MODELLING THE OBSTACLES TO USING BICYCLE SHARING SYSTEMS IN THE TEHRAN METROPOLIS: A STRUCTURAL ANALYSIS

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Abstract**:** The main objective of the current research is to identify and prioritise the obstacles to using bicycle sharing systems (BSSs) in the Tehran metropolis. The methodology of this research is analytical-descriptive and it aims to achieve applied goals. To do so, firstly the obstacles are identified through studying the theoretical and practical foundations of the issue and then by delving into factors associated with BSSs in the Tehran metropolis, extracting them through the content validity method. Then, the interrelations among the specified obstacles and their impact and effectiveness are determined through structural and MICMAC modelling. The data collection tool employed in the research assumes the forms of a survey and a face-to-face interview. According to the results, the following variables are among the ones associated with obstacles having the maximum impact on other obstacles: the financial problems and the disparity within the municipal management, culturalisation, educational shortage and negligence in using the participatory capacities of civilians. Before executing and taking any other strategy to overcome the obstacles, the forthcoming model supports Tehran metropolis municipal managers to identify the existent obstacles of the field in order to enable them to utilise a suitable approach as to lodging BSSs.

Keywords: bicycle, bicycle sharing systems, structural-interpretive modelling, MICMAC analysis, Tehran metropolis

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Introduction

The rapid urbanisation taking place throughout the world has resulted in communities encountering some challenges (Zarghamfard et al. 2019; Meshkini et al. 2021; Zarghamfard, Meshkini 2021). One of these challenges is transport. The demand for novel ways of urban transport has increased. The rising trend of using motor vehicles and private automobiles in many countries has been accompanied by a diverse set of socio-economic problems. The increase in the

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fuel price, energy crisis, environmental issues and traffic jams, and the decrease in life quality, as well as in civilians' health, have given rise to the proposition of using public transport systems as well as other non-motor ways. Enhancing physical activity in communities is not achievable only through recommendations and needs especial programmes and infrastructures (Johnson et al. 2016). Since motorised transport is a contributor to sedentary life, a good strategy to increase physical activity would be to bring non-motorised transport to the routine daily lives of people (Wareham et al. 2005; De Geus et al. 2007; Dill, Voros 2007). A move towards sustainable mobility necessitates a reduction in the inefficient use of private vehicles and an increase in access to environmentally sustainable transport (Beroud et al. 2010). Encouraging commuters to use active travel (cycling and walking) instead of inactive travel (travel by motorised vehicles) would produce health benefits (Forsyth et al. 2012; Taddei et al. 2015) and reduce air pollution (Woodcock et al. 2013). Policymakers conduct environmental interventions, such as improving cycling infrastructure, to encourage cycling to work. Recently, one new way in which cities seek to increase the usage of bikes is by implementing bicycle sharing systems (BSSs) to facilitate short-term bicycle rental in urban areas (Woodcock et al. 2014).

Bike-sharing systems go back to the 1960s (Lindsey et al. 2014). At first, these systems did not show much progress (Xiong 2010). Since the first bicycle sharing system was introduced in Amsterdam in 1965, the number of systems has grown substantially all over the world. Moreover, the services have evolved, using technological advances to address operational issues (Shaheen et al. 2010). The development of, mainly European, BSSs has been typically categorised into four different 'generations' (Parkes et al. 2013). The first system called 'White Bikes' was introduced in Amsterdam in 1965. Ordinary white painted bicycles were provided for public use. The use was possible without personal registration and bicycles could be found throughout the city without permanent stations. We can refer to this first generation as 'communal cheap bicycles for self-service'. Due to the high vandalism and theft rates and the unstructured introduction process, many cities and municipalities were frightened to copy such systems. The second generation, known as the 'Coin Deposit Systems', required users to insert a refundable deposit to unlock and use a bicycle. Unfortunately, the two programs failed due to the number of stolen and vandalised bicycles, and lack of time constraints on their use (DeMaio 2009). The third generation can be christened 'information-technology–based systems' (Shaheen et al. 2010). This system generally incorporated designated docking stations and smart technology for bicycle check-in and check-out, such as the largescale bike-sharing system – Velo'v – launched in Lyon, France in 2005 (DeMaio 2009). Users received a code via text message in order to unlock the bicycles (Midgley 2011). The fourth generation, known as 'Demand Responsive, Multimodal Systems', used integration with larger public transport systems via smart cards as a key feature. This new generation may also introduce kinds of bicycle such as electric bicycles and bicycle redistribution systems (Jensen et al. 2010). A bike-sharing system provides an opportunity to be integrated into urban development. Bike-sharing is a convenient and 'green' transport mode, and therefore plays an important and complementary role in the comprehensive transport system (Li et al. 2009). In general, there are several factors involved in the success or failure of a shared bike system. Factors such as accessibility, spatial distribution of bicycle stations (Zhang 2011), bicycle infrastructure (Schoner, Levinson 2014), street connectivity (Yang, Zacharias 2016), public transport modes (Caggiani et al. 2020), land use (Zhao et al. 2018), slope or morphology of the territory (Lu et al. 2018), population size (Maas et al. 2020), and public transport policy and planning (Caggiani et al. 2021) can affect the success or failure of these programmes.

Tehran, as one of the largest cities among the Middle Eastern metropolises, is struggling with a myriad of problems in urban transport amenities proportionate to the population size, and on the other hand, Tehran's distinct spatial structure together with policies undertaken to provide citizens with affordable financial facilities for purchasing private automobiles, have led to a tremendous spurt in the use of private cars. Tehran's distinct spatial structure along with policies taken there on such as providing civilians with financial facilities for purchasing private automobiles as one of the absorbent factors, has led to further use of private cars. The prevalence of problems that have come to characterise the urban landscape as a result of increased use of automobiles, such as the increase in traffic jams, air pollution, noise pollution, etc., forces municipal officials to take measures to reduce the use of private automobiles, and to encourage people to choose bicycle as a green and sustainable form of transport. Considering the current status of Tehran's urban transport, establishing bicycle routes in different urban spots of Tehran can ameliorate many of the current problems attributable to urban commuting and mass traffic jams, and can additionally eliminate issues such as air pollution and resulting diseases. The existence of such problems, which citizens are grappling with on a daily basis, necessitates a more enthusiastic welcome to the executed bicycle sharing project in Tehran. Despite a warm welcome provided by different countries in the world and in spite of Iran's municipal officials' predictions, a long time has passed since the launch of the project and the investments made by the governmental and private bodies in the creation of infrastructure for bicycle sharing, but this method of transport has not been accepted by citizens yet. Notwithstanding a large number of governmental investments, the trend for using bicycle as a mainstream transport option did not pick up. Thus, the project faced a complete failure, resultant to which it received a downright obliteration. Likewise, the private sector investments from 2018 onwards have remained fruitless. Therefore, the current research is carried out to identify and prioritise the obstacles to the usage and popular acceptance of BSSs in the Tehran metropolis.

Literature review

The World Health Organization (WHO) recommends more active travel (i.e. walking and cycling) in people's daily lives to reduce the risk of non-communicable diseases (Arsenio, Ribeiro 2015). Therefore, policymakers are advised to develop strategies that stimulate active travel and discourage motorised transport (Fishman et al. 2015). Bike-sharing programmes are associated with various benefits such as a decrease in carbon dioxide (CO2) emissions, physical activity and health, a reduction in various diseases (e.g. diabetes and obesity), flexibility, ease of access and use, a decline in traffic congestion and noise pollution through the provision of alternatives to auto-commuting and an increase in public transit use, support for multimodal transport connections, creating a larger cycling population and increasing transit use. Bicycle sharing programmes provide a sustainable mode of urban transport. These systems also address the issue of bicycle theft for users, a common problem for regular cyclists in urban environments (Ji et al. 2014; Legros 2019). Such programmes require less facilities compared to those for motorised transport and can reach some under-served destinations. Also, a bicycle is relatively inexpensive to purchase and maintain. Research suggests that a bicycle is an ideal transport mode in the 2–5 km travel distance range (Li et al. 2009). Cycling usually has advantages compared to car transport on the one hand and walking on the other. It demands less space than car transport, is more environmentally friendly and better facilitates transport from door to door in contrast to public transport (Pucher et al. 2010). The bicycle is an ideal vehicle to discover small regions (Sears et al. 2012). Bike-sharing programmes have been considered a viable option in major European cities to solve environmental problems related to car usage (Zuurbier et al. 2019). We do know that bike-supportive environments, as well as other AT-supportive environments, may help to improve social interaction, social connectedness, liveability, convenience and one's sense of attachment to the community (Litman 2009). In addition to everyday cycling, events and campaigns such as Critical Mass Rides and the Congressional Bike Caucus bring awareness and a social component to biking. Another major social benefit of biking is a reduction in crime (Cozens et al. 2005).

A review of the available literature suggests that features of both the natural and manmade environment (i.e. land use, topography and cycling infrastructure) influence users' decision to use public bicycle share programmes (PBSP), as well as their choice of route (Schoner, Levinson 2013). Research from the United States and Europe (Fraser, Lock 2011) state neighbourhood connectivity, safety (traffic and non-traffic related) and population density as factors driving cycling. Higher residential densities around stations significantly increase the likelihood of

PBSP use (Fuller et al. 2013). Land uses need to be not only mixed but also complementary (i.e. residential and retail, but not agricultural and industrial) in order to link potential PBSP origins and destinations (Ahillen et al. 2016). Population density, job density and access to restaurants and other commercial activities have been shown to have positive impacts on bikeshare use (Wang et al. 2016; Faghih-Imani et al. 2017). A study of the biking scheme in Barcelona found that the proximity of stations to specific land uses, such as retail shops, schools and employment centres, determined peak bicycle use (Kaltenbrunner et al. 2010). In another study, traffic, lack of awareness of bike lanes, pedestrians, safety and campus design were found to be the main impediments to bikesharing usage (Kaplan, Knowles 2015). A research (Bachand-Marleau et al. 2012) used data on BIXI (which is a public bicycle sharing system) users in Montreal, Canada. The authors concluded that the location of docking stations close to the origin point of potential users can increase ridership. Sun et al. (2017) investigated the impacts of environmental characteristics, including population density, employment density, land use mix, accessibility to point of interests (schools, shops, parks), road infrastructure, public transit accessibility, road safety, convenience and public safety on the usage of bicycle sharing schemes (BSS). Results demonstrate that density of bicycle lanes, public transit accessibility and public safety influence the usage of BSS. Results also suggest policy implications that improving bicycle facilities and reducing violent crime rates tend to increase the usage of BSS. Various factors that can promote systems' bicycle ridership warrant study. Factors such as population and employment density, bicycle infrastructure, socio-demographic characteristics and land use, as well as the built environment, were investigated (Gregerson et al. 2011). Faghih-Imani et al. (2014) examined the effect of meteorological data, temporal characteristics, bicycle infrastructure, land use and built environment attributes on bicycle arrival and departure flows at the station level in Montreal, Canada. The bicycle flows are expected to decrease when we go farther from centre business district (CBD) and increase under good weather conditions. Some literature uncompromisingly promotes BSS as "contributing towards more sustainable mobility in cities" (Levy et al. 2019). Swiers et al. (2017) analysed the cycling behaviour of a university-student population and found that the two primary barriers to cycling were weather and safety. Saneinejad et al. (2012) investigated the effect of weather variables such as wind, precipitation and temperature on cycling. The results confirm that the impact of weather on active modes of transport is important. Sears et al. (2012) and Faghih-Imani et al. (2017) studied the effect of weather on bicycling. They found that precipitation, cold temperature, wind and snow had significant negative impacts on bicycle trips and reduced both the likelihood of using bike share and the duration of trips.

Some studies have also provided considerable insight into the relationship between socio-demographic characteristics and bikesharing usage. Temperature, precipitation and the weekend dummy had highly significant and substantial effects on the number of bookings (Guidon et al. 2019). Economic and social activity were key drivers of demand for free-floating bicycle-sharing in an area. Bicycle network density had a positive impact. Neighbourhoods with higher income levels showed higher demand, and demand for free-floating bicycle-sharing was higher in areas well connected by public transport and those close to the central station and urban train stations.

Sturm and Cohen (2004) found an association between urban sprawl in metropolitan areas and the prevalence of chronic diseases. Active transport was also shown to significantly improve population health in California, with potential decreases in chronic diseases (Maizlish et al. 2013). In a study performed in London, <20% of bike-sharing trips were made by females (Goodman, Cheshire 2014). The findings of Akar et al. (2013) indicated that women were less likely to ride a bicycle relative to men. In the Netherlands, in contrast, more women than men use bicycles (Harms et al. 2014); and with regard to income, previous studies found that people who used bike-sharing had a higher average income (Fishman, Schepers 2016). Shaheen et al. (2014) conclude that bike-sharing participants tended to be wealthier.

Barbour et al. (2019) argue that gender, age, income, household size, commute type and length, and vehicle ownership all played significant roles in bike-sharing usage and modal substitution decisions. Regarding health measures, respondents' body mass index (BMI), one of the health-related indicators, was also a significant predictor of bike-sharing usage. Ethnicity has also been found to be an important factor determining whether an individual uses a bike-sharing system. Studies in Washington D.C. and London found that the bike-sharing population was not representative of the overall population composition of those cities (Buck et al. 2013).

We now proceed to examine the bicycle sharing system in Iran. The bicycle was first brought to Iran as a recreational and expensive vehicle before WWII. Gradually, it became popular not only as a means of entertainment but also as a means of work. After the end of WWII, due to the decrease in the price of bicycles, its imports increased and it became very popular as a vehicle (Hataminejad, Ashrafi 2010). Even in some cities such as Isfahan, as a result of using the bicycle as an urban transport vehicle, the city's main routes had approximately 6 km of specified bicycle lanes (bike lanes). Thus, bicycles, except for a short period, largely confined to its first phase of appearance, had no recreational or decorative meaning, and were considered as a means of transport for daily activities in cities in central regions such as Isfahan, Kashan and Yazd. With the rapid pace of the usage of motor transport vehicles due to governmental policies, such as the cheapness of fuel and the exclusive allocation of routes for them to pass through, amid the 1970s, bicycles gradually lost their considerable transport role in many cities, instead being merely restricted to their insubstantial recreational aspect. Currently, the bicycle in Iran is generally thought to be a transport vehicle which is used only when other types of transport—such as private automobiles or motorbikes—are not available; because of such an attitude, the use of bicycles is limited to some specific social strata.

Prior to the Supreme Council of Urban Planning and Architecture of Iran's resolution in 1990, which was concerned with studying and laying out specific routes for bicycles in urban designing for cities with a population of fewer than 50,000 people, there were no particular steps taken towards Tehran's bicycling status. After the resolution was passed and because of the air pollution status between 1991 and 1996, a favourable pretext was created for the then urban programming officials to study and utilise the system. The results of the early studies presented a couple of study plans and executed projects.

The first executed project in Tehran, 2001, was in Kargar street, which, due to not being safe for bicyclers and inappropriate lines, failed (Gharib 2004). In 2009, the first pilot plan of bicycling in Tehran, on a district basis (district 8), was carried out by governmental investments. In this plan, 34 bicycle stations were established, and the bicycles were directed via three ways as follows:

1. using the bicycle lines inside the sidewalks,
2. eliminating the parking spaces on one side of the street and availing a shared route along with a supportive line, and
3. common routes for bicycles and vehicles.

Following the failure of the first bicycle sharing project in Tehran, the second official bicycle sharing project by Bidood Company, the exclusive executor of smart BSSs, started operating in 2017, sponsored by private sector investment. The project was executed in a number of phases; it initiated the job by setting up stations in district 2 of Tehran in the pilot phase and then expanded to the central parts of the city in districts 6, 11 and 12 in 78 stations, running about 2,500 bicycles. The bicycles used in this system are from the fourth generation of bicycles and many of its elements have been designed by Bidood Company. These bicycles, which are similar to Mobike bicycles, are produced and assembled inside Iran out of Iranian investment resources. Each bike has its own license plate and is equipped with several safety systems and GPS for tracking in order to prevent any violations by users. One of the regulations for using these bikes is that it is forbidden to commute with them on highways and urban tunnels. The scoring system used in this network helps encourage and support orderly and well-behaved users. Although users can drop off their bikes anywhere in the project area (parking in houses and on bridges is forbidden), the bikes delivered at the nearest bicycle station will register as an encouraging point for the users.

The cost of using the bikes in this plan is 6 $ (which includes insurance, initial depository money and refundable deposit) and the cost of daily use for each half hour is 5 ¢. Meanwhile, it seems that the company has tried to remove some of the limitations of the previous system. Among the advantages of this plan compared to the previous plan are women's use allowance representing half of the population of the city, wider coverage of Tehran (in four districts), covering the central areas of the city including the busiest areas of Tehran, eliminating the weaknesses of some bicycle systems as much as possible (installing a basket for carrying luggage, headlights, smart locks, unique license plates for each bicycle), removing the restrictions specifying that bicycle delivery should be only at bicycle stations and installing a safety system to control and track bicycles. Apparently, by removing some of the obstacles to using bikes found in the previous plan, a good opportunity may be provided for more citizens to welcome the regular usage of bicycles.

Bike-sharing routes are marked in Fig. 1. The map indicates that bicycle stations and routes are not evenly distributed throughout Tehran. This is attributable to the fact that the slopes of different parts of Tehran are very different and in some cases it is not possible to ride a bike due to the topography. Further, the infrastructure and conditions of the central regions are suitable. Therefore, routes and stations are distributed in these areas. In total, 37 bicycle stations have been installed in Tehran.

Evidence shows that despite the implementation of this system, neither the number of users nor the extent of use of these bicycles was such that it is commensurate with returning the investments and the profitability of Bidood Company. Statistics show that the maximum number of bicycle trips per day is two trips, while to touch the profitability rate, each bicycle needs to go on at least six trips to seven trips. Considering citizens' nonchalance towards the project, the company is minimising the number of current bikes, which per se implies the non-fulfilment of the project as expected in Tehran. Thus, we will try to examine the obstacles hindering the implementation of this project from different angles.

As some years have passed from the plan's execution and despite the large investments being done on the plan and its free availability, this system also failed. Following the failure of the first shared bicycling project in Tehran, some experts attempted to scrutinise the reasons underlying the failure of the plan. The results of these endeavours are partly presented as the literature review of this research. In general, the main reasons behind the low use of bicycles in Tehran are:

1. lack of a positive attitude towards bicycles (Ahmadi et al. 2013),

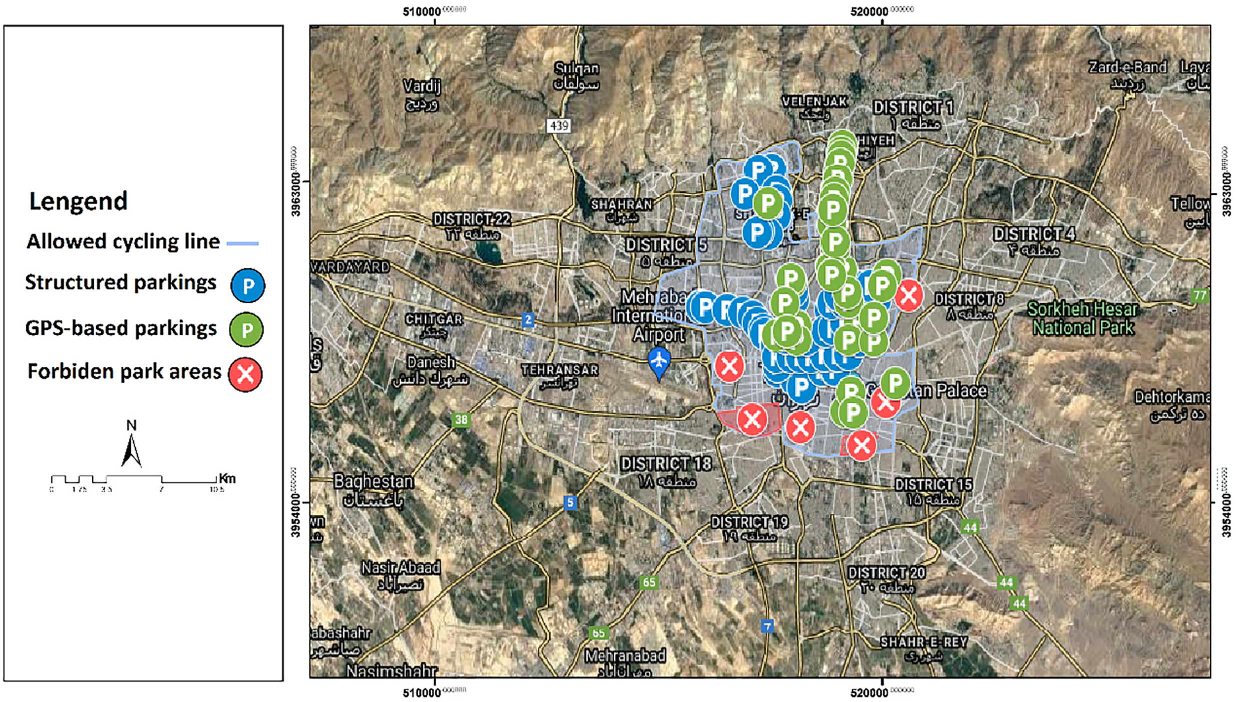

Fig 1. Bicycle routes and stations in Tehran.
Source: own study.

2. unfamiliarity with the culture of bicycling, lower social class, the bicycle lines' shortness, air pollution and the lack of sufficient knowledge about the existence of the system even (Malekhoseini et al. 2012), and
3. disadvantages of bicycle system in Tehran (such as horn, baskets, bike tail lights, bike locks or failure to provide sufficient special bicycle routes) (Ghoreishi 2015).

To summarise, the shared bicycle system in Tehran was not noticed by the citizens, and the responsible organisations also announced the failure of this scheme. There is still very little use of bicycles. There are several reasons for the failure of this scheme, and this study also seeks to organise the factors of failure.

Method

The present study is an applied one in terms of targeting and descriptive-analytical in terms of methodology. In order to model the structural-interpretive obstacles affecting the non-use of BSSs in the metropolis of Tehran, we have adopted the librarian method and have done field studies. In this study, the data collection tool is comprised of a face-to-face interview besides a questionnaire, and the face validity criterion is used to evaluate the validity of the questionnaire or any other evaluation tool.

Methodology

The structural-interpretive modelling method requires information to be received and analysed by experts and specialists. To select the ISM (Interpretive Structural Modeling) team as the purpose of the research so as not to generalise the results, a judgemental or purposeful sampling method was used. The criteria for selecting experts are theoretical mastery, practical experience, willingness and ability to participate in research and accessibility (Karami et al. 2021; Murgante et al. 2021). A noteworthy point in determining the number of experts is to ensure the comprehensiveness of different views in the research. The number of experts usually selected for participating in the ISM reviewed articles is between 14 and 20 people. Considering the above-mentioned criteria, finally 16 urban experts and city specialists have been selected to participate in and cooperate with the research process. The following describes the ISM methodological steps.

Step 1: Identification of the relevant variable

The first step of the modelling is to identify and define the elements whose relationships are modelled. This step is done by reviewing past studies and receiving experts' opinions.

Step 2: Structural Self-Interaction Matrix (SSIM)

Experts' opinions help us to identify and portray the appropriate relationship among these quality attributes. By using pair-wise comparison methodology, we define that either these variables are 'influencing' other variables or are getting 'influenced' by other variables. Four symbols have been defined that demonstrate the association between two elements i and j:

1. V: element i influencing element j,
2. A: element j influencing element i
3. X: elements i and j influencing each other and
4. O: elements i and j are not associated.

Step 3: Initial reachability matrix

The next step in ISM approach is to develop an initial reachability matrix from SSIM. For this, SSIM is converted into the initial reachability matrix by substituting the four symbols (i.e. V, A, X or O) of SSIM by 1 s or 0 s in the initial reachability matrix.

Step 4: Final reachability matrix

After incorporating the transitivity concept as described above, the final reachability matrix is obtained.

Step 5: Level partitions

From the final reachability matrix, for each factor, reachability and antecedent sets are derived. The reachability set consists of the factor itself and the other factor that it may impact, whereas the antecedent set consists of the factor itself and the other factor that may impact it. Thereafter, the intersection of these sets is derived for all the factors, and levels of different factors are determined. The factors for which the reachability and intersection sets are the same occupy the top level in the ISM hierarchy. The top-level factors are those factors that will not lead the other factors above their own level in the hierarchy. Once the top-level factor is identified, it is removed from consideration. Then, the same process is repeated to find out the factors in the next level. This process is continued until the level of each factor is found. These levels help in building the diagraph and the ISM model.

Step 6: Formation of ISM

Based on framework from the final reachability matrix, the structural model is generated. If the relationship exists between the variables j and i, an arrow pointing from j and i shows this. This resulting graph is called a digraph. A digraph is a graphical representation of the elements, their directed relationships and hierarchical levels. On removing the transitivities as described in the ISM methodology, the digraph is finally converted into the ISM model.

Step 7: MICMAC analysis

The purpose of MICMAC analysis is to analyse the driver power and dependence power of factors. The MICMAC principle is based on multiplication properties of matrices 26. It is done to identify the key factors that drive the system in various categories.

Findings

Identification of the relevant variable

Identification of obstacles affecting the non-use of BSSs in the metropolis of Tehran is carried out. Obstacles associated with the problem have been identified and taken into account through field studies and interviews with users and experts.

SSI matrix

After identifying the obstacles leading to the non-use of BSSs in the metropolis of Tehran, these factors have been incorporated in the SSIM. To do so, a questionnaire was laid out first, the general structure of which is similar to that provided in Table 1. In Table 1, the 19 obstacles selected are in the first row and column of the table, and the respondents were asked to determine the type of two-way relationship between the factors.

Table 1. Initial identified barriers.

Elements	Definition of elements	References or bibliography
C1	More travel expenses for people (3,000 tomans per hour)	Field studies and interview with users
C2	High cost of deposit and insurance	Field studies and interview with users
C3	Expensiveness to low-income strata	Interview with experts
C4	Non-refundability of deposit	Field studies and interview with users
C5	Lack of special bicycle route	Field studies and interview with users
C6	Recreational feature of shared bicycling rather than being public transport vehicle	Interview with experts
C7	Physical obstacles (topography and sharp slopes, highways)	Field studies and interview with users
C8	Low level of standard and quality of bicycles	Field studies and interview with users
C9	Lack of bicycles in parking	Field studies and interview with users
C10	Shortage in bicycle stations across the city	Field studies and interview with users
C11	Software problems including not sending messages to users when not having enough bicycles	Field studies and interview with users
C12	Bicycle routes being more symbolic rather than being practical	Interview with experts
C13	Low level of culturalisation and education	Interview with experts
C14	Non-use of citizens' participatory capacities	Interview with experts
C15	Lack of supportive and service-making system	Field studies and interview with users
C16	Non-existence of integrative network of bicycle lanes	Field studies
C17	Financial resource problems and lack of integration in urban management	Field studies
C18	Weather pollution	Field studies
C19	Lack of bicycle reservation system	Field studies

Source: own elaboration.

Initial reachability matrix

The initial reachability matrix is obtained by converting the SSIM into a two-value (0–1) matrix. To extract the reachability matrix, the number 1 in each row must replace the V and X symbols and the number 0 must replace the A and O symbols in the initial reachability matrix.

The result of converting all rows is the formation of the initial reachability matrix (Table 2). Then the secondary relationships between the dimensions/indicators are checked. The secondary

Table 2. Structural self-interactive matrix.

J / I	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14	C 15	C 16	C 17	C 18	C 19
C1	*	A	V	A	X	V	A	A	X	A	O	O	A	X	O	A	X	X	O
C2		*	V	X	X	V	A	A	A	A	O	O	A	X	O	A	V	A	O
C3			*	A	X	V	O	A	O	O	O	O	X	X	O	O	A	O	O
C4				*	A	O	O	A	A	X	O	O	A	X	O	O	A	A	O
C5					*	V	A	X	X	V	O	O	X	X	A	X	A	A	O
C6						*	A	O	X	O	X	A	A	X	A	A	A	A	A
C7							*	O	O	V	O	V	O	X	V	V	A	O	O
C8								*	O	O	X	X	A	X	A	A	A	O	O
C9									*	X	O	O	A	X	A	A	A	A	O
C10										*	O	X	A	X	A	A	A	O	O
C11											*	O	A	X	A	O	A	O	V
C12												*	A	X	A	A	A	O	O
C13													*	V	X	X	A	O	O
C14														*	X	V	A	O	O
C15															*	X	A	A	V
C16																*	A	A	O
C17																	*	V	O
C18																		*	X
C19																			*

Source*:* research findings.

Table 3. Initial reachability matrix.

J / I	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14	C 15	C 16	C 17	C 18	C 19
C1	*	0	1	0	1	1	0	0	1	0	0	0	0	1	0	0	1	1	0
C2	1	*	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0
C3	0	0	*	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0
C4	1	1	1	*	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
C5	1	1	1	1	*	1	0	1	1	1	0	0	1	1	0	1	0	0	0
C6	0	0	0	0	0	*	0	0	1	0	1	0	0	1	0	0	0	0	0
C7	1	1	0	0	1	1	*	0	0	1	0	1	0	1	1	1	0	0	0
C8	1	1	1	1	1	0	0	*	0	0	1	1	0	1	0	0	0	0	0
C9	1	1	0	1	1	1	0	0	*	1	0	0	0	1	0	0	0	0	0
C10	1	1	0	1	0	0	0	0	1	*	0	1	0	1	0	0	0	0	0
C11	0	0	0	0	0	1	0	1	0	0	*	0	0	1	0	0	0	0	1
C12	0	0	0	0	0	1	0	1	0	1	0	*	0	1	0	0	0	0	0
C13	1	1	1	1	1	1	0	1	1	1	1	1	*	1	1	1	0	0	0
C14	1	1	1	1	1	1	1	1	1	1	1	1	0	*	1	1	0	0	0
C15	0	0	0	0	1	1	0	1	1	1	1	1	1	1	*	1	0	0	1
C16	1	1	0	0	1	1	0	1	1	1	0	1	1	0	1	*	0	0	0
C17	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	*	1	0
C18	1	1	0	1	1	1	0	0	1	0	0	0	0	0	1	1	0	*	1
C19	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	*

Source: research findings.

relation is such that if the J dimension leads to the I dimension and then to the K dimension, then the J dimension will lead to the K dimension. By converting the symbols of the SSIM matrix relations to the numbers 0 and 1, the matrix can be obtained according to the following rules.

The final reachability matrix

The final reachability matrix is produced by conducting power iteration analysis based on the initial reachability matrix. In this step, all the secondary relationships between the variables are investigated and the final reachability matrix is obtained according to Table 4. In this matrix, the driver power and dependence power of each variable is shown. The driver power of any obstacle is the final number of obstacles (including itself) that can play a role in creating them. Dependency is the final number of obstacles that causes the variable.

In Table 4, the driver power and dependence power of effective obstacles leading to non-use of BSSs in the metropolis of Tehran are taken into consideration.

The results of the table indicate that financial resource problems and disparities among urban managers (C17) with the highest driver power (17) together function as the most important obstacle to the non-use of BSSs in the metropolis of Tehran. Two factors (low level of culture and education [C13] and the non-use of the participatory capacities of citizens [C14]) are in the second rank (driver power [14]). On the contrary, the factor 'lack of bicycle reservation system in Tehran' (C19) has the least driver power (2).

Levelling the obstacles affecting the non-use of BSSs in the Tehran metropolis

The final reachability matrix must be categorised into different levels. As seen in Table 5, the obstacles affecting the non-use of BSSs in the metropolis of Tehran are classified into 12 levels.

Formation of ISM

In the ISM graph, the interrelationships among the criteria and the relationships of the criteria of different levels are manifested, which leads to a better understanding of the decision-making space in this section; the financial problems and disparities among urban managers (C17) are at the lowest level, and these act as the underlying part of the model. On this account, it is necessary

Table 4. Final reachability matrix.

J I	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14	C 15	C 16	C 17	C 18	C 19	Driver power
C1	1	0	1	0	1	1	0	0	1	0	0	0	0	1	0	0	1	1	0	7
C2	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	7
C3	0	0	1	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	4
C4	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	5
C5	1	1	1	1	1	1	0	1	1	1	0	0	1	1	0	1	0	0	0	11
C6	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0	0	0	3
C7	1	1	0	0	1	1	1	0	0	1	0	1	0	1	1	1	0	0	0	9
C8	1	1	1	1	1	0	0	1	0	0	1	1	0	1	0	0	0	0	0	8
C9	1	1	0	1	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	7
C10	1	1	0	1	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	6
C11	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0	0	0	1	4
C12	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	4
C13	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	14
C14	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	14
C15	0	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	11
C16	1	1	0	0	1	1	0	1	1	1	0	1	1	0	1	1	0	0	0	10
C17	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	16
C18	1	1	0	1	1	1	0	0	1	0	0	0	0	0	1	1	0	1	1	9
C19	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Dependence power	12	10	8	9	12	15	2	8	10	10	6	8	5	15	6	7	2	3	3	–

Source: research findings.

Table 5. Partition of reachability matrix.

Elements	Reachability set	Antecedent set	Intersection set	Level
C1	C3, C5, C6, C9, C14, C17, C18	C2, C4, C5, C7, C8, C9, C10, C13, C14, C16, C17, C18	C5, C9, C14, C17, C18	7
C2	C1, C3, C4, C5, C6, C14, C17	C4, C5, C7, C8, C9, C10, C13, C14, C16, C18	C4, C5, C14	7
C3	C5, C6, C13, C14	C1, C2, C4, C5, C8, C13, C14, C17	C5, C13, C14	4
C4	C1, C2, C3, C10, C14	C2, C5, C8, C9, C10, C13, C14, C17, C18	C2, C10, C14	5
C5	C1, C2, C3, C4, C6, C8, C9, C10, C13, C14, C16	C1, C2, C3, C7, C8, C9, C13, C14, C15, C16, C17, C18	C1, C2, C3, C8, C9, C13, C14, C16	11
C6	C9, C11, C14	C1, C2, C3, C5, C7, C9, C11, C12, C13, C14, C15, C16, C17, C18, C19	C9, C11, C14	3
C7	C1, C2, C5, C6, C10, C12, C14, C15, C16	C14, C17	C14	9
C8	C1, C2, C3, C4, C5, C11, C12, C14	C5, C11, C12, C13, C14, C15, C16, C17	C5, C11, C12, C14	8
C9	C1, C2, C4, C5, C6, C10, C14	C1, C5, C6, C10, C13, C14, C15, C16, C17, C18	C1, C5, C6, C10, C14	7
C10	C1, C2, C4, C9, C12, C14	C4, C5, C7, C9, C12, C13, C14, C15, C16, C17	C4, C9, C12, C14	6
C11	C6, C8, C14, C19	C6, C8, C13, C14, C15, C17	C6, C8, C14	4
C12	C6, C8, C10, C14	C7, C8, C10, C13, C14, C15, C16, C17	C8, C10, C14	4
C13	C1, C2, C3, C4, C5, C6, C8, C9, C10, C11, C12, C14, C15, C16	C3, C5, C15, C16, C17	C3, C5, C15, C16	14
C14	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C15, C16	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C15, C17	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C15	14
C15	C5, C6, C8, C9, C10, C11, C12, C13, C14, C16, C19	C7, C13, C14, C16, C17, C18	C13, C14, C16	11
C16	C1, C2, C5, C6, C8, C9, C10, C12, C13, C15	C5, C7, C13, C14, C15, C17, C18	C5, C13, C15	10
C17	C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C18, C19	C1, C2	C1	16
C18	C1, C2, C4, C5, C6, C9, C15, C16, C19	C1, C17, C19	C1, C19	9
C19	C6, C18	C11, C15, C18	C18	2

Source: research findings.

to start from these obstacles and generalise them to other obstacles. These obstacles are interrelated with others. It goes without saying that all these obstacles are vital factors in the introduction of the non-use of shared bicycles in the metropolis of Tehran. Nevertheless, those obstacles placed at high levels of interpretive-structural modelling hierarchy are of more impact, meaning that factors coming at levels 12, 11, 10 and 9 can exert a considerable effect on the factors placed at levels 3, 2 and 1 (Fig. 2).

MICMAC analysis

At this stage, using the MICMAC method, the type of obstacles is determined in proportion with their impact and effectiveness on other obstacles. According to Fig. 2, the first quarter is the location of autonomous factors, which have both weak driving and dependence power. Most of the obstacles are in this quarter.

In the second quarter, there are factors having less influencing power or weak deriving power but strong dependence power. Obstacles such as travel expenses for people (which adds up to 3,000 tomans per hour) and the recreational aspect of having a shared bike rather than using public transport are among the obstacles of the most dependency degree.

In the third quarter, we have factors which have strong driving power as well as strong dependence power. Non-use of citizens'

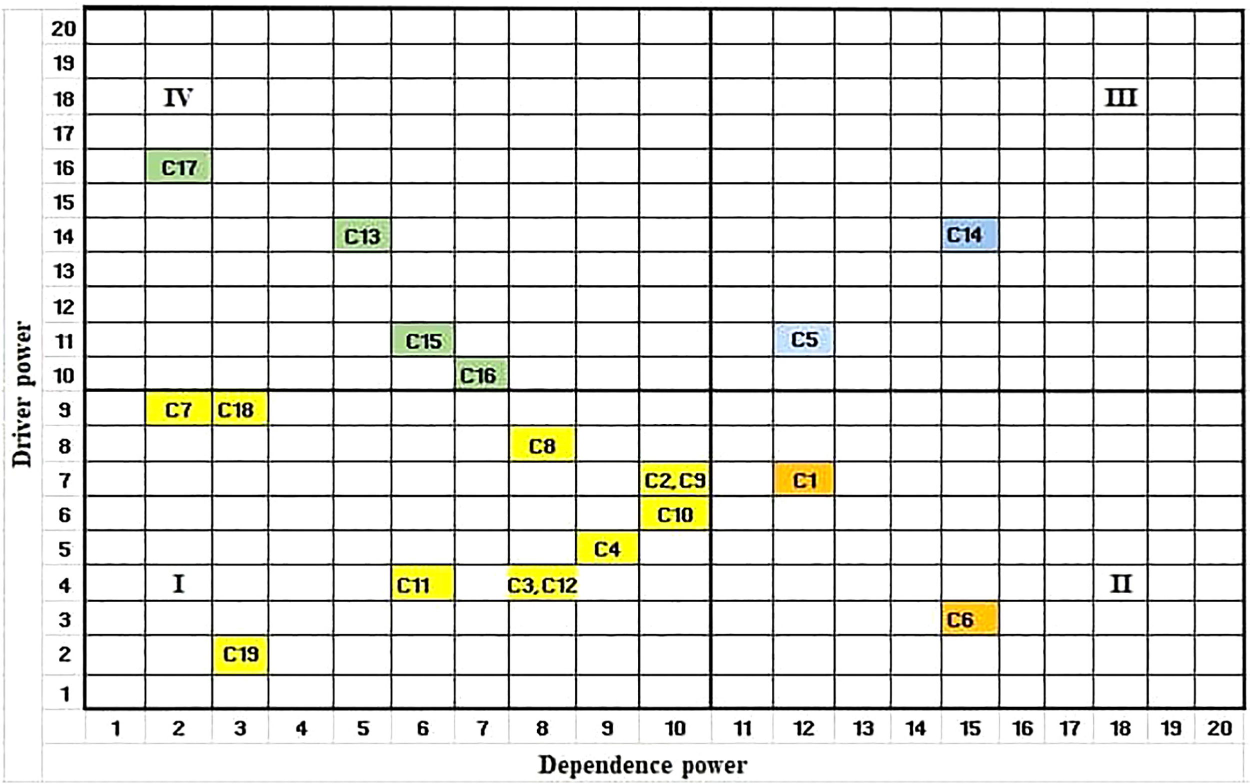

Fig 2. MICMAC diagram of obstacles to the use of BSSs in the metropolis of Tehran.
BSSs – bicycle sharing systems
Source: research findings.

participatory capacities and lack of a special cycling route are all factors located in this quarter.

Finally, the fourth quarter is devoted to financial problems, disparities among urban managers, lack of culture and education, lack of good support and services and non-existence of an integrative network of bicycle lanes. All of these affect the entirety of the obstacles in the system. These elements are the most important obstacles in the use of BSSs in the Tehran metropolis, and the city administration should pay special attention to them so that it can monitor their impact on other obstacles and choose mechanisms so as to be able to prevent apearance of other obstacles and their ability to hinder the strength of these elements.

Conclusions and suggestions

A general reluctance can be observed among citizens of the Tehran metropolis to use bicycle as a habitual mode of transport, and to overcome this issue, it is necessary to identify the main and effective barriers to, and establish better awareness regarding, bicycle usage among them. This research has provided novel insights into and cognition of the nature of the non-use of BSSs in the metropolis of Tehran, which is helpful in identifying priorities pertaining to taking appropriate actions within the decision-making realm. Thus, in this study, the obstacles (19 factors) to the use of a BSS (implemented by Bidood Company) in the metropolis of Tehran were identified and itemised by carrying out theoretical and field studies. The enlisted obstacles were based on the opinions of 16 academics and experts, and scrutinised through the medium of interpretive-structural modelling and MICMAC methods. The results of this study reveal that the variables of financial resource problems and the disparities among urban managers, culture and low education, and the non-use of the participatory capacities of citizens with the highest level of influence exert the highest impact on other obstacles. This model provides the managers of Tehran with a holistic approach with which to identify and remove existing obstacles prior to commencing implementation of any strategy for BSSs, thus ensuring that an appropriate approach remains available as a means by which to establish two-stage BSS projects similar to the one undertaken by Bidood Company. In Fig. 2, it can be seen that the most important obstacles to the use of BSSs in the metropolis of Tehran, which bear an underlying role and which city managers should pay attention to as the theme of this study, are: low level of culturalisation and education, lack of a supportive and service-making system, non-existence of an integrative network of bicycle lanes, financial resource problems and lack of integration in urban management, which affect all the obstacles of the system. These variables have the highest amount of stimulation and provocation based on the MICMAC method used in this study. According to the obstacles highlighted in this study, it can be summarised that, on the one hand, various factors should be considered in the layout and redevelopment of the BSSs in Tehran and, on the other hand, various corrective actions and strategies should be taken to improve the situation in order to meet the favourable conditions. But what matters here is to meticulously pay heed to cultural and social issues in the city of Tehran and the capacities of citizen participation in this field. Additionally, using corrective solutions to tackle the problems of air pollution and unfavourable topographic conditions is of considerable importance. In other words, given the results of studies carried out in this field, notwithstanding Tehran's rather unfavourable topographic and air pollution conditions besides other existing obstacles, none of them have been and none can be a strong obstacle to the expansion of this system in Tehran. What bears leverage is the will to develop a bicycle-based transport system and a proper management for creating smart urban development. Certainly, the sustainable development of BSSs in the long run requires building appropriate urban infrastructures, especially when considering Tehran's current status of urban planning and architecture, which is in need of obtaining a large amount of money as investment. Therefore, the expansion of bicycle use in Tehran should not be pursued in an isolated way; rather, it should be considered within urban designs. Also, the combination of the bicycle system with other transport systems in Tehran should be emphasised; therefore, finally, some managerial and structural proposals for the city of Tehran are presented as follows:

- Completion of the internal structure of non-motorised transport in the Deputy of Transportation and Traffic of Tehran and formation of the city bicycle committee in the Supreme Traffic Council of Tehran being included within a combination of all decision-making institutions.
- Carrying out culturising projects and using participatory capacities taking into account all the project stakeholders.
- Devoting a percentage of the budget for the management and construction of transport infrastructures in Tehran; and particularly, allocation, as part of the annual budget, of a minimum amount to the development of BSSs.
- Correcting the costs of deposit and travel by BSSs compared to other means of public transport.
- Officially proclaiming a day in each year as the bicycle day, on which day high-ranking city officials would also ride bicycles with different groups of people in order to promote the culture of using bicycles.
- Paying serious attention to the issue of public participation and utilisation of system users in the planning, development, dissemination and maintenance of BSSs.
- Integrating decision-making in the fields of non-motorised and motorised transport (i.e., fulfilment of the need to consider non-motorised transport in the comprehensive transport plan).
- Aligning traffic calming measures with the development and design of shared bike lanes.
- Prioritising the allocation of the necessary budget and equipment for the development of BSSs in areas and roads with higher potentials (in all aspects).
- Developing areas suitable for cycling in addition to the central districts of Tehran (districts 6, 7, 11 and 12), connecting favourable districts for cycling with bike routes and the formation of a network of shared bike routes.

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