ASSESSMENT OF THE DIGITALIZATION LEVEL OF THE SIX FOUNDING MEMBERS OF THE EUROPEAN UNION (EU) WITH MOORA METHOD

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ABSTRACT
Industry 5.0 is impacting daily life to production lines and changing the way of doing business with increasing digitalization. The digitalization includes the involvement of a wide range of technologies such as big data analytics, the Internet of Things (IoT), cloud computing, smart manufacturing systems, machine learning (ML), cyber-physical systems, and cybersecurity. Sectors such as finance, healthcare, education, telecommunications, logistics and supply chain, travel and hospitality services, public services, digital marketing, e-commerce, and the entrepreneurship ecosystem are affected by digitalization. Besides sectors, digitalization has a measurable impact at the country level. Therefore, assessment of the level of digitalization of countries is crucial when developing strategic policies and plans at the country level.
This study aims first to identify the criteria affecting level of digitalization from the perspective of country level and rank countries. In this study, the six founding members of the European Union (EU) that evolved from the European Economic Community (EEC) are analysed and ranked by applying the Multi-Objective Optimization on the basis of Ratio Analysis (MOORA). Six founding members of the EU are Belgium, France, Germany, Italy, Luxembourg, and the Netherlands. The literature review reveals that the concept of digitalization is closely related to the Digital Economy and Society Index (DESI). Therefore, DESI data belonging to 2025 were collected from Eurostat. Then, a unique dataset was constructed considering DESI data. Four criteria are identified which are "ICT trust, security and privacy", "Connection to the internet and computer use", "E-commerce Activities" and "Use of Electronic Identification (eID)". The six founding members of the EU are ranked considering equal weights for each criterion by applying the MOORA which is one of the Multi-Criteria Decision Making Methods (MCDM). As a result of this study, Netherlands is ranked at first and Germany last. Luxembourg, Belgium and Italy have close digitalization levels.
Keywords: Digitalization, European Union (EU) Founding Members, Digital Economy and Society Index (DESI), Criteria Selection, Multi-criteria Decision Making (MCDM), Multi-Objective Optimization on the basis of Ratio Analysis (MOORA)

INTRODUCTION
Digitalization has a transformative effect on many different areas, from the economy to business practices and even social life. The European Commission (2022) developed a multidimensional index named The Digital Economy and Society Index (DESI) in 2014.

DESI contributes to measure the level of digitalization in the European Union (EU). DESI is composed of use of internet services, human capital, integration of digital technologies by businesses, connectivity and digital public services on a comparative basis to evaluate the EU country's digital performance (Bánhidi et al., 2020). The digitalization process is covered by the involvement of technologies such as big data analytics, the Internet of Things (IoT), cloud computing, smart manufacturing systems, machine learning (ML), cyber-physical systems, and cybersecurity (Khang et al, 2023; ProkoPowicz et al, 2023).

The digitalization process has an impact on sectors such as finance, healthcare, education, telecommunications, logistics and supply chain, travel and hospitality services, public services, digital marketing, e-commerce, and the entrepreneurship ecosystem. DESI index signifies the weaknesses and strengths of the digital transformation process of EU countries to provide guidance for policymakers and decision-makers (Stavytskyy et al., 2019). DESI is considered as a criterion of digitalization. DESI can be evaluated considering DESI data (Başol & Yalçın (2024).

In this study, firstly it is aimed to identify the criteria affecting the level of digitalization from the perspective of country level. Furthermore, in the scope of this study it is aimed to rank the six founding members of the EU countries by applying the one of the Multi-criteria Decision Making (MCDM) method. The six founding members of the EU which are Belgium, France, Germany, Italy, Luxembourg, and the Netherlands that evolved from the European Economic Community (EEC) are analysed and ranked with Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) method.

The European Commission (2022) examines data regarding DESI along with their explanations in its report. The data under the DESI index are considered as criteria in our study.

Digital Economy and Society Index (DESI) Criteria

Four different DESI criteria are identified in this study which are "ICT trust, security and privacy", "Connection to the internet and computer use", "E-commerce activities", "The use of electronic identification (eID)". Table 1 shows the DESI criteria and their explanations, units of measures, types of criteria. The data were collected from Eurostat. These data are annual and pertain to the year 2025.

Table 1. Digital Economy and Society Index (DESI) Criteria

Criterion Name	Explanation	Unit of Measure	Criterion Type
ICT trust, security and privacy	Privacy and protection of personal data: Individuals use software that limits the ability to track their activities on the internet	Percentage of individuals	Benefit
Connection to the internet and computer use	Individuals - devices used to access internet: Individuals used the internet on a mobile phone or smart phone	Percentage of individuals	Benefit
E-commerce activities	Financial Activities over the Internet: Online purchases (3 months): at least one of the financial activities	Percentage of individuals	Benefit

The use of electronic identification (eID)	The use of eIDs: Individuals who have used their eIDs to access online services for private purpose in the last 12 months	Percentage of individuals	Benefit

Table 1 is adapted from Eurostat data.

METHODOLOGY

Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) Method

The MOORA (Multi-Objective Optimization on the Basis of Ratio Analysis) method is one of the Multiple Attribute Decision-Making (MADM) methods and evaluates the performance of alternatives using a ratio-based approach.

Steps for MOORA are given as follows in brief (Schmohl et al., 2025; Chakraborty, 2011):

1. A decision matrix which is denoted as $[x_{ij}]_{m\times n}$ is established that represents the performance of the alternatives (i) across multiple criteria (j).

2. The decision matrix is normalized and made unitless by Equation 1. Normalized decision matrix is dimensionless and its elements denoted as x_{ij}^* within the range of [0,1].

$$x_{ij}^* = \frac{x_{ij}}{[\sum_{i=1}^{m} {x_{ij}}^2]^{\frac{1}{2}}} \ (j = 1, 2, \dots, n) \qquad \text{(Eq. 1)}$$

3. For multi-objective optimization, the normalized performances of alternatives are summed for maximization (benefit criteria) and deducted from the sum for minimization (cost criteria). For equal criteria weights of the decision problem Equation 2 is used and shown below.

$$y_i = \sum_{j=1}^{z} x_{ij}^* - \sum_{j=z+1}^{n} x_{ij}^* \qquad \text{(Eq. 2)}$$

where z is the count of criteria to be maximized, $n - z$ is the count of criteria to be minimized, and y_i demonstrates the normalized evaluation score of ith alternative regarding all criteria.

4. For the different importance values of the criteria, Equation 3 is used to calculate y_i.

$$y_i = \sum_{j=1}^{z} w_j x_{ij}^* - \sum_{j=z+1}^{n} w_j x_{ij}^* \qquad \text{(Eq. 3)}$$

where the weight of jth criterion is w_j. The value of y_i can take negative or positive values rely on the sum of the minimums (cost criteria) and maximums (benefit criteria) in the decision matrix. The highest value of y_i indicates best alternative, while the lowest values of y_i indicates the worst alternative. Final ranking is gathered by ranking alternatives according to decreasing order of y_i values.

RESULTS

Ranking results of six founding members of EU countries with the MOORA method considering equal weights $(w_j = 1/n = 0.25)$ for four criteria are evaluated. The Decision Matrix is given in Table 2.

Table 2. Decision Matrix

Criterion Weights	0.25	0.25	0.25	0.25
Min/Max (Cost Criteria /Benefit Criteria)	max	max	max	max
Country	ICT trust, security and privacy	Connection to the Internet and computer use	E-commerce Activities	Use of Electronic Identification (eID)
Belgium	51.09	94.23	17.14	80.63
France	60.76	94.71	13.77	87.66
Germany	46.67	92.58	21.91	14.68
Italy	63.26	96.64	20.02	53.17
Luxembourg	46.09	92.92	23.53	74.66
Netherlands	68.16	98.84	40.46	95.09
(sum of squares) ^1/2	138.75	232.73	59.62	178.45

Normalized Decision Matrix is given in Table 3.

Table 3. Normalized Decision Matrix

Country	ICT trust, security and privacy	Connection to the internet and computer use	E-commerce Activities	Use of Electronic Identification (eID)
Belgium	0.37	0.40	0.29	0.45
France	0.44	0.41	0.23	0.49
Germany	0.34	0.40	0.37	0.08
Italy	0.46	0.42	0.34	0.30
Luxembourg	0.33	0.40	0.39	0.42
Netherlands	0.49	0.42	0.68	0.53

Weighted Normalized Decision Matrix is given in Table 4.

Table 4. Weighted Normalized Decision Matrix

Country	ICT trust, security and privacy	Connection to the internet and computer use	E-commerce Activities	Use of Electronic Identification (eID)
Belgium	0.09	0.10	0.07	0.11
France	0.11	0.10	0.06	0.12
Germany	0.08	0.10	0.09	0.02
Italy	0.11	0.10	0.08	0.07
Luxembourg	0.08	0.10	0.10	0.10
Netherlands	0.12	0.11	0.17	0.13

Ranking Results for Six Founding Members of the EU are given in Table 5.

Table 5. Ranking Results for Six Founding Members of the EU

Country	Sum of Max	Sum of Min	Assessment of Alternative	Rank
Belgium	0.38	0.00	0.3781	4
France	0.39	0.00	0.3918	2
Germany	0.30	0.00	0.2960	6
Italy	0.38	0.00	0.3762	5
Luxembourg	0.39	0.00	0.3861	3
Netherlands	0.53	0.00	0.5319	1

Ranking results of the MOORA are shown in Figure 1.

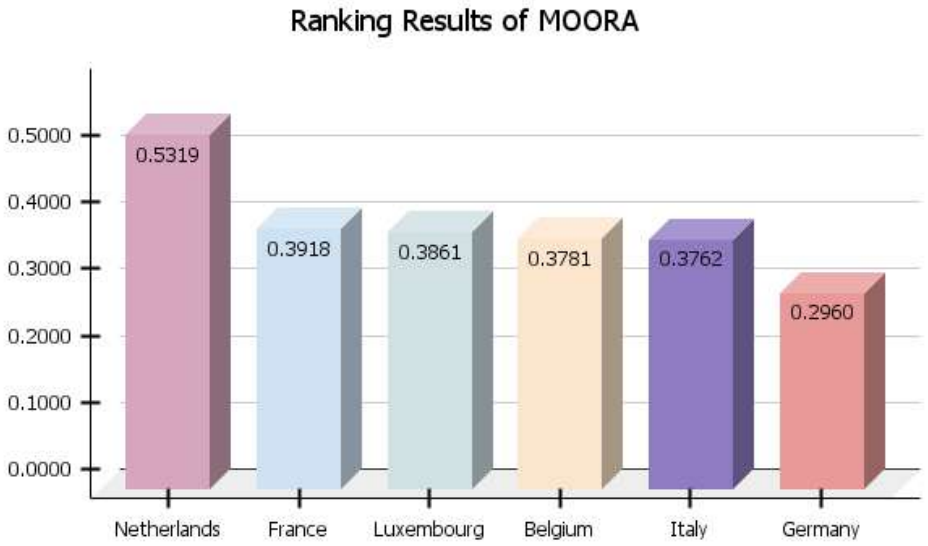

Figure 1. Ranking Results of MOORA

The ranking of the digitalization levels of six founding members of EU countries from first to last country is as follows: Netherlands (0.5319), France (0.3918), Luxembourg (0.3861), Belgium (0.3781), Italy (0.3762) and Germany (0.2960).

DISCUSSION AND CONCLUSION

In this study, the digitalization levels of six founding member countries of the EU were analysed and compared using the MOORA method with selected DESI criteria. The countries were ranked from highest to lowest digitalization levels as follows: Netherlands, France, Luxembourg, Belgium, Italy and Germany.

Netherlands ranked first, while Germany ranked last. France, Luxembourg, Belgium, and Italy had nearly similar levels of digitalization. Germany's low ranking is attributed to its significantly lower eID usage rate compared to other countries. The "Internet and computer use" rate ranged between 90-100% across all countries. This criterion appears less influential than the other three criteria in measuring the level of digitalization in this study. However, "E-commerce activities" showed more fluctuating data. While the "e-commerce activities" rate for the Netherlands was 40.46%, for the other five countries it ranged between 13-24%. The higher "e-commerce activities" rate also contributed to the Netherlands' top ranking.

For future studies, the number of criteria considered can be increased or different criteria can be used. Furthermore, alternative multi-criteria decision-making (MCDM) methods can be applied for conducting deeper and more comprehensive analyses.

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