

Origin			Destination: Kundli	Khekra	Ghaziabad	Modinagar	Meerut
Origin	Kundli	Pay Check/Pay		Khekra IC ---	Rataul TP ---	Rataul TP Muradnagar TP	Rataul TP Muradnagar TP
Origin	Khekra	Pay Check/Pay	Khekra IC ---		Khekra IC Rataul TP	Khekra IC Rataul TP/Muradnagar TP	Khekra IC Rataul TP/Muradnagar TP
Origin	Ghaziabad	Pay Check/Pay	Rataul TP ---	Rataul TP Khekra IC		Muradnagar TP Modinagar IC	Muradnagar TP Meerut TP
Origin	Modinagar	Pay Check/Pay	Modinagar IC Muradnagar TP/Rataul TP	Modinagar IC Muradnagar TP/Rataul TP	Modinagar IC Muradnagar TP		Modinagar IC ---
Origin	Meerut	Pay Check/Pay	Muradnagar TP Rataul TP	Muradnagar TP Rataul TP	Muradnagar TP ---	Modinagar IC ---	



Alternative 3 : Consolidated Toll System

Origin			Destination: Kundli	Khekra	Gaziabad	Modinagar	Meerut
Origin	Kundli	Ticketing Collection		Kundli TP Khekra IC	Kundli TP Ghaziabad TP	Kundli TP Modinagar IC	Kundli TP Meerut TP
Origin	Khekra	Ticketing Collection	Khekra IC Kundli TP		Khekra IC Ghaziabad TP	Khekra IC Modinagar IC	Khekra IC Meerut TP
Origin	Ghaziabad	Ticketing Collection	Ghaziabad TP Kundli TP	Ghaziabad TP Khekra IC		Ghaziabad TP Modinagar IC	Ghaziabad TP Meerut TP
Origin	Modinagar	Ticketing Collection	Modinagar IC Kundli TP	Modinagar IC Khekra IC	Modinagar IC Ghaziabad TP		Modinagar IC Meerut TP
Origin	Meerut	Ticketing Collection	Meerut TP Kundli TP	Meerut TP Khekra IC	Meerut TP Ghaziabad TP	Meerut TP Modinagar IC	

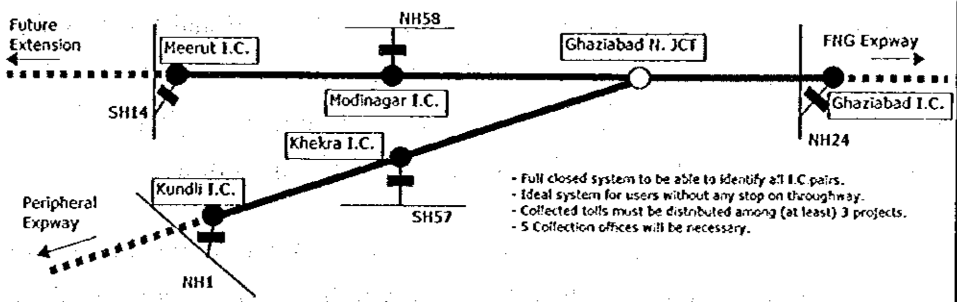


Figure 9.3.1 Alternatives for Toll Levy System

9.3.3 Interchange Type Analysis

As discussed in Section 8.2.2, there are two types of interchanging facilities. The first is a JUNCTION (i.e. expressway-to-expressway interchanging facility; JCT) and the second is an INTERCHANGE (i.e. expressway-to-artery (at-grade) interchanging facility; IC).

There are five interchanges and one junction for K-G and G-M Expressway network. These are shown with their stations and access roads in Table 9.3.1.

Table 9.3.1: List of Interchanges

No.	Names	Station	Access Highway
1	Ghaziabad North JCT	STA41+400 (KG) STA08+400 (GM)	N.A.
2	Kundli IC	STA00+600 (KG)	NH01
3	Khekra IC	STA14+800 (KG)	SH57
4	Ghaziabad IC	STA00-200 (GM)	NH24
5	Modinagar IC	STA23+400 (GM)	NH58
6	Meerut IC	STA39+750 (GM)	SH14

Source: JICA Study Team

The interchange types will depend on the toll levy system, particularly the terminal interchanges of Kundli IC, Ghaziabad IC, and Meerut IC should be discussed with the toll levy system alternatives. On the other hand, it has been identified that intermediate interchanges of Khekra IC and Modinagar IC will not depend much on the toll levy system, which means that whatever toll levy system is adopted, these two interchanges should be designed with entering and exiting toll gates. Based on these understandings, possible interchange types are discussed as follows for a preliminary analysis. These alternatives are shown in Figure 9.3.2

(1) Ghaziabad North JCT

Since this is a three-leg junction, a Y (direct-fastening) type is the best alternative to maximize the radius of ramp curves regardless of directional traffic volumes. The major direction is expected to be Kundli - Ghaziabad and Ghaziabad - Meerut rather than Kundli - Meerut, and the throughway alignment of both expressways was formulated to achieve better alignments for the major directions.

A possible alternative can be a trumpet type if either of the major direction has dominant traffic volume than the other, however, there will be no advantage of setting a loop ramp for an expressway junction if there is an alternative which can obviously avoid it. The necessary right-of-way area for the facility for the direct-fastening type is also considered smaller than trumpet.

(2) Kundli IC

Kundli IC is one of the major interchanges in the expressway network since this is a facility to connect K-G Expressway to NH01. One alternative is to have a partial-cloverleaf type. This type has a more direct access for all of the directions. Since there is a factory at the north-east side of the crossing point, it is not appropriate to furnish a loop ramp at this quadrant. A best ramp arrangement for this type will be as in Figure 9.3.2. This ramp arrangement can avoid having loop ramps for Ghaziabad → Sonipat and Peripheral Expressway → Delhi directions, which are considered to be the major directions for the traffic.

A disadvantage of the partial-cloverleaf type is that it must be based on the toll levy system which has a throughway toll plaza nearby. As discussed in the previous section, if a strategy of 'full-closed system without throughway toll plazas' can be maintained, the interchange must be in double-trumpet type, which enables a full control of access with bunched ramps at the toll gates as is shown in Figure 9.3.2.

The double-trumpet type is highly recommended for Kundli IC to enable the future through operation between Peripheral Expressway and K-G Expressway.

(3) Khekra IC

Khekra IC is an intermediate interchange for an access from/to SH57. The possible interchange types are a) trumpet type or b) Y type. Each type has a variation depending on the access traffic accommodation. The trumpet type can be a double-trumpet type, and Y type can also have a grade separation if the at-grade access highway (SH57) is expected to be a very busy road. The Y type is generally more expensive than the trumpet type since it has a three-story ramp structure, however, it is particularly advantageous when the interchange is planned between hilly topographic conditions, where a loop ramp for the trumpet type is difficult or uneconomical to be adopted. In the case of Khekra IC, this is not the case, and the trumpet type is recommenced.

(4) Ghaziabad IC

Ghaziabad IC is designed as a partial cloverleaf type by FNG Expressway Study.

There is a problem in the original design that there is no service for Meerut→ Ghaziabad (eastbound) traffic from G-M Expressway. It is probably because that directional traffic is designated to use NH24 bypass since NH24 is already very busy. However, this arrangement is really inconvenient for the expressway users from Kundli or Meerut going to Ghaziabad or further east on NH24. It is, therefore, highly recommended that an additional ramp be furnished for that direction.

There is also an issue of the toll levy system for the type of Ghaziabad IC, which is the same as in Kundli IC. Alternative 2 (double-trumpet type) is a recommended type for adopting the full-closed system.

(5) Modinagar IC

The alternatives for Modinagar IC are mostly the same as in the case of Khekra IC. The difference is in the access road. The access road for this interchange is proposed to be a new road from NH58. It can be a exclusive access road only for the expressway traffic, or at-grade road to have an extension beyond the interchange. The interchange type analysis will be the same as in Khekra IC.

(6) Meerut IC

Meerut IC will be a terminal interchange until further extension of G-M Expressway to north is realized. Depending on how soon the expressway extension is furnished, the possible interchange can be grade-separated or at-grade diamond type (direct connection) or trumpet type with which the operation of future extension is taken into account.

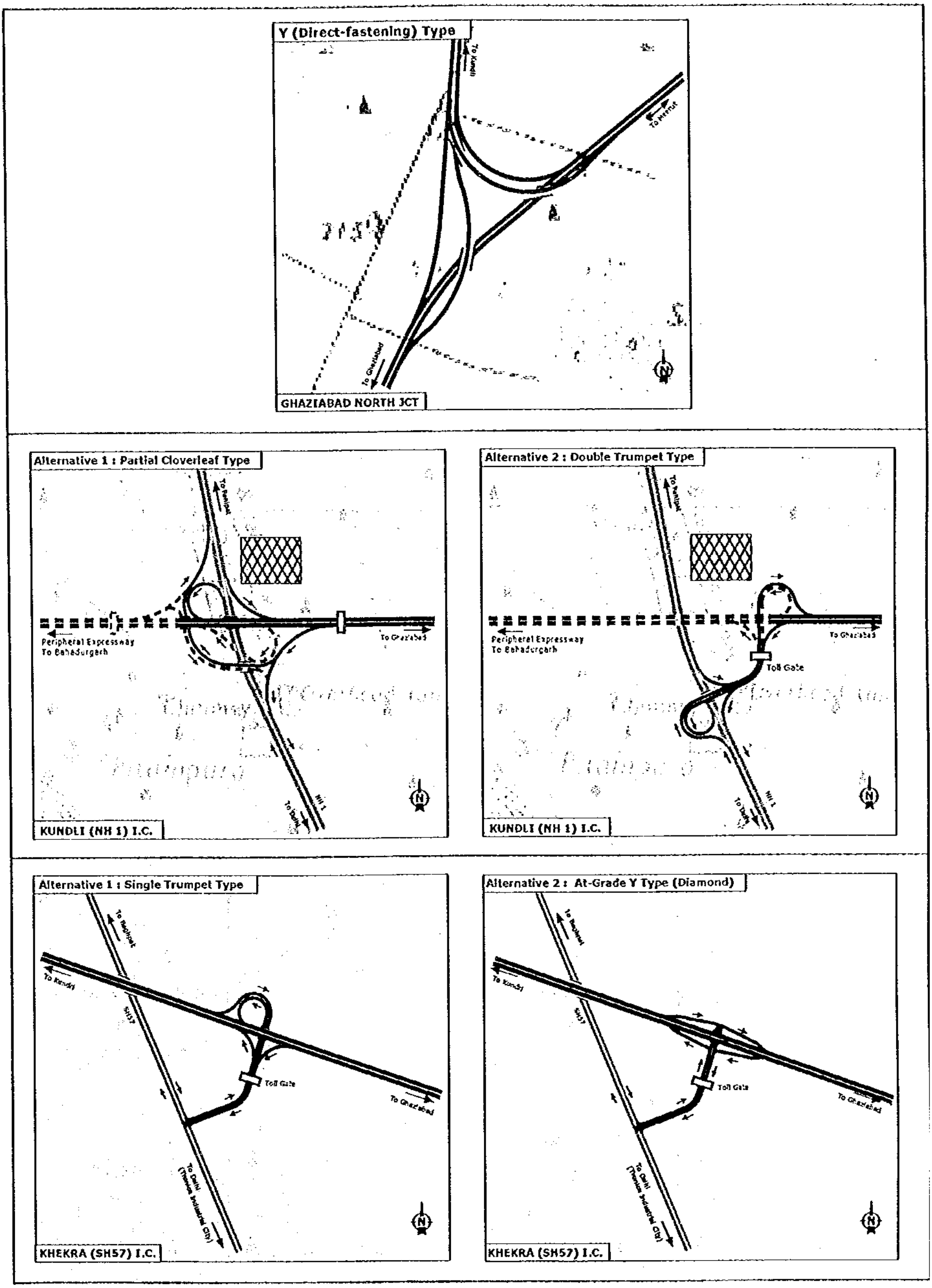


Figure 9.3.2 (1): Interchange Type Alternatives (1)

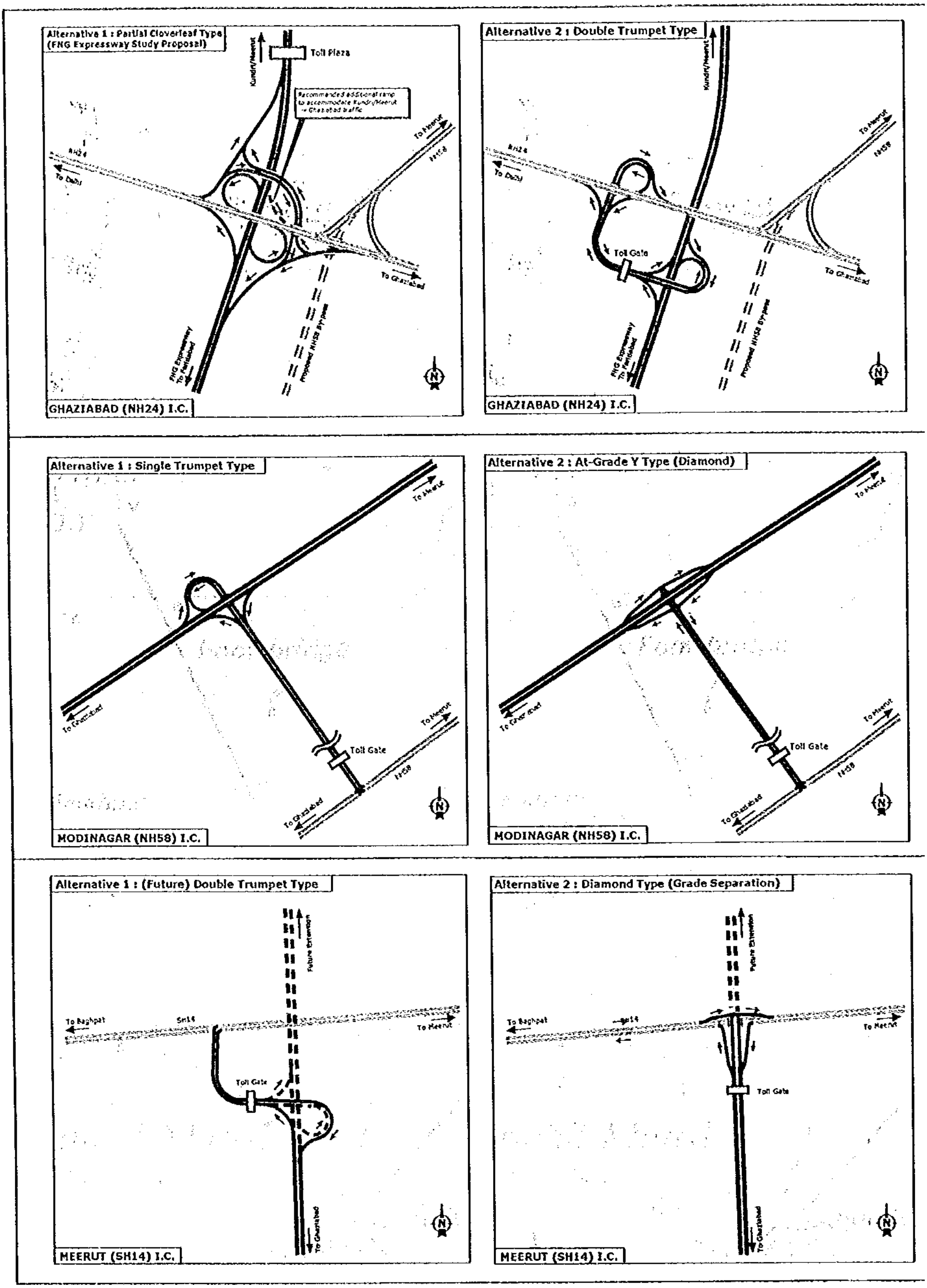


Figure 9.3.2 (2): Interchange Type Alternatives (2)

9.4 Highway Capacity and Number of Lanes

9.4.1 Summary of Traffic Demand Forecast

The result of traffic demand forecast on the expressways is summarized in Table 9.4.1. For the purpose of highway capacity analysis Rp 1.0/km case is used, with an assumption that FNG Expressway, Peripheral Expressway and G-M Expressway Meerut Extension are realized before year 2016.

Table 9.4.1: A Summary of Traffic Demand Forecast

	2006 1)	2016 2)	2021 2)	2026 2)
K-G Expressway				(pcu/day)
Kundli IC – Khekra IC	41,200	67,000	87,400	112,800
Khekra IC – JUNCTION	30,900	52,900	76,100	98,100
G-M Expressway				(pcu/day)
Meerut IC – Modinagar IC	24,300	40,400	56,700	75,200
Modinagar IC – JUNCTION	27,700	50,700	75,500	101,300
JUNCTION – GhaziabadIC	43,100	74,400	102,600	132,300

Note: 1) with FNG Expressway
2) with FNG, Peripheral and G-M Expressway Meerut Extension
Source: JICA Study Team

The traffic demand forecast shows relatively small numbers in initial years and a high growth through the analysis period, and a stage construction scheme is expected to be very effective for these projects to minimize the initial stage cost. The highway capacity analysis, therefore, will be performed to identify the initial and ultimate stage lane configuration and approximate timing for the widening from the initial number of lanes to the ultimate number of lanes.

9.4.2 Highway Capacity and Number of Lanes

Although highway capacity should be analyzed on the peak-hour performance basis in its operational application, the preciseness of traffic forecast data in planning analysis is generally not sufficient for peak-hour performance analysis. Thus, at the planning level, the highway capacity analysis is approximate and serves to give a determination of initial and ultimate stage number of lanes to be constructed. In this study, the highway capacity analysis is carried out on annual average daily traffic (AADT) basis with estimated K-factor, directional factor and other factors to identify appropriate Design Daily Traffic Volume (DDTV), which is an index or threshold capacity to design the necessary number of lanes with designated level of service.

DDTV on K-G and G-M Expressways can be defined as follows:

$$DDTV\ (pcu/day) = BC\ (pcu/hour) \times N / K \times 0.5 / D \times SLF$$

where, BC: Basic Capacity; 2,200 pcu/hr
N: Total number of lanes; 4, 6 or 8
K: K-factor (estimated peak hour volume/AADT); 7.5 %
D: Directional factor; 53 % for K-G, 55 % for G-M
SLF: Service level factor, v/c value for LOS=C; 0.8

The value of BC (2,200 pcu/hour) is a widely accepted international value in many motorized countries. The values of K and D are estimated based on our traffic survey result and other local conditions. The value of SLF is a recommended value, which is slightly higher than LOS=C value in HCM[2] (0.75 at 70 mph). The computed DDTV values for K-G and G-M Expressways are as follows:

Table 9.4.2: Design Daily Traffic Volume for the Expressways

Number of Lanes	K-G Expressway	G-M Expressway
1 (Junction Ramp)	22,000	21,000
2 (Junction Ramp)	44,000	43,000
4 (2 + 2)	88,000	85,000
6 (3 + 3)	133,000	128,000
8 (4 + 4)	177,000	171,000

Source: JICA Study Team (pcu/day)

A comparison of Table 9.4.1 and 9.4.2 shows the following stage construction scheme is recommended as the most appropriate stage construction strategy.

1) Kundli IC - JUNCTION and Meerut IC - JUNCTION will be initially 2 + 2 = 4 lanes, and ultimately 3 + 3 = 6 lanes.
2) JUNCTION - Ghaziabad IC should be initially 3 + 3 = 6 lanes in view of the balance with the above sections, and ultimately 4 + 4 = 8 lanes.
3) For all of the sections on K-G and G-M Expressways, the widening from the initial to the ultimate stage should be implemented between year 2021 and 2026.

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[2] Highway Capacity Manual, Special Report 209, Third Edition, TRB National Research Council, Washington, D.C., U.S.A., 1994