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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Developing Context Sensitive Planning Criteria for Transit Oriented Development (TOD): A Fuzzy-Group Decision Approach

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Abstract

Developing countries like India have started focusing on Transit Oriented Development (TOD) policies for their existing cities. In the absence of a generic definition and generalized criteria in the TOD literature, context-specific planning criteria are essentially required to assess TOD suitability in any city. Multi-Criteria Decision Making (MCDM) techniques have been widely used throughout the past studies to assist multi-stakeholders' in establishing criteria related to TOD planning. This paper presents a Multi-Criteria Multi-Stakeholder Decision Making approach based on Fuzzy-Analytical Hierarchical Process (FAHP) to establish planning criteria which can be further useful to select suitable TOD sites in Delhi, India. A series of 9 criteria and their corresponding indicators are established based on literature review and expert consultation. Three stakeholder groups (researchers, planners, and policymakers) comprising of 31 experts from different fields related to TOD issues were solicited to provide their perspectives on TOD planning in the Delhi city. The expert judgments were converted into fuzzy numbers to capture the vagueness and uncertainty that human attitudes entail when making judgments. In this study, 13 priority indicators were identified based on a balanced consensus in stakeholder groups using the FAHP method. Given that the stakeholder groups diverge in their perspectives, their judgments convergence in believing that TOD planning in Delhi can be best assessed using 'transit service' criterion and least assessed using 'Demographics' criterion. The global weights of criterion and indicators are drawn from multi-stakeholders' perspectives can be effective in achieving TOD planning across existing and future cities in India.

Keywords: TOD Planning, Fuzzy-AHP, Multi-Stakeholders, Definition

1. Introduction

Researchers, planners, and policymakers are the primary stakeholders of any urban transportation planning (UTP) problem (Metaxatos and Thakuriah, 2009). Researchers' view a transportation problem by underpinning knowledge insights, models and frameworks from global case studies. Planners' perspective is towards learning, transferability,

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sharing, and collaborations for emerging solutions. Policymakers' objective is to enhance transportation and infrastructure by applying suitable strategies. Each stakeholders' perspective is usually contradictory with the others (Sirikijpanichkul et al., 2017). However, significant decision making in any UTP could result from a balanced consensus with multi-stakeholders' perspectives (Macharis and Bernardini, 2015; Mihyeon and Amekutzi, 2005).

The connotation between land use and transportation is always a big debate for multi-stakeholders involved in UTP (Wadell, 2011). Traditional urban planning strategies such as new urbanism, transit villages and transit oriented development (TOD) are successful in land use and transportation integration, in order to mitigate urban problems such as traffic congestion and air pollution (Calthorpe, 1993; Cervero and Bernick, 1997; Burton; 2000; Song and Knaap, 2003). Among these planning strategies, TOD is the most popular and embraced in many developed cities as an escape plan to urban problems (Dittmar and Poticha, 2004).

The present study considers multi-stakeholders' (researchers, planners and policymakers) decisions to apply TOD planning criteria for Indian cities, especially for Delhi. It is necessary to identify and properly determine the priorities of criteria for efficient TOD planning (Laaly et al., 2017). A widely used Multi-Criteria Decision Method (MCDM), Analytical Hierarchical Process (AHP) and its Fuzzy extension are applied for decision making, in order to assess the relative importance of criteria and indicators for TOD planning from multi-stakeholders' perspectives. The present study explores the most important criteria and the indicators for TOD planning in fast developing cities like Delhi. A brief literature review on TOD planning and MCDM methods are discussed in the literature review section.

2. Literature Review

2.1. Transit Oriented Development (TOD)

TOD is a development which is dense, mixed-use, non-motorised transport (NMT) friendly streets around efficient and frequent transit that reduce private transport, increase walk and transit usage (Frank and Pivo, 1994; Greenwald and Boarnet, 2001; Chatman, 2003; Arrington and Cervero, 2008). It is believed that, when places (station areas) are dense, vibrant and NMT friendly within walkable distance to public transit, people living in those places (station areas) prefer to walk and use public transit other than the private modes. Such a paradigm shifts from private to public modes will decrease the travel distance and time. This leads to a reduction in traffic congestion and air pollution (Boarnet and Crane, 2001; Cervero and Duncan, 2006; Cervero, 2016). Recently, developing countries like India renowned the concept of TOD as a sustainable approach to its compact cities for a better quality of life (MoUD, 2016).

From the past decade, government bodies of India are very keen to achieve a more sustainable urban form. As a result, TOD policies and guidelines were emulated in association with metro rail transit (MRT) in major Indian cities (UTTIPEC, 2012; MoUD, 2016). However, there are many practical difficulties in attaining high density, vibrant and NMT friendly developments around transit stations or corridors, due to a variety of critical factors, public policies and contextual issues involved in TOD planning (Thomas and Bertolini, 2017). In India, the difficulties in TOD planning and implementation are mainly due to the absence of case studies to frame new TODs and the absence of generalized planning criteria that enhance existing urban areas to TODs. Most of the Indian cities are compact such that new TODs are questionable due to the lack of available land.

2.2. TOD Planning and Criteria

Numerous researchers evaluated the performance of existing TODs across the world. However, limited studies have reported on planning aspects of future TODs (Wey et al., 2016; Singh et al., 2017; Mu and Jong, 2012). Table 1 presents various existing studies on TOD planning. From Table 1, it is evident that the criteria considered in the TOD planning literature were not comprehensive and truly context specific. Suitable planning criteria have to be established for Indian cities to assess and select transit station areas that provide great potential for TOD planning. Although, Sahu (2018) employed 3 planning criteria for a new TOD in Naya Raipur, India. This study is limited to only 3 D's of TOD namely density, diversity and distance, however, other dimensions such as design, demand management, destination accessibility, and demographics should be considered in TOD planning (7 D's of Ewing and Cervero, 2010).

Table 1: TOD Planning Literature

Reference	Case study	Planning Criteria	Methodology	Stakeholders	Inference
Wey (2015)	7 metro stations in Taipei, Taiwan	• Mix Land Uses • Infill Development • Open Space Areas • Compact Building • Housing Choices • Walkable Neighborhoods • Transportation Choices • Stakeholder partnership • Cost Effective Development	Fuzzy-AHP and DEA	6 Academic researchers	Selection of best possible site for TOD planning
Wey et al., (2016)	Ankeng line of the New Taipei City MRT system	• Population density • Spatial density of facilities • Design of pedestrian spaces • Environmental carrying capacity • Mixed land use • Density of open spaces • Inhibition capacity of floor area • Equality in residence accessibility • Daily living safety	Fuzzy-ANP and GIS	1 Industrial expert, 1 Government official and 1 Academic researcher	Performance of metro stations was evaluated using TOD planning criteria
Aston et al., (2016)	Melbourne, Australia	• Density • Diversity • Design	Stepwise Linear Regression	----	TOD Scores for different modes
Motieyan and Mesgari (2017)	Tehran, Iran	• Density • Diversity • Design • Socio-economic development	Fuzzy-AHP	Regional Officials	TOD Index at Neighborhood level
Singh et al., (2017)	21 Train stations in the city region of Arnhem and Nijmegen, The Netherlands	• Density • Land use diversity • Walkability and Cyclability • Economic development • Capacity utilization of transit system • Access and Accessibility • Parking at station	Spatial Multi Criteria Analysis (SMCA) using GIS	Regional Officials	TOD Index at regional level
Strong et al., (2017)	Colorado, US	• Travel Behavior • Built Environment • Economics • Social Diversity	AHP	3 Regional officials	A TOD site selection decision framework
Sahu (2018)	5 BRTS stations of Naya Raipur, India	• Density • Diversity • Distance to transit	AHP and Genetic Algorithm (GA)	3 Researchers, 2 Planners and 1 Engineer	The best alternative plan was compared with Curitiba and Arlington County plans

2.3. MCDM Techniques

Most of the TOD planning studies in the literature have adopted multi-criteria decision making (MCDM) methods for estimating the relative importance and weights to criteria and their corresponding indicators (Wey and Chiu, 2013; Wey, 2015; Strong et al., 2017; Singh et al., 2017; Motieyan and Mesgari, 2017). MCDM methods demonstrate the tradeoffs among the criteria/indicators which assist stakeholders to reflect upon worthy judgments (Kolios et al., 2016). The MCDM methods applied in the TOD planning literature include classical methods such as Analytical Hierarchy Process (AHP) (Strong et al., 2017; Sahu, 2018) and Analytical Network Process (ANP) (Wey and Chiu, 2013), hybrid models such as Data Envelopment Analysis (DEA) with AHP (Wey, 2015) and Geographic Information System (GIS) with AHP (Motieyan and Mesgari, 2017), fuzzy models such as Fuzzy-AHP and Fuzzy-ANP (Wey et al., 2017) and spatial models using GIS (Singh et al., 2017). However, these studies considered either planners, research professionals or policymakers' decisions to assign weights to planning criteria. A decision process on quantification of relative importance and ranking of priority criteria to assess TOD planning is also limited in previous studies (Strong et al., 2016). This study fills this gap by presenting a decision framework for assigning global weights to the priority indicators. This allows one to rank those indicators and utilize weights in any quantitative methods that assess TOD planning in developing cities like Delhi.

3. Methodology

The present study employs AHP and Fuzzy-AHP (FAHP) methods to assign relative preferences and estimate the weights of planning criteria considering the multi-stakeholders' perspectives. AHP is a classical and most popular MCDM method developed by Saaty (2012) to solve complex decision-making processes. AHP method has the ability to solve the inconsistency of the responses but fails to model uncertainties in the responses (Motieyan and Mesgari, 2017). According to Zahir (1991), any weight (W_i) derived from the AHP method, must have an uncertainty (Δw_i) which is represented by the Equation 1

$$W_i = w_i \pm \Delta w_i \tag{1}$$

where w_i is the principal data. To summarize uncertainty concept, Wang (2015) has proposed geometric mean uncertainty index (GMUI) from the viewpoint of consistency index (CI). However, Wang's GMUI determines the uncertainty in a single judgment only. To solve this problem, FAHP is used in this study and compared the results with the classical AHP method. FAHP is the synthetic extension of AHP that supports fuzziness and vagueness existing in the decision makers' judgments. FAHP overcome the uncertainties of judgments in classical AHP method. It also allows missing or unlikely comparisons in the data. The Fuzzy AHP method uses a range of values (optimistic, moderate and pessimistic) known as fuzzy numbers. These numbers represent the highest, middle and lowest values of the range (Mosadeghi et al., 2015). There are several methods to represent fuzzy numbers, however, triangular fuzzy membership functions are simple, fast and reliable (Motieyan and Mesgari, 2017).

In this paper, Chang's (1996) extent analysis method on FAHP is formulated for criteria prioritization. Steps of Chang's (1996) extent analysis can be given in the following steps:

Step 1: We define a fuzzy number M on R to be a triangular fuzzy number if its membership function $\mu_M(x)$: R → [0,1] is equal to Equation 2 as

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, x\epsilon[l,m] \\ \frac{x}{m-u} - \frac{u}{m-u}, x\epsilon[m,u] \\ 0, \quad otherwise \end{cases} \tag{2}$$

where $l \leq m \leq u$, l and u stand for the lower and upper value of the support of M respectively, and m for the modal value. The triangular fuzzy number can be denoted by (l, m, u). The support of M is the set of elements $\{x \in R | l < x < u\}$. When l = m = u, is a non-fuzzy number by convention.

Let X = {x_1, x_2, ……, x_n} be an object set, and U = {u_1, u_2, ……., u_m} be a goal set. According to the method of extent analysis, we now take each object and perform extent analysis for each goal respectively. Therefore, we can get m extent analysis values for each object, with the following signs:

$M_{g_i}^1, M_{g_i}^2, \dots\dots\dots, M_{g_i}^m$, i = 1, 2, ….., n,

where all the $M_{g_i}^j$ (j = 1, 2, ……, m) are triangular fuzzy numbers.

Step 2: Let $M_{gi}^1, M_{gi}^2, \ldots \ldots \ldots, M_{gi}^m$ be values of extent analysis of ith object for m goals. Then the value of fuzzy synthetic extent with respect to the ith object is defined in Equation 3 as

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \quad (3)$$

Step 3: The degree of possibility of M1 ≥ M2 is defined in Equation 4 as

$$V(M_1 \geq M_2) = \underbrace{sup}_{x \geq y} \left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \quad (4)$$

When a pair (x,y) exists such that x ≥ y and $\mu_{M_1}(x) = \mu_{M_2}(y) = 1$, then we have $V(M_1 \geq M_2) = 1$. Since M_1 and M_2 are convex fuzzy numbers we have that
$V(M_1 \geq M_2) = 1$ iff $m_1 \geq m_2$

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = \mu_{M_1}(d) \quad (5)$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (see Fig. 1).

When $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the ordinate of D is given by Equation 6 as

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \quad (6)$$

To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$

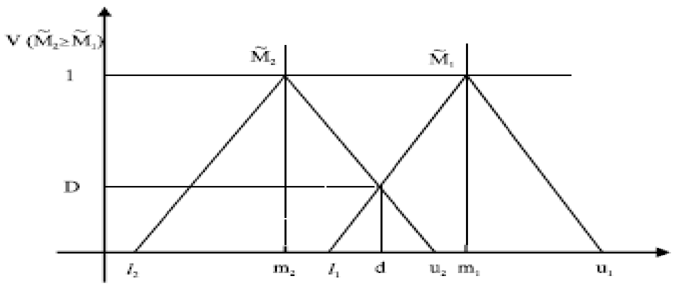

Figure 1: Chang's Two Triangular Membership Function

Step 5: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_1(I = 1, 2, ……, k) can be defined by Eq. 7 as
$V(M \geq M_1, M_2, \ldots \ldots, M_k) = V[(M \geq M_1)\ and\ (M \geq M_2)\ and \ldots \ldots and\ (M \geq M_k)] = minV(M \geq M_i), i = 1,2, \ldots \ldots, k$ (7)

Assume that
$d'(A_i) = minV(S_i \geq S_k),$ (8)
For k = 1,2,….,n; k ≠ i. then the weight vector is given by Eq. 9 as
$W' = (d'(A_1), d'(A_2), \ldots \ldots d'(A_n))^T$ (9)
where A_i $(i = 1,2, \ldots \ldots, n)$ are n elements.
Via normalization, we get the normalized weight vectors given by Eq. 10 as
$W = (d(A_1), d(A_2), \ldots \ldots d(A_n))^T$ (10)
where W is a non-fuzzy number.

4. Study Area and Stakeholder Data

4.1. Study Area

Delhi is the capital city of India, which represent 288 kilometers of metro rail transit (MRT) (DMRC, 2018) system and 5578 fleet of buses plying within and its precinct cities (DTC, 2017). The city is historically car-oriented with extra wide roads, segregated land uses, low to medium density sprawl, and non-walkable tracks which have made citizens of Delhi to private mode dependent. The enormous growth of private vehicles in recent years has resulted in huge traffic congestion and pollution. The average vehicular speed on urban arterials is at down 10 kmph inducing 70% of air pollution (NUTP, 2014). About 8 people die every day of vehicular emission issues in Delhi (WHO, 2013). Moreover, Delhi city requires a paradigm shift and reversal of the polluted environment. Delhi urban structure needs to redefine, restructure and recreate for a better quality of life to its citizens. Therefore, a comprehensive planning strategy that combines sustainable transportation, efficient use of land space and active transport (walk, cycle, and rickshaw) friendly environment is essentially required to the neighborhoods of Delhi.

In view of this alarming situation, Government agencies in India renowned the concept of TOD to address urban problems. The Ministry of Urban Development (MoUD) in association with Delhi Development Authority (DDA) has prepared TOD policy (2015) to recast Delhi's urban structure as part of Master Plan for Delhi (MPD) – 2021 (MoUD, 2016). According to the TOD policy (2015), TOD shall be developed within a maximum of 2000m influence zone around MRT corridors (UTTIPEC, 2015). The key objective of this policy seeks to promote active transport, check environmental pollution, and preserve affordable housing for low and middle-income communities. The TOD policy (2015) highlights the following provisions:

- Enable vertical construction with a maximum of 400 Floor Area Ratio (FAR) which include 30% of residential, 10% of commercial and 10% of community facility use.
- Provide affordable housing for all.
- Ensure safety to women and children while using public or active transport through changes in urban development code aspects such as revised building setbacks, active frontages, etc.

The policy norms will combine density, diversity and design dimensions of the urban structure by developing TOD around metro stations. However, the TOD policy initiative requires to establish suitable planning criteria for selecting the best suitable and potential sites for successful TOD planning and implementation.

4.2. Criteria and Indicators

The characteristics of TOD are multi-dimensional that influence various stages of planning, design, implementation, assessment or evaluation (Thomas and Bertolini, 2017). The study on TOD made difficult by a large set of indicators that must require. Nelson and Niles (1999) identified 16 indicators to determine TOD success on a local and regional scale. Later, Renne and wells (2005) identified 56 indicators by categorizing them into 5 TOD aspects (Renne, 2005) mainly travel behavior, urban structure, economic, environment, and social environment.

Later Renne (2007) added policy context as sixth TOD aspect. More recently, Thomas and Bertolini (2017) defined 16 generalized critical indicators under three criteria namely plans and policies, actors and implementation in TOD implementation. Most of the existing studies focused on urban structure aspects to assess potential sites for TOD planning. Cervero and Kockelman (1997) introduced three dimensions (D) of urban structure that influence travel behavior. The three dimensions are termed as 3D's which are density, diversity, and design. Ewing and Cervero (2001) added two more D's i.e., distance and destination by further extending to 5D's. Later, Ewing and Cervero (2010) suggested 7D's which include demand and demographics. Each dimension act as a criterion for successful TOD planning (Singh, 2017). Each criterion can be evaluated by distinct indicators. This study considered 7 D's as planning criteria for the selection of most suitable TOD sites in India, especially for Delhi. A facilitated discussion was conducted with 3 representative experts to identify additional criteria that should be included in the list. The discussion finalized 9 planning criteria including two more criteria namely 'transit service' and 'governance' to represent TOD in India. Table 2 summarizes the 9 planning criteria and corresponding indicators drawn from a brief literature review and expert consultation.

Table 2: TOD Planning Criteria and Indicators

Criteria	Definition	Indicators	Reference
Density	Optimized residential and employment densities are essential for creating TODs	Population Density	Boarnet and Crane (2001); Lin and Shin (2008); Nasri and Zhang (2012)
		Employment Density	Chatman (2003); Lin and Shin (2008)
		Housing Density	Cervero and Kockelmann (1997)
Diversity	Mixed-use developments create vibrant choices to improve a better quality of life in TOD areas	Entropy	Kockelmann (1997)
		Vertical Mix	Singh et al., (2016)
		Vacant Land Acreage	Bhat and Guo (2007)
Design	NMT friendly street network promote sustainable transportation	Pedestrian Impedance	Schlossberg and Brown (2004)
		Length of Walkable/Cyclable Paths	Singh et al., (2013)
		Pedestrian Satisfaction	Schlossberg and Brown (2004)
		Intersection Intensity	Kockelmann (1995); Kamruzzaman et al. (2014)
Distance	Proximity to transit encourage public transit usage	Distance from CBD	Aston et al., (2016)
		Optimum Distance from Residence to Transit	Singh et al. (2017)
Destination	Highly accessible station areas are essential for TOD success	Transit Accessibility	Bhat et al. (2006); Kamruzzaman et al. (2014); Singh et al. (2015); Rahmat et al. (2016)
		Network Connectivity	Schuerer et al. (2008)
		Accessibility to Jobs	Kockelmann (1997)
		Attractiveness to Opportunities	Bendavid-Val (1991)
Demand	Travel demand management strategies for paradigm shift will develop a sustainable TOD	Parking Area at Station Area	Cervero (2010); Holtzclaw et al., (2002)
		Parking Demand	Tian et al., (2016)
		Parking Supply	Tian et al., (2016)
		Vehicle Ownership of Residents	Kamruzzaman et al., (2014)
		Trip Generation	Cervero (2010)
Demographics	A social friendly environment with affordable housing create TODs	Commuter Age	Chatman (2003); Cervero and Duncan (2006)
		Household Income	Cervero and Duncan (2006); Lin and Shin (2008)
		Workers per Household	Mckibbin (2011), Nasri and Zhang (2012)
		Housing and Transport Cost	Renne (2009)
Transit Service	Seamless transit service is essential for TOD implementation	Transit Frequency	Singh et al., (2013)
		Feeder Concentration	Zemp et al., (2012); Renne (2005)
		Commuter Safety	Singh et al., (2013)
		Transit Routes	Singh et al., (2013)
		Transit Boardings	Renne, (2005); Singh et al., (2017)
Governance	Concerning governance is required for TOD implementation	Earnings of Municipalities	Singh et al., (2013)
		Property Taxes	Boarnet and Crane (2001)

4.3. Stakeholder Groups

Present study considered three stakeholder groups namely researchers, planners, and policymakers in the decision making process. Researchers are academic professionals in land use, transportation planning, and housing backgrounds. Planners are industrial experts working under various TOD projects. Policymakers are agency officers under transportation planning divisions. A five-page AHP questionnaire was designed and communicated to 50 experts under three stakeholder groups. The subjects were identified based on the level of experience, knowledge, and familiarity with TOD issues in Delhi city. A brief description of the TOD planning criteria and their corresponding indicators identified through literature review was included in the questionnaire. The absence of existing TOD case studies in India has necessitated a broad range of multi-stakeholders' decisions to design, weight and rank the planning criteria.

Each expert was solicited to compare the criteria and indicators by referring to the Saaty scale of 1-9, with a score of 1 representing equal importance between the pairs of criteria/indicators and 9 representing absolute relative importance (Saaty and Vargas, 2012; Mosadeghi et al., 2015). The scale of relative importance based on Saaty and Vargas (2012) is represented in Table 3. The relative importance between criterion and indicator pairs were used without considering the interdependency among the criteria and indicators. Consistency test was conducted on individual responses to validate the pairwise comparison matrices. The consistency ratio (CR) of pairwise comparisons was calculated using the Eq. 11 and 12:

$$CR = CI/RI \quad (11)$$

where CI is the consistency index given by the

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (12)$$

RI is the random consistency index for matrices of order n and λ_{max} is the principal eigenvalue of the judgment matrix. A threshold of CR < 0.10 is the acceptable consistency to validate the relative importance values and can be utilized further (Saaty and Vargas, 2012). Out of fifty subjects, thirty-five complete and reliable responses were finalized for calculating weights. The composition of the three stakeholder groups includes 12 researchers, 9 planners, and 10 policymakers.

Table 3: Relative Importance Scale

Definition	**AHP**		**FAHP**	
	Numerical Value	Reciprocal Value	Fuzzy Value	Reciprocal Fuzzy Value
Extremely Important	9	1/9	(9,9,9)	(1/9, 1/9, 1/9)
Very Important	7	1/7	(6,7,8)	(1/6, 1/7, 1/8)
Strongly Important	5	1/5	(4,5,6)	(1/4, 1/5, 1/6)
Moderately Important	3	1/3	(2,3,4)	(1/2, 1/3, 1/4)
Equally Important	1	1	(1,1,1)	(1, 1, 1)

5. Results and Discussion

5.1. Criterion Weights

Consistent questionnaire responses from experts of each stakeholder group were considered for weight calculations of criteria and indicators using both AHP and FAHP methods. The study employs Chang's extent analysis method to obtain FAHP weights. Figure 2 represents the distribution of weights for criteria obtained from the AHP method and the consistency ratio of 31 responses. It is observed in Figure 2 that there exist extreme outliers in the final weights using the AHP method. These outliers are errors which act as some sort of 'fuzziness' underlying the uncertainty in expert judgments (Zahir, 1991). Table 4 represents the comparison of results obtained from AHP and FAHP which pronounced the differences in final criterion weights. These differences are due to the presence of uncertainty or knowledge bias in expert opinions (Mosadeghi et al., 2015). The uncertainties in judgments reflect the divergence in final weights and rank priorities of planning criteria. A criterion might have the same rank in both AHP and FAHP models with different weights. Another criterion might have same weights in both AHP and FAHP models with different ranks. This is due to the FAHP program in moderating the expert opinions by considering a range of values in triangular fuzzy numbers instead of a single value for each criterion, while in the AHP method, the extreme weights assigned by any expert can have a big influence on the final weight.

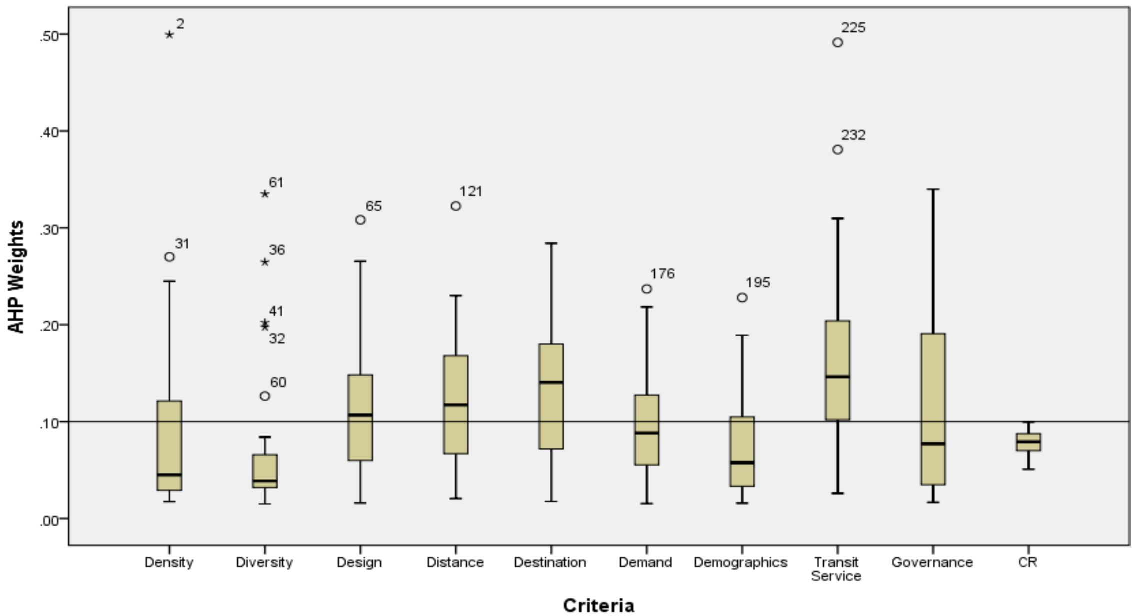

Figure 2: Outliers in AHP Weights

Table 4: Aggregated Weights and Priorities of Criteria using AHP and FAHP Methods

Methodology	Density	Diversity	Design	Distance	Destination	Demand	Demographics	Transit Service	Governance
AHP	0.095	0.072	0.111	0.126	0.133	0.099	0.077	0.168	0.119
Rank	7	9	5	3	2	6	8	1	4
Uncertainty (±)	0.114	0.035	0.125	0.105	0.133	0.100	0.087	0.142	0.162
FAHP	0.000	0.000	0.064	0.131	0.153	0.078	0.000	0.448	0.126
Rank	7	7	6	3	2	5	7	1	4

Note: $Average\ Uncertainty\ within\ i^{th}\ criterion = \frac{max_i - min_i}{2}$

Table 5 represents the Spearman rank coefficient to compare the AHP and FAHP weights. The results have shown that there is a significant correlation between ranks assigned to the planning criteria using both MCDM methods. Except for design and demand criteria (ranks interchanged), all the other criteria show similar rank priorities. Three suitability classes were considered in this study with the cut-off values based on the FAHP weights. Subsequently, these three classes include; highly suitable criterion with weights >0.1; moderately suitable criterion with weights <0.1 and >0; and least suitable with weights = 0. Transit service (Rank 1) is identified as the top priority criteria to assess possible TOD sites in Delhi. In addition, distance (2), distance (3) and governance (4) criteria possess a highly suitable class in TOD planning.

Table 5: Spearman Rank Correlation Coefficient between AHP and FAHP Priorities

Spearman's rho Correlations	AHP Ranking	FAHP Ranking
AHP Ranking	1	0.966**
FAHP Ranking	0.966**	1
Sample Size (N)	9	9

**. Correlation is significant at the 0.01 level (2-tailed).

The global weights of indicators under highly suitable criterion were presented in Table 6. The global weights for the indicators can be calculated by multiplying the indicator weights by the criterion weights to which they belong to. For example, global weight for 'Distance from CBD' indicator can be calculated by multiplying 0.3199 (indicator weight) by 0.1313 (criterion weight), which is equal to 0.0420. The global weights presented herein is believed to enable the decision makers to utilize weights of indicators for TOD planning in Delhi using quantitative methods.

Table 6: Global Weights of Indicators

Indicator	**Local Weight of Indicator**	**Local Weight of Criterion**	**Global Weight of Indicator**
Distance from CBD	0.320	0.131	0.042
Optimum walking distance to Transit	0.680	0.131	0.090
Transit Accessibility	0.340	0.153	0.052
Network Connectivity	0.250	0.153	0.038
Accessibility to Jobs	0.296	0.153	0.045
Attractiveness to Opportunities	0.113	0.153	0.017
Transit Frequency	0.264	0.448	0.118
Feeder Concentration	0.256	0.448	0.114
Commuter Safety	0.183	0.448	0.082
Transit Routes	0.134	0.448	0.060
Transit Ridership	0.164	0.448	0.073
Earnings of Municipalities	0.366	0.126	0.046
Property Taxes	0.634	0.126	0.080

5.2. Multi-Stakeholders' Perspectives

The criterion weights were further analyzed with respect to the strategic plans of each stakeholder group. The final weights of criteria from the FAHP method at group level is presented in Table 7. According to the researchers, TOD planning in Delhi can best be assessed by transit service (0.4318), governance (0.1845), destination (0.1581), and demand (0.1004) criteria. As per planners' perspective, transit service (0.6301), and destination (0.2509) criterion are highly suitable for evaluating TOD ness in Delhi city. Policymakers suggested that distance (0.2656), transit service (0.2081), governance (0.1059) and density (0.1035) criterion play a major role in the evaluation process. Although the stakeholder group decisions diverge in weights and priorities of criterion, there is some convergence involved in their decisions which is presented in Figure 3. In particular, all stakeholder groups believe that 'Transit Service' criterion works well in the evaluation process. In a nutshell, 'Demographics' criterion does not carry any priority in TOD planning.

Table 7: FAHP Weights from Multi-Stakeholders' Perspectives

Criterion	**Researchers**	**Planners**	**Policymakers**
Density	0.000	0.000	0.104
Diversity	0.000	0.000	0.060
Design	0.038	0.019	0.102
Distance	0.087	0.091	0.266
Destination	0.158	0.251	0.082
Demand	0.100	0.009	0.058
Demographics	0.000	0.000	0.015
Transit Service	0.432	0.630	0.208
Governance	0.185	0.000	0.106

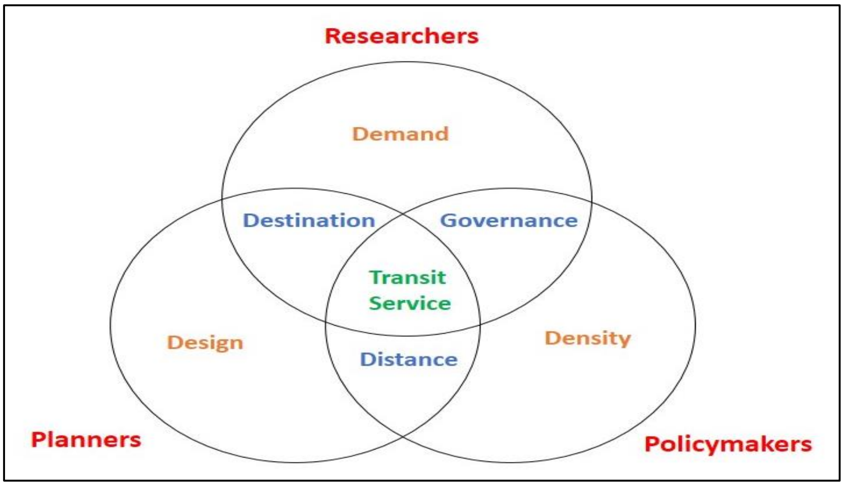

Figure 2: Multi-Stakeholders' Consensus

5.3. Context-Sensitive TOD Definition

The vast literature on TOD concept demonstrates that there is no existing generic definition for TOD. Potential TOD characteristics have been discussed in many research studies and policies that are context sensitive and limited to their jurisdictions. In any city, there exists some degree of transit oriented-ness within its urban structure (Laaly et al., 2017). To comprehensively define TOD-ness in any context, it is necessary to identify the most reliable criteria from a systematic decision-making approach. The study identified four most suitable TOD planning criteria namely transit service, destination, distance and governance from multi-stakeholders' perspectives. In a combined consensus, specific TOD goals for Delhi are to promote transit service, improve destination accessibility, provide transit within acceptable limits and ensure governmental concern towards TOD planning and implementation. The decision makers also opine that the density, diversity, and demographics are the least suitable criteria for TOD planning in Delhi. It is true for the Delhi city, due to the presence of overwhelming density, compact use and a broad range of demographics in its neighborhoods. Unlike, the success of Delhi Metro in attracting commuters, the city still lacks accessibility and proximity issues. Most of the neighborhoods are par within acceptable distance for walking and cycling to transit. This has made Delhi commuters to rely on private transport than public transport. Hence for successful planning and implementation in Indian cities, TOD has to be defined as 'a land use approach that provides seamless walking and cycling accessibility from transit stations, and that maximizes the existing transit usage. It can be achieved only by the diplomatic concern of local and central bodies on TOD planning at a regional scale'.

6. Conclusions

The main objective of this study was to establish criteria for TOD planning in rapidly developing cities like Delhi, India. Since no practical TOD exists in India and Delhi, this study established 9 planning criteria and their corresponding indicators from the literature review and the expert consultation. The study developed a group-FAHP approach which involves multiple stakeholders to rank criteria and determine global weights to the priority indicators. This approach is flexible for decision-makers to consider or eliminate indicators stemming from their own TOD planning criteria and localized weights.

In this study, the weights obtained from traditional AHP and FAHP methods were compared to identify the uncertainty involved in expert judgments. Further, the Spearman rank coefficient evident a significant correlation between AHP and FAHP rankings. The highly suitable TOD planning criteria for Delhi were identified and used to determine final weights of priority indicators. The study assumes that city neighborhoods will possess at least some degree of TOD ness within their urban structure. Based on the study results, a TOD definition has been proposed for Delhi context. The proposed definition can be further extended to other developing cities.

It is important to note that the stakeholder group perspectives contradict with one another. However, some convergence is observed between group decisions. The stakeholder groups have a combined opinion on 'transit service' criterion that acts as the highly suitable criterion for TOD assessment. According to them, efficient transit service, seamless access to all destinations, urban structure proximity to transit and diplomatic concern from government bodies will lead to a successful TOD planning in Delhi. It is also important to note that upcoming TOD projects in Delhi should focus on these most suitable criteria and priority indicators in the planning and implementation stages.

TOD is rather very new and at its nascent stages in existing Indian cities. With many upcoming cities showing interest in the implementation of TOD projects, the concept will continue to attract decision makers involved in TOD related issues. Given, this study is timely and involve multiple stakeholders in providing a balanced consensus with a practical and ready to implement decision approach. This approach can be further useful in choosing the best possible TOD sites to plan and implement in developing cities.

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