The Role of Improving the Infrastructure of multimodal transport to enhance the Efficiency of seaports using Interpretive Structural Modeling.

(Case study Damietta port)

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1. **ABSTRACT:** This study investigates the role of improving the infrastructure of multimodal transport in enhancing the efficiency of seaports, with a specific focus on Damietta Port. The purpose of the research is to assess how strategic enhancements to multimodal transport infrastructure can contribute to increased efficiency in port operations. The methodology employed is Interpretive Structural Modeling (ISM), which enables a comprehensive understanding of the interrelationships among different elements within the multimodal transport system and their impact on port efficiency. Through the analysis of Damietta Port as a case study, this research aims to provide valuable insights into the critical factors and their hierarchical relationships within the multimodal transport infrastructure that influence port efficiency. The findings of this study can inform strategic decision-making processes for port authorities, policymakers, and stakeholders involved in the development and optimization of port facilities and their associated transport networks.

2. INTRODUCTION

Damietta Port, situated on the Mediterranean Sea in northern Egypt, is a vital trade hub and a prime example of a port embracing multimodal transport. It's not just a shipping terminal; it's a gateway connecting Egypt to the world through a seamless blend of maritime, land, and river transportation. Situated about 23 nautical miles north of the Suez Canal entrance, Damietta strategically benefits from the massive traffic passing through this vital waterway. Its proximity to major trade routes further enhances its significance as a regional logistics center.

The port boasts 13 versatile berths catering to various vessel types and cargo, including containerized goods, general cargo, and bulk liquids. An extensive road network of over 22 kilometers connects the port directly to the international coastal highway, facilitating swift inland cargo movement. A dedicated 19-kilometer railway network ensures efficient cargo transportation within the port and beyond. A dedicated river terminal with a 340-meter berth and a 5-meter draft leverages the Nile River for inland cargo transportation, promoting cost- effective and sustainable logistics. Although Damietta Port earned recognition for its multimodal potential in 2021, its journey is far from over. Capitalizing on its geographic, environmental, and infrastructural advantages, the port should prioritize intensifying and optimizing its multimodal links to truly cement its position as a leading multimodal hub.The results of the analysis highlighted that Railway network expansion and modernization,Crane efficiency and capacity upgrades are the most significant barriers hindering application of Improving the Infrastructure of multimodal transport to increase the Efficiency of sea ports which are found to have the highest driving power.

3. LITERATURE REVIEW

3.1 *Railway network expansion and modernization*

Port-rail connectivity is crucial for economic and competitive port development, aiming to mitigate negative impacts on people and the environment while enhancing competitiveness. For effective port expansion, integration with rail connectivity is essential. This connection spatially links dispersed processes, expanding the port's hinterland and its capacity for capturing new value-added goods and services. Railway systems are part of critical infrastructures and the main backbone of economic development in every country.

The positive correlation between rail connectivity and increased port throughput is underscored by studies ,advanced technologies facilitate better logistics performance through reengineering transport routes, scale, modes, or frequencies,conducted by and Song et al. (2018) railways significantly influence port performance, improving efficiency, throughput, and overall competitiveness (Munim & Schramm, 2018). They provide efficient and cost- effective inland transportation for cargo destined for ports, leading to higher cargo volumes handled. Railways extend a port's catchment area, connecting it to inland markets and production centers, enhancing cargo diversification and strengthening the port's position in regional trade networks.Additionally, rail transportation helps alleviate pressure on port facilities by diverting cargo away from congested roads, thereby improving overall operational efficiency (Wang & Zhao, 2017). Effective rail-port integration facilitates seamless cargo transfer between modes, reducing handling times and minimizing delays, as emphasized by Wang et al. (2019).

3.2 *Connecting all seaports directly to railway lines*

Efficient railway connectivity is vital for seaports to expand hinterland access, augment trade volumes, improve multimodal efficiency, and strengthen competitiveness (Hayuth & Wiens, 2015). Direct rail links from ports enable swift transportation of containers to inland destinations at economical rates compared to road or air (Song et al., 2018). This supports growth in port container throughput and attraction of international shipping lines. Tight port-rail integration allows seamless transfer of cargo between ships and trains, avoiding added handling steps or delays (Wang et al., 2019). Furthermore, enhanced inland connectivity facilitates access to remote inland regions, notably important manufacturing and commercial hubs. Strategic investments in dedicated freight routes and terminals directly benefit port traffic by alleviating capacity and network limitations. Robust railway connectivity broadens seaport landside access and fosters sustainable port regionalization (Munim & Schramm, 2018).

2.3 Warehouse and container yard capacity expansion

The Effect of Improved Warehouse and Container Yard Capacity Expansion on Port Performance. Expanding warehouse and container yard capacity at ports significantly influences performance by impacting various aspects of cargo flow and efficiency. Larger warehouse and container yard capacity allows for handling more cargo simultaneously, leading to higher volumes processed through the port (Song et al., 2018). This can attract more shipping lines and boost the port's competitiveness. Improved storage space alleviates pressure on berths and quays, minimizing wait times for ships and optimizing utilization of port infrastructure (Wang & Zhao, 2017). This can improve overall port productivity and responsiveness. Increased capacity opens doors for offering value-added services like cargo consolidation, sorting, and labeling, attracting a wider range of customers and generating additional revenue streams (Liu & Ng, 2013). Increased port performance through capacity expansion can stimulate regional economic growth by generating jobs, attracting investments, and supporting trade facilitation (Hayuth & Wiens, 2015).

3.3 *Developing railway networks to contribute to reducing dependence on traditional land transportation.*

Expanding and upgrading railway infrastructure can serve as a strategic alternative to traditional road transport, alleviating pressure on congested highways and reducing environmental externalities associated with trucking (Wang & Zhao, 2017). High-capacity, efficient rail networks provide cost-effective transportation options for inland cargo movement between ports and internal production centers. Integrating rail transport more tightly within port operations and multimodal logistics networks facilitates a modal shift that promises economic competitiveness as well as climate resilience.

2.5 *River transport infrastructure upgrades (including Nile River utilization).*

Improved river transport, especially in regions with well-developed waterways, is gaining importance. It provides a cost-effective, eco-friendly option for bulky cargo, expanding port catchment areas and increasing volumes. Research in the Yangtze River basin (Zhang et al., 2020) shows a positive link between enhanced river transport and container port throughput. Diverting cargo to waterways, supported by Cullinane et al. (2012) and Rodrigue et al. (2013), eases port congestion. Effective river-port integration, like rail-port, reduces handling times (Wang et al., 2019). It typically has lower emissions and noise pollution, contributing to supply chain sustainability (Wang & Zhao, 2017). In international supply chains, inland port systems, especially riverports, are essential. They serve as inland load centers linked to seaports, marking a shift from a single seaport to a combined seaport and inland port system (Wiegmans et al., 2015). This is crucial for understanding port geography, diversification, and the evolving focus of the transport industry towards inland areas (Rodrigue and Notteboom, 2011).

2.6 *Inland waterway utilization for regional cargo movement.*

Leveraging extensive river networks and inland waterway systems enables efficient, environmentally friendly regional freight distribution connecting ports, industrial clusters, and urban populations (Rodrigue et al., 2013). Waterborne transportation of bulk and containerized goods along major rivers and canal networks helps alleviate highway and railway capacity constraints. Smooth integration of inland waterway transport with seaports, railroads, warehouses, and pipelines fosters seamless door-to-door cargo delivery, positioning river logistics as an essential component of competitive regional supply chains.The multimodal transport network is a complex network made up of several transport agents, including nodes, edges, and transshipment nodes. When network risk impacts a node, the node's resistance absorbs some of the risk. When it surpasses the node's safety threshold, it fails (He et al., 2019).

2.7 *Port access and road connectivity improvements*

Improved port access and road connectivity play a crucial role in enhancing port performance Song et al. (2018) indicating a positive correlation between road accessibility and port throughput. The implementation of better access routes and wider roads facilitates a faster and smoother flow of trucks and cargo, potentially leading to increased handling volumes. This efficiency extends beyond the immediate port area, strengthening regional trade networks and tapping into new markets inland, as highlighted by Liu & Ng (2013). Overall, strategically improving access and connectivity not only optimizes port operations but also serves as a powerful tool for economic growth, boosting trade volumes and promoting regional trade networks. The coordinated operation of numerous modes of transportation facilitates cargo movement, but there are several significant issues that have gradually drawn the attention of the government and the general public. Once a link in a multimodal transport network is disrupted to cause the infrastructure to malfunction, the impact of this failure will spread throughout the network along with the flow of cargo, resulting in cascading failure, affecting the normal operation of the part or even the entire multimodal transport network (Guo et al., 2021).

2.8 *Crane efficiency and capacity upgrades*

Efficient and high-capacity cranes are pivotal for modern ports, and upgrading their technology and capacity is essential for enhancing overall port performance in the context of multimodal transport. In the race for economies of scale in maritime transport, securing hinterland access becomes paramount for ports' competitiveness, aligning with the concept of port regionalization. Upgraded cranes not only enable faster loading and unloading, increasing containers handled per hour and improving port throughput, but also attract larger vessels and more shipping lines. This efficiency minimizes waiting times, reduces congestion, and optimizes quay space usage, leading to faster turnaround times and smoother cargo flow. Advanced automation and precision capabilities of modern cranes broaden the port's service offerings, attracting a diverse customer base and facilitating seamless transfers between different transport modes. This increased efficiency not only lowers operational costs for the port but can also potentially result in reduced freight rates for shippers, benefiting all stakeholders in the multimodal transport chain (Song et al., 2018; Wang & Zhao, 2017; Liu & Ng, 2013; Hayuth & Wiens, 2015).

2.9 *Short Sea shipping connections to regional and international ports*

Short sea shipping (SSS) provides a cost-effective and eco-friendly alternative for short- distance cargo, attracting diverse goods and potentially increasing overall port volume. Shifting cargo to SSS reduces pressure on landside infrastructure, leading to freer space, smoother operations, and quicker ship turnaround times, especially during peak seasons or for specialized cargo, according to Wang & Zhao (2017). Connecting ports to smaller regional ports and inland markets, SSS extends a port's reach, solidifying its position in regional trade networks and opening doors to a wider customer base (Liu & Ng, 2013). Facilitating seamless cargo transfer between ships, trucks, and other transport modes, SSS streamlines intermodal transport processes, minimizing handling times and enhancing overall logistics performance, supported by Wang et al. (2019). Notably, SSS boasts lower greenhouse gas emissions and noise pollution compared to other modes, aligning with sustainable supply chain practices emphasized by Zhang et al. (2020). Strategic implementation and effective management of SSS connections can unlock opportunities, boosting port performance, trade volumes, sustainability, and contributing to regional economic growth.

4. METHODOLOGY

The basic objective of this study is to assess the contribution of improve multimodal transport of maritime port to enhance the Efficiency of seaports. To meet this objective, the following research methodology was followed while conducting the research.

In this research, a qualitative and quantitative research approach was used to study improve multimodal transport of maritime port to performance of Damietta port, which was intended for a reliable, efficient, and convenient transportation system for customers under one invoice and one responsibility. Its aim was to evaluate the improve multimodal transport of maritime port to performance and efficiency of seaports.

A quantitative approach was used to collect data from the secondary source of the Logistics Performance Index report. A qualitative approach was used to collect data from primary sources from the target population. Accordingly, the purposes of the research were to verify and evaluate the contribution, and then the researcher used a descriptive research design because it focuses on answering the basic research question, which is, the extent to which logistical activities contribute to the operation of multimodal transport.

The mixed research approach is defined as the incorporation of various qualitative and quantitative data collection and analysis methods into a single research project. By connecting complementary findings, the combination of both methods allows the researcher to gain a complete picture and a deeper understanding of the phenomenon under investigation.

The Delphi method was used by the researcher because it is a qualitative method. In this regard, data collection was used through previous research and interviews to identify the problem, which revealed that there is a problem , which is the weakness Infrastructure of multimodal transport, as well as the most significant causes of this problem, a quantitative method was used to determine the effect of these factors on the problem, as well as their effect on each other, in order to find a solution to this problem through the use of (ISM).

The distinctness of mixed methods the goal of research studies is to combine methods, establish a priority for each methodology within a study, and the order in which each methodology is used, including complementarity, confirmation, and development (Saracho, 2016).

3.1 *The Delphi Method*

The Delphi method is a structured communication technique used to gather and refine the knowledge of a group of experts on a specific topic. Imagine it as a collective brainstorming session held over multiple rounds, conducted anonymously and iteratively, to gradually converge on informed consensus. A facilitator poses a complex question or issue requiring expert input. Participants, carefully chosen for their knowledge and experience, anonymously submit their initial thoughts and estimates. The facilitator summarizes the diverse responses, highlighting key points and areas of disagreement. Participants receive this summary along with the opportunity to revise their own estimations or perspectives based on the collective wisdom.

This iterative process of anonymous feedback, reflection, and revision continues through multiple rounds until a stable consensus or convergence of opinions emerges. By drawing on the diverse expertise of a group, the Delphi method can uncover insights that might elude individual experts.

3.2 *Applying ISM to Damietta Port Performance:*

Numerous Barriers to were listed and discussed individually in the previous, these barriers will be analyzed using the ISM methodology in this chapter in order to visualize the interrelationships and different levels of the identified barriers. In addition, a classification of those factors will be provided based on their driving and dependence power on one another. (In this regard, the primary goals of the analysis are to first identify and rank the Barriers facing the development of infrastructure for multimodal transport to increase the efficiency of Damietta Sea port.

Poduval et al., (2015) explained and summarised the numerous processes in the ISM technique into eight steps, as follows:

First, identify the factors that influence the system under study and are important to the problem. These factors may include goals, behaviours, and people, among other things.

Second stage: Determine the contextual link between the variables in terms of which pairs of items will be studied using the variables indicated in the first step.

3rd step: Generate a structural self-interaction matrix (SSIM) for variables that depicts the pairwise relationship between variables in the system under investigation.

4th step: Using the SSIM, generate a reachability matrix and test it for transitivity. The transitivity of the contextual relation is a basic assumption of ISM. It asserts that if one variable "A" is related to another variable "B," and "B" is related to "C," "A" must also be related to "C."

Fifth step: Divide the reachability matrix acquired in step four into multiple levels.

6th step: Create a directed graph based on the relationships in the reachability matrix and eliminate any transitive linkages.

7th step: Replace the element nodes with statements to transform the directed graph into an ISM-based model.

8th step: Check the model for conceptual errors and make any necessary adjustments.

3.2.1 *Interpretive Structural Modelling Analysis*

The ISM analysis adheres in the following steps .

Step 1: Define the Elements:

A literature review and reports, as well as semi-structured interviews with experts, farmers, and exporters, have yielded a list of 9 barriers to the implementation of Barriers facing the development of infrastructure for multimodal transport in Damietta port.

Table 1. Identification Barriers facing the development of infrastructure for multimodal transport in Damietta port.

M	Identification Barriers facing the development of infrastructure for multimodal transport
	in Damietta port.
1.	Railway network expansion and modernization
2.	Connecting all seaports directly to railway lines
3.	Warehouse and container yard capacity expansion
4.	Developing railway networks to contribute to reducing dependence on traditional land
	transportation

5.	**River transport infrastructure upgrades (including Nile River utilization)**
6.	**Inland waterway utilization for regional cargo movement**
7.	**Port access and road connectivity improvements**
8.	**Crane efficiency and capacity upgrades**
9.	**Short sea shipping connections to regional and international ports**

Step 2: Establish Relationships:

To create the Structural Self Interaction Matrix (SSIM) with contextual relationships of types “leads to” across barriers, a set of closed-ended questions were created using input from academic and field experts. To indicate the direction of the relationship between the factors I and j), the following four symbols are used:

- V: barrier i will lead to barrier j;
- A: barrier j will lead to barrier i;
- X: barriers i and j will lead to each other; and
- O: barriers i and j are unrelated.

Table 2. Structural self-interaction matrix (SSIM).

M	Barriers	9	8	7	6	5	4	3	2
1.	Railway network expansion and modernization	X	A	O	O	X	X	X	X
2.	Rail-water intermodal connections (e.g., Nile-port integration)	X	X	X	V	X	A	V	
3.	Warehouse and container yard capacity expansion	V	X	X	X	X	X		
4.	Road-rail intermodal connections	V	A	O	X	X			
5.	River transport infrastructure upgrades (including Nile River utilization)	V	A	O	O				
6.	Inland waterway utilization for regional cargo movement	V	A	X					
7.	Port access and road connectivity improvements	X	V						
8.	Crane efficiency and capacity upgrades	A							
9.	Short sea shipping connections to regional and international ports								

Source: Authors' own development based on (J. et al., 2017).

The following example show how to use the symbols V, A, X, and O in the SSIM:

Barrier (1) Railway network expansion and modernization leads to Barrier (2) Connecting all seaports directly to railway lines. Thus, the relationship between Barriers (1) and (2) is denoted by 'X' in the SSIM.

Step 3: Build the Reachability Matrix:

Construct a matrix with elements as rows and columns. Mark cells where element A directly influences element B (A → B).

Calculate the reachability levels of each element by summing the marks in its row and column (direct influences received and given).

In this step, the SSIM is converted into a binary matrix (called the initial reachability matrix) by substituting V, A, X, and O by 1 or 0. The rules of substitution of 1s and 0s are as follows: If the SSIM (I, j) entry is V, the reachability matrix (I, j) entry becomes 1.

If the SSIM (I, j) entry is A, the reachability matrix (I, j) entry becomes 0. If the SSIM (I, j) entry is X, the reachability matrix (I, j) entry becomes 1. If the SSIM (I, j) entry is A, the reachability matrix (I, j) entry becomes 0.

According to these rules, the initial reachability matrix for the barriers is shown in Table (4)

Table 3. Initial reachability matrix

Barriers	1	2	3	4	5	6	7	8	9
1.	1	1	1	1	1	0	0	0	1
2.	1	1	1	0	1	1	1	1	1
3.	1	0	1	1	1	1	1	1	1
4.	1	1	1	1	1	1	0	0	1
5.	1	1	1	1	1	0	0	0	1
6.	0	0	1	1	0	1	1	0	1
7.	0	1	1	0	0	1	1	1	1
8.	1	1	1	1	0	0	0	1	0
9.	1	1	0	0	1	1	1	1	1

Source: Authors' own development based on (J. et al., 2017)

As explained in step four of the ISM methodology, the final reachability matrix in Table 4 is obtained by adding transitivity1. Each barrier's driving power and dependence are also displayed.

Table 4. Final reachability matrix.

Barriers	1	2	3	4	5	6	7	8	9	Driving Power
1.	1*	1	1	1	1	0	0	0	1	6
2.	1	1	1	0	1	1	1	1	1	8
3.	1*	0	1*	1	1	1	1	1	1*	8
4.	1	1	1	1	1	1	0	0	1	7
5.	1	1	1	1	1	0	0	0	1	6
6.	0	0	1	1	0	1	1	0	1	5
7.	0	1	1	0	0	1	1	1	1	6
8.	1*	1	1	1	0	0	0	1	0	5
9.	1	1	0	0	1	1*	1	1	1	7
Dependence power	**7**	**7**	**8**	**6**	**6**	**6**	**5**	**5**	**8**	**58/58**

Source: Authors' own development based on (J. et al., 2017)

The total number of barriers influenced by a specific barrier, including itself, is referred to as its driving power. The total number of barriers, including itself, that can influence a specific barrier is defined as its dependence.

In the Driver-Dependence diagram, the driving power and dependencies shown in Table 4 will be used to classify barriers into four groups: autonomous, dependent, linkage, and independent (driver).

Step 4: Clustering and Model Interpretation:

The reachability set and antecedent set for each barrier are determined using the final reachability matrix. The reachability of a barrier includes the barrier itself as well as the other barriers influenced by it.

The barrier for which the reachability and intersection sets overlap is assigned as a top-level barrier in the ISM hierarchy or Level 1, as shown in Table (5).

As shown in Table (5), the barrier for which the reachability and intersection sets overlap is designated as a top-level barrier in the ISM hierarchy, or Level 1.

Group elements with similar reachability levels into clusters. Analyze these clusters to understand:

Driving Elements: Elements with high driving power (high sum of rows) significantly affect others.

Dependent Elements: Elements with high dependence (high sum of columns) are heavily influenced by others.

Feedback Loops: Identify cycles of mutual influence between elements.

Table 5. Iterations summary

Factors	Reachability set	Antecedent set	Intersection set	Level
1.	1,2,3,4,5,9	1,2,3,4,5,8,9	1,2,3,4,5,9	**Level 5**
2.	1,2,3,4,5,6,7,8,9	1,2,4,5,7,8,9	1,2,5,7,8,9	**Level 2**
3.	1,3,4,5,6,7,8,9	1,2,3,4,5,6,7,8	3,4,5,6,7,8	**Level 1**
4.	1,2,3,4,5,6,9	1,3,4,5,6,8	1,3,4,5,6	**Level 3**
5.	1,2,5,7,10	3,4,5,6,8,9,11	5	**Level 3**
6.	3,4,6,7,9	2,3,4,6,7,9	3,4,6,7,9	**Level 4**
7.	2,3,6,7,8,9	2,3,6,7,9	2,3,6,7,9	**Level 4**
8.	1,2,3,4,8	2,3,7,8,9	2,3,8	**Level 5**
9.	**1,2,5,6,7,8,9**	**1,2,3,4,5,6,7,9**	**1,2,5,6,7,9**	**Level 2**

Source: Authors' own development based on (J. et al., 2017).

[1](1*) means value after applying transitivity.

Transitivity was calculated by using the web-based program http://www.cs.nmsu.edu/~ipivkina/TransClosure/ .

Level 1 is then removed from the remaining barriers, and the iterative procedure is repeated until no further levels are found. The five identified levels in Table (5) contribute to the development of the ISM model.

The partitioned reachability matrix is used to build the conical matrix in Table (6) by rearranging the factors according to their levels, which means that factors with the same levels are clustered together.

Table 6. Conical Matrix

Clustered level	*Factors*	*3*	*2*	*9*	*4*	*5*	*6*	*7*	*1*	*8*
Level 1	*3*	*1*	*0*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
	2	*1*	*1*	*1*	*0*	*1*	*1*	*1*	*1*	*1*
Level 2	*9*	*0*	*1*	*1*	*0*	*1*	*1*	*1*	*1*	*1*
	4	*1*	*1*	*1*	*1*	*1*	*1*	*0*	*1*	*0*
Level 3	*5*	*1*	*1*	*1*	*1*	*1*	*0*	*0*	*1*	*0*
Level 4	*6*	*1*	*0*	*1*	*1*	*0*	*1*	*1*	*0*	*0*
	7	*1*	*1*	*1*	*0*	*0*	*1*	*1*	*0*	*1*
Level 5	*1*	*1*	*1*	*1*	*1*	*1*	*0*	*0*	*1*	*0*
	8	*1*	*1*	*0*	*1*	*0*	*0*	*0*	*1*	*1*

Source: Authors' own development based on (J. et al., 2017)

Step 5: ISM-based Model

The conical matrix helps in the construction of the structural model from the initial direct relation graph . As a result, after removing the transitive links as described in the ISM methodology, the diagraph is finally converted into the ISM model by replacing nodes with statements, as illustrated in Figure 1 below.

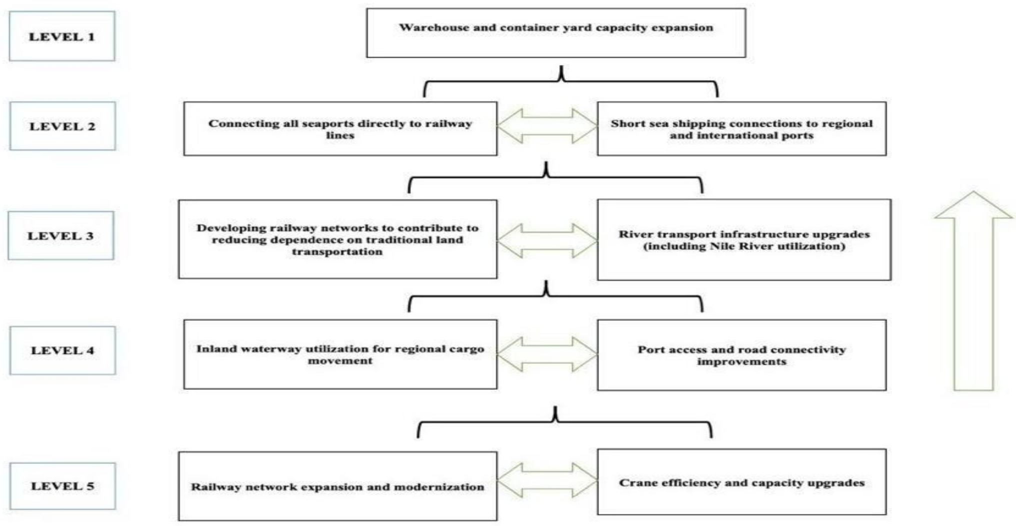

Figure 1. ISM-based model for barriers

A list of the 9 identified Factors. Factors are partitioned into five levels, with level one located at the bottom of the figure (the highest driving power). The direction of the arrow indicates the influence across barriers.

The ISM-based model indicates that Factor (1) – on level 1 ,has the lowest driving power, and it is strongly dependent on the rest of barriers.

The remaining barriers are divided into levels as follows:

Level 2 consists of two Factors: (Factor 2); Connecting all sea ports directly to railway lines

,(Factor 9); Short sea shipping connections to regional and international ports

Level 3 consists of two Factors: (Factor 4); Developing railway networks to contribute to reducing dependence on traditional land transportation, (Factor 5); River transport infrastructure upgrades (including Nile River utilization)

Level 4 consists of two Factors: (Factor 6); Inland waterway utilization for regional cargo movement (Factor 7); Port access and road connectivity improvements.

Level 5 consists of two Factors: (Factor 1); Railway network expansion and modernization (Factor 8); Crane efficiency and capacity upgrades, is very significant

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Factor hindering the application of development of infrastructure for multimodal transport in Damietta port. this barrier forms the bottom Level 5, as this barrier have the highest driving power and the lowest dependence on the rest of the barriers.

Step 6 : Classification of Barriers: MICMAC Analysis

The purpose of the cross-impact matrix multiplication applied to classification, which is known as (MICMAC)2, is to analyse the drive power and dependence power of barriers. The analysis principle is based on the multiplication properties of matrices. Based on the driving power and dependence power, the barriers have been classified into four categories (Attri et al., 2013, p. 7).

Autonomous Barriers: These barriers have weak driving power as well as week dependence. **Linkage Barriers:** These barriers have strong driving power as well as strong dependence. They are considered as unstable because any action on these barriers will affect other barriers and result in a feedback effect on themselves.

Dependent Barriers: These barriers have weak driving power but strong dependence.

Driver Barriers: These barriers have strong driving power but weak dependence. The drive-dependence diagram presented in Figure (2) gives a clear picture of the relative importance as well as the interdependencies among the different barriers. The vertical axis reflects the driving power of factors; the horizontal axis reflects their dependence power

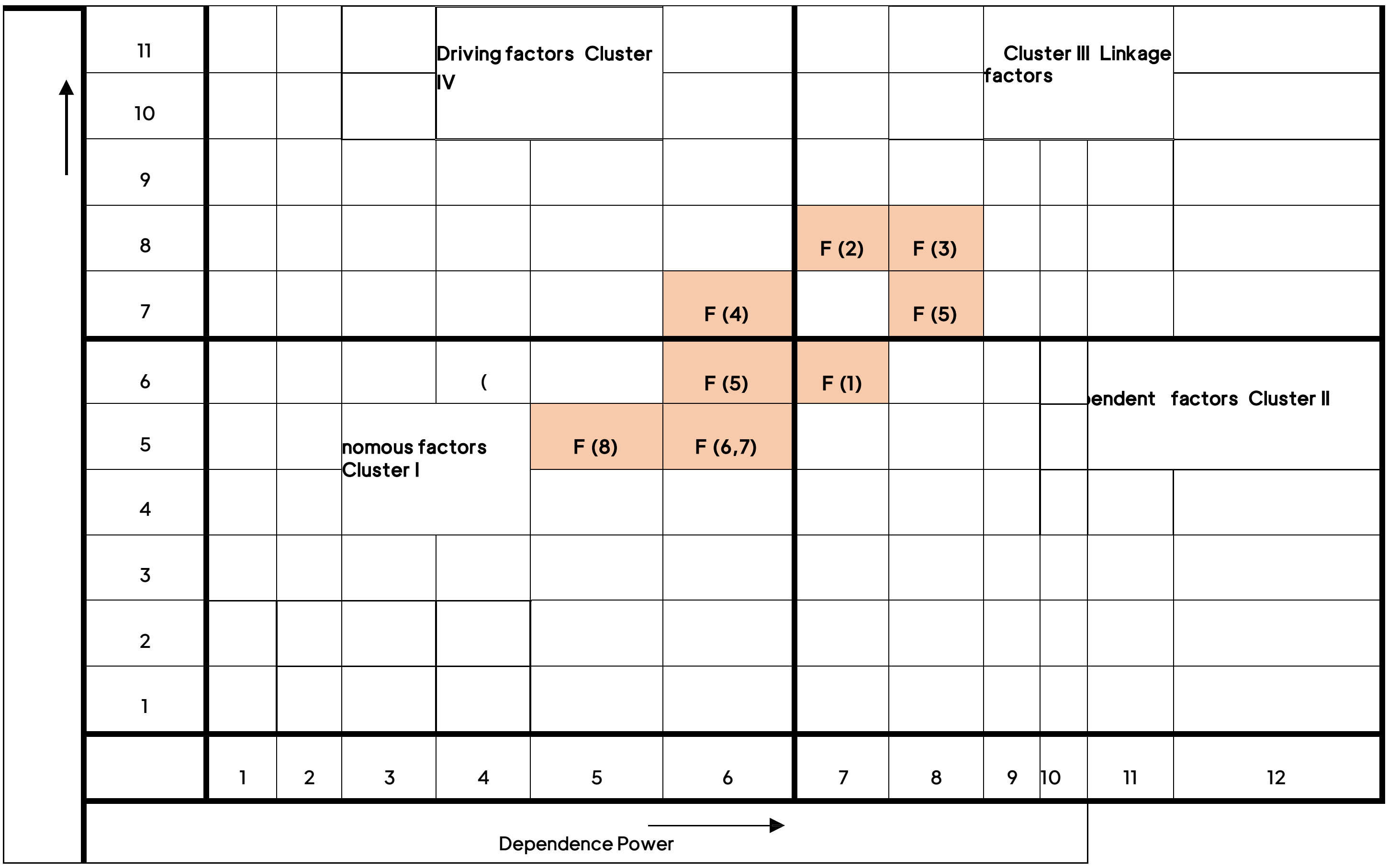

Figure 2. Drive-dependence diagram. Source: Authors' own development based on (J. et al., 2017)

In the MICMAC analysis Figure (2), neither autonomous nor linkage barriers are found. The non-existence of autonomous barriers implies that all the identified barriers affect Improving the Infrastructure of multimodal transport to enhance the Efficiency of seaports. In addition, the absence of linkage factors under the linkage group implies that no barriers are considered unstable and all of them are either driving or dependent barriers. The dependent barriers have week driving power, but they are highly dependent on the driving barriers. According to the analysis, five barriers are dependent and represent the undesirable outcome of the four driving barriers .

4. CONCLUSIONS

This research employs the interpretive structural modeling (ISM) approach, a multi-criteria decision making (MCDM) technique, to elucidate the most salient barriers hindering improvements to multimodal transport infrastructure for enhancing seaport efficiency. Based on an extensive literature review and expert opinions, nine salient factors were identified that significantly influence the implementation of multimodal infrastructure upgrades at seaports. Using an ISM-based modeling methodology, the interrelationships between these variables are systematically analyzed to determine the degree of dependence and driving power of each factor.

The results indicate that railway network expansion and modernization along with crane efficiency and capacity upgrades exhibit the highest driving power among the identified barriers. These two factors display significant dependence that hinders the application of multimodal infrastructure improvements at seaports. From the methodical structural analysis, railway and crane infrastructure limitations surface as prime candidates for priority interventions by port authorities to unlock substantial efficiency gains.

By addressing these high-impact barriers, investments in supplementary multimodal transport integration and seaport infrastructure improvement programs can be translated into discernible productivity and competitiveness gains.

The research framework and empirical analysis provides crucial insights to guide policies and development initiatives focused on seaport infrastructure upgrading for long-term viability amid intensifying maritime trade competition.

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