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Modeling of Barriers to the Adoption of Autonomous Vehicles: DEMATEL Method †

Karan Ashok Jalwani * and Shambo Roy Choudhury

Department of Mechatronics Engineering, Manipal University Jaipur, Jaipur 303007, Rajasthan, India; shamboroy.choudhury@jaipur.manipal.edu
* Correspondence: karan.ashok.jalwani@gmail.com

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Abstract: Autonomous vehicles (AVs) have the potential to increase safety while reducing energy use, pollution, and traffic congestion, to name a few positive effects. Industries, however, are having trouble implementing AVs. The goal of this study was to pinpoint and analyze the obstacles preventing the widespread use of AVs. To do this, a comprehensive review of the literature was conducted to identify the barriers, which were later confirmed by a panel of experts. There were five issues that needed to be addressed: a lack of infrastructure, funding limitations for manufacturing, low customer acceptance, security breach concerns, and potential employment effects. After these barriers were decided upon, the Decision-Making Trial and Evaluation Laboratory method was chosen to model them. The DEMATEL approach makes use of the expertise of groups and experts while relying on matrix tools and graph theory. It develops a visual framework that emphasizes the causal connections between various factors. A DEMATEL digraph is also presented which helps to identify which barrier is the most crucial barrier. Priority ranking was applied to the identified barriers and categorization of barriers was also performed in this study. Two categories were formed, namely, cause and effect barrier categories. Based on the results of DEMMATEL, the lack of funds for manufacturing AVs and the lack of infrastructure are the most crucial barriers to AV adoption. Industries should focus on the cause group barriers first as they run the system. By eliminating cause group barriers, the impact of effect barriers can be reduced. Implications and future directions were provided in the current study.

Keywords: autonomous vehicles; barriers; challenges; DEMATEL; smart vehicles

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1. Introduction

Manufacturers, consumers, and policymakers have expressed interest in autonomous vehicles (AVs), demonstrating a growing understanding of their potential impact [1]. Because they can function without human drivers, AVs have the potential to fundamentally alter how we travel [2]. AVs can improve accessibility, safety, and efficiency, utilizing cutting-edge technologies like artificial intelligence and sensor systems [3,4]. AVs have the potential to transform transport systems and usher in a future where mobility is safer, more effective, and more inclusive as their development and deployment move forward. Over the following few decades, it is anticipated that AV adoption will increase significantly in the United States [5,6]. Around 30% of the fleet of vehicles is anticipated to have Level 4 automation by 2040, which denotes a high level of autonomy. By 2050, this proportion is anticipated to reach 50%. Within the next ten years, the logistics industry is specially prepared to fully automate [1]. An incremental approach to driverless platooning on interstate highways by 2022 will be followed by Level 3 autonomy for autonomous trucks by 2020. Level 4 autonomy is anticipated to be attained by 2025, and Level 5 autonomy, which denotes complete automation without human intervention [3], is anticipated to be attained by 2027. These predictions demonstrate the swift development and revolutionary potential of AVs in the transportation sector [3].

AVs have a wide range of potential advantages, including the ability to improve urban lifestyles and solve a number of transportation-related problems [7]. AVs have the potential to enhance city life by reducing accidents, reducing traffic, and elevating the value of travel time [8]. Additionally, AVs are anticipated to contribute to reducing greenhouse gas emissions, especially when used in conjunction with effective road pricing strategies [1]. This is due to the fact that the transport industry has a large impact on global warming. Waymo, Daimler-Bosch, Ford, Volkswagen, General Motors, Toyota, Audi, and Mercedes-Benz are among the well-known automakers actively pursuing the development and production of AVs to make them an affordable and environmentally friendly mode of transportation on our roads.

Despite the excitement surrounding the potential advantages of AVs, practitioners, and researchers are still unsure of these technologies' long-term effects [9,10]. Due to the coexistence of autonomous and conventional vehicles during the transitional phase, various traffic networks and management strategies, such as dedicated lanes and congestion pricing, must be developed. Like the adoption of any new technology or innovation, the widespread use of AVs faces both physical and psychological barriers, such as public perception and acceptance [11]. To hasten the future adoption of AVs, it is essential to recognize and remove these obstacles.

The purpose of the current study is to identify obstacles to the adoption of AVs and establish a cause-and-effect relationship between those obstacles.

In Section 2, a review of the relevant literature is provided. In Section 3, the methodology for this study is thoroughly explained. Section 4 presents and discusses the findings. Section 5 covers the research's conclusion in its final section.

2. Literature Review

By searching the Scopus database for relevant research papers using the search terms "autonomous AND vehicle AND adoption OR implementation AND barrier AND challenge", the literature review is carried out. There were 27 research articles in total. Only the terms "Year- 2017 to 2023", "Documents Type- Articles, Conference Paper, and Review", and "Language- English" were included in the selection criteria for research articles. The study excluded a total of 14 articles because the study's proposed objectives were not addressed in their titles or abstracts. By reading the full text, a total of four articles were further eliminated. These four articles were not pertinent to the investigation at hand. The study was only found to be relevant to nine articles. By snowballing, 10 articles were added. Consequently, 29 articles are included in the proposed study.

Few studies show that AVs will gather a lot of personal information about users, including information about their travel habits and preferences. The vulnerability of AVs to data breaches, which could cause the leakage of such sensitive information, is a potential concern. The broad adoption of AVs will depend on protecting the security and privacy of this data [11]. When compared to conventional driver-operated vehicles, AVs might be more expensive, which might restrict users to the wealthy population. As a result, AVs may initially target a market of more affluent consumers who own personal vehicles [12]. Potential users of AVs must be on board with them and have faith in them, as their resistance to seeing them as a practical substitute for manned vehicles may slow down the rapid adoption of this technology [13]. AVs have the potential to significantly affect employment, which could act as a roadblock to AVs gaining widespread acceptance and subsequently expanding. To overcome this barrier and ensure a more seamless transition to AV technology, it will be essential to address the worry about job loss and the need for retraining or reemployment opportunities. For AVs to gain acceptance and progress, it will be essential to make efforts to lessen the effects on employment and support impacted workers [1]. Significant infrastructure investments, particularly for the implementation of dedicated lanes that cater to AVs, are necessary for the viability of AVs on the road, necessitating additional financial resources. Smart technologies are also necessary for enabling efficient vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, which are crucial for the efficient operation of AVs within the transportation network [2]. The high cost of AV manufacturing is a significant impediment to their mass market adoption. The sophisticated systems and cutting-edge technologies built into AVs contribute to their high production costs. To get around this obstacle and hasten the adoption of AVs on a large scale, economies of scale, improvements in production methods, and increased manufacturer competition are essential. In order to spur innovation and find affordable solutions in AV manufacturing and ultimately make them more accessible [4] to a wider consumer base, research and development investments are also essential [3]. The inherent uncertainty surrounding the use of AVs in novel contexts is a contributing factor in the paucity of research on AVs. To adequately prepare for the arrival of AVs, it is important to identify the critical research gaps. A thorough analysis of market penetration is a crucial step in understanding the potential impact and adoption trends of AVs [5]. The lack of technical expertise is a major problem [6] because managing and using complex technology requires trained personnel with specialized skills. To ensure a skilled workforce capable of handling AV technologies, closing this skills gap through education, training programs, and professional development opportunities is crucial. Investing in skill development programs can enable people to successfully navigate the complexities of AVs and contribute to their integration into a variety of industries [7] The acceptance of AVs at various levels of autonomy is hampered by the lack of a uniform certification framework and standardized safety norms. Manufacturers and suppliers of AV face challenges as a result of this regulatory uncertainty, which may slow the rate of technological advancement in the sector. To create an environment that is favorable for the development and use of AVs, it is essential to establish clear and standardized regulations, certification procedures, and safety standards [9].

A literature review and the knowledge of the expert team are used to identify a set of five barriers. The following obstacles have been noted:

Lack of Infrastructure (B1): The absence of sufficient infrastructure was the first problem identified. To navigate challenging traffic situations that limit customer acceptance, AVs need advanced technology. To address misconceptions and boost confidence in AV technology, public education and awareness campaigns are necessary to address these challenges [4]

Lack of funds for manufacturing (B2): Costs associated with research, development, production, and testing all contribute significantly to the development and manufacturing of autonomous vehicles. The advancement and scalability of AV technology may be hampered by these financial restrictions because it may be challenging for manufacturers to obtain the funding required for mass production [5].

Lack of customer acceptance (B3): The acceptance of autonomous vehicles depends critically on how the public feels about and trusts them. Customer acceptance is hampered by worries about safety, dependability, and the ability of AVs to negotiate tricky traffic situations. To address misconceptions and boost confidence in AV technology, public education, and awareness campaigns are necessary to address these challenges [6].

Risk of security breaches (B4): Due to their reliance on intricate computer systems and connectivity, AVs are susceptible to cyber security threats. Passengers' safety and privacy are at risk from hacking, unauthorized access, and system errors. To address these issues and increase confidence in the dependability and security of AVs, it is crucial to ensure strong cyber security measures [4].

The potential impact of job loss (B5): The use of autonomous vehicles may change established job roles in the transportation sector. Drivers of cars and trucks, for example, may experience significant job displacement. Proactive measures, such as re-training programs and initiatives to help workers transition into new industries and job opportunities, are needed to address the potential employment effect [2].

The DEMATEL approach makes use of the expertise of groups and experts while relying on matrix tools and graph theory. It develops a visual framework that emphasizes the causal connections between various factors. A causal diagram is created by determining the centre degree and cause degree of each factor. This makes it possible to group factors into cause- or result-related groups. In the end, the approach pinpoints important elements that are necessary for efficient problem solving.

This strategy's practical application entails creating a direct correlation matrix based on the opinions of specialists among the various factors. This matrix is essential to the analysis and decision-making process because it sheds light on how the various factors relate to one another. DEAMTEL is capable of calculating priority ranking and making inter-connections in terms of the cause-effect group.

3. Methodology

A literature review is the first stage of the methodology for this study to identify the barriers to the adoption of AV. This study's methodology is depicted in Figure 1. To validate and model these discovered barriers, a professional team of five senior executives with experience in AV adoption from various organizations was assembled. We sought the team members' opinions on the barriers that had been identified, their connections, and how to rate them in relation to one another. The team members have between five and ten years of relevant experience (Table 1).

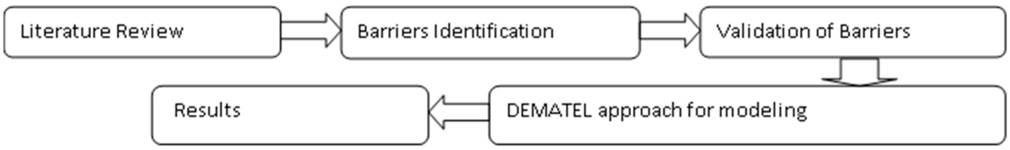

Figure 1. Methodology.

Table 1. Details of expert team.

S. No.	Type	Experience
1	Professor	5 Years
2	Professor	7 Years
3	Professor	9 Years
4	Practitioner	10 Years
5	Practitioner	7 Years

In this research project, DEMATEL has been used as a solution methodology. For policymakers to develop enduring decision-making strategies for achieving the desired outcome, it has been demonstrated that DEMATEL is an effective methodology for addressing the issue [14]. This approach is used to identify the cause-and-effect relationship among the obstacles. The DEMATEL methodology is used for the following reasons:

Some barriers are difficult to quantify due to their arbitrary nature; all decision-making barriers are dependent upon one another.

The integrated methodology provides a way to analyze and quantify the barriers.

When making regulatory decisions regarding the adoption of AV, decision makers may find it advantageous to use DEMATEL methodologies to manage and plan for all possible outcomes in terms of operational and strategic flexibility [15].

The DEMATEL mathematical method can be used to analyze the causal interdependence and association among the dimensions in order to successfully solve a complex management problem. A graphic representation based on graph theory is the process output. The Science and Human Affairs division of the Battelle Memorial Institute in Geneva developed this technique between 1972 and 1976. The DEMATEL methodology recognizes the interaction between the barriers by grouping them into cause-and-effect groups and aids in the identification of workable solutions in a hierarchically structured manner. It can be used to investigate the interdependence [16] seen in causal diagram [17] between a system's barriers, in contrast to AHP, using the constructive modeling method DEMATEL [18]. The causal diagram built using digraphs demonstrates the canonical understanding of the relationships between contexts and the influence of barriers. The detailed steps of this methodology are broken down into the following steps:

Step 1: Create the matrix of direct relationships.

An $n*n$ matrix is first generated to determine the model of the relationships between the n criteria. The element in each row of this matrix has an impact on the element in each column.

If more than one expert is consulted, the matrix must be filled out by each expert. The mathematical averages of each expert's opinions are used to create a direct relation matrix, or X.

$$X = \begin{bmatrix} 0 & \cdots & x_{n1} \\ \vdots & \ddots & \vdots \\ x_{1n} & \cdots & 0 \end{bmatrix} \quad (1)$$

Step 2: The normalized direct relation matrix must be calculated in the following step. To achieve normalization, this entails adding up each row and each column in the matrix. The value "k" can be used to represent the highest sum determined from the row and column sums. Each component of the direct relation matrix must be divided by "k" to make it normal.

$$k = max\left\{ max \sum_{j=1}^{n} x_{ij}, \sum_{i=1}^{n} x_{ij} \right\}$$
$$N = 1/k * X \quad (2)$$

Step 3: Calculate the total relation matrix in step three.

The fuzzy total relation matrix can be computed as follows after the normalized matrix has been determined:

$$T = \lim_{k \to +\infty} \left(N^1 + N^2 + \ldots + N^k \right)$$

In other words, the normalized matrix is first subtracted, and the resulting matrix is reversed, after which an n n identity matrix is generated. To obtain the total relation matrix, multiply the normalized matrix by the output matrix.

$$T = N \times (I - N)^{-1} \quad (3)$$

Step 4: Produce the final product and a causal diagram.

Finding the sum of each row and each column in T is the next step (step 3). The following formula can be used to calculate the sum of rows (D) and columns (R):

$$D = \sum_{j=1}^{n} T_{ij} \quad (4)$$

$$R = \sum_{i=1}^{n} T_{ij} \quad (5)$$

The values of $D + R$ and $D - R$ can then be calculated by D and R, where $D + R$ denotes how significant a factor i is to the system as a whole and $D - R$ denotes the net effects that factor i has on the system.

4. Results and Discussion

In order to begin the survey, we spoke with the experts and asked them to rate the barriers using the prescribed Likert scale based on the relative importance of each barrier. By averaging the expert respondents' responses, the average direct relationship matrix (A) of the primary criteria is created (Table 2). The normalized initial direct relation matrix (N) is then calculated (Table 3) with the aid of Equation (2). The total relation matrix (T) is established (Table 4) in the following stage using Equation (4) as a foundation.

Table 2. Direct relationship matrix.

Barrier	B1	B2	B3	B4	B5	Sum of Row
B1	0	2	1	2	3	8
B2	4	0	1	2	1	8
B3	3	2	0	3	0	8
B4	0	2	3	0	0	5
B5	1	1	1	0	0	3

Table 3. Normalized direct relation matrix.

Barrier	B1	B2	B3	B4	B5
B1	0	0.25	0.125	0.25	0.375
B2	0.5	0	0.125	0.25	0.125
B3	0.375	0.25	0	0.375	0
B4	0	0.25	0.375	0	0
B5	0.125	0.125	0.125	0	0

Table 4. Total relation matrix.

Barrier	B1	B2	B3	B4	B5	D
B1	1.04	1.15	0.94	1.15	0.91	5.19
B2	1.52	1.06	1.03	1.28	0.83	5.74
B3	1.50	1.33	0.99	1.45	0.73	6.00
B4	0.94	1.01	1.00	0.87	0.48	4.31
B5	0.63	0.57	0.50	0.49	0.31	2.49
R	5.64	5.12	4.47	5.24	3.26	

Table 5 illustrates the degree of significance and relationships denoted by (D-R) and (D+R) values, along with their respective ranks. The final column of the table denotes the cause-and-effect relationships. Based on the D+R value, B2 (lack of funds for manufacturing AVs) and B1 (lack of infrastructure) are the most crucial barrier to AV adoption (Figure 2). B5 (potential impact of job loss) has a minimum relationship with other barriers; therefore, it will not have a significant impact. Based on the positive (D-R) value, B2 (lack of funds for manufacturing AVs) and B3 (lack of customer acceptance) fall under the cause group and the remaining barriers fall under the effect group (negative D-R value) (Figure 3). Therefore, practitioners should give attention to B2 and B3 with higher priority.

In Figure 4, a DEMATEL digraph is shown. Points above the base line are cause category barriers, whereas points below the base line are effect category barriers. This digraph helps practitioners to identify most crucial factors instantly.

Table 5. Degree of prominence and relationships.

Barrier	D	R	D − R	D + R	Ranking	Group
B1	5	6	−0.4	10.8	2	Effect
B2	6	5	0.62	10.9	1	Cause
B3	6	4	1.53	10.5	3	Cause
B4	4	5	−0.9	9.55	4	Effect
B5	2	3	−0.8	5.75	5	Effect

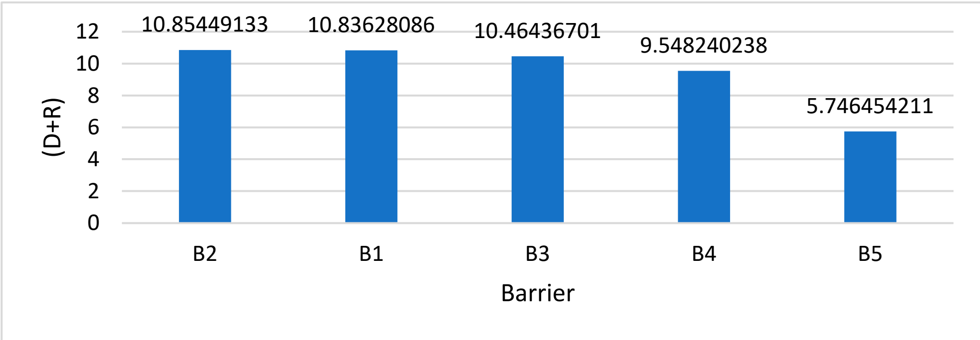

Figure 2. Impacts of each barrier on whole system.

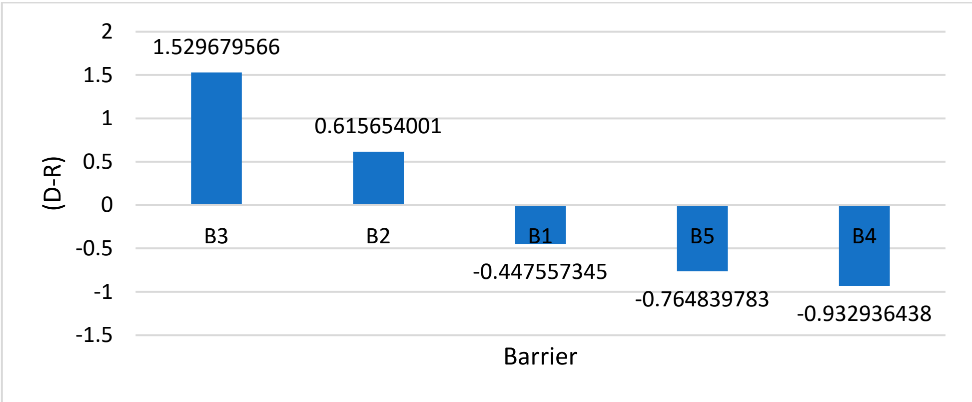

Figure 3. Cause-effect Relationship.

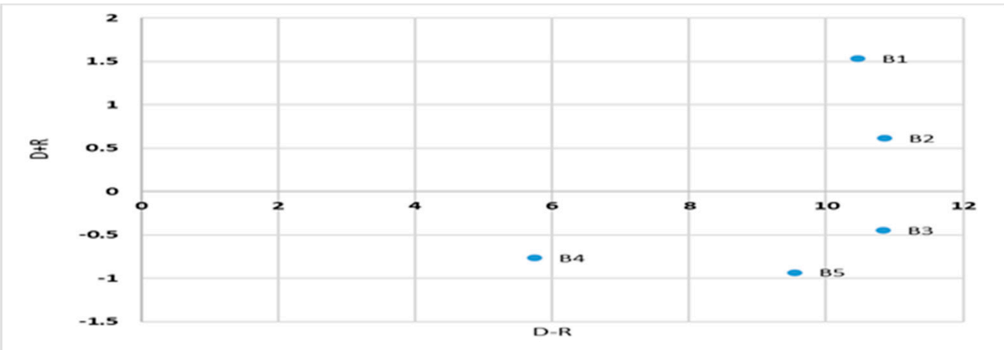

Figure 4. DEMATEL DIGRAPH.

5. Conclusions

In light of the growing interest in this technology, this study aims to comprehensively understand and prioritize the significant barriers preventing the widespread adoption of autonomous vehicles (AVs). The DEMATEL (Decision Making Trial and Evaluation Laboratory) method, which enables the examination of the interconnected relationships between these barriers as a network of interdependent components, is used in the study to accomplish this.

By using this strategy, this study hopes to produce insightful findings that can aid in the development of sensible laws and regulations as well as well-informed decision making. The ultimate objective is to get rid of these barriers and hasten AV commercialization for the good of society. The results of this study point out two significant obstacles to the use of AVs: the inability to pay for manufacturing expenses and the lack of consumer acceptance. Progress in this area may be hampered by a lack of funding for AV manufacturing, as producing and developing cutting-edge autonomous technologies requires sizable investments. This obstacle may prevent production from being scaled up, which would limit consumer access to and affordability of AVs. This study also acknowledges the significance of consumer acceptance in propelling the broad adoption of AVs. It becomes difficult to build trust and generate demand if consumers are hesitant or skeptical about the safety, dependability, or usability of autonomous vehicles. This lack of acceptance may seriously impede the market entry of AVs and postpone the widespread adoption of these technologies. One efficient solution to the problem of high manufacturing costs is to make investments in R&D. In conclusion, this study highlights the critical importance of financial resources and consumer acceptance and highlights the main barriers preventing the widespread adoption of AVs. The problem of high manufacturing costs can be solved by making a research and development investment. Such investments may result in technological developments and innovations that ultimately drive down manufacturing and component costs, lowering the price of AVs and increasing consumer access to them.

6. Implications and Future Direction

In order to encourage the use of AVs, governments and industry stakeholders can work together to offer financial incentives and subsidies to manufacturers and consumers. This may help to reduce the initially high manufacturing costs and increase consumer access to AVs. Collaboration between a number of stakeholders is required to build consumer trust. This could entail government agencies getting involved in imposing national standards for AV testing and production. In the meantime, cost-cutting initiatives can be focused on by technology manufacturers and innovators to address issues of social inequity. This study could be helpful for industries that are trying to adopt AVs as it provides a better understanding of barriers and relationships among barriers.

Further research could be carried out on dimensions-based barriers such as economic, technological, and consumer awareness. The DEMATEL method has its own limitations, so other MCDM tools can be used such as ISM, AHP, ANP, or hybrid methods.

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Conflicts of Interest: By using the DEMATAL method, we appropriately calculate the barriers and their effect on autonomous vehicles. These data are helpful for building an environment for autonomous vehicles and their challenges.

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