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Clustering Entrepreneurial and Innovative Universities in Turkey According to Their Relevance to Industry 4.0

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Abstract

Industry 4.0 differentiates production and business models through connecting embedded system, production technologies, and smart production processes. Preparing the young generation to this change is a challenge for higher education. In this study, the adaptation of the entrepreneurial and innovative universities in Turkey to Industry 4.0 is linked with their relevance level to Industry 4.0. To represent the relevance level of universities, a cluster analysis is put forward. Three criteria, named as the number of academic publications related to Industry 4.0, the number of physical structures that facilitate the adaptation to Industry 4.0, and the number of events organized by the universities within the Industry 4.0 concept, were selected for the clustering analysis. To access the number of academic publications of universities, ISI Web of Science database was used. "Industry 4.0" and its components were used as keywords. Both the websites of the each university and Google search results were used to access the values of remaining two criteria. The obtained data were used for K-means clustering analysis. The optimal number of cluster was determined as five with the elbow method. It is thought that the results of the study could be used as an indicator for universities to determine their Industry 4.0 road maps.

Keywords: Industry 4.0, Elbow method, K-means algorithm.

1. INTRODUCTION

The fourth industrial revolution-also named as Industry 4.0- has been the agenda of both businesses and academicians. It considers gathering data in real time, analyzing them, providing quality, faster, cheaper, and useful information about the system [2]. It allows monitoring physical processes with cyber physical systems. The robots can be work collaboratively with the people and communicate with each other. With the entering of smart

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production processes, connecting embedded systems, the production and business models have been changed. These changes have also leaded to differentiation in the ways of people works. The study of Janis and Alias [3] is a good example of this point. They defined the workforce needs, and competencies that are required by the Industry 4.0 with using systematic literature survey. The findings have shown that the tasks of low skilled, semi-skilled, and high skilled workers will differentiate with the introduction of the human-machine interface, advanced computation and digitalization. For the high skilled workers, the non- technical competencies such as problem solving and decision-making will come to the forefront especially.

It is expected that, qualified employees will be able to control work environments, which will radically transform. In this case, the education systems play a major role in raising qualified young generations. Especially, the adaptation of the higher education to this technological change is important. Dostal and Wang [4] emphasized this necessity in their study. The potential risks and possible benefits associated with the digital transformation were presented. Preparing the young generation for the threats of technological change in reality has been defined as a challenge. The inclusion of technological change in teaching is evaluated as critic.

Baygın et al. [5], Carutasu and Carutasu [6], and Lensing and Friedhoff [7] support adaptations of the curriculums to Industry 4.0. Baygın et al [5] suggested taking into consideration to the concept and principles of the Industry 4.0 in the curriculums. The laboratory practices were also presented as necessary activities. Carutasu and Carutasu [6] represented the advantages of using digital laboratories. By using ERP and Office 365, enterprise activities and internal workflow of companies were simulated and the professional and soft skills of graduates were measured. It is concluded that, these simulated or digital laboratories provide experiencing the real world business activities without fear of failure. Lensing and Friedhoff [7] focused on the mechanical engineering curricula. The conceptual design for the Internet of Things Laboratory is constructed which attract high school students, undergraduates, and graduates. The importance of working in interdisciplinary is also emphasized. This didactic design provides excellent conditions and options for the setting.

The study of Coskun et al. [8] is an important part of this literature for our research. The methodology of this study helps the selection of the criteria in our analysis. They focused on the adaptation of the engineering education to the requirements of Industry 4.0 vision. For this purpose, the road map was presented. It included three pillars which describe the changes to be conducted in the areas of curriculum development, laboratory concept and student club activities. The other important point of this study is the implementation of this framework in Turkish- German University. It is found feasible to adapt the engineering education to Industry 4.0 vision. Since the Industry 4.0 was introduced in the Hannover Fair by the Germans, it is meaningful to use the framework presented and implemented by Turkish- German University as a reference study.

This review shows that the emerging technologies have huge effect on the education programs. To overcome the new requirements of Industry 4.0, higher education programs should be viewed. This study aims to present the relevance to Industry 4.0 of entrepreneurial and innovative universities in Turkey with using K- means clustering algorithm. These universities are clustered according to three criteria. For defining these criteria, the approach in the study of Coskun et al. [8] is used. The remaining parts of this study are constructed as follows. Section 2 gives the methodology, materials, and methods of the study. The experimental results will be presented in Section 3. The summary of the results, limitations and the suggestions for the future works will be discussed in last section.

2. MATERIALS AND METHODS

There are 207 universities in Turkey. Following the new technological trends and the adaptation to requirements of the new industrial revolution are already important for all of them. However, to evaluate the relevance to Industry 4.0 of all universities is not the focus of this paper. When the list of universities is evaluated, it can easily be seen that some of them is newly established. For this reason, the availabilities of the selected criteria for these universities are impossible. Other challenge is related to the number of criteria in this study. Only three criteria were selected for clustering the universities. It cannot be very comprehensive for the comparison of all universities. Therefore, the focus of this study is limited with the Entrepreneurial and Innovative Universities in Turkey.

The list of Entrepreneurial and Innovative Universities in Turkey has been released by Turkey Scientific and Technological Research Institution (TUBITAK) annually since 2012. This list includes the first fifty universities, which assessed within five dimensions. These dimensions are “Scientific and Technological Research Competence”, “Intellectual Property Pool”, ”Cooperation and Interaction”, “Entrepreneurship and Innovation Culture”, and “Economic Contribution and Commercialization”. With using these five dimensions, entrepreneurship and innovation index is constructed. The aim of this index is measuring the performance of universities regarding the entrepreneurship and innovation. It also contributes to the development of entrepreneurship and innovation indirectly.

In this study, the 50 universities which are in the list of entrepreneurial and innovative universities index in 2018 [9], are evaluated. It is expected that, each university in this list notice the adaptation to requirement of new industrial revolution. The university which takes place near the top, has high relevance towards Industry 4.0.

Figure 1 represents the methodology of this study. It begins with data gathering for clustering. For this process, ISI Web of Science, Google search results and the websites of each university are used as data sources. The scores of universities for each criterion are obtained in this step. The definitions of the criteria and the searching processes are given in the following title.

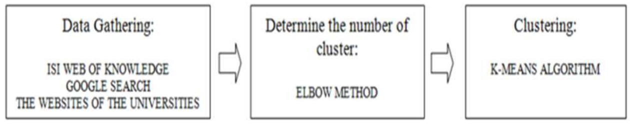

Figure 1 Methodology of this study

In Step 2, the number of clusters is determined with using elbow method. The “K” states the number of clusters for K-means algorithm. Since the success of the clustering algorithm depends on this user defined parameter, determination of the number of clusters is required systematic approach. With the elbow method, the performances of the clustering algorithm for different number of clusters are evaluated. The within- cluster sum of squares is used as a performance indicator of clustering for this method.

The last step of our analysis is clustering the 50 universities according to selected criteria and the determined number of clusters. For this purpose, K- means algorithm is used. It constructs the clusters with the principle of greater similarity within a cluster and greater difference between clusters. The steps of the algorithm are given in the following title. The constructed clusters are named as the relevance level to Industry 4.0. The relevance levels and the entrepreneurial and innovative index number of the universities are compared.

2.1. Inputs of the Clustering Analysis

The three inputs – in other words criteria- are selected for our analysis. These criteria are determined with the help of the study of Coskun et al. [8]. They presented a road map, consisted three pillars, for adaptation of the engineering education to the requirement of Industry 4.0. These three pillars describe the changes in the areas of curriculum development, laboratory concept, and student club activities.

The first pillar is related to the changes in the curriculum. It helps the application and improvement of Industry 4.0 concept in numerous areas. The second pillar, which is named as the changes in laboratory concepts, is presented for understanding the application of the Industry 4.0.

The last pillar represents the changes in the student club activities. These activities are key actors for disseminating the Industry 4.0 vision.

In our study, three criteria are associated with the three pillars of the Coskun et al. [8]. The first pillar in the roadmap, which is named as the changes in the curriculum, is represented as the number of academic publications of universities. To access the curriculums of the all programs in the universities is found a time consuming process. For this reason, the number of academic publications is used to reveal the contribution of universities to improvement of Industry 4.0 concept. ISI Web of Science database is selected to access the number of academic publications of universities. The list of keywords included “Industry 4.0”, “Fourth industrial revolution”, and the paradigms related to Industry 4.0 named as “Big Data”, “Internet of Things”, “Cyber security”, “System Integration”, “Autonomous Robots”, “Cloud Computing”, “Augmented Reality”, and “Additive Manufacturing”. These components pointed out that Industry 4.0 is a value added information processing process [2]. Therefore, they are added the list of keywords.

The Industry 4.0 was first introduced at the Hannover Fair in 2011. For this reason, only time is restricted from 2011 to 2019 during the searching process. The search results are refined by using the affiliation information on the database and the number of publications of each university is accessed. These results are divided by the number of academic member of universities to eliminate the effect of inequality in personal resources. It is assumed that the higher number of publications shows the high relevance towards Industry 4.0.

The second pillar of the roadmap is associated with the number of physical structures in this study. In roadmap, this pillar only represents the laboratories activities. It shows that the quality of education is not only depending on the personal content, but also related to the quality of the educational environment and tools [10]. The technology transfer offices, incubation centers, and techno parks are the important part of this environment. They facilitate the collaboration between university and industry and commercialization of the design of the academicians and students. This provides keeping pace with new technological changes for universities. Therefore, the content of the second pillar of the roadmap is extended for our study and the number of techno parks and technology transfer offices are also evaluated during our analysis. The values of the number of physical structures are obtained by searching the websites of each university. It is expected that the universities, which have the opportunity to access these types of foundations, adapt the new technological era easily. Therefore, they show the high relevance towards Industry 4.0.

The number of events organized by universities within the Industry 4.0 concept is the last criterion of this study, which is associated with the change in the student club activities in roadmap. The content of this pillar is also extended. The number of conferences, seminars, workshops, trainings, and meetings related to Industry 4.0 concept are evaluated. It is assumed that the student clubs related to Industry 4.0 support or held these types of organizations. The values of this criterion are accessed by searching the websites of each university and Google. It is expected that, the university, which organizes an event related to Industry 4.0 concept, attract the students. This facilitates realizing the importance of technological changes, attendance to the event and communicating with experts. Therefore, the high number of events related to Industry 4.0 shows the high relevance towards Industry 4.0.

2.2. Clustering Analysis: Integration K- Means Clustering and Elbow Method

Clustering analysis is a form of unsupervised classification. It partitions or groups a given set of data into disjoint clusters [11]. The goal is that the objects within a group be similar (or related) to one another and different from (or unrelated) to objects in other groups. The greater similarity within a group and the greater difference between groups mean the better clustering [12].

K- means clustering algorithm is the most commonly used one of the partitional clustering techniques [13]. The general logic of this algorithm is to divide a data set consisting of n data objects into a user-specified number of clusters (K) [13], [14].

The steps of the algorithm, which follow a simple way to cluster a given data set, can be summarized as follows [15]:

1. The algorithm starts with the choosing of initial centroids.
2. Each object is assigned to the closest centroid. Each collection of these objects, assigned to a centroid, is a cluster.
3. When all objects have been assigned, the centroid of each cluster updated based on the objects assigned to the cluster.
4. The assignment is repeated until no object changes its cluster.

The quality of clustering is measured by total sum of squares error (total SSE). It measures the total deviation of the response values. The smallest values for SSE mean that the centroids of clustering are a better representation of the points in their cluster. R- square can also be used for the evaluation of the performance of K-means clustering. It shows how successful the fit is in explaining the variation of the data. Therefore, the R-square value closer to 1 indicates that a greater proportion of variance is accounted by the model.

The advantages of this clustering algorithm are its low memory consumption, ease of implementation and high computational efficiency. However, the quality of the resulting clusters depends on the choice of the initial centroids. For this reason, determining the number of clusters is a fundamental issue for K-means clustering. Elbow method is a popular method to determine the optimal value of K. Its basic idea is that with the increasing of the clustering number of K, the total within-cluster sum of squares (WSS) is decreasing [16]. The WSS values of the clustering algorithm are calculated for alternative values of K in increments of one. If increasing the number of K does not contribute significantly to decrease of WSS value, this number should be an optimal number of clusters.

3. EMPIRICAL RESULTS

Before given the results of clustering algorithm, the performances of universities are discussed for each criterion. The scores of the universities for each criterion and the references of the criteria for four universities are presented in Table 1 (in Appendix 1) and Table 2[3] (in Appendix 2) respectively. Considering the number of academic publications related to Industry 4.0 for period between 2011 and 2019, "Middle East Technical University", "İstanbul Technical University" and "İhsan Doğramacı Bilkent University" are the first three universities with the 93 publications, 88 publications and 52 publications respectively.

When the number of physical structures is reviewed, the results show that each university in the list has at least one of the technology transfer office, techno park or incubation center. For this criterion, the programs and departments related to Industry 4.0 are also evaluated. "Istanbul Technical University" and "Dokuz Eylül University" have Industry 4.0 and Digital Transformation Certification Program. "Sakarya University" establishes Industry 4.0 Coordination Office in the faculty of computer and information science. "Bahçeşehir University" and "Yeditepe University" offer M.Sc. programs related to Industry 4.0. "Düzce University" is uniting with open campus policy and beginning open courses. These situations are added the universities scores for the number of physical structures criterion. The result of this search shows that only "Dokuz Eylül University" has the strategic plan about the Industry 4.0. Coordination Office of Industry 4.0 is established by the university to coordinate this plan.

When universities are ranked according to the number of events related to Industry 4.0 concept, "Yıldız Technical University", "İstanbul

[3] This table is limited to four universities due to space unavailability. We can provide the full table upon request by e-mail.

Technical University", and "Sakarya University" are placed among the first three. The existing platforms related to Industry 4.0 and its components are also evaluated for this criterion. While, "Ankara University" has the Community of Industry 4.0, Industry 4.0 platforms are constructed in "Boğaziçi University", "Gaziantep University", and "Middle East Technical University".

For clustering the universities according to these three parameters, K- means algorithm is performed. The number of clusters is determined by using elbow algorithm. The determination of K value with elbow method is choosing the number of clusters which contributes the significant decreasing in WSS value. The WSS values of clustering algorithm for different number of cluster number can be seen in Figure 2.

Number of Cluster	Result of WSS	The difference between WSS
2	104.4162	104.4162
3	75.2189	29.1973
4	52.9822	22.2367
5	41.1163	11.8659
6	36.1968	4.9195
7	31.7245	4.4723
8	29.2364	2.4881
9	24.6876	4.5488
10	23.8138	0.8738

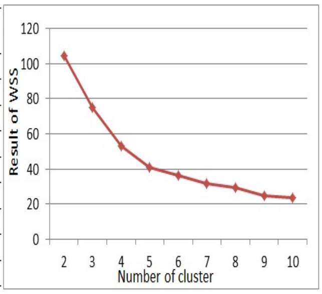

Figure 2 Number of clusters and WSS values

Through observations, when the K value is greater than five, the decreasing range of WSS tends to be flat. This means that adding another cluster does not improve the total WSS. According to the elbow method, the optimal number of clusters is determined as five.

When the clustering performance is examined, the total SSE is found 150. The fit explains 72.59% of the total variation in the clustering. Figure 3 shows the averages of each criterion for each cluster. While the horizontal axis represents the clusters, vertical axis represents the averages of each criterion. The average of the number of academic publications increases from cluster 1 to cluster 2, and then decreases from cluster 2 to cluster 5. The average of the number of physical structures increases from cluster 1 to cluster 4. However, the average of this criterion decreases from cluster 4 to cluster 5. The average of the number of events does not show gradually increasing or gradually decreasing from cluster 1 to cluster 5.

It is assumed that getting the higher averages for each criterion means the higher relevance to Industry 4.0. However, the cluster, which has the high averages for all criteria, does not existed in our analysis, or vice versa. For this reason, the averages of each criterion in clusters compare with the total averages of the each criterion in data set.

Cluster 3 has the high averages for all criteria while the cluster 5 has low averages for all. Therefore, the cluster 3 presents the universities, which shows "very high relevance to Industry 4.0" and the cluster 5 represents the universities which shows "very low relevance to Industry 4.0". When evaluating the average of other clusters, Cluster 2, cluster 4 and cluster 1 link to the "high relevance to Industry 4.0", "medium relevance to Industry 4.0 and "low relevance to Industry 4.0" respectively.

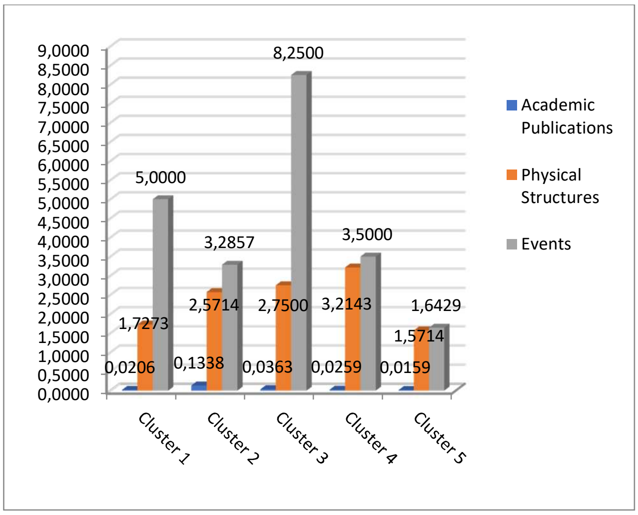

Figure 3 Comparison of averages of criteria in clusters

Clustering results are illustrated in Table 3. The sequence number of universities in entrepreneurial and innovative universities index is also given in the table to compare with the relevance level. The cluster sizes showed that, 14 out of 50 universities have been labeled as "very low relevance to Industry 4.0". It includes 4 foundation and 10 state universities. These 14 universities have low averages for three criteria. "Selçuk University" points out in this cluster. Its ranking in the index is better than the half of the universities. Especially, its low performance in the number of publications causes the assignment to very low relevance cluster.

The cluster of “low relevance to Industry 4.0” includes 9 state and 2 foundation universities. While “Gebze Technical University” and “Izmir Institute of Technology” are at the top 10 in entrepreneurial and innovative universities index ranking, they show low relevance to Industry 4.0. These situations result from their low performance in the number of events and the number of physical structures.

The cluster of “medium relevance to Industry 4.0” includes 14 universities. 10 state and 4 foundation universities exist in this cluster. While “Boğaziçi University” and “Hacettepe University” have high rankings in the index, they are assigned to the medium relevance to Industry 4.0 cluster. Their low performances in the number of events criterion cause these results. The performance of “Başkent University” also points out in this cluster. Its ranking is in the last positions in the index. Because of the advantages of its physical structures, it takes part in this cluster.

When the cluster of “high relevance to Industry 4.0” is evaluated, it is seen that one state university and 6 foundation universities fall into this cluster. “Middle East University” is the only state university in this cluster. Because of its ranking in entrepreneurial and innovative universities index, it is expected to show very high relevance to Industry 4.0. This situation is also in question for “Sabancı University” and “İhsan Doğramacı Bilkent University”. The reason for existing in high relevance to Industry 4.0 cluster is their low performance in the number of events criterion. “Istanbul Şehir University” shows good performance. While it is ranked as a last in the index, it falls into high relevance cluster. The number of publications related to Industry 4.0 supports its relevance level.

Finally, the cluster of “very high relevance to Industry 4.0” is evaluated. Only four universities fall into this cluster and all of them are state universities. The averages of all criteria in this cluster are higher than the total averages. The “İstanbul Technical University” and “Yıldız Technical University” are assigned to this cluster. It is the expected results, because of their high rankings in the index. “Dokuz Eylül University” and “Sakarya University” are also in this cluster. Especially, their good performances in the number of events criterion provide to exist in this cluster.

Table 3
The result of clustering

Sequence number in the index	University	Relevance to Industry 4.0	Sequence number in the index	University	Relevance to Industry 4.0
19	SELÇUK UNIVERSITY	Very Low	5	BOĞAZİÇİ UNIVERSITY	Medium
28	ABDULLAH GÜL UNIVERSITY	Very Low	8	HACETTEPE UNIVERSITY	Medium
29	MEDİPOL UNIVERSITY-İSTANBUL	Very Low	10	EGE UNIVERSITY	Medium
33	MARMARA UNIVERSITY	Very Low	13	GAZİ UNIVERSITY	Medium
35	KARADENİZ TECHNICAL UNIVERSITY	Very Low	18	ANKARA UNIVERSITY	Medium
36	FIRAT UNIVERSITY	Very Low	20	ANADOLU UNIVERSITY	Medium
37	İZMİR UNIVERSITY OF ECONOMY	Very Low	22	BURSA ULUDAĞ UNIVERSITY	Medium
40	MERSİN UNIVERSITY	Very Low	23	GAZİANTEP UNIVERSITY	Medium
42	HASAN KALYONCU UNIVERSITY	Very Low	24	AKDENİZ UNIVERSITY	Medium
43	NİĞDE ÖMER HALİSDEMİR UNIVERSITY	Very Low	25	KOCAELİ UNIVERSITY	Medium
45	ACIBADEM MEHMET ALİ AYDINLAR UNIVERSITY	Very Low	26	ATILIM UNIVERSITY	Medium
47	DÜZCE UNIVERSITY	Very Low	38	YAŞAR UNIVERSITY	Medium
48	ÇANAKKALE ONSEKİZ MART UNIVERSITY	Very Low	39	ÇANKAYA UNIVERSITY	Medium
49	TEKİRDAĞ NAMIK KEMAL UNIVERSITY	Very Low	46	BAŞKENT UNIVERSITY	Medium
7	GEBZE TECHNICAL UNIVERSITY	Low	1	MIDDLE EAST TECHNICAL UNIVERSITY	High
9	İZMİR INSTITUTE OF TECHNOLOGY	Low	3	SABANCI UNIVERSITY	High
12	İSTANBUL UNIVERSITY	Low	4	İHSAN DOĞRAMACI BİLKENT UNIVERSITY	High
17	ERCİYES UNIVERSITY	Low	11	KOÇ UNIVERSITY	High
27	ÇUKUROVA UNIVERSITY	Low	14	ÖZYEĞİN UNIVERSITY	High
30	SÜLEYMAN DEMİREL UNIVERSITY	Low	15	TOBB UNIVERSITY ECONOMICS AND TECHNOLOGY	High
31	YEDİTEPE UNIVERSITY	Low	50	İSTANBUL ŞEHİR UNIVERSITY	High
32	PAMUKKALE UNIVERSITY	Low	2	İSTANBUL TECHNICAL UNIVERSITY	Very High
34	ATATÜRK UNIVERSITY	Low	6	YILDIZ TECHNICAL UNIVERSITY	Very High
41	ESKİŞEHİR OSMANGAZİ UNIVERSITY	Low	16	DOKUZ EYLÜL UNIVERSITY	Very High
44	BAHÇEŞEHİR UNIVERSITY	Low	21	SAKARYA UNIVERSITY	Very High

4. CONCLUSION

Industry 4.0 comes into view with the need for new concepts, skills, and qualifications. To equip the students with these new requirements of industry, the universities are the key actors. The purpose of universities is not only providing proficiencies and skills according to major; but also promoting their students for independent search for getting new knowledge and practical techniques. Their efforts during the adaptation of new technological era ensure knowledge and development of competencies.

In this study, the level of relevance towards Industry 4.0 of the entrepreneurial and innovative universities in TUBITAK list (the first 50 universities) is presented. For this purpose, three criteria are selected. They are named as the number of academic publications, the number of physical structures, and the number of events organized by the university. The optimum number of cluster for the K- means clustering algorithm is determined as five with using elbow algorithm. For this reason, universities are divided to five clusters, which are labeled from “very high relevance” to “very low relevance”.

The results show that the half of the universities shows very low or low relevance towards Industry 4.0. Only, “Dokuz Eylül University” has the strategic plan for this new era. The number of constructed programs, platforms, and centers related to Industry 4.0 are incapable. However, providing basis knowledge and infrastructure for the applied training and preparing the students to the opportunities and threats of the real world should be the major role of universities.

When the number of universities in high relevance and very high relevance clusters are considered, 11 universities are assigned to them. The 5 state and 6 foundation universities exist in these clusters. It means that there is no difference between the state and foundation universities relevance to the Industry 4.0.

It can be also seen that, the number of events organized by the universities has an important role during the clustering. The universities, which have high performance for this criterion, show high relevance to the new era. This result reminds the importance of the promoting the willingness of students for getting new knowledge, research methods and practical techniques with the congress and conferences.

The limitations of this study are summarized in two fold. The first one related to the number of criteria. According to the study of Coskun et al. [8], the number of academics publications, physical structures and events are used for this research. Different parameters, which show the relevance towards Industry 4.0 such as curriculum development, can also be added. The second limitation is related to the contents of the criteria. Only the quantitative aspects of the each criterion are evaluated for this study. However, the qualitative aspects have also important role. For the number of academic publications, the number of citations to the studies can be considered to show the quality of the paper. For the number of physical structures criterion, the number of projects conducted in these centers, the number of collaborations with the industry and the number of technological firms in techno parks can be evaluated. They are very good indicators to show the performances of these structures. The impacts of the events related to Industry 4.0 can be used to represent the quality of the number of events criteria. The number of attendance, the number of keynote speakers and the number of workshops given during the organizations can be good indicators to consider this impact.

As a future work, the qualitative aspects of the indicators will be taken into account. The content of the study can also be broadened with using alternative keywords during the web search and using alternative databases such as Science Direct, ULAKBİM, and Scopus. If the number of criteria is increased and the content of the study is broadened, all universities in the Turkey will be clustered according to their relevance to Industry 4.0.

Appendix 1

Table 1
Industry 4.0 related statistics of universities

#	University	The number of academic member	The number of academic publications	The number of physical structures	The number of events organized within the Industry 4.0 concept
1	MIDDLE EAST TECHNICAL UNIVERSITY	829	93	3	4
2	İSTANBUL TECHNICAL UNIVERSITY	1109	88	3	8
3	SABANCI UNIVERSITY	203	33	3	4
4	İHSAN DOĞRAMACI BİLKENT UNIVERSITY	352	52	2	4
5	BOĞAZİÇİ UNIVERSITY	465	39	4	5
6	YILDIZ TECHNICAL UNIVERSITY	897	30	3	10
7	GEBZE TECHNICAL UNIVERSITY	272	10	1	6
8	HACETTEPE UNIVERSITY	1807	10	3	3
9	İZMİR INSTITUTE OF TECHNOLOGY	189	12	2	5
10	EGE UNIVERSITY	1668	15	3	3
11	KOÇ UNIVERSITY	393	49	2	2
12	İSTANBUL UNIVERSITY	1882	40	2	5
13	GAZİ UNIVERSITY	1439	51	3	4
14	ÖZYEĞİN UNIVERSITY	197	35	2	4
15	TOBB UNIVERSITY ECONOMICS AND TECHNOLOGY	218	24	3	3
16	DOKUZ EYLÜL UNIVERSITY	1629	24	3	7
17	ERCİYES UNIVERSITY	1074	10	2	4
18	ANKARA UNIVERSITY	1767	16	4	4
19	SELÇUK UNIVERSITY	1101	5	2	2
20	ANADOLU UNIVERSITY	730	20	4	5
21	SAKARYA UNIVERSITY	842	15	2	8
22	BURSA ULUDAĞ UNIVERSITY	1117	4	3	3
23	GAZİANTEP UNIVERSITY	672	12	3	5
24	AKDENİZ UNIVERSITY	1299	11	3	2
25	KOCAELİ UNIVERSITY	957	20	3	5

Table 1
Industry 4.0 related statistics of universities (cont.)

#	University	The number of academic member	The number of academic publications	The number of physical structures	The number of events organized within the Industry 4.0 concept
26	ATILIM UNIVERSITY	231	13	3	1
27	ÇUKUROVA UNIVERSITY	1021	3	2	4
28	ABDULLAH GÜL UNIVERSITY	82	8	1	1
29	MEDİPOL UNIVERSITY-İSTANBUL	646	7	1	1
30	SÜLEYMAN DEMİREL UNIVERSITY	859	11	2	5
31	YEDİTEPE UNIVERSITY	540	9	1	5
32	PAMUKKALE UNIVERSITY	974	6	2	5
33	MARMARA UNIVERSITY	1675	16	1	3
34	ATATÜRK UNIVERSITY	1532	15	2	4
35	KARADENİZ TECHNICAL UNIVERSITY	941	19	2	2
36	FIRAT UNIVERSITY	960	33	2	1
37	İZMİR UNIVERSITY OF ECONOMY	209	6	2	3
38	YAŞAR UNIVERSITY	192	7	3	2
39	ÇANKAYA UNIVERSITY	183	8	3	4
40	MERSİN UNIVERSITY	778	3	2	1
41	ESKİŞEHİR OSMANGAZİ UNIVERSITY	813	9	2	5
42	HASAN KALYONCU UNIVERSITY	174	0	1	2
43	NİĞDE ÖMER HALİSDEMİR UNIVERSITY	499	0	2	0
44	BAHÇEŞEHİR UNIVERSITY	471	17	1	7
45	ACIBADEM MEHMET ALİ AYDINLAR UNIVERSITY	468	1	1	0
46	BAŞKENT UNIVERSITY	882	4	3	2
47	DÜZCE UNIVERSITY	544	5	2	3
48	ÇANAKKALE ONSEKİZ MART UNIVERSITY	962	2	1	2
49	TEKİRDAĞ NAMIK KEMAL UNIVERSITY	532	0	2	2
50	İSTANBUL ŞEHİR UNIVERSITY	148	15	2	2

Appendix 2

Table 2
The snapshot of the data set including references of criteria

#	University	Number of Academic Member (YÖK- Last Access 20.01.2020)	Number of Academic Publications (ISI Web of Science- Last Access 20.01.2020)	Physical Structures of Universities (Websites of the Universities- Last Access 21.01.2020)	Link of Events Organized by Universities within the Industry 4.0 Concept (Websites of the Universities and Google Search- Last Access 22.01.2020)
1	MIDDLE EAST TECHNICAL UNIVERSITY	829	93	Teknolojik Dönüşüm/Endüstri 4.0 Platformu, ODTÜ Teknokent, ATOM	https://www.facebook.com/METUSPS/posts/1522567977775687/ https://twitter.com/odtugimer/status/826402235844268034 http://www.milscint.com/tr/savtek-savunma-icin-endustri-4-0-paneliyle-kapanisi-yapti/ https://ymg.odtuvt.org.tr/
2	İSTANBUL TECHNICAL UNIVERSITY	1109	88	İTÜNOVA TTO, İTÜ Arı Teknokent, İTÜ ÇEKİRDEK	https://www.endustri40.com/dijital-donusum-ve-endustri-4-0-itu-is-dunyasi-zirvesi/ http://www.hurriyet.com.tr/kampus/itude-saglikta-endustri-devrimi-icin-onemli-bulusma-40431392 https://twitter.com/ieeeitutk/status/842052911844720640 https://etkinlik.webrazzi.com/etkinlik/detay/24-itu-emos-sanal-ronesans/698 http://www.milliyet.com.tr/ekonomi/endustri-4-0-yerine-milli-teknoloji-hamlesi-2428479 https://erphaber.com.tr/itu-endustri-muhendisligi-bolumunde-uygulamali-caniaserp-egitimleri-basliyor/ https://biletino.com/tr/e-4m6/elektrikli-araclar-zirvesi-2018/ https://itusem.itu.edu.tr/egitimler-ve-programlar/isletme-fakultesi-sertifika-programlari/endustri-40-ve-dijital-donusum-uzmanligi-sertifika-programi
3	SABANCI UNIVERSITY	203	33	Sanayi İşbirlikleri ve Teknoloji Lisanslama Ofisi (I·LO), SUCool, Boğaziçi Üniversitesi İnovita	https://gazetesu.sabanciuniv.edu/2017-07/sanayide-dijitallesme-stratejileri-calistayi-sabanci-universitesi-ev-sahipliginde https://www.endustri40.com/maktek-avrasya-endustri-4-0-semineri/ https://biletino.com/tr/e-41v/buyuk-bulusma-18-mega-trendler http://www.aia-istanbul.org/etkinlikler/akilli-enduestri-ve-enduestri-4-0-eurostars-ikili-goeruesme-etkilnigi-28-mayis-2019-liege
4	İHSAN DOĞRAMACI BİLKENT UNIVERSITY	352	52	Bilkent Üniversitesi TTO, Bilkent Cyberpark	http://web2.bilkent.edu.tr/ttoweb/2017/07/24/endustri-4-0-proje-uretme-calistayi-ve-eslestirme-etkinligi/ http://web2.bilkent.edu.tr/ttoweb/2017/05/26/endustri-4-0-adaptasyon-sureci/ https://www.bilkent.edu/www/ctis-i-endustri-4-0-ogan-ozdogan-kidemli-cozum-satis-yoneticisi-sap-dogu-kampus-c-binasi-sinif-no-cd-b01-900-22-subat-tr/ https://www.linkedin.com/pulse/turizm-40-etkinli%C4%9Fi-bilkentmezunlar-merkezi

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Authors' Contribution

TD: supervision, conceptualization, methodology, writing-revision and finalizing.

ÖV: literature review, methodology, data analysis, experimental study, writing initial draft.

AD: supervision, conceptualization, methodology, writing-revision and finalizing.

The Declaration of Ethics Committee Approval

The authors declare that this document does not require an ethics committee approval or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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