REPUBLIC OF TURKEY

ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF INDUSTRIAL ENGINEERING

R&D PROJECT SELECTION BY DATA ENVELOPMENT ANALYSIS BASED ON DEMATEL-COPRAS EVALUATION

ECEM ÖZKAN

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ASSOC. PROF. DR. CANSU DAĞSUYU

ADANA 2021

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

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Ecem ÖZKAN

ABSTRACT

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Department of Industrial Engineering

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Firms create many R&D project proposals to develop. Considering the various constraints and feasibility of the projects, only a few of these suggestions can be implemented. In this case, R&D project selection becomes a problem for companies. In this thesis, various MCDM methods in the literature were studied and analyzed. Then the appropriate methods were chosen and implemented for one of the leading bus and midibus manufacturers with 50 years of experience. In the first stage of the thesis, opinions of senior personnel with at least seven years of experience from R&D, production, marketing, and finance departments were considered together with the previous studies in the field for determining R&D project selection criteria. Four primary and 24 sub-criteria were determined with this approach, and 14 of the 24 criteria were thesis-specific criteria specified together with experts. These criteria were prioritized using the DEMATEL method in the second stage. According to DEMATEL analysis, capital investment requirement, the relative cost of the developed product, and the rate of return on investment sub-criteria of the finance main criterion prominent with their highest weight values. The defined criteria were used to evaluate alternative R&D projects in the DEMATEL-COPRAS method. The input-oriented CCR DEA model was used to assign the weight of each candidate project. As a result of the analysis, Project 4 (Axle production for domestic customer market) was selected among five projects with the highest performance value. The obtained project selection results were compatible with the experts' criteria scores. This situation reveals that the used methodology can also be applied in sectors having similar dynamics.

Keywords: R&D project selection, DEMATEL, COPRAS, DEA

ÖZET

DEMATEL-COPRAS DEĞERLENDİRMESİNE BAĞLI VERİ ZARFLAMA ANALİZİ İLE ARGE PROJE SEÇİMİ

Ecem ÖZKAN
Endüstri Mühendisliği Anabilim Dalı
Danışman: Doç. Dr. Cansu DAĞSUYU

Haziran 2021, 53 sayfa

Firmalar gelişebilmek için pek çok ARGE proje önerisi oluşturmaktadır. Çeşitli kısıtlardan ve projelerin yapılabilirlikleri dikkate alındığında bu önerilerin birkaçı hayata geçirilebilmektedir. Bu durumda firmalar için ARGE proje seçimi bir problem haline gelmektedir. Bu tezde literatürdeki çeşitli çok kriterli karar verme yöntemleri incelenmiş ve analiz edilmiştir. Ardından 50 yıllık tecrübeye sahip lider otobüs ve midibüs üreticilerinden biri için uygun yöntemler seçilerek uygulanmıştır. Tezin ilk aşamasında Ar-Ge proje seçim kriterlerinin belirlenmesinde Ar-Ge, üretim, pazarlama ve finans departmanlarından en az yedi yıl deneyime sahip kıdemli personelin görüşleri, sahadaki önceki çalışmalarla birlikte dikkate alınmıştır. Bu yaklaşımla dört ana ve 24 alt kriter belirlenmiş olup, 24 kriterden 14'ü uzmanlarla birlikte teze özgü kriterler olarak belirlenmiştir. İkinci aşamada DEMATEL yöntemi kullanılarak bu kriterler önceliklendirilmiştir. DEMATEL analizine göre finans ana kriterine bağlı, sermaye yatırım gerekliliği, geliştirilen ürünün maliyeti ve yatırımın getirisi oranı alt kriterleri en yüksek ağırlığa sahip üç alt kriter ile öne çıkmıştır. Alternatif Ar-Ge projeleri, belirlenen kriterlere göre DEMATEL-COPRAS yöntemi ile değerlendirilmiştir. Son aşamada ise projenin değerlendirilmesi için girdi odaklı CCR VZA modeli kullanılmıştır. Yapılan analiz sonucunda, beş proje arasından performans değeri en yüksek olan Proje 4 (Yurt içi müşteri pazarı için aks üretimi) seçilmiştir. Elde edilen proje seçim sonuçları, uzmanların kriter puanlandırmalarıyla uyumluydu. Bu durum, uygulanan metodolojinin benzer dinamiklere sahip sektörlerde de uygulanabileceğini ortaya koymaktadır.

Anahtar Kelimeler: Ar-Ge proje seçimi, DEMATEL, COPRAS, VZA

Dedicated to my daughter Ada ÖZKAN and my son Kıvanç ÖZKAN

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Ecem ÖZKAN

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NOMENCLATURE

MCDM	: Multiple Criteria Decision Making
DEMATEL	: Decision-Making Trial And Evaluation Laboratory
COPRAS	: Complex Proportional Assessment
DEA	: Data Envelopment analysis
AHP	: Analytic Hierarchy Process

I. INTRODUCTION

Automotive is one of the most important sectors linked to different sectors operating in various fields. This sector provides profound contributions to employment and the economy and contains a serious background of knowledge. At the same time, the automotive industry has an essential share in world trade. World automotive market data are given in Table 1 (ODD, 2020).

Table 1. World automotive market data by regions (ODD, 2020)

REGION	VEHICLE TYPE	2019 ('000pcs)	2020* ('000 pcs)	2020/ 2019 Change	2021* ('000a pcs)	2021/ 2020 Change
North America	Car	16.030	13.115	-18.2%	14.354	9.5%
	Ligth Commercial	4.198	3.843	-8.5%	4.214	9.6%
	Heavy Commercial	628	486	-22.6%	569	17.1%
	Total	20.856	17.444	-16.4%	19.137	9.7%
South America	Car	3.419	2.405	-29.7%	3.059	27.2%
	Ligth Commercial	698	585	-16.3%	796	36.1%
	Heavy Commercial	125	97	-22.3%	123	26.2%
	Total	4.242	3.086	-27.2%	3.978	28.9%
West Europe	Car	14.305	10.805	-24.5%	12.297	13.8%
	Ligth Commercial	1.992	1.635	-17.9%	1.767	8.1%
	Heavy Commercial	336	249	-25.9%	293	17.4%
	Total	16.634	12.689	-23.7%	14.357	13.1%
East Europe	Car	3.690	3.432	-7.0%	3.569	4.0%
	Ligth Commercial	430	454	5.5%	466	2.6%
	Heavy Commercial	176	157	-10.7%	181	15.2%
	Total	4.296	4.043	-5.9%	4.215	4.3%
Asia / Pacific	Car	34.930	31.670	-9.3%	35.224	11.2%
	Ligth Commercial	6.320	6.109	-3.4%	6.428	5.2%
	Heavy Commercial	2.112	2.260	7.0%	2.025	-10.4%
	Total	43.362	40.039	-7.7%	43.677	9.1%
Middle East	Car	1.974	1.891	-4.2%	2.154	13.9%
	Ligth Commercial	256	274	7.1%	313	14.2%
	Heavy Commercial					
	Total	2.230	2.165	-2.9%	2.467	13.9%
Africa	Car	740	488	-34.1%	695	42.4%
	Ligth Commercial	258	185	-28.3%	217	16.9%
	Heavy Commercial	29	23	-19.0%	27	16.0%
	Total	1.028	697	-32.2%	939	34.7%
Others	Car	932	706	-24.2%	732	3.7%
	Light Commercial	203	146	-28.0%	174	19.1%
	Heavy Commercial	34	79	132.0%	38	-52.1%
	Total	1.170	932	-20.4%	944	1.4%
World	Car	76.021	64.512	-15.1%	72.085	11.7%
	Light Commercial	14.357	13.231	-7.8%	14.374	8.6%
	Heavy Commercial	3.440	3.352	-2.6%	3.255	-2.9%
	Total	93.818	81.095	-13.6%	89.714	10.6%

**2021 values are 4th Quarter 2020 forecasts of LMC Automotive.*

The Covid 19 pandemics affected all sectors as well as the automotive sector, and many factories had to stop their production for this reason. In the challenging competitive environment, companies need to follow the rapidly developing technology and produce new technologies to continue their activities and gain superiority in the market. The intensification of competition has caused R&D to come to the fore and the necessity to use the limited resources more efficiently. It has become more important to select the project with the highest probability of success among alternative projects. From the beginning of the pandemic until May 2021, nearly 160 million people were infected, and approximately 3.3 million people died due to the Covid-19. In the same period, about 5.1 million cases and 43k dead were reported in Turkey (WHO, 2021). Automotive was not the only industry affected by the pandemic, but it has suffered more than many and will likely recover later than others. With this effect, sales fell to the lowest level in 15 years in the third quarter of 2020 (LMC, 2021). The world automotive market decreased by 13.6%, and total production decreased by 15.5% in 2020 compared to the previous year, as seen in Table 1 (ODD, 2020). This situation narrowed the market and made the competitive environment more challenging. In the challenging competitive environment, companies need to follow the rapidly developing technology and produce new technologies to continue their activities and gain superiority in the market. Companies set up research and development departments to develop new technologies and integrate them into their products. Research and Development (R&D) opportunities are generally provided from the same sources as other activities in a company. The most successful companies in today's competitive environment apply project management processes to achieve successful results. R&D is the whole of the activities carried out by companies to innovate and introduce new products and services. R&D activities are expected to have the purpose of increasing knowledge in a particular area. For instance, it may be necessary to develop a new model or be involved in the modeling and simulation process. The goal is for R&D to lead to something new eventually. Regardless of the level of certainty associated with R&D objectives, the application of project management developed with complementary disciplines provides a powerful toolset for managing activities than considered a traditional project (Wintage, 2015).

1.1. Project and R&D Terms

A project can be defined as an activity with a defined scope or goal to be carried out in a particular time and budget. Operations-type activities can be defined using the following standard project management categories:

- Content of activity
- Expected results from the study
- Risks of not completing the process within the created plan
- Scheduling of specific works
- How to ensure the best fit organizational structure?
- The required budget to carry out the works (labor, supplies, overheads, facility)

It would be desirable for R&D activities to increase knowledge in a particular area, develop a new model, or deal with modeling and simulation. The goal is for R&D to lead to something new eventually. Regardless of the level of certainty associated with R&D objectives, the project management application developed with supplementary fields provides a powerful toolkit for managing activities other than those considered a traditional project such as these (Wingate, 2015).

1.2. Traditional and R&D Project Management

The traditional project management approach uses a systematic, consecutive approach to achieve the goals of the project. This process includes the following stages; developing the project's scope, defining the goals/outcomes, formalizing the plan that includes specific requirements, start-up, and timetable; management of the planned process, including performance metrics, communication, change and risk management.

Wingate (2015) defined the components of project management as scope, outcomes, requirements, approach, organization, schedule, budget, risk management, performance measurement, and communications. Defining the project scope is a critical first stage in project management. At this stage, what will be done in the project should be clearly defined. The scope does not include detail of the requirements but provides a summary-level statement about the requirements. The expected outcomes that will emerge when the requirements are met should be defined. Expected outcomes (results, product, service, etc.) should be defined. The final results should be compared against the project plan created to verify that the performance is achieved as expected and the objectives are achieved. The approaches to be used to reach the project objectives should be clearly defined. In the case of alternative methods, low-cost and less time-consuming ones should be preferred. The roles of the project manager and scientific experts who will cooperate in the project should be clarified in the organization. While the project manager is responsible for process management, the scientific expert should concentrate on the scientific part of the project. A formal organizational chart should be established to align with the process and personnel areas of expertise. Such organizations will increase the probability of the project's success. Another essential part of project management is the definition of project schedule. It can be defined as listing the activities performed at each stage according to their start and end dates. Unlike classical projects, R&D project activities can contain uncertainties, so these risks should be considered in scheduling. It can be continued with the budgeting process over the scheduling. The funds foreseen for each task in the project can be assigned to these activities on the schedule. If the scheduling is done well, the estimated budget will be compatible with the consumptions to be realized (Wingate, 2015).

1.3. R&D project selection

Companies have limited resources, so efficient use of these resources is possible with the selection of R&D projects with a higher probability of success. In this context, objective evaluation techniques should be used to determine the R&D projects that provide higher benefits among the project proposals. A project selection decision is a process that includes many interactive and sometimes conflicting criteria. Evaluation, prioritization, and selection decisions of projects are accepted as Multiple Criteria Decision Making (MCDM) problems (Yalcin et al., 2020). MCDM is one of the well-known decision-making approaches, and these methods can be classified in many ways. One way is to classify them according to the used data type as stochastic, fuzzy, etc., or combinations of them. A taxonomy of several MCDM methods is given in Figure 1. The three steps to using any decision-making technique that involves numerical analysis of alternatives are as follows: (Triantaphyllou, 2000).

I. Identifying relevant criteria and alternatives
II. Definition of numerical measures to the relative effect of factors and the effects of alternatives
III. Analyzing the numerical values to determine the rank of each alternative

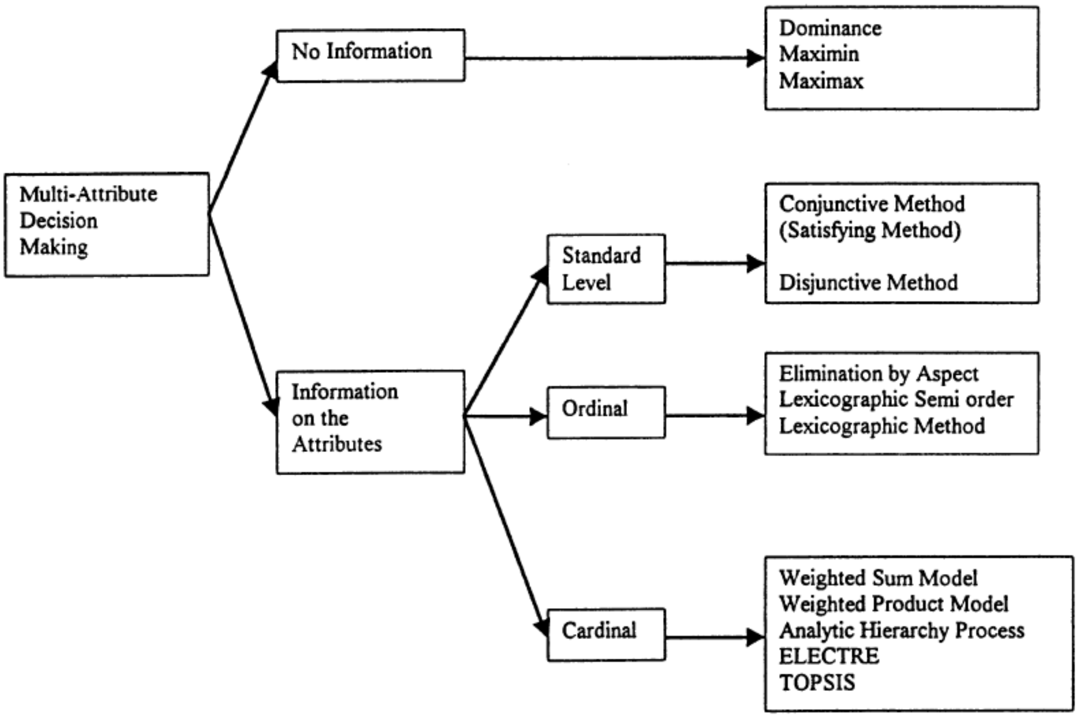

Figure 1. Taxonomy of several MCDM methods (Triantaphyllou, 2000)

1.4. Aim of Study

This thesis aims to determining the criteria that are important in the company's R&D project selection process and using these criteria for the selection of R&D projects having the highest probability of success, thus ensuring the most efficient use of business resources such as time, budget, workforce, etc. If the project selection is made incorrectly, the firm may invest its capital in the wrong sources, and the firm may not achieve the targeted profit. At the same time, experts are used in ineffective work, productivity may decrease. As a result of all these, the brand value of the company in the market is negatively affected and hinders its future success. Project selection is of great importance to avoid any negative situations like this. There are many criteria taken into consideration in the fields of R&D, finance, marketing, and manufacturing, etc. in the selection of the project. The impact level of each criterion on the projects is different. MCDM can be used when evaluating projects in terms of these criteria. For this purpose, the combination of DEMATEL, DEMATEL-COPRAS, and Data Envelopment Analysis (DEA) methods was implemented in the R&D project selection process of one of the leading bus and midibus manufacturers with 50 years of experience. Previous studies have studied project selection issues many times with many methods and models in different sectors. In general, selection criteria were determined based on expert opinions and literature. Similarly, the R&D project selection criteria were defined based on the literature review and opinion of the experts who have at least seven years of experience. Differently from the previous studies, 14 specific sub-criteria that were not encountered in the literature were defined. And also, the combination of DEMATEL, DEMATEL-COPRAS, and DEA methods was used to achieve the aim of the research. The developed methodology presents a multi-criteria decision support system that includes the detailed evaluation of the effective factors on the success of the R&D project, instead of the currently used heuristic method in a company that is based on basic constraints such as budget and time.

II.LITERATURE REVIEW

The 1950s and 1960s were unique growth years for R&D project selection modeling. The number of models has grown exponentially, with users' interest in implementing them (Souder and Mandakovic, 1986). Methods and techniques for selecting projects have been used in the studies for at least 60 years, and there are a lot of published papers in the literature. Various research approaches include quantitative and qualitative techniques, from complex operations research methods to social science-based interactive methods. R&D project selection methods can generally be placed in the following categories: unstructured peer review, scoring, mathematical programming, economic models, decision analysis, interactive techniques, artificial intelligence, and portfolio optimization (Traynor and Henriksen, 1999).

The previous studies, including the most commonly used methods in R&D project selection related to the thesis, are summarized below.

Stewart (1991) developed a decision support system (DSS) for the selection of R&D projects for a large electricity distribution company. In the research, the problem was accepted as MCDM, and a suitable decision support system (DSS) was carried out in this context. The developed MCDM supported DSS was positively evaluated by the company management and fulfilled the system targets (Stewart, 1991).

Kumar et al. used the DEA method as a tool for developing the six sigma project selection model. Researchers focused on the customer satisfaction six sigma project. They created a mathematical model to provide the maximum benefit to the company in the six sigma project selection processes (Kumar et al., 2007).

Morcos (2007), in a case study, aimed to structured MCDM to help companies efficiently assigned the limited resources to different R&D projects within accessible portfolios aligning R&D investments with long-term corporate goals. The results of the research exhibited that the method used provides the decision-maker with the ability to easily evaluate the impact of short-term profits and intangible benefits (reliability and risk) of R&D project portfolios against limited budget resources (investment costs) (Marcos, 2007).

Huang et al. studied the selection process of government-sponsored R&D projects with a fuzzy AHP approach, including a group decision-making method for developing a hierarchical structure for the industrial technology development program project selection. In the design process, they used the in-depth interviews of the ITDP review committees to obtain their evaluating criteria and a triangular fuzzy number for scoring these experts' opinions. The study results revealed that scientific and technological merits are the primary evaluation criteria considered in the general technical committees (Huang et al., 2008).

Dodangeh et al. examined an actual application of project selection for Telecommunication projects using experts' opinions by one group decision-making model. They considered four criteria as contract period, resection in a degree of contractor, project risks, and profit to select the best project amongst five and rank them. In the study, the DELPHI method was used to convert qualitative criteria to quantitative in the 1 to 9 scales. Also, the rank of the projects was evaluated with the Group TOPSIS method (Dodangeh et al., 2009).

Büyüközkan and Öztürkcan developed an approach based on the combined analytical network process (ANP) and DEMATEL technique to prioritize projects in logistics companies and identify the most appropriate project alternative. Dimension of six Sigma project evaluation and components were determined in the research, and the DEMATEL method was applied to establish the relationships between the criteria. The ANP was used to obtain the weights of the criteria. They used an experimental case study from the logistics industry to explore the effectiveness of the proposed approach. The study also noted that an effective project selection method helps to ensure optimal resource utilization and more significant contribution of projects toward the missions and goals of companies (Büyüközkan and Öztürkcan, 2010).

Amiri (2010) proposed an AHP-fuzzy TOPSIS based methodology to provide a simple approach for evaluating alternative projects and choosing the best one for a petroleum company. Six criteria as size/complexity, reasonableness, cost, scope–adequacy, duration, technology, and location used to compare five investment alternatives as criteria in techniques. In the study, the AHP was used to determine the criteria weights and the final ranking obtained by the fuzzy TOPSIS method. The researcher noted that the proposed model helped choose the best alternative. In addition, in the Fuzzy TOPSIS method, it is important to calculate the weights of criteria as it affects the ranking of the projects. (Amiri, 2010).

Rouyendegh and Erol used the fuzzy ELECTRE method to solve multicriteria decision-making MCDM problems and to select the best project among the three. In the study, it was made that a real application of project selection in the field of construction using the opinion of experts to be applied into the fuzzy ELECTRE method. There are four criteria; net present value, quality, contractor's technology, and contractor's economic status to evaluate alternative projects. The researchers stated that the fuzzy ELECTRE method is appropriate because it involves an ambiguous perception of the ideas of decision-makers (Rouyendegh and Erol, 2012).

Velasquez and Hester examined the advantages and disadvantages of the MCDM method in their literature review study. In the study, DEA's advantages are identified as capable of handling multiple inputs and outputs; efficiency can be analyzed and quantified. DEA's disadvantages are defined as follows; it does not deal with inaccurate data; assumes that all input and output are precisely known (Velasquez and Hester, 2013).

Uygun et al. studied the DEMATEL, ANP and TOPSIS integrated approach methods for evaluating and ranking R&D projects. In the research, four main criteria as Originality, Quality of the Methodology, Feasibility, Impact, were used for the evaluation of project alternatives. The cause and effect interaction among main criteria was detected with the DEMATEL method. The weights of each criterion are calculated with the ANP method and the ranking of the projects determined by the TOPSIS method. The study noted that the mentioned approach could be implemented to multicriteria and group decision-making problems (Uygun et al., 2014).

Ortíz et al. were used ANP and DEMATEL-ANP methods to evaluate six sigma project alternatives in a medical center. Researchers used three strategies, four main (Benefit, Opportunity, Cost, and Risk) and 15 sub-criteria in the evaluation process. It was noted that the DEMATEL-ANP hybrid method provided a better performance compared to the ANP technique when evaluating influences and generating consistent results (Ortíz et al., 2015).

Pangsri used a combined method, including Delphi, AHP, and TOPSIS techniques, to providing decision methods for project managers in construction companies. In the study, experts in construction companies determined the five criteria as manpower, capital, responsibility, the experience of workers, and machine&equipment. Mentioned criteria were used for evaluating the seven projects and the weight of criteria assigned by the AHP method. Besides, project alternatives that were prioritized by weight were assessed by the TOPSIS method (Pangsri, 2015).

Swarnakar applied a Hybrid MCDM method based on fuzzy DEMATEL–ANP–TOPSIS to select the optimal Lean Six Sigma project in an automotive component manufacturing organization. In the research, 20 criteria in 6 dimensions were used in the evaluation process. Maximum benefit and minimum risk were chosen as the key objectives, and DEMATEL–ANP was used to determine the degree and importance weight of selection criteria. TOPSIS method was used to select the best project (Swarnakar, 2015).

Mary and Suganya analyzed the software prioritization with ranking techniques in the software industry with a web-based decision support model using ELECTRE. The study considered the following nine factors; importance, penalty, cost, risk, time, volatility, availability of resources dependency, changing priorities for prioritization. Researchers specified that the method proposed in the research is appropriate for the ranking problem due to the provide a convenient way of ranking requirements (Mary and Suganya, 2016).

Karasakal and Aker used DEA-based multiple criteria sorting methods for evaluating the R&D projects. They used the AHP method for obtaining the weight intervals of the criteria. In the study, developed models used the ranking of the projects proposed to the government funding agency (Karasakal and Aker, 2017).

Lee et al. proposed a new R&D project evaluation model and process that incorporating both technological potential and customer-perceived value in the automobile industry. Four perspectives (Technology attractiveness, Technology fit, Market attractiveness, Business fit) and eighth criteria (Innovativeness, Appropriability, R&D capabilities, Manufacturing capabilities, Perceived functional value, Perceived economic value, Fit with product plan, Fit with R&D plan) were identified in the study. The researchers used a scoring model, including financial and risk aspects as criteria for project selection, adopted as a basic model. The AHP technique was applied to assign weights to each criterion (Lee et al., 2017).

Drejeris and Miceikiene developed the COPRAS-based assessment methodology, which allows the assessment to use widespread indicators as maximizing and minimizing in agriculture field.

In the research, the standard method of COPRAS was developed by adding one more component that requires a questionnaire of farmers to evaluate the content. They used 11 criteria in the model. It was noted that the proposed model provided a flexible system that enables to assess farms engaged in the same type of activities or farms with different activities and to rank them according to the relative index of innovativeness (Drejeris and Miceikiene, 2018).

Jain et al. worked on a headlamp supplier selection using the integrated fuzzy multicriteria decision-making approaches in an automobile company. The criteria identified are based on literature review and the opinion of industry experts. In the study, weights of criteria were assigned using AHP, and suppliers were ranked with AHP and TOPSIS. Consistency tests were carried out to check the quality of the expert's inputs. Besides, sensitivity analysis was done to check the robustness of the approach. It was concluded that the AHP results were more robust so used for the final ranking (Jain et al., 2018).

Yazdani et al. introduced a combined compromise solution (CoCoSo) method with a new strategy to solve an MCDM problem through some specific modifications to the main structure for logistics and transportation companies. The authors considered a distance measure, which originates from the grey relational coefficient and targets to enhance the flexibility of the results. Hence, the weight of the alternatives was placed in the decision-making process. In the last stage, an aggregated multiplication rule was used to release the alternatives' ranking and end the decision process. It was noted that the comparative analysis approved the stability of the CoCoSo algorithm, and it can compete with favorite tools like COPRAS, MOORA, and VIKOR as well (Yazdani et al., 2019).

Tolga and Durak applied the fuzzy COPRAS method to assess the offered innovation projects of the airline cargo company. They determined the criteria for the selection process with the management team that evaluates innovation projects. They applied the fuzzy COPRAS technique in the selection process of six alternative projects. In the study, 18 criteria were defined based on the searched literature and interviews with responsible people from the corporation. They expressed that the number of proposed criteria might decrease or increase according to apply the sector or company (Tolga and Durak, 2019).

Güler et al. examined the R&D project selection process in a mould manufacturing company. They designed the structure with four main criteria (Project, Risk, Conformity, Cost), 12 sub-criteria for five alternative projects. In the study, the 12 criteria were reduced to 8 by the AHP method. Then IF-TOPSIS was applied, and three decision-makers made assessments. Researchers specified that the applied method is an effective method for handling the hesitant in human thought. It can be used for other selection problems such as supplier selection, investment problem, software selection, and production system selection as alternative fuzzy MCDM methods (Güler et al., 2019).

Yalcin et al. discussed the R & D projects selection problem for the mold sector. In accordance with experts' opinions, twelve criteria were detected for the selection problem. IF-DEMATEL was used to eliminate the inefficient criteria, and twelve criteria were reduced to seven. Afterward, using the selected effective criteria, the most appropriate project alternative was found via IF-TOPSIS (Yalcin et al., 2019).

Castro and Parreiras compiled MCDM studies related to the automotive industry. They noted that the integrated approaches were more usual than individual ones, and the AHP and TOPSIS were identified as the common techniques in the automotive industry. Besides, the application of fuzzy methods to tackle uncertainties in the data was also observed. It is also stated that fuzzy methods are applied to remove the uncertainties in the data (Castro and Parreiras, 2020).

Hamurcu and Eren proposed a multicriteria decision-making process using AHP and TOPSIS techniques in the context of an electric bus. In the study, researchers implemented a hybrid AHP–TOPSIS method to select the best alternative electric bus, where a hierarchy composed of criteria and nine alternatives was first determined. The weights of the criteria were determined using AHP, and then TOPSIS was used to evaluate six options (Hamurcu and Eren, 2020).

When the literature is evaluated in general, MCDM methods are used for the project or R&D project selection problems in various fields such as electricity (Stewart, 1991), manufacturing (Morcos, 2007; Güler et al., 2019; Yalcin et al., 2019), telecommunication industry (Dodangeh, 2009), logistics industry (Büyüközkan and Öztürkcan, 2010), oil industry (Amiri, 2010), construction sector (Rouyendegh and Erol, 2012; Pangsrie et al., 2015), government projects

(Huang et al., 2008; Uygun et al., 2014), healthcare (Ortíz et al., 2015), automotive sector (Vinodh and Swarnakar, 2015; Lee et al., 2017), Cargo sector (Tolga and Durak, 2019).

AHP (Huang et al., 2008; Amiri, 2010; Pangsri 2015; Jain et al., 2018; Güler et al., 2019; Hamurcu and Eren, 2020), ANP (Büyüközkan and Öztürkcan, 2010; Amiri, 2010; Uygun et al., 2014; Ortíz et al., 2015; Swarnakar, 2015), DEMATEL (Büyüközkan and Öztürkcan, 2010; Uygun et al., 2014; Ortíz et al., 2015; Swarnakar, 2015; Yalcin et al., 2019), COPRAS (Drejeris and Miceikiene, 2018; Tolga and Durak, 2019), TOPSIS (Amiri, 2010; Uygun et al., 2014; Pangsri, 2015; Swarnakar, 2015; Jain et al., 2018; Güler et al., 2019; Castro and Parreiras, 2020; Hamurcu and Eren, 2020), DEA (Kumar et al., 2007; Karasakal and Aker, 2017) methods and and and binary combinations of these methods have been encountered in the literature.

In this thesis, the weights obtained from MCDM methods were used as the input values in DEA, and these values tried to be maximized for the first time in the literature. There has not encountered any study that uses the scores obtained from two MCDM methods as input for DEA in the studies conducted in the automotive sector. Besides, important criteria were determined by the literature and expert opinion for R&D projects selection in the automotive industry and contributed to the literature.

III. MATERIALS AND METHODS

3.1. Material

R&D project selection process has increasing importance in the competitive business world. Considering that limited resources should be used efficiently, it is essential to identify the more likely project to gain a competitive advantage in this environment. For this purpose, project selection issues have been studied many times in the literature with many methods and models in different sectors to assist decision-makers.

3.2. Thesis Methodology

In this thesis, various MCDM methods in the literature were studied and analyzed. Then the appropriate methods were chosen and implemented for one of the leading bus and midibus manufacturers with 50 years of experience. The mentioned company has an R&D center and experienced R&D personnel who have worked in many national and international partnership projects. The company has sales success to approximately 70 countries in Turkey and abroad.

The thesis aims to help the R&D project manager prioritize the project by combining three methods: Expert interviews, The DEcision-MAking Trial and Evaluation Laboratory (DEMATEL) method, The COmplex PRoportional ASsessment (COPRAS), and Data Envelopment Analysis in group decision making. R&D project selection flow diagram showing the steps and techniques used in the thesis is given in Figure 2.

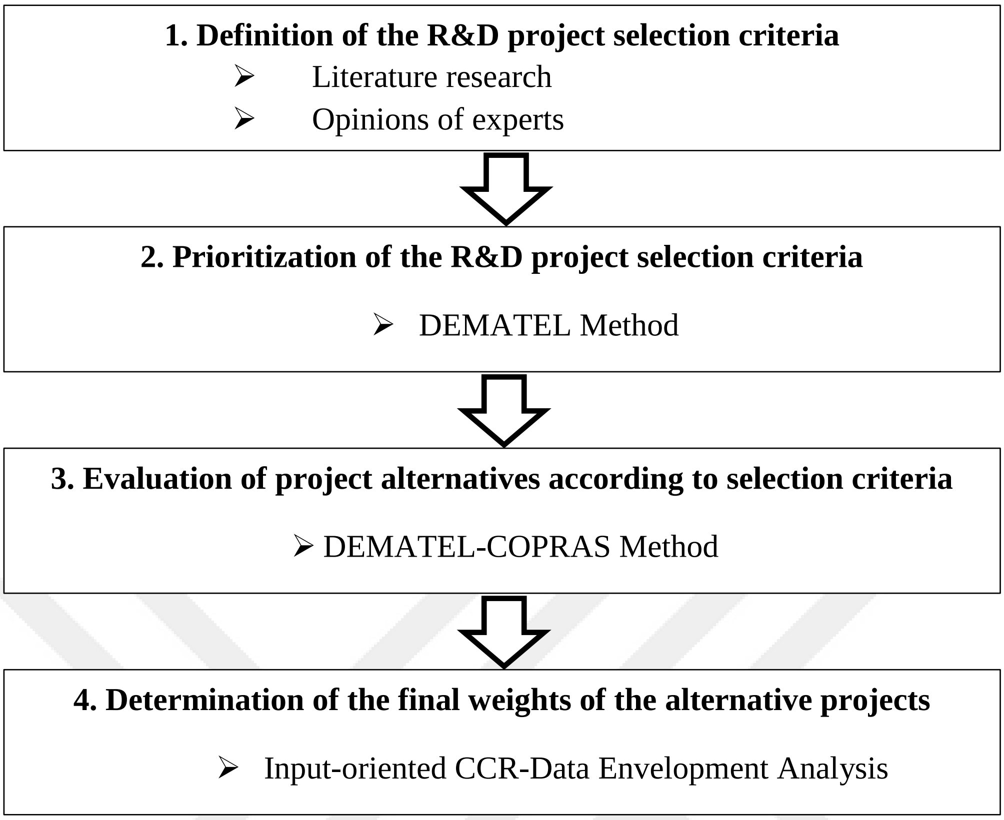

Figure 2. R&D project selection flow diagram in the thesis

The detailed methodology includes four steps to achieve the thesis objective as the following;

Step1: Definition of the R&D project selection criteria based on the literature review and opinion of the experts who have at least seven years of experience in the automotive company.

Step2: Prioritization of the R&D project selection criteria using the DEMATEL method.

Step 3: Evaluate the alternative R&D projects according to criteria via the DEMATEL-COPRAS method (criteria weights obtained from DEMATEL used as an input in COPRAS model).

Step 4: Prioritize the best project and assign the weight of each candidate project by the technique for order preference by input-oriented CCR-Data Envelopment Analysis.

3.3. Definition of the R&D project selection criteria

There may be many projects offered from different departments in companies. With limited resources, companies need to select projects that will provide a competitive advantage in the market using limited resources such as budget and labor. In this case, the projects should be evaluated according to specific criteria, and such a selection should be made. With this perspective, in the first phase of the thesis, the project selection criteria were determined based on previous research results and expert opinion.

Various criteria have been defined in researches conducted in different sectors for the selection of R&D projects. It is not possible to use the same criteria in all situations due to differences in the market, product, and company operations in actual applications.

In the thesis, the opinions of senior personnel with at least seven years of experience from R&D, production, marketing, and finance departments were considered together with the previous studies in the field for determining R&D project selection criteria. Four primary and 24 sub-criteria were determined with this approach, and 14 of the 24 criteria were thesis-specific criteria specified together with eight experts. Two experts were selected from the R&D department. One of them is a mechanical engineer with 12 years of experience. The other is an automotive engineer with eight years of experience. 2 experts were selected from the Finance department. One of them is an industrial engineer with ten years of experience. The other is a business economy specialist with nine years of experience. 2 experts were selected from the Production department. One of them is a mechanical engineer with 15 years of experience. The other is an automotive engineer with seven years of experience. 2 experts were selected from the Marketing department. One of them is a marketing specialist with eight years of experience. The other is an industrial engineer with seven years of experience. The evaluation criteria are shown in Table 2.

Table 2. Main and sub-criteria for used in the R&D selection process

Main Criteria	Sub-Criteria		Literature
R&D (R)	Probability of technical success	R1	Liberatore, 1986; Cheng et al., 2017
	Availability of labor resources in R&D	R2	
	*R&D internal resource ratio in the project	R3	
	*R&D external resource ratio in the project	R4	
	Applicability to other products and processes	R5	Liberatore, 1986; Cheng et al., 2017
	*The rate of tests to be carried out domestically	R6	
	*The rate of tests to be carried out abroad	R7	
Manufacturing (M)	*Internal resource rate to be used in production	M1	
	*External resource rate to be used in production	M2	
	*The ratio of intra-plant equipment to be used in the project	M3	
	*New equipment supply rate to be used in the project	M4	
	*The domestic supply rate of raw materials / semi-finished products to be used in the project	M5	
	*The international supply rate of raw materials / semi-finished products to be used in the project	M6	
Marketing (MR)	The potential size of the market	MR1	Liberatore, 1986; Cheng et al., 2017; Jung and Seo, 2010
	Existing or ongoing competitor studies in the sector	MR2	
	Probability of market success of the product	MR3	
	Product lifetime	MR4	
	*Contribution to market share	MR5	
	*Periodic maintenance costs	MR6	
	*Spare parts costs	MR7	
Finance (F)	Capital investment requirement	F1	Liberatore, 1986; Cheng et al., 2017; Dodangeh et al., 2009
	Rate of return on investment	F2	
	The relative cost of the developed product	F3	
	*Test costs	F4	

* Thesis-specific criteria

Each of the 24 sub-criteria based on R&D, Manufacturing, Marketing, and Finance sub-criteria are explained below.

Probability of technical success (R1): The feasibility of the project in terms of R&D. Projects are generally carried out to meet customer demands and follow new technologies. However, not all projects are technically feasible. The R&D department evaluates the technical feasibility of the project.

Availability of labor resources in R&D (R2): Refers to the project's compliance with the competencies of existing R&D staff. The competencies of the people who can work in the project must be compatible with the project. For this reason, it is considered a criterion in project selection.

R&D internal resource ratio in the project (R3): Refers to the ratio of resources required for the project to internal R&D resources. Insufficiency of resources for R&D negatively affects the feasibility of the project.

R&D external resource ratio in the project (R4): Refers to the ratio of the resources required for the project to the resources to be used in R&D. Being externally dependent in the selection of projects and external resource acquisition creates a negative effect in terms of budget and time.

Applicability to other products and processes (R5): Refers to the applicability of project outputs to existing products. While working on a project, being able to apply it to other products simultaneously provides the opportunity to produce different products with less cost. In addition, many new project ideas may arise during the project period. These create a positive effect on the selection of projects.

The rate of tests to be carried out domestically (R6): Refers to the ratio of tests to be carried out domestically in the project to total tests. Many tests require different technical features, machinery, equipment, and personnel competence in the projects. Especially in terms of budget, it is beneficial that the tests are carried out domestically.

The rate of tests to be carried out abroad (R7): Refers to the ratio of the tests to be done abroad. Due to regulations, some tests have to be done abroad. Increasing the C7 increases the project costs, so it is important in project selection.

Internal resource rate to be used in production (M1): It is the ratio of total resources used in the project's production phase, such as labor, to resources to be used within the company. The fact that the resources to be used in production can be obtained from within the company is considered an important criterion in project selection, as it directly affects the duration and budget of the project.

External resource rate to be used in production (M2): It is the ratio of the labor force to be used in the production phase of the project, etc. from external sources. Since foreign dependency will adversely affect the duration and budget of the project, a high rate will also affect the project selection negatively.

The ratio of intra-plant equipment to be used in the project (M3): It is the ratio of the total equipment to be used in the project to the number of resources to be used in the company. The availability of existing equipment reduces the project budget and time.

New equipment supply rate to be used in the project (M4): It is the ratio of the total equipment to be used in the project to the number of external resources to be used. The procurement of new equipment negatively affects the project duration and budget. In addition, the staff whose equipment will be used must go through a training process to use the new equipment. These are seen as risks in project selection.

The domestic supply rate of raw materials / semi-finished products to be used in the project (M5): It is the ratio of the raw materials required in the project's production phase to the raw materials available in the company. The availability of the raw materials from within the company is considered an advantage in project selection.

The international supply rate of raw materials / semi-finished products to be used in the project (M6): It is the ratio of the raw materials required for the project during the production phase to the raw materials to be procured from abroad. Obtaining it from abroad will adversely affect the project budget and duration.

The potential size of the market (MR1): The number of potential customers of the project in the market. The number of potential customers refers to the size of the market. The limited number of potential customers will increase the competition more. Accordingly, the project will appeal to a limited segment. This situation, which directly affects the project's sales success, is an important criterion in project selection.

Existing or ongoing competitor studies in the sector (MR2): Refers to projects that have been made for the current market. The existence of competing studies that have been tried and succeeded before will confirm the project. For this reason, efforts are made to select projects made in parallel with the current studies.

Probability of market success of the product (MR3): The potential market size evaluates the project's probability of success by looking at completed and ongoing competitor studies. Past and unsuccessful projects in the selected market affect the likelihood of market success.
Product lifetime (MR4): It expresses how long the product will take an active market. It also directly affects the service life. Products that do not last long are an undesirable criterion by the customer. For this reason, it is essential in project selection.

Contribution to market share (MR5): The contribution will make to the current market share and evaluating whether new market places can be reached. The potential of the project to reach new marketplaces directly affects its sales and profit success. However, being a leader in the market affects the prestige of the company positively. For these reasons, it is a fundamental criterion in project selection.

Periodic maintenance costs (MR6): It covers the maintenance intervals and cost of the product to be obtained as a result of the project. The high periodic costs of the product are undesirable by the customer as it will bring additional costs. This situation is directly affecting the sales success of the project.

Spare parts costs (MR7): Refers to the spare parts that the customer should use depending on the periodic maintenance processes throughout the product's life and their costs. The high cost of spare parts negatively affects the sales success of the product.

Capital investment requirement (F1): Refers to whether a capital investment is required depending on the amount to be spent for the project. Capital investment directly affects the cost of the project. It is of high importance in the selection of projects depending on the financial situation of the company.

Rate of return on investment (F2): It calculates the total expenditures to be made for the project and at what point in the potential sales forecast profit can be made. The long time to reach the land negatively affects the choice of the project.

The relative cost of the developed product (F3): It is the calculation of the total cost required during the product's life. The high cost of the project also causes the product to be costly. This situation also restricts the customer base from being targeted. Addressing a limited market also affects sales success. For these reasons, it is an undesirable criterion in project selection.

Test costs (F4): Refers to the costs of tests to be made for the project. Many tests must be done during the project process. Some of these are mandatory regulation tests. Some of them are tests that need to be measured at certain stages of the project. The high cost of these tests will directly affect the project cost and prevent non-compulsory tests. This situation affects the healthy progress of the project.

Since the importance of selection criteria will differ, the selection criteria were prioritized in the second step of the thesis. DEMATEL, one of the multicriteria decision-making methods, was used at this stage.

3.4. The Decision-Making Trial And Evaluation Laboratory Method

The decision-making trial and evaluation laboratory was introduced (DEMATEL) method in 1971 by Fonetla and Gabus. It is applied to create a network relationship design to examine the internal relationship between attributes. DEMATEL technique has been used successfully in different applications, such as project selection and the e-learning programs evolution. Features of the DEMATEL can be listed as follows:

- It is a compensatory method;
- Does not require feature independence;
- Qualitative attributes are converted into quantitative.

Unlike other methods, DEMATEL is one of the attribute evaluation methods in which features are evaluated based on the opinions of experts on the direct relationship matrix. This method is combined with other attribute evaluation methods. Thus, the method is used in different fields extensively. The direct relationship matrix was obtained using the arithmetic mean of the pairwise comparison matrices for each attribute which is determined and used by the decision-maker. Besides, a direct relation matrix Eq. (1) should be used to convert qualitative attributes into quantitative attributes (Alinezhad and Khalili, 2019).

$$M=\begin{bmatrix} m_{11} & \cdots & m_{1j} & \cdots & m_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ m_{i1} & \cdots & m_{ij} & \cdots & m_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ m_{n1} & \cdots & m_{nj} & \cdots & m_{nn} \end{bmatrix}_{n\times n} \quad ; \; i,j \in \{1,\dots n\} \tag{1}$$

In Eq. (1), the matrix element for the ith attribute in a jth attribute is represented with mij. The steps of DEMATEL are summarized in Figure 3. Application steps and used formulations of DEMATEL are explained in the following section (Alinezhad and Khalili, 2019).

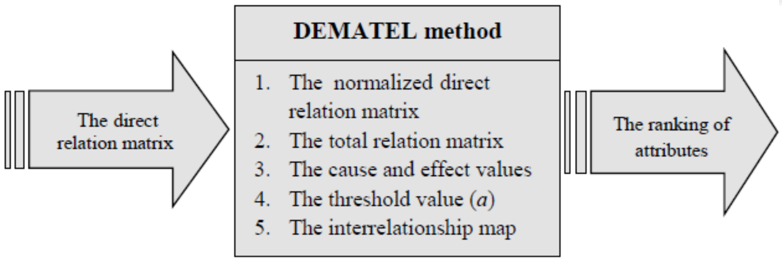

Figure 3. The steps of DEMATEL (Alinezhad and Khalili, 2019)

Evaluation of criteria was conducted by the experts with The DEMATEL relation scale as shown in Table 3.

Table 3. The DEMATEL relation scale

Influence level	Influence score
No influence	0
Very low influence	1
Normal influence	2
High influence	3
Very high influence	4

3.4.1. The Normalized Direct Relation Matrix

Equation 2 is used to normalized the direct relation matrix, and the k value is calculated from Equation 3.

$$D = k \times M \tag{2}$$

$$k = max_{ij}\left\{\frac{1}{max_i \sum_{j=1}^{n}|m_{ij}|}, \frac{1}{max_j \sum_{i=1}^{n}|m_{ij}|}\right\} \tag{3}$$

3.4.2. The Total Relation Matrix

Equation 4 is used to compute the full penetration value of an attribute. When lim X^l =$[0]_{nxn}$ and $l \to \infty$ as:

$$\begin{aligned} T &= D + D^2 + D^3 + \cdots + D^l \\ &= D(l + D + D^2 + D^3 + \cdots + D^{l-1})(l - D)(l - D)^{-1} \\ &= D(l - D^l)(\mathrm{l} - D)^{-1} \end{aligned} \tag{4}$$

(I) is the identity matrix In Eq. (4), and Equation 5 represents the total relation.

$$T = D(\mathrm{l} - D)^{-1} \tag{5}$$

In equations, t_{ij} indicates the direct relation amount for the *ith* attribute in the *jth* attribute (Alinezhad and Khalili, 2019).

3.4.3. The Cause and Effect Values

In this stage, Equations 6 and 7 are used for calculating the r and c values, representing the sum of the row and column values (Alinezhad and Khalili, 2019).

$$r = [r_i]_{n\times 1} = \left[\sum_{j=l}^{n} t_{ij}\right]_{n\times l} \quad ; i = 1,\cdots,n \tag{6}$$

$$c = [c_j]'_{l\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{l\times n} \quad ; j = 1,\cdots,n \tag{7}$$

In Eq. (7), $[cj]'$ is the *jth* column's transpose value; *cj* is the sum of the *jth* column values which is indicated that the effect of attribute *jth* on others, and *ri* is the sum of *ith* row values, as the cause of *ith* attribute on others.

If $i = j$, $(ri + ci)$ as the horizontal vector indicates the impact and effect of the *ith* attribute. So, when $(ri + ci)$ is greater, the attribute has more interactions with other attributes. The influence power of *ith* attribute is represented by the vertical vector $(ri + ci)$. The positive $(ri + ci)$ value means that it is a causal variable; in the case of negative, it is considered an effect.

3.4.4. The Threshold Value (a)

For drawing the interrelationship map, the threshold value should be determined. For equations whose values in the full penetration matrix are greater than the threshold value, they are plotted on the interrelationship map. Equation 8 is used for calculating the average of elements of the full penetration matrix.

$$a = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{N} \tag{8}$$

3.4.5. The Interrelationship Map

The interrelationship map is drawn at this stage for convenient analysis of the final solution with $(ri + ci)$ and $(ri - ci)$ values for each attribute for the threshold value (Alinezhad and Khalili, 2019).

3.4.6. The Final Ranking of Attributes

The interrelationship map and the values $(ri + ci)$ and $(ri - ci)$ arranging in descending order are used for obtaining a possible structure and ranking of the factors.

3.3.7 Calculation of weights

As the last step, weight calculation is made with Equation (9) and Equation (10), depending on the $(ri + ci)$ and $(ri - ci)$ values.

$$w_i = \{(r_i + c_i)^2 + (r_i - c_i)^2 \tag{9}$$

$$W_i = {}^{w_i}/_{\sum_{i=1}^{n} w_i} \tag{10}$$

Project selection criteria DEMATEL is an attribute evaluation method in which features are evaluated based on experts' opinions on the direct relationship matrix differently from the other methods. This method is combined with other attribute evaluation methods.

In the third stage of the thesis, alternative projects of the company were evaluated with The COmplex PRoportional ASsessment (COPRAS) in terms of project selection criteria. The score of each project was obtained using the COPRAS method. In this stage, the weights obtained from DEMATEL were used in the COPRAS formulations. Thus, the scores of projects were obtained with the combination of DEMATEL-COPRAS.

3.5. The COmplex PRoportional ASsessment (COPRAS) Method

Zavadskas et al. introduced the COPRAS method in 1994. COPRAS method is used to maximize and minimize index values. Besides, the effect of maximizing and minimizing feature indexes in evaluating results is considered separately. This method is applied in various fields such as assessment of risks, project and material selection. The features given below are taken into account for the COPRAS method :

- COPRAS is a compensatory method;
- The attributes are independent;
- Quantitative attributes are obtained from the conversion of the qualitative attributes

In the COPRAS method, the complete and final ranking of alternatives is performed using the value evaluation of maximizing and minimizing indexes. Thus, this technique is used in various fields according to method steps and compensatory properties. Recently, the COPRAS has been used with other methods in fuzzy and grey environments. In this technique, the information received from a decision-maker is used to form the decision matrix as given in Equation 11 (Alinezhad and Khalili, 2019).

$$X=\begin{bmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mj} & \cdots & r_{mn} \end{bmatrix}_{m\times n} \quad ; \ i = 1, \dots, m, \ \ j = 1, \dots, n \tag{11}$$

In Equation 11, *rij* element of the decision matrix represents an *i*th alternative in the *j*th attribute. Besides, the attribute weights are provided by the decision-maker [$w_1; w_2; \dots; w_n$].

The application steps of COPRAS are given in Figure 4. Application steps and used formulations of COPRAS are also explained in the following sections (Alinezhad and Khalili, 2019).

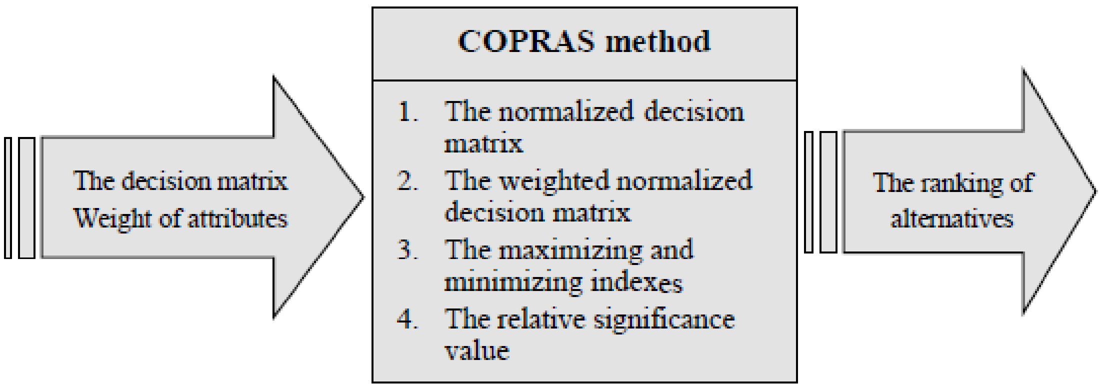

Figure 4. The application steps of the COPRAS method (Alinezhad and Khalili, 2019)

3.5.1. The Normalized Decision Matrix

The decision matrix is normalized using Equation 12.

$$r_{ij}^* = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}}\ ; \quad j = 1, \dots, n \tag{12}$$

Here, r_{ij}^* represents the normalized decision matrix value of the *i*th alternative in *j*th attribute.

3.5.2. The Weighted Normalized Decision Matrix

The weighted normalized decision matrix values are calculated with Equation 13.

$$\hat{r}_{ij=}r*_{ij}.w_j; \quad i = 1, \dots, m \;, \quad j = 1, \dots, n \tag{13}$$

In Eq. (13), *wj* is the weight of attribute [w_1, w_2, ..., w_n].

3.5.3. The Maximizing and Minimizing Indexes

The maximizing and minimizing indexes of the negative or positive attributes are obtained by Equations 14 and 15.

$$S_{+i} = \sum_{j=1}^{g} \hat{r}_{ij} \; ; \quad i = 1, \dots, m \tag{14}$$

$$S_{-i} = \sum_{j=g+1}^{n} \hat{r}_{ij} \; ; \quad i = 1, \dots, m \tag{15}$$

In Equations, the number of positive attributes is indicated by g, and n-g shows the number of negative attributes, maximizing and minimizing indexes of the *ith* attribute is described by S_i according to the type of attribute.

3.5.4. The Maximizing and Minimizing Indexes

Equations 16 is used for the calculation of each alternatives' relative significance value.

$$Q_i = S_{+i} + \frac{\sum_{i=1}^{m} S_{-i}}{S_{-i} \sum_{i=1}^{m} \frac{1}{S_{-i}}} \tag{16}$$

3.5.5. The Final Ranking of Alternatives

The relative importance values of the alternatives are ranked in descending order, with the highest final value having the highest rank. Performance index values (P_i) of alternatives are calculated according to Equation 17. The option with the found P_i performance value index of 100 is the best alternative. The preference ranking of the options is concluded by listing the P_i values in descending order.

$$P_i = \frac{Q_i}{Q_{max}}.100\% \tag{17}$$

In decision-making processes, ranking is an essential step in choosing among alternatives after evaluations. In Multi-Qualified Decision-Making problems, there are n alternatives evaluated according to the m criterion. The final ranking values of the alternatives are provided from the results of the assessments. Generally, the higher the ranking value exhibited, the better the performance of the alternative. Thus the option having the highest-ranking value is considered as the best alternative (Hwang et al., 2016).

In the fourth step of the thesis, Input-oriented Charnes, Cooper, and Rhodes Model (CCR), one of the data envelopment analyses (DEA) was used to determine the final weights of alternative projects. DEMATEL-COPRAS scores, profitability values, break-even point (BEP)/duration ratio, and Costs for alternative projects were used as inputs in the input-oriented CCR DEA model.

3.6. The Data Envelopment Analysis (DEA)

DEA is one of the math-based performance evaluation technique for a set of Decision Making Units (DMUs). This technique is widely used for evaluating the various systems having different inputs and outputs in various areas. DEA is used to determine the strengths and weaknesses of a group of DMUs. In the analysis, relative efficiency, pattern coordinates, rankings, congestion in inputs, return on the scale, Malmquist productivity index, cost-effectiveness, and profitability can be evaluated based on data analysis for each DMUs. The relative efficiency of a set of heterogeneous DMUs is calculated with the DEA technique. Firstly, a production possibility set is created by using the actual observations. In this cluster, it is possible to investigate whether there is a better point than the considered DMU. If there is no better point, the unit will be efficient; otherwise, DMU will be einfficient. For this aim, firstly, it is considered a fix direction for improvement, and then try to improve the unit under evaluation in the production possibility set. Since the production possibility set is the smallest set that can be considered, the resulting relative efficiency is optimistic (Lotfi et al., 2020).

3.6.1. Input-oriented CCR-DEA Model

Suppose that the *n* DMUs are considered to be evaluated, each of which uses *m* different inputs for producing *s* different outputs. Symbolically, a DMU can be shown in Figure 5 (Lotfi et al., 2020).

Figure 5. Symbolic representation of Decision Making Units

In Figure 4, where $Xj = (x_{1j}, ..., x_{mj})$ and $Yj = (y_{1j}, ..., y_{sj})$ represent the input and output vector of the decision making unit *j*, respectively.

First, let *X* and *Y* be the input and output vectors, respectively, and assume $Yj \neq 0$, $Yj \geq 0$, and $Xj \neq 0$, $Xj \geq 0$.

Equation 18 defines the absolute efficiency of the DMU_p.

$$E_P = \frac{U^t Y_p}{V^t X_p} = \frac{\sum_{r=1}^{s} u_r y_{rp}}{\sum_{i=1}^{m} v_i x_{ip}} \tag{18}$$

In Eq.18, v_i and u_r are the weights of *i*th input and *r*th output, respectively, whichever $v_i > 0$, $u_r > 0$. Then the DMU_p*'s* relative efficiency defines with Equation 19.

$$RE_P = \frac{E_P}{Max\{E_j:\ \ j = 1, \dots, n\}} = \frac{E_P}{Max\left\{\frac{U^t Y_j}{V^t X_j}:\ \ j = 1, \dots, n\right\}} \tag{19}$$

As DEA aims to derive a score of optimistic relative efficiency, Equation 20 is formulated the model.

$$Max\ \ RE_P = \frac{E_P}{Max\left\{\frac{U^t Y_j}{V^t X_j}:\ \ j=1,\dots,n\right\}} \tag{20}$$

$$\text{s.t}\ \ U > 0,\ V > 0$$

Model in Eq.(20) can be converted into the model in Equation 21 using variable transformation presented by Charnes (Charnes et al., 1985).

$$Max \quad RE_P = \frac{U^t Y_p}{V^t X_p} \tag{21}$$

$$\text{s.t.} \quad \frac{U^t Y_j}{V^t X_j} \leq 1, \quad j = 1, \dots, n$$

$$U > 0, \qquad V > 0$$

The model in Eq. (21) is solved to use optimization methods, instead of constraints u > 0 and v > 0, constraints U ≥ 1/s Ɛ and V ≥ 1/m Ɛ should be used. In this case, the model in Equation 22 will be obtained by using variable transformation.

$$\begin{aligned} &Max \quad RE_P = UY_o \\ &\text{s.t.} \quad VX_o = 1, \\ &UY_j - VX_j \leq 0, \quad j = 1, \dots, n, \\ &U \geq 1\varepsilon, \quad V \geq 1\varepsilon. \end{aligned} \tag{22}$$

The model in Eq. (22) is referred to as the input-oriented CCR multiplier model. Equation 23 is the dual of this linear model.

$$\begin{aligned} &Min \;\; \theta - 1\varepsilon(S^- + S^+) \\ &s.t. \;\; \lambda X + S^- = \theta X_o \\ &\qquad \lambda Y - S^+ = Y_o \\ &\qquad \lambda \geq 0, \\ &\qquad S^- \geq 0, \; S^+ \geq 0. \end{aligned} \tag{23}$$

Equations 24 and 25 represent the vector forms of models 22 and 23.

$$Max \quad RE_P = \sum_{r=1}^{s} u_r \, y_{ro}$$

$$s.t \quad \sum_{i=1}^{m} v_i \, x_{io} = 1, \tag{24}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, \dots, n,$$

$$u_r \geq 1\varepsilon, \qquad v_i \geq 1\varepsilon \qquad\qquad r = 1, \dots, s, \qquad i = 1, \dots, m.$$

$$\begin{aligned}
& Min\ \ \theta - 1\varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right) \\
& s.t.\ \ \textstyle\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{io}, \quad i = 1, \dots, m, \\
& \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro}, \quad r = 1, \dots, s, \\
& \lambda_j \geq 0, \qquad\qquad j = 1, \dots, n, \\
& s_i^- \geq 0, \qquad s_r^+ \geq 0. \qquad\qquad i = 1, \dots, m, \ \ r = 1, \dots, s.
\end{aligned} \tag{25}$$

Eq. (21) and the equivalent of it in Eq. (25) refer to the input-oriented CCR envelopment two-phase model. According to the strong duality theorem, the optimal objective values for a pair of bounded primal and dual problems are the same. If the efficiency scores are equal to one for a couple of models, the evaluated DMU is called efficient; otherwise, DMU is called inefficient (Lotfi et al., 2020).

IV. RESULTS AND DISCUSSIONS

4.1. Determination of project selection criteria weights

Although there are many criteria, the importance levels of these criteria on projects differ from each other. Therefore, the importance level of criteria was determined after defining the project selection criteria. R&D projects were evaluated and compared according to defined main and sub-criteria. The scores of the main criteria were calculated by the DEMATEL method based on experts' evaluations based on the DEMATEL relation scale (Table 3) and given in Table 4.

Table 4. The score of the main criteria

	R&D	**Manufacturing**	**Marketing**	**Finance**
R&D		4	2	4
Manufacturing	2		2	3
Marketing	3	2		3
Finance	3	3	3	

Expert evaluations of the main criteria are given in Table 4. In this evaluation matrix, the weights in Table 9 were obtained by considering Eq (2-10). In Table 9, the weight of R&D, Manufacturing, Marketing, and Finance criteria are obtained as 0.261, 0.239, 0.229, 0.272. According to these values, product financing (F) and R&D success (R) stand out among the main criteria of the project selection. These criteria are followed by manufacturing (M) and the marketing success (MR) main criteria.

The assessment for the sub-criteria for R&D, manufacturing, marketing, and finance main criteria are given in Tables 5, 6, 7, and 8, respectively.

Table 5. The scores of seven sub-criteria of R&D

	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**
R1		0	1	1	4	1	1
R2	4		4	2	2	4	1
R3	4	4		2	4	4	2
R4	3	2	2		2	2	2
R5	2	2	2	0		1	1
R6	3	3	3	0	1		2
R7	3	1	0	3	1	2	

As a result of the expert evaluation in Table 3, the assessment of sub-criteria for R&D is given in Table 5, and the sub-criteria weights in Table 9 were obtained by considering Eq (2-10). The weighted DEMATEL score was obtained by multiplying the sub-criteria weights with the weights of the main criteria. When the sub-criteria are evaluated within themselves, the R&D internal resource ratio in the project (R3) and the availability of labor resources in R&D (R2) have the highest importance. These criteria are highly influential on the feasibility and the probability of the success of the R&D project. The rate of tests to be carried out abroad (R7) was the least important criterion. R&D internal resource utilization rate and availability of existing R&D resources will increase the probability of success and reduce the project cost and duration. Since the ratio of the tests to be carried out abroad (R7) will generally include the regulation tests that must be done compulsorily. R7 has the lowest importance as a sub-criterion.

Table 6. The scores of six sub-criteria of manufacturing

	M1	**M2**	**M3**	**M4**	**M5**	**M6**
M1		0	1	1	4	1
M2	4		4	2	2	4
M3	4	4		2	4	4
M4	3	2	2		2	2
M5	2	2	2	0		1
M6	3	3	3	0	1	

As a result of the expert evaluation in Table 3, the assessment of sub-criteria for manufacturing are given in Table 6 and the sub-criteria weights in Table 9 were obtained by considering Eq

(2-10). The weighted DEMATEL score was obtained by multiplying the sub-criteria weights with the weights of the main criteria. Accordingly, sub-criteria of manufacturing were examined. The internal resource rate to be used in production (M1) had the highest importance. Projects with high internal resource utilization have higher selection priority. The least important criterion was found as the international supply rate of raw materials / semi-finished products to be used in the project (M6). The ratio of internal resources to be used in production confirms that the project can be done with the company resources. The internal resource rate (M1) has high importance due to the direct effects on the cost and duration of the project.

Table 7. The scores of seven sub-criteria of marketing

	MR1	**MR2**	**MR3**	**MR4**	**MR5**	**MR6**	**MR7**
MR1		3	2	2	3	1	1
MR2	4		4	3	3	1	1
MR3	2	2		4	4	3	3
MR4	3	2	3		4	4	4
MR5	3	3	4	3		1	1
MR6	1	1	3	3	2		1
MR7	1	1	3	3	2	3	

Using Table 3, 7 sub-criteria were evaluated under the main criterion of Marketing, and evaluation results were given in Table 7. According to the expert scoring in Table 7, the weights in Table 9 were obtained by considering Eq (2-10). When the sub-criteria are considered within themselves, the most important criteria were the probability of market success of the product (MR3) and product lifetime (MR4); the least important criteria were found as the periodic maintenance costs (MR6) and spare parts costs (MR7).

In the bus market, customers expect the product to be long-lasting. MR3 and MR4 criteria support the probability of market success. Therefore, their weight is higher than other criteria.

Table 8. The scores of four sub-criteria of finance

	F1	**F2**	**F3**	**F4**
F1		4	4	1
F2	3		3	1
F3	4	4		1
F4	3	3	3	

As a result of the expert evaluation for finance in Table 8, the sub-criteria weights in Table 9 were obtained by considering Eq (2-10). The weighted DEMATEL score was obtained by multiplying the sub-criteria weights with the weights of the main criteria. When the sub-criteria of finance are evaluated, the most important criteria are capital investment requirement (F1) and relative cost of the developed product (F3); The least important criteria was the test costs (F4). The higher cost is generally considered a risky situation. Since the capital investment requirement and the cost of developed products directly affect the project's total cost. So, F1 and F3 criteria have high importance in project selection. Test costs (F4) are tolerable in the total project cost, so this criterion has lesser importance.

As shown in Table 9, when 24 sub-criteria were evaluated in terms of project selection, the first three sub-criteria having the highest weight as "capital investment requirement", "relative cost of the developed product" and "rate of return on investment" were sub-criteria of the Finance main criterion. It was also determined that the last three criteria with the lowest weight were " periodic maintenance costs", "spare part costs" depending on the marketing main criterion, and "the rate of tests to be carried out abroad" under the R&D main criterion. These inferences confirm the internal evaluations of the main criteria.

Table 9. The weights of the main and sub-criteria obtained by the DEMATEL method

Main Criteria	Weight	Sub-Criteria		Weight	Weighted DEMATEL Score
R&D	0.261	R1	Probability of technical success	0.155	0.040
		R2	*Availability of labor resources in R&D	0.164	0.043
		R3	R&D internal resource ratio in the project	0.179	0.047
		R4	R&D external resource ratio in the project	0.119	0.031
		R5	*Applicability to other products and processes	0.134	0.035
		R6	The rate of tests to be carried out domestically	0.146	0.038
		R7	The rate of tests to be carried out abroad	0.104	0.027
Manufacturing	0.239	M1	Internal resource rate to be used in production	0.214	0.051
		M2	External resource rate to be used in production	0.177	0.042
		M3	The ratio of intra-plant equipment to be used in the project	0.173	0.041
		M4	New equipment supply rate to be used in the project	0.173	0.041
		M5	The domestic supply rate of raw materials / semi-finished products to be used in the project	0.139	0.033
		M6	The international supply rate of raw materials / semi-finished products to be used in the project	0.124	0.030
Marketing	0.229	MR1	*The potential size of the market	0.126	0.029
		MR2	*Existing or ongoing competitor studies in the sector	0.136	0.031
		MR3	*Probability of market success of the product	0.170	0.039
		MR4	*Product lifetime	0.173	0.039
		MR5	Contribution to market share	0.158	0.036
		MR6	Periodic maintenance costs	0.118	0.027
		MR7	Spare parts costs	0.118	0.027
Finance	0.272	F1	*Capital investment requirement	0.270	0.073
		F2	*Rate of return on investment	0.265	0.072
		F3	* Relative cost of the developed product	0.270	0.073
		F4	Test costs	0.196	0.053

4.2. Determining Project Significance Levels

After calculating the weights of effective criteria in R&D project selection with the DEMATEL method, the rankings of project alternatives were determined by the COPRAS method. In the COPRAS method, positive criteria refer to criteria where higher values indicate better status in achieving the goal. For example, in the project selection process, sub-criteria related to the main criteria of R&D (R); The probability of technical success (R1), availability of labor resources in R&D (R2), R&D internal resource ratio in the project (R3), R&D external resource ratio in the project (R4), applicability to other products and processes (R5), and The rate of tests to be carried out domestically (R6) are positive criteria. The high values of these criteria positively affect the choice of alternative. In addition, the criteria that will positively affect the selection of alternatives when their values are low among the criteria are defined as useless criteria. Similarly, sub-criteria related to the main criteria of R&D in the project selection; R&D external resource ratio in the project (R4), and The rate of tests to be carried out abroad (R7) are useless criteria. The project alternative with low values in terms of these criteria is more likely to be selected. Table 10 shows the main and sub-criteria situation used in the selection process of R&D projects.

Table 10. Types of the main and Sub-criteria in the COPRAS method

Main Criteria	Sub-Criteria	Code	Type
R&D (R)	Probability of technical success	R1	Max
	*Availability of labor resources in R&D	R2	Max
	R&D internal resource ratio in the project	R3	Max
	R&D external resource ratio in the project	R4	Min
	*Applicability to other products and processes	R5	Max
	The rate of tests to be carried out domestically	R6	Max
	The rate of tests to be carried out abroad	R7	Min
Manufacturing (M)	Internal resource rate to be used in production	M1	Max
	External resource rate to be used in production	M2	Min
	The ratio of intra-plant equipment to be used in the project	M3	Max
	New equipment supply rate to be used in the project	M4	Min
	The domestic supply rate of raw materials / semi-finished products to be used in the project	M5	Max
	The international supply rate of raw materials / semi-finished products to be used in the project	M6	Min
Marketing (MR)	*The potential size of the market	MR1	Max
	*Existing or ongoing competitor studies in the sector	MR2	Max
	*Probability of market success of the product	MR3	Max
	*Product lifetime	MR4	Max
	Contribution to market share	MR5	Max
	Periodic maintenance costs	MR6	Min
	Spare parts costs	MR7	Min
Finance (F)	*Capital investment requirement	F1	Min
	*Rate of return on investment	F2	Max
	* Relative cost of the developed product	F3	Max
	Test costs	F4	Min

The data of the criteria used in the evaluation process of the project alternatives were obtained from the company. Five different projects have been evaluated according to the project selection criteria in Table 11. Project 1 is a battery production that is very popular in the industry. While Project 2 and 3 refer to the production of new vehicles for the foreign customer market, project 4 refers to producing a new axle for the domestic customer market. Project 5 refers to the development of a new seat-back screen as a customer request. A decision matrix was created based on the obtained data using Eq (11) and given in Table 11.

Table 11. Decision matrix

Main Criteria	Sub Criteria	P1	P2	P3	P4	P5	Total
R&D	R1	10	9	8	4	5	36
	R2	7	7	8	9	5	36
	R3	7	8	8	6	4	33
	R4	3	2	2	4	6	17
	R5	4	7	6	4	5	26
	R6	7	6	3	9	8	33
	R7	3	4	7	1	2	17
Manufacturing	M1	5	7	6	6	4	28
	M2	5	3	4	4	6	22
	M3	6	7	6	8	6	33
	M4	4	3	4	2	4	17
	M5	5	6	5	9	9	34
	M6	5	4	5	1	1	16
Marketing	MR1	9	8	9	4	5	35
	MR2	10	7	10	4	4	35
	MR3	9	7	9	6	5	36
	MR4	10	10	10	5	6	41
	MR5	10	10	10	4	5	39
	MR6	5	7	8	4	6	30
	MR7	5	7	8	4	8	32
Finance	F1	8	6	7	2	2	25
	F2	10	8	9	4	5	36
	F3	6	7	9	5	8	35
	F4	4	5	9	3	6	27

In the second stage of the COPRAS method, the decision matrix was normalized according to Eq (12). The normalized decision matrix is given in Table 12.

Table 12. Normalized decision matrix

Main Criteria	Sub Criteria	P1	P2	P3	P4	P5
R&D	R1	0.278	0.250	0.222	0.111	0.139
	R2	0.194	0.194	0.222	0.250	0.139
	R3	0.212	0.242	0.242	0.182	0.121
	R4	0.176	0.118	0.118	0.235	0.353
	R5	0.154	0.269	0.231	0.154	0.192
	R6	0.212	0.182	0.091	0.273	0.242
	R7	0.176	0.235	0.412	0.059	0.118
Manufacturing	M1	0.179	0.250	0.214	0.214	0.143
	M2	0.227	0.136	0.182	0.182	0.273
	M3	0.182	0.212	0.182	0.242	0.182
	M4	0.235	0.176	0.235	0.118	0.235
	M5	0.147	0.176	0.147	0.265	0.265
	M6	0.313	0.250	0.313	0.063	0.063
Marketing	MR1	0.257	0.229	0.257	0.114	0.143
	MR2	0.286	0.200	0.286	0.114	0.114
	MR3	0.250	0.194	0.250	0.167	0.139
	MR4	0.244	0.244	0.244	0.122	0.146
	MR5	0.256	0.256	0.256	0.103	0.128
	MR6	0.167	0.233	0.267	0.133	0.200
	MR7	0.156	0.219	0.250	0.125	0.250
Finance	F1	0.320	0.240	0.280	0.080	0.080
	F2	0.278	0.222	0.250	0.111	0.139
	F3	0.171	0.200	0.257	0.143	0.229
	F4	0.148	0.185	0.333	0.111	0.222

The weighted normalized decision matrix was created in the third stage according to Eq (13) by using the criteria weights obtained by the DEMATEL method. The weighted normalized decision matrix is given in Table 13.

Table 13. Weighted normalized decision matrix

Main Criteria	Sub Criteria	P1	P2	P3	P4	P5
R&D	R1	0.011	0.010	0.009	0.004	0.006
	R2	0.008	0.008	0.009	0.011	0.006
	R3	0.010	0.011	0.011	0.008	0.006
	R4	0.005	0.004	0.004	0.007	0.011
	R5	0.005	0.009	0.008	0.005	0.007
	R6	0.008	0.007	0.003	0.010	0.009
	R7	0.005	0.006	0.011	0.002	0.003
Manufacturing	M1	0.009	0.013	0.011	0.011	0.007
	M2	0.010	0.006	0.008	0.008	0.012
	M3	0.008	0.009	0.008	0.010	0.008
	M4	0.010	0.007	0.010	0.005	0.010
	M5	0.005	0.006	0.005	0.009	0.009
	M6	0.009	0.007	0.009	0.002	0.002
Marketing	MR1	0.007	0.007	0.007	0.003	0.004
	MR2	0.009	0.006	0.009	0.004	0.004
	MR3	0.010	0.008	0.010	0.006	0.005
	MR4	0.010	0.010	0.010	0.005	0.006
	MR5	0.009	0.009	0.009	0.004	0.005
	MR6	0.005	0.006	0.007	0.004	0.005
	MR7	0.004	0.006	0.007	0.003	0.007
Finance	F1	0.023	0.018	0.021	0.006	0.006
	F2	0.020	0.016	0.018	0.008	0.010
	F3	0.013	0.015	0.019	0.010	0.017
	F4	0.008	0.010	0.018	0.006	0.012

In the fourth stage of the COPRAS, S_{i+} for positive criteria for different project proposals and S_{i-} values for unhelpful criteria were calculated using Equations (14) and (15). Relative importance value (Q_i)and performance index (P_i) for each alternative were calculated using Equations (16) and (17), respectively. The calculated values for different project alternatives are presented in Table 14.

Table 14. S_{i+}, S_{i-}, Q_i ve P_i Values for alternative projects

Alternatives	S_{i+}	S_{i-}	Q_i	P_i
P1	0.142	0.079	0.494	100.000
P2	0.143	0.070	0.143	29.050
P3	0.146	0.094	0.146	29.666
P4	0.110	0.042	0.110	22.191
P5	0.107	0.067	0.107	21.681

According to Table 13, the project with a performance index of 100 is considered the best alternative. When all projects are evaluated based on P_i values, it can be said that the worst alternatives are the P5 and P4 projects with performance index values of 21.68% and 22.19%, respectively. The best project alternative is the P1 project with the 100% performance index value. Similarly, when the relative importance values (Q_i) of alternative projects are compared, it is seen that the P1 project has the highest level of importance among the alternatives with a value of 0.494, which supports the conclusion that P1 is the best project alternative.

4.3. Data Envelopment Analysis

In the thesis, data envelopment analysis was used to evaluate the relative effectiveness of alternative projects. Input-oriented CCR is one of the alternatives DEA model was used for evaluating the project. In the DEA model created in the thesis, break-even point (BEP)/project duration and cost were considered as input variables. Time-based performance and the economic dimension of the project were taken into account in the model with BEP/project duration (x_1) and the cost (x_2) variables, respectively.

Project weights (y_1) obtained from the DEMATEL-COPRAS method and profitability (y_2) value of each project were considered as output variables in the model. Thus, together with the DEMATEL-COPRAS weight point, the project selection that will also maximize profitability was realized. The input and output values of each project are given in Table 15.

Table 15. Input and output values for each project

	P1	**P2**	**P3**	**P4**	**P5**
Profitability (%)	40	33	36	25	20
Break-even point/Duration	2	1.67	1.33	1.2	1.29
Cost (TL)	9.302.482	3.674.504	8.924.542	2.848.471	1.021.398

According to Table 15, the DEA model obtained for Project 1 is given below. The maximization of the sum of weight and profitability values obtained from the DEMATEL-COPRAS method is shown in Equation (26) for project 1. The considered constraints in the DEA model are given in Equations (27-36). Equation (26) objective function was solved in the LINGO package program by considering constraints in the Equations (27-36), and the objective function and decision variable values in Table 15 were obtained.

$$Max\ Z = y_1 + 0.4\ y_2 \tag{26}$$
$$2\ x_1 + 9302482\ x_2 = 1 \tag{27}$$
$$y_1 + 0.4\ y_2 - 2\ x_1 - 9302482\ x_2 \leq 0 \tag{28}$$
$$0.29\ y_1 + 0.33\ y_2 - 1.67\ x_1 - 3674504\ x_2 \leq 0 \tag{29}$$
$$0.30\ y_1 + 0.36\ y_2 - 1.33\ x_1 - 8924542\ x_2 \leq 0 \tag{30}$$
$$0.22\ y_1 + 0.25\ y_2 - 1.2\ x_1 - 2848471\ x_2 \leq 0 \tag{31}$$
$$0.22\ y_1 + 0.2\ y_2 - 1.29\ x_1 - 1021398\ x_2 \leq 0 \tag{32}$$
$$x_1 \geq 0 \tag{33}$$
$$x_2 \geq 0 \tag{34}$$
$$y_2 \geq 0 \tag{35}$$
$$y_1 \geq 0 \tag{36}$$

Table 16. The objective function and decision variable values

	Objective Function	X_1	X_2	Y_1	Y_2
Project 1	1	0.5	0	0.392	1.521
Project 2	1	0.3796	0.996	0	2.957
Project 3	1	0.752	0	0	2.778
Project 4	1	0.700	0.561	0.497	3.563
Project 5	1	0	0.979	4.545	0

Equation (37), which was solved in the LINGO package program considering the constraints of Equations (28-36) and (38), is the objective function for Project 2. The obtained objective function and decision variable values are seen in Table 16.

$$Max\ Z = 0.29y_1 + 0.33\ y_2 \tag{37}$$
$$1.67\ x_1 + 3674504\ x_2 = 1 \tag{38}$$

For Project 3, Equation (39) objective function was solved in the LINGO package program by considering the constraints of Equations (28-36) and (40), and the objective function and decision variable values in Table15 were obtained.

$$Max\ Z = 0.30\ y_1 + 0.36\ y_2 \tag{39}$$
$$1.33\ x_1 + 8924542\ x_2 = 1 \tag{40}$$

For Project 4, Equation (41) objective function was solved in the LINGO package program by considering the constraints of Equations (28-36) and (42), and the objective function and decision variable values in Table 15 were obtained.

$$Max\ Z = 0.22\ y_1 + 0.25\ y_2 \tag{41}$$
$$1.2\ x_1 + 2848471\ x_2 = 1 \tag{42}$$

For Project 5, Equation (43) objective function was solved in the LINGO package program by considering the constraints of Equations (28-36) and (44), and the objective function and decision variable values in Table15 were obtained.

$$Max\ Z = 0.22\ y_1 + 0.2\ y_2 \tag{43}$$
$$1.29\ x_1 + 1021398\ x_2 = 1 \tag{44}$$

With the data envelopment analysis, the projects were evaluated in terms of the main criteria of R&D, Manufacturing, Marketing, and Finance considered in the Dematel-Copras evaluation, their sub-criteria, and profitability. Therefore, when the projects are evaluated with data envelopment analysis, the effective solution is determined as Project 4. According to the analysis results, if Project 4 is preferred among the five alternative projects, the expected benefit will be maximized. When the objective function, which is the decision-making unit, is 1, the solution is effective if all the elements of the set of x and y values are greater than zero. Therefore, Project 4 was chosen according to the results given in Table 16. As a result of the analysis, Project 4, with the highest performance, is the domestic axle production project. The axle is a product used in every type and model vehicle, at least two pieces. Accordingly, an improvement to this product would apply to all vehicle models in general. This product has the advantages of being produced with internal resources, existing labor, being tested domestically, and long-lasting. Foreign dependency will also reduce by making the project/product locally. When the project is evaluated in detail based on criteria, it can be said that the obtained project selection result is compatible with the expert opinions.

V. CONCLUSIONS

In the challenging competitive environment, companies need to follow the rapidly developing technology and produce new technologies to continue their activities and gain superiority in the market. Companies set up research and development departments to develop new technologies and integrate them into their products. Opportunities reserved for Research and development (R&D) are generally provided from the same sources as other activities in a company. The most successful companies in today's competitive environment apply project management processes to achieve successful results. Research and development (R&D) include activities that companies undertake to innovate and introduce new products and services.

This thesis aims to select the most likely R&D project to be successful, thus ensuring the most efficient use of business resources such as time, budget, workforce, etc. For this purpose, the combination of DEMATEL, DEMATEL-COPRAS, and DEA methods were implemented in the R&D project selection process of one of the leading bus and midibus manufacturers with 50 years of experience. In the first part of the thesis, the R&D project selection criteria were defined based on the literature review and opinion of the experts who have at least seven years of experience in the automotive company. In this stage, the opinions of senior personnel with at least seven years of experience from R&D, production, marketing, and finance departments were considered together with the previous studies in the field for determining R&D project selection criteria. Four primary and 24 sub-criteria were determined with this approach, and 14 of the 24 criteria were thesis-specific criteria specified together with experts.

In the second stage, R&D project selection criteria were prioritized using the Dematel method. The scores of the main criteria were calculated by the DEMATEL method based on experts' evaluations and the DEMATAL relation scale. According to the weights, product financing (F) and R&D success (R) stand out among the main criteria of the project selection. Evaluation of sub-criteria of the R&D showed that the R&D internal resource ratio in the project (R3) and the availability of labor resources in R&D (R2) have the highest importance. The internal resource rate to be used in production (M1) had the highest importance for manufacturing. The probability of market success of the product (MR3) and product lifetime (MR4) stand out among the sub-criteria of marketing. The most important criteria are capital investment requirement (F1) and relative cost of the developed product (F3) for the finance main criterion.

In the third stage, the alternative R&D projects were evaluated according to criteria via the DEMATEL-COPRAS method. In this method criteria weights obtained from DEMATEL are used as an input in COPRAS model. After that, the rankings of project alternatives were determined by the COPRAS method. In the COPRAS method, useful criteria refer to criteria where higher values indicate better status in achieving the goal. Probability of technical success (R1), availability of labor resources in R&D (R2), R&D internal resource ratio in the project (R3), applicability to other products and processes (R5), the rate of tests to be carried out domestically (R6), internal resource rate to be used in production (M1), the ratio of intra-plant equipment to be used in the project (M3), the domestic supply rate of raw materials / semi-finished products to be used in the project (M6), the potential size of the market (MR1), existing or ongoing competitor studies in the sector (MR2), probability of market success of the product (MR3), product lifetime (MR4), contribution to market share (MR5), rate of return on investment (F2), the relative cost of the developed product (F3) were defined as positive criteria. R&D external resource ratio in the project (R4), the rate of tests to be carried out abroad (R7), external resource rate to be used in production (M2), new equipment supply rate to be used in the project (M4), the international supply rate of raw materials / semi-finished products to be used in the project (M6), periodic maintenance costs (MR6), spare parts costs (MR7), capital investment requirement (F1), test costs (F4) were defined as negative criteria. Evaluation of alternative projects based on performance index value showed that the worst alternatives are the P5 and P4 projects, and the best project alternative is the P1 project.

In the last stage, the input-oriented CCR DEA model was used for evaluating the project. In the model, break-even point (BEP)/project duration and cost were considered as input variables. The result of data envelopment analysis showed that an effective solution was found.

Project 1 is battery production and needs capital investment with six years break-even point. Also, the probability of technical success is low. Project 4 refers to producing a new axle for the domestic customer market, and improvement to this product would apply to all vehicle models in general. This product has the advantages of being produced with internal resources, existing labor, being tested domestically, and long-lasting. When the project selection method of the factory is examined, it is seen that the factory only meets customer demands with an intuitive approach. P2 was chosen according to the practice of the factory. The result of the study was shared with the factory and it was recommended that the project that would provide maximum benefit to the factory was the P4 project.

VI. RECOMMENDATIONS

The DEMATEL and COPRAS are among the most used methods in MCDM. Similarly, the DEA technique, which is a valuable tool in measuring the relative effectiveness of alternatives, has been the subject of many studies. In the thesis, we used DEMATEL, COPRAS, and DEA methods to build a decision support model for R&D project selection problems. We considered the budget constraint in R&D project selection problems and developed a mathematical model to avoid the disadvantage. Different criteria may be defined with different approaches for future studies, and budgets and constraints can be expressed in explicit numerical values. Besides, a new decision-support model can be designed using other MCDM methods and combinations of them. The fuzzy logic method can also be integrated into these models.

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