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Applying multi-criteria analysis in a port system

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Abstract

This work presents a study developed in a medium port system composed of 50 public and private actors interacting with their macro-environment, which can generate strategic synergistic relationships. In order to determine these synergistic links between their components, the strategic phrases contained in their missions are analysed and classified according to the multi-criteria that are part of the macro-environment of each port actor: political, economic, social, technological, environmental, risk and learning. Likewise, new characterizations and classifications are proposed for groups and sub-groups of port actors. From absolute frequencies, Contingency Tables and the Chi-square test, quantitative results are obtained, which show the potential cases of strategic synergistic relations in the port system and the behavior of each group and sub-group of actors, as well as dependence / independence between every pair of criteria. Finally, it is verified that it is possible to use quantitative methods to analyze the strategic synergistic relationships between the actors of the port system.

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Keywords: Multi-criteria; strategic information; statistical analysis; Port System

1. Introduction

A publicly owned port is understood as a complex system and, at the same time, a mixed network interacting with a suitable degree of synergy, becoming more competitive at a global level. The network is coordinated by a Port Community comprising a Port Authority and actors from the Terminals who, by law, manage strategic purposes and actions with the remaining public and private actors interacting with it [1-2-3]. The Port Community makes strategic decisions that affect business and operational relationships it holds with other actors who interact and integrate the port system, as those private enterprises providing services to the export and import logistics chains, trade associations, social groups and public components that play a regulatory role [3-4].

Furthermore, the port business is subject to frequent changes coming from the macro-environment, which may not be part of the annual Strategic Planning devised by the Port Authority and the State. The interaction with

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political, economical, social, technological, environmental, risk and learning multi-criteria, exogenous to the port industry, generates uncertainty in the management and development of port activities [3-5-6-7].

Concerning the research done and focused on ports, it should be pointed out that between 2005 and 2009 most publications deal with a conceptual analysis in fields like Economics, Geography and Research of Operations and a low percentage of studies are focused on statistical analysis in port organizations [8]. Likewise, varied authors have explored different attributes of the above multi-criteria: previous works have confirmed the existence of strategic synergy between politics and technology because of a relationship of slightly inverse dependence between them [1]. Applying both the Matrix of Eigenvalues and the Matrix of Pearson Correlation, existing synergic relationships between two port actors were explored [9]. The impact of the economic aspect in a port was examined by using the Solow model and the econometric analysis [10]. The cluster analysis was used to study the relationship between the economic and the environmental aspects of a Spanish port system, where the relationship between both aspects was determined [11].

In a qualitative way, an inverse correlation between the agglomeration of actors and the financial results was also determined [12]. In addition, the pressures on the Port Authority were studied. They can be economic, produced by market influence; public, coming from the government; and social tension, caused by negative external issues due to port development [13]. In relation to technology, there is a link with the strategic need to develop ICT; as for knowledge, the actors of the Port Community have a relational or commercial capital when dealing with providers/clients but require structural capital from other enterprises in order to develop new technologies [14]. It is concluded that external political, social and technological factors neither always show any coherence, nor take the same direction [13].

Other studies state that the multi-criteria of the micro-environment can present synergic relationships between them; however, it is noticed that it is difficult to generate technological synergy in terms of innovation when there is intervention of political aspects [15]. With regard to the economic aspect, it is linked to a network of actors under risk, which, consequently, may affect profitability [16]; in relation to the information and knowledge shared through the green social network, it is linked to the sustainable development of an industry [17]. Thus, in ports, we can find synergy among logistics, urban economy, environmental protection, government laws and policies [18].

Based on the qualitative data from the available strategic information [1], a statistical analysis was performed using Contingency Tables [19] and the Chi-square test [20] of independence to identify eventual synergy relationships quantitatively between the 50 actors who comprise the port system and the political, economic, social, technological and environmental multi-criteria. As a result, it was determined that in those cases where the application conditions of the statistical tests are met, there is a low amount of strategic synergistic relationships, and a slightly inverse relationship between the political and technological criteria. In this research paper that study has been expanded and two additional criteria have been incorporated: risk and learning. It is a descriptive study on the presence of synergy in the multi-criteria, and the strategic attributes found in the mission statements of each port actor have been determined.

2. Multi-criteria of the Port System

2.1. Determining the strategic criteria

The Chilean port system comprises 50 private and public actors (including a private non-profit enterprise) who individually declare their mission statements as an expression of strategic purpose which may be the outcome of the Strategic Plan declared to achieve a leading level in a complex system [1-3-8]. As presented in Table 1, for each strategic purpose a relationship with the macro-environment can be determined which can be classified as a specific criterion: political, economic, social, technological, environmental, risk and learning [1-

3-8]. Learning is identified when there are strategic statements that imply leadership, cultural aspects or generate knowledge.

Table 1. Multi-criteria in strategic purposes in the Port System

Actor	Strategic purpose of a port actor	Multi-criteria of The Ambience
3. Port Authority	Ensure the provision of Port Services to the logistics chain, investors and citizens with efficient and timely solutions, in a framework of permanent innovation and sustainable development.	Economic Social Technological Environmental Risk
...	…	…
12. Shipping Carrier	…transport service of physical goods by sea.	Risk
…	…	…
34. General Directorate of Public Works	Guide, coordinate and supervise the management of public infrastructure works and services... in order to ensure competition, transparency and efficiency in compliance with the policies and objectives of the Ministry of Public Works.	Political Economic Technological
…	…	…
50.Regional Health Department	Improve and protect the health of people, families and the community of the Region through actions that encourage sectorial and intersectoral work, as well as citizen involvement.	Social

It should be noted that the results have been validated by expert's opinion-executives from two relevant ports [1-3-8].

3. Analysis of eventual relationships between multi-criteria in the port system

3.1. Absolute frequency of the groups of actors

Figure 1 shows the classification of actors according to capital property. Private enterprises own private capital, whereas, the capital belongs to the State in the case of public components. Then, they are subdivided according to: the destination of their surplus (profit and non-profit), their position in the value chain (primary / support activities), and their group level (the Logistics Forum brings together private enterprises and public components).

In the case of associations, there are those that defend labour interests (social groups or unions) and those that promote the rationalization, development and protection of activities that are common to them (trade associations).

Each private and public actor can be classified under the attributes or multi-criteria: political (P), economic (E), social (S), technological (T), environmental (A), risk (R), and learning (L). They can be observed in Figure 1 (each bar represents the amount of aspects where synergy is present). Thus, the actors from the Port Authority, who coordinate the port mixed network, meet 71% of the criteria. It is noted that The National Chamber of Commerce and The Roads Directorate (part of the Ministry of Civil Works) are organizations that control port activities and, by law, the Ministry of Transport and Telecommunications has legal responsibility over the port and must deliver policies, regulations, plans, programs and projects to be carried out by the Port Community.

		Enterprise	Multi-criteria
Private Companies	*Port Community*	Externalized Port Terminal	|E|T|A|
		Internal port terminal	|E|T|
		Port Authority	|E|S|T|A|R|
	Diary port operation	Dockage Agency	|E|
		Shipping company	|E|A|L|
		. . .	. . .
		Technology Enterprise	|T|L|
	Indirect Relationship Port	National and international bank	|E|
		Exporter / importer	|E|R|
		Freight Forwarder	|E|R|
	Logistics Community	Logistic Forum	|E|
	Non profit	Work Security Institution	
Social Groups		Port Logistic Chain Labor Union	
		Labor Union	
Gremials Asc.	*Fiscalization of port activities*	National Chamber of Commerce, Service and Tourism of Chile	|P|E|S|A|R|
		Maritime and Port Chamber of Chile	|P|E|R|
		Customs Chamber of Chile	|S|R|L|
	Indirect Port Relationship	Industrial Development Association	|P|E|
		Customs Agents National Association	|E|
Public Components	*Fiscalization of port activities*	Harbourmaster's office	|P|
		Chilean Police	|S|A|
		Production Development Corporation	|E|T|R|
		. . .	. . .
		Regional Secretariat of Health	|S|

Fig. 1. Presence of Multi-criteria of Port System

With regard to the strategic synergy between pairs of actors in the system, taking into account the possible interactions with each criterion, 7 mixed networks are formed, where $8{,}575\left(\binom{50}{2} * 7\right)$ maximum possible relationships could be observed between all possible actors. Since not all of the actors evidence synergy in all the multi-criteria, only 1,273 of them can be labelled as potential cases, representing 14.85% out of the total cases. It is worth noting that the main percentage of potential cases corresponds to the economic aspect: 46.7%, being risk in second place with 18.1%. These percentages show a low integration of the aspects under research with the existing strategic purposes.

Figure 2 shows the absolute frequency of the groups of actors according to the classification presented in Figure 1. It should be noted that the economic criterion is shared by almost all of the groups of actors, having also the highest frequency. This happens because the port has defined in its strategic objectives to increase the efficiency of the export and import logistics chains. The social groups are the exception since they do not declare economic strategic aspects, but only the risk attribute. This situation is explained by the fact that unions express in their strategic purposes only concern for the defense and promotion of labour interests of port workers and for those who give support to the operational activities. In fact, risk is the only criterion that is present in all of the actors.

It is also observed that private enterprises do not include the political factor; though by law, the State legislates and controls port investments and grants them concession to operate in the Port Community. In the same way, the distribution of synergy throughout the criteria seems erratic, being higher for private enterprises and public components, whereas social associations show low synergy but steady because their aim, by law, is to promote rationalization, development and protection of the common activities of their members.

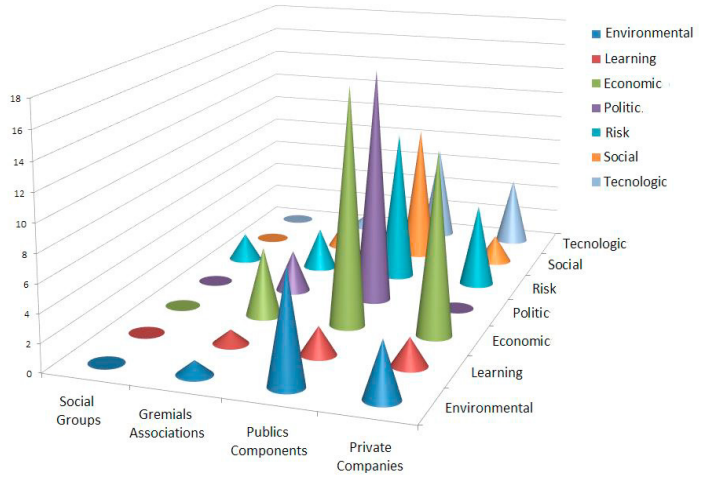

Fig. 2. Absolute frequency of the groups of actors

In order to determine the most relevant strategic criteria (maximum), the attributes found in the strategic purposes and which present the highest frequency in each group of actors have been characterized. See Table 2:

Table 2. Multi-criteria classification and strategic attributes in the Port System

Actors	Determining Criteria	Characterized by
Private enterprises	Economic	Competitiveness Investment Governance Entry barriers Efficiency Foreign Trade
Public components	Economic Political	Investment Legal regulatory mechanisms
Trade associations	Economic	Investment Foreign Trade Principles of free competition
Social groups	Risk	Steadiness Timely and reliable solutions

It is observed that the economic criteria and the investment attribute are common to private enterprises, trade associations and public components. This situation is in line with the State policies on port and coastal infrastructure by 2020, which includes expanding the port platform, implementing better port cities, and increasing connectivity in isolated areas.

In Figure 3, the average synergy of the different groups of actors has been represented and they have also been classified according to the sub-group they belong. The average represents the arithmetic mean of the synergy observed between the companies belonging to each group formed by a certain type of company and a certain type of institutional scope. It is noted that the group of actors, as an average, do not reach the possible maximum of synergy in any aspect (they are less than 5). Likewise, the behaviour of private enterprises is regular since the

group controlling port activities is not among them. Thus, public components only control, while trade associations not only control but also hold indirect relationships with the port because their strategic purposes are countrywide. Social groups or unions do not match the proposed classification.

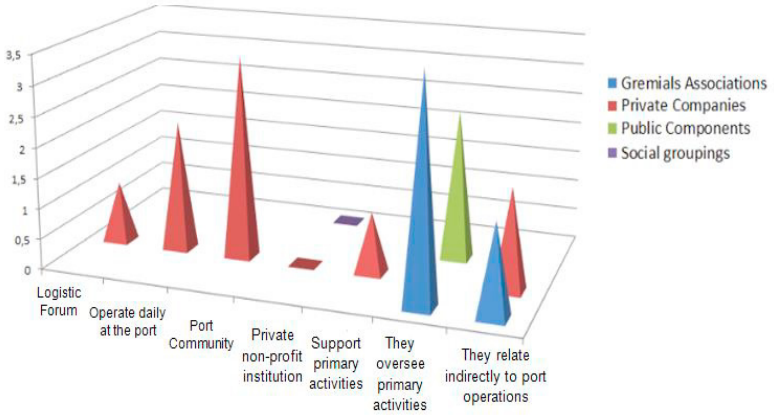

Fig. 3. Average synergy of the sub-groups of actors

In the current research extension, Contingency Tables and the Chi-square Test, used in the first research, have been complemented to search for possible strategic synergy relationships in the port system and to check the independence between pairs of criteria.

Given two categorical variables A and B, where A has r levels and B has c levels, their frequencies can be tabulated in a matrix. If we take p_{ij} as the probability that a randomly chosen element falls in an ij-th position when exists independence, then $p_{ij}=u_i*v_j$, where u_i is the probability that a randomly chosen element falls in the i position, and v_j when it falls in the j position.

Under the assumption of independence, the expected frequency of the cells is:

$$E_{ij} = n\hat{u}_i\hat{v}_j = \frac{1}{n}\sum_{j=1}^{c} O_{ij} \sum_{i=1}^{r} O_{ij} \quad (1)$$

Where r and c are levels in the Contingency Table (r rows and c columns).

Then, when n is large, an approximate Chi-square distribution is obtained with (r-1) (c-1) degrees of freedom:

$$X^2 = \sum_{i=1}^{r}\sum_{j=1}^{c} \frac{(O_{ij}-O_{ij})^2}{E_{ij}} \quad (2)$$

The results in Figure 5 are obtained by applying the codes in the statistical pack R, summed up in Figure 4, on the data represented in Figure 1.

```
head(Data)
Data$Rec_P[Data$P==0] <- "NO"
Data$Rec_P[Data$P==1] <- "SI"
.
library(MASS)
tbl_P_R = table(Data$Rec_P, Data$Rec_R)
tbl_P_R
chisq.test(tbl_P_R)
.
tbl_R_L = table(Data$Rec_R, Data$Rec_L)
tbl_R_L
chisq.test(tbl_R_L)
```

Fig. 4. Code R for the analysis of mails and Chi-square test

Figure 5 shows the results that are significant for the analysed data.

Relationship between two criteria	Chi-squared test P-Value	Phi Coefficient
Politic / Economic	0.5287	0,0891
Politic / Ambiently	0.2772	0.0745
Politic /technologic	**0.0352**	**-0.2978**
Politic / social	0.7970	0.0364
Politic / Risk	1.0000	0.0000
Economic / Risk	1.0000	0.0000
Social / Risk	0.3952	0.7230
Technologic / Risk	0.4281	0.6279
Ambiently / Risk	0.8864	0.0204

Fig. 5. Results of independence test

As shown in the table, there is no evidence to doubt the independence of the variables, except in the political/technological aspects where there is a slight inverse dependence between these variables.

4. Discussion and conclusions

In this research, from the qualitative information found in the strategic purposes and the connection that each private and public actor has with the macro-environment, it has been possible to characterize the port system.

The analyses based on frequencies show the behaviour of the groups and sub-groups of port actors. Particularly, it is concluded that the predominant aspect is the economic, result that is in accord with the State policies to increase investment on port infrastructure by 2020 and with the experts' opinion whose only concern is the efficiency of operational activities in the export and import logistics chains, especially to improve the port competitiveness worldwide.

There is a lack of concern for including other aspects, especially learning, being the least observed (5 actors). It is because the strategic phrases of the actors in the port system lack the incorporation of attributes linked to: innovation networks, know-how, cluster development, marine safety research, among others.

By adding two new criteria, it was possible to verify the results of the previous research [1], since the only synergetic relationship evidenced in the said multi-criteria takes place between politics and technology. Thus, the political criterion is eventually independent from almost all of the attributes, since it is the State who applies legal and regulatory mechanisms to the other actors. These results are generated because the political aspects are not included in the strategic phrases of most port actors, despite the fact that the State through the Ministry of Transport plays a relevant role, especially for the actors that form the core of the business. The State performs important strategic actions such as assigning the composition of the port authority board, proposing strategic plans to improve the efficiency and competitiveness of the port and encouraging the introduction of new technologies in the operation of port services.

Similarly, risk is also eventually independent from the other aspects, it is included by all of the actors and it is random; hence, it is difficult to control because it does not always depend on the strategic decisions made, but on any operational or business decision made. Moreover, it should be taken into account that the results in Figure 5 represent only the 25% of the relationships between criteria. Consequently, a larger sample should be studied to match the conditions of the independence test. It is necessary to incorporate 'risk' in the strategic purposes the risk, which is implicit in the synergy that is generated between two actors by the transfer of information transference, fees collection, coordination of actions, good practices and the incorporation of new technologies. It is relevant to consider the risk associated with the contracts that are made between the actors that integrate the export and import logistics chains, which regulate negotiations with carriers, shipping routes, workers, the use of roads and development, the maintenance and operation of the Port Terminals.

As a conclusion, it is possible to say that more multi-criteria should be added into the strategic phrases, and more quantitative research is needed on the strategic synergic relationships between the actors involved in the

port system and their macro-environment. It is also necessary that the port system declares more multi-criteria in their strategies that help them face the coming changes for the 20 years ahead, aspects outside the port industry: cultural changes, environmental and climatic considerations, geographical and territorial changes, value of strategic positions, competitive tension between ports, among others.

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