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Analysis of Barriers to Effective Public Transport: A Multi-Criteria Decision Making Approach

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Abstract

Efficient public transportation (PT) offers significant opportunities as an environmentally friendly, affordable, and inclusive mobility option. It contributes to reduced vehicle emissions, decreases reliance on fossil fuels, and increases accessibility, particularly for low-income individuals who are often captive users of PT. Despite these benefits, PT systems globally usually fall short of meeting their key performance indicators (KPIs). The underperformance is largely attributed to a variety of barriers that adversely hamper strategic planning, execution, and system optimization. A comprehensive understanding of these barriers and their interactions is valuable for policymakers, and PT operators seeking to develop strategies and policies to maximise the potential of PT systems. In response to this situation, the present study identified 23 barriers affecting the effectiveness of PT through an extensive literature review and consultations with industry experts. The barriers identified were then structured hierarchically using interpretive structural modelling (ISM) and categorised using "Matrice' d' Impacts Croises Multiplication Applique' an Classment" (MICMAC) method. The analysis identified "financial constraints", "lack of strategic visionary leadership", "excessive trade unionism and political interference", "high implementation and maintenance costs", "inadequacy of designed training programs", "lack of qualified and committed superiors", "corruption within the organisation" and "lack of knowledgeable, committed, trained and motivated staff" as the most influencing barriers within the PT system. Policymakers need to address these highly influential barriers through robust regulatory interventions and appropriate strategic plans and to unlock the full potential and create a sustainable, resilient and competitive PT system.

Keywords: Public Transport, Barriers, Policy, Interpretive Structural Modelling, MICMAC.

Introduction

A co-ordinated and dedicated public transport (PT) systems can control the use of personalised vehicles like two wheelers, cars etc. and bring benefits like considerable reduction in traffic congestion, air pollution, traffic injuries, and carbon emissions, and also deliver remarkable socio-economic merits to societies, such as (a) job opportunities, (b) life quality improvement, (c) safety, (d) health benefits, and (e) physical activity encouragement (Vasudevan et al., 2020). But in this era PT is treated as the travel mode of "poor people" by the growing middle class, and consequently, private cars or motorbikes are preferred over PT for reasons of comfort, convenience, and prestige [1-3]. The inefficiencies of public transportation systems by way of poor service delivery, outdated infrastructure, and low levels of integration with other modes of transport accelerates the modal shift to personalised mobility modes. Consequently, only a small fraction of urban commuters utilises formal PT services, while the majority depend on informal transport methods like shared autos, minibuses, or two-wheelers, which are less safe and contribute to high per-capita emissions [4]. The underperformance of PT systems stem from various barriers or challenges that adversely hamper the strategic planning, execution, and optimization. In a study Alonso et al. (2018) found that financial crisis and urban sprawl with increased use of cars have adversely affected the PT efficiency. Mallqui et al. (2017) identified that capital funding, political interference, competition from paratransit modes, institutional fragmentation are barriers. A thorough understanding of these barriers and their interactions can provide valuable insights for policymakers, transport planners, and PT operators in developing strategies and policies to maximise the potential of PT systems such that the social, economic, and environmental issues associated with rapid urbanisation can be mitigated to a greater extent. This situation demands a deliberate and systematic approach to identifying, prioritising, and addressing the multifaceted barriers that undermine the performance and attractiveness of public transport. So, this study has identified 23 barriers affecting the effectiveness and analysed using MCDM techniques. The aim of this study is

- To identify the barriers to public transport (PT) effectiveness, analyse the interrelationships, prioritise and develop a hierarchical structure using ISM and categorise them using MICMAC analysis.
- To highlight the findings of the study so that the policy makers and decision makers can develop suitable strategies to mitigate these barriers.

The remainder of the study is organised as follows. Section 2 contains the details of the literature review conducted to identify the barriers. Section 3 explains the research methodology in detail. Results and discussions of the research are incorporated in Section 4 and 5. Conclusion, policy implications and future scope are incorporated in section in 6.

Literature Review

According to Porru et al. (2020), a well-organized PT system can positively influence economic growth of a region by improving social inclusion, accessibility, and mobility in rural areas and holds transformative potential to alleviate many of the challenges faced by modern society. But PT systems often fail to deliver the expected levels of service due to its inherent inefficiencies and passively promotes the growth of personalised transport modes. The potentials of PT can only be evinced when its systemic inefficiencies are tackled at their root, but it suffers due to poor inter-agency coordination among various authorities [5]. In a study about the barriers to the bus policy implementation, McTigue et al. (2020) concluded that lack of funding, lack of specific policy document, inter-organisational support & communication and characteristics of the organisation are important barriers. It has been highlighted in the study conducted by Bagaini et al. (2020) that economic barriers, technological barriers, behavioural barriers and corruption are the major obstacles. In separate studies Nallusamy et al. (2015) and Erdo & Kaya (2019) identified that age, and wear and tear of vehicles are correlated to breakdowns and accidents of vehicles and are barriers to service reliability and safety. Lack of training to staff is a barrier [6, 7]. Brakewood et al. (2015) and Handte et al., (2016) identified web enabled real-time information and bus navigation systems are enablers of increasing patronage. Vandalism was ranked an important barrier faced by PT authorities since due to the loss from multiple repairs and replacements [8]. Gota (2014) warned that use of high fuel consuming vehicles is a barrier to financial efficiency in PT. Supporting infrastructure like parking space near the starting point has positive influence on the likelihood of using PT [9]. According to Vitkūnienė et al. (2020) lack of cleanliness, mechanical condition, seat availability are barriers. Lack of visionary leadership is another barrier [10]. Likewise, there are many studies to address the enablers or barriers to the PT effectiveness but in piece meal manner. The review of scientific literatures reveals that there is a dearth of literature that address many barriers together from a holistic management perspective. Hence, this study conducts the structural analysis of 23 barriers identified from an extensive literature review and by interacting with industry experts. Barriers identified and their sources are shown in table 1.

Table 1: Barriers Identified and Their Sources

Barrier No	Description of Barriers	Source
B1	Lack of designed training	Pozueco et al. (2015), Durai (2021)
B2	Financial constraints	Alonso et al. (2018) McTigue et al. (2020), Mallqui and Pojani (2017)
B3	Lack of strategic visionary leadership	Kim & Lee, (2021);
B4	Excessive trade unionism and political interference	Mallqui and Pojani (2017)
B5	Lack of qualified and committed superiors	Lee and Kim (2021)
B6	Corruption within the organisation	Mallqui et al. (2017), Bagaini et al., (2020)
B7	Poor inter-agency coordination in transport infrastructure developments	Mallqui et al. (2017)
B8	Low priority for PT infrastructure development and maintenance	IIHS (2015)
B9	Lack of facilities like "park and ride" safe pavements, wheel chair ramps etc	Gronau and Kagermeier (2007)
B10	High implementation and maintenance costs	IIHS (2015)
B11	Employees' resistance	Expert opinion

B12	Limited use of modern fleet management and vehicle maintenance systems	Expert opinion
B13	Use of "aged and outdated vehicles"	Nallusamy et al. (2015); Erdoğan and Kaya (2019)
B14	Irrational "vehicle procurement and disposal practices"	Expert opinion
B15	Lack of knowledgeable, committed, trained and motivated staff	Pozueco et al. (2015); Nor et al. (2020)
B16	Vehicle damages due to Vandalism	Mong et al., 2019,
B17	Lack of physical facilities, equipment, tools etc. like vehicle lifts, power tools etc	Industry experts.
B18	Inadequate real-time tracking and scheduling technologies (Inefficient scheduling and despatching of vehicles).	Cats and Gkioulou (2017); Brakewood et al., (2015)
B19	Congestion, strikes, unpredictable incidents, poor road conditions, dwell-time delays, and frequent stops.	Luo et al. (2020)
B20	Lack of dedicated bus lanes / priority corridors, and signal prioritization for buses.	Cats and Gkioulou (2017), Mohr et al. (2021)
B21	Increased rate of Break downs and accidents	Erdoğan and Kaya (2019), Nallusamy et al., (2015)
B22	Use of low fuel-efficient vehicles (High fuel consumption)	Gota (2014)
B23	Use of untidy, dirty and uncomfortable vehicles	
	Vitkūnienė et al. (2020)	

Research Methodology

The methodology covers the literature review and consultation with industry experts for the identification of barriers to the public transport effectiveness. The identified barriers are then analysed using Interpretive Structural Model (ISM) and MICMAC techniques and develop hierarchical structural model that prioritise the barriers based on their influencing power in the public transport system.

Interpretive Structural Modelling (ISM) Methodology

ISM is a concept coined by Warfield in 1974. ISM is an iterative learning process that makes use of a matrix model, partitioning of the matrix and digraphs, a structural model, and testing this model against the existing mental model (Warfield, 1974). ISM is interpretive because the judgements of the expert group decide the nature of the relationship between variables; it is structural because an overall structure of the system is derived from a set of complex elements based on the expert judgements. ISM establishes the hierarchical structure and the interrelationships among the variables, whereas the MICMAC (Matrice' d' Impacts Croises Multiplication Applique' an Classment) categorises the variables to different groups based on their driving and dependence powers.

Steps in ISM: - The various steps involved in the ISM technique are:

Step 1: Identification of variables: The most important elements (barriers to PT effectiveness) have to be identified.

Step 2: Structural Self-interaction Matrix (SSIM) and establishing contextual relationships among variables: Establishing a contextual relationship between these 'barriers' using a structural self-interaction matrix (SSIM) is the second step. The experts have to compare the item in column ('i') with the item in row ('j') for each cell and to choose either V, A, X or O, for each barrier subject to the following.

- 'V' when the row ('i' values) influences the column ('j' values).
- 'A' when the 'column ('j' values) influences the row ('i' values.).
- 'O' when there is no relation between the row ('i' values) and the column ('j' values).
- 'X' when row ('i' values) and column ('j' values), influence each other.

Step 3: Developing Initial Reachability Matrix (IRM): In this step, an Initial Reachability Matrix is to be developed from the SSIM by substituting binary value '0' for 'A' and 'O' and '1' for 'V' and 'X'.

Step 4: Embedding transitivity and making Final Reachability Matrix (FRM): Transitivity is a basic assumption in ISM. It is that if element P is related to Q and Q is related to R, then P is related to R. To start the process, an identity matrix of same order is added to the IRM. The IRM when added to identity matrix will be having '1' in its diagonal cells. The IRM having '1' in diagonal cells is then raised to successive powers such that two consecutive powers of the matrix give the same result. That is, $Mn-1 < Mn = Mn+1$. The process of raising the matrix to the successive powers is continued until no new entries are there, and at this stage, the initial reachability matrix will be embedded with all indirect relationships The IRM embedded with all transitive relationships will be the FRM. This matrix portrays the driving and dependence power of each barrier. Driving power of a barrier is the sum of all the barriers which it affects including the barrier itself (i.e. the sum of the binary values across the row). Dependence power of a barrier is sum of the barriers by which it is affected including itself (ie. the sum of binary values in the column) [11].

Step 5: Level Partitioning and Development of Lower Triangular Matrix (Conical Matrix) - The final reachability matrix has to be partitioned into different levels in the fifth stage. The "reachability set" for a KPI is the KPI itself and the other KPIs that are influenced by it. The "antecedent set" of this KPI is the KPI itself and all other KPIs that may influence it. The intersection of the reachability set and antecedent set forms the “intersection set”. The KPI for which the reachability and intersection sets are the same comes at the top level of the level hierarchy. KPIs in higher levels will not influence any lower-level KPIs and hence KPIs that have obtained a level in iteration will be removed from all the remaining reachability sets. Then another level emerges with the common reachability and intersection KPIs and seats in the next lower level and forms the 2nd level. This process is repeated until all KPIs have reached their levels. Then the reachability matrix is rearranged according to the levels obtained in the level partitioning iteration. The matrix obtained is called the lower triangular matrix or conical matrix.

Step 6: Developing Digraph: A digraph is a structural model generated by means of vertices or nodes and lines of edges showing the relationship between barriers by using arrows that point from one barrier to another related barrier. The initial digraph is created from the lower triangular matrix and the transitive links are removed to get the final digraph [12].

Step 7: Developing of ISM Model: The final step is the creation of an ISM model by converting the final digraph by replacing element nodes with name of barriers.

Step 8: Review of ISM: The ISM is then checked for conceptual inconsistency, and necessary modifications are made.

Results and Discussion

A Structural Self Interaction Matrix (SSIM) of 23 barriers has been created (Table 2) to identify and analyse the contextual relationships between barriers. The process of identifying the interrelationships of the identified barriers has been undertaken by the PT experts having more than 10 years of experience in decision making roles. Opinions of such three officers from a PT organisation functioning in one of the southern states of India were obtained and developed the SSIM.

Table 2: Structural Self Interaction Matrix (SSIM)

	B23	B22	B21	B20	B19	B18	B17	B16	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2
B1	O	V	O	O	O	O	O	O	V	O	O	O	O	O	O	O	O	O	V	O	A	A
B2	V	O	O	V	O	V	V	O	O	O	V	V	O	A	V	V	O	O	O	O	O	
B3	V	V	O	V	O	V	V	O	V	V	V	V	O	O	V	V	O	V	V	O		
B4	O	O	O	O	O	O	O	V	V	O	O	V	V	O	O	O	O	O	V			
B5	V	V	O	O	O	O	O	O	O	V	O	O	V	O	O	O	O	O				
B6	O	O	O	O	O	O	O	O	O	V	O	O	O	O	O	O	O					
B7	O	O	O	V	O	O	O	O	O	O	O	O	O	A	O	O						
B8	O	O	O	V	O	O	O	O	O	O	O	O	O	A	V							
B9	O	O	O	O	O	O	O	O	O	O	O	O	O	O								
B10	O	O	O	V	O	V	V	O	O	O	O	V	O									
B11	O	O	O	O	O	O	O	O	A	O	O	V										
B12	O	V	V	O	O	O	O	O	O	O	O											
B13	V	V	V	O	O	O	O	O	O	A												
B14	O	O	O	O	O	O	O	O	O													
B15	V	V	V	O	O	O	O	O														
B16	O	O	O	O	O	O	O															
B17	O	O	V	O	O	O																
B18	O	O	O	O	O																	
B19	O	O	O	O																		
B20	O	O	O																			
B21	O	O																				
B22	O																					

Initial Reachability Matrix

Table 3: Initial Reachability Matrix

No.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21	B22	B23
B1	1	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1
B2	1	1	0	0	1	0	0	1	1	0	0	1	1	0	1	0	1	1	0	1	1	1	1
B3	1	0	1	0	1	1	0	1	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1
B4	0	0	0	1	1	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0	1	1	1
B5	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
B6	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
B7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
B8	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
B9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B10	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1	1	0	1	1	1	0
B11	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0
B12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0
B13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1
B14	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1
B15	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	1
B16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
B17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
B18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
B19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
B20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

B21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
B22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
B23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Source: Created by authors

Initial reachability matrix (IRM) is developed by substituting ‘0’ and ‘1’ for ‘A’ and ‘O’ and ‘1’ for ‘V’ and ‘X’ in the SSIM. The IRM is shown in Table 3.

Final Reachability Matrix

The initial reachability matrix embedded with all transitivities will be the final reachability matrix (FRM). It is created as per step 4 in section 3.2 and shown in table 4.

Table 4: Final Reachability Matrix

No.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21	B22	B23
B1	1	0	0	0	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	1
B2	1	1	0	0	1	0	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1
B3	1	0	1	0	1	1	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1
B4	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	1
B5	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	1
B6	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1
B7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
B8	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
B9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B10	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1	1	1	1	1	1	0
B11	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0
B12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0
B13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1
B14	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1
B15	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	1
B16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
B17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
B18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
B19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
B20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
B21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
B22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
B23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Level Partitioning

The final reachability matrix (Table 4) has to be partitioned into different levels as explained in step 5 in section 3.2. Level partitioning iterations have deployed these 23 barriers in 6 levels. The reachability sets, antecedent sets, intersection sets of barriers and their levels are shown in Table 5.

Table 5: Level Partition

Barrier No.	Reachability set	Antecedent set	Intersection set	LEVEL
2	[1,2,5,8,9,11,12,13,14,15,17,18,19,20,21,22,23]	[2]	[2]	VI
3	[1,3,5,6,8,9,11,12,13,14,15,17,18,19,20,21,22,23]	[3]	[3]	VI
1	[1,5,11,12,13,14,15,21,22,23]	[1,2,3]	[1]	V
4	[4,5,11,12,13,14,15,16,21,22,23]	[4]	[4]	V
5	[5,11,12,13,14,21,22,23]	[1,2,3,4,5]	[5]	IV
6	[6,13,14,21,22,23]	[3,6]	[6]	IV
15	[11,12,15,21,22,23]	[1,2,3,4,15]	[15]	IV
10	[8,9,10,12,17,18,19,20,21,22]	[10]	[10]	III

11	[11,12,21,22]	[1,2,3,4,5,11,15]	[11]	III
14	[13,14,21,22,23]	[1,2,3,4,5,6,14]	[14]	III
7	[7,20]	[7]	[7]	II
8	[8,9,20]	[2,3,8]	[8]	II
12	[12,21,22]	[1,2,3,4,5,10,11,12,15]	[12]	II
13	[13,21,22,23]	[1,2,3,5,6,13,14]	[13]	II
17	[17,21]	[2,3,10,17]	[17]	II
18	[18,19]	[2,3,10,18]	[18]	II
9	[9]	[2,3,8,9,10]	[9]	I
16	[16]	[4,16]	[16]	I
19	[19]	[2,3,10,18,19]	[19]	I
20	[20]	[2,3,7,8,10,20]	[20]	I
21	[21]	[1,2,3,4,5,6,10,11,12,13,14,15,17,21]	[21]	I
22	[22]	[1,2,3,4,5,6,10,11,12,13,14,15,22]	[22]	I
23	[23]	[1,2,3,4,5,6,13,14,15,23]	[23]	I

Source: Created by authors

Lower Triangular Matrix

In this stage, the final reachability matrix is transformed to a lower triangular matrix (conical matrix) format (Table 6) by rearranging the barriers according to their levels obtained in level partitioning. A lower triangular matrix helps to develop the digraph.

Table 6: Lower Triangular Matrix

	B9	B19	B20	B21	B22	B23	B16	B18	B7	B17	B8	B12	B13	B11	B14	B6	B15	B5	B1	B10	B4	B2	B3
B9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B19	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B20	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B21	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B22	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B23	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B16	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B18	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B7	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B17	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
B8	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
B12	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
B13	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
B11	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
B14	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
B6	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
B15	0	0	0	1	1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0
B5	0	0	0	1	1	1	0	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0
B1	0	0	0	1	1	1	0	0	0	0	0	1	0	1	1	0	1	1	1	0	0	0	0
B10	1	1	1	1	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0
B4	0	0	0	1	1	1	1	0	0	0	0	1	0	1	1	0	1	1	0	0	1	0	0
B2	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	0	0	1	0
B3	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1

Source: Created by authors

Initial Digraph

The initial digraph (Figure 1) has been created by showing all interrelationships between barriers.

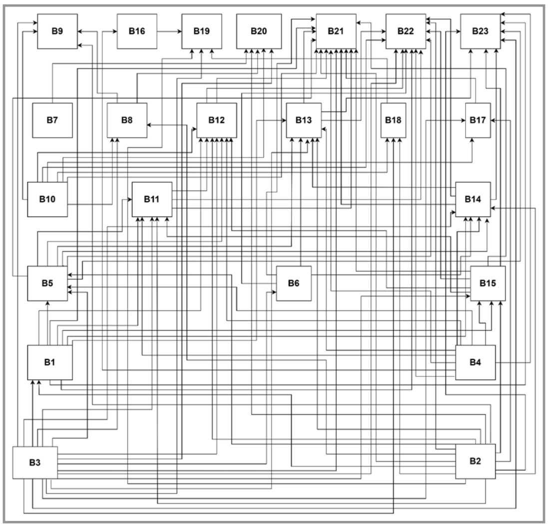

Figure 1: Initial digraph containing all transitive relationships

Final Digraph

Final digraph (Figure 2) is developed by removing all transitive relationships from the initial digraph. It shows all indirect relationships but no transitivity.

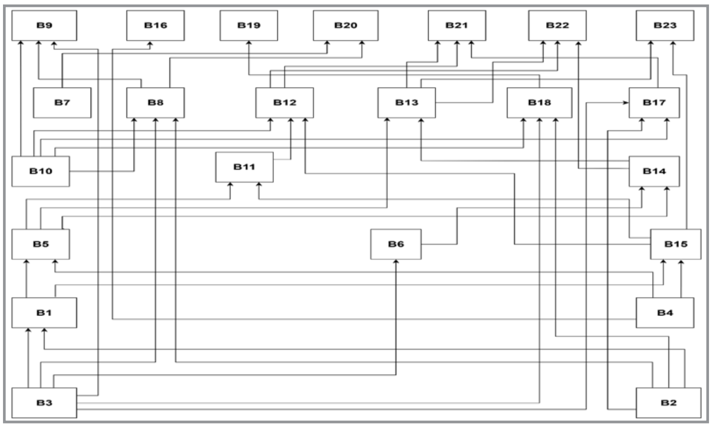

Figure 2: Final digraph.

Interpretive Structural Model (ISM)

ISM (Figure 3) is developed using the final digraph, conical matrix, and levels obtained in level partitioning. The higher-level barriers in the level partitioning are placed at the bottom of the ISM structure. All direct and indirect relations are depicted in the ISM but without transitivities. In this study, B2 (financial constraints) and B3 (lack of visionary leadership) have occupied the bottommost level. These barriers having the highest driving power. That means B2 and B3 are capable of influencing all the remaining barriers directly or indirectly. But B7 (poor inter agency co-ordination in transport infrastructure developments) and B10 (high implementation and maintenance cost) are not being influenced by the bottom most barriers in ISM, but stand alone in the system and influence the other barriers deployed above them [13-16].

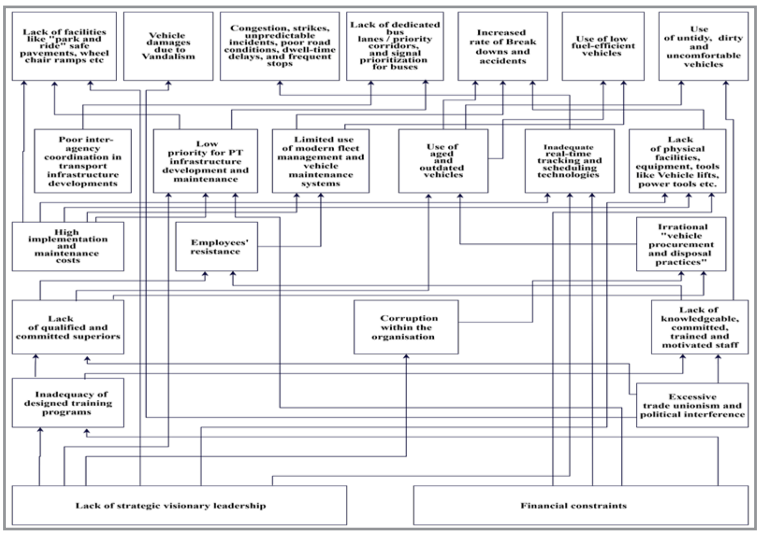

Figure 3: Interpretive Structural Model (ISM)

MICMAC Analysis

The driving power and dependence power of the barriers obtained from the FRM are used for MICMAC analysis which means cross-impact matrix multiplication applied to classification. The dependence power and driving power of every barrier is plotted on a cartesian surface with dependence power on the X-axis and driving power on the Y-axis. The MICMAC diagram (Figure 3) groups the barriers into four categories, viz., Autonomous (Quadrant I), Dependent (Quadrant II), Linkage (Quadrant III), and Independent/driver (Quadrant IV).

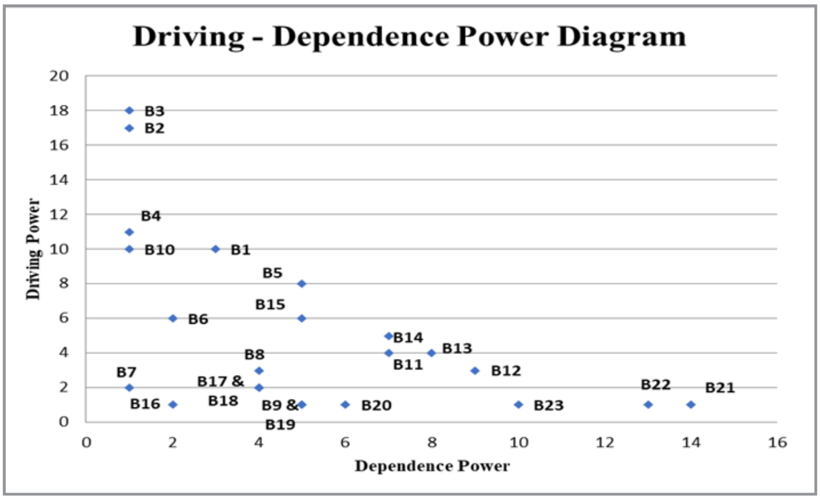

Figure 4: MIMAC diagram

Autonomous barriers (Q-I) - B7, B8, B9, B16, B17, B18, and B19
Dependent barriers (Q-II) - B11, B12, B13, B14, B20, B21, B22 and B23
Linkage barriers (Q-III) - NIL
Independent /driver barriers (Q-IV) - B1, B2, B3, B4, B5, B6, B10, and B15

Autonomous barriers (B7, B8, B9, B16, B17, B18, and B19) grouped in quadrant I are having releatively low driver and dependence powers and hence their significance is low. Dependent barriers (B11, B12, B13, B14, B20, B21, B22 and B23) which are are having higher dependence powers combined with low driving powers are categorised in quadrant II. Quadrant III houses the linkage barriers which have relatively high driving and dependence power. Linkage group is sensitive to manipulations. There are no linkage barriers in this case. The independent (driver) barriers (B1, B2, B3, B4, B5, B6, B10, and B15) which are grouped in quadrant IV are the most influential barriers in the system [17-22].

Conclusion and Policy Implications

PT offers significant opportunities as an environmentally friendly, affordable, and inclusive mobility option by reducing per capita vehicle emissions, and fuel import costs, and improving accessibility for all including captive users having low income [23-26]. But, PT systems fall short of the expected performance levels in service reliability, affordability, environmental sustainability, user satisfaction, etc. It is found from the literature that the reasons for PT underperformance stem from various barriers that adversely hamper the strategic planning, execution, and optimization of PT systems. Hence this study identified such 23 barriers and created a hierarchical structure of these barriers using interpretive structural modeling (ISM) and categorised the barriers using "Matrice' d'Impacts Croises Multiplication Applique' an Classment" (MICMAC) methods. The study found that (i) inadequacy of designed training programs-B1, (iii) financial constraints-B2, (iii) lack of strategic visionary leadership-B3, (iv) excessive trade unionism and political interference-B4, (v) lack of qualified and committed superiors-B5, (vi) corruption within the organisation-B6, (vii) high implementation and maintenance costs-B10 and (viii) lack of knowledgeable, committed, trained and motivated staff (B15) are the independent (driver) elements and are the most influencing barriers that hinder the effectiveness of PT.

Policy implications: The findings of the study will be an insight for the policymakers or decisions makers who are behind the PT enhancement strategies. They need to develop appropriate strategic plans and regulatory measures to overcome the most influencing barriers to create a sustainable and competitive PT system. Properly designed training and training facilities are essential for organisational effectiveness (Anlesinya, 2018 and Durai, 2021). High implementation and maintenance costs and financial constraints often hinder the development of PT infrastructure . Moen (2017) identified trade union interference as a barrier to organisational success and suggested atypical employment forms to overcome trade union interference. Thus, the findings of this study corroborate with the existing literature and emphasise the need and importance of mitigating the barriers through the formulation of strong policy frameworks [27-30].

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Competing Interests

Authors hereby declare that they have no competing financial or non-financial interests to declare.

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