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Investigating car purchasing decision-making process using Multi-Objective Optimization Ratio Analysis based Analytical Hierarchy Process Model: An empirical case from Vietnam

PHI-HUNG NGUYEN[1,*]
[1]Ph.D. Researcher, Faculty of Business, FPT University, Hanoi, Vietnam.
Postal Address: Hoa Lac High-Tech Park, Km 29, Thang Long Boulevard, Hanoi, 100000, Vietnam.
[*] Corresponding Author: Email: hungnp30@fe.edu.vn

Abstract
This study aims to define and quantify the factors affecting selecting the best car among the market's available alternatives. Many criteria are involved while deciding to purchase the best car from various car models; therefore, car purchasing behaviour is a multi-criteria decision-making problem (MCDM). Proposed criteria are based on the customers' survey when they are willing to purchase the cars, including Price, Branding, Safety, Performance, Exterior, Fuel efficiency, Maintainance cost, After-Sale Service, and Resale. In this study, the AHP technique calculates each criterion's weight, and then Multi-Objective Optimization Ratio Analysis (MOORA) is employed to rank the car models in a numerical example from Vietnam. The results show that this proposed model can minimize the consumer effort to select a car and make accurate decisions. Furthermore, this study's findings could provide car manufacturers with valuable insight into the criteria that reflect the customer's assessment of the car selection process.
JEL: C02, C61, D53, Q14
Keywords: Car purchasing, MCDM, AHP, MOORA, Vietnam

INTRODUCTION

The growth of the Vietnamese income, coupled with their increasing purchasing power, and the strong growth of the economy over the past few years have attracted significant auto manufacturers to the Vietnamese market and drives the market demand for purchasing private cars. The car market is gearing up for all kinds of vehicle models. According to the latest statistical number derived from the website of Vietnam Register **(Vr.org.vn)** and Vietnam Automobile Manufacturers' Association (VAMA), annual sales of approximately 32,000 cars/month hit cumulative sales of over 384.000 vehicles in 2019, setting a new record. It thereby reached approximately 290.000 cars in 2018 and the number showing 304.000 cars for the Vietnamese auto industry in 2016. Recently, the website Seasia has released data on car

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ownership rates per 1.000 people of Southeast Asian countries. Accordingly, Brunei tops the list with 721 vehicles, followed by Malaysia with 443 and Thailand 225; Vietnam is near the bottom of the table with only 23 vehicles per 1000 people. However, the rate of automobile ownership per 1.000 citizens in Vietnam has been increasing over the years. For that reason, they are designing a family and the most efficient car in terms of cost, fuel efficiency, and performance has become a fundamental duty for any car manufacturers aiming to the Vietnamese market.

Every year, various models with the latest technology and excellent features are introduced in the market; thus, consumers have to face difficulties in selecting the best car among the available alternative from the market according to their needs. It has become challenging to design and produce a car that can match customers' demands with time changes in a competitive business environment. The process of designing the new vehicle should follow the needs and demands of customers and the market. Finding and implementing the customer's needs and demand into vehicle design has become the first step of car development. Meeting all expectations and requirements of the customer also has a critical role in car development. Due to high competition among mid-segment cars in the market, the manufacturers focus on delivering additional features other than price and fuel economy.

There are many automotive brand names in Vietnam, from the middle class to the luxury class, such as Toyota, Honda, Nissan, BWM, Mercedes-Benz, Range Rover, etc. With changing consumer needs, automobile makers have also developed their designs by implementing modern innovations such as hybrid and electric vehicles. Thus, it is relatively challenging to pick a particular vehicle with a vast range of options, so it is a dynamic decision-making method. Variety of vehicle choices that come with all sorts of ranges for people with all backgrounds. It may seem like a simple task to only pick a car based on its cost and space, but due to developments in technology and a rise in the number of suppliers, it has become a costly task. Before anyone buys a vehicle, they take guidance from peers and professionals or re-examine the reviews of consumers of a car who can easily be found on reputable websites. In these cases, MCDM procedures that have proven successful in complicated decision-making situations are taken into account (Nguyen et al., 2020c; Nguyen, 2021; Nguyen et al., 2020d).

After the introduction section, this study is organized as follows: Section 2 briefly literature analysis of influencing factors and MCDM method for the car selection from previous researches. In section 3, proposed MCDM approaches of AHP, MOORA with mathematical formulations are summarized. Next, an application of the suggested MCDM model in a numerical example is presented. The final section concluding our results, discussion, and direction for future studies are clarified.

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LITERATURE REVIEW

MCDM techniques are popular ways to organize knowledge and decision-making across various topics of multiple and overlapping priorities. Since decision-making involves multiple considerations and sometimes multi-dimensional information in challenging real-world contexts, this research area is still attractive and has been commonly utilized in many fields (Hatami-Marbini & Kangi, 2017).

MCDM techniques are typically categorized into multi-objective decision-making (MODM) and multi-attribute decision-making (MADM) techniques. MODM has usually been analyzed using mathematical programming methods with well-formulated theoretical constructs where we have either an infinitive or a broad number of alternative options, the better of which should be satisfied by the decision-maker (DM) constraints and priority priorities. Previously, numerous MCDM methods have been used to overcome decision-making issues. The most common are AHP, Fuzzy AHP, simple additive weighting (SAW), elimination and choice expressing reality (ELECTRE), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS); (Biswas & Saha, 2019; Chand & Avikal, 2016; Ertuğrul & Karakaşoğlu, 2009; Karim & Karmaker, 2016; Nguyen et al., 2020a; Nguyen et al., 2020b; Rezaie et al., 2014; Salardini, 2013; Shaverdi et al., 2014; Zapolskytė et al., 2020). Although many researchers use MCDM methods in other fields, few researchers use MCDM methods in car purchasing behaviors.

Regarding the research of (Tang & Beynon, 2005), they approached the Fuzzy AHP system to support the car rental firm in choosing the type of fleet car. The earlier study of Byun (2001) applied the AHP model for the car selection problem; this paper failed to recognize the pollution criteria for the assessment process. Tzeng et al. (2005) used AHP and other outranking approaches to find the most appropriate bus in Taiwan. Consequently, the results showed that the hybrid electric bus was the most viable replacement bus for Taiwan's metropolitan areas in the short and medium term. Nevertheless, if the electric bus's cruise distance was increased to an appropriate range, the pure electric bus might be the better option. Later, Lim et al. (2007) employed PROMETHEE to study the impact of massive duty diesel buses, fuel properties, and engine working conditions. Their research indicated that the driving conditions of the vehicle highly determined the pollution of the elements. Simultaneously, the PCA loadings showed that the elements' emission factors were associated with other contaminants, such as particle number, total suspended particles, CO, CO_2, and NO_x. Partially the least square study showed that the elements' emission factors were heavily dependent on fuel parameters such as the sulfur content of the fuel, the fuel density, the distillation point, and the cetane index. Powerful associations have also been found between these emissions and the engine power or exhaust temperature.

In another study in the same field by (Chand & Avikal, 2016), the AHP model was used in this paper to pick moderate-cost cars based on different car parameters such as car cost, efficiency, fuel consumption, etc. The most critical consideration for selecting a car was established at the initial level, and these criteria are measured based on people's preferences. Recently, the study of (Ali et al., 2020) established a modern hybrid model of Full Consistency Fuzzy TOPSIS. To

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achieve the goal, seven different alternatives were evaluated concerning the chosen assessment criteria following the secondary data review obtained from Pak wheels based on design, fuel efficiency, price, comfort, and output.

Based on the above discussion, the other previous MCDM techniques have inaccuracies in their performance, either alone or in a hybrid combination with other techniques. This study aims to fill the research gap of the proposed method with a less computing process and a more accurate output. This study proposes integrating AHP and MOORA to obtain the best car among the numerous Vietnamese car market options. The AHP method is used to identify the weight coefficients of the criteria. After that, the evaluation and selection of car alternatives are carried out using the MOORA approach.

METHODOLOGY

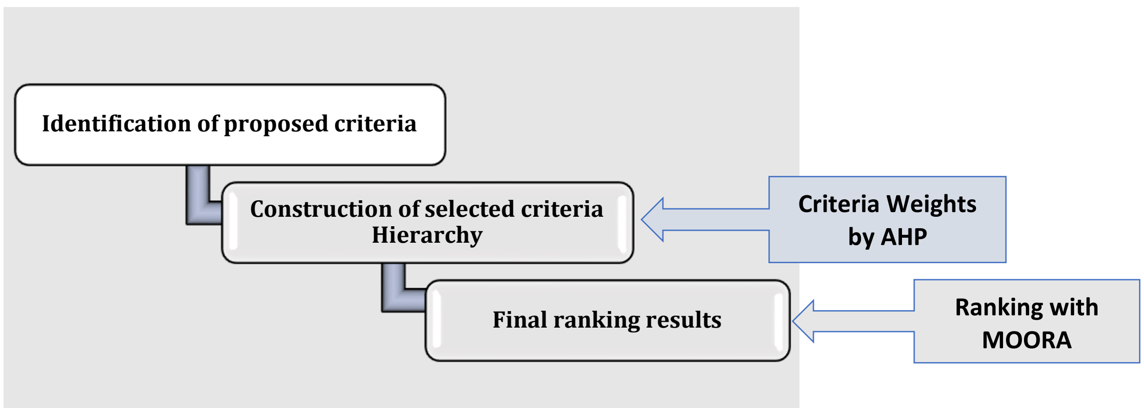

Fig.1. The Evaluation Procedure.

Multi-criteria decision making (MCDM) is the process of finding the best alternatives from all of the feasible alternatives where all the alternatives can be evaluated according to a number of criteria or attributes. This study proposed a hybrid method of AHP and MOORA. AHP method is employed to identify the weights of critical car purchasing criteria extracted based on the customers' survey results. The MOORA technique is used to evaluate and rank car alternatives. The evaluation procedure in this paper consists of three main steps, as follows in **Figure 1**.

Analytical Hierarchy Process (AHP)

AHP was suggested by (Saaty, 2000; White, 1987) to analyze various MCDM problems. This method is applied to determine the weights of hierarchical level criteria. Saaty suggested a widely known 5-point scale (1-3-5-7-9) be used for evaluation. The procedure was adopted from Saaty's method and modified to suit the context of this study.

Step 1: Creating the Hierarchical Structure: The study's goal and criteria suitable for the criteria are determined, and the alternatives.

Step 2: Constructing the pairwise comparison Matrices and Superiority. The importance scales proposed by (White, 1987) are used to prepare the matrix.

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$$A=\begin{bmatrix} 1 & a_{21} & \cdots & a_{n1} \\ \frac{1}{a_{21}} & 1 & \cdots & a_{n2} \\ \frac{1}{a_{31}} & \frac{1}{a_{32}} & \cdots & a_{n3} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{n1}} & \frac{1}{a_{n2}} & \cdots & 1 \end{bmatrix}_{nxn} \tag{1}$$

Step 3: Determining of normalized decision matrix and constructing the weights of alternatives.

$$c_{ij}=\frac{a_{ij}}{\sum_{J=1}^{n} a_{ij}} \tag{2}$$

$$i=1,2,3,\ldots.n,\quad j=1,2,3,\ldots n$$

$$w_i=\sum_{J=1}^{n}\frac{C_{ij}}{n}\quad i=1,2,3,\ldots.,n \tag{3}$$

$$W=\begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ w_n \end{bmatrix}$$

Step 4: Calculation of Matrix Consistency: The Consistency Ratio (CR) formula introduced by Saaty is used to measure consistency, and it is expected to be smaller than 0.10. RI values can be calculated for up to 15-dimensional matrixes.

$$Consistency\ \ Ratio=\frac{Consistency\,Index\,(CI)}{Random\,Index\ (RI)} \tag{4}$$

Calculation of CI is given in Equation (5)

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{5}$$

If CR> 0.10, it is accepted that the comparison matrix is inconsistent. In this situation, the comparison matrix is revisited, and the necessary arrangements are made for its consistency.

Multi-Objective Optimization Ratio Analysis (MOORA)

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The MOORA method, introduced to the academic world by Brauers and Zavadskas (2006), is such a multi-objective optimization technique that can be successfully applied to solve various types of the complex decision-making problems under certain constraints.

Step 1: Starting with a decision matrix

Step 2: Developing a ratio system for all the alternatives concerning that attribute. The equation is used for matrix normalization is shown as follows with Eq. (6)

$$x_{ij}^{*} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \quad (6)$$

i = 1,2, … ,m and j =1,2,… ,n

Step 3: Normalized goal values in the table are determined as maximum or minimum and aggregated among themselves. The collected minimum goal values are subtracted from the collected maximum goal values with their corresponding weights by Eq. (7).

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^{*} - \sum_{j=g+1}^{n} w_j x_{ij}^{*} \; (j = 1, 2, ..., n) \quad (7)$$

The y_i value can be positive or negative depending on the totals of its maxima (beneficial attributes) and minima (non-beneficial attributes) in the decision matrix. The best alternative has the highest y_i value, while the worst alternative has the lowest y_i value.

EMPIRICAL CASE

Data

The criteria must be most usual and crucial in choosing the right vehicle. Choosing the possible criteria for choosing the right automobile that meets the purchaser's needs requires a decision-making mechanism that comprises professionals within the company involved. Criteria were considered and implemented in this work from the literature survey and current customers. Based on the survey and the experts' opinion, nine key parameters were finalized to select the best model vehicle.

A numerical example contains five-car alternatives in the same market segment, namely, Kia Rondo (A1), Mitsubishi Xpander (A2), Suzuki Ertiga (A3), Ford Ecosport (A4), Toyota Avanza (A5), which are popular models in the Vietnamese car market at the research time. Nine criteria are considered by customers when they are willing to purchase the cars, namely, Price (C1); Branding (C2); Safety (C3); Performance (4); Exterior (C5); Fuel efficiency (C6); Maintainance cost (C7); After-Sales Service (C8) and Resale (C9**) (Table 1).**

Table 1: Proposed Criteria

Code	**Criterion**
C1	Price
C2	Branding

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C3	Safety
C4	Performance
C5	Exterior
C6	Fuel efficiency
C7	Maintainance cost
C8	After-Sales Service
C9	Resale

The proposed criteria are explained below:

- **Price (C1):** Before purchasing a car model, buyers often review the budget. Consumers should be happy with the budget when choosing a vehicle. It is evaluated as a price.
- **Branding (C2):** Is defined as the name of car manufacturers.
- **Safety (C3):** Is the state of safety. A single consumer seeks this criterion during the purchasing of a vehicle. It is considered as seatbelt, body, warning, effects, Anti-lock braking system, and airbags.
- **Performance (C4):** Is defined as how well the vehicle work including Speed, braking, torque, noise, comfort, and cornering.
- **Exterior (C5):** The customer is pleased only by looking at the commodity they are purchasing. They should be appealing and meet their desires. It deals with the model, paint, design
- **Fuel efficiency (C6):** Is expressed as kilometre per litre (KMPL). It represents the number of kilometres the vehicle can go using a quantity of fue
- **Maintainance cost (C7):** Refers to any cost incurred by an individual or business to keep their assets in good working condition. These costs may be spent for the general maintenance of items like running anti-virus software on computer systems or being used for repairs such as fixing a car.
- **After-Sales Service (C8):** Is the service quality of the supplier after-sales
- **Resale (C9):** Is the probability of selling in the second-hand market.

Results of Criteria Weighting by AHP

As stated in the AHP method, the key point of this technique is how to achieve a consistency ratio (CR) of less than 10%, which provides a measure of the probability that the pairwise comparison matrix was filled in at random. Because repeating the survey is difficult and expensive. Consistent responses from respondents and experts can sometimes not be obtained, as they may refuse to respond to a question that seems to be burdensome. With respect to a specific criterion, some pairwise comparison matrixes can only be included, even with a CR > 0.1. This study proposes AHP computation with a value of CR ≤ 0.2, which is generally considered to be tolerable to fulfill the CR of Saaty. The 0.2 number means a 20% chance that the decision-maker will answer the questions at random. All data from the survey were tabulated in a worksheet using Microsoft Excel **(Table 2).**

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Table 2: Pairwise comparisons

Item	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
C1	1.00	3.00	3.00	5.00	7.00	3.00	3.00	3.00	7.00
C2	0.33	1.00	0.33	0.20	0.33	0.20	0.33	0.20	0.33
C3	0.33	3.00	1.00	1.00	3.00	3.00	7.00	3.00	3.00
C4	0.20	5.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00
C5	0.14	3.00	0.33	0.33	1.00	0.20	0.20	0.14	0.33
C6	0.33	5.00	0.33	0.33	5.00	1.00	3.00	5.00	3.00
C7	0.33	3.00	0.14	0.33	3.00	0.33	1.00	3.00	3.00
C8	0.33	5.00	0.33	3.00	3.00	0.20	0.33	1.00	3.00
C9	0.14	3.00	0.33	0.33	3.00	0.33	0.33	0.33	1.00

Priority weights and rankings of each factor are presented in **Table 3**. The results showed that Price (C1), Safety (C3), and Performance (C4) are the top 3 of affecting criteria and Branding (C2); Exterior (C5) and Resale (C9) tied as 3 factors at the bottom which are less influenced the car selection. This corroborated the findings of (Sakthivel et al., 2013) and (Byun, 2001), wherein Price (C1) and Safety (C3) are still primary concerns in developing countries like Vietnam when purchasing a car. Furthermore, supporting the results (Ali et al., 2020), Performance (C4) is considered as higher ranking among other factors. Hence, Fuel efficiency (C6) is presented as the chief criterion for customers to buy a car. Other less important factors are concerned as less Maintainance cost (C7); After-Sales Service (C8), and Resale (C9).
However, After-Sales Service (C8) strongly relates to customers' satisfaction and customers' behavioural intentions. As reported in the study of (Tran et al., 2020), after-sales service quality influences satisfaction, which impacts purchasing intentions. After-sales service in the automobile industry plays an important role, whether before buying a product or after buying the product. One of the necessary evaluation criteria for customer satisfaction is the availability of after-sales service. In today's situation, after-sales service quality can be measured by administering a customer satisfaction survey.

Table 3: Weights and Rankings.

CR= 0.18	C1	C2	C3	C4	C5	C6	C7	C8	C9	**Weight**	**Ranking**
C1	0.317	0.097	0.441	0.434	0.247	0.266	0.165	0.161	0.296	0.27	1
C2	0.106	0.032	0.049	0.017	0.012	0.018	0.018	0.011	0.014	0.03	9
C3	0.106	0.097	0.147	0.087	0.106	0.266	0.385	0.161	0.127	0.16	2
C4	0.063	0.161	0.147	0.087	0.106	0.266	0.165	0.161	0.127	0.14	3
C5	0.04	0.09	0.04	0.02	0.03	0.01	0.01	0.00	0.01	0.03	8

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	5	7	9	9	5	8	1	8	4		
C6	0.106	0.161	0.049	0.029	0.176	0.089	0.165	0.268	0.127	0.13	4
C7	0.106	0.097	0.021	0.029	0.106	0.030	0.055	0.161	0.127	0.08	6
C8	0.106	0.161	0.049	0.260	0.106	0.018	0.018	0.054	0.127	0.10	5
C9	0.045	0.097	0.049	0.029	0.106	0.030	0.018	0.018	0.042	0.05	7

Results of MOORA Based on AHP Weights

Table 4: Decision matrix

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Alternatives	*Non-Beneficial*	*Beneficial*	*Beneficial*	*Beneficial*	*Beneficial*	*Non-Beneficial*	*Non-Beneficial*	*Beneficial*	*Beneficial*
A1	590	3	5	5	4	10	4	5	480
A2	615	3	4	4	5	7	4	4	585
A3	595	2	3	3	5	6.8	5	2	590
A4	620	5	5	2	3	6.5	5	5	550
A5	612	4	1	4	4	7	4	5	595

Table 5: Matrix Normalization

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Alternatives	*Non-Beneficial*	*Beneficial*	*Beneficial*	*Beneficial*	*Beneficial*	*Non-Beneficial*	*Non-Beneficial*	*Beneficial*	*Beneficial*
A1	0.0321	0.0476	0.0658	0.0714	0.0440	0.0349	0.0408	0.0526	0.0304
A2	0.0334	0.0476	0.0526	0.0571	0.0549	0.0244	0.0408	0.0421	0.0371
A3	0.0323	0.0317	0.0395	0.0429	0.0549	0.0237	0.0510	0.0211	0.0374
A4	0.0337	0.0794	0.0658	0.0286	0.0330	0.0227	0.0510	0.0526	0.0349
A5	0.0333	0.0635	0.0132	0.0571	0.0440	0.0244	0.0408	0.0526	0.0377
W	0.27	0.03	0.16	0.14	0.03	0.13	0.08	0.1	0.05

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Table 6: Grade Value and Ranking of Alternatives

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**		
Alternatives	*Non-Beneficial*	*Beneficial*	*Beneficial*	*Beneficial*	*Beneficial*	*Non-Beneficial*	*Non-Beneficial*	*Beneficial*	*Beneficial*	*Yi*	*Rank*
A1	0.0087	0.0014	0.0105	0.0100	0.0013	0.0045	0.0033	0.0053	0.0015	0.0136	1
A2	0.0090	0.0014	0.0084	0.0080	0.0016	0.0032	0.0033	0.0042	0.0019	0.0101	2
A3	0.0087	0.0010	0.0063	0.0060	0.0016	0.0031	0.0041	0.0021	0.0019	0.0030	5
A4	0.0091	0.0024	0.0105	0.0040	0.0010	0.0029	0.0041	0.0053	0.0017	0.0088	3
A5	0.0090	0.0019	0.0021	0.0080	0.0013	0.0032	0.0033	0.0053	0.0019	0.0051	4

The results of the proposed methodology are tabulated in **Table 6**. With the highest performance value, Kia Rondo (A1) is selected as the best car using AHP- MOORA methodology. Mitsubishi Xpander (A2) got second, Ford Ecosport got third, Toyota Avanza (A5) got fourth, and finally Suzuki Ertiga (A3) Active got the last position in car ranking.

CONCLUSIONS

The topic of car selection requires individual assessment requirements for evaluating car model alternatives. The AHP integrated MOORA method has been used in this suggested methodology. The AHP is applied to measure the weights of the parameters, and then the MOORA technique is used to evaluate the alternatives' preferences. The numerical example demonstrates the efficiency of the suggested solution. This research study proves to be beneficial in two aspects. Firstly, it can provide a reasonable solution to the individuals looking to buy a vehicle based on the criteria as mentioned earlier. Secondly, the research study has proposed a new hybrid technique with reliable results to help the researchers implement future research studies. This study's limitations are mainly based on time constraints, which resulted in a lower number of responses. Secondly, the lack of accessibility of online resources such as ***oto.vn, otofun.vn***, provided a comparative overview of car users' feedback if present. For this study, the analysis had to rely on just one source. In future work, the fuzzy approach may also be used to improve the results. Other ranking techniques such as Fuzzy theory integrating with GRA, TOPSIS, ELECTRE etc., may also be used to rank the cars under inaccurate assessments.

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