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Improvement of Parameters Affecting the Vehicle's Handling and Ride Comfort Using the Taguchi Experimental Design and TOPSIS Method

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In this paper, the optimization of the suspension system's parameters is performed using a combined Taguchi and TOPSIS method, in order to improve the car handling and ride comfort. The car handling and ride comfort are two contradictory dynamic indices; therefore, to improve both car handling and ride comfort, there is a need for compromising between these two indices. For this purpose, the criteria affecting these two are first identified. The lateral acceleration and the body roll angle were used to evaluate the handling, and the RMS of vertical acceleration of the vehicle body was used to evaluate the ride comfort. The design factors including stiffness of springs and damping coefficient of dampers in the front and rear suspension system were also taken into account. On this basis, the results obtained from the vehicle's motion in the DLC test were evaluated in the CarSim software. Then, the ideal tests were identified using the combined entropy and TOPSIS technique; this method has been proposed for managing the handling and ride comfort criteria. Finally, the optimal level of the suspension system's factors was extracted using Taguchi method. It is evident from the results that, for different speeds, the body roll angle was improved up to 6.5%, and the RMS of the vertical acceleration of the vehicle body was optimized up to 4% to 7%.

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1. Introduction

Ride comfort and handling are two important indices in dynamic performance evaluation of a vehicle (Lu and DePoyster 2002). Although, with an increase in the springs' stiffness of the suspension system the quality of ride comfort will increase, but increasing the sprigs' stiffness, on the other hand, will improve the handling (Kazemi et al. 2000; Mahmoodi-Kaleibar et al. 2013; Ning et al. 2010; Wong 2008). Therefore, these two indices are inversely related, means that by increasing one index, the other reduces (Rongshan et al. 2010). As a result, to achieve an optimal design of the suspension system's parameters, a compromise between the handling and the ride comfort is required (Hegazy and Sandu 2009; Kazemi et al. 2000; Luo et al. 2013). Hence, the attention of vehicle's designers has been attracted to an optimal design of the suspension system in order to improve both above-mentioned dynamic indices. One of the first investigations done by Dahlberg was investigating the effect of ride comfort and handling simultaneously (Dahlberg 1978). (Eskandari et al. 2006), by studying the optimization of the geometric position of the McPherson suspension system's parameters and by taking into account the effective parameters on the lateral dynamic using the experimental design will lead to an improvement in the handling. (Shim and Velusamy 2011), performed a study concerning the improvement of roll stability of a vehicle. They evaluated the dynamic behavior of a vehicle by changing the wheels' angles and the geometry of steering and suspension system, such as Toe, Camber, Caster, and Kingpin angles, of a vehicle model in the Adams car software. This eventually has led to improved vehicle's role stability in a passive suspension system. (Paluskar and Vaidya 2011), investigated the effect of changing the parameters suspension system's geometrical dimensions such as connection arms and their corresponded bush's position on the rolling stiffness.(Babaian et al. 2012), investigated the effect of changing the suspension system's parameters on the Toe, Camber, Caster and transverse distance between two wheels using the McPherson suspension system model; finally, they addressed the Placket-Burman sensing using the design of experiment method and performed the optimization of these parameters using genetic algorithm.(Qian and Shi 2012), successfully improve the Toe and Camber angles by changing the geometric position of a double wishbone suspension system, and stimulation and kinematic analysis in the Adams software. (Baghaeian and Akbari 2017), investigated the stability of the vehicle by controlling the geometric parameters of an active suspension system. They found that the robust adaptive fuzzy control is the most appropriate controller for improving the stability of the vehicle. (Khaknejad et al. 2013), successfully improve the vehicle's low steering by changing the angle and bush' stiffness of the rear suspension system of a class-B vehicle using the Taguchi method on the constant-radius cornering up to 31%. (Meshkatifar and Esfahanian 2014), tested three McPherson suspension systems with different rolling center positions. To perform the test, they used car passing a fixed radius cornering with speeds in the range of 40 to 70 km/h. They finally improve the changes in the Camber, steering angle, and dynamic behavior of the vehicle.(Norouzi et al. 2015), improved the performance of vehicle's suspension system, by using the appropriate Camber and Toe angles, as well as changing the geometrical dimensions of McPherson suspension system.(Sert and Boyraz 2016), investigated the effect of changing the components of the rear suspension system of a minibus on the car overturning using the design of experiment with Taguchi method. They could reduce the car overturning, by optimizing the suspension system parameters such as rolling center and rolling stiffness. (Yerrawar and Arakerimath 2017), investigated the effect of changing the parameters such as springs' stiffness, sprung mass, and magneto-rheological (MR) damper coefficient and the ride comfort by performing and experimental test on a one-fourth model of the semi-activate suspension system.

(Nawathe and Dhande 2016), investigated the effect of changing the parameters such as springs' stiffness, sprung mass, damping factor, and speed on the ride comfort by performing an experimental test on a one-fourth modal of the activate suspension system. Since the handling and ride comfort conflict with each other, therefore, there is a need for a method that can optimize both handling and ride comfort simultaneously. Recently, TOPSIS method has been used in different applications for simultaneous multipurpose optimization. The TOPSIS method was introduced for the first time by (Hwang and Yoon 1981). (Zhang et al. 2019), have addressed the optimizing the parameters affecting an electric vehicle using Taguchi and TOPSIS methods. They improved the dynamic stability of the vehicle by using these two methods. (Mojaver et al. 2020), with the help of triple Taguchi/AHP/TOPSIS method and by designing SOFC, converting the chemical energy to electric energy, concluded that the fluid density has the maximum effect on the electrical power. (Kumar and Mondal 2020) by a combination Taguchi and Topsis of optimization Effective parameters EDM machine. They successfully achieve the maximum material elimination rate and a minimum ratio of electrode wearing to steel surface roughness.

(Chang and Chen 2014), by introducing the Taguchi and TOPSIS methods for achieving the maximum attractiveness of product design, they designed a very attractive passenger car for a special group of consumers in Taiwan. The peoples which their features coincide with this special group were participated in a set of tests which they were able to successfully improve the attractiveness of the car's profile.(Jiang and Wang 2015), improved the handling and ride comfort of the vehicle by simulating a complete car’s model in Adams car software and using the Taguchi and TOPSIS methods.(Jiang and Wang 2016), successfully improved the handling and ride comfort of vehicle by simulating a complete model of a truck in Adams Car software and applying the Taguchi and TOPSIS methods.

In this research, the criteria affecting the handling and ride comfort and the factors affecting these criteria were determined in order to improve both of handling and ride comfort, simultanously. For this purpose, the stiffness coefficient of front and rear springs and the damping coefficient of front and rear dampers of the car’s suspension system were used to measure the handling and ride comfort. In the next step, by using the design of experiment with Taguchi method and with help of L25 orthogonal table, the simulation results of a C-class car were investigated in double lane change (DLC) test using the SimCar software. To measure the handling, the lateral acceleration and body roll angle were used. Also, to measure the ride comfort the root mean square (RMS) of the body vertical acceleration was used. For decision-making and extracting the optimal conditions using the TOPSIS method, the rating between the tests was performed and eventually, the optimal level was obtained using the Taguchi method. The entropy method was used for weighing the options. The results show that the proposed method can optimize the handling and ride comfort simultaneously.

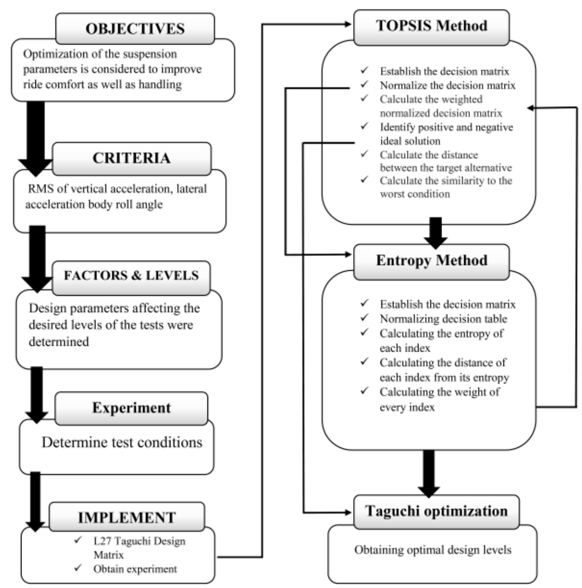

Figure 1: Proposed optimization framework.

2. Proposed method

The overall framework of optimization is shown in Fig. (1). First, reaching the desired handling and ride comfort were defined as the main targets of the optimization. In the second step, the optimization criteria for handling and ride comfort were introduced. In the third step, the design parameters affecting the desired levels of the tests were determined. The test conditions were set in the fourth step. The

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CarSim software and DLC standard test is used for the test. In the fifth step, the corresponding factors and their levels were introduced with the Taguchi method and the arrangement of tests was set according to the L25 standard orthogonal array. The car simulation results for the criteria have been extracted according to this table. In the next step, the TOPSIS method has been used to simultaneously optimize the criteria. The effect of parameters on the criteria was investigated by entropy method. Finally, after extracting the closeness coefficient, the optimal level was determined by Taguchi method.

2.1. TOPSIS method

This method was presented by Huwang and Yuan in 1981 (Hwang and Yoon 1981). In this method, m options are evaluated by n indices; and every problem can be considered as a geometrical system consists of m points in an n-dimension space. This technique has been constructed on the basis that the selected option must have the minimum and maximum distances with a positive ideal A^+ and negative item A^-, , respectively (Chen et al. 2003). The steps of the TOPSIS method are as follow (Yang and Chou 2005):

1. Forming decision matrix: TOPSIS method evaluates the decision matrix which includes *m* options and *n* indices.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

2. Normalizing the decision matrix using the Euclidian norm, called r_{ij}, which is obtained from Eq. (2):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{2}$$

3. Calculating the weighing metrics: to do this, a weight is assigned to criteria. The weight can be directly selected by the decision-maker so that each of the weights falls in the range between 0 to 1, and the sum of the weights be equal to one, or the entropy method can be used. In this research, the entropy mentored (section 2.2) was used to determine the weights. After determining the weights by the entropy method, the weight matrix is obtained using Eq. (3).

$$v_{ij} = w_j . r_{ij} \quad \sum_{i=1}^{n} w_j = 1 \tag{3}$$

where v_{ij} is the nondimensional weighting matrix and w is the diagonal matrix of the weights obtained from the indices.

4. Determining the assumed options for the negative ideal and positive ideal: for forming the positive ideal option, according to Eq. (4), the best value should be selected in each of the columns of the matrix v_{ij}; means that if the index corresponding to that column has a negative aspect (such as cost), the minimum value is selected and if that has the positive aspect, the maximum value should be selected.

To determine the negative and positive ideals, the following notes are important: (1) for criteria which have a positive load, the positive ideal is the maximum value of that criteria. (2) for criteria which have a positive load, the ideal negative is the minimum value of that criteria. (3) for criteria which have a negative load, the positive ideal is the minimum value of that criteria. (4) for criteria which have a negative load, the ideal negative is the maximum value of that criteria.

$$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\} \rightarrow A^- = \{v_1^-, v_2^-, \dots, v_n^-\} \tag{4}$$

where $A^+$and A^-denote the positive ideal and negative ideal respectively.

5. The Euclidian distance for each option of the positive and the negative ideal is calculated by Eqs. (5) and (6).

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)} \tag{5}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)} \tag{6}$$

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where, $S_i^{+}$is the distance from options to positive ideal and $S_i^{-}$is the distance from the options to the negative ideal.

6. Calculating the scores (ratio of closeness to ideal option): the ratio of closeness to the ideal option, C_i , is calculated by Eq. (7)

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{7}$$

2.2. Entropy mentored

The entropy method was used in order to create a weighing between the tests. The decision-making table was considered as the input for the entropy method. The steps of the entropy method are as follow (Zhang et al. 2007):

1. Forming the decision matrix: To evaluates the decision matrix using the entropy method, the decision matrix of the problem should be formed according to Eq. (8).

$$X_{ij} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{8}$$

2. Normalizing decision table: the second step of the entropy method is normalizing the decision matric or making it dimensionless. For normalizing, the simple normalizing method, i.e. the arithmetic mean is used. The simple normalizing relation is given in Eq. (9):

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} x_{ij}} \rightarrow j = 1, \ldots, n \tag{9}$$

3. Calculating the entropy of each index: in this step, the entropy of each index should be calculated by Eq. (10). The k value keeps the entropy value in each index remains in the range of 0 to 1.

$$E_j = -k \sum_{i=1}^{m} P_{ij} \,.\, Ln(P_{ij}) \rightarrow i = 1,2, \ldots, m \tag{10}$$

$$k = \frac{1}{Ln(m)}$$

4. Calculating the distance of each index from its entropy, d_j: in this step, the distance of each index from the entropy value calculated in the previous step should be obtained. To do this, Eq. (11) is used.

$$d_j = 1 - E_j \tag{11}$$

5. Calculating the weight of every index: finally, the weight of every index could be calculated using Eq. (12).

$$w_j = \frac{d_j}{\sum d_j} \tag{12}$$

3. Modelling and design of experiments

In this section, the car's dynamic model, dynamic criteria, and the selected parameters are studied. Selecting the tests for optimization will be also described.

3.1. Car's dynamic model

In this research, the CarSim software has been used to simulate the car model. CarSim is dynamic software which is widely used and can simulate and analyze the dynamic behavior of vehicles in different driving conditions. This software has a complete car model with 27 degrees of freedom wherein the nonlinear model of tires and artificial sensors are included (Jin et al. 2015). In many researches, simulation with CarSim has been investigated and validated experimentally. (Ji et al. 2018), performed a comparison of the real car with real sensors and its simulation in CarSim software in a road with low adhesion (μ = 0.2~0.4) with steer input having periodic change between +60 and -60 degree. The results of the test show that there is an appropriate agreement between the CarSim and the real test. Since the default models of CarSim have data tested with high accuracy, therefore, the default models of the CarSim software were used to test the stability and ride comfort. The C-class hatchback car is used in the CarSim software to create the dynamic model, and also to perform the analyses.

Table 1: Dimensions and weight of this car.

Parameters	Value	Units
Vehicle sprung mass	1274	kg
Front unsprung masses	71	kg
Rear unsprung masses	71	kg
Roll moment inertia of the sprung mass	606.1	$kg.m^2$
Pitch moment inertia of the sprung mass	1523	$kg.m^2$
Yaw moment inertia of the sprung mass	1523	$kg.m^2$
Distance from center of gravity to front axle	1.016	m
Distance from center of gravity to rear axle	1.562	m
Wheel Track	1.539	m
Height from CG to ground	0.540	m
Effective tyre radius	0.316	m
Wheel base	2.578	m
Tires	205/55 R 16	-

3.2. Handling and ride comfort evaluation criteria

In this study, the RMS of car body vertical acceleration was used to evaluate the ride comfort, and the body roll angle and lateral acceleration of car were used to evaluate the handling. In DLC test, these criteria are evaluated by comparing the car movement with the road specifications shown in Fig. (2). Car speed was also considered to be 90km.

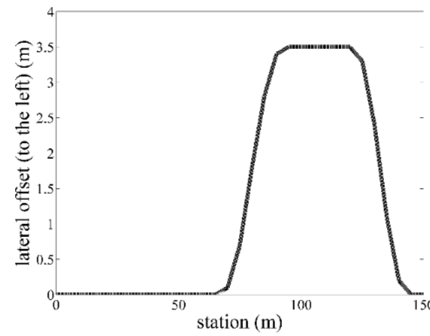

Figure 2: Test road used in the CarSim software.

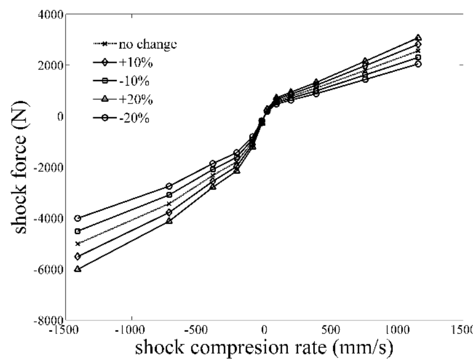

Figure 3: Design surfaces of the front and rear dampers.

3.3. Selected surfaces and factors

Although, several parameters are affecting the improvement of handling and ride comfort, but in the present research, the factors which are considered for improving the handling and ride comfort include the stiffness of front and the rear springs, and the front and rear shock absorber's damping coefficient of the car's suspension system car. The default values defined for these factors are varied in five levels ($\pm20\%$ and $\pm10\%$) which are shown in Table 2 and Fig. 3.

Table 2: Input factors and levels used in the tests.

Factors	Levels				
	1	2	3	4	5
$Kf(N/mm)$	21.6	24.3	27	29.7	32.4
$Kr(N/mm)$	24	27	30	33	36
$Cf(N.s/mm)$	-20%	-10%	front	+10%	+20%

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$Cr(N.s/mm)$	-20%	-10%	rear	+10%	+20%

3.4. Design of experiment with Taguchi method

Factorial design of experiment for 4 factors and five levels needs ($level^{factor} = 5^4 = 625$) tests, which is not affordable in terms of time and cost. On the other hand, it is not statistically necessary to test all combinations at the factors' levels under the test (Zandieh and Niaki 2003); therefore, the Taguchi method has been used to obtain a maximum information from a minimum test [35]. The Taguchi method reduces 625 tests to 25 tests with the help of orthogonal arrays. The Taguchi method is a good way to predict the effects of design parameters on system performance. This method is a combination of statistical and mathematical techniques used in experimental studies (Sheikhani et al. 2015). Designing tests with Taguchi method used in this study are shown in Table 3.

Table 3: Arrangement of required tests according to L25 standard array.

Runs	Kf	Kr	Cf	Cr
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	1	5	5	5
6	2	1	2	3
7	2	2	3	4
8	2	3	4	5
9	2	4	5	1
10	2	5	1	2
11	3	1	3	5
12	3	2	4	1
13	3	3	5	2
14	3	4	1	3
15	3	5	2	4
16	4	1	4	2
17	4	2	5	3
18	4	3	1	4
19	4	4	2	5
20	4	5	3	1
21	5	1	5	4
22	5	2	1	5
23	5	3	2	1
24	5	4	3	2
25	5	5	4	3

4. Experimental results and optimization

The results obtained from the tests according to the L25 orthogonal array for RMS of car body vertical acceleration (a_z), body roll angle ($\emptyset$), and lateral acceleration (a_y)are listed in Table 4. It should be noted that the minimum values obtained from the results are used to optimize the factors in order to achieve the desired handling and ride comfort. The TOPSIS method is used to simultaneous optimization of criteria.

Table 4. Results obtained from simulation according to L25 standard array.

Runs	$\emptyset$(deg)	$a_y(g)$	$a_z(g)$
1	2.4100	0.46397	0.0071
2	2.3261	0.46386	0.0081
3	2.2495	0.46376	0.0084
4	2.1802	0.46368	0.0088
5	2.1152	0.46361	0.0091
6	2.3010	0.46352	0.0082
7	2.2260	0.46339	0.0085
8	2.1574	0.46329	0.0089
9	2.1382	0.46303	0.0086
10	2.1483	0.46422	0.0079
11	2.2038	0.46297	0.0086
12	2.1848	0.46272	0.0084
13	2.1183	0.46273	0.0088
14	2.1264	0.46395	0.0080
15	2.0646	0.46385	0.0084
16	2.1655	0.46237	0.0086
17	2.0996	0.46237	0.0089
18	2.1065	0.46367	0.0081
19	2.0452	0.46354	0.0085
20	2.0272	0.46314	0.0083
21	2.0825	0.46196	0.0090
22	2.0875	0.46331	0.0082
23	2.0691	0.46287	0.0081
24	2.0103	0.46288	0.0084

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25	1.9562	0.46289	0.0087

4.1. Optimization using TOPSIS and entropy method

In this research, in order to optimize the parameters affecting the RMS of car body vertical acceleration, body roll angle, and lateral acceleration, indeed the TOPSIS method was used to minimize these three criteria.

The output obtained from the tests according to the L25 orthogonal arrays, forming the decision matrix in TOPSIS method. After forming the decision matrix, the normalized matrix should be obtained by Eq. (6), which is shown in Table 5.

Table 5: Normalized matrix

Runs	∅	a_y	a_z
1	0.224568	0.200305511	0.168359931
2	0.216750	0.200258021	0.192072598
3	0.209612	0.200214849	0.199186398
4	0.203155	0.200180312	0.208671464
5	0.197098	0.200150091	0.215785264
6	0.214411	0.200111236	0.194443864
7	0.207422	0.200055113	0.201557664
8	0.201030	0.200011940	0.211042731
9	0.199241	0.199899693	0.203928931
10	0.200182	0.200413441	0.187330064
11	0.205354	0.199873790	0.203928931
12	0.203583	0.199765860	0.199186398
13	0.197387	0.199770177	0.208671464
14	0.198141	0.200296876	0.189701331
15	0.192383	0.200253704	0.199186398
16	0.201785	0.199614757	0.203928931
17	0.195644	0.199614757	0.211042731
18	0.196287	0.200175994	0.192072598
19	0.190575	0.200119871	0.201557664
20	0.188898	0.199947182	0.196815131
21	0.194051	0.199437752	0.213413997
22	0.194517	0.200020575	0.194443864
23	0.192802	0.199830618	0.192072598
24	0.187323	0.199834935	0.199186398
25	0.182282	0.199839252	0.206300197

To obtain the effectiveness of criteria on the options, the weight of options should be obtained using entropy method and by Eqs. (8)-(12). As can be seen from Table 6, the weighting values assigned to RMS of body vertical acceleration, body roll angle, and lateral acceleration of the car, were 0.51%, 0.45%, and 0.03%, respectively.

Table 6: Entropy method results

	∅	a_y	a_z
E_j	0.999636000	0.999975734	0.999588403
d_j	0.000364434	2.42657E-05	0.000411597
W_j	0.455374000	0.030320891	0.514305251

The weighting matrix is obtained from Eq. (3) (Table 7).

Table 7: Weighted matrix

Runs	∅	a_y	a_z
1	0.102262	0.006073442	0.086588397
2	0.098702	0.006072002	0.098783946
3	0.095452	0.006070693	0.102442610
4	0.092511	0.006069645	0.107320830
5	0.089753	0.006068729	0.110979494
6	0.097637	0.006067551	0.100003501
7	0.094455	0.006065849	0.103662165
8	0.091544	0.006064540	0.108540385
9	0.090729	0.006061137	0.104881720
10	0.091158	0.006076714	0.096344836
11	0.093513	0.006060351	0.104881720

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12	0.092706	0.006057079	0.102442610
13	0.089885	0.006057210	0.107320830
14	0.090228	0.006073180	0.097564391
15	0.087606	0.006071871	0.102442610
16	0.091887	0.006052497	0.104881720
17	0.089091	0.006052497	0.108540385
18	0.089384	0.006069514	0.098783946
19	0.086783	0.006067813	0.103662165
20	0.086019	0.006062577	0.101223055
21	0.088366	0.006047130	0.109759940
22	0.088578	0.006064802	0.100003501
23	0.087797	0.006059042	0.098783946
24	0.085302	0.006059173	0.102442610
25	0.083006	0.006059304	0.106101275

The TOPSIS method aims to get furthering from negative ideal and getting close to the positive ideal. On this basis, in order to obtain negative and positive ideals, according to Eq. (4), the value of minimum positive ideal and the value of maximum negative ideal are obtained from corresponding weighting matrix. The values can be seen in Table 8.

Table 8: Positive and negative ideal values

	$\emptyset$	ay	az
A^{+}	0.083006	0.006047130	0.086588397
A^{-}	0.102262	0.006076714	0.110979494

The distances between each option to the positive ideal and the negative ideal are determined using Eqs. (5) and (6), respectively. Finally, according to Eq. (7), the closeness coefficient and ranking of each option are obtained. In this way, the highest values of the first rank and the lowest values received lower rank were compared to other options; these results are seen in Table 9. From this table, it can be concluded that test 10 is the best answer and test 4 is the worst answer.

Table 9: TOPSIS method results

Runs	C_i	S_i^-	S_i^+	Rank
1	0.558826879	0.024391	0.019256	6
2	0.389932637	0.012705	0.019877	14
3	0.351414925	0.010921	0.020156	20
4	0.313488724	0.010415	0.022807	25
5	0.330787422	0.012509	0.025307	23
6	0.375013293	0.011911	0.019850	15
7	0.342338276	0.010701	0.020557	21
8	0.318196312	0.010992	0.023554	24
9	0.396502004	0.013046	0.019857	13
10	0.590999391	0.018371	0.012713	1
11	0.335788567	0.010665	0.021096	22
12	0.408081464	0.012814	0.018586	12
13	0.371417031	0.012907	0.021844	17
14	0.578347891	0.018022	0.013139	3
15	0.506770325	0.016961	0.016508	9
16	0.371774461	0.012034	0.020335	16
17	0.370286404	0.013395	0.022780	18
18	0.563080822	0.017736	0.013762	4
19	0.494730916	0.017122	0.017486	11
20	0.559110909	0.018948	0.014942	5
21	0.369701958	0.01395	0.023783	19
22	0.547030757	0.017542	0.014526	7
23	0.590832979	0.01892	0.013103	2
24	0.542392039	0.018988	0.016020	8
25	0.504460522	0.019864	0.019513	10

4.2. Optimizing with Taguchi method

To obtain an optimal combination, the calculation of the relative average closeness coefficient in the Taguchi method is used. these values are obtained from Eqs. (13) and (14).

$$F_i = \frac{1}{m}\sum_{j=1}^{m} y_i \tag{13}$$

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$$\Delta F = \max\{F_1, F_2, \dots, F_n\} - \min\{F_1, F_2, \dots, F_n\} \quad (14)$$

The mean value of the relative closeness coefficient is shown in Table 10. The values that have been assigned the most value are the most effective levels in optimizing handling and ride comfort at the same time. The delta value is also calculated from the difference between the maximum and minimum mean of the relative closeness coefficient in each factor. Fig. 4 also clearly shows the effect of factor levels on ride comfort and handling, so that the highest points in each factor are optimal levels.

Table 10: The effect of factors on the mean relative closeness coefficient.

Level	K_f	K_r	C_f	C_r
1	0.3889	0.4022	**0.5677**	**0.5027**
2	0.4046	0.4115	0.4715	0.4533
3	0.4401	0.4390	0.4262	0.4359
4	0.4718	0.4651	0.3832	0.4191
5	**0.5109**	**0.4984**	0.3677	0.4053
Delta	0.1220	0.0962	0.1999	0.0974

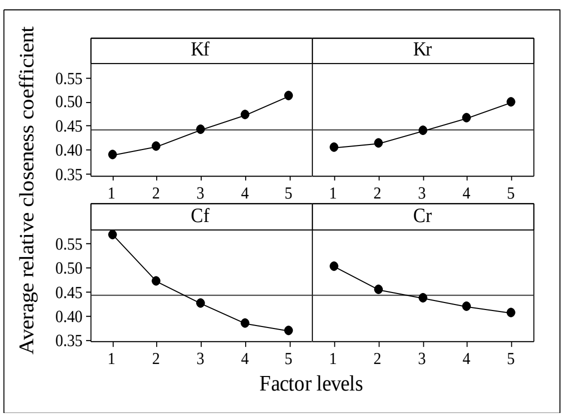

Figure 4: The effect of factors on the mean relative closeness coefficient.

According to Table 10 and Fig. (4), the front spring stiffness in the fifth level, the rear spring stiffness in the fifth level, front suspension system's damping coefficient in the first level, and rear suspension system in the first level, are the optimal values for handling and ride comfort. It should be noted that the optimal levels of 5, 1, 5, 1 have not located next to each other in any of the 25 tests shown in Fig. (4). But Taguchi method succefully obtained these optimal levels of the test.

4.3 Validating the optimization solution

To validate the optimization of handling and ride comfort at the same time, the DLC test with speed of 90km was used in CarSim software. By comparing the default factors' level with the optimal factors' level, shown in Table 11, it can be concluded that the body roll angle was reduced by 6.5% and RMS of body vertical acceleration was reduced by 7.10%. Fig. (5) shows the reduction in body roll angle in the default case compared with the optimal case. It should be noted that the lateral acceleration is affected by speed and path curve and also affected less by the springs' stiffness and damping of the suspension system's dampers.

Table 11: The comparison of default design responses with the optimal design responses.

comparison	$\emptyset(\mathbf{deg})$	$a_y(g)$	$a_z(g)$
Initial design	2.1376	0.46328	0.0085
Optimal design	1.9991	0.46338	0.0079
Improvement	6.50%	0.02%	7.10%

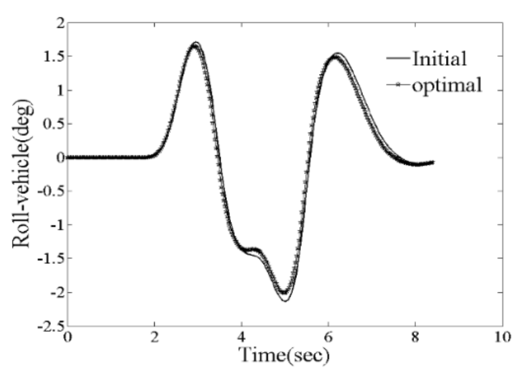

Figure 5: The body roll angle.

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To validate this method, the RMS of body vertical acceleration at different speeds (10, 30, 50, 70, 90, 110, 120km) has been tested. According to Table 12 and Fig. (6), it can be concluded that the optimization of RMS of body vertical acceleration at different speeds has the appropriate performance.

Table 12: The improvement percentage of RMS of body vertical acceleration in two default and optimal cases at different speeds.

Speed (km/h)	Initial design	Optimal design	Improvement
10	0.00082337	0.00077175	6.26%
30	0.0025	0.0024	4.00%
50	0.0042	0.0040	4.76%
70	0.0061	0.0057	6.55%
90	0.0085	0.0079	7.05%
110	0.0112	0.0106	5.35%
120	0.0127	0.0120	5.51%

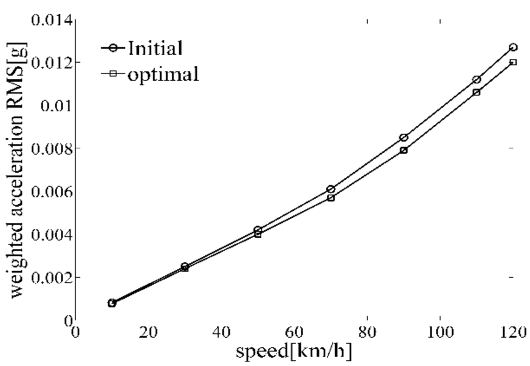

Figure 6: The value of RMS of body vertical acceleration.

5. Conclusion

In This research, after identifying the criteria affecting the handling and ride comfort, and taken into account the effective factors on these criteria, the simulation of car motion in DLC test has been performed by CarSim software. The evaluating criteria for handling are body roll angle and lateral acceleration, and for ride comfort is RMS of body vertical acceleration. For optimizing the handling and ride comfort, some criterial (targets) were investigated. Therefore, there is a need for an auxiliary method which can make decisions on multiple goals simultaneously. For this purpose, the entropy and TOPSIS methods have been used. It can be concluded that the proposed combined method has led to a reduction in RMS of body vertical acceleration by 7.10%, and a reduction in body roll angle by 6.5%. Consequently, this method is capable of simultaneously optimizing multi targets.

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