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How should the sustainability of the location of dry ports be measured?

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Abstract

The global economic structure, with its decentralized production and the consequent increase in freight traffic all over the world, creates considerable problems and challenges for the freight transport sector. This situation has led shipping to become the most suitable and cheapest way to transport goods. Thus, ports are configured as nodes with critical importance in the logistics supply chain as a link between two transport systems, sea and land. Increase in activity at seaports is producing three undesirable effects: increasing road congestion, lack of open space in port installations and a significant environmental impact on seaports. These adverse effects can be mitigated by moving part of the activity inland. Implementation of dry ports is a possible solution and would also provide an opportunity to strengthen intermodal solutions as part of an integrated and more sustainable transport chain, acting as a link between road and railway networks. In this sense, implementation of dry ports allows the separation of the links of the transport chain, thus facilitating the shortest possible routes for the lowest capacity and most polluting means of transport.

Thus, the decision of where to locate a dry port demands a thorough analysis of the whole logistics supply chain, with the objective of transferring the largest volume of goods possible from road to more energy efficient means of transport, like rail or short sea shipping, that are less harmful to the environment.

However, the decision of where to locate a dry port must also ensure the sustainability of the site. Thus, the main goal of this article is to research the variables influencing the sustainability of dry port location and how this sustainability can be evaluated.

With this objective, in this paper we present a methodology for assessing the sustainability of locations by the use of Multicriteria Decision Analysis (MCDA) and Bayesian Networks (BNs). MCDA is used as a way to establish a scoring, whilst BNs were

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chosen to eliminate arbitrariness in setting the weightings using a technique that allows us to prioritize each variable according to the relationships established in the set of variables. In order to determine the relationships between all the variables involved in the decision, giving us the importance of each factor and variable, we built a K2 BN algorithm. To obtain the scores of each variable, we used a complete cartography analysed by ArcGIS.

Recognising that setting the most appropriate location to place a Dry Port is a geographical multidisciplinary problem, with significant economic, social and environmental implications, we consider 41 variables (grouped into 17 factors) which respond to this need.

As a case of study, the sustainability of all of the 10 existing dry ports in Spain has been evaluated. In this set of logistics platforms, we found that the most important variables for achieving sustainability are those related to environmental protection, so the sustainability of the locations requires a great respect for the natural environment and the urban environment in which they are framed.

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Keywords: dry ports; industrial location; sustainability; Bayesian Networks; Multicriteria Decision Analysis

1. Introduction

The dry port concept is based on moving intermodal terminals further inland from the port areas (Jaržemskis, A., Vasiliauskas, A. V. 2007). This logistics platform is presented as a solution to the most important problems arising from the accumulation of activities in port areas: increasing road congestion, lack of open spaces in port installations and the significant environmental impact of seaports (Rodrigue 2006).

Connecting cargo handling from the port to a logistics centre helps achieve a better port operation, which leads to a greater efficiency in ship operations (reduction in ship time in port) and to energy efficiency issues in shipping and, particularly, to operational issues such as the minimisation of fuel consumption and resulting greenhouse gas emissions (Moon, D.S.H.,Woo, J. K. 2014). It helps also to avoid traffic bottlenecks, which relates to a decrease in road and railway emissions.

In addition, dry ports allow the separation of the various links of the transport chain. Thus, they are also presented as an opportunity to strengthen intermodal solutions as part of an integrated and more sustainable transport chain, allowing for the shortest possible routes for the lowest capacity and most polluting means of transport (Roso 2007; Regmi, M. B., Hanaoka, S. 2013).

All these conditions present dry ports as a solution that provides a more sustainable logistics supply chain. But while taking into account the sustainability of the logistics supply chain it is also necessary to ensure the sustainability of the site. The main goal of this article is to investigate the variables influencing the sustainability of dry port location and how this sustainability can be evaluated.

2. Factors influencing the location of dry ports

The diversity of factors involved in the location of industry has prompted economists over the last century to build models that try to explain the complexity of the real world. For Weber (1909), the main objective when deciding on the location for any industry is to reduce the transport and labour costs. Hotelling (1929) and Reilly (1931) include the presence of competitors. Christaller (1933) adds the “minimum demand threshold” in order for the location to be profitable. As a result of this threshold, the best locations are close to large population centres. But for Lösch (1940), the relationship between population size and type of industry is very important because the impacts on a big population density could lead to social problems. In 1979, Smith introduces the concept of “subtracted value”, which consists of the negative externalities that must be considered against the positive. According to Brown (2005), accessibility to and from the centres of origin and destination of the various flows should be maximised, which is achieved through the connection with the transportation and communication systems, generally located alongside transportation facilities forming hubs.

As can be seen, location problems are multi-objective problems and the implications on levels of economic growth, social welfare, environmental acceptability, accessibility and territorial conditions must all be taken into account. From the research of Pons (2008), and incorporating the elements described above, the set of variables of this study is presented in Table 1. These 41 variables are grouped into 17 factors which in turn correspond to

4 categories: environmental factors, economic and social factors, accessibility factors, and location factors (gathered in Table 1). The variables can be considered as either a Benefit, when a higher value is better in geographical analysis, or a Cost, when a lower value is better.

Table 1. Factors influencing the location of dry ports.

Category	Factor	wk	Variable code	Variable	Kind	Wk
Environmental factors	Impact on natural environment	5.00	DNS	Distance to natural spaces	Profit	10.00
			CNE	Connectivity on natural environment	Profit	0.00
			NIS	Number of isolated spaces	Cost	9.10
			DFA	Density of the facility area	Profit	0.00
	Impact on urban environment	7.25	DUS	Distance to urban spaces	Profit	8.20
			CUE	Connectivity on urban environment	Cost	8.20
	Hydrology	6.00	DSW	Distance to surface water	Profit	7.30
			FL	Flooding level	Profit	7.30
			GP	Groundwater presence	Profit	6.40
Economic and social factors	Land Price	7.00	LP	Land price	Cost	7.30
	Potential Demand Growth	6.40	IPI	Industrial production index	Profit	6.40
			GDP	Gross Domestic Product	Profit	5.50
			EL	Employment rate	Cost	6.40
	Hosting municipality range	5.00	PL	Population level	Profit	4.60
			PD	Population density	Cost	5.50
Accessibility factors	Accessibility to the rail network	10.00	NRA	Number of railway accesses	Profit	5.50
			IRE	Importance of the railway environment	Profit	8.20
			CD	Centrality of demand	Profit	5.50
			QR	Quality of the railway	Profit	0.00
	Accessibility to high capacity roads network	10.00	DAHCN	Direct access to the high capacity network	Profit	4.60
			DHCR	Distance to a high capacity road	Cost	3.70
			NL	Number of lanes	Profit	3.70
	Accessibility to airports	5.00	DA	Distance to an airport	Cost	5.50
	Accessibility to ports	10.00	DP	Ports nearer than 400 Km	Profit	2.80
	Accessibility to supplies and services	8.00	CSS	Currency of supplies and services	Profit	0.00
Location factors	Weather	3.00	CV	Climatic variety	Profit	5.50
			RL	Rainfall level	Cost	2.80
			WF	Winter frosts	Profit	2.80
	Orography	5.00	TC	Terrain curl	Profit	5.50
			SL	Slope	Cost	2.80
	Geology	5.00	EX	Excavability	Cost	8.20
			CS	Compressive strength	Profit	8.20
	Relation with other logistics platforms	8.00	NNLP	Number of nearby logistic platforms	Cost	1.90
			NMDLP	Number of middle-distance logistic platforms	Profit	3.70
			BICA	Belonging to an industrial consolidated area	Profit	1.00
	Integration into the main supply chain infrastructures	5.50	DPFC	Distance to a principal freight corridor	Cost	5.50
	Potential optimization of the modal shift	5.05	DPPC	Distance to a principal passenger corridor	Profit	6.40
			NPT	Number of passenger trips	Cost	6.40
			NRADT	Nearest roads' ADT	Cost	1.00
			DTENT	Distance to the TEN-T Core Network Corridors	Profit	3.70

3. Bayesian Networks and Multicriteria Decision Analysis: a proposed mixed methodology

By triangulating different techniques we have established a methodology for assessing the sustainability of the location of dry ports that can also be used to evaluate their overall quality. To reduce the arbitrariness of the weightings of the Multicriteria Decision Analysis algorithm, we decided to use an Artificial Intelligence model based on Bayesian Networks that establishes the relationship between the variables for a given sample.

The proposed methodology has been developed with the following tasks (see Figure 1):

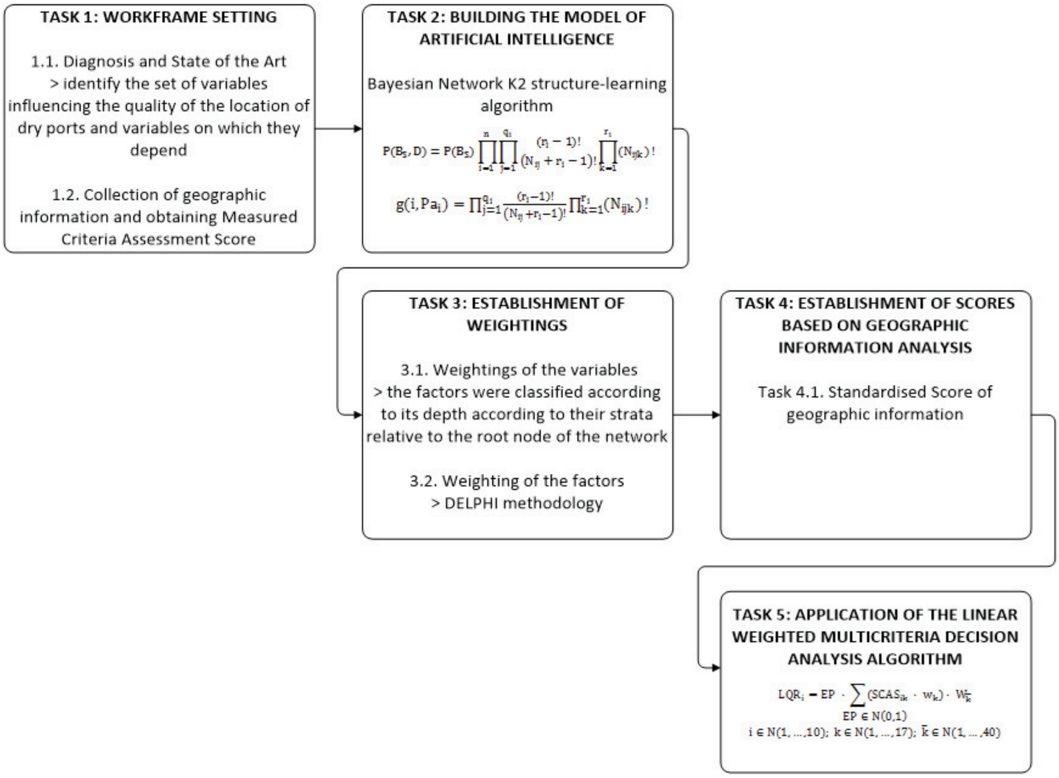

Fig. 1. Methodology diagram.

3.1. Task 1: work setting

Task 1.1. Diagnosis and State of the Art: first step is reviewing the state of the art to identify the set of variables influencing the quality of the location of dry ports and variables on which they depend.

Task 1.2. Collection of geographic information: in this stage geographic information of each variable is gathered and entered in the Geographic Information System software.

3.2. Task 2: building the model of Artificial Intelligence

We have chosen to use Bayesian Networks for their ability to represent a causal model using a graphical representation of dependencies between variables that are part of the application domain. According to the type of structure of the data, different structure-learning methods can be applied. To build the Bayesian Network we chose a K2 structure-learning algorithm (Equation 1), because it allows the variables to be ordered. This way, the network can be stratified.

$$P(B_S,D) = P(B_S)\prod_{i=1}^{n}\prod_{j=1}^{q_i}\frac{(r_i-1)!}{(N_{ij}+r_i-1)!}\prod_{k=1}^{r_i}(N_{ijk})!\ \text{when}\ g(i,Pa_i) = \prod_{j=1}^{q_i}\frac{(r_i-1)!}{(N_{ij}+r_i-1)!}\prod_{k=1}^{r_i}(N_{ijk})! \quad (1)$$

In this kind of algorithm, all structures are equally likely at the start. The K2 algorithm begins by assuming that a node has no parents and at each step incrementally adds that node's parent whose inclusion increases. For each node, the algorithm searches for the K2 parents that maximize.

3.3. Task 3: establishment of weightings

Task 3.1. Weightings of the variables: to obtain the weighting of each variable, the factors were classified according to their strata relative to the root node of the network, and thresholds were defined based on the "depth" of the factor within the network.

Task 3.2. Weighting of the factors: these are established by applying the DELPHI methodology. It is based on the analysis of the ideas of a group of experts in the search for a consensus of opinion. Owing to the length limits of this document, it is advisable to look in the full working document for more information on any particular theme about the conducted methodology in Awad (2014).

3.4. Task 4: establishment of scores based on Geographic Information Analysis

Each variable is graded according to the value of geographic information, obtaining a Criteria Assessment Score. This value was normalized using a spline. Depending on the grade of the spline, there were 3 different kinds of boundary conditions. The kind of interpolation is selected by minimizing the distance between the Measured Criteria Assessment Score (MCAS) and the Standardised Criteria Assessment Score (SCAS).

3.5. Task 5: application of the linear weighted Multicriteria Decision Analysis algorithm

Using the weightings obtained in Task 3 and the Standardised Criteria Assessment Score of Task 4, and then from Equation 3, the quality of the location of dry ports is obtained.

$$\begin{gathered} LQR_i = EP \cdot \sum(SCAS_{ik} \cdot w_k) \cdot W_{\bar{k}} \\ EP \in N(0,1) \\ i \in N(1,\ldots,10);\ k \in N(1,\ldots,17);\ \bar{k} \in N(1,\ldots,40) \end{gathered} \quad (2)$$

where LQR (Location Quality Rate) is the ratio of the quality of each location; EP (Environmental Protection) is the dichotomous function "Environmental Protection", which serves to exclude protected areas (worth 0 for protected locations and 1 for locations without environmental protection); SCAS (Standardised Criteria Assessment Score) is the score of the evaluation criteria for each variable and location. Finally, W are the weightings obtained in the DELPHI questionnaire to fix the importance of each factor and the w are the weightings of each factor. The locations with a higher LQR value will be most appropriate for solving the problem.

4. Case of study: sustainability of the existing dry ports in Spain. Results and discussion

Equation 2 requires the following inputs: 1) the weightings of each variable and factor and 2) the Standardised Criteria Assessment Score of each variable and location.

Using the geographic information of the 10 existing dry ports in Spain, a K2 algorithm Bayesian Network has been built. The result determines the relationship between all the variables involved in the decision. The network obtained is represented in Figure 2.

As can be seen, DNS is the root node of the whole network because no path enters it. By assessing the importance of each variable by depth compared with the root of the network, a certain weighting is set for each variable.

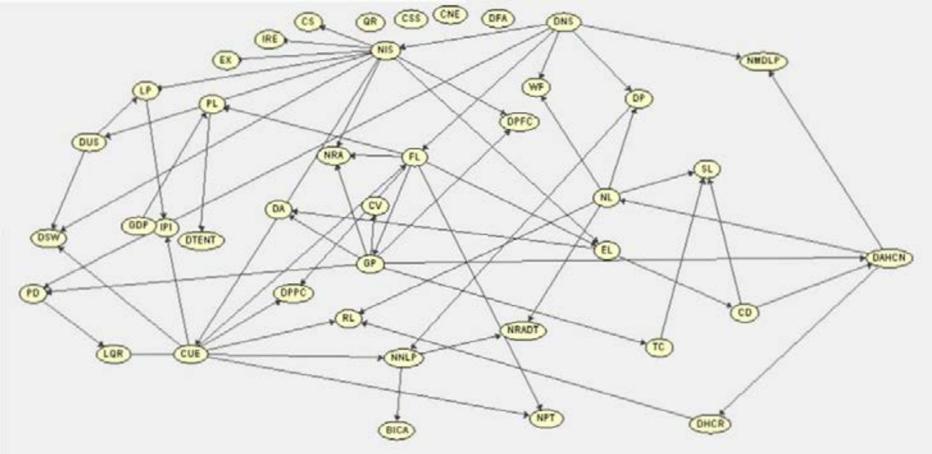

Fig. 2. K2 algorithm Bayesian Network.

Depth is related to the number of steps to reach DNS and the number of relationships between the evaluated variable and the other variables. As there are 11 layers: the layer 1 receives a weighting of 10; the layer 11, a weighting of 1; and intermediate layers, the corresponding linearly interpolated values. The variables that are outside the BN have a weighting of 0. Table 1 shows the weightings of the variables resulting of this procedure. The weightings of each factor are also compiled in this table. As shown in Awad et al. (2014), only 14 factors were employed, compared with 17 considered in this research. The weightings of the 3 additional factors were obtained through missing data analysis techniques (statistical inference), maintaining the weightings of the factors that are known and their importance as given by the questionnaire.

Applying Equation 3 with the weighting from Table 1 and the Standardised Criteria Assessment Score from the geographic information analysis using ArcGIS (see Table 2), we obtained the results compiled in Table 3.

Each dry port presents a weighted score for each category: environmental, economic and social, accessibility, and location. Merging the results of the environmental, and economic and social variables, we obtained the sustainability of each dry port. Taking into account all the full set of variables, quality can be observed.

The best dry port in each category in Table 5 is highlighted in green and the worst one is highlighted in red. The most sustainable dry port is Monforte de Lemos, which scored well in terms of social and environmental factors and was balanced in the economic section, with 60.3% of the maximum possible score. Meanwhile, the least sustainable locations are Coslada, Abroñigal and Santander-Ebro, all of them with low social and environmental scores that are not compensated by the economic section.

For its part, Coslada has the best quality location if all the variables are taken into account, with 57.2%. These modest results show that both sustainability and quality of dry port locations in Spain is moderate. This can also be seen in the median values, of 41.3% and 48.8% respectively.

Analysing sustainability, scores in economic and social variables are much better than in environmental variables. As environmental variables appear to be the ones with the biggest weightings, this produces moderate sustainability ratings. Also the set of sustainability assessments of the locations has a standard deviation of 11.1%, so it can be considered that the quality of the locations is grouped around the central values.

By looking at the overall quality of the locations, we saw that dry ports have higher grades than 60% in accessibility and higher than 50% in location. However, as was the case for sustainability, these ratings are not able to pull up the overall rating because the environmental variables are the most weighted of the model. Again, we can say that there is little dispersion in the sample, in this case with a standard deviation of 6%.

Table 2. Compilation of Standardised Criteria Assessment Score.

Variable	Standardised Criteria Assessment Score									
	I	II	III	IV	V	VI	VII	VIII	IX	X
DNS	1.5	0.9	2.3	10.0	5.8	2.1	2.3	0.8	4.0	6.4
CNE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NIS	0.0	7.5	5.0	2.5	2.5	7.5	5.0	5.0	0.0	0.0
DFA	10.0	10.0	0.0	0.0	10.0	10.0	10.0	10.0	10.0	10.0
DUS	2.5	0.0	0.0	2.0	2.0	0.0	3.5	6.1	2.0	0.0
CUE	6.7	0.0	3.3	6.7	8.3	0.0	3.3	6.7	0.0	0.0
DSW	0.8	2.0	1.6	0.0	0.0	4.6	4.7	1.8	9.1	0.0
FL	10.0	0.0	5.0	0.0	10.0	10.0	0.0	10.0	0.0	5.0
GP	0.0	0.0	0.0	0.0	10.0	0.0	0.0	10.0	0.0	0.0
LP	4.7	5.5	6.5	9.2	9.2	9.0	8.8	8.4	1.5	1.5
IPI	5.3	10.0	3.5	8.0	8.0	8.0	8.0	4.5	3.1	3.1
GDP	5.8	8.6	6.1	7.6	7.6	7.6	7.6	7.1	10.0	10.0
EL	0.0	4.5	4.7	3.5	3.5	6.5	4.6	5.1	5.6	5.6
PL	10.0	0.3	10.0	1.3	0.6	10.0	1.8	5.6	10.0	10.0
PD	9.4	9.6	0.0	9.5	9.1	0.0	5.5	9.0	0.0	0.0
NRA	10.0	3.0	8.0	10.0	8.0	10.0	5.0	5.0	10.0	10.0
IRE	6.0	2.0	4.0	6.0	6.0	2.0	8.0	4.0	10.0	10.0
CD	4.0	3.0	10.0	4.0	3.0	7.0	4.0	7.0	7.0	10.0
QR	10.0	10.0	10.0	10.0	5.0	10.0	10.0	5.0	10.0	10.0
DAHCN	0.0	5.0	10.0	5.0	5.0	10.0	5.0	0.0	10.0	10.0
DHCR	4.0	0.0	10.0	0.0	6.7	10.0	7.3	0.0	10.0	10.0
NL	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	10.0	10.0
DA	0.0	2.7	3.3	2.7	0.0	9.7	0.0	0.0	8.5	6.8
DP	8.8	8.8	2.5	8.8	10.0	6.3	6.3	8.8	2.5	2.5
CSS	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
CV	5.0	0.0	0.0	0.0	5.0	0.0	0.0	10.0	0.0	0.0
RL	4.5	6.9	5.5	2.3	3.3	4.5	5.5	0.0	5.6	5.6
WF	10.0	10.0	10.0	0.0	10.0	0.0	0.0	10.0	10.0	10.0
TC	10.0	10.0	10.0	2.0	2.0	10.0	10.0	2.0	10.0	10.0
SL	10.0	10.0	5.0	2.5	2.5	7.5	10.0	5.0	10.0	10.0
EX	6.4	0.4	0.0	8.3	0.9	0.4	0.0	0.4	10.0	8.3
CS	6.5	2.7	2.3	8.7	3.0	2.7	2.3	2.7	10.0	8.7
NNLP	8.0	5.0	0.0	6.0	0.0	3.0	2.0	8.0	0.0	3.0
NMDLP	2.8	5.9	10.0	7.0	7.0	10.0	6.0	5.0	10.0	10.0
BICA	5.0	10.0	10.0	5.0	5.0	10.0	5.0	5.0	10.0	10.0
DPFC	1.0	7.0	8.0	2.0	0.0	6.0	5.0	3.0	9.0	10.0
DPPC	8.6	2.9	6.4	4.7	7.3	3.7	0.0	6.7	4.6	1.7
NPT	8.9	4.0	6.6	7.8	9.1	7.9	5.5	8.7	7.2	0.0
NRADT	9.6	8.0	8.4	9.4	8.8	7.8	8.9	9.9	7.6	4.3
DTENT	10.0	5.0	10.0	10.0	5.0	0.0	10.0	10.0	10.0	10.0

I. Antequera; II. Santander-Ebro (Luceni); III. Azuqueca de Henares; IV. La Robla; V.Toral de los Vados; VI. Villafría (Burgos); VII. Venta de Baños (Ventasur); VIII. Monforte de Lemos; IX. Coslada; X. Abroñigal

Table 3. Multicriteria Decision Analysis algorithm results.

	Environmental		Economic and Social		Accessibility		Location		Sustainability		Quality (LQR)	
I	1091.2	32.1%	1152.8	52.7%	2025.0	55.1%	2224.2	67.8%	2244.1	40.1%	6022.0	48.0%
II	474.3	13.9%	1444.5	66.0%	1412.2	38.4%	1583.6	48.2%	1918.8	34.3%	4827.0	38.5%
III	827.5	24.3%	1116.3	51.0%	2679.9	72.9%	1839.0	56.0%	1943.8	34.8%	6174.5	49.2%
IV	1129.0	33.2%	1495.5	68.4%	2180.2	59.3%	1841.8	56.1%	2624.5	46.9%	6646.5	53.0%
V	1841.0	54.1%	1469.8	67.2%	2223.7	60.5%	1359.4	41.4%	3310.8	59.2%	6071.8	48.4%
VI	1085.3	31.9%	1548.9	70.8%	2741.3	74.6%	1561.6	47.6%	2634.1	47.1%	6297.6	50.2%
VII	953.2	28.0%	1423.9	65.1%	2197.3	59.8%	1363.8	41.6%	2377.2	42.5%	5732.5	45.7%
VIII	1928.2	56.6%	1445.4	66.1%	1233.0	33.6%	1635.4	49.8%	3373.6	60.3%	5341.2	42.6%
IX	719.2	21.1%	1017.7	46.5%	3257.7	88.6%	2622.8	79.9%	1737.0	31.1%	7217.0	57.5%
X	537.2	15.8%	1017.7	46.5%	3377.0	91.9%	2228.2	67.9%	1554.9	27.8%	6941.1	55.3%
Average	1058.6	31.1%	1313.3	60.0%	2332.7	63.5%	1826.0	55.6%	2371.9	42.4%	6127.1	48.8%
Median	1019.3	29.9%	1434.2	65.6%	2210.5	60.1%	1737.2	52.9%	2310.6	41.3%	6123.2	48.8%
Std Dev	373.2	11.0%	338.3	15.5%	662.2	18.0%	561.5	17.1%	623.0	11.1%	754.4	6.0%
Max	3404.0		2187.2		3675.0		3282.3		5591.2		12548.5	

5. Conclusions and future research

In this research we have tried to convey the idea that the determination of the most appropriate location to place dry ports is a geographic and multidisciplinary problem, with environmental, economic, social, accessibility and location repercussions.

Although the results of the DELPHI questionnaire show a greater importance in the search for the location of a dry port for the aspects considered in the classical theories of industrial location (accessibility to the rail network, accessibility to high-capacity main roads and accessibility to seaports), the DELPHI weightings are corrected according to the relationships established between variables by taking into account the Bayesian weightings. Ultimately, environmental variables prove to be the most important in deciding the location. Although four variables are unrelated to the rest of the network (Connectivity with the natural environment, Density of facility area, Quality of the railway and Currency of supplies and services), we must not lose sight of these variables in future evaluations since the lack of relationship is related to the inability to establish preferential relationships between them because their values are practically the same for all locations of dry ports in Spain.

A very important conclusion is that the satisfactory results allow us to confirm the great power of applying Bayesian Networks and Multicriteria Decision Analysis to the assessment of dry port location. In addition, the triangulation of different independent techniques provides greater confidence in the results, because the use of Bayesian Network and DELPHI methodology reduces the arbitrariness of the weightings of the Multicriteria Decision Analysis algorithm.

By implementing the Multicriteria Decision Analysis algorithm into a McHarg Geographic Information System, we will be able to develop a powerful decision-making tool. Furthermore, the versatility of the model will allow, with small changes in the variables, the location of other logistics platforms or NIMBY facilities other than dry ports.

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