CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.0 GENERAL:

The orientation of research design and methodological framework for supply system planning is attempted with reference to its enhancement strategy development to address urban mobility problems, infrastructure and functionality issues which is hampered due to variety of reasons such as demand centralization and concentration on unfavorable spatial structure, imbalance in modal split, inadequate and suboptimal use of infrastructure, rapid growth of urbanization etc. The urban transport environment is deteriorating leading to poor quality of life, uneconomic travel, risk etc. Indian policies and academic literature concerned with the mobility have identified the need for infrastructure planning to tackle mobility issues. The majority of the existing studies on supply system address on network design and route choice are based on conventional travel demand modeling but there is no scientific approach for spatial planning of a hierarchical system that deconcentrates the demand uniformly and homogeneously making optimal use of the existing supply system. This study provides a conceptual framework for design of supply system enhancement strategies through optimal use of existing infrastructure to attain demand supply equilibrium.
3.1 ORIENTATION OF RESEARCH DESIGN:

Urban transportation – land use interaction characterization through demand – supply – system have been crucial in defining urban transportation policy objectives and strategies in developed and developing countries. Initiatives to tackle urban transportation problems are more driven towards demand and system based planning with strategic approach formulations. There is a hidden gap in defining a strategic approach in supply based planning with respect to functionality and utility inspite of complexity observed in supply – demand and supply – system interactions. Moreover, the trend of policy sequence formulations are varied in different development scenarios and traffic growths with a more independent and parallel formulations of demand – supply – system in developing and undeveloped nations and integrated - subset formulations in developed nations.

The policy gap for a developing economy is addressed in this study by developing a strategic approach for supply based planning that leads to demand - supply equilibrium through maximization of road utility and consolidating the supply system functionality in a static and dynamic frame. Moreover, the study presents a strategic lead in reducing the supply utility gap that is observed in the sequence of urban transport policy operations in developed and developing countries that are in pace with economic development of urban area. Comprehension and consolidation of supply utility gap
shall attain a sustainable system that suits for a better efficient application of demand management and system integration leading to a more congenial urban environment promoting land use controls and demand deconcentration (Antonio M. Bento et al 2004, Satoshi TOI et al 2005, Stephen Marshall 2005, Bhanu Yerra and David Levinson 2005). Hence supply system planning is considered to be one of the key strategy for better traffic efficiency (Vinod R V et al 2003) resulting in less transport intensive, less costly, more efficient and congenial environment (Lim Lan Yuan 1997, Morris et al 1979). Moreover, supply infrastructure planning can significantly affect land use development and deconcentrate the land use over a time frame (Violletta Cavalli- Sforza and Leonard Ortolano 1984).

Supply based planning involves its characterization / generalization, evaluation and design. Supply system characterization of static entities (node, link, path, and network) through topological formulations give a lead to its evaluation and design. The evaluation derives the need for the type of design required for the existing development patterns. The design of supply system involves new infrastructure development planning and existing infrastructure reorientation planning to improve operationality and sustenance among environment, economy and social aspects. Since supply system is often subjected to underutilization in many urban areas (Traffic and Transportation Policies and strategies in urban areas in India 2008, Stephen R Alderson and Yorgos J Stephanedes 1986), the design for
the supply system optimal utility with existing configuration constraint is formulated through a planning framework of network orientation that defines the crucial / critical entities in performance of network. Moreover, utilization of existing infrastructure is important than new construction (USDOT FHWA 1996). The orientation of these supply entities i.e.; node, link, path, network through demand and supply normalization with supply utility configures the demand and deconcentrates over the supply system. Hierarchy / functionality of the supply system are emerged with the critical components that derive maximum supply utility and promotes a fractal spatial structure (Nikos A Salingaros 2003). This fractal system reduces travel costs in urban areas (Anas et al 1998; Frankhauser 1998) and hence is necessary to meet the demand (Nikos A Salingaros 2003). Derived and existing supply entities are promoted as a planning strategy that induces a functional and sustainable environment in an urban fabric. The planning strategy for improving the existing functional supply entities are designed through prioritization analysis. Moreover, supply based planning implementation must consider the improvement of existing functional elements for optimizing the existing facilities.

Planning and Design of functional entities of supply systems is considered for the analysis as the topology of functional roads has a more direct and essential impact on overall travel mobility of a road network than that of less functional roads such as local streets and also, since the functional network is smaller than the whole road
network and demonstrates clearer patterns that are easier to define and identify (Feng Xie and David Levinson 2007). Moreover, functional roads provide more mobility whereas less functional roads provide more accessibility. These crucial components development and improvement if not planned scientifically reduce reliability, survivability and efficiency of the transport system (Ahmed Abdel – Rahim et al 2007). Hence a scientific framework for supply system planning is designed in this study that strengthens the traffic network which is presented below.

3.2 METHODOLOGY AND RESEARCH DESIGN:

Supply system planning is attempted in three phases: 1) Characterization; 2) Evaluation and 3) Design which is presented below

3.2.1 CHARACTERISATION:

Demand is normalized over supply system to form a common platform for analyzing demand – supply equilibrium and promote maximum utility of supply entities. Hence demand and supply characterization are made to evaluate and design the supply system. Characterization of demand and supply to analyze in a normalized mode is made with respect to travel patterns and urban form respectively which are presented below.
3.2.1.1 SUPPLY CHARACTERIZATION – URBAN FORM GENERALISATION:

The urban form characterization imparts supply system generalization through nodes, links, and network and built up area / land use. Static supply characterization for representation and generalization of road network are made from graph theoretical formulations to facilitate structural and topological analysis of network. The graph theory formulation indicate supply system characterization with respect to nodes as major and minor intersections, links as segments, paths as major corridors and network that represents the topology of nodes and links. The analysis of urban form contributes to a reinvigorated approach to transportation planning (Batty 1995) and is attempted with Geographic Information System (GIS) base map. Development of base map involves the following series of steps.

(a) Step 1: Selection of GIS Software
(b) Step 2: Creation of Geodatabase
(c) Step 3: Generation of feature classes
(d) Step 4: Creation of aspatial database
(e) Step 5: Spatial adjustment for geocoding the vector data
(f) Step 6: Defining the Spatial reference (Geographic Coordinate System)
(g) Step 7: Projection and Transformation of the Spatially Referenced Vector
(h) Step 8: Generation of base map
3.2.1.2 DEMAND CHARACTERIZATION – TRAVEL PATTERN GENERALISATION:

Travel pattern characterization imparts travel demand generalization with intensity, orientation and length. The normalization of trip intensity over node and link, trip orientation and trip length over path is made in a network that allows for a comparative analysis of demand and supply over a space frame.

Intensity is measured in static and dynamic modes to signify the relative loading of trips on the supply entities. Dynamic demand characterization is based on the road user concepts and the utility of the supply entity in terms of dynamic trip intensity and dynamic overlap size (OS). The concepts of utility maximization and user perspective planning were used by some of the researchers in many applications of route choice (Feng Xie and David Levinson 2006, Pursula and Talvitie 1992, Alder et al 1993). Demand is also assessed in static form measured in static OS, the magnitude of which indicates the potential of trips getting more attracted in the future. The static demand is considered since the supply is static and the demand coming on the supply system is variable. The overlap size is the inherent utility of the supply system entity and indicates the degree of overlap. The lead for the degree of overlap concept is obtained from the route choice modeling attempted by Yongtaek Lim and Hyunmyung Kim 2005 where shortest path overlaps were used in formulation of shortest paths. Demand orientation is characterized with respect to trip movements and length is user preferred trip length.
between the origin – destination (OD) pairs. Algorithmic steps for development of static and dynamic demand analyzers is given below.

A) IDENTIFICATION OF DEMAND ANALYSERS - STATIC:

Demand analyzer measured in terms of Static OS is obtained from the user preferred paths developed between the OD pairs. The user preferred path is shortest path between the OD pairs which users choose for making a trip with distance as the assumed impedance. Other impedances such as travel time, cost were considered by many researchers in route choice applications (Huchingson et al 1977, Duffell and Kalombaris 1988, Pursula and Talvitie 1992, Shier 1976, Skiscim and Golden 1989, James Campbell 1992, Tan 1966, Tanner 1968, Newell 1980, Pearce 1974). The operational steps for identification of static OS are given below.

a. Define the network with ‘n’ number of zones (OD pairs) with i as origin and j as destination.

b. Initialize the network by setting OS = 0 where OS = overlap size on the node / link.

c. Run the following iteration to measure the overlap size on the supply entities of the network

```plaintext
for i = 1 to n;
{
    for j = 1 to n;
    {
        ...
    }
}
```
Identify the path between i and j using Dijkstra’s algorithm (Chachra et al. 1979) with distance as the impedance factor.

OS = OS + 1 (When the path passes through the link / node)

OS = OS + 0 (When the path does not pass through the link / node)

}

j++
}

i++

The same procedure is adopted to determine the dynamic overlap size when trip exists i.e.; considering only the OD pairs where trip interactions exist

B) DETERMINATION OF DEMAND ANALYSERS - DYNAMIC:

Dynamic demand analyzers are assessed with dynamic trip assignment to supply entities in terms of trip intensity and determination of dynamic OS.

Dynamic assignment of trips to the nodes / links identified from static analysis is made using all-or-nothing assignment technique which assumes that the whole user flow is funneled along the user preferred path (Maria Gloria Battista et al 1995, Florian 1977). Trip intensity on each link is the sum of all the flows of paths between any origin and destination that passes through the link which is calculated from the following steps.
a. Define the network with ‘n’ number of zones (OD pairs) with i as origin and j as destination.

b. Initialize the network by setting $T_I = 0$ where $T_I$ = trip intensity on the node / link. $T_{ij}$ is the number of trips per day between OD pairs and is obtained from OD matrix.

c. Run the following iteration

```c
{
for i = 1 to n;
{
    for j = 1 to n
    {
        Identify the path between i and j using Dijkstra’s algorithm with distance as the impedance factor.
        $T_I = T_I + T_{ij}$ (When the path passes through the link / node)
        $T_I = T_I + 0$ (When the path does not pass through the link / node)
    }
    j++
}
i++
}
```

Dynamic overlap size is measured from the trip interactions observed in the OD matrix. It is the number of overlaps on the supply entity when the trip interaction is observed on the corresponding path.
3.2.2 EVALUATION:

Evaluation of topological spatial supply structure with respect to shape / morphological characteristics of network is made that measures the complexity in similarity of supply entities and urban form, functionality and its relation among the similarity patterns over a space. The evaluation is attempted using the concept of fractal geometry that measures the topological spatial structure implying inherent properties of connectivity, hierarchy and accessibility. The concept of fractal geometry was used to evaluate demand and supply of an urban form by many researchers (Chen and Luo, 1998; Shen, 1997, Yongmei Lu, Junmei Tang (2004), Junmei Tang (2003), Guoqiang Shen 2002, De Keersmaecker Marie Laurence et al 2003). The Fractal dimension (FD) evaluates self similarity in an urban fabric (Zhongxiang Huang and Zuomin Li 2000) and in the present study it is used to evaluate the similarity in urban form elements like minor nodes, road lengths, hierarchical road length and built up area. A comparison of FD of various parameters indicates the correlation between the growth of the parameters at different scales. The magnitude of static self similar fractal dimension and comparison with other static feature dimension in urban form can be used to develop policy guidelines in transportation planning.

The spatial dispersion and centrality of the network entities are measured with standard deviation ellipse (SDE) and coverage index (CI) as a proxy to topology which indicates the state of static supply
system. The SDE is a centrographic measure in ARCGIS tool which is used to characterize the dispersion of point observations along two orthogonal axes and will be oriented in the direction of maximum dispersion. SDE measures whether a distribution of features exhibits a directional trend (whether features are farther from a specified point in one direction than in another direction). A coverage index (CI) is developed for the study which operates on grid topology and is measured by the ratio of number of grids covering major nodes (or) corridors and the total number of grids required to cover the spatial extent of the area. The grid size reflects the spacing between the nodes and number of desired nodes per km length of road to attain desired speed. A grid size of 0.5 sq.km is assumed based on the optional spacing between the nodes. The value of CI near to 1.0 indicates uniform spatial distribution of the major nodes in the network which reflects a balanced demand in a traffic network that controls spatial disparities. CI near to 0.0 indicates non uniform spatial distribution of major nodes.

Summary of the evaluation parameters is presented in the table3.1.

**Table 3.1: Evaluation parameters for supply system analysis:**

<table>
<thead>
<tr>
<th>Evaluation parameter</th>
<th>Measurement characteristic</th>
<th>Target feature of urban form</th>
<th>Key elements for calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation ellipse</td>
<td>Spatial dispersion of urban form</td>
<td>Major corridors and major nodes</td>
<td>Based on Euclidean distance / Manhattan distance for formation of long and short axis in the ellipse – Locus</td>
</tr>
<tr>
<td></td>
<td>Centrality characteristics of network</td>
<td>Major junctions and major corridors</td>
<td>Grid overlay</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------------------</td>
<td>-------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Coverage index</td>
<td>Fractal dimension</td>
<td>Similarity characteristics of urban form</td>
<td>Nodes, Links, Functional corridors and Built up area</td>
</tr>
</tbody>
</table>

Calculation steps are indicated in figure 3.1 below.

**SDE:**

**Coverage index:**

- Coverage index = No of grids in which nodes are present / Total number of grids

**Fractal dimension:**
FD (mass radius method) = \[ D(X_i) = \frac{\log[X(R_i)/X(R_{i+1})]}{\log[R_i/R_{i+1}]} \]

Where \( X \) - parameter defining the urban form such as road length, number of nodes, built up area, population, household income etc.

\( X(R_i) \) = Value of the parameter considered in radius of scale \( i \) from the centre of the spatial extent of the area.

\( X(R_{i+1}) \) = Value of parameter in radius of scale \( i+1 \).

\( R \) = Radius of buffer zone.

\( R_{i+1} \) = Radius of predecessor buffer zone.

\( i \) = Scale of the buffer zone which is decided based on the spatial extent of the system.

**Figure 3.1: Framework for evaluation of supply system**

An ideal supply system exhibits a circular SDE with major and minor axis being equal, coverage index of 1.0 and uniform fractal dimension at all scales. This type of supply system is often observed in central business district (CBD) areas which have planned spatial structures and which are already policy driven in many planning aspects. The variation in these evaluation parameters is dominant in urban sprawls that are a result of urbanization (Garreau 1991, Stoel 1999) as they are less developed with an undefined functionality of the supply system (Dae –Sikkim et al 2003). Hence transitional urban areas i.e., sprawls are selected for the study that exhibit scattering of urban settlements (Harvey and Clark 1971, Ottensmann 1977), low density urbanization (Pendall 1999, Kent B. Barnes et al 2002) and discontinuous development (Weitz and Moore 1998). Moreover, reorientation of network is difficult in CBD areas due to problems of land acquisition. Study locations must also be viewed with respect to common explicit features describing the urban form with varied implicit characteristics within them.
The need for planning and designing the supply system is identified based on the evaluation framed in the study. An evaluation of the supply system is made before designing the orientation to know the state of the existing supply system (Masuo Kashwadani and Yasao Asakura 1995).

3.2.3 DESIGN OF SUPPLY SYSTEM PLANNING

The design of supply system planning through reorientation of network to optimally utilize the existing infrastructure is made by configuring the topology of the supply system that act as a proxy to performance and improving the existing functional supply system. The topology is addressed in 3 aspects: a) Node; b) Link / Path and c) Network. The role of existing entities that are functional is emphasized and their behavioural pattern in the network orientation is assessed by prioritization which recommends an order of improvement that can serve as an efficient tool to lead road administrators on implementation at field level. Thus a framework for functional supply system planning is attempted with a) Development of inherent / emergent functional supply system in a fractal environment – Fractal supply system orientation and b) Identification / Prioritization of existing functional supply system for its capacity enhancement – Path prioritization.
3.2.3.1 FRACTAL SUPPLY SYSTEM ORIENTATION

Traffic network decentralization provides a favorable spatial structure and leads to an even access of the demand to the supply system resulting in economy of spatial disparities. Hence to achieve demand deconcentration, reorientation of network by defining functionality uniformly and homogeneously throughout the network is required to the supply entities. Similarity of the supply entity is achieved by node, link, path and network homogeneity which is correlative with respect to functionality, spatial dispersion, movements and demand transition. Approaches for attaining the consistent structure with respect to node, links, paths and network similarity to form a fractal supply system are presented below. The approach designed is based on graph based analysis with static supply system and dynamic demand.

3.2.3.1.1. NODE SIMILARITY:

The configuration of node is made with the attainment of node similarity that promotes uniform access to the area and facilitates equitable demand transition to the supply system. The node in a network is viewed as a facility at which traffic enters and leaves the system (Lary J. Leblanc et al 1975, Prescott 1993, Bhanu M. Yerra and David Levinson 2005, Feng Xie and David Levinson(2006)) and its development as a major control point uniformly over a space induces a control on the dynamic traffic demand. Identification of such crucial supply nodes / links in a network were analyzed by graph based
approaches and simulation tools that focus on connectivity and vulnerability of the network (Erik Jenelius et al 2006, Taylor et al 2006, Gupta 1997, Galil and Italiano 1991, Karypis and Kumar 1998, Ahmed –Abdel Rahim et al 2007, Erik Jenelius 2008). In the present research, since node is viewed as a facility, the location of a node in a network is analytically viewed as a facility location problem which is typically used to place any type of service in a network from hospitals to fire station to triage areas (Paluzzi 2004, Carson and Batta 1990, Mandell 1998, Serra and Marianov 1999). The basic concept of P-Median method (Hakimi 1964) is conceptualized for identification of nodes as a facility which minimizes the average (total) distance between demands and facilities (Richard C Larson and Ghazala Sadiq 1983, Ulla Seppala 2003). The approach identifies how the nodes and links interact in a network and compares the importance of the node with respect to the neighborhood nodes in a network. The lead for measuring the node importance over the other nodes is obtained from the work attempted by Ahmed Abdel Rahim et al 2007 where he identified the critical nodes in a network through graph connectivity analysis for improving the efficiency of ITS operation.

The basic model form of p-Median method is

\[ J(X_k) = \sum_{j=1}^{n} h_j \cdot d(X_k, I) \]  
\[ d(X_k, J) = \min_{x_i} \sum X_k \]

Where \( G(N,A) \) is a unidirected network with ‘n’ nodes, \( K \) - some positive integer which are distinct points on network \( G \);
$X_k = \{x_1, x_2, \ldots, x_k\}$; $d(X_k, J)$ - Minimum impedance between any one of the points $X \in X_k$ and the node $J$ on $G$; $h_j$ - demand weight of node $J$.

The nodes identified are the 'k' medians of network $G$.

The conceptualization of the method involves identification of demand weight of node and minimum distance between the nodes. The demand weight of the node is the demand potential of the node that reflects the potential to be converted as a highly functional intersection. The node will be highly functional to attain the demand when the utility of the node is high and its counter supply elements around the node are favouring for smooth transitioning of demand. Hence the node potential of each node in the supply system is evaluated based on the node as well as neighborhood characteristics around the node. Neighborhood effect concepts were used in literature mostly in cellular automata concepts for studying urban form patterns (Ward D. P. et al 2003, Batty and Xie 1994, Semboloni 1997, White et al 1997). Since the analysis needs assessment of each node potential and identification of medians through a static impedance factor of distance, the iterations are made in a GIS interface with module addition with VB / VC ++ support. GIS is chosen as a supportive tool as it has a long trend research in transportation applications related to travel demand forecasting (Golledge 1998), activity based travel analysis (Greaves and Stopher 1998, Miller 1998 and MC Nally 1998), transit route planning (Racca 1998), transportation /Land use planning (You and Kum 1998), traffic analysis zone design (You et al

**Figure 3.2 : Framework for p – Median method**

Demand homogeneity to sectoral planning adopted in Singapore (Lim Lan Yuan 1997) has given a lead in identification of node. Node characterization reflects the utility pertaining to the node with respect to static and dynamic utility /demand which are achieved by the
demand analyzers through travel pattern characterization. Neighborhood node characterization must reflect the favorable spatial structure around the functional node which is function of urban form characteristics that are static in nature. The extent of the influence of neighborhood characteristics on a node is taken as a function of acceptable walking distance i.e.; 0.5 km. The different node and neighborhood characteristics considered in the analysis are given in table 3.2 below.

**Table 3.2: Node and Neighborhood characteristics conceptualized in demand potential estimation of p-Median method:**

<table>
<thead>
<tr>
<th>Characteristic type</th>
<th>Parameter</th>
<th>Calculation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node characteristics</td>
<td>Number of external based trips passing through that node</td>
<td>O-D matrix, Trip assignment</td>
<td>Trips / day</td>
</tr>
<tr>
<td></td>
<td>Number of path overlaps when trip exists – Dynamic OS</td>
<td>O – D matrix. Trip assignment</td>
<td>Number</td>
</tr>
<tr>
<td></td>
<td>Number of path overlaps when trips doesn’t exist – Static OS</td>
<td>Static analysis, User preferred paths</td>
<td>Number</td>
</tr>
<tr>
<td></td>
<td>Trip intensity</td>
<td>O-D matrix, Trip assignment</td>
<td>Trips /day</td>
</tr>
<tr>
<td>Neighborhood characteristics</td>
<td>No of access points</td>
<td>GIS base map</td>
<td>Number</td>
</tr>
<tr>
<td></td>
<td>Percent of perfect connectivities</td>
<td>GIS base map</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Built up area</td>
<td>GIS base map</td>
<td>Sq.km</td>
</tr>
<tr>
<td></td>
<td>Road length</td>
<td>GIS base map</td>
<td>Km</td>
</tr>
<tr>
<td></td>
<td>Higher order road length</td>
<td>GIS base map</td>
<td>km</td>
</tr>
</tbody>
</table>
The development of inputs requires urban form and travel pattern characterization. Urban form characterization involves GIS base map development for acquiring the spatial and aspatial data related to Link length, Link width, Built up area, Minor nodes and Status of connectivity of each node. The status of connectivity indicates a measure of hierarchy of the node. The different possibilities of node for connectivity are classified based on the link widths with arterials > 15m road width, sub arterials 7.0 to 15 m, collector streets 3.5 – 7 m and the remaining being local streets. If a node is connecting link with Arterial to sub arterial, it is considered as a perfect connective node. The ideal connection / perfect connectivity in a network shall maintain a hierarchy of Arterial – Sub Arterial – Collector – Local. The perfect connectivity nodes are assumed to be the nodes connecting Arterial – Sub Arterial, Sub Arterial – Collector, Collector – Local, Arterial – Arterial, Sub Arterial – Sub Arterial, Collector – Collector and Local – Local.

The demand analyzers and static analyzers formulated in travel demand and urban form characterization are the basis for assessment of potential of the node. The impedance factor considered is the distance between all the nodes in the network. The steps for identification of nodes using p-Median method is presented below

**STEPS FOR P-MEDIAN METHOD:**

As the objective is to identify the nodes with self similarity throughout the area, the nodes must be spread uniformly with high coverage
index to reflect uniformity in functionality and demand transition. Hence a constraint of setting a grid of 0.5 sq.km which moves horizontally and vertically throughout the spatial layout is made. The algorithmic steps for p-Median method are given below:

1. Formation of grid topology in the spatial extent of the study area with an area of 0.5 sq.km as shown in figure 3.3.
2. Urban form and travel pattern characterization for identification of node and neighborhood characteristics of each node with static supply and dynamic demand analyzers.

Figure 3.3 : Identification of node characteristics around the node

3. Normalization of node and neighborhood data to standardize in relative terms
4. Determination of total potential matrix of the nodes with node and neighborhood characteristics falling within the grid
5. Determination of impedance matrix between all nodes in the grid with a controlling factor of distance
6. Determination of p-Median by multiplying the impedance matrix and potential matrix

7. Determination of rank of each node with the least p-Median ranked from lowest which represents the highest potential to be converted as a demand transitioning intersection by opening access to the study area

8. Identification of nodes to be developed based on the rank.

The nodes thus identified uniformly over the spatial extent are the critical supply entities which are similar in functionality and demand homogeneity. Hence they exhibit fractal nature which is a desired phenomenon for urban areas to meet the demand and deconcentrate it over space and time. A similar concept of attaining link/path similarity is developed that induces hierarchy, functionality and maximizes supply system utility.

**3.2.3.1.2 LINK / PATH SIMILARITY:**

Link similarity in the study is the similarity in the functional corridors [Arterial and Sub arterial roads]. In a centralized and dissimilar spatial road network, alternative routes to reach from one node to another routes are less as the topology of the structure is concentrated only on few corridors that are not uniformly distributed spatially. This poses heavy congestion during critical times especially during peak hours. Hence a similar decentralized road structure is preferred that gives a shape of parallel routes longitudinally and transitionally in an area. These paths are termed as longitudinal and
transitional corridors in urban sprawl that configure as circumferential and radial routes geometrically to the CBD. Since these paths are highly functional in nature, they shall be configured based on the demand and existing supply characteristics.

Link identification is attempted with a coordinated analysis of supply system characteristics and demand characteristics. The supply system functional links/path which indicate an existing hierarchy and the demand inherent supply links with the network are integrated in a framework of subset analysis to identify the functional corridors. The inherent demand is assessed through travel demand analysis with static and dynamic supply analyzers. An unforeseen demand is analyzed with static demand analyzers (OS) in terms of utility of the link which remains constant irrespective of the dynamic demand patterns. The existing demand is configured by superimposing the dynamic travel patterns on the supply system and analyzing in terms of trip intensity and external trip dominated movements. A user preferred system with static and dynamic analyzers is developed in a spatial decision environment and is coordinated with the existing functional system to identify the links that are functional in nature. The integration of links and nodes falling under the user preferred system is made to form continuous paths / corridors that are similar in nature. This framework of a Spatial decision support system (SDSS) is shown in the figure 3.4.
The algorithmic framework for identification of longitudinal and transitional corridors, thus achieving link/path similarity is given below.

1. Development of GIS based road network created by coding all the nodes and link with a unique ID.
2. Determination of travel profiles based on demand profiles in the region which includes generation of OD matrix.
3. Static analysis of the spatial structure by identification of user preferred paths.
4. Dynamic assignment of trips to the links identified from static analysis using all-or-nothing assignment technique.

5. Identification of OS and assignment to the road network through static analysis.


7. Identification of functional corridors /paths which are subsets and union of the following paths.
   a. User preferred paths identified from static analysis between all OD pairs.
   b. Paths that are oriented towards external based movements.
   c. User preferred paths having high dynamic trip intensity.
   d. User preferred paths having high static demand derived from overlap size.
   e. Paths that pass through high ordered junctions having maximum trip intensity identified through dynamic assignment of trip.
   f. Paths that indicate existing emerged/derived demand i.e., existing major corridors.

The interfacing analysis for SDSS is shown in the figure 3.5 below. The paths thus identified are categorized as transitional and longitudinal corridors based on the orientation they divide the study area. These roads are connected to transform into continuous corridors which can be made functional thus forming a fractal network as the properties of these paths / links coincide. This approach indentified for development of self similar structure
considers network topology and demand cross-sectionally that improves operational performance of a network.

The modeling framework for development of functional network configuration with path / link similarity is presented below

Let $S$ be a set of links in the network.

Let $S = \{ S_1, S_2, S_3, \ldots, S_n \}$ where $n$ is the number of links in a network.

Let 'p' be the number of internal zones and 'q' be the number of external zones.

Hence, number of paths identified between internal zones = $(p \times p) - p = p(p - 1)$

Number of paths between internal and external zones = $p \times q$

Number of paths between external and internal zones = $q \times p$

Number of paths between external zones = $(q \times q) - q = q(q - 1)$
Total number of combinations of paths possible between OD pairs which are a subset of \( S = p(p - 1) + p \times q + q \times p + q(q - 1) \)

Let \( A \) be the subset of links for the path of all internal – internal zones.
\[
A = \{ A_1, A_2, A_3, \ldots, A_{n_1} \}, A \subset S
\]

Let \( B \) be the subset of links for the path of all internal – external zones.
\[
B = \{ B_1, B_2, B_3, \ldots, B_{n_2} \}, B \subset S
\]

Let \( C \) be the subset of links for the path of all external – internal zones.
\[
C = \{ C_1, C_2, C_3, \ldots, C_{n_3} \}, C \in S
\]

Let \( D \) be the subset of links for the path of all external – external zones.
\[
D = \{ D_1, D_2, D_3, \ldots, D_{n_4} \}, D \in S
\]

Here \( n_1, n_2, n_3, n_4 \in n \). The corridors facilitating external corridors are defined by the set of \( F = \{ C \cup D \} \)

Let \( M \) be the set of links falling under major corridors in study area.
\[
M = \{ M_1, M_2, \ldots, M_m \}, m \in n
\]

Let \( T \) be set of links where the trip intensity is high. In the study area the link is considered to have a high trip intensity when the trip intensity is greater than 60 to 75 percentile value.
\[
T = \{ T_1, T_2, \ldots, T_t \}, t \in n
\]

If \( k \) are the number of nodes in the study area which are defined as the intersection points / minor junctions in the study area, \( k_s \) represent the nodes falling under shortest path analysis. \( k_s \in k \)

Let \( k_d \) represent the nodes whose trip intensity is high. \( k_d \in k_s \)
Let $Q$ represent the set of links connecting the nodes ($k_d$) with high intensity.

$$Q = \{ Q_1, Q_2, \ldots, Q_l \}, \; l \in n$$

The higher order road system (H) or arterial system / sub arterial system in the study area is set of links satisfying the one of the following decision criteria.

$$H = (F) \cup (M) \cup (T) \cup (Q) \quad \text{Equation 3.3}$$

$$H = (F) \cap (M) \cap (T) \cap (Q) \quad \text{Equation 3.4}$$

$$H = (F) \cup (M) \cap (T) \cap (Q) \quad \text{Equation 3.5}$$

$$H = (F) \cup (M) \cup (T) \cap (Q) \quad \text{Equation 3.6}$$

$$H = (F) \cap (M) \cup (T) \cap (Q) \quad \text{Equation 3.7}$$

$$H = (F) \cap (M) \cup (T) \cup (Q) \quad \text{Equation 3.8}$$

$$H = (F) \cup (M) \cap (T) \cup (Q) \quad \text{Equation 3.9}$$

$$H = (F) \cup (M) \cup (T) \cup (Q) \quad \text{Equation 3.10}$$

The selection of the equation depends on the intersection of different links in various sets. If for example, the set of links falling in F and M are same or almost same, then intersection is adopted. If they are different and only few links are present, then union is adopted.

3.2.3.1.3 NETWORK SIMILARITY : INTEGRATION OF NETWORK WITH NEIGHBOURHOOD NETWORK

The fractal spatial structure developed with respect to nodes, links, paths/ corridors shall be integrated with the neighborhood networks to attain a network similarity. The integration must be based on the
continuity of the route which depends on connectivity patronage. If the core urban area exhibits a circular shape and the sprawls are spread around the core area, the integration of longitudinal and transitional corridors exhibit radial and circular routes around and from the core area. The formation of an integrated network opens uniform access to the transitioning and core urban areas facilitating deconcentration of demand over space and time and defining a functional – hierarchical network, thus promoting uniformity of land use with priority based land use activities. The network orientation is thus made from the hidden hierarchy in the supply system that makes its utility to an optimal level over a time.

Supply utility can be further enhanced if the existing hierarchy derived from the road users and system owner are improved to meet the demand requirements. The order of improvement of these critical supply elements / major corridors shall be made based on system wide perspectives with network analysis rather than confining to localized approaches. An approach for path prioritization is designed using multi criteria analysis for prioritizing the road development over a time.

3.2.3.2 PATH PRIORITISATION - PRIORITISATION OF EXISTING FUNCTIONAL SUPPLY SYSTEM FOR ITS CAPACITY ENHANCEMENT:

A subset to planning the supply system is to identify the critical paths that reduce the operational performance in the network and improve
them. The order of improvement of the critical paths depends on the funds available. Hence, a technique for prioritization is suggested based on a network level analysis rather than confining to the traditional approach of considering V/C analysis that leads to a localized solution (Scott D.M. et al 2005). The prioritization is also useful for the purpose of road management, prioritization of road investment, maintenance and repair, contingency planning and for assessment of spatial disparities (Erik Jenelius et al 2006). Several researchers have worked in this direction to develop priority ranks for the available network of roads (Reddy and Veeraragavan 2002, Chen et al. 1993, Sharaf 1993, Golabi & Pereira 2003, Bandara and Gunaratne 2001, Sandra A.K et al. 2006). The existing methodologies range from single criteria cost / benefit analysis (CBA) to multiple criteria models and mathematical programming approaches (Jennifer S. Shang, Youxu Tjader and Yizhong Ding 2004). Majority of the models offer localized solutions to manage demand on individual congested portions of the network and do not address system wide impacts (Scott D.M. et al 2005, Dheenadayalu et al 2004). There is a need to address prioritized planning from a system wide perspective taking into account network topology (Scott D.M.et al 2005).

Prioritization has to be made based on the functional attributes of the link which serves as a performance indicator. The objective of functional attributes in performance such as geometric, traffic and land use characteristics are conflicting to each other such
as maximization of speed and minimization of delay. It is considered as a complex and dynamic process as there are conflicting multi attributes acting at one point of time which have to be evaluated cross-sectionally in a single framework. Hence a mathematical framework supporting multi criteria evaluation (MCE) is used for analyzing the multi faceted functional attributes.

MCE for path prioritization is formulated in five phases:
1) Input phase, 2) Design phase, 3) Analysis phase, 4) Evaluation and Validation phase and 5) Choice phase. The framework for prioritization is given in the figure 3.6 below

Figure 3.6 : Framework for MCE analysis

3.2.3.2.1 INPUT PHASE:

This is an intelligent phase formulated in GIS with objective function operationalisation and evaluation criteria formulation. The
objective function is operationalised to identify the critical path in the network and the improvement of which can enhance the mobility in the network. Evaluation criteria for attaining the objective function are the path characteristics that influence the mobility characteristics of the path. A lead in identification of functional characteristics is obtained from the study by Nesamani K.S et al (2005) and Stephen R. Alderson and Yorgos Stephanedes (1986) where link is evaluated based on geometric, traffic and road side characteristics and a strong influence is found on overall performance of network. The main criterion and sub criterion characteristics formulated are indicated in the figure 3.7 with their objective functions for the critical path.

<table>
<thead>
<tr>
<th>Geometric characteristics</th>
<th>Traffic characteristics</th>
<th>Landuse and Road side characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Carriageway width (Min)</td>
<td>• Headway (min)</td>
<td>• Commercial area (Max)</td>
</tr>
<tr>
<td>• Roadway width (Min)</td>
<td>• Volume / Capacity ratio (Max)</td>
<td>• Residential area (max)</td>
</tr>
<tr>
<td>• Stopping sight distance (Min)</td>
<td>• Speed (Min)</td>
<td>• Semi Residential area (Max)</td>
</tr>
<tr>
<td>• Number of curves (Max)</td>
<td>• Delay (Max)</td>
<td>• Industrial area (Max)</td>
</tr>
<tr>
<td>• PCI (Min)</td>
<td>• Trip Intensity (Max)</td>
<td>• Intensity of parking, business and encroachments (Max)</td>
</tr>
<tr>
<td>• Number of access points (Max)</td>
<td>• Overlap size (Max)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.7: Main and Sub criterions formulated in Input phase of MCE.

Note: Max and Min in the figure represent maximization and minimization of the criteria.
### 3.2.3.2.2 DESIGN PHASE:

Design phase is the MCE interface to assess weightage factor for the main and sub evaluation criterions to define the role of each contributing factor. The weightage factor for the main criterions is assessed through a technique of relational analysis which determines the influential patterns on each characteristic. The weightage factor for sub criterions is assessed with pair wise comparison technique which relatively judges the importance of one criterion over the other. The techniques adopted for assessment of weightages of main and sub criterions is indicated in the figure 3.8 below.

![Figure 3.8: Assessment of weightages](image)

The steps for relational analysis and pair wise comparison are given below.

**A) RELATIONAL ANALYSIS – WEIGHTAGE FACTOR ASSESSMENT FOR MAIN CRITERIONS**
The steps for assessment of weightage factor for main criterions with relational analysis:

1. *Categorization of study zones with respect to built up area*:

Since the performance of path with functional attributes varies according to the built up area densities, the study zones are categorized according to built up area densities as Low, Medium and High.

2. *Identification of Evaluation sub criterions*:

The sub criterions under each main criterion are selected to best represent and define the criterions empirically. The parameters defining each criterion are given in the figure 3.9 below.

![Figure 3.9: Relational analysis attributes considered for weightage factor determination](image-url)
Geometric characteristics of a road network describe the topological structure of the road network relating to the static characteristics of the network. The density is a common measure of the urban form in literature exploring the connection between urban form and travel behavior (Frank and Pivot 1994, Kockelman 1997) and hence is considered for analysis. Structural measures were proposed by Kansky to analyze the network efficiency interpreted through graph theory which is widely used in road network generalization (Mackaness and Beard 1993; Mackaness 1995; Thomson and Richardson 1995; Jiang and Claramunt 2004; Jiang and Harrie 2004). Three structural measures – Alpha, Beta and Gamma indices are considered for the analysis. Density and fractal dimension of the network also represent the geometric properties of the network.

Fractal dimension of the road network is an index identified in the recent research for analysis the topology of the road networks. Extent of possible optimal use of network is generalized in the percent of shortest path obtained from static analysis to the available road length in a network. This is a new index developed to describe the road network orientation, utility and its involvement in the mobility. Shortest path concepts were used in many planning applications related to route choice models in recent studies by researchers (Ramming and Micheal Scott 2002, Dalton and Turner 2005, Cascetta 2001; Lam et al 1999). The extent of functional roads available are identified based on the available roadway width of the
links in the network and are expressed in terms of percentage of arterial, sub arterial and collector streets in the network.

Traffic characteristics are the dynamic characteristics of the road that influence the operational performance of the road network. They are density of trip origins (CATS 1962, Roger L. Creighton 1970), travel patterns (Trip intensity in terms of overlap size, trip length and trip orientation) and mobility characteristics such as speed.

Land use and road side characteristics are the static elements of the path which influence the operational performance of the network. The percentages of different types of land uses (residential, semi residential, industrial and commercial) are considered in this category.

3. Relational analysis:

The relational analysis is done between the homogeneous characteristics (Geometric – Geometric, Traffic – Traffic etc) as well as between heterogeneous characteristics (geometric – traffic, geometric – land use, traffic – land use etc). Various correlation measures can be used to measure the covariance between the characteristics such as Spearman correlation coefficient, Pearson correlation, Kindell correlation etc which were effectively used in urban planning applications (Xuedong Lu and Eric I. Pas 1999, Ronald G. Arbogast et al 1981, Clarke K et al 1997, Dekeersmaecker Marie – Laurence et al 2003). The correlation between each of the characteristics is tested with Spearman coefficient correlation which assesses the relationship between two variables without making any assumptions about the
frequency distribution of the variables (Feng Xie and David Levinson 2007). The number of perfect correlations (having correlation coefficient greater than 0.75) under each category of relation are identified and weightage is assessed based on the majority of the correlations through normalization.

B) PAIR WISE COMPARISON – WEIGHTAGE FACTOR FOR SUB CRITERIONS:

Pair wise comparison method has been adopted in assessing the criterion weights for sub criterions. This method involves pair wise comparisons to create a ratio matrix / pair wise comparison matrix based on Satty scale (Satty 1980). Pairwise comparison method for assessment of weights to the criteria were used in many problems like route choice planning (Reza Benai 2006), land use planning (Hong Jiang and Ronald Eastman 2000, Jose Ignacio Barredo and Joaquin Bosque Sendra 1991, Jose F.G. Mendes 2001), Transportation project evaluation (Jennifer S. Shang et al 2004), corridor evaluation (Keiron Bailey 2003) and traffic assignment (Gwo – Hshiung Tzeng et al 2005). Steps for pair wise comparison are presented below
1. Comparison matrix is established in a continuous scale with values from 1/9 (least influence) to 9 (largest influence) to rate the preferences for two main-criteria (Jose Ignacio Barredo and Joaquin Bosque – Sendra 1991). The comparison matrix is obtained from the Delphi approach (John S. Hoffman 1975, Violetta Cavalli Storza and Leonard Ortolano 1984).

If the number of main-criteria is q under consideration, the comparison matrix \( M = \{m_{ij}\} \) \( i = 1, 2, 3 \ldots, q; \ j = 1, 2, 3 \ldots, q \) can be constructed as

\[
\begin{pmatrix}
C_1 & C_2 & \ldots & C_q \\
C_1 & m_{11} & m_{12} & \ldots & m_{1q} \\
C_2 & m_{21} & m_{22} & \ldots & m_{2q} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
C_q & m_{q1} & m_{q2} & \ldots & m_{qq}
\end{pmatrix}
\]

Here \( (C_1, C_2, \ldots, C_q) \) are main-criteria.

The main diagonal entries \( (m_{ij}) \) in \( M \) are always equal to 1 because of equally preferred main-criteria. The upper right corner of the entries \( (m_{ij}) \) in \( M \) represent the direct scores with respect to main-criteria set. The lower left corner of the entries \( (m_{ij}) \) in \( M \) represent the reciprocal score of their corresponding upper left corner entries score.

2. By using the comparison matrix \( M \), the normalized comparison matrix \( A = \{a_{ij}\} \) \( i = 1, 2, 3 \ldots, q; \ j = 1, 2, 3 \ldots, q \) is defined as
### Table 1

<table>
<thead>
<tr>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>( C_q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m_{11} / \Sigma m_{i1} )</td>
<td>( m_{12} / \Sigma m_{i2} )</td>
<td>...</td>
</tr>
<tr>
<td>( m_{21} / \Sigma m_{i1} )</td>
<td>( m_{22} / \Sigma m_{i2} )</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>( m_{q1} / \Sigma m_{i1} )</td>
<td>( m_{q2} / \Sigma m_{i2} )</td>
<td>...</td>
</tr>
</tbody>
</table>

3. The normalized weight \((\alpha_j)\) is defined by using the normalized comparison matrix \(\alpha_j = \Sigma (a_{ij}) / q\); Where \(\alpha_j\) is the weight of the \(j^{th}\) attribute or criterion and \(\Sigma \alpha_j = 1\).

4. The consistency ratio is calculated to test the validation of the weights adopted and indicative of inconsistent / consistent judgments (Saaty 1995, 1997, Reza Banai 2006).

Design phase also includes standardisation of the raw data for analysis. The problems are analyzed by maximizing or minimizing a linear function of number of variables (Black W.R. 2003). The transformation of a multi criteria problem to a single criterion problem can be solved through linear programming or weighing method (Malczweski J. 1999). Two methods of standardisation for normalizing the data are formulated - Linear function and Value function standardization techniques.
A) LINEAR FUNCTION STANDARDISATION:

Vector normalization through linear function is used to eliminate the units of criterion functions (Serafim Opricovic and Gwo-Hshiung Tzeng 2002). The normalized value is termed as the utility value. The normalization is to a scale of 0.0 to 1.0 where 1.0 is considered as an ideal point (Sumbangan Baja et al. 2005). The normalized values are interpreted as the change in the overall value for a criterion that results from a unit change in the criterion value function (Greg Rybarczyk and Changshan Wu 2006)

B) VALUE FUNCTION STANDARDISATION:

The mid value method is used in assessing the value function (or curve). This method involves the following steps:

Step 1: Determine the range over which the curve is to be assessed (ie., set the lower and upper bounds of the value scale) and assign a value of 0.0 and 1.0 to these end points, respectively. Based on the objective function defined as above, the end points are assigned to each scale. For eg., the objective function defined for one of the traffic characteristics is “Maximization of speed”. The speed values are arranged in ascending or descending order. As the objective function is maximization, the maximum value in the range is the path which has better performance. Hence this value will be assigned a value of 1.0 and the lowest value in the data will be assigned a value of 0.0. In case of minimization functions like Minimization of delay, the
minimum value in the range will be assigned a value of 1.0 whereas maximum value will be assigned a value of 0.0.

Step 2: Find the midpoint between these end points in the raw data and assign a value of 0.5 to that point.

Step 3: Find the mid value points between step 1 and the midpoint defined in step2, and between the midpoint and the maximum value, assign the values 0.25 and 0.75 to these points, respectively.

Step 4: Repeat the step 3 to find the mid value points between the outcomes already assessed and to assign the subsequent values of 0.125, 0.375, 0.625, and 0.875 and so on, to the corresponding mid value points, until as many points are obtained as needed. More points indicate greater accuracy level of the curve.

Step 5: Draw the value curve through the assessed points and fit an analytical expression into the points.

Step 6: For each attribute / factor in all the criterions, the curve is plotted for the data range. The value function for the data range is obtained by the analytical expression fitted to the curve.

3.2.3.2.3 ANALYSIS PHASE:

Analysis is made with three analyzers – Ideal point analysis (IPA), Analytic hierarchy process (AHP) and Concordance method which frame decision rules in MCE.
A) IPA ANALYSER:

The main analyzer considered in the analysis stage is Ideal Point analysis method (IPA). Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) (Hwang and Yoon 1981)/IPA method matches closely with the problem scenario as it evaluates the relative distance of the functional attributes from the ideal point and priorities based on relative closeness. This approach avoids some of the difficulties associated with the interdependence – among – attributes assumption. In this method, an alternative is treated as an inseparable bundle of attributes for which it would be pointless to treat dependence as separable and assess value and preferential dependence (Zeleny 1982; Pereira and Duckstein 1993). Some of the typical applications of Ideal point analysis are found in land use planning (Serafim Pricovic 2002), traffic assignment (Gwo Hshiung Tzeng, Cheng – Ho Chen 1993), land suitability analysis (Sumbangan Baja, David M. Chapaman and Deirdre Dragovich 2005) etc.

The basic model form of IPA method is

\[ S_{i+} = \left[ \sum_j (w_{ij} - V_j)^p \right]^{1/p} \]  \text{ Equation 3.11}

Where \( p \) is a power parameter ranging from 1 to \( \infty \)

\( S_{i+} \) = separation measure; \( w_{ij} \) = weighted standardized function of the attributes; \( V_j \) = Ideal point. The steps for IPA method are presented below

Step 1: Determination of weighted standardized decision matrix:
Weighted standard matrix = \( w_{ij}(x) = \alpha_j x U_{ij}(x) \)  \( \ldots \) \( \text{Equation 3.12} \)

Where \( \alpha_j \) = weightage factor of subcriterion \( j \) and \( U_{ij} \) = Value function utility for \( j^{th} \) characteristic in path \( i \).

**Step 2: Determination of positive ideal and negative ideal point:**

The ideal point \( (V^{+}_j) \) is defined as

\[
V^{+}_j(x) = \max(w_{ij}(x)) \quad \ldots \quad \text{Equation 3.13},
\]

\( j=1,2,3, \ldots n; \ i=1,2, \ldots m \)

The negative ideal point is given by

\[
V^{-}_j(x) = \min(w_{ij}(x)) \quad \ldots \quad \text{Equation 3.14}
\]

\( j=1,2,3, \ldots n; \ i=1,2, \ldots m \) Where \( m \) is number of alternatives and \( m \) is number of criterions.

**Step (3) Determination of separation measures:**

Using a separation measure, calculate the distance between the ideal point and each alternative \( (S^+_i) \) given by (Malczewski, 1999)

\[
S^+_i(x) = (\sum_j (w_{ij} - V^{+}_j)^{P})^{1/P} \quad j=1,2,3, \ldots n; \ i=1,2, \ldots m \quad \text{-- Equation 3.15}
\]

Using the same separation measure determine the distance between the negative ideal point and each alternative \( (S^-_i) \) given by (Malczewski, 1999)

\[
S^-_i(x) = (\sum_j (w_{ij} - V^{-}_j)^{P})^{1/P} \quad j=1,2,3, \ldots n; \ i=1,2, \ldots m \quad \text{-- Equation 3.16}
\]

Here \( p \) is a power parameter ranging from 1 to \( \infty \). In general, larger values of \( p \) reflect greater concern for minimizing the maximum separation from the ideal. If the parameter is set at 1, rectangular
distance is calculated. For $p = 2$ the straight-line distance is obtained (Malczewski, 1999). If $p = \infty$, the minimum of the maximum separation is obtained. In this model both separations are calculated using Euclidean (or straight-line) distance metric. So, the equations (3.15) and (3.16) become

\[
S_{i+}(x) = \left( \sum_{j} (w_{ij} - V_{+j})^2 \right)^{0.5} \quad j = 1, 2, 3, \ldots, n; \quad i = 1, 2, \ldots, m \quad - \text{Equation 3.17}
\]
\[
S_{i-}(x) = \left( \sum_{j} (w_{ij} - V_{-j})^2 \right)^{0.5} \quad j = 1, 2, 3, \ldots, n; \quad i = 1, 2, \ldots, m \quad -- \text{Equation 3.18}
\]

**Step (4) Determination of relative closeness.**

Relative closeness to the ideal point ($RC_{i+}$) is given by

\[
RC_{i+} = \frac{s_{i-}}{s_{i+} + s_{i-}} \quad i = 1, 2, 3, \ldots, m \quad ------ \text{Equation 3.19}
\]
Subject to $0 < RC_{i+} < 1$; that is an alternative is closer to the ideal point as $RC_{i+}$ approaches 1. The above equation represents the “basic principle” in the Ideal point analysis method (Chen and Hwang, 1992). The best alternative is the one that has the shortest distance to the ideal solution (Triantaphyllou, 1997).

**Step (5) Determination of ideal point matrix**

Transfer the relative closeness to the ideal point ($RC_{i+}$) values to some other relative closeness to the ideal point matrix ($C_{ij+}$); $j = 1, 2, 3, \ldots, n; \quad i = 1, 2, \ldots, m$) for objective function calculation.

**Step (6) Determination of rank of all the alternatives**

Repeat the step (1) to step (5) until all the main-criteria under consideration were calculated. Best alternative is selected according to the
descending order of $OF_i$; the alternative with the highest value of $OF_i$ is the best alternative. The highest priority is given to high $OF_i$ value.

The framework for IPA is given in the figure 3.10 below
Figure 3.10: Schematic view of Multi criteria evaluation analysis
**B) AHP ANALYSER:**

Single level AHP is used for analysis. This method prioritizes the alternatives based on the hierarchy in standardisation. This analyzer has been successfully used in transportation planning by many researchers. Azis [1990] and Saaty [1997], [1995] apply AHP to transportation decision-making. Holguin-Veras [1995] compared AHP with multiattribute analysis in highway planning. The basic form of AHP method is:

\[
P(r) = \text{Max} \sum_{i=1}^{n} W_{ij} \quad \text{------- Equation 3.20}\]

Where \( p(r) \) = prioritized rank; \( W_{ij} \) = weighted standardized value = \( l_{ij} \cdot c_i \); \( l_{ij} \) = linear function standardization of criterions (maximization for worst attributes); \( C_i \) = weightage of characteristic attributes

**C) CONCORDANCE:**

This method evaluates the concordance between the alternatives and compares possible alternatives on a criterion by criterion basis. (Florent Joerin et al. 2001). Formula and variables used to compute the closeness relationship between two elements A and B characterized by their scores in the set of criteria is given in table 3.3.
Table 3.3: Formula and weights used to compute the closeness relationship between two elements A and B characterized by their scores in the set of criteria.

<table>
<thead>
<tr>
<th>Formula</th>
<th>Variables used</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r(A, B) = C(A, B)$</td>
<td>Degree of credibility of closeness relationship between A and B, $r(A, B) \in [0, 1]$</td>
</tr>
<tr>
<td>$I = {i: d_i(A, B) &gt; C(A, B)}$</td>
<td>$C(A, B)$: Global Concordance, $C(A, B) \in [0, 1]$</td>
</tr>
<tr>
<td>$C_i(A, B) = \begin{cases} 1 &amp; \text{if } X_i &lt; q_i \ \frac{p_i - X_i}{p_i - q_i} &amp; \text{if } X_i \in [q_i, p_i] \ 0 &amp; \text{if } X_i &gt; p_i \end{cases}$</td>
<td>$c_i(A, B)$: Concordance index on criteria $i$, $c_i(A, B) \in [0, 1]$</td>
</tr>
<tr>
<td>$X_i =</td>
<td>N_{A,i} - N_{B,i}</td>
</tr>
<tr>
<td>$d_i(A, B) = \begin{cases} \frac{p_i - X_i}{p_i - q_i} &amp; \text{if } X_i \in [q_i, p_i] \ 0 &amp; \text{if } X_i &gt; v_i \end{cases}$</td>
<td>$d_i(A, B)$: Discordance index on criteria $i$, $d_i(A, B) \in [0, 1]$</td>
</tr>
</tbody>
</table>

3.2.3.2.4 EVALUATION AND VALIDATION PHASE: SENSITIVITY AND UNCERTAINTY ANALYSIS:

The significance difference between the rankings obtained by IPA, AHP and concordance methods are tested using spearman’s rank correlation coefficient. Uncertainty and sensitivity analysis of the 3 methods is made to check the robustness of the method (Jennifer S. Shang et al. 2004). This analysis assesses the stability of the optional
solution under possible changes in weightage criteria values [Evans JR. 1984].

3.2.3.2.5 CHOICE PHASE:

The recommendations based on the prioritization obtained are made in the choice phase.

The prioritization through MCE analysis facilitates a flexibility in analyzing the supply system alternatives with system wide impacts.

Supply system planning has been addressed to attain a sustainable development of urban areas in which spatial nature of urban form has economic, environmental and social implications (Ward D.P. et al 2003).