Journal of Infrastructure, Policy and Development 2024, 8(11), 8789.
https://doi.org/10.24294/jipd.v8i11.8789

Article

Correlates of spatial structure variability in Bushehr port-city: A comprehensive analysis using fuzzy cognitive mapping methodology

Melika Zarei[1], Fatemeh Mohseni[2,*], Poya Sohrabi[3], Sayyed Nouroddin Amiri[1,*], Ebrahim Seyedebrahimi[4]

[1] Department of Urban Planning, Faculty of Architecture and Urban Planning, Persian Gulf University, Bushehr 7516913817, Iran
[2] Department of Urban Planning, Faculty of Art & Architecture, Tarbiat Modares University, Tehran 14115, Iran
[3] Department of Planning, Design, Technology of Architecture, Sapienza University of Rome, 00196 Rome, Italy
[4] School of Architecture, Planning and Preservation, University of Maryland, College Park, M 20740, United States
*** Corresponding authors:** Fatemeh Mohseni, f.mohseni@modares.ac.ir; Sayyed Nouroddin Amiri, n.amiri@pgu.ac.ir

CITATION

Zarei M, Mohseni F, Sohrabi P, et al. (2024). Correlates of spatial structure variability in Bushehr port-city: A comprehensive analysis using fuzzy cognitive mapping methodology. Journal of Infrastructure, Policy and Development. 8(11): 8789. https://doi.org/10.24294/jipd.v8i11.8789

ARTICLE INFO

Received: 26 August 2024
Accepted: 20 September 2024
Available online: 9 October 2024

Abstract: It is critical for urban and regional planners to examine spatial relationships and interactions between a port and its surrounding urban areas within a region's spatial structure. This paper seeks to develop a targeted framework of causal relationships influencing the spatial structure changes in the Bushehr port-city. Hence, the study utilizes Fuzzy Cognitive Maps (FCMs), a computational technique adept at analyzing complex decision-making processes. FCMs are employed to identify concepts that act as drivers or barriers in the spatial structure changes of Bushehr port-city, thereby elucidating the causal relationships within this context. Additionally, the study evaluates these concepts' relative significance and interrelationships. Data was collected through interviews with ten experts from diverse backgrounds, including specialists, academics, policymakers, and urban managers. The insights from these experts were analyzed using FCMapper and Pajek software to construct a collective FCM, which depicts the influential and affected concepts within the system. The resulting collective FCM consists of 16 concepts, representing the varied perspectives and expertise of the participants. Among these, the concepts of management and planning reform, economic growth of the city-port, and port development emerged as the three most central concepts. Moreover, the effects of all influential concepts on the spatial structure change in Bushehr port-city were evaluated through simulations conducted across four different scenarios. The analysis demonstrated that the system experiences the most significant impact under the fourth scenario, where the most substantial changes are observed in commercial and industrial growth and the planning of port-city separation policies.

Keywords: port; city; port-city spatial structure; fuzzy cognitive mapping; FCMapper; Pajek; Bushehr

1. Introduction

Ports, the primary gateways for importing and exporting goods across a region, play a significant role in shaping and transforming the spatial structure of a territory (Yan et al., 2021). The critical role of ports in strengthening supply chains and fostering urban spatial development has led many researchers since the mid-20th century to focus their studies on this topic within the specialized field of spatial planning. A review of research in this area indicates that a portion of these studies emphasizes the evolution of spatial structures and the development of spatial relationships and interactions between ports and cities (Chang et al., 2024; Li et al., 2023; Lugo and Martínez-Mekler, 2022; Rossetto Ribeiro and Beloto, 2022). This focus has been so influential that port-city studies can be characterized into five thematic areas: physical-spatial, infrastructural-support, economic, managerial-social, and environmental (Zarei et al., 2024).

In practice, many researchers analyze the diffusion of port development towards urban areas to explain the relationships and delineate the spatial structure of port-cities, thereby defining new phases of port-related activities within urban regions (Daamen and Vries, 2013; Guo and Qin, 2022). While this diffusion can lead to spatial equilibrium between the port and the city, it can also contribute to spatial inequality in surrounding regions (Bottasso et al., 2014; Schubert, 2020; Solak Fiskin, 2024). In Iran, there is clear evidence of polarization, spatial inequality, and regional imbalance in southern port cities (Dadashpoor and Taheri, 2023a, 2023b).

This research focuses on the port-city of Bushehr in Iran. Geographically located at 50°56′29.637″ E longitude and 28°46′7.9064″ N latitude in southwestern Iran (**Figure 1**), Bushehr covers approximately 984.5 square kilometers and serves as the capital of Bushehr province (Tayebeh et al., 2023). As of the last census in 2016, Bushehr had a population of 223,504, making it the most populous city in the province and the fourth most populous in southern Iran. The city is situated along an 11 kilometer coastline at 18 m above sea level in a coastal region of the Persian Gulf (Mohammadi et al., 2023).

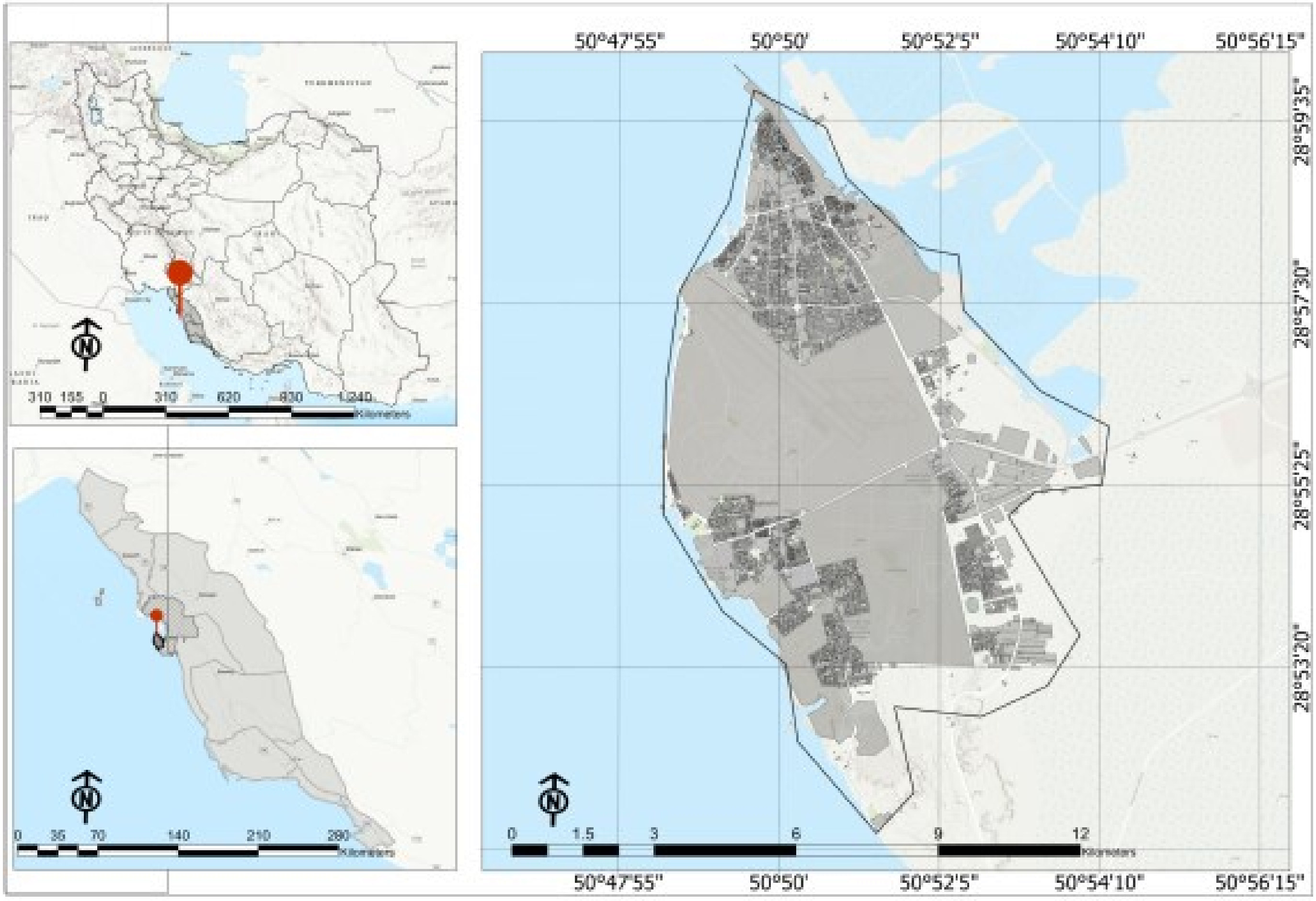

Figure 1. Location of Bushehr port-city within Bushehr province, Iran.

Historically, Bushehr has played a significant role in developing port-city relationships and strengthening other ports within Bushehr province, both economically and geopolitically (Adnani, 2016; Floor, 2014). Today, Bushehr has become a key hub for the supply chain in foreland areas, particularly in trade with countries like China, Kuwait, and Qatar. It has also significantly contributed to the foreign exchange earnings from the export of oil derivatives (such as base mineral oils, other light oils, and products excluding gasoline) and metal products (such as non-alloy steel or iron sheets), which are chiefly engaged towards Iran's capital, Tehran (Ports and Maritime Organization reports, 2023).

Despite notable research on the factors influencing spatial organization and the formation of spatial structures in Iran (Asadzadeh and Hatami, 2023; Rabiei-Dastjerdi, 2023), there is a lack of documented studies explicitly examining the role of critical concepts in the spatial structure changes of Bushehr city. Therefore, this study aims to establish a targeted framework of causal relationships among the fundamental concepts influencing the spatial structure changes in the Bushehr port-city using the Fuzzy Cognitive Mapping (FCM) method. Given that the concepts influencing these changes may be ambiguous, FCM helps identify hidden relationships between concepts and uncovers tacit knowledge, providing insights into how changes in one concept can impact others (Meechang and Watanabe, 2023). This study addresses the following research questions:

1) What are the key concepts that exert the most influence and are most affected by changes in the spatial structure of Bushehr city, with a focus on the Bushehr port?
2) How do the identified concepts influence the spatial structure changes of the Bushehr port-city across different scenarios?

The findings aim to develop a targeted framework for understanding the spatial structure changes in the Bushehr port-city, considering its specific spatial and geopolitical context. This framework could be invaluable even for stakeholders who might find it challenging to predict such changes.

The rest of this study is structured as follows. Section 2 discusses the FCM method and the development process. Section 3 presents the aggregated FCM and scenario analysis results. Section 4 discusses the results and suggests an FCM-based strategy for practitioners. Finally, Section 5 concludes this study and suggests future studies.

2. Materials and methods

This study was conducted using the Fuzzy Cognitive Mapping (FCM) method, as it not only models and simulates the complex relationships among identified factors but also reflects the causality among all factors involved in decision-making (Kanellos et al., 2024). This capability allows for potential changes in the relationships between the factors within the system, providing a more realistic depiction of what occurs in a decision-making process (Infante-Moro et al., 2022).

The FCM method relies on expert judgment and is maintained by data collected through interviews. To gather data for this study, specialists discussed the causal relationships between qualitative factors. They analyzed and evaluated quantitative data based on their experiences, knowledge, and perceptions of the interrelationships among these factors (Singh et al., 2019). Interviews were conducted from 1 July to 31 July 2023, with ten specialists from various backgrounds, including experts, academics, policymakers, and urban managers, to identify the key concepts influencing the spatial structure changes in port-city relationships and to quantify and analyze all causal relationships between these concepts.

Interviewees were provided with a table listing concepts identified during the literature review, and they were requested to determine which concepts are involved in the spatial structure changes in the port-city relationship in Bushehr. Additionally, they were encouraged to add new concepts if necessary and analyze the causal relationships between all identified concepts. They were then requested to assess the degree and nature of the relationships between these concepts.

For instance, the concepts C_i and C_j might have a direct or indirect relationship or no relationship (Kang et al., 2004). The relationships between the concepts could be positive, negative, or neutral, indicating the type of relationship and the degree of causality (Papageorgiou et al., 2006). The value W_{ij} represents how C_i influences C_j (Bağdatlı et al., 2017). Thus, a positive and/or negative causal relationship between two concepts, C_i and C_j, indicates that an increase in the activity level of C_i leads to an increase and/or decrease in C_j. Similarly, a decrease in the activity level of C_i leads to a decrease and/or increase in C_j (Tsadiras and Zitopoulos, 2017). **Figure 2** provides an example of the FCM method and its components.

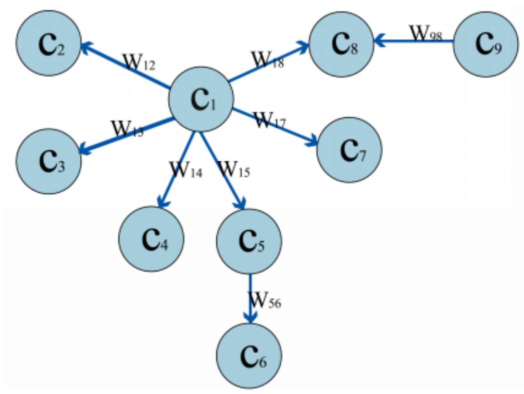

Figure 2. An example of a fuzzy cognitive map (FCM).

In graph theory, the relationship between concepts evolves from a binary state {0, 1} or {1, 0, −1} to a set of states represented by a number within the range [0, 1] or [−1, 1] or through fuzzy linguistic terms (Bakhtavar et al., 2021). A Fuzzy Cognitive Map (FCM) comprises n concepts organized within an $n \times n$ matrix (Pérez et al., 2019). In this matrix, concept C_i is placed on the vertical axis, and concept C_j on the horizontal axis, forming a square matrix (Özesmi and Özesmi, 2004). Suppose a positive relationship exists between two concepts, $W_{ij} > 0$, so if a negative causality is present, $W_{ij} < 0$, and if no relationship exists between two concepts, $W_{ij} = 0$. Accordingly, the values of W_{ij} indicate the extent to which one concept C_i influences another concept C_j (Salmeron et al., 2019).

In fuzzy systems, the results of approximate reasoning typically appear as one or more fuzzy sets. In these cases, it is necessary to convert the fuzzy output into a crisp (non-fuzzy) number. Various methods exist, including the center of gravity, center of area, center of maximum, sum, and weighted average methods. This study employs the weighted average defuzzification method in the FCMapper software to create the causal map. FCMapper first emerged as a beta version in 2009 and was the first tool based on Microsoft Excel designed for analyzing fuzzy cognitive maps (Infante-Moro et al., 2022). The free version (commonly licensed) of this was used.

Subsequently, this causal map is altered into an adjacency matrix. An adjacency matrix is a square matrix composed of all concepts involved in the system and represents the causal relationships identified by the interviewees between these concepts. Each input matrix representing a scenario is multiplied by the adjacency matrix of the fuzzy cognitive map, which indicates the weight of the connection between any two concepts in the map. Since FCMs are dynamic systems, where a change in one concept may influence other concepts, affecting the input concept's value, this process continues until stability is reached. The stabilized values of the FCM concepts for each scenario are documented in a matrix for ranking scenarios in the next step.

Given these considerations, FCMs in this study offer several advantages over other quantitative research methods, such as Structural Equation Modeling (SEM) (Hair et al., 2021) and Bayesian models (Hinne et al., 2020). They provide a visual representation of causal relationships between concepts, enabling intuitive understanding and analysis of complex systems and allowing for discovering hidden feedback within a system (Meechang and Watanabe, 2023). Moreover, due to critical concepts, FCMs enable experts to express their perceptions in evidence-based decision-making to identify and determine uncertainties and dynamic changes in the spatial structure of port-city relations in Bushehr. Additionally, this method allows for adjusting the adjacency matrix based on expert-provided changes in the FCM (Sztubecka et al., 2020).

Furthermore, this study employs a scenario-based approach to assess which concepts significantly influence the spatial structure changes in Bushehr's port-city relations. This method enables the exploration of various geographic or hypothetical situations, guiding strategic choices influenced by different concepts. Each scenario, detailed in the results section, examines unique metric combinations and reveals their specific impacts on the spatial structure changes in Bushehr's port-city relations. These scenarios, designed to simulate changes under the influence of critical concepts, provide practical insights for optimizing the integration of expert analysis.

3. Results and discussion

3.1. Analysis of the CVR

In this study, the CVR (Content Validity Ratio) method is used to assess the validity of each criterion (Norshahira and Lukman, 2021). The results are shown in **Table 1**, indicating that all requirements have been validated.

Table 1. CVR values.

No	Criteria	N*	Ne*	CVR*	Result
1	C1	10	9	0.8	Accept
2	C2	10	9	0.8	Accept
3	C3	10	9	0.8	Accept
4	C4	10	10	1	Accept
5	C5	10	9	0.8	Accept
6	C6	10	9	0.8	Accept
7	C7	10	10	1	Accept
8	C8	10	10	1	Accept
9	C9	10	9	0.8	Accept
10	C10	10	9	0.8	Accept
11	C11	10	9	0.8	Accept
12	C12	10	9	0.8	Accept
13	C13	10	10	1	Accept
14	C14	10	9	0.8	Accept
15	C15	10	10	1	Accept
16	C16	10	10	1	Accept

* The number of expert panels that have rated the item as essential. ** Content Validity Ratio (CVR) = (Ne-N/2)/(N/2) involved Ten expert panels ($N = 10$), and items with CVR values of 0.62 and above were Accepted as instruments. In comparison, the CVR value that is less than that value has been rejected.

3.2. Analysis of the FCM network

In our study on the spatial structure changes in the port-city relationship of Bushehr, we initially identified 127 factors impacting port-city dynamics, as discussed in this article (Zarei et al., 2024). Based on the opinions of ten experts, only 16 factors were found to impact the spatial structure of the Bushehr port-city relationship significantly. We employed these 16 concepts to analyze the changes in the spatial structure of the Bushehr port-city relationship using the fuzzy cognitive mapping (FCM) method. Subsequently, each expert created a map based on the defined concepts and determined the strength of the relationships between the concepts. As a result, we integrated the experts' opinions using a weighted average in the FCMapper software, leading to the creation of the FCM map. This FCM map was then converted into an adjacency matrix. **Table 2** shows that this matrix comprises 256 relationships, of which 229 are positive, and 27 are negative. The map has a density of 0.85, meaning that 85% of the links are displayed compared to the maximum number of possible links among the 16 concepts.

Figure 3, illustrates the fuzzy cognitive map, generated using FCMapper software coding and visualized with Pajek 3.1, an open-source software used free version (Landherr et al., 2010). Dashed lines and positive influences by solid lines represent negative influences. Moreover, the circles' size corresponds to the concept's centrality, with larger circles indicating a higher degree of influence or susceptibility. It is important to note that each concept can influence and be influenced by another. Therefore, a bidirectional relationship between two concepts is possible. Hence, except for the matrix diagonal, which indicates a concept's influence on itself and remains empty, all other matrix cells are filled with values between −1 and 1.

Table 2. The adjacency matrix of the studied system.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	0.00	0.82	0.91	0.69	0.12	0.51	0.90	0.91	0.90	0.97	0.95	0.95	0.99	0.00	0.91	0.83
C2	0.94	0.00	0.62	0.11	0.21	0.00	0.69	0.80	0.81	0.80	0.93	0.81	0.90	0.00	0.81	0.59
C3	0.96	0.81	0.00	0.50	0.81	0.70	0.90	0.81	0.69	0.90	0.80	0.89	0.81	0.00	0.88	0.79
C4	−0.47	−0.60	−0.82	0.00	−0.89	0.80	−0.70	−0.49	0.00	0.00	−0.52	0.00	−0.50	0.00	−0.81	−0.89
C5	0.70	0.60	0.81	0.99	0.00	0.67	0.78	0.90	0.20	0.00	0.81	0.00	0.81	0.00	0.69	0.61
C6	−0.52	−0.19	−0.59	0.91	−0.81	0.00	0.81	0.80	0.00	0.80	0.80	0.00	0.70	0.00	0.69	0.81
C7	0.90	0.80	1.00	0.91	0.49	0.90	0.00	0.89	0.20	0.79	0.89	0.32	0.80	0.00	0.80	0.91
C8	0.99	0.71	0.91	0.80	0.80	0.89	0.70	0.00	0.15	0.80	0.89	0.90	0.90	0.00	0.90	0.91
C9	0.81	0.70	0.50	0.83	0.39	0.90	0.72	0.81	0.00	0.71	0.80	0.78	0.81	0.00	0.19	0.81
C10	0.97	0.79	0.90	0.91	0.42	0.87	0.81	0.82	0.19	0.00	0.90	0.88	0.82	0.00	0.90	0.90
C11	0.96	0.81	0.93	0.91	0.79	0.80	0.82	0.82	0.80	0.91	0.00	0.98	0.90	0.00	0.80	0.81
C12	0.96	0.81	0.89	0.81	0.60	0.91	0.91	0.90	1.00	0.90	0.91	0.00	0.80	0.00	0.82	0.69
C13	0.96	0.90	0.90	0.81	0.69	0.89	0.99	0.99	0.98	1.00	0.99	0.96	0.00	0.00	0.82	0.78
C14	−0.81	−0.70	−0.60	−0.70	−0.61	0.88	−0.80	−0.80	−0.80	−0.90	−0.90	−0.89	−0.81	0.00	0.90	−0.80
C15	0.90	0.92	0.70	0.79	0.91	0.90	0.80	0.90	0.90	0.98	0.97	0.80	0.89	0.83	0.00	0.95
C16	1.00	0.81	0.91	0.93	0.93	0.90	0.90	0.00	0.99	0.94	0.94	0.91	0.97	0.90	0.93	0.00

Source: own data.

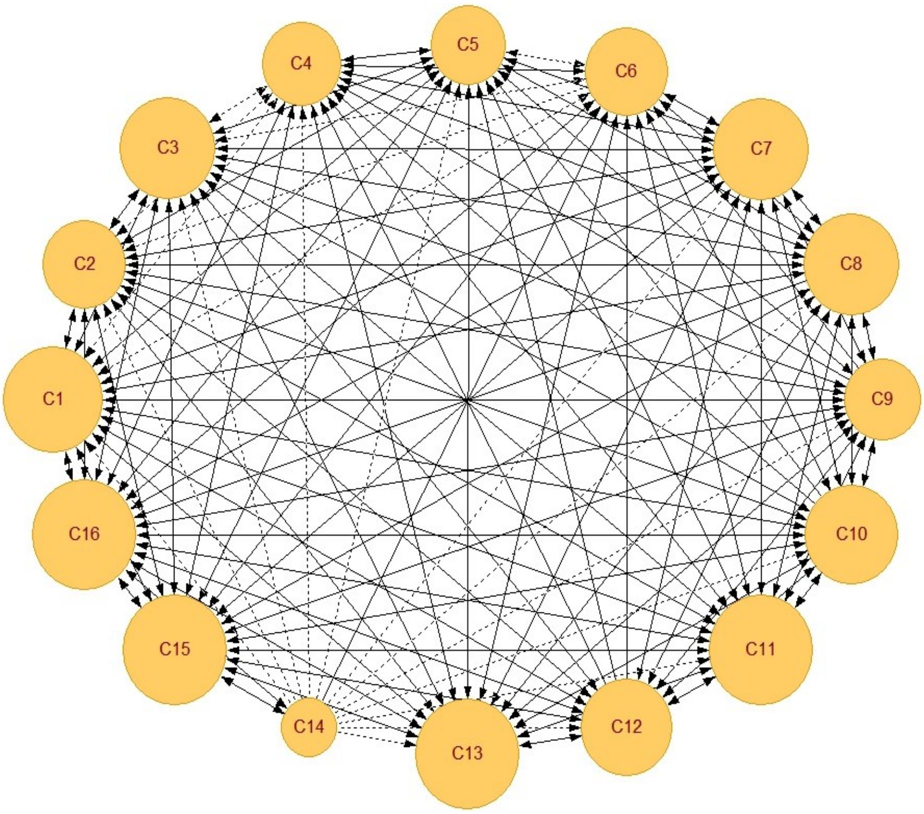

Figure 3. Cause and effect relationships from FCM network.

The centrality measures in network analysis are a theory to illustrate a map structure. This step revealed critical features of the map and concepts. The concept with the highest out-degree is the economic growth of the city-port (C11), weighing 13.00 and 15 outbound links. To explain, the economic growth of the city-port influences 13 concepts in which the strong influence as a two-score rating includes the development of port activities (C1), domestic and foreign investments (C7), different planning approaches (C3), urban redevelopment plans (C15), and port development (C16).

Thus, economic development in the port-city not only shapes the spatial structure and development strategy of the port-city but also drives the port to enhance the quality of its services continuously. The economic growth of the port-city and the development of ports, influenced by domestic and foreign investments, are aligned with various planning approaches to adapt to global conditions and advanced global technologies. The concept with the highest in-degree is an urban redevelopment plan (C15), weighing 13.14 and holding 15 inbound links. It is strongly affected by port development (C16), different planning approaches (C3), economic growth of the city-port (C11), and modifying the management and planning method (C13).

Based on a literature review and successful experiences, urban redevelopment projects especially for the construction of affordable housing (Dadashpoor et al., 2024; Mansourihanis et al., 2024a, 2024b; Mansourihanis et al., 2023) and satisfaction with one's social life are a crucial factor driving spatial structure changes (Ahmadi et al., 2024; Ahmadi et al., 2022; Abrishami and Chamberlain, 2023; Hamidi et al., 2024; Kookhaie and Masnavi, 2014; Mohimi and Esmaeily, 2024). Advancements in maritime technology, the restructuring of economies, and the emergence of globally organized production and transportation systems have highlighted some of the main trends in coastal port areas (Moeremans et al., 2023). In other words, when the significant economic potential of coastal development projects in the port city of Bushehr became evident, regulatory bodies began exerting pressure to reform management and planning methods and implement various planning approaches on coastal sites to align with global trade conditions.

Furthermore, a map depicts the critical role of modifying the management and planning method (C13) from the highest degrees of centrality. Unexpectedly, commercial and industrial growth (C14) has the lowest degree of centrality and out-degree, which means low interactions with the other concepts. One of the primary factors contributing to this phenomenon is the imposition of trade sanctions on Iran, which has stifled growth in both the commercial and industrial sectors. The overall centrality measures are comprehensive in **Table 3**.

Table 3. Overview of each concept indices of the FCM network.

Code	Criteria	In-degree	Out-degree	Centrality	Rank
C1	Development of port activities	11.36	12.85	24.21	5
C2	Port freightage capacity	9.02	10.97	19.99	11
C3	Different planning approaches	11.25	11.99	23.24	6
C4	Urban congestion around ports	7.49	11.60	19.09	13
C5	Planning the policy of separating the port and the city	8.57	9.47	18.04	15

Table 3. (*Continued*).

Code	Criteria	In-degree	Out-degree	Centrality	Rank
C6	Market structure and business strategy	8.43	11.52	19.95	12
C7	Domestic and foreign investments	10.60	12.23	22.83	8
C8	Oil revenues	11.25	11.64	22.89	7
C9	Institutions and government actors	9.76	8.61	18.37	14
C10	Gross Domestic Product [GDP]	11.08	11.40	22.48	9
C11	Economic growth of the city-port	12.04	13.00	25.04	2
C12	The amount of export and import of goods	11.91	10.07	21.98	10
C13	Modifying the management and planning method	12.66	12.41	25.07	1
C14	Commercial and industrial growth	11.90	1.73	13.63	16
C15	Urban redevelopment plans	13.14	11.85	24.99	4
C16	Port development	12.96	12.08	25.04	3

3.3. Validation of FCM results using the DEMATEL method

The DEMATEL method was used to validate the results. The input matrix from the FCM was entered as the initial matrix in the DEMATEL method, and the final results were obtained, as shown in **Table 4**. The correlation between the DEMATEL and the FCM methods results is 0.979, indicating a very high correlation.

Table 4. Validation of FCM results.

	D	***R***	***D* + *R***	***D* − *R***	**Type Criteria**	**Rank DEMATEL**	**Rank FCM**
C1	5.032	5.594	10.626	−0.563	Effect	5	5
C2	4.130	4.825	8.955	−0.695	Effect	11	11
C3	4.930	5.312	10.242	−0.382	Effect	6	6
C4	3.300	5.064	8.364	−1.764	Effect	13	13
C5	3.744	4.198	7.942	−0.453	Effect	15	15
C6	3.715	4.980	8.695	−1.265	Effect	12	12
C7	4.636	5.331	9.967	−0.695	Effect	8	8
C8	4.929	5.045	9.974	−0.116	Effect	7	7
C9	4.242	3.773	8.015	0.469	Cause	14	14
C10	4.865	4.996	9.861	−0.131	Effect	9	9
C11	5.209	5.624	10.833	−0.416	Effect	4	2
C12	5.151	4.412	9.563	0.739	Cause	10	10
C13	5.466	5.400	10.866	0.066	Cause	2	1
C14	5.206	0.820	6.026	4.385	Cause	16	16
C15	5.684	5.187	10.871	0.496	Cause	1	4
C16	5.595	5.271	10.866	0.324	Cause	3	3
					Correlation	0.979	

3.4. FCM network simulations

There are several considerations to consider in scenario writing within the FCMapper software. One of these is that the software predefined an initial scenario, which calculates the system's steady state. This initial scenario indicates the direction the system will take if all concepts remain unchanged, serving as a baseline against which the scenarios proposed by researchers can be compared. Another critical point in scenario writing with FCMapper is that to fix the values of specific concepts, the range [0, 1] is used. A zero value means the concept does not exist in a system iteration.

In contrast, one value indicates that the concept exists at its highest level within the system, with the most significant activity level and/or relative frequency. The concept is then held constant at the defined value, blocking the effects of internal relationships that could increase or decrease it. After simulating all the scenarios (Scenarios 1 to 4), the results were arranged, and the changes in each concept within each scenario and the impact of each scenario on the overall system were intended. These results are presented in **Table 5**.

Table 5. Results of the scenarios for concepts examined in the spatial structure changes of Bushehr port-city.

Criteria	Base Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario Changes 1	Scenario Changes 2	Scenario Changes 3	Scenario Changes 4
Development of port activities (C1)	0.99997	0.99999	0.99998	0.99999	1.00	0.003%	0.002%	0.002%	−0.127%
Port freightage capacity (C2)	0.99988	0.99997	0.99993	0.99995	0.99677	0.009%	0.005%	0.007%	−0.311%
Different planning approaches (C3)	0.99988	0.99998	0.99996	0.99996	0.99655	0.011%	0.008%	0.008%	−0.333%
Urban congestion around ports (C4)	0.99999	0.00000	0.00000	0.00000	0.99964	−100%	−100%	−100%	−0.035%
Planning the policy of separating the port and the city (C5)	0.99723	0.99971	0.99943	0.00000	0.93479	0.249%	0.220%	−100%	−6.261%
Market structure and business strategy (C6)	1.00000	0.00000	0.00000	0.00000	0.99983	−100%	−100%	−100%	−0.017%
Domestic and foreign investments (C7)	0.99997	0.99998	0.99995	0.99996	0.99902	0.002%	−0.001%	−0.001%	−0.095%
Oil revenues (C8)	0.99996	0.99997	0.99993	0.99994	0.99947	0.001%	−0.003%	−0.002%	−0.049%
Institutions and government actors (C9)	0.99968	0.99985	0.99960	0.99982	0.98985	0.017%	−0.008%	0.013%	−0.984%
Gross Domestic Product [GDP] (C10)	0.99998	0.99998	0.99994	0.99998	0.99914	0.000%	−0.004%	0.000%	−0.084%

Table 5. (*Continued*).

Criteria	Base Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario Changes 1	Scenario Changes 2	Scenario Changes 3	Scenario Changes 4
Economic growth of the city-port (C11)	0.99999	0.99999	0.99998	0.99998	0.00000	0.001%	−0.001%	0.000%	−100%
The amount of export and import of goods (C12)	0.99991	0.99996	0.99990	0.99996	0.99733	0.005%	−0.001%	0.005%	−0.258%
Modifying the management and planning method (C13)	0.99998	0.99999	0.00000	0.99997	0.00000	0.001%	−100%	−0.001%	−100%
Commercial and industrial growth (C14)	0.93492	0.00000	0.00000	0.00000	0.65905	−100%	−100%	−100%	−29.508%
Urban redevelopmen t plans (C15)	0.99999	0.99997	0.99993	0.99994	0.00000	−0.001%	−0.005%	−0.004%	−100%
Port development (C16)	0.99994	0.99997	0.99994	0.99995	0.00000	0.003%	0.000%	0.001%	−100%
Total changes						18.769%	25.016%	25.003%	27.379%

Scenario 1 focuses on three concepts that have negative impacts on the system, namely commercial and industrial growth (C14), market structure and business strategy (C6), and urban congestion around ports (C4). In Scenario 1, a zero value was allocated to each concept. According to the results of Scenario 1, which are also depicted in **Figure 4** the most significant changes occurred in planning the policy of separating the port and the city (C5) and institutions and government actors (C9). Scenario 1 results in an overall system change of 18.769%.

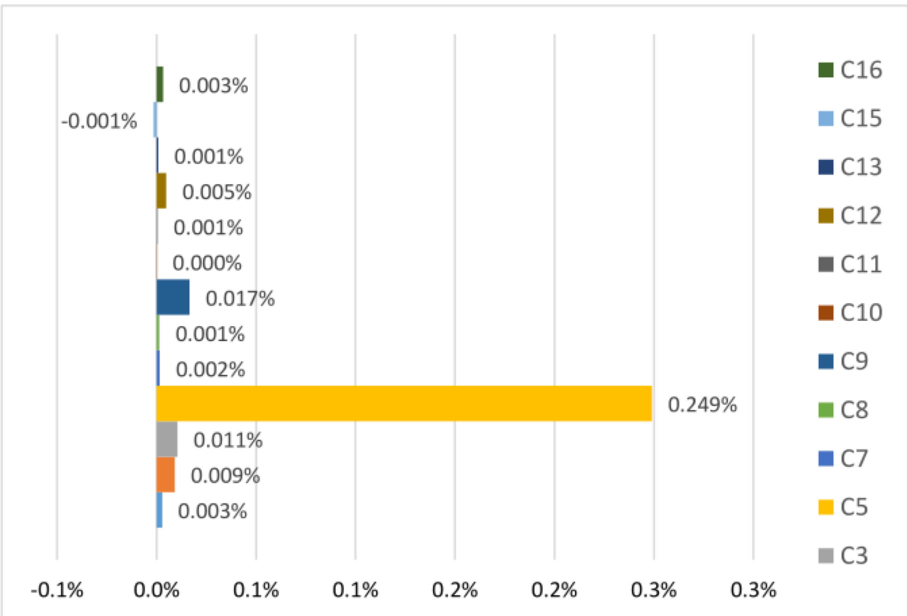

Figure 4. The impact of scenario 1 on other collective FCM concepts.

Scenario 2 is intended around three concepts that have negative impacts on the system—namely, commercial and industrial growth (C14), market structure and business strategy (C6), and urban congestion around ports (C4) as well as the concept with the highest centrality, which is the modification of management and planning methods (C13). In this scenario, a zero value was allocated to each concept. According to the results of Scenario 2, which are also depicted in **Figure 5** the most significant changes occurred in the concepts of planning the policy of separating the port and the city (C5), different planning approaches (C3), and institutions and government actors (C9). Scenario 2 results in an overall system change of 25.016%.

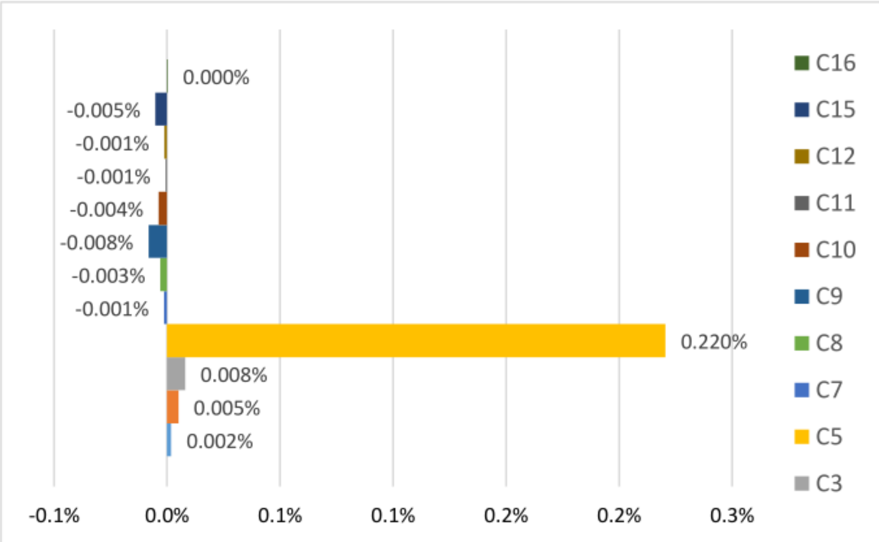

Figure 5. The impact of scenario 2 on other collective FCM concepts.

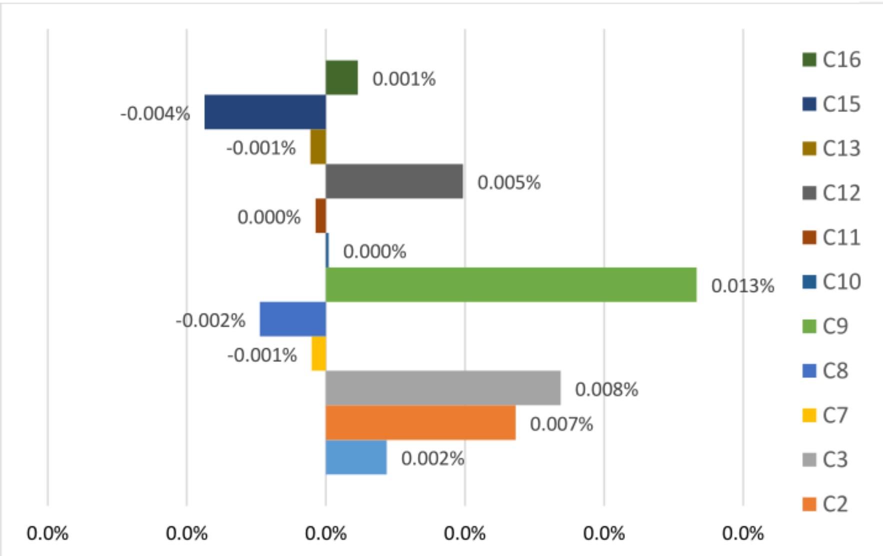

Figure 6. The impact of scenario 3 on other collective FCM concepts.

Scenario 3 focuses on three concepts that negatively impact the system—commercial and industrial growth (C14), market structure and business strategy (C6), and urban congestion around ports (C4)—as well as the concept that experienced the most changes in the previous two scenarios, which is planning the policy of separating the port and the city (C5). In this scenario, a zero value was allocated to each concept. According to the results of Scenario 3, which are also depicted in **Figure 6** the most significant changes occurred in the concepts of institutions and government actors (C9) and different planning approaches (C3). Scenario 3 results in a system-wide change of 25.003%, the most prominent change observed across the scenarios.

Scenario 4 emphasizes the four concepts with the highest impact and centrality: economic growth of the port city (C11), modification of management and planning methods (C13), urban redevelopment plans (C15), and port development (C16). In this scenario, each concept was assigned a value of zero. The outcomes of Scenario 4, illustrated in **Figure 7** indicate that the most significant changes occurred in commercial and industrial growth (C14) and the policy planning for separating the port from the city (C5). Scenario 4 resulted in the most substantial overall system change, quantified at 27.379%.

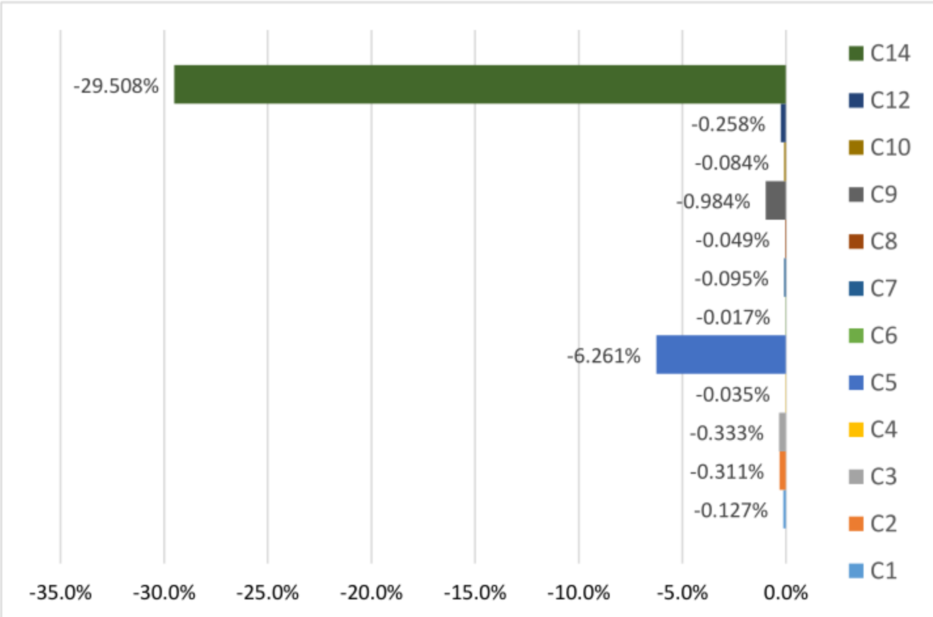

Figure 7. The impact of scenario 4 on other collective FCM concepts.

4. Discussion

The evolution of port functions, driven by diverse operational roles, has led to substantial changes in the development of urban spaces and the structural transformation of port cities. This study seeks to develop a targeted framework of causal relationships among key concepts influencing spatial structural changes in the Bushehr port-city, employing the Fuzzy Cognitive Mapping (FCM) method. The FCM results identify the modification of management and planning methods (C13) as the most central concept, consistent with extensive research in port management that underscores the critical role of governance practices in port-city contexts. For example, Akhavan (2017) notes that in Dubai's port-city, substantial internal and external investments, coupled with effective management and governance across local (port area), city, and regional levels, have propelled Dubai into the ranks of the top ten global commercial and container ports (Akhavan, 2017).

The most influential concept (Out-degree) in driving spatial structure changes in Bushehr port-city is the economic growth of the city-port (C11). In contrast, urban redevelopment plans are the most affected concept (In-degree) (C15). By applying the FCM inference technique, the study tested common concepts influencing spatial structure changes in Bushehr port-city across four scenarios. Notably, specific concepts, such as commercial and industrial growth (C14), market structure and business strategy (C6), and urban congestion around ports (C4), consistently emerged as sensitive factors adversely affecting the system in three of the scenarios.

Similar patterns have been observed in other European port-cities, as documented by researchers like De Langen (2006) and Debrie and Raimbault (2016). They concluded that effective coordination among private landowners, especially in areas adjacent to ports and urban coastlines, flexible management and planning practices, and collaboration between port-area managers and urban planners can transform potential conflicts between the port and city into cooperative efforts. Conversely, the absence of such coordination can severely impact commercial and industrial growth, market structure and business strategy, and the development of urban spaces.

Scenario 4 has the most pronounced impact on the spatial structure of Bushehr port-city, with a change of 27.379%. The most significant alterations are observed in commercial and industrial growth (C14) and planning efforts to separate the port from the city (C5). The current spatial changes in Bushehr port-city emphasize the increasing spatial separation between the port and the city, leading to internal land use changes that fail to address the connection between these two entities. This separation has resulted in the port becoming geographically distanced from the city, reducing the overlap in land use between the port and city and negatively affecting the commercial and industrial growth of the port-city.

Developing the spatial structure of port-city relationships requires a comprehensive approach that considers all relevant concepts. The unique characteristics of each port-city and the governing systems can influence the relative significance of specific aspects. Urban managers and planners' priorities for targeted spatial development will depend on their perspectives and the necessary actions. In the context of Bushehr port-city, where multiple sanctions against Iran and existing barriers to attracting foreign investment exist, it is crucial to create favorable conditions for foreign investment and private sector participation. This could be accomplished through incentivizing measures, particularly economic incentives, such as reducing export and import tariffs, which should be prioritized.

5. Conclusion

The findings of this study reveal that among the concepts analyzed, the most influential factors driving spatial structural changes in Bushehr port-city are management and planning reforms, economic growth of the city-port, and port development. The spatial transformations in Bushehr can be attributed to the strategic allocation of trade revenues, a portion of which is reinvested into vital transportation infrastructure, including airport expansions and new dock construction. This rapid development significantly impacts enhancing the economic growth of the Bushehr port-city, with the port's expansion being propelled by capital flows aimed at adapting to global conditions and incorporating advanced technologies. The economic growth of Bushehr not only reshapes the city's spatial structure and development strategy but also steers the port's evolution to improve service quality and meet changing demands continuously. Presently, Bushehr port serves a pivotal role as an international transport and transit hub, substantially contributing to the industrial and commercial growth of the city and occupying a key position in the Middle East's regional trade network.

Reforming management and planning practices in Bushehr port-city is crucial for attracting investment, fostering free trade activities, and sustaining a stable and favorable economic environment. The port-city's stable political conditions have consistently bolstered the confidence of both domestic and international investors, as well as the presence of transport companies. In the long term, enhancing national management and fostering international collaboration with other globally recognized port-cities while addressing economic challenges and adapting to evolving trade networks, technological advancements, and social needs will likely shape the future spatial development of Bushehr port-city.

Based on the findings of this study, it can be concluded that the trend of spatial structure changes in the Bushehr port-city is similar to other port cities in the northern Gulf region and the Oman Sea, such as Bandar Abbas, Chabahar, Mahshahr, Abadan, Assaluyeh, and others. In the development of north ports, efforts have been made to address challenges arising from the increasing demand for trade and port services through the expansion of port facilities, such as advanced cargo handling and storage services, and the development of hinterland infrastructure, including road and air infrastructure, industrial and processing zones, and new ports and docks. Additionally, the northern ports of these two seas, which are located along the southern maritime borders of Iran, have a strategic advantage due to their geographic position and access to international hinterland areas, as well as their connection to the South-North transit corridors (linking China and India to Russia and Europe). Like other northern ports, this locational advantage has allowed Bushehr to adapt to global trends and align its functionality and facilities with contemporary global development. Extra notable point regarding the spatial structure changes of the northern Gulf and Oman Sea port cities is the similarity in how these ports interact with their associated cities. Although the most southern ports in the Gulf and the Oman Sea have sought to enhance the relationship between ports and cities through the integration of recreational tourism and residential land uses, thereby softening the spatial-functional disconnection between port and city, the northern port-cities of the Gulf and the Oman Sea continue to exhibit an evident lack of integration between the port and its dependent town and/or vice versa.

It is important to note that port cities in the Middle East may exhibit distinctive development patterns due to the influence of both endogenous and exogenous forces, potentially mirroring those observed in East Asian port cities. Future research is recommended to explore further the issues raised in this study, emphasizing the significance of urban governance and decision-making processes in driving spatial structural changes in Bushehr port-city. Additionally, various statistical methodologies are suggested for deciphering the structural changes in other Iranian port cities.

Author contributions: Conceptualization, MZ and FM; methodology, MZ and PS; software, MZ; formal analysis, MZ and ES; investigation, FM and PS; resources, MZ, FM, PS and SNA; data curation, MZ and ES; writing—original draft preparation, MZ, FM, SNA, PS and ES; writing—review and editing, FM and PS; visualization, MZ; supervision, MZ and FM; project administration, MZ, FM and SNA; funding acquisition, FM, PS, SNA and ES. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: We extend our gratitude to the anonymous reviewers for their insightful comments and constructive suggestions on our manuscript.

Conflict of interest: The authors declare no conflict of interest.

References

Abrishami, M., & Chamberlain, B. (2023). Comparing Transportation Metrics to Measure Accessibility to Community Amenities. Wichmann Verlag. https://doi.org/10.14627/537740037

Adnani, A. (2016). A Review on the Designing of Bushehr Port Commercial Center for Revitalization of its Past and History. Specialty Journal of Urban Planning and Development, 1(1), 1–8.

Ahmadi, R., Asemani, M., Hamidi, N., et al. (2024). Analyzing the relationship between place attachment and residential satisfaction through the mediation of social capital—the case of affordable housing. Journal of Housing and the Built Environment. https://doi.org/10.1007/s10901-024-10146-1

Ahmadi, R., Ghahremani, S., Kivi, S. B., et al. (2022). Investigating Social Factors of Residential Satisfaction and the Impact on Housing Price in Spontaneous Settlements in Tehran Fringe. Open Access Library Journal, 09(10), 1–21. https://doi.org/10.4236/oalib.1109176

Akhavan, M. (2017). Development dynamics of port-cities interface in the Arab Middle Eastern world—The case of Dubai global hub port-city. Cities, 60, 343–352. https://doi.org/10.1016/j.cities.2016.10.009

Asadzadeh, H., & Hatami, A. (2023). Future Study of Regional Spatial Structure in Iran (Horizon 2040). In: Urban and Transit Planning: City Planning: Urbanization and Circular Development. Cham: Springer International Publishing. pp. 81-92.

Bağdatlı, M. E. C., Akbıyıklı, R., & Papageorgiou, E. I. (2017). A Fuzzy Cognitive Map Approach Applied in Cost—Benefit Analysis for Highway Projects. International Journal of Fuzzy Systems, 19(5), 1512–1527. https://doi.org/10.1007/s40815-016-0252-3

Bakhtavar, E., Valipour, M., Yousefi, S., et al. (2021). Fuzzy cognitive maps in systems risk analysis: a comprehensive review. Complex & Intelligent Systems, 7(2), 621–637. https://doi.org/10.1007/s40747-020-00228-2

Bottasso, A., Conti, M., Ferrari, C., et al. (2014). Ports and regional development: A spatial analysis on a panel of European regions. Transportation Research Part A: Policy and Practice, 65, 44–55. https://doi.org/10.1016/j.tra.2014.04.006

Chang, W., Li, N., & Zhao, Y. (2024). Resilience of regional container port network: based on projection correlation and dynamic spatial Markov Chain. Maritime Policy & Management, 1–17. https://doi.org/10.1080/03088839.2024.2385846

Daamen, T. A., & Vries, I. (2013). Governing the European port–city interface: institutional impacts on spatial projects between city and port. Journal of Transport Geography, 27, 4–13. https://doi.org/10.1016/j.jtrangeo.2012.03.013

Dadashpoor, H., & Taheri, E. (2023a). The evolution of port-city relations in the era of technological development: case study of Bandar-Abbas County, Iran. GeoJournal, 88(3), 2423–2447. https://doi.org/10.1007/s10708-022-10752-y

Dadashpoor, H., & Taheri, E. (2023b). Port-city interface dynamics for the Bandar-Abbas port, Iran. GeoJournal, 88(5), 4645–4670. https://doi.org/10.1007/s10708-023-10828-3

Dadashpoor, H., Sheydayi, A., & Esmaeili, M. (2024). Perspectives on the Public Interest and Social Justice in Planning. Journal of Planning Education and Research. https://doi.org/10.1177/0739456x241237540

de Langen, P. W. (2006). Chapter 20 Stakeholders, Conflicting Interests and Governance in Port Clusters. In: Research in Transportation Economics. Science Direct. pp. 457–477.

Debrie, J., & Raimbault, N. (2016). The port-city relationships in two European inland ports: A geographical perspective on urban governance. Cities, 50, 180–187. https://doi.org/10.1016/j.cities.2015.10.004

Floor, W. (2014). Bushehr: Southern Gateway to Iran. In: Potter, L. G. (editor). The Persian Gulf in Modern Times: People, Ports, and History. Palgrave Macmillan US. pp. 173–197.

Guo, J., & Qin, Y. (2022). Coupling characteristics of coastal ports and urban network systems based on flow space theory: Empirical evidence from China. Habitat International, 126, 102624. https://doi.org/10.1016/j.habitatint.2022.102624

Hair, J. F., Hult, G. T. M., Ringle, C. M., et al. (2021). An Introduction to Structural Equation Modeling. In: Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook. Springer International Publishing. pp. 1–29.

Hamidi, N., Besharati Kivi, S., Ahmadi, R., et al. (2024). The mediating role of sense of place in relationship between localized social ties and residential satisfaction. Journal of Housing and the Built Environment, 1–22. https://doi.org/10.1007/s10901-024-10154-1

Hinne, M., Gronau, Q. F., van den Bergh, D., et al. (2020). A Conceptual Introduction to Bayesian Model Averaging. Advances in Methods and Practices in Psychological Science, 3(2), 200–215. https://doi.org/10.1177/2515245919898657

Infante-Moro, A., Infante-Moro, J. C., Gallardo-Pérez, J., et al. (2022). Key Factors in the Implementation of E-Proctoring in the Spanish University System. Sustainability, 14(13), 8112. https://doi.org/10.3390/su14138112

Kanellos, N., Terzi, M. C., Giannakopoulos, N. T., et al. (2024). The Economic Dynamics of Desktop and Mobile Customer Analytics in Advancing Digital Branding Strategies: Insights from the Agri-Food Industry. Sustainability, 16(14), 5845. https://doi.org/10.3390/su16145845

Kang, I., Lee, S., & Choi, J. (2004). Using fuzzy cognitive map for the relationship management in airline service. Expert Systems with Applications, 26(4), 545–555. https://doi.org/10.1016/j.eswa.2003.10.012

Kookhaie, T., & Masnavi, M. R. (2014). Environmental Design for Ecological Infrastructure of Urban Landscape through Aggregate with Outlier Principle (AWOP) in Order to Enhance the Quality of Urban Life; the Case of District Two, Tehran City. Journal of Environmental Studies, 40(3), 559–572.

Landherr, A., Friedl, B., & Heidemann, J. (2010). A Critical Review of Centrality Measures in Social Networks. Business & Information Systems Engineering, 2(6), 371–385. https://doi.org/10.1007/s12599-010-0127-3

Li, Z., Luan, W., Zhang, Z., et al. (2023). Research on the Interactive Relationship of Spatial Expansion between Estuarine and Coastal Port Cities. Land, 12(2), 371. https://doi.org/10.3390/land12020371

Lugo, I., & Martínez-Mekler, G. (2022). Theoretical study of the effect of ports in the formation of city systems. Journal of Shipping and Trade, 7(1). https://doi.org/10.1186/s41072-022-00117-6

Mansourihanis, O., Maghsoodi Tilaki, M. J., Yousefian, S., et al. (2023). A Computational Geospatial Approach to Assessing Land-Use Compatibility in Urban Planning. Land, 12(11), 2083. https://doi.org/10.3390/land12112083

Mansourihanis, O., Maghsoodi Tilaki, M. J., Kookhaei, T., et al. (2024). Integrating geospatial intelligence and spatio-temporal modeling for monitoring tourism-related carbon emissions in the United States. Management of Environmental Quality: An International Journal. https://doi.org/10.1108/meq-04-2024-0156

Mansourihanis, O., Maghsoodi Tilaki, M. J., Sheikhfarshi, S., et al. (2024b). Addressing Urban Management Challenges for Sustainable Development: Analyzing the Impact of Neighborhood Deprivation on Crime Distribution in Chicago. Societies, 14(8), 139. https://doi.org/10.3390/soc14080139

Meechang, K., & Watanabe, K. (2023). Modeling to Achieve Area Business Continuity Management Implementation via a Fuzzy Cognitive Map. Sustainability, 15(18), 13531. https://doi.org/10.3390/su151813531

Moeremans, B., Dooms, M., & Haezendonck, E. (2023). Long-term analysis of traffic flows in European inland ports: implications for the port-city interface. Maritime Economics & Logistics, 25(2), 272–300. https://doi.org/10.1057/s41278-022-00233-x

Mohammadi, A., Malakootian, M., Dobaradaran, S., et al. (2023). Determination and seasonal analysis of physicochemical characterization and metal(oid)s of landfill leachate in Bushehr port along the Persian Gulf. Toxin Reviews, 42(1), 161–175. https://doi.org/10.1080/15569543.2022.2027454

Mohimi, A., & Esmaeily, A. (2023). Spatiotemporal analysis of urban sprawl using a multi-technique approach and remote sensing satellite imagery from 1990 to 2020: Kerman/Iran. Environment, Development and Sustainability, 26(7), 18033–18068. https://doi.org/10.1007/s10668-023-03378-8

Norashida, S. R., Norshahira, O., & Lukman, Z. M. (2021). Content Validity of Drug Addiction Recovery Test Instruments Using Content Validity Ratio (CVR) Method. Journal of Drug Delivery and Therapeutics, 11(4), 24–29. https://doi.org/10.22270/jddt.v11i4.4949

Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecological Modelling, 176(1–2), 43–64. https://doi.org/10.1016/j.ecolmodel.2003.10.027

Potter, L. G. (2014). The Persian Gulf in Modern Times. Palgrave Macmillan US. https://doi.org/10.1057/9781137485779

Papageorgiou, E. I., Stylios, C., & Groumpos, P. P. (2006). Unsupervised learning techniques for fine-tuning fuzzy cognitive map causal links. International Journal of Human-Computer Studies, 64(8), 727–743. https://doi.org/10.1016/j.ijhcs.2006.02.009

Pérez, Y. F., Corona, C. C., & Estrada, A. F. (2019). Fuzzy Cognitive Maps for Evaluating Software Usability. In: Bello, R., Falcon, R., & Verdegay, J. L. (editors). Uncertainty Management with Fuzzy and Rough Sets: Recent Advances and Applications. Springer International Publishing. pp. 141–155.

Ports and Maritime Organization. (2023). Miscellaneous reports. Ports and Maritime Organization.

Rabiei-Dastjerdi, H. (2023). One Thousand and One Cities: Socio-Spatial Patterns and Challenges over a Half-Century of Urbanization in Iran. Middle East Critique, 32(4), 473–489. https://doi.org/10.1080/19436149.2023.2256144

Rossetto Ribeiro, R., & Beloto, G. E. (2021). Diagrams as a comparative tool to understand the territorial evolution of port city regions. European Planning Studies, 30(8), 1514–1528. https://doi.org/10.1080/09654313.2021.1935493

Salmeron, J. L., Mansouri, T., Moghadam, M. R. S., et al. (2019). Learning Fuzzy Cognitive Maps with modified asexual reproduction optimisation algorithm. Knowledge-Based Systems, 163, 723–735. https://doi.org/10.1016/j.knosys.2018.09.034

Schubert, D. (2020). Spatial Restructuring of Port Cities: Periods from Inclusion to Fragmentation and Re-integration of City and Port in Hamburg. In: Carpenter, A., Lozano, R. (editors). European Port Cities in Transition: Moving Towards More Sustainable Sea Transport Hubs. Springer International Publishing. pp. 109–126.

Singh, P. K., Papageorgiou, K., Chudasama, H., et al. (2019). Evaluating the Effectiveness of Climate Change Adaptations in the World's Largest Mangrove Ecosystem. Sustainability, 11(23), 6655. https://doi.org/10.3390/su11236655

Solak Fiskin, C. (2024). Inter-Port Evolutions and Prospects of Three Major Port Hubs in Europe: a Visualization Perspective Using Ternary Diagram Method. Applied Spatial Analysis and Policy, 17(2), 521–545. https://doi.org/10.1007/s12061-023-09553-8

Sztubecka, M., Skiba, M., Mrówczyńska, M., et al. (2020). Noise as a Factor of Green Areas Soundscape Creation. Sustainability, 12(3), 999. https://doi.org/10.3390/su12030999

Tayebeh, P., Gholamreza, J., Ali, S., & Jafarpour Ghalehteimouri, K. (2023). Introducing Creative City Factors as a Solution in Sustainable Urban Development: A Case Study from Bushehr City in Iran. Journal of Urban Culture Research, 26, 206–225. https://doi.org/10.14456/jucr.2023.12

Tsadiras, A., & Zitopoulos, G. (2017). Fuzzy cognitive maps as a decision support tool for container transport logistics. Evolving Systems, 8(1), 19–33. https://doi.org/10.1007/s12530-016-9161-9

Yan, J., Xiao, R., Su, F., et al. (2021). Impact of Port Construction on the Spatial Pattern of Land Use in Coastal Zones Based on CLDI and LUT Models: A Case Study of Qingdao and Yantai. Remote Sensing, 13(16), 3110. https://doi.org/10.3390/rs13163110

Zarei, M., Arasteh, M., & Shahab, S. (2024). Exploring Port-City Relationships: A Bibliometric and Content Analysis. Sustainability, 16(11), 4341. https://doi.org/10.3390/su16114341