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Integrating Transit Oriented Development (TOD) Principles with Industrial Mobility: A Case of Industrial Areas in Chhatrapati Sambhajinagar

[1] Gayatri D. Supekar

[1] Department of Planning, College of Engineering Pune Technological University (COEP TU), Pune, India
Corresponding Author Email: [1] gdsupekar26@gmail.com

Abstract— ***Industrial corridors developed under India's National Industrial Corridor Development Programme (NICDP) are reshaping urban growth and regional connectivity. Industrial growth driven by Shendra- Bidkin MIDC under the Delhi - Mumbai Industrial Corridor (DMIC), along with the expansion of Waluj MIDC, has significantly accelerated economic growth and employment generation. However, mobility systems have not evolved proportionately, resulting in changing travel pattern behaviour of workers, inadequate public transport integration, unsafe commuting environments, rising travel expenditure and increasing dependence on private and informal transport modes among industrial workers. Conventional Transit-Oriented Development (TOD) principles primarily focus on high-density mixed-use development along BRT corridors, metro lines, or mass transit systems and do not adequately address industrial mobility characteristics, where worker commute, freight movement, and travel patterns play a significant role. This gap is particularly evident in rapidly urbanizing Tier-2 cities, where industrial expansion precedes integrated transport planning. This study examines the integration of TOD principles with industrial mobility in the Waluj- Shendra- Bidkin MIDCs using a mixed-method approach involving GIS spatial analysis, worker travel surveys and NMT audits, along with the evaluation of multimodal integration, last-mile connectivity, housing accessibility, transport affordability and freight connectivity. The study proposes an integrated industrial mobility planning approach that contextualizes TOD principles for MIDCs, aiming to support compact urban growth, improved worker and freight mobility and enhanced multimodal integration in emerging Tier-2 cities such as Chhatrapati Sambhajinagar.***

Keywords: DMIC, freight connectivity, GIS spatial analysis, last mile connectivity, MIDC, NMT, TOD, workers mobility.

I. INTRODUCTION

The Government of India, with the aim to transform India form service-driven economy to global manufacturing powerhouse launched National Industrial Corridor Development Programme (NICDC), to create futuristic smart industrial cities for employment generation, socio-economic development [1]. Currently 32 projects in 4 phases under 11 corridors under NICDC are carried, under which Delhi-Mumbai Industrial Corridor (DMIC) is one of the flagship initiative to integrating infrastructure with industry and also by reduce logistic costs through multimodal connectivity.

Industrial investment primarily focuses on infrastructure and logistic network development, industrial mobility receives less attention comparatively. It not only deals with freight movement and connectivity but also with workers travel pattern. Generally MIDC are located in the urban fringe, thus problems like poor public transport, poor last mile connectivity, etc. leads excessive use of private transport, more travel time and travel cost, thus efficient industrial mobility is required.

Transit Oriented Development (TOD) is the integration of land use and transport planning that aims to develop planned sustainable urban growth centres having walkable and liveable communes with high density mixed land-use [2]. Transportation and Development Policy (ITDP) states that TOD principles of including walkability, cycling, mixed land use, compact development and integration with public transport [3]. Traditionally, TOD focuses on Central Business Districts (CBD), Metro corridors in urban areas but research related to TOD principles integration with industrial area remains limited. Thus emphasising the need for planning a framework that integrates industrial mobility with TOD principles.

II. STUDY AREA

Maharashtra plays significant role under DMIC and is India's leading state significantly contributing highest to Gross State Domestic Product, Industrial Output value and Foreign Direct Investment. Waluj MIDC is one of the Maharashtra's largest MIDC and Aurangabad Industrial City (AURIC) which comes under the influence zone of DMIC comprise of Shendra MIDC and Bidkin MIDC are India's first Greenfield Smart Industrial City under the NICDC. These 3 MIDC are considered for assessment, as Waluj is an existing, old MIDC, Shedra being partially developed and Bidkin is still developing with a stage of land acquisition and plotting stage.

III. LITERATURE REVIEW

From the literature studied, it is observed that there is lack of framework that studies industrial mobility (freight & workers) in current planning approaches. The studies

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emphasize on industrial mobility, last mile connectivity, land use integration, pedestrian infrastructure, public transport, multimodal integration. Limited focus is observed in terms of affordability, gender sensitive mobility, land value etc. From the reviewed literatures TOD mostly adopted for compact mixed used high density urban area but its application to industrial area is limited due to workers & freight mobility and dispersed land use. Thus, to address the research gap, a framework is proposed that integrates TOD principles and industrial mobility.

On the bases of literature reviews following parameter mentioned in Table no. 2 were identified for analysing the MIDC area which would help further for making framework.

IV. METHODOLOGY

Mixed method research approach is adopted for this research study, which integrated spatial analysis, workers travel survey, NMT audits for the evaluation on industrial mobility and TOD parameters. The methodology consists of four stages which are literature review, study area & data collection, analysis, proposal as illustrated in Fig no. 1.

V. ANALYSIS

A. Industrial Mobility & Accessibility:

1) Workers Mobility:

a) Mode of Travel:

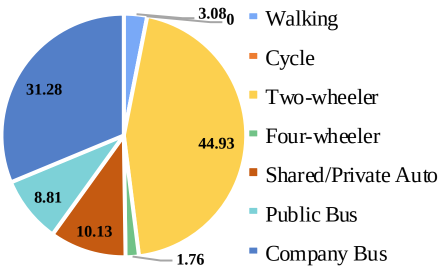

Fig. 1. Pie Chart Mode Share, Waluj MIDC

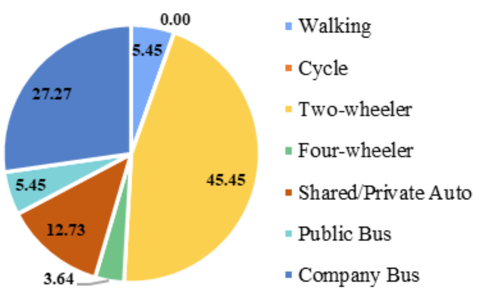

Fig. 2. Pie Chart Mode Share, Shendra MIDC

In both the MIDC's i.e. Waluj & Shendra, two wheelers have dominate travel mode share by 43.9% & 45.45% respectively, followed by company buses having 31.28% & 22.27%. It is prominently observed that public transport remains limited with 8.18% & 5.45% and NMT mode (walking, cycling) mode contributes almost negligibly as seen in Fig. 2 & Fig.3. If action not taken in right direction similar trends would be seen for Bidkin MIDC. Principally, a higher share of NMT (walking, cycling) and public transport reflects stronger accessibility and TOD characteristics [3].11.89%,10.91% & 11.40% are the shares of NMT an public transport together for Waluj, Shendra, Bidkin MIDC respectively which show low TOD potential. If the mode share of company buses is added then it became 43.17%, 38.18%, 40.68% which suggest emerging potential for TOD. This indicates that improving public transport service, NMT, and integrating company bus services can improve the sustainable travel pattern of workers.

b) Mode share variability between city and non-city trips:

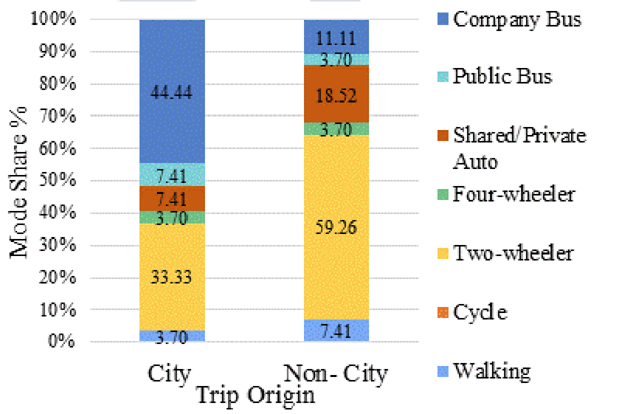

Fig. 3. Mode Share between City & Non-City, Waluj MIDC

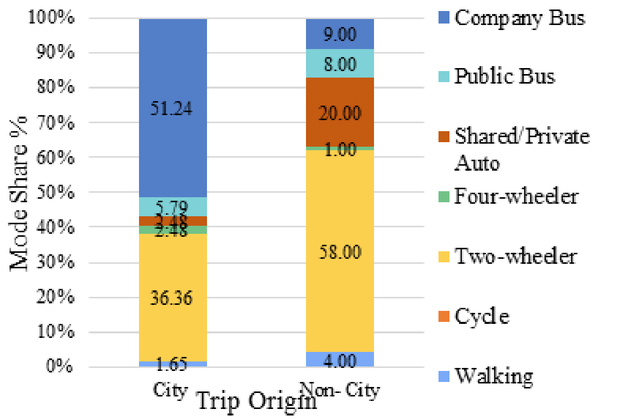

Fig. 4. Mode Share between City & Non-City, Shendra MIDC

Workers commuting from the Chhatrapati Sambhajinagar Municipal Corporation (CSMC) i.e. city area show higher dependency on company buses, whereas workers form non city area primarily use two-wheelers, shared auto, etc. similar trend is observed in both MIDCs as seen in Fig. 4 & Fig. 5, and assuming similar trend for Bidkin MIDC. This indicates there is limited access to formal transit services for non-city trips; thus, private vehicle use increases, suggesting a need for feeder services, and integration of peripheral village to industrial transit network.

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c) Mode share w.r.t distance:

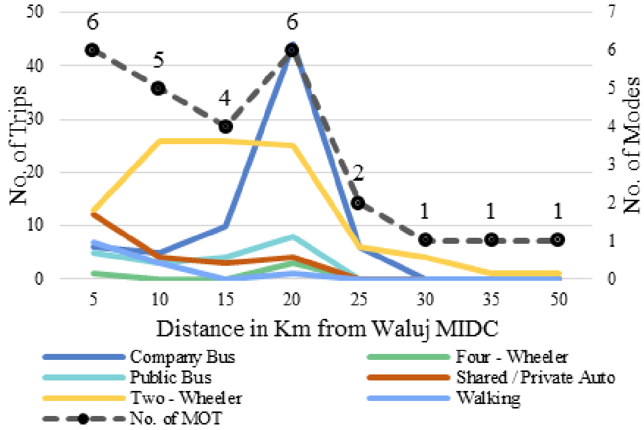

Fig. 5 Mode w.r.t Distance, Waluj MIDC

For both the MIDC, and assuming for Bidkin, it is observed trips generated within 10km have dominance over NMT and shared auto, followed by two wheeler and company buses for 10-20 km and beyond 25 km use of two wheelers increases. Trips till 20 Km from MIDC have 4-6 mode choices, for 20-25 km distance have 2-3 modes and beyond 25 km on 1 mode of transport is observed, which shows decline in mode choice with increasing distance form MIDC. This finding are similar to multimodal literature that states integration of different transport modes has become crucial to guarantee fast and sustainable flow of people [20].

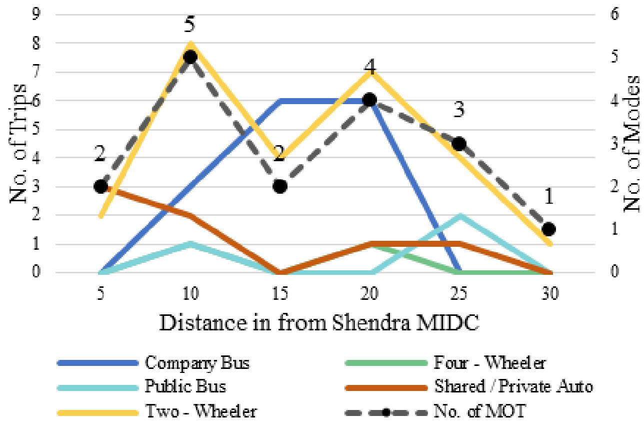

Fig. 6 Mode w.r.t Distance, Shendra MID

d) Travel time w.r.t distance:

The Fig.8 & Fig 9, a positive relationship is observed between travel time and distance across all modes in both the MIDC, considering similar trend for Bidkin. Waluj MIDC, two wheeler trip show low travel time for 15-30 km but substantial increase after 30 km. Shendra MIDC trips public buses show relatively increase in travel time comparatively two wheeler have low travel time for 15-30 km. Time rise rises sharply after 25 km. Waluj has comparatively lager commuting catchment than Shendra, resulting longer average travel time. The MIDC's exceed the 45 min threshold beyond 20-25 km, indicating declining accessibility with increasing distance.

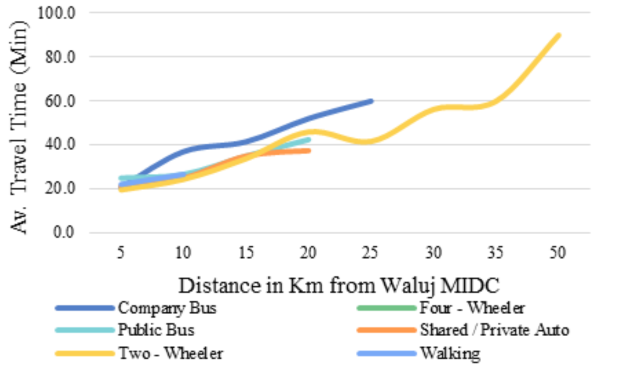

Fig. 7 Travel Time w.r.t Distance, Waluj MIDC

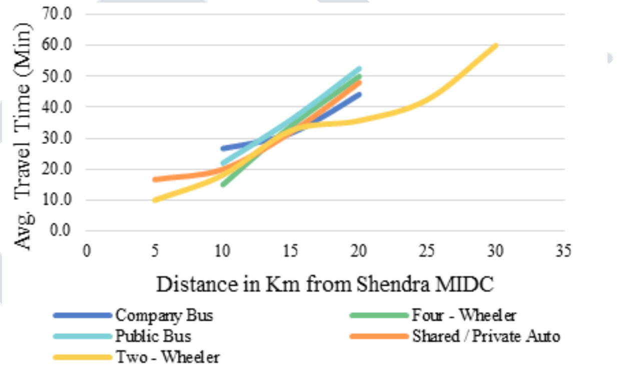

Fig. 8 Travel Time w.r.t Distance, Shendra MIDC

e) Travel time distribution:

From the Fig. 10 & Fig. 11, largest share of workers for Waluj is 34.60% require 40-50 minutes, that of Shendra is 30.59% require 30-40 minutes. The thresholds is adopted from commuting and well-being literature, that demonstrates longer commuting time report lower subjective well-being [21], life satisfaction begins to decline after approximately 45 minutes of commuting, with the greatest negative impacts occurring between 60 and 90 minutes [22]. Thus from the survey data of Waluj & Shendra MIDC, and interpretation of Bidkin is that 50.75%, 36.91% & 43.83% of workers require more than 45 minutes and 31.72%, 14.12% & 22.92% require more than 60 minutes, suggests that a large percentage of workers reflect mobility stress, indicating towards the need for enhancement of public transport, multimodal integration, last mile connectivity.

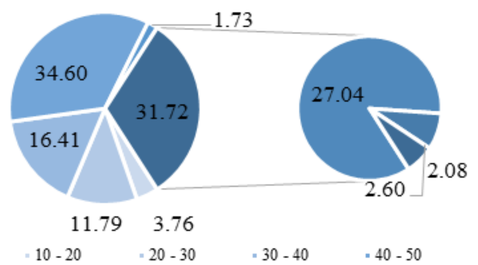

Fig. 9 Travel Time Distribution, Waluj MIDC

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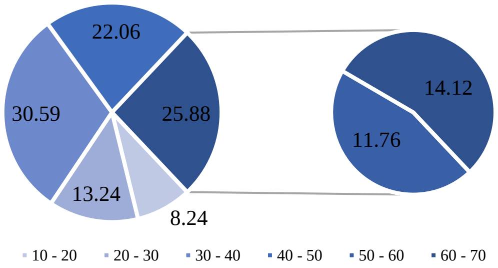

Fig. 10 Travel Time Distribution, Shendra MIDC

2) Freight Connectivity:

This sub parameter was carried out by using Alpha, Beta, Gamma network connectivity indices along with junction type analysis on Arc-GIS. Waluj MIDC has hierarchical network with high proportion of T-junctions and low Alpha value which indicates limited route redundancy and dependency on major roads. Shendra MIDC shows slightly better connectivity because of high proportion of four-way intersection which leads to circuit development and alternating freight movement. Bidkin MIDC has better interconnected network, with highest percent of four way intersection, high Beta & Gamma value.

3) Last Mile Connectivity:

It is analysed based on a ratio, which is percentage of proportion of workers using walking, cycling, shared auto & public transport to the total no. of workers for the respective samples collected. Waluj MIDC has 10.14 % of workers using public or NMT share, and that of Shendra MIDC is 23.63 % which is slightly higher but still below the threshold required for TOD policy objective of achieving 80% or more for walking, cycling and public transport [23].

B. Land- Use and Industrial Integration:

1) Mixed Used Diversity:

The assessment of the mix use diversity for MIDC is done by the most commonly used Shannon entropy [24]. Mixed land use which indicates diversity is recognized as principal components of TOD [25]. The normalized Shannon Entropy has a range from 0 – 1, where index close to 1 indicates more diversity in land-use and closer to 0 represent dominance of single land-use. Thus Waluj & Shendra Phase- 1 values are 0.5 and 0.41, respectively which indicates moderate-low diversity exhibiting more industrial dominance, whereas Shendra Phase-2 & Bidkin MIDC newly planned, indicates higher entropy index 0.72 & 0.75, respectively which indicates high diversity. Thus, index value close to 1 indicates more land-use diversity, supporting higher TOD potential.

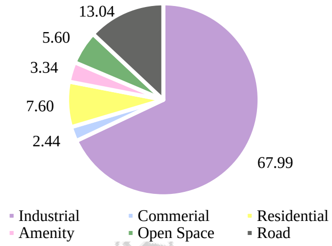

Fig. 11 Pie Chart, Land-use Percent, Waluj

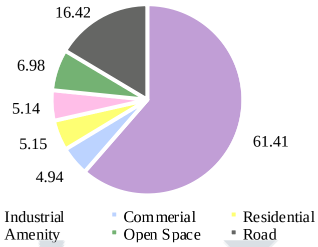

Fig. 12 Pie Chart, Land-use Percent, Shendra

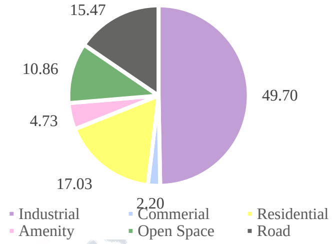

Fig. 13 Pie Chart, Land-use Percent, Bidkin

2) Workers Density:

The population density and workers density was calculated from census data of 2001 & 2011 and, population projection for 2026 were calculated by Geometric Increase method. Further this density of villages in CSMRDA are represented using GIS choropleth map for spatial analysis. Waluj MIDC has population density of 313.42 persons/ ha, and workers density of 107.97 workers/ ha, Shendra has 23.45 & 9.78 and Bidkin with 3.86 & 3.87 density respectively. As per the UN-Habitat urban area should have 150 persons/ha for compact development [26] and as per URDPFI guidelines 75 persons/ha is the minimum benchmark [27]. Thus Waluj MIDC shows compact environment supporting TOD development while Shendra MIDC low density indicating future industrial growth. Bidkin MIDC has significantly low density indicating rural environment, since it is in early planning stage thus has potential to company high density development.

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C. Inclusivity & Social Equity:

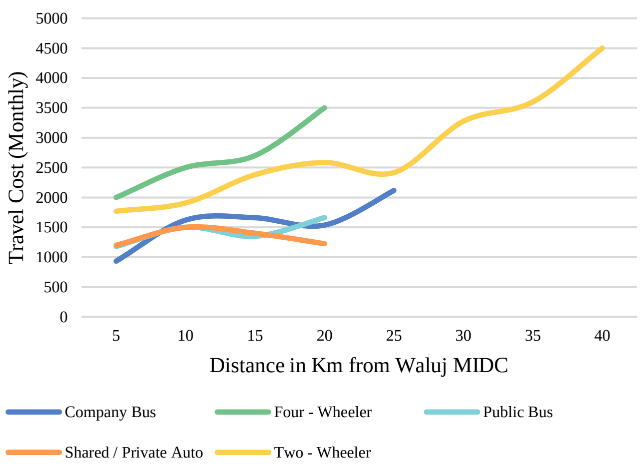

Fig. 14 Distance w.r.t Travel Cost (Monthly), Waluj MIDC

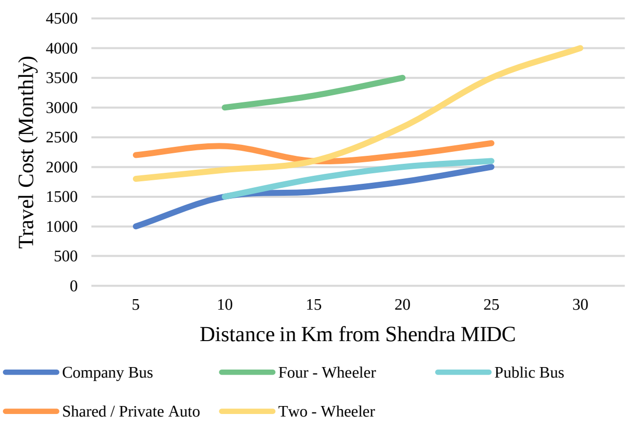

Fig. 15 Distance w.r.t Travel Cost (Monthly), Shendra MIDC

1) Transport Affordability:

It is commonly evaluated by the proportion of household income spent on transport expenditure. This parameter is analysed by distance- time- mode relation and Transport Affordability Index which is the percentage of monthly travel cost to monthly income [29]. The average TAI of Shendra MIDC is higher than Waluj MIDC, which suggests Shendra MIDC has lower transport affordability as compared to Waluj MIDC. In both the MIDC company buses are the most affordable mode of travel. Public bus and shared auto experience are substantially higher, compared to Waluj. Conversely, two wheeler have the higher ratio in Waluj compared to Shendra. This suggest that Waluj have relatively mature transport network as compared to Shendra MIDC. These finding are similar previous studies which suggests then importance of improving public transport services, last mile connectivity and workers housing near MIDC to improve affordability and sustainable industrial mobility [30].

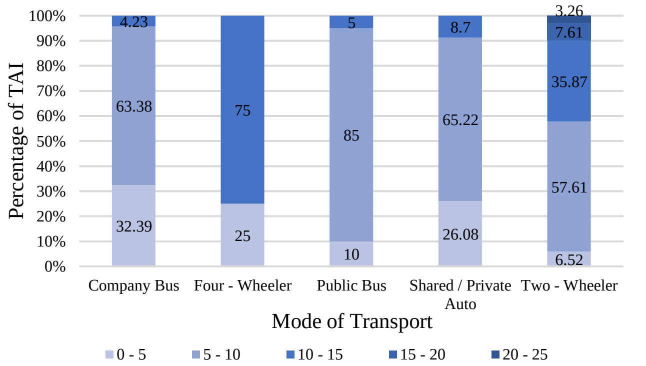

Fig. 16 Distance w.r.t Travel Cost (Monthly), Waluj MIDC

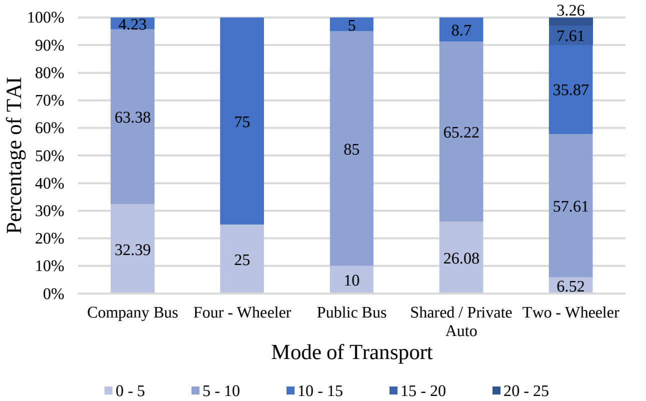

Fig. 17 Distance w.r.t Travel Cost (Monthly), Shendra MIDC

2) Gender Sensitivity Safety:

This sub parameter was analysed by using composite indicator approach, where seven binary safety indicators were aggregated using equal weighted Simple Additive Weighing for every response. Both Waluj and Shendra MIDC come under the moderate risk category. Comparatively Shendra has higher SPS than Waluj, suggesting relatively higher worker safety concerns. Shendra has concerns about freight traffic, absence of pedestrian infrastructure and Waluj has major concerns related to congestion, unsafe crossing. In both the MIDCs female workers have higher safety concerns than male workers, highlighting the importance of gender responsive mobility, which is similar to the finding from UN Women, women's perception of safety influence mobility, travel choices, and access to employment [31]. Similar research related to TOD safety dimensions enhance perceive safety and also influences the likelihood of an individual to choose public transport [32].

3) Proximity to Workers Housing:

This sub-parameter is analysed by taking percentage of workers living in the 5 Km radius from MIDC area, 5 Km threshold since it is a feasible catchment for walking, cycling, and feeder transit. In case of Waluj and Shendra MIDC the percentages area 18.84 and 9.43 respectively, which are way below the desirable benchmark of 40-60%, indicating a

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significant mismatch of workers housing in the industrial area.

D. Transit Oriented Infrastructure:

1) Pedestrian & Cycling Infrastructure:

Road inventory survey was conducted for Waluj and Shendra phase 1, from which there no availability of cycle track at both the MIDC. Waluj only have 1.05% footpath present and that of Shendra is 0%, due to which workers walk along the carriageways with freight and other vehicles leading to safety risk. This reflects poor presence of pedestrian and cycling infrastructure suggesting poor TOD compliance, leading to poor last mile connectivity and discourages NMT. This implies that pedestrian-oriented urban environment is the foundation of TOD [33]. As per the ITDP TOD standards, "a safe cycling network connecting buildings and destinations by the shortest routes through developments and station catchment areas is a basic feature of TOD" and "short and direct pedestrian and cycling routes require highly connected network of paths and streets" [3].

2) Public Transport Frequency:

Under the smart city mission there are total 100 buses on 31 routes running in CSMRDA out of which Waluj have 16, Shendra and Bidkin are 4 routes each of them are mapped on the GIS, along with company bus route of two companies. The average span of operation, minimum and maximum frequency and head way are given in Table no. III. Transit Capacity and Quality of Service Manual (TCQS), states that headway as a measure of transit availability and passenger waiting time [34]. The headway greater than 30 minutes are considered as infrequent and less adopted for daily commuting and headway 10-15 min or less than are considered to have high frequency [34]. Furthermore, services system having frequency 5 or more buses per hour i.e. headway less than or equal to 12 *minutes are considered high frequency services [35]. Based on the above benchmark Shendra has better frequency as compared of Waluj and Bidkin.*

Table I. Public transport and company bus details of all midc

Sr. No	Parameters	CSMRA	Waluj MIDC	Shendra MIDC	Bidkin
01	No. of Daily Trips	1405	421	106	46
02	Total No. of Routes	31	24	4	4
03	First Trip	3:11 AM	4:45 AM	6:10 AM	6:57 AM
04	Last Trip	12:30 AM	10:55 PM	9:15 PM	9:15 PM
05	Span of Operation	21.19 Hrs	18.10 Hrs	15.25 Hrs	8:40 PM
06	Min Frequency	17 Mins	12 Mins	19 Mins	15 Mins
07	Max Frequency	1 Hr 24 Mins	5 Hr 12 Mins	47.5 Mins	1 Hr 15 Mins
08	Frequency	2	1.3	7.03	3.35
09	Headway	22 Mins	44 Mins	30.25 Mins	18 Mins

3) Multimodal Integration:

It was assessed by considering four transport infrastructural parameters, road connectivity (National & State Highways), proximity to DMIC node, rail and airport connectivity, they represent principal modes which support industrial goods movement, regional logistic connectivity, accessibility. All the parameter were assigned equal weight (25%), and scores were given based to the distance form respective MIDC, as done in the EIA report [36]. Shendra MIDC has the highest score 36 out of 40 making its average 9, followed by Waluj MIDC having score 33, average 8.25 and Bidkin MIDC exibits lowest score 23 average 5.75. This suggests that Shendra and Waluj MIDC possess high multimodal connectivity. Bidkin MIDC relatively shows moderate multimodal connectivity, offering future potential for improving the transport infrastructure for better regional logistic connectivity and efficient multimodal integration.

E. Planning Suggestions and Recommendations:

Through the analysis it was found that there is high dependence on private vehicles, less use of public transport service, poor last mile connectivity, high travel cost and commuting time, sparsely located workers housing, etc. Thus by strengthening the public transport services, improving last mile connectivity, ensuring compact development, improving freight and modal connectivity, etc. a planning framework is proposed for by adopting TOD principals in industrial area. Below mentioned are the few intervention through which it can be achieved.

1) Strengthening the public transport services:

On the bases of workers mobility & public transport frequency parameter it is observed that there less use of public transport, gaps in the frequency of bus services, thus need improve the bus services, increase the bus frequency, introduce new bus routes, integration of bus stops with other

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road infra, shared mobility, and NMT services.

2) Improving Last mile connectivity and NMT transport:

Form the last mile connectivity, road inventory analysis it is found that there is poor pedestrian and cycling infrastructure. Workers from non-city origin largely depend on shared auto and private vehicles due to inadequate feeder connectivity. Thus to improve this, updated road section with infrastructure like footpath, cycle track, shuttle bus service, integration of bus stops with NMT mode and shared auto services, which will enhance the last mile connectivity.

3) Compact Development:

Achieving compact mixed used development in the 5 km radius of industrial area so that there is easy for workers to commute to the MIDC, reduce travel cost. This can be achieved by policy interventions by giving extra FSI, taxation benefits for company and invest in affordable housing, rental housing, etc. in such ways use of public transport will increase and improve accessibility as achieved by TOD principles.

4) Strengthening Freight and Multimodal Connectivity:

As mentioned in the analysis NICDP promotes enhancement of goods & logistics via enhancing rail connectivity. As Shendra has a DFC node, but for Bidkin MIDC it's poor, road proposal connecting Bidkin MIDC to Karmad node will help to reduce the travel time and enhance freight mobility. In addition to the proposing a new railway stop like Karmad delicately for goods and logistic movement. Proposing a road connectivity that connected Bidkin, Shendra and Waluj MIDC for logistic multimodal integration and enhancing the reginal connectivity of the region.

VI. CONCLUSIONS

From the above analysis of the three MIDC, the findings show that industrial areas faces issues like less use public transport showing high dependency on private vehicles, poor last mile connectivity, high travel cost, poor pedestrian and cycling infrastructure, etc. Thus, integrating the TOD principles density, diversity, design, last- mile connectivity, multimodal integration, freight connectivity, improving pedestrian, cycling infrastructure, etc. with industrial mobility will help the MIDC to function in an more efficient and effectivity way both for the workers as well as the freight and logistic connectivity.

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APPENDIX

Figure

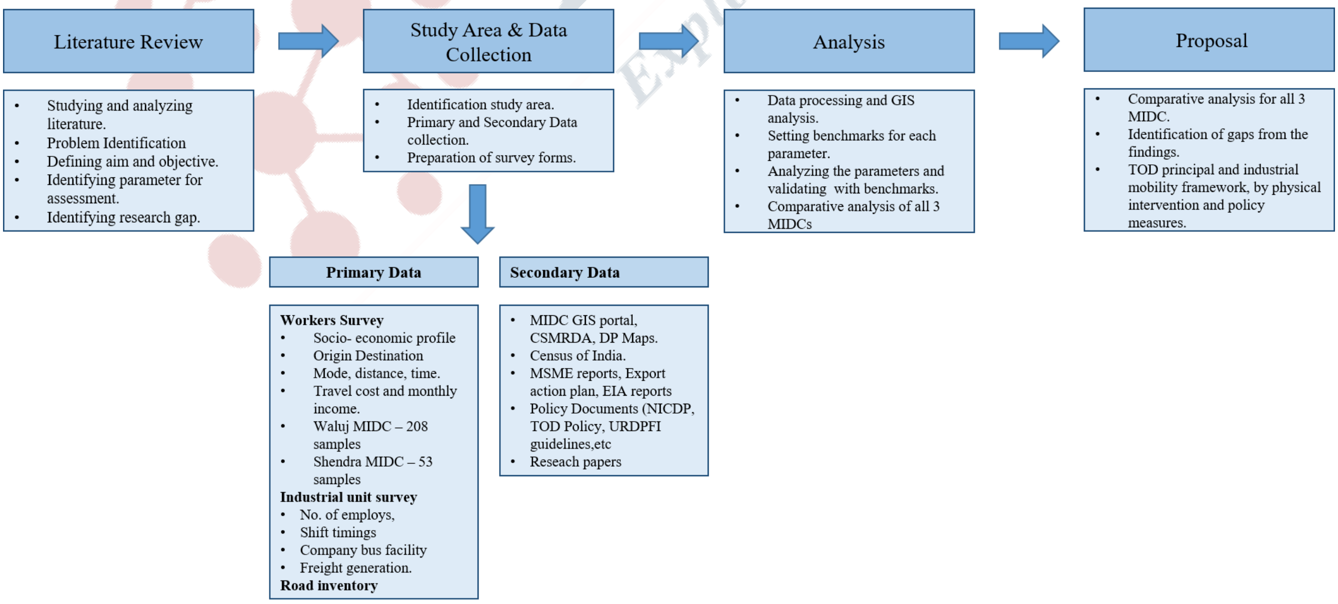

Fig. 18. Methodology flow chart

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Tables:

Table II. Literature review matrix

Sr. No	Research papers	Industrial Mobility	Freight Connectivity	Last Mile Connectivity	Land-Use Integration	Employment Density	Land Value	Inclusivity	Affordability	Gender Safety	Workers Housing	Pedestrian Infrastructure	Public Transport	Multimodal Integration
01	T.V. Ramachandra et al. (2018) [4]	X			X									
02	Manasi Madhukar Khollam et al. (2023) [5]	X		X	X							X		
03	Srishti Meena, Prasanth Vardhan (2025) [6]			X	X							X		
04	Jiaoe Wang et al. (2024) [7]	X			X								X	X
05	Murari Srinivasa et al. (2024) [8]	X								X				
06	Pengyu Zhu et al. (2022) [9]	X			X	X							X	
07	Yuan X. et al. (2024) [10]	X	X		X					X				
08	Julio Cesar dos Santos et al. (2024) [11]	X		X				X						
09	Safiul Nazmi et al. (2025) [12]				X							X		
10	David Greenwood et al. (2014) [13]											X		
11	Bhargav Adhvaryu et al. (2021) [14]	X											X	X
12	Constantin Marius Prioriu (2025) [15]	X						X	X				X	
13	Prasanth V. Satheesh (2022) [16]	X	X	X			X						X	X
14	Csik Prasad (2022) [17]				X		X						X	X
15	Priyanka Kumar & Sanjay Gupta (2024) [18]	X	X	X										X
16	Rek P. Desai et al. (2016) [19]	X		X									X	
	Total	12	3	6	8	1	2	2	1	2	0	4	7	5

Table III. Parameters for evaluation

<table>
<tr><th>Sr. No</th><th>Parameters</th><th colspan="2">Sub- Parameter</th><th>Description</th></tr>
<tr><td rowspan="5">01</td><td rowspan="6">Industrial Mobility and Accessibility</td><td rowspan="5">Workers Mobility</td><td>Mode of Travel</td><td rowspan="5">Analysis the travel pattern behaviour of industrial workers, through which the efficiency and accessibility of the transport system is analysed.</td></tr>
<tr><td>Mode share variability between city and non-city</td></tr>
<tr><td>Mode share w.r.t Distance</td></tr>
<tr><td>Travel time w.r.t Distance</td></tr>
<tr><td>Travel time Distribution</td></tr>
<tr><td>02</td><td>Freight Connectivity</td><td></td><td>It evaluates the freight movement within MIDC area through by using Alpha (α), Beta (β), and Gamma (γ) network connectivity indices, which quantify road network connectivity, complexity and completeness.</td></tr>
</table>

Sr. No	Parameters	Sub- Parameter		Description
03		Last Mile Connectivity		It is measured by taking percentage of workers using NMT, shared auto, public transport. A higher percentage shows better last mile connectivity.
04	Land-use and Industrial Integration	Mixed used Diversity		It is evaluated by Shannon entropy index which is used to measure the diversity of land use inside MIDC boundary.
05		Workers Density		It measure the concentration of population or workers across all villages in CSMRDA as well the MIDC area.
06		Land Value Increment		It measures the impact of land value by using spatial Increment value, correlation and regression analysis to evaluate relation between land value and its distance from MIDC.
07	Inclusivity & Social Equity	Transport Affordability		It is evaluated by taking the ratio of monthly travel cost to monthly income for every mode type.
08		Gender Sensitivity Safety		It is evaluated by user perception score based on the survey responses.
09		Proximity to Workers Housing		Assess by the percentage of workers that live in the 5 km radius of MIDC.
10	Transit Oriented Infrastructure	Pedestrian & Cycling Infrastructure		Assessed by means of road inventory and by taking the percentage of availability of footpaths and cycle tracks inside the MIDC area.
11		Public Transport Frequency		Evaluated by analysing the public transport frequency and head way of the public transport service available.
12		Multimodal Integration		It evaluates the integration of transport infrastructure like roads, rail, airport, DFC node for the logistic purpose.