**GREEN DIGITAL TRANSFORMATION IN MANUFACTURING**

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**Abstract**

Digitization research describes the regulations on information systems since the late 1990’s. With the digital explosion of streaming, the way data is shared, produced, and communicated to its owners has changed dramatically. An important research area analyzes the optimization of digital technologies to increase investment innovation performance or measurement results. With the use of DT (digital technology) in manufacturing, traditional industry exists today as a process with smart technologies. The biggest difference between traditional production systems and the production systems of the future is the digital transformations experienced in robots, unmanned factories, autonomous systems, big data, IoT (internet of things) patients. Along with these developments, investment also contributes to green. Times are used in the manufacturing process in modern business models. These models can be listed as artificial intelligence, smart factory / laboratory, military factory of the future, electronic business, digital business, electronic manufacturing system and web systems. Concepts such as modern production process Approaches, just-in-time production, rapid manufacturing, holonic manufacturing, green manufacturing, lean manufacturing, cloud-based manufacturing systems are new concepts based on the literature. While producing by carrying out the digital transformation and green manufacturing process together, it was also used for even lower energy consumption. The growth of the economies and the increase in competition are due to production, especially the production of "value". The most strategic and non-critical one to play a role in this process is the "Digital Transformation", which has emerged with the adaptation of the advances in information technologies to the manufacturing and business world. Therefore, I will examine the green and digital output AHP, TOPSIS and VIKOR methods in the manufacturing sector, with the direction taken from TEKNOROT OTOMOTİV ÜRÜNLERİ SAN.VE TİC.A.Ş, which is a good example of digital transformation.

**Keywords:** Green, Digital Transformation, Manufacturing, R&D, Holonic Manufacturing

# INTRODUCTION

With the rapid technological developments, international competition, the importance of efficiency and quality, the spread of information technology, computer-based production and design techniques, etc. The development of innovations has put the classical industrial relations system in search of restructuring. [1]

In terms of working history, the oldest change has been experienced with the industrial revolution. With this change, while production took place in factories with the help of machines transferred by steam power, the value and importance of work gained a positive meaning incomparable to previous societies. The current level of the manufacturing sector and its competitive advantage is an important element among the indicators of the technological development and welfare level of the countries [2]. Stable growth in the economies of Western countries started to slow down after the 1970s. While the crises experienced with the oil shocks, the unions were seen as faulty and the increase in unemployment with inflation, the employee-employer relationship in the working life deteriorated over time. Information technologies that emerged since the 1970s not only developed the automation of production systems, but also paved the way for digitalization. Thus, the new process that started with digitization and progressed with the transition to systems that connect the physical world to the virtual computing world with the help of sensors, that is, cyber-physical systems that took their place in the literature as industry 4.0 in 2000, initiated the digital transformation. This transformation emerges as a set of values consisting of IoT (Internet of Things), AI (Artificial Intelligence) and CPS (Cyber-Physical Systems), which play a major role in the formation of smart factory systems.

Green manufacturing encompasses production systems that have low environmental impact, have the highest efficiency, contain very low or zero waste, and do not pollute the environment. With this definition, green production recycling can be considered within the framework of activities that have the prevention or reduction of waste and environmental pollution and green product design. Green product design is the process of producing products whose effects on the environment are minimized through their design, composition and use throughout their life cycle. It is to emphasize that it can create a competitive advantage by reducing negative environmental effects and increasing productivity. Thus, it is aimed to spread green manufacturing practices in the manufacturing industry of our country.[3]

It is thought that this study is needed due to insufficient information and resources about green and digital transformation in our country. The digital transformation created by the digitization and digitization process and the green digital transformation in manufacturing will be evaluated with the AHP (Analytical Hierarchy Process), TOPSIS method and VIKOR method within the framework of the Industry 4.0 phenomenon. As a result of this evaluation study, it aims to show which criteria should be given more importance to those working in the manufacturing sector and to show the importance degrees of alternatives that are important for businesses aiming to switch to digital transformation in manufacturing.

As carbon dioxide emissions increase from year to year, countries around the world have agreed to reduce their greenhouse gases. Green development is the key to achieving carbon peak and carbon neutrality, as well as the key to improved production, livable life and beautiful ecology. [4 ] The green development of the manufacturing industry has formed a consensus that also needs its high-quality development [5]. Under the background of peak carbon and neutral carbon, low carbon and energy saving are the general trends of manufacturing improvement and transformation, and also the inevitable result of high-quality development of the manufacturing industry[6]. How to achieve green and low-carbon development while reducing costs and increasing efficiency in the manufacturing industry has become the focus of business survival and competitiveness. "Green + smart" is an important link to improve the competitiveness of digital green manufacturing enterprises [7]. The empowerment of digital technology is key to accelerating the greening and intellectualization of the manufacturing industry[8].

Currently, digital technology is penetrating widely in production and life, and the digital economy is booming. Digital industrialization and industrial digitization are accelerating. The deep integration of the digital economy and the real economy has become an important way to promote the green and high-quality development of the manufacturing mode of production [9] On the one hand, the digital economy not only effectively improves the production process and improves the efficiency of equipment operation, but also improves the accuracy of production process management. Production efficiency, energy savings and emission reduction are improved through smart collaborative management [10] On the other hand, the digital economy can effectively optimize the resource allocation model. Digital infrastructure in industrial internet, big data, artificial intelligence and other fields can realize the integration and sharing of various resource elements in different industries and businesses. Resource allocation efficiency helps to be further improved through digital technology [11]. In addition, the main production factor of the digital economy is data. Data features high efficiency, cleanliness, low cost and repeatability [12]. Therefore, the traditional industrial structure and ecosystem can only be optimized when the data elements are used well to accelerate the deep integration of the digital economy with the real economy.

Digital Transformation (DT) refers to the idea of new products or services driven by an increasing number of innovations and use of digital technologies. This move towards products is due to the fact that DT must be driven by a broad business strategy [13]. The purpose of DT is limited to a group or business area as it works for the entire company [14]. The potential of digital technologies enables the development of new sustainable business models that still need to gain legitimacy to be adopted [15].

A company seeking good economic performance must meet the economic, environmental and social requirements of its performance[16]. Sustainability in the environmental context is included in the strategy of companies in order to minimize their environmental impacts, provide commercial benefits, and increase their performance and competitiveness in the market in which they operate [17].

To summarize, current studies focus on green innovation assessment and high-quality development of the manufacturing industry. There is little research on the convergence of green transformation and digital transformation. There is a lack of research on the effective integration of green and numbers. Relevant index systems and evaluation methods of digital green transformation in the manufacturing industry are explained systematically. There is a lack of research on macro policies and micro countermeasures based on improving the level of development of the regional green digital transformation. Therefore, in this study, the development path of digital green transformation in the manufacturing industry will be analyzed. An evaluation index system of the green digital transformation level will be established. In theory, this study will establish the research perspective and method of green digital transformation assessment in the manufacturing sector.

# LITERATURE REVIEW

Since there is not much research on green digital transformation in manufacturing, generally dealt with academic sources [18-26]. The sources in the literature, which was inspired by the determination of the criteria in this research are indicated in Table 1.

Table 1 – Literature Review Table

|  |  |  |  |
| --- | --- | --- | --- |
|  | METHOD | CONTRIBUTION | CRITERIA |
| Savastano, M., Amendola, C., Bellini, F., & D’Ascenzo, F. (2019). Contextual impacts on industrial processes brought by the digital transformation of manufacturing: A systematic review. Sustainability, 11(3), 891 | Innovation Management, Operations Management and Information systems | Conceptualization, MS; Data optimization, MS; Official analysis, MS; Research, MS; Methodology, MS; Project management, FD; Resources, CA | Technology/Process Type,Country/Regional Context,Focus/Main Topic,Field/Research Area,Sector/Industry/Company Size, |
| Xue, L., Zhang, Q., Zhang, X., & Li, C. (2022). Can digital transformation promote green technology innovation?. Sustainability, 14(12), 7497. | Variable Selection | Conceptualization, LX and QZ; data optimization, QZ; formal analysis | Green technology innovation Degree of digital transformation Financing constraints Government subsidy Business age |
| Yin, S., Zhang, N., Ullah, K., & Gao, S. (2022). Enhancing digital innovation for the sustainable transformation of manufacturing industry: a pressure-state-response system framework to perceptions of digital green innovation and its performance for green and intelligent manufacturing. Systems, 10(3), 72. | AHP method | Conceptualization, SY and NZ; methodology, SY; software, SG; verification, SY and NZ; writing—original drafting, SY; writing—reviewing and editing, | Pressure system(PC),State system(SC),Response system(RC) |
| YANKIN, F. B. (2019). DİJİTAL DÖNÜŞÜM SÜRECİNDE ÇALIŞMA YAŞAMI. Trakya Üniversitesi İktisadi ve İdari Bilimler Fakültesi E-Dergi, 7(2), 1-38. | Empirical Analysis | Cloud computing applications, within the company and between companies. Because it is web-based compared to traditional methods. It makes significant contributions to the profitability of companies by increasing productivity. | Fiber Infrastructure(Spine + Access),High SpeedBroadband InternetNumber of Subscribers |
| YALÇINER, D., & TAŞKIN, D. H. (2019). İmalat Bilişim Sistemleri: Dijital Dönüşümde Temel Anahtar. Ankara: Iksad Publications. | Analytical Hierarchy Process(AHP) | According to the results of this study, new developments for Industry 4.0It is necessary to give importance to vocational education in accordance with technologies andIt has been stated that the demand for skilled labor will increase. | Hardware cost capitalSoftware cost capitalProject maintenance costCurrent maintenance costEducation costInstallation costData transfer costLabor savingsSubcontracting savings |
| Etyemez, A., & Güngör, F. (2018, November). Dijital Dönüşüm Ve Makine İmalat Sektöründe Olası Etkileri. In 6th International Symposium on Innovative Technologies in Engineering and Science (pp. 9-11). | Create a poll | Which jobs and tasks will decrease with digital transformation in the machinery manufacturers sector, which new jobs andIt has been researched that professions will come to the fore | Gender, age, education level, position at work, Industry 4.0 knowledge, businessabout how many years it has been operating, the number of employees and its technologies. |
| Feroz, A. K., Zo, H., & Chiravuri, A. (2021). Digital transformation and environmental sustainability: A review and research agenda. Sustainability, 13(3), 1530. | Systematic literature review (SLR) | Conceptualization, and Formal analysis, Methodology, Validation | Social, mobile, analytics cloud and Internet of Things, artificial intelligence and digital technologies involved and their disruptions in environmental sustainability |
| Wang, H., Cao, W., & Wang, F. (2022). Digital Transformation and Manufacturing Firm Performance: Evidence from China. Sustainability, 14(16), 10212. | Text Analysis Method | Conceptualization, methodology, software, verification, formal analysis, WC; investigation, HW; resources, data remediation, authoring—original drafting, HW; writing—analyzing, editing, visualizing | Company sizeThe nature of the propertyFinancial leverageEnterprise valueMarket value book-to-invoice ratioInventory turnover rateEarnings Volatility |
| Costa, I., Riccotta, R., Montini, P., Stefani, E., de Souza Goes, R., Gaspar, M. A., ... & Larieira, C. L. C. (2022). The Degree of Contribution of Digital Transformation Technology on Company Sustainability Areas. Sustainability, 14(1), 462. | Systematic Literature Review -PRISMA Method | Conceptualization, IC and AAF; SLR, PM, ES and RL; Data optimization, PM and RR; Official analysis, IC and ES; Financing acquisition, IC; Investigation, RR and IC; Methodology, FSM;, | Conceptualization, IC and AAF; SLR, PM, ES and RL; Data optimization, PM and RR; Official analysis, IC and ES; Financing acquisition, IC; Investigation, RR and IC; Methodology, FSM; Project management, IC; Resources, IC; Supervision, IC; Verification, CM, MAG |

# METHOD

## Analytical Hierarchy Process

The Analytical Hierarchy Process was first mentioned by the Myers and Alpert duo in 1968, and in 1977, Professor Thomas Lorie Saaty at the Wharton School of Business was developed as a model and made available for decision-making processes [20]. In the 1970s, Saaty worked in the US Department of Defense on complex problems such as planning unexpected problems, examining the distribution of stocks in the electricity industry in order to contribute to increasing the welfare of the society, the Middle East Problem, the development of the transportation system for Sudan. Saaty, who has made many theoretical contributions to the field of operations research and mathematics, has developed the AHP method, which is one of the modern decision support methods, the importance of which has increased in recent years and its use has become widespread in every field. AHP is an approach where knowledge, experience, personal thoughts and preliminary opinions are applied logically as a result of creating a decision hierarchy. The main problems encountered in multi-criteria decision making problems are to determine weight, importance and order in order to be able to choose among many alternatives by considering more than one criterion. AHP is an effective MCDM method to solve this problem. In AHP, both subjective and objective thoughts of decision makers can be included in the decision process. For this reason, AHP is a mathematical method that takes into account the priorities of the group and the individual, and evaluates qualitative and quantitative variables together in decision-making. This makes AHP more powerful than other decision-making methods.

## TOPSIS Model

The TOPSIS method, which can be defined as multidimensional weighting with ideal points, is a method that helps decision makers in making the optimal choice and ranking among many alternatives. TOPSIS method, developed by Hwang and Yoon in 1981, is frequently used in multi-criteria decision making methods [21].

## VIKOR Model

VIKOR stands for VIseKriterijumsa Optimizacija I Kompromisno Resenje. In the case of conflicting criteria, it provides ranking and optimal selection among the alternatives. In the VIKOR method, an aggregation function that considers the 'ideal proximity' is used for the measurement of closeness to the ideal solution and linear normalization is applied for the criteria [22].

# 3. Findings and Discussion

The first step in the green digital transformation solution process in manufacturing is to determine the main criteria and sub-criteria that are considered to be used in the solution. Therefore, at the design stage of the decision hierarchy, the most time and effort is to determine how these criteria will be measured and what kind of indicators will be used. In order to provide benefits such as solving problems, making decisions, improving performance and encouraging with the measurements made, a relationship should be established between the indicators and the strategy of the company studied. Otherwise, the relationship between the metrics and the business would not be established. Our second step in measurements is to decide on the important criterion. The really important constraints between economic and time constraints are a very difficult process in terms of personal considerations [23]. In the selection of the criteria to be selected in the measurements, alternative scenarios should be considered and other situations such as tactics, plans and project activities should be considered during the planning phase[24]. In the company that has an important place in the manufacturing sector, it is envisaged that green digital transformation in manufacturing will be decided by using AHP, TOPSIS and VIKOR methods. The criteria in the literature created the Decision Hierarchy criteria to be used for green digital transformation in manufacturing.

Fig. 1.Decision Hierarchy

***Solution with AHP Method***

In our study of comparing the importance levels of the criteria in Green Digital Transformation in Manufacturing, the AHP (Analytical Hierarchy Process) method was used to compare the main criteria with each other with the help of the binary decision matrix, and in the second step, pairwise comparisons were made at the sub-criteria level. In order to compare the priority data obtained, the application was continued with the AHP method. Excel program was used for this method. The data obtained by 3 experts for the main criteria were created.

CR (consistency ratio) values were verified. The next step is to calculate the comparison matrices as normalized comparison matrix and priority vectors for each matrix.

Table 2 - Software/Infrastructure Criteria Normalized Comparison Matrix.

|  |
| --- |
| **Software/Infrastructure Criteria** |
| **DECISION CRITERIA** | **Fiber Infrastructure(Backbone + Access)** | **High Speed Broadband Internet** | **CPS (Cyber-Physical Systems)** | **Cloud Computing** | **AI (Artificial Intelligence)** | **IoT (Internet of Things)** | **Priority Vector** |
| **Fiber Infrastructure(Backbone + Access)** | 0,479 | 0,645 | 0,389 | 0,283 | 0,256 | 0,224 | **0,379** |
| **High Speed Broadband Internet** | 0,149 | 0,201 | 0,440 | 0,256 | 0,263 | 0,199 | **0,251** |
| **CPS (Cyber-Physical Systems)** | 0,157 | 0,058 | 0,127 | 0,371 | 0,232 | 0,175 | **0,187** |
| **Cloud Computing** | 0,122 | 0,057 | 0,025 | 0,072 | 0,199 | 0,155 | **0,105** |
| **AI (Artificial Intelligence)** | 0,093 | 0,039 | 0,019 | 0,018 | 0,050 | 0,247 | **0,078** |
| **IoT (Internet of Things)** | 0,093 | 0,044 | 0,023 | 0,020 | 0,006 | 0,044 | **0,038** |

In Table 2, the normalized encounter matrix was obtained by dividing the numbers in each cell by the totals of the columns. Then, the priority vector was obtained by taking the average of each line.

Table 3 - Demographic / Social Criteria Normalized Comparison Matrix.

|  |
| --- |
| **Demographic / Social Criteria** |
| **DECISION CRITERIA** | **Education level** | **State System** | **State Subsidy** | **Priority Vector** |
| **Education level** | 0,701 | 0,835 | 0,321 | **0,619** |
| **State System** | 0,122 | 0,145 | 0,598 | **0,288** |
| **State Subsidy** | 0,176 | 0,020 | 0,081 | **0,092** |

In Table 3, the normalized encounter matrix was obtained by dividing the numbers in each cell by the totals of the columns. Then, the priority vector was obtained by taking the average of each line.

Table 4 - Environmental Criteria and B.G. Data from N.K.M. and Priority Vector.

|  |
| --- |
| **Environmental Criteria and Historical Data of the Region** |
| **DECISION CRITERIA** | **Firm Size** | **Nature of Property** | **Company Age** | **Gender** | **Priority Vector** |
| **Firm Size** | 0,664 | 0,831 | 0,620 | 0,386 | **0,625** |
| **Nature of Property** | 0,098 | 0,122 | 0,253 | 0,345 | **0,204** |
| **Company Age** | 0,106 | 0,020 | 0,099 | 0,192 | **0,104** |
| **Gender** | 0,132 | 0,027 | 0,028 | 0,077 | **0,066** |

In Table 4, the normalized encounter matrix was obtained by dividing the numbers in each cell by the totals of the columns. Then, the priority vector was obtained by taking the average of each line.

Table 5 - Economic Criteria N. K. M. and Priority Vector.

|  |
| --- |
| **Economic Criteria** |
| **DECISION CRITERIA** | **Project Maintenance Cost** | **Software Cost Capital** | **Financing Restrictions** | **Establishment Cost** | **Hardware Cost Capital** | **Priority Vector** |
| **Project Maintenance Cost** | 0,550 | 0,635 | 0,479 | 0,325 | 0,244 | **0,447** |
| **Software Cost Capital** | 0,183 | 0,249 | 0,439 | 0,383 | 0,319 | **0,315** |
| **Financing Restrictions** | 0,072 | 0,028 | 0,063 | 0,223 | 0,174 | **0,112** |
| **Establishment Cost** | 0,104 | 0,030 | 0,007 | 0,062 | 0,189 | **0,078** |
| **Hardware Cost Capital** | 0,090 | 0,058 | 0,012 | 0,008 | 0,074 | **0,048** |

In Table 5, the normalized encounter matrix was obtained by dividing the numbers in each cell by the totals of the columns. Then, the priority vector was obtained by taking the average of each row. Then we compare our software/infrastructure main criteria. It is aimed to get the result from there by multiplying the matrix with the priority vectors of the main criteria.

Table 6 - Software/Infrastructure Criteria Eigenvalue calculation.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **DECISION CRITERIA** | **Fiber Infrastructure(Backbone + Access)** | **High Speed Broadband Internet** | **CPS (Cyber-Physical Systems)** | **Cloud computing** | **AI (Artificial Intelligence)** | **IoT (Internet of Things)** | x | **Eigenvector** | = | **Eigenvalue** |
| **Fiber Infrastructure(Backbone + Access)** | 1 | 3,21415 | 3,05214 | 3,914867641 | 5,1299 | 5,1299 | 0,379 | 2,763446576 |
| **High Speed Broadband Internet** | 0,311124247 | 1 | 3,45545 | 3,547841711 | 5,2776 | 4,5448 | 0,251 | 1,971390501 |
| **CPS (Cyber-Physical Systems)** | 0,327638968 | 0,289397908 | 1 | 5,12992784 | 4,6542 | 4 | 0,187 | 1,437458162 |
| **Cloud computing** | 0,255436477 | 0,281861504 | 0,194934516 | 1 | 3,9791 | 3,5569 | 0,105 | 0,754866385 |
| **AI (Artificial Intelligence)** | 0,194934516 | 0,194934516 | 0,146970379 | 0,251315814 | 1 | 5,6548 | 0,078 | 0,471516603 |
| **IoT (Internet of Things)** | 0,194934516 | 0,220030837 | 0,178780707 | 0,281144222 | 0,1208 | 1 | 0,038 | 0,239900521 |

In Table 6, Software/Infrastructure criteria and eigenvectors were multiplied by matrix and eigenvalue was calculated. In Table 7, the matrix multiplication of the Demographic / Social Criteria and the eigenvectors was performed and the eigenvalues were calculated.

Table 7 - Demographic / Social Criteria Eigenvalue calculation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Demographic / Social Criteria** |  |  |  |  |
| **DECISION CRITERIA** | **Education level** | **State System** | **State Subsidy** | **Eigenvector** | **Eigenvalue** |
| **Education level** | 1 | 5,738793548 | 3,979057208 | 0,619 | 2,64187578 |
| **State System** | 0,174252653 | 1 | 7,398636223 | 0,288 | 1,07890381 |
| **State Subsidy** | 0,251315814 | 0,135160044 | 1 | 0,092 | 0,28687162 |

In Table 8, Matrix multiplication of Software/Infrastructure criteria and eigenvectors was done and eigenvalue calculation was made.

Table 8 - Environmental Criteria and Historical Data of the Region Eigenvalue calculation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Environmental Criteria and Historical Data of the Region** | x |  | = |  |
| **DECISION CRITERIA** | **Firm Size** | **Nature of Property** | **Company Age** | **Gender** | **Eigenvector** | **Eigenvalue** |
| **Firm Size** | 1 | 6,804092116 | 6,240251469 | 5,013297935 | **0,625** | 2,998534 |
| **Nature of Property** | 0,146970379 | 1 | 2,54668 | 4,481404747 | **0,204** | 0,858371 |
| **Company Age** | 0,160249952 | 0,159812706 | 1 | 2,496 | **0,104** | 0,402255 |
| **Gender** | 0,199469494 | 0,223144317 | 0,281144222 | 1 | **0,066** | 0,265775 |

Table 9 - Economic Criteria Eigenvalue calculation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Economic Criteria** |  |  |  |  |
| **DECISION CRITERIA** | **Project Maintenance Cost** | **Software Cost Capital** | **Financing Restrictions** | **Establishment Cost** | **Hardware Cost Capital** | x | **Eigenvector** | = | **Eigenvalue** |
| **Project Maintenance Cost** | 1 | 2,548256 | 7,611662611 | 5,277632088 | 3,31151 | **0,447** | 2,674195 |
| **Software Cost Capital** | 0,333333333 | 1 | 6,975418475 | 6,21545 | 4,326748711 | **0,315** | 1,940741 |
| **Financing Restrictions** | 0,131377342 | 0,111111111 | 1 | 3,621 | 2,35546 | **0,112** | 0,603432 |
| **Establishment Cost** | 0,189478915 | 0,120820041 | 0,111111111 | 1 | 2,5646 | **0,078** | 0,337618 |
| **Hardware Cost Capital** | 0,164414138 | 0,231120425 | 0,189478915 | 0,135160044 | 1 | **0,048** | 0,226361 |
|  |  |  |  |  |  |  |  |

In Table 9, the matrix multiplication of the Software/Infrastructure criteria and the eigenvectors was done and the eigenvalue calculation was made for all our criteria.

**Solution with TOPSIS Method**

In our Green Digital Transformation in Manufacturing study, the Software/Infrastructure main criterion of the priority vector was found in the comparison table of the main criteria previously made with the AHP method, and we calculated the priority vectors of these criteria in Table 8. We need alternatives for the solution made by the Topsis method. In Table 10, which we have created as a result of the research conducted in the literature, the alternative table has been decided by experts in their fields.

Table 10 - TOPSIS decision matrix.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Priority Vector** | 0,463208 | 0,23326 | 0,1756 | 0,086 | 0,041 | 0,034 |
|  | **Fiber Infrastructure(Backbone + Access)** | **High Speed Broadband Internet** | **CPS (Cyber-Physical Systems) Cloud Computing** | **Cloud Computing** | **AI (Artificial Intelligence)** | **IoT (Internet of Things)** |
| **Digital Transformation Degree** | 8 | 8 | 8 | 5 | 7 | 7 |
| **Green Technology Innovation** | 6 | 3 | 2 | 5 | 5 | 4 |
| **Government Incentive** | 7 | 6 | 6 | 2 | 4 | 3 |

Obtaining the distance values from the ideal and negative ideal points and then calculating the Ci values are calculated in Table 11.

Table 11. Distance to ideal and negative ideal points and Ci values.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Si+ | Si- | Ci | Order |
| **Digital Transformation Degree** | 0,076 | 0,153 | 0,668 | 1 |
| **Green Technology Innovation** | 0,149 | 0,084 | 0,36 | 3 |
| **Government Incentive** | 0,077 | 0,1 | 0,567 | 2 |

Ci value close to 1 indicates that the decision point is close to the absolute ideal solution point. As seen in Table 11, the most optimal decision alternative is Digital Transformation Degree.

Optimal ranking: **Degree of Digital Transformation >Government Incentive >Green Technology Innovation**

According to the execution obtained by Multi-Criteria Decision-Making Methods-Topsis Method, it is envisaged to start with Green Technology Innovation for the green digital progress and software/infrastructure main criterion in manufacturing.

**Solution with the VIKOR Method**

We have calculated the reward vectors for our Software/Infrastructure Criteria. For the comparison in the AHP method, in the Green Digital Transformation alternatives research method in manufacturing, then we need the optimal ranking by comparing the closeness values to the ideal alternative with the Vikor method for our criterion alternatives, which it is examined in the Topsis method.

Table 12 - Best ($f\_{1}^{\*}$) and worst ( $f\_{j}^{-}$) values.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Fiber Infrastructure(Backbone + Access)** | **High Speed Broadband Internet** | **CPS (Cyber-Physical Systems)** | **Cloud computing** | **AI (Artificial Intelligence)** | **IoT (Internet of Things)** |
| **Digital Transformation Degree** | 8 | 8 | 8 | 5 | 7 | 7 |
| **Green Technology Innovation** | 6 | 3 | 2 | 5 | 5 | 4 |
|  | 7 | 6 | 6 | 2 | 4 | 3 |
| $$f\_{1}^{\*}Government Incentive$$ | 8 | 8 | 8 | 8 | 7 | 7 |
| $$f\_{j}^{-}$$ | 6 | 3 | 2 | 2 | 4 | 3 |

In our next step, Si and Ri values for each of our alternatives were calculated in Table 13.

Table 13. Si and Ri values.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Fiber Infrastructure(Backbone + Access)** | **High Speed Broadband Internet** | **CPS (Cyber-Physical Systems)** | **Cloud computing** | **AI (Artificial Intelligence)** | **IoT (Internet of Things)** | **Si** | **Ri** |
| **Digital Transformation Degree** | 0,00 | 0,00 | 0,00 | 0,04 | 0,00 | 0,00 | 0,04 | 0,04 |
| **Green Technology Innovation** | 0,46 | 0,23 | 0,18 | 0,09 | 0,03 | 0,03 | 1,01 | 0,46 |
| **Government Incentive** | 0,23 | 0,09 | 0,06 | 0,03 | 0,04 | 0,03 | 0,49 | 0,23 |

In the next step, the Qi values for each i alternative are calculated in Table 14. The Qi values are

then ordered from smallest to largest.

Table 14 - Qi values.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Si** | **Ri** | **Qi** | **Sıralama** |
| **Digital Transformation Degree** | 0,05 | 0,05 | 0 | 1 |
| **Green Technology Innovation** | 0,99 | 0,46 | 1 | 3 |
| **Government Incentive** | 0,39 | 0,13 | 0,282519 | 2 |
| **S\*R\*** | 0,05 | 0,05 |  |  |
| **S-R-** | 0,99 | 0,46 |  |  |

# The closer the calculated Qi values are to 0, the closer they are to the optimal solution point.

# Optimal Solution: Degree of Digital Transformation>Government Incentive > Green Technology Innovation

# According to the result obtained with the Multi-Criteria Decision Making Methods-VIKOR Method, it is envisaged to start the Digital Transformation Degree for the green digital transformation, software/infrastructure main criterion in manufacturing.

1. **CONCLUSIONS AND RECOMMENDATIONS**

The digital transformation planned in Industry 4.0 aims to move away from the understanding of people working like machines and to make machines work smartly. Green digital transformation in the manufacturing industry also aims to manufacture old-fashioned production efficiently, safely, sustainably and more conveniently. DTs are also known to convert carbon gases into usable plastics and fuels in the automotive factory. TEKNOROT, which works to find digital solutions to produce lower energy and more efficiency by producing, optimizes it using data analytics, internet of things (IoT) and smart algorithms technologies, and it is seen that it reduces the energy it uses while producing a product.

Today, making a decision in our daily life and working life is a troublesome and difficult process. It is normal for decision makers to make decisions based on their private lives and experiences. Therefore, they are faced with some kind of difficulties in the decision-making process. MCDM methods play a major role in decision making. These MCDM methods are both subjective and when choosing for large firms or communities, as in green digital transformation work in manufacturing; It is aimed to minimize the risk factor, to eliminate the uncertainty during the selection, to make the correct decisions and to reach effective decisions.

In this study, AHP, TOPSIS and VIKOR methods, which are among the MCDM methods, were used as a decision-making method for the evaluation of criteria and alternatives that are important in green digital transformation in manufacturing by taking the opinions of experts working in Teknorot, which produces automotive sub-industry products. The reason why many decision making methods are used in the study is that while the Topsis method applies normalization for vectors, the Vikor method applies linear normalization. In addition, Topsis evaluates the closest and farthest point to the ideal solution within the alternatives, but the Vikor method makes a ratio of positive and negative solutions was deemed appropriate [25].

In the study, after various foreign articles in the applications and the guidance of the decision makers, the decision criteria and alternatives that are considered important in the manufacturing sector were determined. Then, decision matrices were created from the sub-criteria, and experts who were interested in green digital transformation in manufacturing were evaluated between 1-9. The priority vector (importance weight) of each criterion was calculated with the AHP method. It has been revealed that the highest criterion in the criterion weight is the software/infrastructure and then the demographic/social main criteria. The priority vector (importance weight) of each calculated criterion is used in TOPSIS and VIKOR methods. The factors that affect the transition to green digital transformation in our company, which produces TOPSIS and VIKOR methods for automotive supply industry products, have been determined by experts as the degree of digital transformation, green technology innovation and government incentives. As a result of the evaluation made with the TOPSIS method, one of the MCDM methods, it has resulted in the Digital Transformation Degree > Government Incentive > Green Technology Innovation ranking. As a result of the evaluation of the alternatives made in the VIKOR method, it is listed as Digital Transformation Degree > Government Incentive > Green Technology Innovation.

In the process of evaluating the necessary alternatives for digital transformation with the Topsis and VIKOR methods, the optimal rankings came out as Digital Transformation Degree > Government Incentive > Green Technology Innovation and can be evaluated by experts.

Looking at some of the articles in the literature using similar MCDM methods, Azadnia et al. (2013) in a study in which MCDM methods were applied, environmental criteria took the first place and then took place in economic and social criteria [26]. When we look at many leading studies like this, it is obvious that environmental criteria have been a leading criterion recently. But when domestic studies are done like in this study, the leading criterion has been economic criteria.

# The thought derived from the evaluation made has been tried to reduce the environmental damage caused by industrial production in the leading countries in the world, but unfortunately it is observed that our country should not think about the economic sense. Increasing government incentives in order to ensure digital transformation and increase green innovation in Industry 4.0 will not only increase its contribution to our country both environmentally and economically, but will also provide a serious opportunity for our country to increase its place in the industry.

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