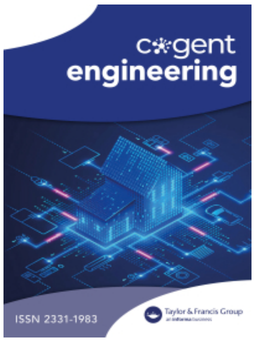

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Technological maturity of the OECD countries: A multi-criteria decision-making approach using PROMETHEE

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Abstract: Measuring and assessing the degree of technological readiness at macro level is crucial in guiding the overall technological development for the countries. The problem is multi-criteria in nature, involving assessment and consolidation over multiple dimensions. This study develops a composite index to measure basic technological maturity from supply chain integration perspective and utilizes multi-criteria decision-making method PROMETHEE to obtain a ranking among 28 OECD countries. Based on OECD data and metrics set availability, a composite index is developed using 10 relevant metrics. Then a comparative study is performed for 28 countries for the year 2019 under six different scenarios using Visual PROMETHEE. The study is original in developing a composite index with corresponding metrics, providing a comparative evaluation across OECD countries, and offering a comprehensive analysis utilizing almost all major visual analysis tools of the Visual PROMETHEE. The results indicate that the metric set selected and the methodology applied with the visual tools of PROMETHEE provide a systematic which enables country-based benchmarking under different dimensions and enable policymakers to identify the improvement opportunities for each dimension.

Subjects: Industrial Engineering & Manufacturing; Engineering Management; Technology

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Keywords: technological maturity; OECD; MCDM; PROMETHEE

1. Introduction

The use of Information and Communication Technology (ICT) is a vital factor in the development of countries, showing significant degrees of variation in the level of access, assimilation, diffusion and use (Asongu & Acha-Anyi, 2019; Kyriakidou et al., 2013). It is well supported in the literature that systemic developments related with ICT facilitate and enhance the economic development, boost economic activities and bring cost reductions as well as efficiencies. Hence, there exists a positive significant relationship between economic growth of a country and ICT (Afshar Ali et al., 2020; Ali et al., 2020; Becker et al., 2018; Kyriakidou et al., 2013), providing a clear support that ICT maturity enhances economic development. In today's era, ICT redefines connectivity, restructures business processes and enables collaboration across different business partners (Akyuz, 2012; Dzemydienė et al., 2020; Fawcett et al., 2011; Gunasekaran & Ngai, 2004). Integrating the overall value chain across the partners is made possible via digitalization, leading to the development of digital business models and fully integrated cross-partner solutions (Barata, 2021; Bravi & Murmura, 2021; Gunasekaran et al., 2017; Rocha et al., 2019). As such, ICT is highlighted as a major driver to global competitiveness at the country, industry and firm levels (Contieri et al., 2021; Yunis et al., 2012). Consequently, it is of vital importance to assess, evaluate and monitor the ICT maturity of different countries and to observe the variability in terms of availability and use of different technological components (Ali et al., 2020; Azman et al., 2014; Becker et al., 2018; Kyriakidou et al., 2013). With increasing complexity and dependencies among organizational contexts, the problem inherently involves multiple criteria and falls into the class of multi-criteria decision-making (MCDM).

This study is motivated by the importance of assessing technological maturity of the countries, obtaining ICT-based cross-country rankings, multi-criteria nature of technological maturity measurement, multiplicity of metrics and methodologies, and lack of a focused and lean metrics set with a supply chain integration focus.

The aim of this study is to provide a macro-level composite index for measuring the technological maturity, and offer a comparative study among 28 Organisation for Economic Cooperation and Development (OECD) countries utilizing a MCDM approach.

The study answers the following research questions:

- How can a composite and macro-level index be developed to measure and compare the basic technological maturity of the countries under multiple criteria with a supply chain integration focus?
- How do maturity performances of countries vary for the defined dimensions?
- What kind of a clustering pattern do countries exhibit?

Therefore, the study is of interest for researchers working in the areas of MCDM, technological/ICT maturity, macro-level technology policy development and supply chain integration.

The rest of the article is structured as follows: Section 2 contains the literature review. Section 3 offers the methodology. Section 4 contains the comparative analysis and findings. Discussion and conclusion are offered in Section 5.

2. Literature review

Use of a variety of multi-criteria methods in ICT-related topics is well supported in the literature. There exists a variety of metrics development and measurement efforts regarding the presence, adoption and utilization of various ICT components; and the topic is investigated in different country and regional settings and contexts.

Metric development efforts in the early 2000s are supported to focus mainly on the basic access and use, while developments after 2009 witness composite indices with more composite structures, submetrics and different weighting schemes (Ali et al., 2020). Hanafizadeh et al. (2009) develop a composite index utilizing infrastructure and access as two components of ICT diffusion to be the indicator of ICT development. In their study, Kien and Giang (2013) perform group fuzzy analytical network process (ANP) to measure ICT maturity under the dimensions of policy, infrastructure, application and human resources. Kyriakidou et al. (2013) develop an ICT maturity level index based on the dimensions of access, use and skills, and apply it along with structured equation modelling to provide a clustering among 159 developed and developing countries. Becker et al. (2018) perform a study to analyse the ICT usage for Central European Enterprises via ANP and k-means clustering, utilizing 13 selected metrics under four metric groups based on EUROSTAT (European Statistics) data set.

In their recent study, Ali et al. (2020) developed a modified ICT maturity index with the dimensions of access, affordability, quality, efficiency, skill and use. This index set is applied to United Nations Educational, Scientific and Cultural Organization (UNESCO) data set utilizing partial least-squares structured equation modelling. Afshar Ali et al. (2020) investigate the relationship between ICT maturity and economic development in the OECD countries, providing clear support that ICT maturity enhances economic development. Biswas et al. (2022) utilize Entropy MARCOS framework and TOPSIS to compare the socio-ecconomical development of G7 and BRICS countries. Genç and Dinçer (2013) also take development approach, applying PROMETHEE (The Preference Ranking Organization Method for Enrichment Evaluation) and GAIA (Geometrical Analysis for Interactive Decision Aid) plane for determining the regional socio-economical development of Turkey.

It is important to highlight that recent studies related with ICT become more Industry 4.0 focused, and deal with more contemporary ideas such as digitalization, cloud adoption, business intelligence and enterprise resources planning (ERP). In this context, Gupta et al. (2021) utilized fuzzy analytical hierarchy process (AHP) in the context of logistics operation digitization via three groups of factors and 18 subfactors. Samaranayake et al. (2017) investigated the relative importance of multiple key enabling factors towards Industry 4.0 technological readiness utilizing AHP. Honti et al. (2020) developed a composite regional Industry 4.0 readiness index and applies PROMETHEE. Sadeghi-Niaraki (2020) performed a multi-criteria assessment for Industry 4.0 development using a methodology integrating fuzzy DEMATEL (Decision Making Trail and Evaluating Laboratory), AHP and VIKOR (VIse KriterijumsaOptimiz acija I Kompromisno Resenje) under six major groups of criteria. Similarly, Maadi et al. (2016) used fuzzy PROMETHEE in business intelligence context. Ziemba and Becker (2019) utilized fuzzy numbers and the NEAT F-PROMETHEE (New Easy Approach to Fuzzy-PROMETHEE) method to obtain a ranking for Central and Eastern Europe countries covering 11 countries.

We also witness the use of PROMETHEE in different contexts. Lopes et al. (2018) applied PROMETHEE and GAIA methods in Portugal tourism context. Biswas (2020) mentioned various uses of PROMETHEE for the evaluation of stock performance for portfolio selection.

Sharma et al. (2020) used fuzzy AHP and AHP in the context of cloud computing to prioritize different factors related with cloud technology adoption. Mahadevan et al. (2006) performed an AHP-based study in ERP-training context. Qushem et al. (2017) analyzed BI maturity via a questionnaire-based approach. Halicka (2020) performed a TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)-based study for technology selection by ranking among technology alternatives. Contieri et al. (2021) focused on the implementation priorities and difficulties in the emerging country context and utilizes Fuzzy-TOPSIS approach. Hsu and Yeh

(2017) investigated the factors affecting the IoT via DEMATEL country context. Medic et al. (2019) studied the evaluation of advanced digital technologies using Fuzzy AHP and PROMETHEE. Dzemydienė et al. (2020) took small and medium enterprises (SME) perspective and utilized TOPSIS and simple additive weighting (SAW) methods for ICT usage. We also witness a number of fuzzy applications in different decision-making and decision-support contexts (Abdullah et al., 2022; Ahmad et al., 2022; Qiyas et al., 2022).

Hence, it is observed that there exists a variety of studies trying to measure different aspects of digitalization as well as utilization and maturity of ICT components. Different terms (digitalization, ICT maturity, ICT usage, Industry 4.0 maturity, business intelligence maturity, Industry 4.0 readiness) are used within quite different study contexts (such as SME context, regional context, country context, specific technologies such as cloud, service-oriented architecture). Recent studies directly focusing on the Industry 4.0 maturity are catching attention, and a significant diversity of metric sets with different aims, breakdowns and sub-criteria are also important to highlight. Therefore, it can be easily argued that the literature still lacks a consistent and lean set of metrics to measure maturity with a supply chain integration focus.

Literature review clearly supports the applicability and use of a wide range of multi-criteria approaches, along with the hybrid approaches combining more than one multi-criteria method. The use of AHP, ANP, TOPSIS and PROMETHEE with their hybrids appears to be the most frequently encountered ones.

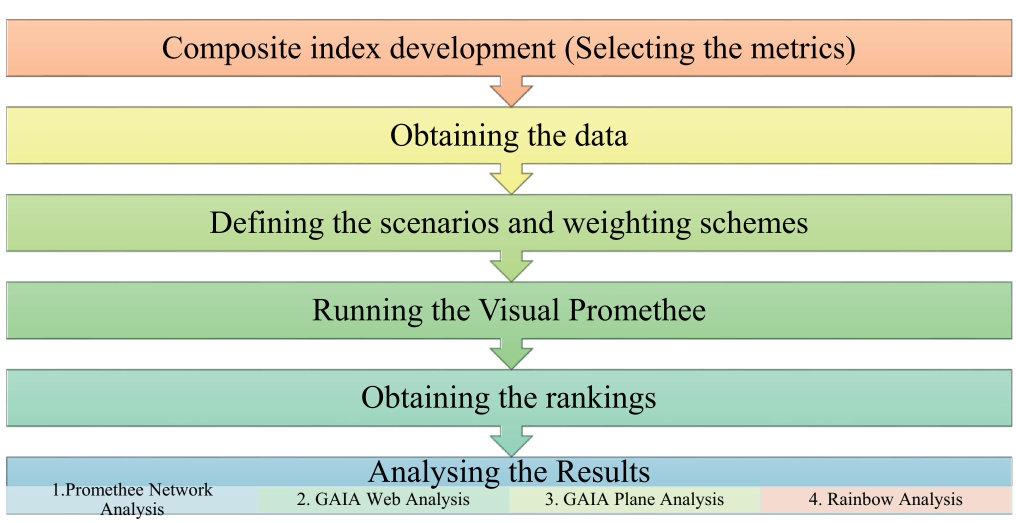
Our study differs from the above studies by providing a macro-level, composite metric for assessing the basic technological integrity level of the countries. The developed metric set is beyond the basic internet access/utilization or focusing on a specific technology. Specifically, it has a "supply chain integration" focus. Therefore, it contributes to the literature from integration perspective and fills the research gap by providing a lean set of metrics.

3. Methodology

Since the problem context inherently involves multiple criteria and ranking, a multi-criteria index is developed, and PROMETHEE MCDM approach is utilized. Steps of the methodology used in the study are depicted in the flowchart (Figure Figure 1).

Index development, data set and metrics utilized, multi-criteria method and scenario settings applied in the analysis are described in the following subsections. PROMETHEE analysis and sensitivity of the results according to the defined scenarios are performed using the Visual

Figure 1. Flowchart of the methodological steps applied in the study.



PROMETHEE software. Visual PROMETHEE offers a variety of visual tools for the analysis. Results of the analysis are reported in Section 4 by using the Network, GAIA Web (radar chart representation), rainbow, GAIA Plane and walking weights visual reporting options of Visual PROMETHEE software.

3.1. Composite index development

In this study, a composite index is developed utilizing the criteria and metrics available in the OECD Statistical Data Repository OECD.Stat under "ICT Access and Usage by Businesses" (OECD, 2021; https://stats.oecd.org/) to assess the basic technological integration level among business partners for different countries.

In its original form, OECD data utilized contains various groups of indicators for the year interval 2005–2021 related with the technological dimensions as explained below:

- A group metrics related with internet availability: 16 metrics
- B group metrics related with website and customer web ordering metrics: 2 metrics
- C group metrics related with electronic data sharing among partners: 5 metrics
- D group metrics related with online order receiving: 10 metrics
- E–F group metrics related with ICT policy: 4 metrics
- G group metrics related with recent technologies: 15 metrics
- H group metrics related with ICT skills and training: 7 metrics

Among this data set, most relevant 10 criteria and corresponding indicators related with the basic technological integration maturity among partners are selected. The criteria selected question the following capabilities: availability of website; availability of online ordering, reservation or booking via website; ERP software usage; customer relationship management (CRM) software usage; sharing electronically supply chain management (SCM) information with suppliers and partners; receiving orders over the network; placing orders over the network; usage of cloud computing services; and usage of social media. This metric set is selected towards measuring the connectivity of the partner enterprise systems within the supply chain. Core ERP integration, supply-side and customer-side integration, basic traceability across the partners and order connectivity on both sides are the focused aspects. Hence, the criteria and the percent-based metric set are chosen as the indicators of basic technological integration maturity among business partners from supply chain integration perspective. In other words, the most relevant metrics to measure the fundamental integration degree are included in the study. Various other advanced metrics corresponding to more advanced technologies (such as artificial intelligence, data mining, Internet of Things, 3D printer technology, big data analysis, business intelligence, manufacturing execution systems) are not included in the metric set since such a metric set would be towards measuring add-on technologies rather than fundamental supply chain integration. Furthermore, these advanced technologies are quite recent and not existing at comparable levels in different countries. Data for many of them (such as RPA and MES) were not available in the data set. For others (such as AI and IoT), data availability was limited by only 1 or 2 years. Therefore, we preferred to focus on the integrity-related metrics to obtain a consistent, comparable analysis horizon. Selected metrics coming from different levels of the original OECD hierarchy are given in Table 1. Such a selection also enabled us to keep the number of metrics at a reasonable level at a flat hierarchy. Therefore, we avoided complex and complicated metric hierarchy and obtained a lean, focused metric set. Undoubtedly, different metric sets can also be created in time with data availability.

Table 1. Metrics table (percentages are based on number of enterprises)

Metric code (as coded in the data set)	Metric description	Unit
B1	Businesses with a website or home page	%
B2	Businesses with a website allowing for online ordering, reservation or booking	%
C3A	Businesses using enterprise resources planning (ERP) software	%
C3B	Businesses using customer relationship management (CRM) software	%
C3D	Businesses using radio frequency identification (RFID) technology	%
C4	Businesses sharing electronically supply chain management (SCM) information with suppliers and customers	%
D1	Businesses receiving orders over computer networks	%
D7	Businesses placing orders (i.e. making purchases over computer networks)	%
G3	Businesses purchasing cloud computing services	%
K1	Businesses using social media	%

In this metrics set:

- Availability of the web site and social media indicators represent the general visibility.
- Availability of order receipt and order placement functionality represent the basic selling and purchasing connectivity on the supplier and customer ends.
- ERP usage corresponds to the core integration of enterprise business processes, where CRM and SCM usage represent the integrations level on the customer and supplier side, respectively. Therefore, when evaluated together, metrics of CRM + ERP + SRM are selected to serve as the indicator of overall supply chain integrity.
- RFID and cloud-related metrics are included in the selected criteria set as the most fundamental technologies providing the connectivity across partners. Thus, they are included in the metrics set to measure the readiness of the countries in terms of these technologies.

This metric set is original and valuable in

a) covering supplier, enterprise and customer sides;

b) handling the order connectivity for both supplier and customer ends;

c) handling information sharing across SCM partners;

d) covering the presence of well-proven RFID and cloud technologies;

e) including the visibility on the web and social media;

f) going beyond the basic internet access and utilization or focusing on a specific technology and having a "supply chain integration" perspective; and

g) providing a basic, practical, and macro perspective of technological maturity level of integration for the countries.

Being based on a proven and reliable database, this metrics set enables the utilization of consistent data for comparison and ranking across countries. It also reveals the dimensions for which countries should make improvements and investments.

3.2. Data set utilized

Due to variations in terms of yearly data availability and differences in country breakdowns for the 10 indicators utilized, the year 2019 is selected as the base year for the analysis to enable comparison at a common basis. It is important to highlight that many indicator values for the years 2020 and 2021 were missing in the data set, and the year 2019 corresponds to the beginning of the COVID-19 pandemic. Hence, the year 2019 was taken as the base.

Out of 36 countries, 8 were suffering from significant degree of missing data points in the data set. Therefore, they are discarded, and this resulted in 28 countries to be included in the analysis. The remaining few missing data are completed by intrapolating or extrapolating through the years or assuming the overall average of 36 countries, as appropriate.

3.3. MCDM approach used

Based on the index logic and the data set described, country-based ranking problem is solved by PROMETHEE. This method is one of the frequently used MCDM methods, aimed at building outranking relations and having a wide range of application areas (Behzadian et al., 2010; Gonçalves & Belderrain, 2012; Lopes et al., 2018). Mainly used for ranking problems, PROMETHEE requires from the analyst the preference function associated with each criterion along with weights defining their relative importance (Behzadian et al., 2010; Brans & De Smet, 2016). The method results in positive, negative and net flow calculations for every alternative, and a final ranking is obtained depending on the weighting schemes (relative importance of the criteria) used (Boatemaa et al., 2018; Brans & De Smet, 2016; Gonçalves & Belderrain, 2012; Mareschal & De Smet, 2009; Sapkota et al., 2018). While obtaining the ranking, preference degrees (a score between 0 and 1) are calculated, expressing how an alternative is preferred over the other (preference degree 1 means total or strong preference, whereas 0 means no preference at all). Pairwise comparisons are based on the preference functions associated with each criterion to reflect the perception of the criteria scale (Ishizaka & Nemery, 2013). Based on the positive and negative outranking flows, PROMETHEE I provides the partial ranking, and PROMETHEE II gives the complete ranking (Lopes et al., 2018). Hence, the method is characterized by clearness, stability and simplicity (Behzadian et al., 2010; Genç & Dinçer, 2013).

This study prefers PROMETHEE over many other MCDM methods due to the following: (a) structure of the decision problem required ranking among countries and multiple criteria from OECD data set, making PROMETHEE structurally fitted to the problem; (b) proven stability and simplicity of the method; (c) flexibility in weighting schemes; and (d) availability of various visual representation tools (GAIA Plane, Network Representation, GAIA Web Representation), allowing the decision-maker to geometrically interpret the results in multiple dimensions.

PROMETHEE steps are executed via Visual PROMETHEE with V-shape preference functions for all the criteria. Criteria units and thresholds are percentages. The preference values (P) are used as system suggested values based on the overall data set.

PROMETHEE is applied and sensitivity analysis is performed for the following six different scenarios with six different weight sets. Table 2 shows the scenarios and the weight sets utilized corresponding to each scenario:

These scenarios and weight sets are created by the consensus of six experts coming from manufacturing sector by gathering their expert opinions during two successive face-to-face meetings. Each scenario is described in detail as follows:

- Scenario 1: Equal weighting: All weights are considered equal at 10%.
- Scenario 2: Almost-equal weighting: Except for the relatively lower weights of 6% having basic web sites and social media usage, the rest of the criteria are given equal weights of 11% each.
- Scenario 3: ERP-focused scenario: Having basic web sites and social media usage are given relatively lower weights of 5%, having the ERP integration is given the highest score of 15%, and order connections at the customer and supplier side are given relatively high weights of 13%. This scenario puts higher importance on the web-based order connectivity and ERP connection in the overall evaluation and ranking.
- Scenario 4: CRM-focused scenario: Having basic websites and social media usage are given relatively lower weights of 5%, sharing CRM information is given the highest score of 15%, and order connections at the customer and supplier side are given relatively high weights of 13%. This scenario puts more weight on the web-based order connectivity and CRM in the overall evaluation and ranking.
- Scenario 5: SRM-focused scenario: Having basic websites and social media usage are given relatively lower weights of 5%, sharing SRM information is given the highest score of 15%, and order connections at the customer and supplier side are given relatively high weights of 13%. This scenario puts higher importance on the web-based order connectivity and SRM information sharing in the overall evaluation and ranking.
- Scenario 6: Social-oriented scenario: having basic websites, social media usage and CRM are given the highest weights of 15%, and the rest of the criteria are given significantly lower values. This scenario is created to provide a visibility perspective with a customer focus.

4. Comparative analysis and findings

4.1. Summary ranking results

Utilizing Visual PROMETHEE tool with six different weight sets and six scenarios, multi-criteria ranking problem is solved. Country-based ranking results and the p-net values obtained for the countries under each scenario are summarized in Table 3.

The following observations are made regarding the ranking results:

- Netherlands is consistently number 1 in all the scenarios, and Sweden is consistently at the bottom of the ranking.
- In general, many countries move one or two positions up or down in their ranking across scenarios, but their general positioning did not significantly change on the overall list. This is a sound indication that the metric set and the methodology applied converged to a relatively stable ranking. For Turkey and Korea, the results showed more variation across scenarios. Social scenario gave the lowest ranking of 18 (five steps down when compared to 13) for Turkey; and SRM scenario resulted in the lowest ranking of 19 (four steps down when compared to 15) for Korea.
- While Norway and Sweden are at the bottom of the list, Denmark appears relatively high in the rankings for all the scenarios.

Table 2. Weight sets (in percentage) utilized for six different scenarios

Scenarios	Criteria									
	B1	**B2**	**C3A**	**C3B**	**C3D**	**C4**	**D1**	**D7**	**G3**	**K1**
1: Equal weighting	10	10	10	10	10	10	10	10	10	10
2: Almost equal weighting	6	11	11	11	11	11	11	11	11	6
3: ERP-focused scenario	5	7	15	10	10	10	13	13	12	5
4: CRM-focused scenario	5	7	10	15	10	10	13	13	12	5
5: SRM-focused scenario	5	7	10	10	10	15	13	13	12	5
6: Social-oriented scenario	15	8	8	15	7	8	8	8	8	15

- France, Italy and Canada are lower in the ranking when compared with Turkey and exhibit quite different rankings when compared with Belgium, Spain and Germany.

Related with the phi net values, the following can be mentioned:

- Phi+ is a value that represents the strengths of the alternatives. In contrast, Phi− is a value that shows the weaknesses of the options when compared with other choices concerning each criterion and the given importance weights (Brans & De Smet, 2016; Lopes et al., 2018). Sum of the Phi+ and Phi- values, which represents the net flow (phinet) for each alternative, is the measure of net strength for each alternative.

- Dominance of Netherlands in all the scenarios is evident from the phi net values given in Table 3.

- Sweden has the lowest phi net value consistently for all the scenarios.

- When the phi net values for Turkey are considered, they appear consistently in the middle of the list.

For the sake of compactness, all the visual representations in the following subsections are provided for ERP-focused scenario.

4.2. Network representation

PROMETHEE Network representation for the equal-weight scenario is given in Figure Figure 2. This diagram is a powerful graphical tool of Visual PROMETHEE, indicating the results, that is a partial order of alternatives with phi values obtained for the countries. In other words, Figure Figure 2 shows which alternative outperforms which of the others, and which other alternatives are outperformed. Positioning of the Netherlands, Sweden, Norway and Turkey is clearly seen in this network representation. Consistent with the ranking given in Table 1, distancing for the Netherlands and Finland are highly differentiated, being the top 2 countries in the list. Sweden and Norway, which appear at the bottom of the list, are positioned far away in totally opposite direction.

It is striking to observe that Finland, Sweden, Norway and Denmark exhibit totally different rankings in Table 3 and totally different positionings in the network diagram despite the fact that all of them are developed Nordic countries with high welfare levels. Being at the top of the list, Finland exhibits a technological maturity much higher than developed OECD countries. Denmark is nearer to the main OECD cluster, Sweden and Norway showing the lowest maturity. This is a clear indication of significantly different technological levels among the Nordic countries, and insufficient technological investment of Sweden and Norway.

As can be seen from the ellipse on the left-hand side of the diagram, many European countries are positioned very tightly. The UK, Poland and France appear very close to each other, while Austria, Germany and Spain exhibit maturity levels very near to each other. Appearing at the middle of the ranking, Turkey exhibits a positioning closer to Denmark and Greece, and appears slightly differentiated from the main clustering behaviour.

The network representation diagram shows the phi+ and phi- values for each country. These values represent positive outranking flows (how a certain alternative dominates all other alternatives) and negative outranking flows (how a certain alternative is dominated by all the other alternatives), respectively (Genç & Dinçer, 2013; Genç, 2013; Hayez et al., 2011). Domination of the Netherlands and Finland are again evident with the highest phi+ values of 0.05 and 0.04. It is seen that many countries on the leftside have phi+ values of 0.01, showing the closeness of their maturity level in terms of technological performance. Sweden and Norway have the largest phi-values, showing their performance being dominated by the other countries.

Table 3. Rankings and phi net values for each country obtained by PROMETHEE under six scenarios

Countries	Equal		Almost equal		ERP		CRM		SRM		Social	
	Rank	Phi net	Rank	Phi net	Rank	Phi net	Rank	Phi net	Rank	Phi net	Rank	Phi net
Netherlands	1	0,0478	1	0,0522	1	0,0477	1	0,0442	1	0,0493	1	0,0363
Finland	2	0,0412	2	0,0450	2	0,0422	2	0,0388	2	0,0436	2	0,0312
Latvia	3	0,0126	3	0,0142	4	0,0134	4	0,0132	4	0,0139	6	0,0076
Brazil	4	0,0126	4	0,0138	3	0,0142	3	0,0111	3	0,0148	3	0,0074
Austria	5	0,0092	5	0,0100	5	0,0092	5	0,0085	5	0,0097	4	0,0067
Belgium	6	0,0074	7	0,0079	6	0,0081	6	0,0078	8	0,0085	5	0,0086
Spain	7	0,0071	6	0,0079	7	0,0080	7	0,0070	7	0,0086	8	0,0052
Germany	8	0,0059	8	0,0065	9	0,0052	9	0,0066	9	0,0092	9	0,0066
Denmark	9	0,0057	9	0,0059	8	0,0070	8	0,0051	6	0,0086	7	0,0055
Slovak republic	10	0,0051	10	0,0059	10	0,0047	10	0,0037	10	0,0045	10	0,0026
Slovenia	11	0,0006	11	0,0007	11	0,0008	11	0,0002	12	0,0009	12	−0,0002
Lithuania	12	−0,0005	12	−0,0005	12	0,0001	12	−0,0001	11	0,0014	11	0,0007
Turkey	13	−0,0015	13	−0,0013	13	−0,0020	14	−0,0014	13	−0,0009	18	−0,0014
United kingdom	14	−0,0020	14	−0,0025	14	−0,0024	13	−0,0019	14	−0,0015	13	−0,0034
Korea	15	−0,0025	15	−0,0027	15	−0,0028	18	−0,0025	19	−0,0028	17	−0,0029
Czech republic	16	−0,0032	17	−0,0034	16	−0,0032	17	−0,0034	16	−0,0024	15	−0,0030
Poland	17	−0,0032	16	−0,0031	17	−0,0033	16	−0,0036	15	−0,0054	16	−0,0023
Ireland	18	−0,0039	19	−0,0045	18	−0,0034	15	−0,0037	17	−0,0065	14	−0,0005
Greece	19	−0,0039	18	−0,0041	19	−0,0056	20	−0,0056	21	−0,0015	20	−0,0046

(*Continued*)

Table 3. (*Continued*)

Countries	Equal		Almost equal		ERP		CRM		SRM		Social	
	Rank	Phi net	Rank	Phi net	Rank	Phi net	Rank	Phi net	Rank	Phi net	Rank	Phi net
France	20	−0,0055	20	−0,0060	20	−0,0057	21	−0,0057	20	−0,0060	19	−0,0043
Canada	21	−0,0060	21	−0,0067	22	−0,0082	19	−0,0057	18	−0,0059	21	−0,0046
Italy	22	−0,0068	22	−0,0073	21	−0,0061	22	−0,0059	22	−0,0088	22	−0,0056
Luxembourg	23	−0,0124	23	−0,0138	23	−0,0132	23	−0,0118	23	−0,0131	23	−0,0084
Estonia	24	−0,0150	25	−0,0164	25	−0,0163	25	−0,0145	24	−0,0149	24	−0,0112
Hungary	25	−0,0153	24	−0,0164	26	−0,0155	26	−0,0145	25	−0,0168	27	−0,0126
Portugal	26	−0,0159	26	−0,0172	24	−0,0158	24	−0,0155	26	−0,0168	25	−0,0139
Norway	27	−0,0200	27	−0,0223	27	−0,0198	27	−0,0174	27	−0,0197	26	−0,0123
Sweden	28	−0,0378	28	−0,0419	28	−0,0372	28	−0,0333	28	−0,0501	28	−0,0274

4.3. GAIA Web representation
Another powerful aspect of PROMETHEE analysis is the geometric and visual reporting in the form of GAIA Web representations. Sample GAIA Web representations in the form of radar charts for the ERP-focused scenario are given in Figure Figure 3 for the Netherlands, Sweden, Turkey and the UK. These countries are selected to represent the top, bottom and mid-list countries in the ranking to be compared against Turkey.

As can be seen from Figure Figure 3, these radar charts provide compact, multi-dimensional and visual reporting of the PROMETHEE results in terms of all the criteria. Low performance of Sweden is clearly reflected on these radar charts, especially for C4 (information sharing in SCM) and C3D (RFID) dimensions. It is clearly seen that the UK and Turkey exhibit extremely similar maturity results.

4.4. GAIA plane
GAIA planes are vital and frequently used visual representations for geometrically interpreting the PROMETHEE results based on the principal component analysis (Alencar & Almeida, 2010; Behzadian et al., 2010; Genç & Dinçer, 2013; Gonçalves & Belderrain, 2012; Mareschal & De Smet, 2009; Sapkota et al., 2018). Based on net flow calculations, GAIA plane offers a two-dimensional view (Lopes et al., 2018) and groups similar alternatives in one area, showing the clustering. GAIA plane for the ERP-focused case is given in Figure Figure 4.

In GAIA plane, the criteria are represented by the labelled axes, and points represent the alternatives. Hence, criteria and countries can be seen on a two-dimensional space (Genç & Dinçer, 2013). The value representing the quality of the two-dimensional analysis is 94%, which represents a significantly high degree of quality for interpreting the results since values greater than 60 are considered reliable in the literature (Sapkota et al., 2018).

In GAIA planes, criteria corresponding to the longest vectors indicate more variable criteria (Gonçalves & Belderrain, 2012) and interpreted as the criteria that appear to be more powerful in discriminating the results (Sapkota et al., 2018). In the diagram, C4 (information sharing in SCM) and C3D (RFID) have relatively long axes. Therefore, C4 and C3D are the criteria that represent the highest degree of variability in the data set, showing that SCM integration and RFID usage are not stable across the countries. These criteria also stood out in the GAIA Web radar chart of Sweden in

Figure 2. PROMETHEE network representation (ERP-focused case).

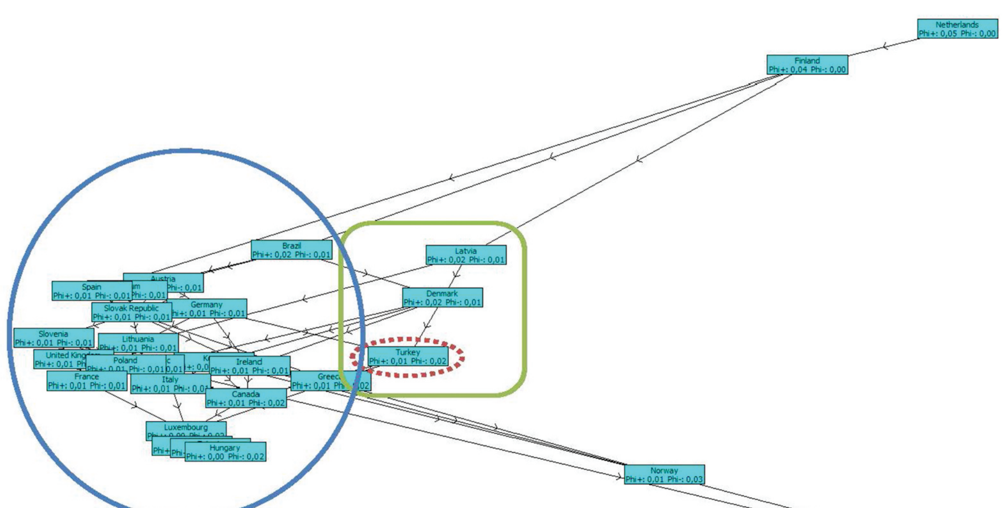
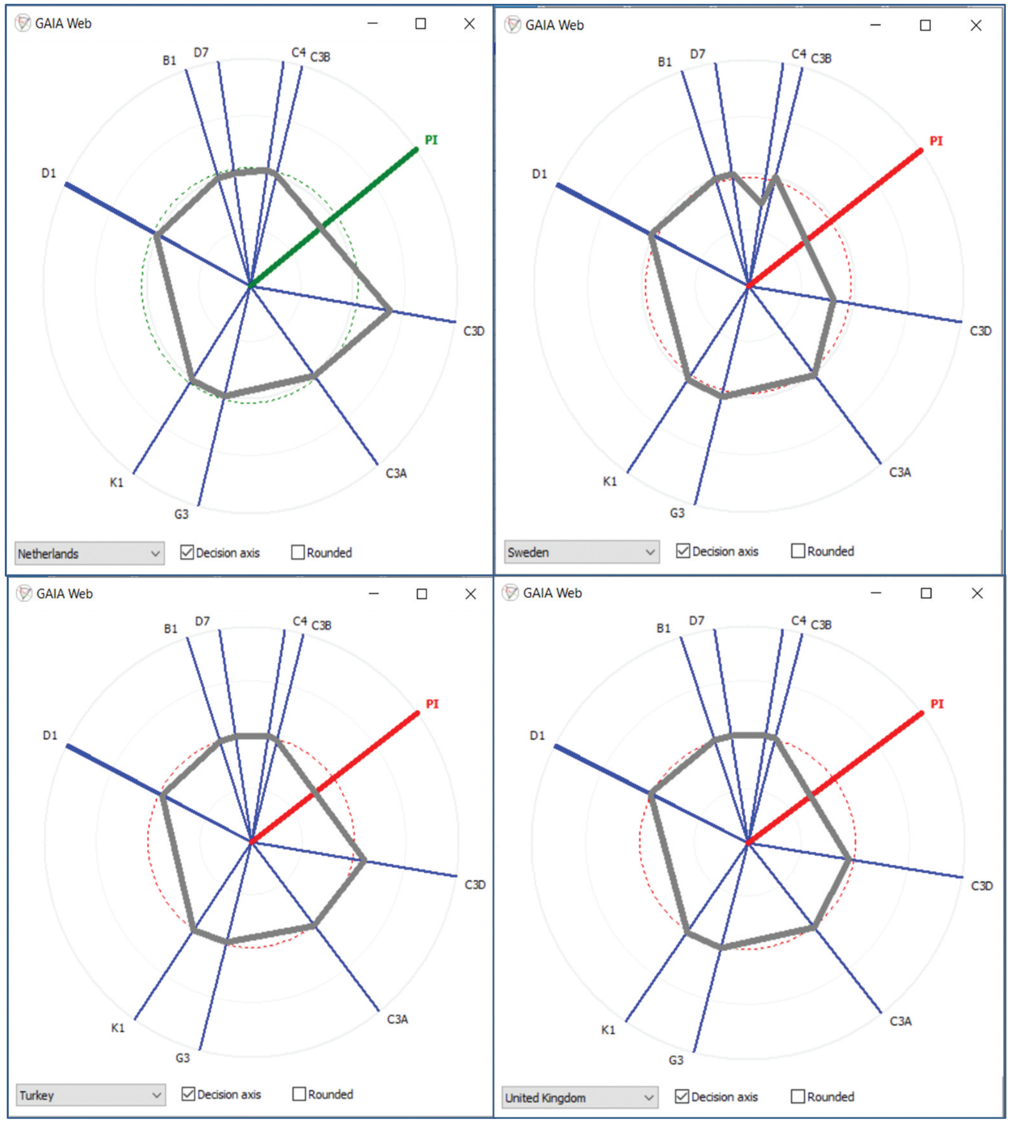


Figure 3. GAIA web representations for the Netherlands, Sweden, Turkey and the UK (ERP case).

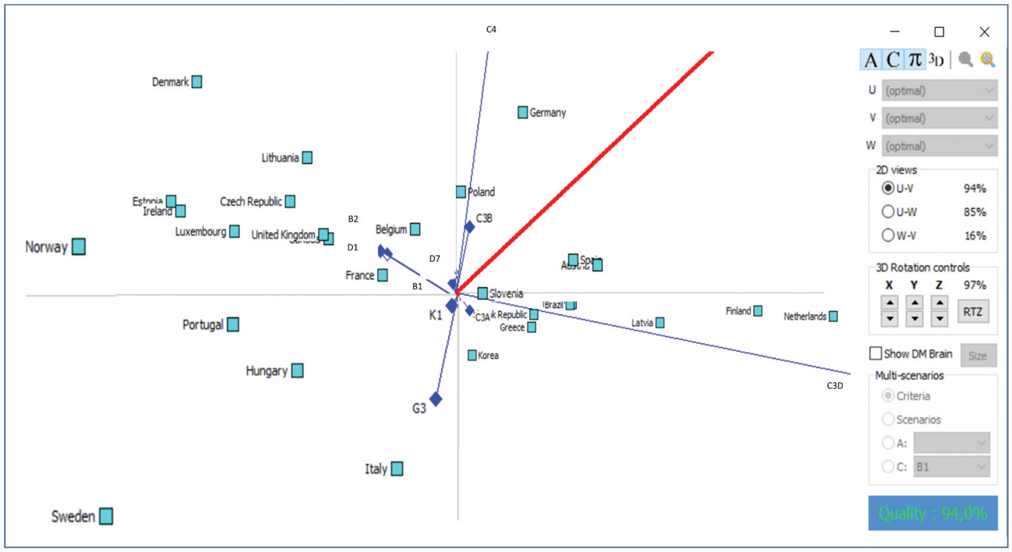


Section 4.3 as the dimensions having low values. Hence, these two criteria appear to be the main determinants of the maturity.

Criteria corresponding to vectors in orthogonal direction are the ones which are not statistically correlated (Gonçalves & Belderrain, 2012). Hence, it is interesting to see in our results that RFID usage and SCM information sharing are not statistically correlated. Results show that other criteria such as electronic order placement, receipt and ERP appear to be more correlated with the overall SCM information sharing.

Directions of B1 and D1 are totally aligned, hence the criteria of having a web site and receiving orders over the network are effective in the same direction. Similarly, C3B and C4 (use of CRM and electronic SCM information sharing, respectively) work in the same direction. It is interesting to see that G3 (cloud usage) has opposite direction with C3B and C4 (use of CRM and electronic SCM information sharing). This can be interpreted as the immaturity of the use of cloud services in CRM

Figure 4. GAIA plane for ERP-focused case.



and SCM information sharing. It appears that there exists significant non-cloud-based implementation of CRM and SCM information sharing for the countries analysed.

Intense localization of many European countries on the upper-left quadrant of the diagram is compatible with the main clustering obtained in Figure Figure 2 network representation. In this quandrant, many of the countries are aligned with B1 and D1 (having a website and receiving orders over the network, respectively). Again, there is a clustering along C3D (RFID usage) in the lower-right quadrant. As can be seen in the graph, relative positioning of many of the alternatives are too close to each other in these two quadrands. Sweden and Norway are positioned radically differently, being far away from the axes.

In GAIA analysis, the non-labelled axis (red line) is called as the decision stick (or the decision axis). It is obtained by projecting the weight vectors onto the GAIA plane, showing the current best direction for a compromise solution, and its length being related with the angle between the weight vector and the GAIA plane (Hayez et al., 2011; Sapkota et al., 2018). Decision stick length is interpreted in relation to the decision power, with long axes meaning stronger decision power, and short axes no decision power (Brans & De Smet, 2016). Therefore, the length obtained in the graph can be interpreted as representing a high level of decision power.

4.5. PROMETHEE Rainbow representation

The results are also reported in the rainbow diagram given in Figure Figure 5.

In this diagram, countries appear in the decreasing rank order from left to right. Components contributing to the positive and negative flows are indicated for each country. When summarizing the number of criteria which results in positive and negative flows, the Netherlands and Finland are positive in all the criteria, and Hungary has no positive criteria. Table 4 shows the count of the countries having positive and negative flows on the basis of the criteria used.

It is seen that B2 (online ordering), D1 (receiving orders over the network) and G3 (cloud) have positive effect in half of the countries and negative effect in the remaining half of the countries (14 positive, 14 negative countries). C4 (electronic SCM information sharing) has positive effect for 21 countries out of 28, and D7 (order placement) has positive effect on 18 countries out of 28. B1, C3A and C3B (website, ERP and CRM, respectively) are positive in 17 countries.

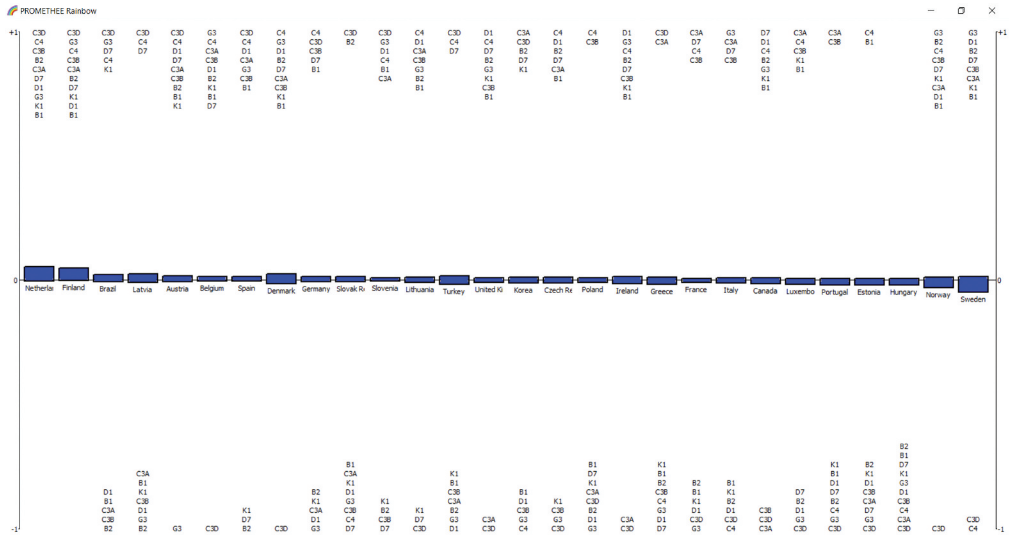


Figure 5. PROMETHEE Rainbow representation for ERP-based case.

It is seen that C3D (RFID), K1 (social media), B2 (online ordering) D1 (order receipt) and G3 (cloud) criteria are creating negative effects in 16, 15, 14, 14 and 14 countries, respectively (more than half of the countries). Hence, they represent the dimensions having high opportunity to improve the maturity of many countries if necessary; priority and attention are given to these criteria.

5. Discussion and conclusion

The analysis offered in Section 4 provided a clear picture of technological maturity for the 28 countries in the dimensions selected and their relative positioning with respect to each other. Hence, the dimensions in which each country has strengths and weaknesses are revealed. Undoubtedly, further similar visual reports can be obtained for any scenario or any other country (e.g. GAIA Web comparative diagram across any country).

The study has put forward the clear dominance of the Netherlands and Finland, mid-list positioning of Turkey, and low performance of Norway and Sweden among 28 countries. Turkey has positive outflows in three criteria but has negative outflows in seven criteria: social media,

Table 4. Count of countries having positive and negative flows on the basis of criteria

	Positive effect	Negative effect
B1	17	11
B2	14	14
C3A	17	11
C3B	17	11
C3D	12	16
C4	21	7
D1	14	14
D7	18	10
G3	14	14
K1	13	15

website, CRM, ERP, online ordering, cloud and receiving orders. Hence, as a country appearing at the middle of the list, Turkey has significant potential to obtain improvements in the dimensions of the core ERP system, order connections on both supplier and customer ends, as well as customer-centric aspects.

The approach followed has the following advantages:

- The systematic applied and the composite index developed out of the standard data set provide an overall ranking based on multiple criteria among the countries. The systematic allows for assessing the maturity in multiple dimensions for each country, and visual tools of PROMETHEE clearly reveal the dimensions in which countries have weaknesses or outperform the others.

- The study has used almost all of the reporting tools of Visual PROMETHEE. Thus, it has clearly demonstrated the strength of the applied methodology in terms of providing multi-dimensional and visual support to decision-makers. Policymakers can use these visual tools for an overall, multi-dimensional snapshot of the technological maturity within and across countries.

- Since the approach is based on a formal and standard data set, it can be refreshed as new yearly data becomes available. Therefore, tracking how the overall ranking and dimensional performances change throughout the years is possible. Improved or worsening overall rankings and performances in different dimensions can be monitored across and within the countries.

- Governmental authorities and policymakers which are in search of maturity indices in both digital and technological dimensions can benefit from our study as the basic set of metrics to enable county-based comparison.

- Improvements in this basic metric set can act a roadmap towards the improvements in more advanced IoT technological components.

- The approach can be used as a systematic macro-level benchmarking tool to guide the policymakers for (a) seeing the deficiencies under different dimensions and observing which dimensions to improve, (b) monitoring the change in the rankings across years, (c) setting yearly targets for rankings and dimensional performances, (d) selecting and updating the upper ranking countries as benchmark, (e) assigning priorities for the technological dimensions to be improved, (f) prioritizing their macro-level investment decisions for the dimensions having deficiencies or weaknesses and (g) enabling macro-level improvement decisions and strategies to be deployed more successfully across different sectors and companies, especially IT-related ones, after seeing a clear picture of the rankings and dimensions of weaknesses.

This study is limited with the data availability of the OECD database in terms of countries, time periods and the existing metrics set. It is important to highlight that metric set developed here can be extended or modified in time depending on the new requirements and future data availabilities regarding other technological components. The standard data set is also suited to develop other composite metrics. Different hierarchical, multi-level metrics can be developed depending on further needs. This study focused on PROMETHEE method. Different MCDM methods can also be applied with the selected metric set, and further comparative studies can be developed. Consequently, the authors believe that the study opens up many further research opportunities for comparing performance across the years (longitudinal studies), modifying the indices or developing new indices.

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Disclosure statement
No potential conflict of interest was reported by the authors.

Data availability statement
The data that support the findings of this study are openly available in: OECD Statistical Data Repository OECD.Stat (ICT Access and Usage by Businesses) at https://stats.oecd.org/

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