Journal of Transportation Technologies, 2022, 12, 711-731
https://www.scirp.org/journal/jtts
ISSN Online: 2160-0481
ISSN Print: 2160-0473

Evaluation of Lean Product Development Stages of Autonomous Vehicle Technologies with AHP Method

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How to cite this paper: Paker, F.A. (2022) Evaluation of Lean Product Development Stages of Autonomous Vehicle Technologies with AHP Method. *Journal of Transportation Technologies*, **12**, 711-731.
https://doi.org/10.4236/jtts.2022.124041

Received: August 27, 2022
Accepted: September 27, 2022
Published: September 30, 2022

Abstract

The potential innovation and emerging workforce created by autonomous vehicle technologies, which have just entered the lean product development disciplines, play an important role in the development or change of the automotive manufacturing industry. Therefore, the intensity of work and the innovation practices brought by the technologies in question at each step of very different and interdisciplinary studies deeply affect the new and lean product development steps. Comparatively measuring the operating weight of new autonomous vehicle technologies in different company structures in these lean product development steps has important consequences for the development and change of the automotive industry under heavy global competition. On the other hand, it is difficult to measure the innovation input or the use of new autonomous technology under the AHP mathematical model of each part that constitutes the whole of the lean product development process, but it also creates the future predictions of the sector. The Analytical Hierarchy Process (AHP), which is one of the multi-purpose decision-making methods, was used to determine the most intense value creation, the design and development phase where there is innovation input, or the lean product development discipline throughout the whole process. The AHP method was preferred for the comparative analysis and synthesis of different applications or similar approaches in the automotive manufacturing industry companies (global and local) and lean product development processes in the field study of the research, under qualitative data. Under the AHP mathematical model created in the research, it was aimed to measure interdisciplinary clusters with a focus on new technology and to identify similarities or differences under alternative applications created by different company structures and to compare them systematically and evaluate them mathematically. In the study, the AHP mathematical model was used to compare lean product development processes and the use of new autonomous vehicle technologies, and the Expert Choice program was preferred in the application of the method.

Keywords

Analytical Hierarchy Process, Lean Product Development, Automotive Design Process, Automotive Industry, Decision Making Methods

1. Introduction

Today's automotive industry continues its developments in the processes it uses in the application and design of innovation or new autonomous vehicle technologies, and in the final new products, continues its development with its productions in an increasingly competitive environment. Therefore, global automotive manufacturing industry companies design and develop new vehicle products and update them by increasing their efficiency within defined life cycles in order to maintain their competitive structure and increase market penetration. In this sense, both lean product development steps and interdisciplinary stage clusters created by new autonomous vehicle technologies in practice emerge as a result of the restructuring of different and new expertise-based collaborations, which are formed by intensive application and adaptation studies, on the basis of simplification and value creation. On the other hand, interdisciplinary collaborations created by autonomous technologies in practice; it has been observed that it has a positive effect on potential innovation creation and new technology adaptation, reducing the application cost of autonomous technologies within the scope of outsourcing, increasing flexibility in the use and functions brought by new technologies, and ensuring customer satisfaction with innovation.

One of the critical activities of the design and development process management is the adaptation of the new technologies procured through the foreign procurement channel to the new vehicle. Considering that lean product development and design activities basically constitute high resource management and investment, incorporating new outsourced new technology into the product in existing processes requires special solutions and measurements. Outsourcing of automotive manufacturing industry companies constitutes an important decision point in how new technology can be included in existing lean product development processes, in practice, in which stages. The correct evaluation of the parameters within the basic discipline or function and process values created by each lean product development step with autonomous technologies will make the whole flow efficient. In this study; an AHP mathematical model was established to analyse the clustering or adaptation density created by new product development departments and disciplines in practice, including new autonomous technologies. In this comparison structure, which works with the mathematical model included in the AHP method, the lean product development process steps of 3 global automotive manufacturing industry companies (GC) and 3 local automotive manufacturing industry companies (LC) were evaluated. After evaluating the new product development disciplines of each automotive manufacturing industry company with the AHP model, a total score was obtained for the expertise and discipline in autonomous technology applications. Among these values, it is clear that the new product development discipline, which has the highest clustering workload, needs a high resource investment.

2. Lean Product Development Process and Research Model

New and lean product development management focuses on how effectively businesses use their innovation or creation processes and capabilities, and how successful they are in coordinating resource management and updating in company functions [1] [2] [3]. Therefore, value creation and preservation in the new product development management or process constitute an important roadmap for the company's innovation and new technology acquisition. To create an effective design and lean product development process, or to provide competitive advantage with new products, lies in the details of the iterative structure of the firm's innovation acquisition and deployment implementation processes [4] [5] [6] [7]. As a result of the increase in international competition, automotive manufacturing industry companies create important values by directing mass production with their products in high demand in that region, with product development center specialized for variables, realizing vehicle adaptations of new autonomous technologies that come into play specifically for the region, and optimizes resource management in a repetitive manner in order to spread in production [8] [9]. In addition, depending on the shortening of the product life cycle (PL) from today's global market conditions, automotive manufacturing industry companies are developing plans to expand, update or change their existing product ranges, or to offer new products to certain markets under the autonomous technologies that come into play in certain periods. For this reason, prioritizing the determination and operation of lean product development that require labor intensive in the application, adaptation or design of new autonomous vehicle technologies provides significant benefits in the global competition of automotive manufacturing industry companies [10] [11] [12]. Lean product development revealed by AHP mathematical model comparisons play an important role in the future of new autonomous vehicle technologies [13] [14]. The order of importance or the comparative structure of the disciplines in the lean and new product development process according to autonomous vehicle technology applications plays an active role in the definition, design and development of new transportation solutions or requirements intertwined with the new life model [15].

2.1. Determination Process of Lean Product Development

The importance given to new product or innovation management provides long-term technology design or development that does not depend only on the design and new product development process stakeholders, and this structure positively affects the competitive power of automotive manufacturing industry companies in the long run [16] [17] [18] [19]. A collective upgrade investment for new autonomous technology adoption to all new product development disciplines and stakeholders could result in significant financial and operational losses for automotive manufacturing industry companies (**Figure 1**). Therefore, under the measurement of the density, innovation and workforce amount created by the new autonomous vehicle technologies in the application of lean

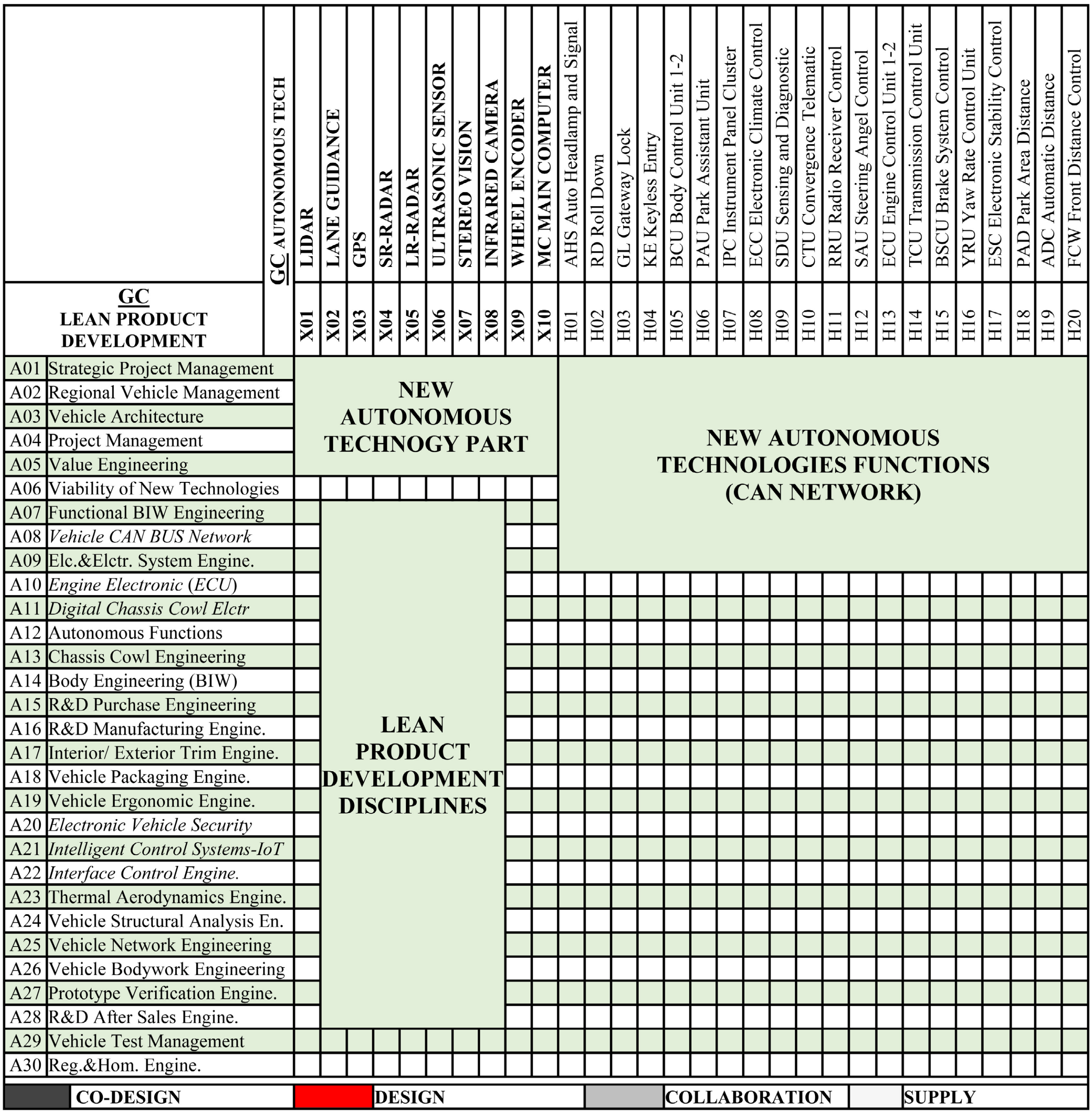


Figure 1. Autonomous technology use to lean product development process [19].

product development disciplines, the decision to invest in order of priority or to increase software, hardware and resources step by step according to the whole flow effect, increases the efficiency of the total flow or prevents losses (**Figure 1**). In addition, the selection or determination of new product development disciplines, where new autonomous vehicle technologies constitute a heavy workforce, the definition of decision criteria, and the pre-selection of specialization departments where potential innovations can increase consist of two stages (**Figure 1**).

In Paker's (2018) research, lean product development process disciplines realized in automotive industry companies were detailed and the basic functions of the value stream map, new project scale, and value creation and preservation focused specialties, which were affected by innovations, professions and the hardware and software used were conveyed in the study (**Figure 1**). In **Figure 1**, the investment budget, the lean product development teams that will be activated, the hours of expertise, software and hardware, as well as strategic markets and market shares are also included in other sources at the project entry level in the new project plans with the aforementioned initial setup [20] [21] [22].

2.2. Identification of New Autonomous Vehicle Technologies

In order to define and select new autonomous vehicle technologies; one-on-one meetings with global automotive manufacturing industry companies (GC), which are both developers and users of these technologies, as well as local automotive industry companies (LC), which are only users through the supply channel, were first conducted with field studies, as planned. New autonomous technologies and lean product development disciplines were revealed in the light of one-on-one interviews conducted during the first field research of the study (**Figure 2**). The second field study of the study covers the analyses under the AHP survey method, as shared in this publication. Therefore, the most comprehensive and widespread studies for the sub-criterion values used in the definition and evaluation or selection of decision criteria in the AHP survey study have formed the main and sub-criteria that are closest to the mathematical model made by Paker (2018) and Dickson (1966) [23] [24]. 6 main and 23 sub-criteria have been determined that can be used in the selection and evaluation of processes or systems in Dickson's or Paker's studies. In these process or system selection evaluation studies, the main and sub-criteria with the highest share, in order of importance, of value creation or preservation, supply chain variables or selection, efficiency or performance measurements and similar comparisons were examined. In the study conducted by Wind (1980), a sequence of criteria was created according to the importance of main and sub-criteria, cost, time, quality, product, capacity, place and similar evaluations respectively [25]. Yang's evaluation criteria (2008), Paker's (2018) and Dickson's (1966) 23 - 29 criteria, or Wind's (1980) comparison studies were analyses under the AHP mathematical model [23] [24] [25] [26]. Therefore, in the results of this study; performance, efficiency, order of importance, clusters and selection, similar main

CAN (Controller Area Network)											
Class	**Transfer Range**	**New Autonomous Technologies**			**Data Rate**	**Network Protocol**					
A-CAN	**10 Kbps**	A1	AHS	Auto Headlamp and Signal							
		A2	RD	Roll Down	Low Data Rate	OEM	RADAR				CAN
		A3	GL	Gateway Lock							
		A4	KE	Keyless Entry		LIN					
B-CAN	**10-125 Kbps**	B1	BCU	Body Control Unit					ACC ECU		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							
		D13	LG	Lane Guidance	Peak Data Rate	Flex Ray	Display				

Figure 2. New autonomous vehicle technology on CAN network [30] [31] [32].

and sub-criteria were among the alternatives with the highest importance, respectively. In the repetitive review of the research that Ho (2010) made and started in 1991; performance, price, quality, production capacity and distribution has been determined among the supply chain and similar evaluations, the four most important sub-criteria considered [27]. In this direction, sub-criteria of price, quality, service and distribution are considered as the most important criteria in many studies. As a result of process or supply channel selection and evaluation, hundreds of criteria are summarized and in order of importance quality, delivery, price/cost, production capacity, service, management, technology, R & D, finance, flexibility, relations, risk and security, etc. priority order of the sub-criteria was compared among the alternative structures according to the order of importance [23] [27]. Traditionally, measuring the performance or efficiency of the sub-stages constituting the main process on the basis of basic criteria, evaluation methods in order of importance, while measuring only the use of resource management criteria in the decision-making process; it has been revealed that the performance criterion alone is not sufficient for the alternative process selection and evaluation methods developed in the following years, and that other criteria should also be taken into account.

Various methods come to the fore in pre-selection of processes that can be evaluated on the AHP mathematical model. Categorical methods, data envelopment analysis, clustering analysis and event-based inferential systems are widely used in the preselection of processes that can be included in the AHP comparison structure. The minimum conditions required for each main and sub-criteria evaluated with these methods are determined or if at least one of these criteria does not have the desired feature or minimum value, it is eliminated from the alternatives. Another main and sub-criteria pre-selection method is to determine the most important criterion and to create an evaluation model according to this criterion among all alternatives [28]. AHP artificial intelligence models developed for the solution of the selection problem of alternative applications focused on the evaluation of the process stages; expert systems developed with event-based inference and neural networks yield valuable results. Expert Systems are aimed at solving important problems in a specialized field by imitating the way of thinking of experts. There is no need to formulate the decision-making process while performing the formation or selection of the process-oriented stages by utilizing neural networks. With this feature, the neural networks of the AHP mathematical model cope better than other models when it comes to decision making situations where uncertainty and complexity are involved. Development process performed process evaluation and selection with a decision support system based on neural networks [29].

In the survey part of the research, the autonomous vehicle technologies questioned with the companies are included in **Figure 2**. The autonomous vehicle technologies in **Figure 2** are 10 autonomous vehicle technology pieces that determine the speed and distance of the vehicle and its environmental conditions; Lane directs with 30 subsystems working in CAN network using Lidar, GPS, Infrared Camera, Ultrasound, Wheel Encoder, Short-long wave Radar and similar units [30] [31] [32]. The time elapsed during the instantaneous reception and transmission of information on the CAN line above is the key point in determining the distance, and the frequency shift in the reflected beam is calculated with the Doppler Effect to determine the vehicle speed (**Figure 2**). The CAN system consists of a standard network structure that uses 2 basic cables to receive and transmit data from the ACC system (**Figure 2**). Therefore, each node coming to the CAN system transmits 0 to 8 bytes of messages in the message header. The main role of the message header in question is to decide the priority of the message. Thus, the message with the highest priority is transmitted first. When it finds a free space to transmit the secondary message, it tries to send its message again (**Figure 2**). On the other hand, among the systems connected to the CAN line, the engine control module (ECU): regulates the travel speed by controlling the digital throttle of the vehicle power engine. When the autonomous vehicle engine control ECU receives information from the ACC module, it controls the vehicle speed. Brake control module (BAC), which directs the counterforce of this system: it is to activate the digital brake system when needed by the ACC module [30] [31]. Sensors (Brake Pedal Sensor, Accelerator Pedal Sensor, Radar

Sensor, Four Wheel Sensor, etc.) and actuators in autonomous vehicles (Brake Actuator (BA), Throttle Actuator (TA), etc.) are increasing with newly added functions. The main function of the brake actuator (BAC) is to determine vehicle speed or reduce vehicle speed by signalling the vehicle throttle actuator (TAC). The main function of the digital throttle actuator (TAC) is to control the throttle valve according to the need of the ACC system [31] [32].

3. Research Method

The AHP research method approach, developed by Thomas L. Saaty in the early 1970's, is a tool to assist decision making in complex, unstructured and multi-criteria decision processes [33]. The AHP method was preferred for this study because of its ability to use qualitative and quantitative criteria together [33] [34] [35]. In addition, it is a method that is easy to understand and implement by global and local automotive manufacturing industry company managers who participated in the second field survey, and it is also a method that can help improve the decision-making process. The aim of the AHP research method; for a given set of alternatives, by scaling the associated priorities, taking into account the intuitive judgments of the decision maker and the consistency of comparison of the alternatives in the decision-making process, is to ensure that this process (decision making process) is completed in the most effective way [33] [34] [35]. With the AHP mathematical model method, the problem is decomposed in a hierarchical manner while it is applied in the process steps and in the selection of alternative products or companies. The basic structure of the hierarchy consists of three level relationship levels developed to calculate the pairwise comparison matrix ratios and weights [36] [37]. In this process, the decision maker pairwise comparison matrix ratios are defined. Therefore, this method is strictly related to people's decision-making ability. Under the AHP mathematical model, the main problem is decomposed in a hierarchical manner, while choosing the importance of the process stages or choosing the firm with alternative applications. The hierarchy is basically evaluated at three levels: the first level creates the main purpose, the second level creates the information, criteria, main and sub-criteria that should be included in the formula, and the third and last level includes the characteristics of the alternatives [33]. Creating the basic hierarchical structure under the AHP model helps to avoid complexity, while also determining the basic elements of the problem [33]. The criteria can be separated into main and sub-criteria depending on the purpose of the research, this situation also increases the number of levels created in the hierarchy. The selection of the interdisciplinary study corresponding to the most effective technology, which is the aim of the highest-level problem, shows the alternative automotive manufacturing industry firm practices at the last level. Therefore, the second and subsequent third levels indicate the main and sub-criteria of cluster selection in order of importance, respectively [38].

When the application steps of the AHP research method developed by Saaty are examined in detail [33]: 1 definition of the problem and determination of the target in this problem, 2 starting from the target, placing the criteria in the middle level and the alternatives in the hierarchical structure at the lowest level, 3 determining which alternative or criterion is dominant, 4 for each column in the binary comparison matrix, column sums and normalizing the matrix by dividing the elements in the matrix by the relevant column sum, taking the totals of rows formed for each alternative or criterion in the 5 retrieval of row sums for each alternative or criterion in the normalized matrix, 6 multiplying the priority values obtained for each criterion or option in the priority matrix created with the priority vector, with all the elements in the column in the binary comparison matrix of that criterion or option, 7 calculating the n value by dividing the row total values in the weighted total matrix by the row values in the priority matrix and calculating the arithmetic average of the values in the last matrix of (n.1.) size, 8 calculation of consistency index, 9 Calculation of the consistency ratio by using comparison tables, 10 Calculation of the final priority value to be reached by multiplying the priorities of the alternatives calculated on the basis of the criteria and the criteria priorities obtained as a result of the pairwise comparison of the criteria among themselves, for each alternative (**Figure 3**).

If the consistency ratio is less than 0.10, the comparison matrix is considered consistent (**Figure 3**). On the other hand, the pairwise comparison scale is given in **Figure 4**. The binary comparison scale is an evaluation system developed to reduce the effect of intermediate values in the decimal system (**Figure 4**).

If the consistency ratio is smaller than the basic deviation ratio, the consistency ratio of the scale evaluations in the matrix structure increases (**Figure 4**). The formula that creates the binary comparison scale uses the scale values in **Figure 4**.

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R1	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Figure 3. Average random consistency (RI) table [33].

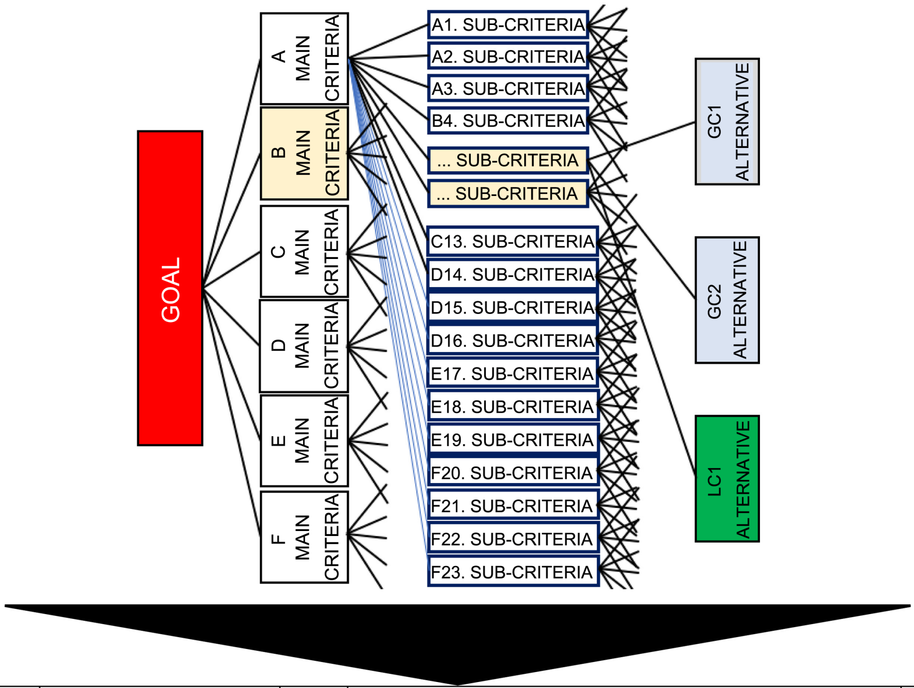
Level of Importance	Definition	Interpretation
1	Equally preferred	Two activities contribute equally to the objective
3	Moderately	Experience and judgment slightly favour one activity over another
5	Strongly	Experience and judgment strongly or essentially favour one activity over another
7	Very strongly	An activity is strongly favoured over another and its dominance demonstrated in practice
9	Extremely	The evidence favouring one activity over another is of the highest degree possible for affirmation
2, 4, 6, 8	Intermediatevalues	1 - 3, 3 - 5, 5 - 7, 7 - 9, Used to represent a compromise between preferences listed above

Figure 4. AHP rating scale [33].

4. AHP Implementation of Findings

The research was carried out with 30 employees, who have been performing the automotive manufacturing and new product development functions in the same location (Turkey) since the 1960' s, and who have taken on managerial positions in local (LC) and global partnered (GC) automotive industry companies (1 local, 2 global), and new to the design stages. It focuses on the impact of autonomous vehicle technologies in practice. 3 participating automotive manufacturing industry companies, which still continue their manufacturing and new product development functions at the said location; has been carrying out new vehicle design and development, simultaneous new product projects, robotic manufacturing technologies, local and global sales and service network, mixed product assembly lines, current lean product development processes and similar activities for more than half a century.

AHP mathematical model problem definition used in the research: with new product development processes and disciplines realized in local and global automotive manufacturing industry companies, it constitutes a comparison of the intensity of use of new autonomous vehicle technologies. The depth question created by the problem is to determine the clusters with the intensity experienced by the disciplines that make up the lean product development process of autonomous vehicle technologies, which are at the center of innovation in the automotive industry. The needs of software, hardware and analysis studies of new technologies in the field or the needs of different areas of expertise in practice are revealed in technology creation (GC global automotive companies) or acquisition (LC local automotive companies). Therefore, a comparison structure has been designed under the technology adaptations of different autonomous technologies, which are carried out in partnership with 2 global automotive companies, and also supplied by 1 local automotive companies. The company that realizes the most efficient technology adaptation in newly developed vehicles and the purpose or model of the selection of new product development disciplines or the order of importance set an example for an efficient structure in value creation and preservation. On the other hand, when the definition of the criteria in the AHP mathematical model structure is examined: the main criteria of the study are the vehicle constituting the new product development; A (electrical & electronic systems), B (power train systems), C (ergonomics & package), D (interface & Instruments Panel (IP) control), E (upper body & prototype), F (test & Homoglation systems), to be there are a total of 6 (**Figure 5**). In addition, the 23 sub - criteria (A7 - 9, B10 - 13, C14 - 19, D20 - 22, E23 - 25, F26 - 29) of 6 main criteria (A, B, C, D, E, F); in new product development, it constitutes 23 specialization disciplines that perform the application and adaptation of new autonomous vehicle technologies on the vehicle (**Figure 5**). The interdisciplinary productivity among 1 local or 2 global automotive manufacturing industry firms, which constitute the alternatives in the comparison structure of the AHP mathematical model, was measured with a focus on autonomous vehicle technologies (**Figure 5**).



GOAL		MAIN CRITERIA		SUB- CRITERIA	
Lean Product Development Process on New Autonomous Vehicle Technologies	A	Electric & Electronic Systems (0.087)	A07	Functional BIW Engineering- ECU (0.188)	
			A08	Vehicle CAN Network (0.81)	
			A09	Elc. & Elctr. System Engine (0.731)	
	B	Power Train Systems (0.045)	B10	Digital Chassis Cowl (0.161)	**GC1** Automotive Company
			B11	Chassis Cowl Engineering (0.464)	
			B12	Body Engineering (0.207)	
			B13	R & D Manufacturing Engine. (0.168)	
	C	Ergonomic & Package (0.338)	C14	Vehicle Packaging Engine. (0.289)	**GC2** Automotive Company
			C15	Vehicle Ergonomic Engine. (0.108)	
			C16	Electronic Vehicle Security (0.245)	
			C17	Interior & ExteriorIoT System(0.105)	
			C18	Autonomous Routing (0.090)	
			C19	AC Climatization (0.163)	
	D	Interfaces & IP (0.105)	D20	Interface Control Engine. (0.249)	
			D21	Thermal Aerodynamics Engine. (0.157)	
			D22	Vehicle Structural Analyses (0.594)	
	E	Upper Body & Prototype (0.155)	E23	Vehicle Network Engineering (0.637)	**LC1** Automotive Company
			E24	Vehicle Bodywork Engineering (0.105)	
			E25	Prototype Verification Engine. (0.258)	
	F	Test and Homoglation System (0.269)	F26	Cross-Regional Test Engin. (0.563)	
			F27	Vehicle Test Management (0.093)	
			F28	Regulation & Homologation Test Engine. (0.281)	
			F29	Vehicle Certifications (0.062)	

Figure 5. AHP comparison mathematical model and EC software impact rates.

Mathematical model formation provides the most important structural unit in the AHP method (**Figure 5**). Starting from the purpose determined in the method approach in question, the relationship setup determined at all stages, the sub-criteria determined for each criterion, and finally the order of importance in the alternatives, created an inductive hierarchical structure (**Figure 5**). In **Figure 5**, the basic flow structure of the AHP mathematical model established in the research is shown. In this study, the AHP method was used to evaluate the qualitative and quantitative elements together and to preserve the quality of being fast in decision making (**Figure 5**).

5. Discussion and Evaluation

Similar items at each level of the AHP hierarchy established within the framework of the research were compared in terms of criteria at the next level. A pairwise comparison matrix of all items was created. Since the comparison of an item with itself in these binary matrices will be expressed with the number 1, the value 1 is placed on the diagonals of the matrix. Therefore, it represents $n(n-1)/2$ comparisons in a matrix with "n" elements. The main criteria in the AHP mathematical model, together with the elements within their homogeneous classes, were placed in the pairwise comparison matrix and after the priority vector was found, the consistency of the created vector was calculated according to the AHP method. The consistency ratio does not exceed 0.10 as stated before.

While comparing the sub-criteria in the AHP model structure, first priority was given to the comparisons of the first-level criteria. Thus: A (Electrics & Electronics systems), B (Powertrain), C (Ergonomics & Package), D (Interface & Instruments Panel (IP) control), E (Upper body & Prototype), F (Test & Homoglation) assessments were made, under binary matrices (**Figure 6**). The pairwise comparison matrix of the main criteria is presented in **Figure 6**. In the next step, the comparison values of the sub-criteria related to each main criterion at the first level were calculated. In the final stage calculations of the mathematical model structure, each criterion was compared in terms of alternatives. The main and sub-criteria determined under the AHP model carried out within the

		A	**B**	**C**	**D**	**E**	**F**
		Electric & Electronic	Power Train Systems	Ergonomic& Package	InterFace&IP	Upper Body & Prototype	Test and Homologation
A	Electric& Electronic Systems	1	1/2	5	3	3	3
B	Power Train Systems	2	1	5	3	3	3
C	Ergonomic & Package	1/5	1/5	1	1/3	1/3	1/3
D	Interface & IP	1/3	1/3	3	1	3	2
E	Upper Body & Prototype	1/3	1/3	3	1/3	1	2
F	Test and Homologation	1/3	1/3	3	1/2	1/2	1
	Total	**4.2**	**2.7**	**20**	**8.166**	**10.833**	**11.333**

Figure 6. Calculation of AHP main criteria on column weighted.

framework of the research were compared in three alternative automotive industry company structures. These comparisons were made with 30 automotive industry company managers who played an active role in decision making. The AHP mathematical model, which was designed according to the working structure, was both calculated and carried out using Expert Choice (EC) software, in order of importance according to the new autonomous technology adaptations of different expertise and disciplines in the new product development process according to the comparative company structure. The EC program offers various evaluations in the comparison of main and sub-criteria and alternatives. These consist of options that convey verbal, numerical or graphic expression and analysis. In Figure 6; while B (2.7) uses less autonomous technology than A (4.2), F (11.333) is moderate compared to D (8.166) and E (10.833) uses moderately autonomous technology relative to C (20). While B (Power Train Systems) shows a weak advantage over A (Electric & Electronic Systems), F (Test and Homologation) is moderate compared to D (Interface & IP) and E (Upper Body & Prototype) are all of than moderately important compared to (Ergonomic & Package) C (Figure 6). According to A and B the D order of importance is weak, while E and F test and homologation are moderately unimportant according to C ergonomic and package system. D, while it shows moderate insignificance according to A and B, it is moderately insignificant according to C, E and F is calculated as the weakest link in the ranking. A, B, D, E and F show moderate insignificance relative to C but A, B, D, E show moderate insignificance relative to F the weakest in ranking. A and B show moderate insignificance compared to F, C shows moderate insignificance for F but A, B, D, E shows weaker insignificance than F and C. Thus, the first stage of the AHP method is completed and the next stage is passed to find the priority vector (Figure 6).

In the second step, the values in each column in matrix [A] are summed up (Figure 6). After the total is found, each row element is divided by the resulting total to create a new [B] $n \times 1$ vector. Figure 6 shows the calculation of the weights of the main criteria. The consistency ratio was calculated as 0.05 (Figure 7). Since the consistency ratio was less than 0.10, the evaluation method was

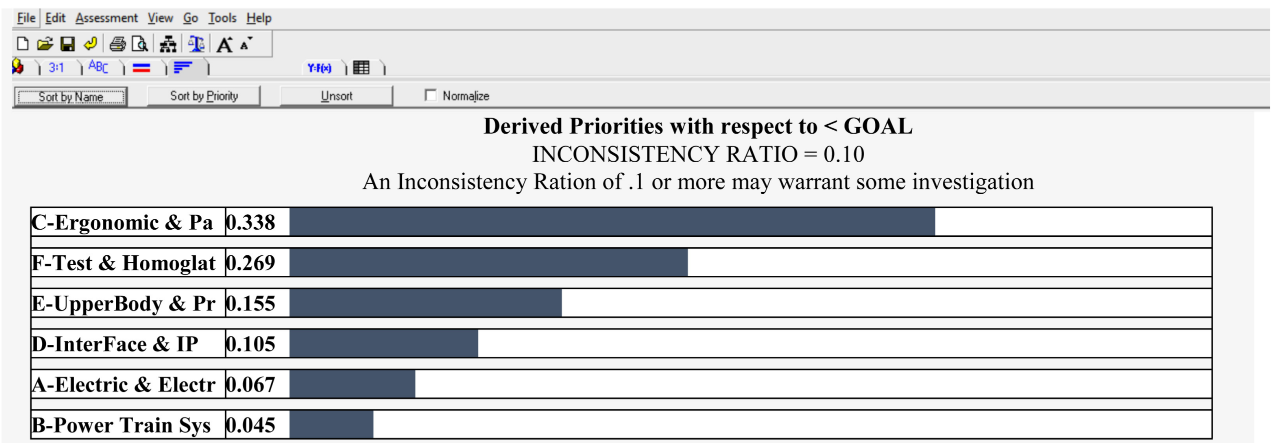


Figure 7. Comparative effect rates of lean product development stages (EC view).

accepted as consistent. In Figure 6, different from Figure 7, a graphical comparison was made. The importance values of the main criteria A, B, C, D, E, F, respectively, are shown on the matrix (Figure 7). In order to perform the consistency analysis, the priorities of the sub-criteria were calculated among the main criteria and for each main criterion. To summarize what has been done at this stage, priorities have been determined in terms of the general purpose, based on the priorities obtained in the solution stages of the problem. Here, depending on each criterion, the priorities of each alternative are arranged in a matrix, and each column of this matrix is multiplied by the priority of the criteria in this column, and these products are collected along the rows. Thus, the vector of priorities for each alternative is obtained. Total priorities for all of the criteria, sub-criteria and alternatives are resolved in the EC software (Figure 7). When the analysis is made with EC software, the importance criteria of the main criteria are respectively; C (ergonomics & package) 33.8%, F (test & homologation) 26.9%, E (upper body & prototype) 15.5%, D (interface & IP control) 10.5%, A (electrical & electronic systems) 8.7%, B (power train systems) was obtained as 4.5% and the importance values of the alternatives were determined as 52.4% for GC1 global automotive manufacturing industry company, GC2 global automotive manufacturing industry company 33.0%, LC1 local automotive manufacturing industry company 14.6% importance values. GC1 is the global automotive manufacturing industry firm with the highest clustering (Figure 7), with 52.4% using the newest autonomous vehicle technologies.

In Figure 7 above, the main criteria and the distribution of alternatives are solved in the EC computer program, and in Figure 8 below, the criteria, main and sub-criteria or the relative importance values of alternative automotive industry company applications are shown together (Figure 8).

In Figure 8, the priority vectors found for each alternative in the previous stage were compared and the alternative with the highest value was revealed. GC1 global automotive industry company 52.4%, GC2 global automotive industry company 33%, LC1 local automotive industry company 14.6% were calculated in the model and with the resulting difference, GC1 global automotive industry company, which is the highest priority alternative, was selected. A graph showing the performance, dynamics, slope and break-even sensitivity analyses of the EC software is included (Figure 9).

The first of the sensitivity graph for each automotive industry company in Figure 9 is the performance sensitivity graph. While GC1 and GC2 global automotive manufacturing industry firms are around 60%, LC1 local automotive manufacturing industry firm is over 20% (Figure 9). While GC1 global automotive manufacturing firm is above 95% in C discipline (Ergonomics & Package), GC2 global automotive manufacturing firm is defined as below 35% and LC1 local automotive manufacturing firm is defined by 15% (Figure 9). While GC1 global automotive manufacturing industry firm has around 75% in F discipline (Test and Homoglation), GC2 and LC1 automotive manufacturing industry

GOAL		MAIN CRITERIA		SUB-CRITERIA	GC1	GC2	LC1
New Autonomous Technology on Lean Product Development Process	**A**	Electric & Electronic Systems (0.087)	**A07**	Functional BIW Engineering-ECU(0.188)	0.311	0.493	0.196
			A08	Vehicle CAN Network (0.81)	0.157	0.594	0.249
			A09	Elc. & Elctr. System Engine. (0.731)	0.625	0.238	0.136
				A Total	1.093	1.818	0.581
	B	Power Train Systems (0.045)	**B10**	Digital Chassis Cowl (0.161)	0.258	0.105	0.637
			B11	Chassis Cowl Engineering (0.464)	0.528	0.333	0.140
			B12	Body Engineering- BIW (0.207)	0.528	0.333	0.140
			B13	R & D Manufacturing Engin (0.168)	0.413	0.327	0.260
				B Total	1.727	1.098	1.177
	C	Ergonomic & Package (0.338)	**C14**	Vehicle Packaging Engin. (0.289)	0.731	0.188	0.081
			C15	Vehicle Ergonomic Engin. (0.108)	0.637	0.258	0.105
			C16	Electronic Vehicle Security (0.245)	0.637	0.258	0.105
			C17	Interior & ExteriorIoTSystem (0.105)	0.731	0.188	0.081
			C18	Autonomous Routing (0.090)	0.637	0.258	0.105
			C19	AC Climatization (0.163)	0.637	0.258	0.105
				C Total	4.010	1.408	0.582
	D	Interfaces & IP (0.105)	**D20**	Interface Control Engine. (0.249)	0.352	0.559	0.089
			D21	Thermal Aerodynamics Engine. (0.157)	0.258	0.637	0.105
			D22	Vehicle Structural Analysis (0.594)	0.528	0.333	0.140
				D Total	1.490	1.529	0.334
	E	Upper Body & Prototype (0.155)	**E23**	Vehicle Network Engineering (0.637)	0.528	0.333	0.140
			E24	Vehicle Bodywork Engineering (0.105)	0.258	0.105	0.637
			E25	Prototype Verification Engine. (0.258)	0.637	0.258	0.105
				E Total	1.423	0.696	0.882
	F	Test and Homoglation (0.269)	**F26**	Cross-Regional Test Engin. (0.563)	0.528	0.333	0.140
			F27	Vehicle Test Management (0.093)	0.559	0.352	0.089
			F28	Regulation & HomoglationTest (0.281)	0.105	0.637	0.258
			F29	Vehicle Certifications (0.062)	0.258	0.637	0.081
				F Total	1.450	1.959	0.568

Figure 8. Values for criteria, sub-criteria, and alternatives weighted.

companies have 40% ratio. While GC1 global automotive manufacturing industry firm was 70% in E discipline (Upper Body & Prototype), GC2 global automotive manufacturing industry firm was determined as 40% and LC1 global automotive manufacturing industry firm was determined as 25%. GC1 global automotive manufacturing industry company achieved 65% in D discipline (Interface & IP Control), GC2 global automotive manufacturing industry company achieved over 60%, LC1 local automotive manufacturing industry company achieved 20%. GC1 global automotive manufacturing company has a performance sensitivity of 75% in A discipline (Electrics & Electronics Systems), GC2 global automotive manufacturing company is around 45%, while LC1 local automotive manufacturing company has a performance sensitivity of over 20% (Figure 10). When the value of any criterion is changed, the changes consisting of other criteria and alternatives are automatically seen simultaneously. The second of the four sensitivity graphs for each automotive company in Figure 10

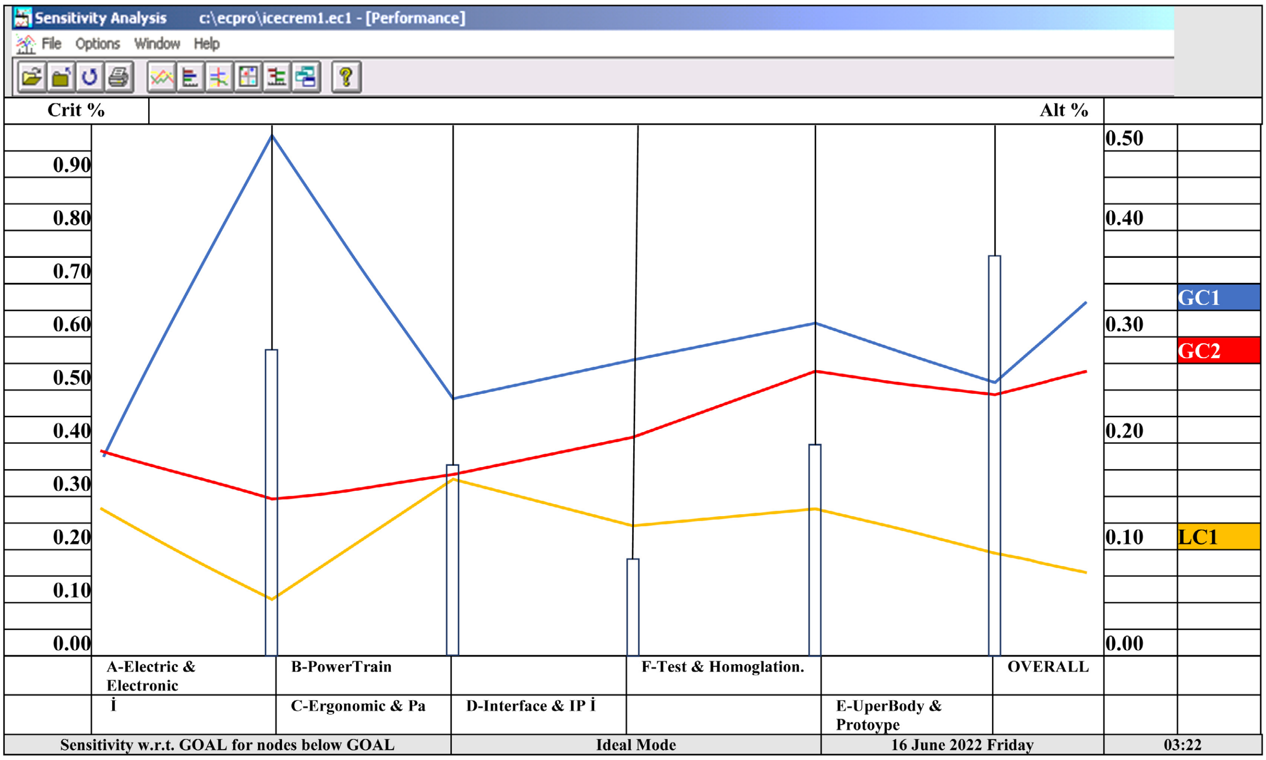


Figure 9. AHP performance and sensitivity measurement analysis.

26.9%	F-Test &Homoglation	52.4%	GC1 Automotive Comp
33.8%	C- Ergonomics & Package	33.0%	GC2 Automotive Comp
04.5%	B- PowerTrain System	14.6%	LC1 Automotive Comp
15.5%	E- UpperBody& Prototype		
10.5%	D- InterFace& IP Control		
08.7%	A- Electrics & Electronics Systems		

Figure 10. Value of lean product development stages affecting the new autonomous technology (EC view).

is the slope sensitivity graph. This chart shows the relationship between alternatives on the basis of criteria (Figure 10). GC1 global automotive manufacturing industry firm shows a negative slope from 55% to 45%; GC2 global automotive manufacturing industry firm shows a positive slope from 30% to 45%. GC1 global automotive manufacturing industry firm shows a negative slope from 50% to 55%, while GC2 global automotive manufacturing industry firm shows a positive slope from 30% to 35%. LC1 local automotive manufacturing industry firm shows very little positive slope from 14% to 15% (Figure 10).

The third of the four sensitivity graphs for each automotive manufacturing industry company in Figure 10 belongs to the dynamic sensitivity analysis. The main criteria are; A (Electrical & Electronics Systems) 8.7%, B (Power trains systems) was the highest with 4.5%, C (Ergonomics & Package) was the lowest with 33.8%, D (Interface & IP control) 10.5%, E (Upper Body & Prototype) 15.5% and

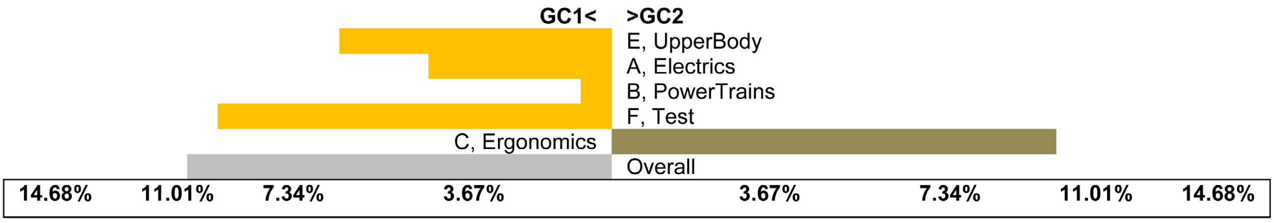


Figure 11. Weighted head to head between GC1 and GC2.

F (Test & Homoglation) 26.9% indicate dynamic sensitivity (Figure 10). GC1 global automotive manufacturing industry company was calculated as 52.4%, GC2 global automotive manufacturing industry company was calculated as 33%, LC1 local automotive manufacturing industry company was calculated as 14.6% and GC1 global automotive manufacturing industry company was selected as the alternative with the highest priority (Figure 11).

The third of the four sensitivity graphs for each automotive industry company in Figure 11 indicates the comparison of the changes in the criteria priority values of the two alternatives selected in the breakeven sensitivity graph, relative to each other. GC1 and GC2 global automotive industry company in break-even sensitivity; C (Ergonomics & Package), F (Test & Homoglation), E (UpperBody & Prototype), D (Interface & IP control), A (Electrical & Electronic systems), B (Powertrain), main in terms of main criteria, the alternative GC1 global automotive manufacturing industry company was selected with the highest priority.

6. Conclusion and Recommendations

Automotive manufacturing industry companies, which perform new product development functions under heavy competition conditions, while performing on-vehicle adaptations of newly introduced autonomous vehicle technologies, they also struggle with the efficient addition of innovations and new expertise or disciplines to the process. New product development process for an automotive manufacturing company; it consists of the combination of the newly designed products or parts, the development or redesign of existing and critical technology parts, their defined usage scenarios or assembly templates, the establishment of modular structure and product diversity in a platform structure, and the elements at all similar stages. Efficiency is targeted in the design and development process of any innovation or new technology that adds value to the new product under heavy competition conditions, or in each of the company functions that set up the optimization of process disciplines.

Newly introduced autonomous vehicle technologies have a significant impact and workload on both the automotive industry and the new product development process disciplines it is involved in. For this reason, the investment decision of new R & D center to be made with the supply developer of the new technology integrated with the application of the digital autonomous function that new product development process disciplines plan to achieve is of great importance. Therefore, the adaptation of new technology or the cooperation structure with the new technology supply channel creates new values that directly affect application performance. Because the automotive industry updates its new product development processes in line with its own targets for its sustainable competitive structure in the face of constantly changing market conditions. These developments not only create the need for different new product development process disciplines in different automotive industry company structures, but also create different performance values from autonomous vehicle technologies on new vehicle products to design or supply alternatives.

The AHP mathematical model in the research has transformed the hierarchical formulation of the problem of importance order or importance selection and measuring how much intensity the expertise studies responsible for the adaptation of new autonomous vehicle technologies create in which new product development discipline. The AHP mathematical model is a multi-criteria decision-making method. AHP provides the decision maker with the opportunity to consider both qualitative and quantitative criteria together in the decision-making process. The decision-making process in the AHP method is based on the evaluations of experts or people who have knowledge about the subject. After all the elements in the hierarchical structure of the model established with the help of the AHP method were compared in pairs, the priorities of each element were determined. By measuring the consistency of the evaluations made by the decision maker in AHP, the subjectivity in reaching the solution is reduced. As the decision support system that supports the model, EC software was chosen because of its ease of implementation and high reliability.

In the study, in order to evaluate the integration of the stage disciplines in the lean product development departments of the automotive manufacturing industry companies and the newly introduced autonomous vehicle technologies on the vehicle, the clusters of the expertise in the process were revealed through the AHP mathematical model comparisons. A sequence system was created by measuring the efficiency of the lean product development phase discipline, which realized the most intensive new technology adaptation. The new disciplines created by autonomous vehicle technologies, newly introduced in automotive industry companies, and the specializations that interdisciplinary studies will focus on are determined in order of importance. After determining the purpose of the study, in the second degree; there are six main criteria's as: A (Electrical & Electronic systems), B (Powertrain systems), C (Ergonomics & Package), D (Interface & IP control), E (Upper Body & Prototype), F (Test & Homoglation systems). At the last level, three alternative structures, namely GC1 global automotive manufacturing industry company, GC2 global automotive manufacturing industry and LC1 local automotive manufacturing industry company, were evaluated comparatively. Among the three-analysis automotive manufacturing industry companies, the weighted scores of the automotive industry companies obtained by the AHP method were calculated. According to this; GC1 global automotive industry firm had the highest performance with 0.524, GC2 global automotive industry firm was calculated with a secondary value of 0.330 and

LC1 local automotive industry firm was placed in the lowest ranking with 0.146 points.

As a result, a competitive business operating in any industry, in order to sustain his life due to the conditions he is in, be able to articulate innovations in every sense with high performance, be able to control the creation or preservation of value in processes, should have a new product development flow structure that can turn disadvantages into opportunities as well as advantages, should increase work efficiency. It is not an easy process to establish this efficient and flexible new product development structure and ensure its high performance. Therefore, in the light of science, important decisions to be taken within the scope of the targeted new process structure, with the efficiency support of modern techniques and methods, which occurs under variable conditions, ensure the company under competitions' always one step ahead.

Acknowledgements

Author (F. A. Paker) served before: Iveco Otoyol (Fiat Group), BMC, Ford Otosan, Denso-Alj (Toyota Group), Chevrolet (GM Group), etc., automotive companies as a design and project manager for 25 years. These and other automotive company's employees, thank you for their support to the study.

Conflicts of Interest

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

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