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Autonomous Vehicle Technologies Effects the Automotive Concept Design Stages with AHP Method

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Abstract

In the automotive concept design stages, functionally positioning the newly introduced autonomous technologies or remodelling the vehicle accordingly and evaluating the steps or determining the workload together with the collaboration intensity in the current flow is the initial step for the entire process efficiency. Therefore, the main purpose of the research is to reveal the effects of the autonomous technologies, which are newly included in the automotive concept design stages in automotive manufacturing industry companies that continue their lives under heavy competition conditions, according to the order of importance. The objective of this research is to both increase the efficiency of automotive concept design stages and to determine the measurement of the effects of new autonomous vehicle technologies in practice. Under the AHP method used in the research, the automotive concept design stages constitute the alternatives in the order of importance of the working structure, as well as the application variables of autonomous vehicle technologies, the criteria of the mathematical model. In addition, the research method modelled in the study, under the AHP mathematical model, reveals the performances or order of importance of the automotive concept design stages under autonomous technologies. Therefore, the resulting process performances constitute important inputs for efficiency and optimization studies under different research approaches. When the results of the study are examined, due to the high level of influence on the new vehicle concept design performance in automotive industry companies, the adaptation or application steps of autonomous vehicle technologies create new needs in the whole process. The determination of innovation creation clusters in the design process steps or the selection of the density of new technology adaptation in the stages and the order of importance provide a competitive advantage along with optimization in the basic functions of the automotive industry companies. However, the determination of new workload clusters in the mentioned automotive concept design process steps or the effect of autonomous technologies in the design stages, selection, transfer from theory to practice, multiple conflicting criteria and uncertain parameters create a very complex situation. For all these reasons, the Analytical Hierarchy Process (AHP), which is one of the widely used multi-criteria decision-making tools, is considered as a suitable approach for creating such order of importance and solving problems. In this study, an AHP mathematical model was created that determines the workload clusters created by autonomous vehicle technology applications that have just begun to guide the automotive concept design process, which is the main function of automotive manufacturing industry companies. Therefore, in line with the innovations, changes and adequacy criteria created by the current automotive concept design stages in the new autonomous vehicle technology adaptation, a stage order of importance has been selected.

Keywords

AHP, Automotive Industry, Autonomous Vehicle Technology, Automotive Concept Design, Lean Product Development, Design Process

1. Introduction

In recent years, technological superiority led by, especially developed countries in the world and its application in the market has led many developing countries to seek. The exemplary mathematical model or new approach created in the research is to reveal the application effects of new autonomous technologies on the stages of vehicle design, together with quantitative values, in qualitative depth. Therefore, the new approach planned in the study stems from the remodeling of the performance criteria created by the flow particles against innovations rather than the product or process selection realized with the AHP method._It shows that it is not a coincidence that countries are able to meet their specific requirements for new product, original design or service design at a level that can compete globally (innovation management, new technology acquisition or adaptation, and time), on the contrary, it is the result of a systematic study. For this reason, especially automotive industry companies have turned to the important effect of choosing the appropriate process step sequence or rearranging new concept design steps in order to ensure the adaptation and application of autonomous vehicle technologies, which are added every day, on the vehicle. The purpose of determining the workload clusters focused on new technology adaptation at the stages constituting the automotive concept design process and choosing the order of importance of the implementation steps; ensuring that the innovation or technology required by an automotive industry company is compatible with the entire new product development flow and the main process stakeholders who undertake to realize it at the desired time, with acceptable implementation costs or new software hardware needs, has a positive effect on the final new product. In the study, the order of importance of the stages in question or the workload intensity selection process of the steps creates a broad comparison structure formed by new and different autonomous technology features by using both quantitative and qualitative criteria that contradict each other. Therefore, the basic criteria used in examining potential new stages and specializations or existing disciplines on the verge of change differ according to the needs of the companies [1] [2] [3] [4] [5]. In addition, the most popular criteria considered by decision makers in the evaluation of the process stages or in the selection of the order of importance according to the workload and innovation contribution of the stages; price/cost, design capability, product development process efficiency, resource management, innovation and technology management, research and development, flexibility, brand, product, risk, security, etc. constitute the main variables. It is a multi-criteria decision problem that includes the measurement of the effects of the stages that make up the particles of the holistic process on the final innovation, the selection decision or order of importance, and the evaluation of new and different criteria. Evaluating the impact of the sub-stages that support the basic process on the result or determining the priorities creates focus in the diffusion triggered by the innovation [5] [6] [7] [8].

Today, automotive industry companies are compared using various methods as a result of the performance measurement of many criteria such as design and new product development, innovation management, new product, manufacturing, cost, sales and delivery, and the results obtained from the final comparison are to perform important functions in the organizational structure, it constitutes the necessary inputs for developing, resource management or making long or short-term investment decisions. In this context, multi-criteria decision-making methods; It is a frequently preferred method in today's research in terms of ordering the importance of the determined alternatives, making selection, evaluation and classification among the alternatives, and finally, the results obtained are suitable and applicable. In this study; in the automotive industry, which has a critical importance in the high economic returns of the nations, in 3 local and 3 global automotive industry companies that carry out automotive concept design activities together with manufacturing; together with the determination of the workload and operational needs created by the autonomous vehicle technology parts carried out on a project basis in practice; is aimed to measure the order of importance.

The innovations and workload in the application of the said new autonomous vehicle technology parts are driven by the reasons for the development of the new technology or the technical competence in the application problems of the new technology. In addition, the inter-firm design collaboration model, which will benefit from critical technology, reveals the determination of resource management or investment priority, together with software and hardware investments of similar variables in practice. Determining the priorities of the resource needs created by autonomous vehicle technologies, which have just entered the automotive concept design stages, increases the success rate of priority order adaptation studies. On the other hand, renewing all of the automotive concept design stages at the same time, creates undefined values for the measurement of value creation and conservation. However, the workload intensity and innovation management in the technology applications of the automotive design stages of the main and sub-criteria in the working model have a great importance in competition [8] [9] [10]. Therefore, the measurement of flow stages with appropriate methods or the selection and order of importance by evaluating the flow steps is the initial step for process optimization. For the solution of the problem, the mathematical model included in the AHP method was constructed and multi-criteria decision-making steps were applied in the study [10] [11] [12].

2. AHP Analytical Hierarchy Process

The evaluation of the efficiency of the process stages or the determination of the importance values of the stages that make up the process creates mathematical data for the simultaneous functioning and balance of the entire flow. The order of importance of a flow or critical selection problem is a subject that is frequently addressed and of great importance for businesses, and there are many studies on the product, part or system preference problem type [10]-[15]. When the aforementioned studies are examined, the commonly identified process or supply channel selection problem; price, performance, efficiency, product, part, system and service, similar variable structures were determined as the main criteria and appropriate alternatives were examined and measured. The AHP method measures the selection rank or efficiency within the approach of determining the importance of the main criteria and sub-criteria. Considering that the alternatives included in the calculations are formed at different values as a result of a process, because of the complex nature of the selection problem, feedbacks, interactions and too many criteria, it turns out that effective and realistic criteria for the solution are in an analytical network structure. Millet (2002) defined the machine selection problem for a company operating in the manufacturing sector and applied the AHP multi-criteria decision-making method for machine selection, since many qualitative and quantitative criteria should be considered together for the right machine selection [16]. In their studies, Paker (2018) and Chan (2002) weighed all the main and sub-criteria related to the problem, in which the importance effect of the stages forming the whole flow in the process was evaluated, and 26 process stakeholders, professional software, hardware, number of employees were evaluated in depth [17] [18].

3. Automotive Concept Design Stages

Automotive concept design stages are the first step in the new and lean product development process where innovations and project goals are determined [19] [20] [21]. Therefore, the features of the new vehicle to be designed, the requests and expectations from the users or the improvements on the product that has been designed and entered into mass production, (aftermarket claim parts, critical fabrication parts, cost reductions, etc.) takes place in the automotive concept design phase, which is at the beginning of the project. Keeping the customer requests and expectations at the forefront among the project objectives is very important for the concept design phase because all new product development studies and disciplines will move in this direction. In the automotive concept design phase, vehicle design alternatives with targeted innovations and desired features are being developed. For example, if lidar, one of the autonomous technology parts, will be adapted or designed on the vehicle, by creating various combinations of form, capacity, size, location, serviceability and similar features, concept design alternatives and clay model prototypes are developed and evaluated by subjecting them to various tests. Until the compatibility of the said new piece of technology with the new concept design alternatives produces a satisfactory result; renewal and modification of prototypes continues [19] [20]. In addition, in the adaptations of new technology pieces like this, involvement of relevant expertise in automotive concept design phases, guiding or part location approval prevents repetitive development in the next new product development steps. This approach, in the creation or preservation of value within the entire current lean and new product development process, provides significant efficiency definition and advantage [21].

Elementarily, the purpose of the automotive concept design stages, to define the long-term new vehicle project goals for lean product development engineering stages, under the boundary conditions within the vehicle body structure, to eliminate the errors and deficiencies in terms of application of innovations on the product and to deliver the perfect new product to mass production. In addition, the studies to determine the position and function of the new technology parts on the body structure, which were realized during the automotive concept design stages, reveals the design of the product's needs for usage performance along with it. Designing a functional vehicle with the features expected by the new automotive product user and implementing the project innovations within this scope is the main focus for the concept design stages. For example, a truck manufacturer automotive industry company, while designing the truck it produces in line with the expectations of its customers, primarily aims to make the vehicle go from point A to point B quickly, easily and efficiently by carrying a certain load. Therefore, the design of an autonomous truck in accordance with its target customer group includes autonomous vehicle technologies and systems as innovations in the project objectives, again in the appropriate technology, in line with technical and economic possibilities.

Automotive concept design stages in new vehicle projects, while applying new technologies and autonomous vehicle parts and the functional structure brought by the parts on the vehicle, it either makes the vehicle suitable for technology adaptation, or it can adapt the technology to suit the vehicle. These two sharp distinctions are carried out in direct proportion to the position of the supplier of the new technology piece or the role of the patent owner of the automotive industry company. In today's global automotive industry, targeted innovations or new functions on the vehicle in the future are determined under autonomous vehicle technologies, and necessary part developments are designed under business structures with multi-brand, multi-disciplinary partnerships. Therefore, the development of new autonomous technologies, which are expected to be introduced in the automotive industry in the near future, continues under the global software and hardware R&D enterprises established with the partnerships of global automotive industry companies. From a commercial point of view, since the information required for the development of autonomous vehicle technology parts of these multi-partner R&D structures comes from the partners, the right to sell the software and hardware suitable for the newly designed product belongs to the founding stakeholders.

Another important approach is, in the maintenance, repair and new version updates or adaptation to the vehicle of the semi-finished product created by the R&D enterprises established for the design and development of new autonomous vehicle technologies is to present a reliable design that will not cause any problems that the customer may experience in the future, causing losses in both automotive products and the main brand image. In addition, in such cases, the design and form of the new vehicle concept lags behind the functional usage features of the new autonomous technology. On the other hand, in the adaptation of the new autonomous technology and usage functions within the sample, the automotive concept design stages realize the functional packaging adaptation of the new technology within the vehicle body concept. As an approach the form, form, closure of a new piece of technology can be considered as an extension of innovation and affects the acceptance of the product by the consumer. During the automotive concept design stages, the functional usage features of the new technology or the application criteria and adaptation tolerance information are collected by the developer of the technology before the new autonomous vehicle technology parts are functionally packaged in a form structure inside the vehicle body. Therefore, in order for the new autonomous vehicle technology to be packaged in the automotive concept design stages and to have a functional form structure, it receives phase transition approval in new product development engineering disciplines together with the developer of this technology. In addition, implementation decisions are made for the new autonomous technologies included with the project objectives, both in the initial stages of the automotive concept in the adaptation of the first vehicle, and afterwards, together with the engineering studies related to the expertise in new product development processes.

Compliance approval tests of the part are carried out with intensive studies at every flow step with new product development engineering in the continuation of the process of new autonomous vehicle technologies, which are included in the automotive concept design stages with new on-vehicle adaptations. This cycle continues until the new autonomous vehicle technology piece fulfils its function on the vehicle. After the new project targets are given at the beginning of the automotive concept design stages, preliminary information is obtained from all new product development specialists through design sketches along with the usage scenarios that can fulfil these targets. In the automotive concept design phase, which is the first process of new product development, even if the initial concept designs made on paper from the expertise and engineering departments in the continuation of the process are a bit of an exaggeration, adaptation problems of new technology or design alternatives that are impossible or difficult to produce are rearranged and some changes are made. In the automotive concept design stages, where the new project goals are embodied and form, after the vehicle is approved to be produced at the desired innovation level and within the acceptable investment cost limits, detailed engineering tests and analyses begin in the new product development process [20] [21].

When evaluating alternative vehicle concepts, the way the outer body structure accommodates technology parts or demonstrates innovation, the number of parts, the method of joining parts, tolerances and the complexity of the product are among the factors that affect the final concept selection. The aim is to select the alternatives with the most preferable value in the market among the concept design alternatives that meet the functional requirements of new technologies or to define the modification. In the selection at the end of the automotive concept design stages, especially the technical drawings that clearly show the new vehicle design, the selection of all materials, machinery and equipment to be used in production and their placement, plant capacity and many other issues, together with investment decisions, the process is related to new product development disciplines.

In order for the new vehicle design data revealed by the automotive concept design stages to not lose value in new product development processes, innovations are approved by the automotive concept design department at each stage transition, this time until the product is implemented (**Table 1**). With the introduction of new product development processes, the automotive concept design stages pass into a status that gives approval for the implementation of the targeted innovations in the body structure (**Table 1**). Since the changes to be made for the approved vehicle concept to go into production lead to both time and cost losses, each modification is thoroughly examined and approved [21].

After the concept vehicle design is transferred to the new product development stages, and after the process flow or studies are completed, physical and virtual road tests, trial productions and final trials of the new automotive product are carried out as the final process (**Table 1**). After seeking answers to questions such as whether the design was made as desired, whether it could meet customer expectations, and whether there was a need for changes, if the answers are positive, the promotional part of the business comes into play and by focusing on issues such as introducing the product to the market and informing the

Table 1. Automotive concept design stages [21].

Automotive Concept Design Process Time Line																									
	Automotive Concept Design Stages	Project Time Line (Phases/ Month)																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
D01	2D Idea, Doodle																								
D02	2D New Vehicles Sketch																								
D03	2D Technical Drawing																								
D04	2D Presentation - Approval																								
D05	3D Clay Model																								
D06	3D Digital Scanning - CNC																								
D07	3D CAD Vehicle model																								
D08	*3D Virtual Prototype*																								
D09	3D User Experian																								
D10	3D Interface Control																								
D11	Interior&Exterior IoT system																								
D12	3D Rapid Prototype																								
D13	*3D Interior/ Exterior Trim*																								
D14	*3D Interior/ Exterior Mock-Up*																								
D15	3D Virtual Production Assembly																								
D16	3D A- Class CAD Surface																								
D17	3D CAD Vehicle Data Transfer																								

users about the product, all necessary steps in the transition to life cycle management are planned (Table 1). Along with the development of new technology in the automotive industry, concept design studies are an ongoing process and the designer continues to do his job on four fundamentals. The first is the work done to make minor changes to the design of the automotive product being manufactured, which requires modifications over time. The second is the work done to update the vehicle design based on technological innovation and new application changes. Third, new vehicle concept design studies require great innovation. Fourth, project studies involving the design of new vehicle concepts based entirely on new technologies and concepts. The distinction of concept vehicle design projects based on these four foundations; It is defined as the design of a new version of the vehicle in the current production or the design from scratch of a product that is not included in the product range. Although these two approaches seem basically close to each other, they constitute two opposite poles. It embodies contrasting approaches between new product development and research and development concepts and processes. While the new product development approach is focused on time and competition, the concept of research and development considers innovation-oriented variables. Automotive concept design phases begin at the beginning of the new product development process, with the dominant emergence of a new idea or new technology, and continue until it becomes a value ready to be presented to the customer (Table 1). Even after the new product or service is presented to the customer, concept design studies continue [21].

4. Autonomous Vehicle Technologies

Autonomous vehicle technologies show a rapid development under increasing traffic accidents, increasing population, increasing travel time in traffic, increasing communication need or changing life comfort and model. The instant availability of accurate real-time information on traffic, roads, toll infrastructure and other relevant conditions opens up more possibilities for autonomous vehicle technologies and comes to life. Therefore, while autonomous vehicles provide various benefits for new comfort and living conditions, they also reveal various costs. In addition, it has physical features that will allow the design of mobile game room, office or bedroom and similar living spaces in autonomous vehicles by allowing the driver and passengers to be more productive or relax during their travels. This leads to the probable result that the unit costs of travel time will decrease. On the other hand, autonomous vehicles bring new stresses and inconveniences. In order to protect and clean the natural environment, to minimize the costs of new waste or vandalism, the safety parts of fully autonomous taxis or buses, small additional accessories or the design of materials with different internal structures (different seat materials and stainless-steel interior trim surface) come into play. With the increase in the different types of travel in question, travel safety and travel time will decrease in response to demand. This is because, especially in scattered urban areas with dead-end-street, each additional boarding and landing will result in a delay of several minutes to other passengers [22].

Autonomous vehicles require various hardware and software or additional services. These are: sensors, radar, lidar, ultrasound, cameras, vending control, software, park and ride subscriptions, various business or entertainment services (servers), power supplies, wireless networks, short-distance vehicle-to-vehicle communication, long-distance map access, software upgrades, road reports, navigation, global positioning systems (GPS), special high-quality maps, and critical element testing and maintenance requirements (**Table 2**). Therefore, although autonomous vehicles will reduce external costs, including traffic congestion, energy consumption, pollution emissions, and road and parking facility costs, these benefits are being envisioned today (**Table 2**). In addition, significant alternative designs are planned today regarding the benefits, costs, travel effects, speed and consumer demands of autonomous vehicles (**Table 2**). In these new integrated designs, digital product brands with financial interest are already working on user experience-based service designs within personal computers, smartphones and digital cameras and other similar innovative additional Technologies (**Table 2**).

In **Table 2**, data rates and protocol connections are transferred along with the on-vehicle functions of new autonomous technologies. The realization time of the said functions on the vehicle results in instant vehicle guidance proportional to the data flow rate (**Table 2**). As the basic design and implementation of today's autonomous vehicle technologies are incorporated into most vehicles in manufacturing, new structures are emerging that have a lasting impact on the powertrain of these vehicles, due to reduced accident rates and the consequent

Table 2. Autonomous vehicle technology in CAN BUS functions [22] [23] [24].

CAN (Controller Area Network)												
Class	**Transfer Range**	**Autonomous Technologies**			**Data Rate**	**CAN Protocol**						
A-CAN	**10 Kbps**	A1	AHS	Auto Headlamp and Signal								
		A2	RD	Roll Down	Low Data Rate	OEM	RADAR		ACC ECU		CAN
		A3	GL	Gateway Lock	↓						
		A4	KE	Keyless Entry		LIN					
B-CAN	**10-125 Kbps**	B1	BCU	Body Control Unit							CAN
		B2	PAU	Park Assistant Unit			Distance setup				
		B3	IPC	Instrument Panel Cluster		J1850					
		B4	ECC	Electronic Climate Control							
		B5	SDU	Sensing and Diagnostic Unit		VAN					
		B6	CTU	Convergence Telematics Unit			Break lamp				
		B7	RRU	Radio Receiver Control Unit							
C-CAN	**125 Kbps – 1Mbps**	C1	SAU	Steering Angel Control Unit		Safe-by-Wire			PCM ECU		CAN
		C2	ECU	Engine Control Unit			Cruise control				
		C3	BCU2	Body Control Unit-2							
		C4	TCU	Transmission Control Unit							
		C5	BSCU	Brake System Control Unit			Electronic throttle				
		C6	YRU	Yaw Rate Control Unit							
		C7	ESC	Electronic Stability Control							
D-CAN	**5 Mbps**	D1	PAD	Park Area Distance		D2B optic	Wheel speed		DSC ECU		CAN
		D2	ADC	Automatic Distance Control			G Sensor				
		D3	FCW	Front Distance Control			Break Pressure				
		D4	LDW	Lane Departure Wide							
		D5	SV	Stereo Vision -Video		Most					
		D6	IC	Infrared Camera			Break Actuator				
		D7	LD	Lidar (Laser Scan)							
		D8	RD	Radar (High & Low Range)							
		D9	US	Ultrasound		IEEE 1394	Steering angle sensor		BCM ECU METER		
		D10	WE	Wheel Encoder							
		D11	GPS	Global Position Navigasyon							
		D12	LKA	Lane Key Appoint	↓	Flex Ray	Display				
		D13	LG	Lane Guidance	Peak Data Rate						

reduction in vehicle weight from the bodywork (Table 2). One of the autonomous vehicle technologies in Table 2, Lane Change Assistant (LCA): this system monitors the areas on the left or right, front or rear of the vehicle, at a distance of 50 meters, and warns the driver against possible dangerous situations under the warning signals flashing in the exterior mirrors; Park Distance Control (PDC): the system supports the driver to manoeuvre in tight spaces, the display transmits the distances to obstacles via audio or optical signals; Lane Departure Warning (LDW): warns the driver with seat or steering wheel vibration that the vehicle is about to unintentionally leave its lane; Forward Collision Warning (FCW): the system uses a radar sensor to detect situations where the distance to the vehicle ahead is critical and helps to reduce the vehicle's stopping distance [22] [23] [24]. Adaptive Cruise Control (ACC): the cruise control system uses a distance sensor and a lever for the driver around the steering wheel to measure distance and speed relative to vehicles ahead. Including stop-and-go function (SACC): in addition to adaptive cruise control, it includes automatic distance control (0 - 250 km/h control range) and detects the vehicle ahead within system limits. Lane Keeping Assist (LKA): automatically at a certain speed (normally about 60 km/h), the system detects lane markings or takes corrective measures for vehicle position and deviation from the lane. Park assist (PA): automatically guides the vehicle to parking spaces and supports the driver by automatically performing optimum steering movements to park back on the ideal line. In addition, it automatically performs the measurement of the parking space, the allocation of the starting position, and the gas-brake steering movements (Table 3). The fully autonomous vehicle must be able to make all the rides from point A to point B without any input from the passenger. The driver can always override or shut down the system. The CAN communication network on the vehicle and the data rates on this network are exemplified below [22] [23]. The sensors and technologies used in autonomous vehicles are increasing functionally day by day (Table 3).

5. Research Method

The decision-making, process selection and evaluation model with the AHP method is a strategically important approach that is handled with short-term planning, but that makes companies strong with its long-term effects. Therefore, AHP decision making method, which can evaluate quantitative and qualitative data together or use in-depth information for quantitative results, was preferred in the research. Determining the needs of traditional automotive concept design stages in new autonomous vehicle technology applications according to the order of importance or evaluating them under the AHP mathematical model can increase the efficiency of the flow steps, as well as include optimization information for the resource management of the process. Under the first field study of the research, new autonomous vehicle technologies and automotive concept design stages were determined. Therefore, in the second field study, the application criteria or eigenvectors of the new autonomous vehicle technologies needed in the automotive concept design stages (the AHP is included as alternatives in the mathematical model for the formation of the order of importance) were calculated together with the AHP questionnaires. Although the main and sub-criteria considered vary on the basis of companies, products or conditions, small deviations occur in the desired results. In all organizations for profitability, product or service with expected values, correct timing and performance, adding new processes that enable them to reach their values, strengthening their existing structures under heavy competition conditions, is a continuity function. Therefore, companies struggling to survive in today's competitive conditions are renewing their business models and processes quickly and efficiently. In addition, the increase in efficiency in the processes in question is due to the optimization of the flow steps by evaluating them based on workload and time. In this framework, the efficiency of process optimization or resource management is realized by determining the needs of each process step by measuring the effect on the entire flow._On the other hand, organizations that attach importance to the use or evaluation of scientific studies and methods in such high-importance strategic decisions can increase their efficiency by strengthening the firm's expertise functions in new systems they establish under the right choices and process or product preferences in the desired structure. Businesses prefer multi-criteria decision-making methods in order to increase their internal functioning, ways of doing business or process efficiency, and to measure their existing systems in sustainable value creation and preservation. In particular, companies with R&D and P&D functions update their current processes, along with the problems and solutions, and their current flow evaluations with decision-making methods, focusing on innovation and original design, in order to take their current processes one step further. Therefore, companies gradually invest in design and new product development processes under current technologies. Therefore, the efficiency evaluation problem of stakeholder relations or interdisciplinary studies within the process structure finds a solution under a mathematical model. In general, the process evaluation and importance selection problem provides a secure relationship between the process stakeholders and the job description to be made, and ensures the establishment of a regular, traceable and strategic relationship. An efficient process selection and evaluation decision is of great importance for the success of a manufacturing business.

The joint selection of appropriate process stakeholders with appropriate job descriptions positively affects the success of businesses. In the opposite case, the increase in time and high costs and similar factors in the implementation of new products and technologies impose a negative burden on businesses. Innovation management of companies; functional selection of new product design processes is an important decision-making problem involving many criteria such as cost, technology, performance and so on. Not only the time cost in resource management, but also innovation commissioning costs, technology acquisition and implementation cost, design and development costs are among the variables that should be considered in this process selection and evaluation. Therefore, there is a need to evaluate and prioritize the main and sub-criteria or performance-related variables to be used in the selection of a systematic process [10] [11] [12] [13] [14].

The AHP method is a valuable tool with mathematics that can be applied to the evaluation of many complex decisions. The solution to the problem of identifying a high-value option among alternative applications or ranking the options according to their importance score yields a consistent result in the AHP method. In addition, the AHP method divides the decision into smaller, more understandable parts, analyses each main and subsection separately, and integrates the parts to produce a meaningful solution (**Table 3**). In **Table 3**, the automotive concept phase steps created by one-on-one interviews at the first stage of the field research are given in the vertical column. In addition, the vertical columns of the table below include autonomous vehicle technologies (**Table 3**). Therefore, the automotive concept design stages that will constitute the main criterion measurement of the AHP mathematical model are defined in the method (**Table 3**).

Table 3. Autonomous technology and automotive concept design stage matrix.

AUTOMOTIVE DESIGN PHASES		LIDAR	LANE GUIDANCE	GPS	SR-RADAR	LR-RADAR	ULTRASONIC SENSOR	STEREO VISION	INFRARED CAMERA	WHEEL ENCODER	MC MAIN COMPUTER	AHS Auto Headlamp and Signal	RD Roll Down	GL Gateway Lock	KE Keyless Entry	BCU Body Control Unit 1-2	PAU Park Assistant Unit	IPC Instrument Panel Cluster	ECC Electronic Climate Control	SDU Sensing and Diagnostic	CTU Convergence Telematics	RRU Radio Receiver Control	SAU Steering Angel Control	ECU Engine Control Unit 1-2	TCU Transmission Control Unit	BSCU Brake System Control	YRU Yaw Rate Control Unit	ESC Electronic Stability Control	PAD Park Area Distance	ADC Automatic Distance	FCW Front Distance Control
	AUTONOMOUS TECHNOLOGY	X01	X02	X03	X04	X05	X06	X07	X08	X09	X10	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20
D01	2D Idea, Doodle																														
D02	2D New Vehicles Sketch																														
D03	2D Technical Drawing																														
D04	2D Presentation - Approval									Autonomous Vehicle Technology																					
D05	3D Clay Model																														
D06	3D Digital Scanning - CNC																														
D07	3D CAD Vehicle model																														
D08	*3D Virtual Prototype*																														
D09	3D User Experian																														
D10	3D Interface Control																														
D11	Interior&Exterior IoT system		Automotive Concept Design Process																												
D12	3D Rapid Prototype																														
D13	*3D Interior/ Exterior Trim*																														
D14	*3D Interior/ Exterior Mock-Up*																														
D15	3D Virtual Assembly														Supply or Development for Technology																
D16	3D A- Class CAD Surface																														
D17	3D CAD Vehicle Data Transfer																														

CO-DESIGN | DESIGN | COLLABORATION | SUPPLY

In **Table 3**, there are new autonomous vehicle technologies, which constitute the sub-criteria of the AHP mathematical model, in the vertical columns. In the cross-matrix structure, the work patterns and workloads that occur when new autonomous technologies take form on the vehicle according to their functional structures are defined in the first field study (**Table 3**). The AHP model put forward by Saaty (1996) is an effective tool for dealing with complex decision-making problem and helps the decision maker to prioritize and make the best decision [21]. AHP functionally reduces complex decisions under a series of pairwise comparisons and helps to capture the subjective and objective aspects of the final decision by synthesizing the results. In addition, it reduces bias in the decision-making process, along with a useful technique for checking the consistency of the decision maker's evaluations. There are 6 steps to be performed in order to solve a decision-making problem with AHP: 1) Decision making problem definition, 2) Pairwise comparison matrix formation, 3) Percentage importance distribution of the criteria, 4) Consistency measurement in the comparisons of the criteria, 5) Percentage importance distribution at the decision point for each criterion, 6) distributions of results at decision points; determines the result of the method.

6. Discussion and Finding

In the AHP surveys conducted with 60 employees of 3 local and 3 global automotive industry companies within the scope of the second field study of the research; it is aimed to reveal the comparison values created by autonomous vehicle technologies, which are included in the automotive concept design stages with their innovation values, in different application structures. Both types of automotive manufacturing industry companies participating in the research implement their automotive concept design activities along with manufacturing, the new time-oriented autonomous vehicle technology application requirements created by heavy global competition, on a project basis, in their own internal processes. Both types of participating 6 automotive industry companies within this scope have been carrying out original design studies along with manufacturing within the defined research limits since the 1960's. AHP survey application, which was carried out within the scope of the second field research of the study: It was carried out under the observation of alternative energy and autonomous vehicle technologies new application project studies of the participant companies.

In the concept design studies of autonomous vehicle technology parts, two different methods have emerged in the research, depending on the type of company. In the first method, the concept design is determined by receiving support from the developer of autonomous vehicle technologies supplied through the supply channel in local automotive industry company applications. In the second method, direct information transfer to the concept design works of the sister brand of the R&D company, which develops autonomous technology within the same organizational structure, causes small problems in practice due to the coding compatible with the vehicle system in production. Therefore, in line with their competencies in designing and developing technologies for the near future, global automotive industry companies primarily implement the technological innovations they have developed in their own partnered R&D companies in vehicles in their own product range. In addition, global automotive industry companies, both developers and first users of next generation technologies, establish their own competitive perspective and conditions. On the other hand, local automotive industry firms, compared to global firms, concept design studies of planned near future autonomous technologies, under heavy competition conditions, it is advancing with its after-sales research.

The two opposite poles in the comparison structure, the process-oriented measurement of the requirements created by the autonomous vehicle technologies in the project-based adaptation studies carried out in global and local automotive industry companies during the automotive concept design stages, is of critical importance for the vehicle adaptation of the next generation innovations and technologies. For local automotive industry companies that obtain innovation and technology from foreign supply channels; process innovations and updating of critical concept design stages at the stages of low importance calculated under the AHP model can result in more efficient project results of effective innovation practices with the desired value. In the global automotive industry applications, the form structure or modifications of new autonomous vehicle technologies according to functional needs during the concept design stages are evaluated on the customer, under after-sales, test and analysis information. Therefore, the functional structures that affect the concept design stage structure of new technologies are guided under different regions and usage habits as a result of field tests or user experience studies. In particular, the workload and clustering of new technology-oriented variables added to the automotive concept design stages, and the alignment of the flow steps accordingly, are still an operational problem in local automotive industry companies. Therefore, local automotive industry companies (LC2 and LC3), which try to create the appropriate infrastructure for the development and adaptation applications of new autonomous technologies, outsource R&D services.

This situation in the global automotive industry companies of the comparison structure; The flow difference in the initial step of the new autonomous vehicle technology adaptation projects carried out under defined and ready infrastructure environmental conditions or in the different innovation applications of the concept design stages varies according to the project size. This differentiation creates the difference between the introduction of autonomous vehicle technologies, which have gained a form structure with the automotive concept design stages, and the installation of the environmental needs of the new technology. Multi-stage, multi-disciplinary new autonomous vehicle technology adaptation projects in global automotive industry companies come to life in the function-form-secondary function sequence, automotive concept design stages (**Table 1**): Doodle design, sketch design, clay model, data transfer and similar steps order of importance constitutes the subset of the AHP mathematical model. In the research, 17 pieces were found as a result of the automotive concept design stages and field studies, which were desired to be measured with the AHP mathematical model structure. In addition, the new autonomous vehicle technology, which led to the studies in the automotive concept design stages, was determined as 10 parts and 17 functions in the field researches. The AHP survey application, which is included in the second field study, was carried out on the concept design stages with 60 employees of 6 automotive manufacturing industry companies within the research boundaries. The Acceptable Level (TAL) method was used for the importance selection ranking scores realized in alternative company applications (global and local automotive manufacturing industry companies) [25]. The purpose of applying this method is that there are too many pieces of technology and concept design stages, after the criteria definition of 10 technology pieces and 10 design stages, the selection results were calculated according to a certain order of importance among the remaining alternatives. Scoring in the use of the TAL method: the scoring value used in the elimination of autonomous vehicle technologies is 2, the difficulty value in automotive concept design stages and adaptation studies is 1, the value of alternative automotive manufacturing industry firm applications is 3, the average of the evaluation given between 0-10 survey points in the mathematical model is determined. The acceptable barrier score level in the TAL value was given by the managers of 60 companies participating in the study and was defined as the common acceptance value for the mathematical model. These barrier values assigned for automotive concept design stages and new autonomous vehicle technologies were compared according to the acceptable level value and subjected to elimination. The 10 autonomous vehicle technologies to be used in the selection are coded as shown in Table 4 below. In Table 4, a matrix structure was created for the automotive concept design stages and autonomous vehicle technologies, and the evaluation scores in the mathematical model were calculated. For the evaluation of all main and sub-criteria, a selection process was made under this method among all automotive concept design stages with the importance score value. As a result of the calculations, the importance ranking value of 4 automotive concept design stages for 4 autonomous vehicle technologies was revealed (Table 4). Only other automotive concept design phases and autonomous vehicle technologies that are

Table 4. TAL method of automotive concept design stages.

	Automotive Concept Process	2D Doodle Sketch	2D Technical Drawing	3D Clay Model	3D Digital Scanning	3D CAD Vehicle model	3D Virtual Prototype	3D Interface Control	3D Rapid Prototype	3D Interior/ Exterior Mock-Up	3D Interior/ Exterior Trim	3D Virtual Production Assembly	3D A-Class CAD Surface	3D CAD Vehicle Data Transfer		
	Autonomous Technology	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13		
T1	Lidar	2	4	1	3	6	2	2	2	5	1	3	3	4	≤2	D1-D3-D6-D7-D8-D10
T2	GPS	7	5	8	7	6	4	7	3	6	8	1	2	1	≥7	D1-D3-D4-D7-D10
T3	Lane	10	4	8	8	5	7	8	8	7	9	7	7	6	≥8	D1-D3-D4-D7-D7-D10
T4	SR Radar	8	6	7	5	4	4	7	5	6	8	5	4	5	≥6	D1-D2-D3-D7-D9-D10
T5	LR Radar	7	4	9	6	3	5	8	3	2	6	5	5	3	≥5	D1-D3-D4-D6-D7-D10
T6	Ultrasonic Sensor	8	6	9	6	5	6	9	4	5	10	6	6	7	≥8	D1-D3-D7-D10
T7	Stereo Vision	7	6	9	4	7	6	8	3	4	8	4	6	5	≥7	D1-D3-D5-D7-D10
T8	Infrared Camera	7	4	8	6	5	6	8	5	3	7	6	6	8	≥6	D1-D3-D4-D6-D7-D10
T9	Wheel Encoder	8	5	9	7	5	7	9	6	4	7	6	5	3	≥7	D1-D3-D4-D6-D7-D10
T10	Mc Computer	8	4	8	6	6	5	7	4	7	7	6	5	5	≥7	D1-D3-D7-D9-D10
	Decision	Automotive Concept Design Stages														**D1-D3-D7-D10**

less important or involve less adaptation work are used to eliminate them from the AHP model (Table 4). The order of importance of the automotive concept design stages that require high adaptation in the determined autonomous technologies (according to the TAL method); 2D Doodle Sketch (D1); 3D Clay Model (D3); 3D Interface Control (D7); 3D Interior & Exterior Trim (D10); The first four order of importance of the stages were determined (Table 4).

In Table 4, there are autonomous vehicle technologies included in the evaluation under the TAL method. Therefore, the code definitions of autonomous vehicle technologies included in the automotive concept design stages are given in the AHP mathematical model (Table 4). Criteria and importance scales were determined by the evaluations made separately in their natural environments with 60 company managers who participated in the study (Table 5). The data obtained and the pairwise comparison matrix for the criteria are given in Table 5. The critical point in the mathematical model is the weight ratios of the main and sub-criteria relative to each other and the result evaluation (Table 5). Therefore, the dominant main and sub-criteria directly affect the ranking result. The scale values used in the importance scoring of the main and sub-criteria constitute the result of the average given by the company managers (Table 5).

In Table 5, the AHP mathematical model scale values used in the questionnaire scoring of the criteria are given. In Table 6, these values were calculated to

Table 5. Criteria of AHP survey response scale.

AHP Survey Response	Survey of Technology Adaptation & Transfer					
	Technology Function	Technology Hardware	Technology Software	Technology Occupation	Technical Competence	Technology Location
2	1 - 2	1 - 3	9 - 11	1 - 3	1 - 2	1 - 4
4	2 - 4	3 - 5	7 - 9	3 - 5	2 - 4	4 - 8
6	4 - 6	5 - 7	5 - 7	5 - 7	4 - 6	8 - 12
8	6 - 8	7 - 9	3 - 5	7 - 9	6 - 8	12 - 16
9	8 - 10	9 - 10	1 - 3	9 - 11	8 - 10	16 - 20

Table 6. Criteria of comparison matrix.

Criteria of Autonomous Technology Transfer	Criteria of Autonomous Technology Adaptation & Transfer					
	Technology Function	Technology Hardware	Technology Software	Technology Occupation	Technical Competence	Technology Location
Technology Function	1.00	4.00	6.00	1.00	7.00	1.00
Technology Hardware	0.25	1.00	2.00	0.33	1.00	0.50
Technology Software	0.16	0.50	1.00	0.20	0.80	0.80
Technology Occupation	1.00	3.00	5.00	1.00	1.50	2.00
Technical Competence	0.14	1.00	1.25	0.66	1.00	1.00
Technology Location	1.00	2.00	1.25	0.50	1.00	1.00

be used in the methods, as shown in Table 5, and the values to be used under the AHP model with even numbers between 2 and 10 were calculated.

The AHP mathematical model proposes a process for measuring consistency in the comparison matrix (Table 6). It provides the opportunity to test the consistency ratio (CR) and the priority vector found, and thus the consistency of one-to-one comparisons between the criteria (Table 6). In Table 5, it is seen that the consistency ratio (CR) is between 0 and 0.1. In Table 7, the calculated CR value is less than 0.10, shows that the comparisons made by the decision maker are consistent. CR value greater than 0.10, indicates either a computational error in the AHP or inconsistency in the decision maker's comparisons. Eigenvectors (weights) of Criteria and Alternatives are shown in Table 7. These values are obtained by dividing the sum of the value of each criterion after the comparison matrix between the main and sub-criteria in Table 6 is normalized by the total number of criteria. As seen in Table 7, the result is obtained by multiplying the criteria and alternative values.

As seen in Table 7 as a result of the pairwise comparison and other steps: 2D Doodle Sketch (D1) is in the first place, followed by 3D Interior/Exterior Trim (D10), 3D Interface Control (D7) and 3D Clay Model (D3) stages are the autonomous vehicle technologies. Therefore, in Table 7, the criteria (Technology Function, Hardware, Software, Occupation, Competence, Location) created by autonomous technologies in practice and the order of importance of the eigenvectors (weights) as alternatives (D1, D3, D7, D10) of the automotive concept design stages are given. In addition, as reported in Table 7, pre-transferring the functionality of the new autonomous technology (0.43) and software (0.44) information to the "2D Doodle Sketch" phase of the automotive concept design process can optimize the cyclical structure of the flow that can create repetitive modifications. On the other hand, as can be seen in Table 7, transferring the software and hardware information of the new autonomous vehicle technology to the "3D Interface Control" stage, which is secondary in importance, optimizes the resource management of the automotive concept design flow in interface

Table 7. Eigenvector of criteria and alternatives.

Prioritise		Eigenvector	AutonomousTechnology Adaptation & Transfer						Decision
			Autonomous Technology Function	Autonomous Technology Hardware	Autonomous Technology Software	Autonomous Technology Occupation	Autonomous Technical Competence	Autonomous Technology Location	
			0.33	0.09	0.07	**0.26**	0.10	0.15	
1	D1	2D Doodle Sketch	0.29	0.11	**0.44**	0.39	**0.43**	0.30	**0.33**
2	D7	3D Interface Control	0.19	**0.33**	**0.33**	0.26	0.10	0.20	**0.26**
3	D3	3D Clay Model	**0.26**	0.11	0.11	0.09	0.19	**0.30**	**0.22**
4	D10	3D Interior/ Exterior Trim	0.26	**0.44**	0.11	0.26	**0.29**	0.20	**0.19**

studies. Unlike AHP, it is not a pairwise comparison of criteria, but a method based on scoring and weighting alternatives on the basis of criteria. The weighting has been determined as the common opinion of the company managers who determined the criteria and is shown in Table 7. Looking at the result, it can be seen in Table 6 that "2D Doodle Sketch (D1)" is in the first place and "3D Interface Control (D7)" is in the second place. Looking at the results of the AHP method, the rankings change after GC1 global automotive industry company. The values expressed as percentages in Table 6 express their closeness to the ideal solution. The eigenvector values obtained from the AHP method are used in the comparison weight ratios. The weighted normalized decision matrix is obtained by multiplying the weight ratios from the AHP mathematical model after the decision matrix in Table 6 is normalized (Table 6). The weighted normalized decision matrix is shown in Table 6. The values expressed as percentages in Table 7 express their closeness to the ideal solution. As a result of the applied method, it can be seen in Table 7 that "2D Doodle Sketch (D1)" took the first place, "3D Interior/Exterior Trim (D10)" took the second place, and "3D Interface Control (D7)" took the third order of importance. The results were discussed with the executives of the participating automotive industry companies that provided input for the selection of the evaluation of the process and it was decided that the priority selection was consistent.

7. Conclusion

AHP, process selection, or process evaluation problems, which is one of the multi-criteria decision-making solutions, is one of the productivity measurements frequently encountered in manufacturing industry applications. However, manufacturing, equipment or product development process evaluations provide important inputs for the optimization and simplification of the flow [9] [17] [24]. Therefore, in solving problems; it is very important to determine the appropriate main and sub-criteria and to express the interactions clearly, and to make the comparisons consistently. In order for companies to determine their preferences correctly, the use of scientific methods in the order of importance selection and evaluation of alternatives has important results. Scientific approaches that make up the preferences in question, reveal the selection and order of importance or evaluation of the alternatives, provide optimization and productivity increase with repetitive measurements [9] [21] [22] [24]. Otherwise, alternatives and evaluations that are not suitable for the determined purposes direct the process. Using the specified method, four alternative automotive companies were evaluated in the study, and the automotive concept design phase, which performed the most intensive adaptation work, was calculated according to the order of importance. The result of the application of the AHP method to the problem: In autonomous vehicle technology adaptation studies, the "2D Doodle Sketch (D1)" automotive concept design stage took the first place in the mathematical model structure. In terms of its general structure, "2D Doodle

Sketch (D1)", the automotive concept design process begins with preliminary preparation or the collection of new information and the search for a compatible form on the vehicle. Therefore, in the preliminary research, information and opportunities are defined and determined. If a new technology's on-board form structure, function objectives, and the definition of location or prior information are unclear, the 2D doodle sketch phase is also subject to iterative modification with new information. In addition, innovations made under undefined or insufficient information during the design and product development stages cause iterative cycles and significant losses in the design verification steps in the phase transitions [20] [21] [22]. In such a case, the automotive concept designer will act in accordance with the information presented to him and his range of action will be limited. In other automotive concept design phases of the line-up, it reveals vague and repetitive technology adaptations.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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