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Evaluation of different evaluation methods for selection of a conceptual design

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Abstract

Designing plays an important part in the production of an artifact, as it is the mental creation before the product becomes a reality. It also plays an interesting engineering activity that affects almost all areas of human life and uses the laws and insights of science. After the various design concepts have been successfully carried out, the evaluation stage becomes crucial in the selection of the best solution. A thorough study of the literature suggests that not too many works have been done on evaluating different evaluation methods in selecting a concept. The objective of this study was to evaluate four design concept evaluation methods for selecting a car hitch. The study found that for a robust selection of solutions, Verein Deutscher Ingenieure (VDI) guidelines and Technical Economic Evaluations were more appropriate to be used.

Keywords: Designing; Engineering activity; Solution; Design concept evaluation methods

1. Introduction

Cars are movable objects that need humans or other advanced mechanisms to control it. It transports both people and goods from one location to another, and it has made transportation easier and faster. However, certain road conditions such as sandy, muddy, and water-logged areas can hinder the smooth running of cars as they find it difficult to pull through [1],[2]. Cars that find themselves in such situations need to be towed by a truck or other special vehicles with the use of a tow hitch [3]. According to Kumar et al. [4], towing is the process of connecting one object to another for the purpose of pulling. The connection is made possible by the two tow hitches attached to the chassis of cars [5]. A tow hitch is a device that can be used to secure a connection between the towing vehicle and a trailer [6]. The design of the tow hitch is of much importance since it plays an active role in towing cars in cases of emergency.

Designing plays an important part in the production of an artifact, as it is the mental creation Pahl et al. [7] before the product becomes a reality. It also plays an interesting engineering activity that affects almost all areas of human life and uses the laws and insights of science [7] According to [8],[9] design is a complex process that depends on the information the design task to perform. In performing the task, the design process goes through a c the design process diagram.

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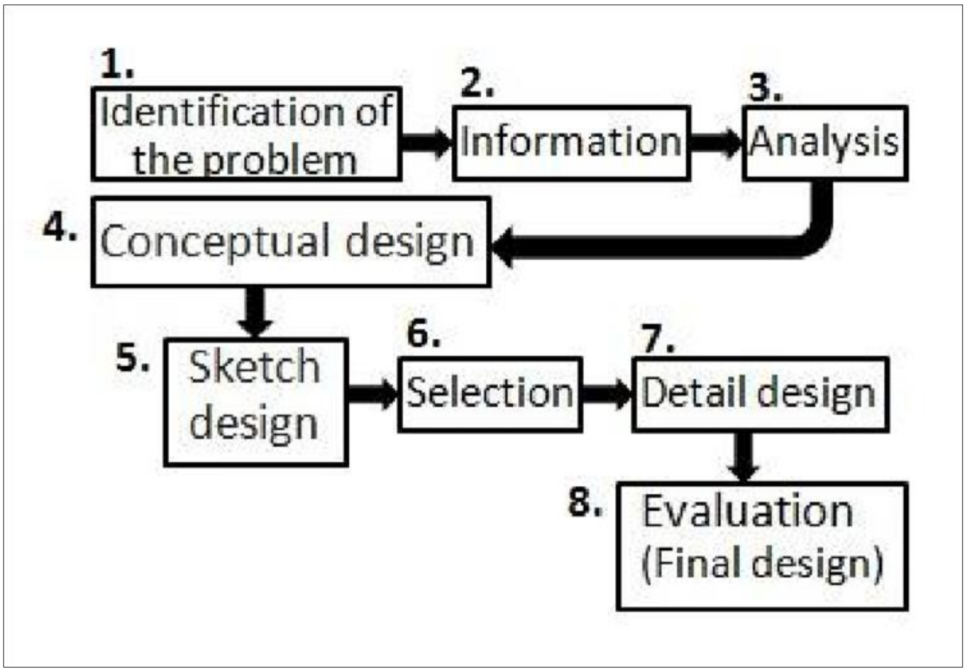

Figure 1 Design process diagram (Suwankarjank and Wiwitkunkasem, 2018)

After the various design concepts have been successfully carried out, the evaluation stage becomes important in the selection of the best solution. According to Suwankarjank and Wiwitkunkasem [10], any error at this stage will result in the selection of a bad concept, which can increase the work rate of the designer. Turan and Omar [11] contend that evaluation has a significant impact on the downstream development processes as well as on the success of the product being developed. As defined by Turan and Omar [11] design concept evaluation is a complex multi-criteria decision-making process, which includes many factors stretching from initial customer needs and constraints of the manufacturing company.

Khannade et al. [12] designed a tow bar for medium-sized and portable compressor units and subjected the design to no evaluation criteria. However, there was a stress analysis done on the design. Equally, the work of Turan and Omar [11] used only one method, the modified Rough-grey analysis method to evaluate a design. This could not reflect the overall potential of the design. Scott [13] reports on the Analytical Hierarchy Processes, but this single evaluation method in practical situations may not produce significant differences, which can affect the decision of the designer.

A thorough study of the literature suggests that not too many works have been done on the evaluation of different design concept evaluation methods in the selection of a concept. The current study, therefore delves into using different design concept evaluation methods in assessing the suitability of a variant, which could help designers to make an informed judgment when it has to do with a selection of a concept.

The objective of this study was to evaluate different design concept evaluation for the selection of a car hitch.

2. Methods

2.1. Objective tree

The objective tree was constructed and assigned values that were used to evaluate the four evaluation methods discussed. The high-quality product was coded E1 and it was divided into two parts, which were the technical and economic criteria. The economic criteria were assigned with E11 and it was subdivided into different criteria, where each criterion was also coded. The same applied to the technical criteria, which had E12 as its code. Figure 2 shows the objective tree, and Table 1 shows the criteria with their codes.

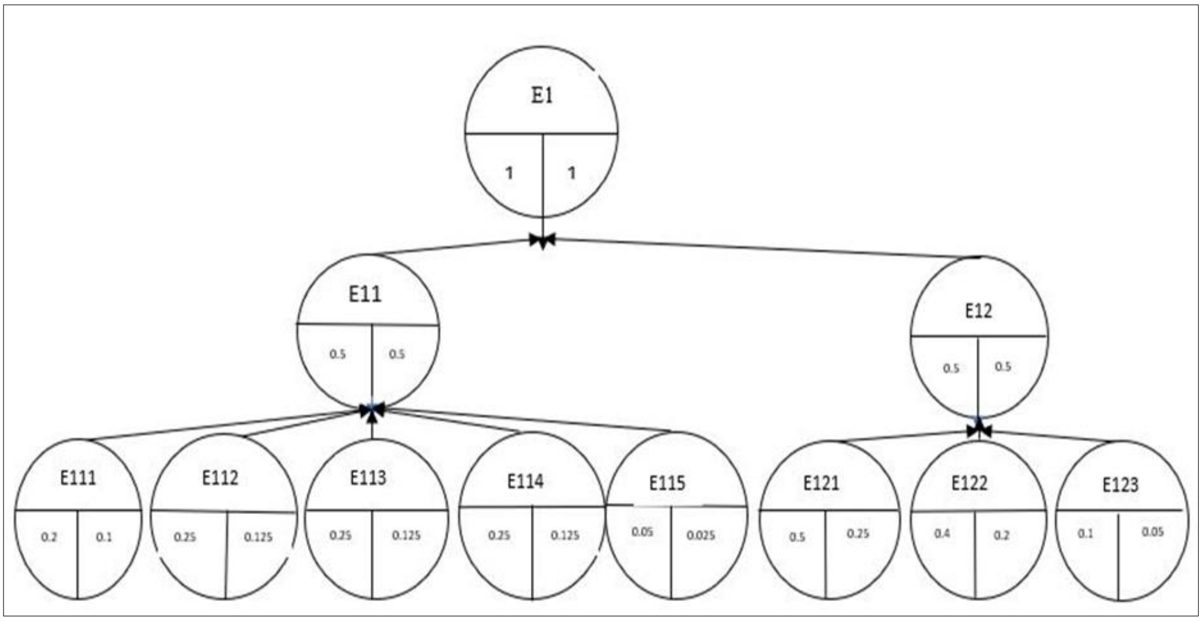

Figure 2 Objective tree

Table 1 Criteria and codes

S/N	Criteria	Code
1	Low design	E111
2	Infrequent servicing	E112
3	Cheap manufacturing cost	E113
4	Easy installation	E114
5	High aesthetics	E115
6	High heat resistance	E121
7	High breaking point	E122
8	Easy Flexibility	E123

2.2. Verein Deutscher Ingenieure (VDI) guideline 2225

The objectives or the criteria for the design were set, and it was grouped into technical and economic criteria [14]. Afterward, weighting factors were determined and assigned to each objective. Again, each objective was assessed and a point was allocated. This point usually ranges from 0-4 (VDI-Richtlinie 2225 [15], where 4 indicates very good, 3 means good, 2 refers to adequate, 1 denotes just tolerable, and 0 indicates unsatisfactory. The weighting factors were calculated with **Equ. 1**. Finally, the weighted values were summed up using **Equ. 2**. The total weighted values for both the technical and economic were used to construct the Strength diagram, where the various concepts were compared.

$$Weighted\ value = Weight\ \times Value\ \ \ldots\ldots\ldots\ldots.(1)$$

$$Total\ weighted\ value = wv_1 + wv_2 + wv_3 \ldots wv_n\ \ \ldots\ldots\ldots\ldots..(2)$$

Where wv is the weighted value.

2.3. Preference matrix

The criteria were determined and clustered into technical and economic criteria. Each criterion was assigned a code, which ranged from E111 to E123 for easy identification. The structure of the preference matrix was constructed such that each criterion was mapped to another criterion. Then, where the criteria were met, the criterion with the utmost importance was chosen against the other. The number of wins for each criterion was recorded, and the highest wins was chosen as the reference value, and used to calculate the normalized weightings using **Equ. 3**. The weighted value for each criterion was determined with Equ. 4.

$$Normalized\ weighting = \frac{Number\ of\ wins}{Reference\ value} \ \ldots\ldots\ldots\ldots..(3)$$

$$Weighted\ value = Normalized\ weight \times Point\ value \ \ldots\ldots..(4)$$

The weighted values were summed together with Equ. 5 to determine the ratings.

$$Rating = Wv1 + wv2 + wv3 \ldots wvn \ \ldots\ldots\ldots\ldots.(5)$$

The normalized rating was calculated with Equ. 6.

$$Normalized\ rating = \frac{Rating}{Highest\ rating} \ \ldots\ldots\ldots\ldots\ldots..(6)$$

The normalized ratings were ranked, and the highest normalized rating was chosen as the best concept.

2.4. Technical -Economic Evaluation

The criteria for the selection were chosen and divided into technical and economic. Point values ranging from 0-4 were chosen for each criterion. The rating for each criterion was determined with Equ. 7.

$$x = \frac{p_1 + p_2 + \cdots + p_n}{n \cdot p_{max}} = \frac{1}{n \cdot p_{max}} \sum_{i=1}^{n} p_i \ \ldots\ldots\ldots\ldots.(7)$$

Where x is the rating, p is the criterion, n is the total number of criteria, and Pmax is the highest criterion value.

2.5. Objectivated Weighted Evaluation

This method follows the procedure outlined by Ehrlenspiel et al. [16]. The evaluation criteria were selected based on the design concepts, and the highest number was 4. All the criteria in every conceptual design were added and the overall rating was calculated using Equ 8.

$$s_{overall,j} = \frac{m_{1j} + m_{2j} + \cdots + m_{nj}}{n.m_{max}} = \sum_{i=1}^{n} m_i \ \ldots\ldots..(8)$$

Where, $s_{overall,j}$ is the overall rating, m is the individual criterion, n is the total number of the criterion and m_{max} is the highest number scored by a criterion.

The overall rating for each conceptual design was then multiplied by the weighting value. The values for each of the conceptual designs were then summed up, and based on the values, the highest was chosen as the preferred solution.

3. Results and discussion

3.1. VDI Guideline 2225 Evaluation

Tables 2, 3, and 4 show the analyses for the three conceptual designs. Conceptual Design 2 had an economical and technical sum of 3.35 and 3.6, respectively. Figure 2 shows the Strength Diagram, which shows Concept 2 ahead of the other two conceptual designs, and this made it the best followed by Concept 3 and lastly, concept 1.

Table 2 Analysis of Conceptual Design 1

Evaluation criteria			**Parameter name**		**Concept 1**	
	ID	**Weight**	**Parameter**	**Unit**	**Value**	**Weighted value**
Economic value			0.4			
Low design effort	A	0.20	Design effort		3	0.6
Infrequent servicing	B	0.25	Servicing		4	1
Cheap manufacturing cost	C	0.25	Manufacturing cost		4	1
Easy installation	D	0.25	Installation		4	1
High aesthetics	E	0.05	Aesthetics		2	0.1
Sum						3.7
Technical value						
High heat resistance	F	0.40	Heat resistance		3	1.2
High breaking point	G	0.50	Breaking point		4	2
Easy Flexibility	H	0.1	Flexibility		2	0.2
Sum						3.4

Table 3 Analysis for Conceptual Design 2

Evaluation criteria			**Parameter name**		**Concept 2**	
	ID	**Weight**	**Parameter**	**Unit**	**Value**	**Weighted value**
Economic value			0.4			
Low design effort	A	0.20	Design effort		2	0.4
Infrequent servicing	B	0.25	Servicing		4	1
Cheap manufacturing cost	C	0.25	Manufacturing cost		3	0.75
Easy installation	D	0.25	Installation		4	1
High aesthetics	E	0.05	Aesthetics		2	0.1
Sum						3.25
Technical value						
High heat resistance	F	0.40	Heat resistance		3	1.2
High breaking point	G	0.50	Breaking point		4	2
Easy Flexibility	H	0.1	Flexibility		4	0.4
Sum						3.6

Table 4 Analysis of Conceptual Design 3

Evaluation criteria			Parameter name		Concept 3	
	ID	**Weight**	**Parameter**	**Unit**	**Value**	**Weighted value**
Economic value			0.4			
Low design effort	A	0.20	Design effort		1	0.20
Infrequent servicing	B	0.25	Servicing		3	0.75
Cheap manufacturing cost	C	0.25	Manufacturing cost		4	1
Easy installation	D	0.25	Installation		3	0.75
High aesthetics	E	0.05	Aesthetics		1	0.1
Sum						2.8
Technical value						
High heat resistance	F	0.40	Heat resistance		3	1.2
High breaking point	G	0.50	Breaking point		4	2
Easy Flexibility	H	0.1	Flexibility		3	0.3
Sum						3.5

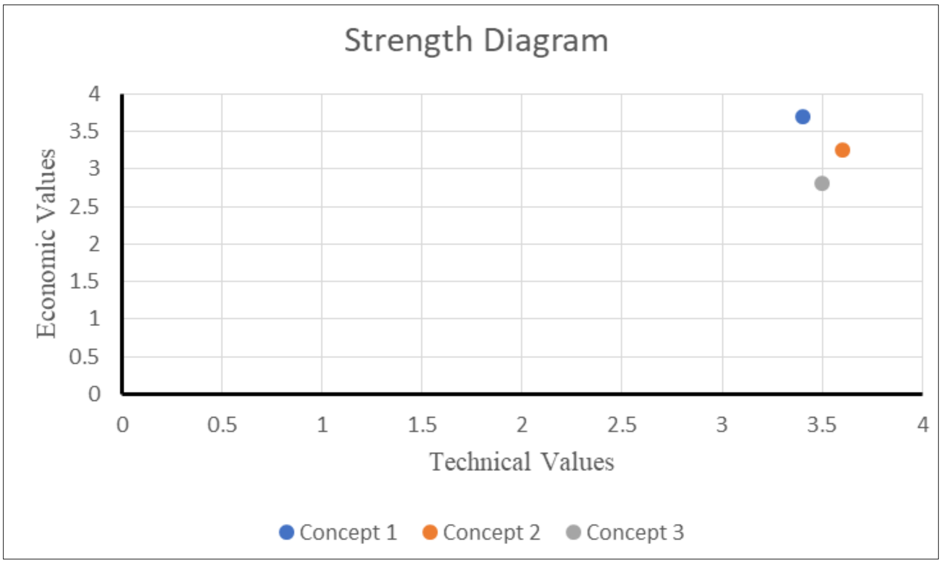

Figure 3 Strength Diagram for the three conceptual designs

3.2. Preference Matrix Evaluation

Tables 5 and 6 show the rating of the criteria and the computational values for the three conceptual designs. Concerning the rating of the solutions, 7 was found to be the highest number, which indicated that criteria E113 had more wins, hence it was used as the reference value.

Conceptual design 1 had the highest value ratings and normalized ratings of 14.71 and 1, respectively, and this made it the best conceptual design since it was ranked 1st.

Table 5 Rating of solution

Evaluation criteria	E111	E112	E113	E114	E115	E121	E122	E123
Number of wins	1	4	7	4	0	4	6	2
Normalize weightings	0.14	0.57	1	0.57	0.00	0.57	0.86	0.29

Table 6 Computational values for the three conceptual designs

Evaluation criteria	Normalized weightings	Value	Weighted value	Value	Weighted value	Value	Weighted value
			Concept 1		Concept 2		Concept 3
1	2	3	4	5	6	7	8
Low design effort	0.14	3	0.42	2	0.28	1	0.14
Infrequent servicing	0.57	4	2.28	4	2.28	3	1.71
Cheap manufacturing cost	1	4	4	3	3	4	4
Easy installation	0.57	4	2.28	4	2.28	3	1.71
High aesthetics	0	2	0	2	0	1	0
High heat resistance	0.57	3	1.71	3	1.71	3	1.71
High breaking point	0.86	4	3.44	4	3.44	4	3.44
Easy Flexibility	0.29	2	0.58	4	1.16	3	0.87
Value/Ratings			14.71		14.15		13.58
Normalized Value/Ratings			1		0.96		0.92
Ranking			1		2		3

3.3. Technical-Economic evaluation

Table 7 displays the computational values for the three conceptual designs. It could be seen that Conceptual Design 2 had the lowest economic rating of 0.75 and the highest technical rating of 0.92. With respect to **Fig. 4**, it could be seen that Concept 2 was slightly ahead of Concept 1 and this made it the best.

Table 7 Computational values for the three conceptual designs

	Evaluation Ratings of the Alternatives Solutions (p = 4)		
Evaluation criteria	Concept 1	Concept 2	Concept 3
	Value	Value	Value
1	2	3	4
Economic Criteria			
Low design effort	3	2	1
Infrequent servicing	4	4	3
Cheap manufacturing cost	4	3	4
Easy installation	4	4	3

High aesthetics	2	2	1
Value/Ratings	17	15	12
Economic Rating y	0.85	0.75	0.6
Ranking	1	2	3
Technical criteria			
High heat resistance	3	3	3
High breaking point	4	4	4
Easy Flexibility	2	4	3
Value/Ratings	9	11	10
Technical Rating X	0.75	0.92	0.83
Ranking	3	1	2

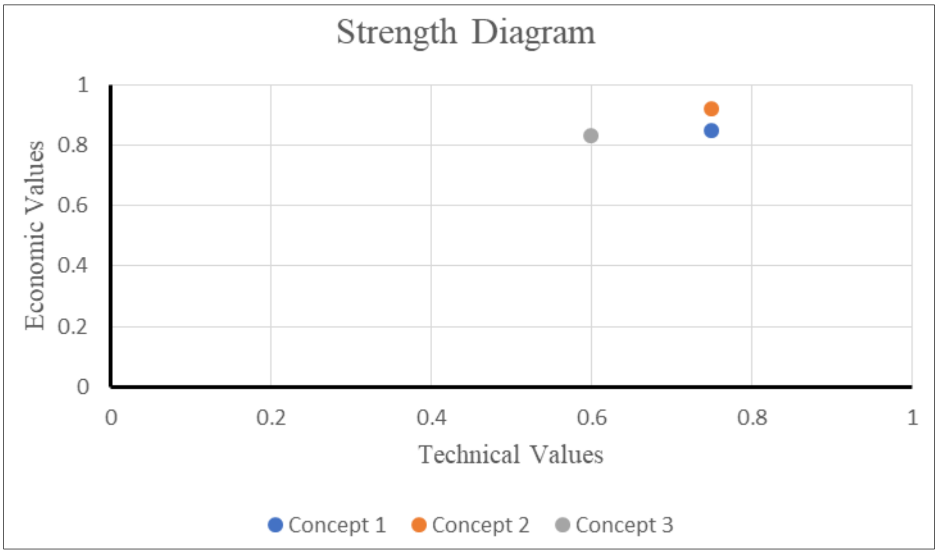

Figure 4 Strength Diagram for the three conceptual designs

3.4. Objectivated weighted evaluation

Table 8 and 9 presents the weighting criteria, analysis, and evaluation of the conceptual designs, respectively. Conceptual Design 2 had an average reliability of 0.75 and 0.92 for cost and function, respectively. In summing up the values of conceptual designs, Conceptual Design 2 had the highest of 0.87, which made it the best conceptual design.

Table 8 Computational values for the three conceptual designs

Criterion	**Cost [$ 4]**			**Function [4]**			**Reliability [4]**		
	Con. 1	**Con. 2**	**Con.3**	**Con. 1**	**Con. 2**	**Con.3**	**Cost**	**Function**	**Remarks**
Low design effort	3	2	1				0.5-0.75	0.8-0.85	Acceptable
Infrequent servicing	4	4	3				0.8-1	0.5-0.75	Average
Cheap manufacturing cost	4	3	4				0.8-1	0.0-0.70	Good
Easy installation	4	4	3						

High aesthetics	2	2	1						
High heat resistance				3	3	3			
High breaking point				4	4	4			
Easy Flexibility				2	4	3			
Total	17	15	12	9	11	10			
Overall Rating	0.85	0.75	0.6	0.75	0.92	0.83			

Table 9 Evaluation of the conceptual designs

Function			**Cost**		**Reliability**	
$w_1 = 0.4$			$w_2 = 0.4$		$w_3 = 0.3$	
Con. 1	0.85		0.75		Acceptable	
Con. 2	0.75		0.92		Average	
Con. 3	0.6		0.83		Good	
	P_1	$P_1 \cdot w_1$	P_2	$P_2 \cdot w_2$	P_3	$P_3 \cdot w_3$
Con. 1	10	4	8	3.2	3	0.9
Con. 2	8	3.2	10	4	5	1.5
Con. 3	5	2	9	3.6	8	2.4
			$\sum P_1 \cdot w_1$			
			Con. 1	8.1		
			Con. 2	8.7		
			Con. 3	8		

4. Conclusions

The Verein Deutscher Ingenieure (VDI) Guideline and Technical-Economic evaluations, which make use of combinations of values and graphs, and objectivated weighted evaluation accepted Concept 2 as the best. Preference Matrix evaluation makes use of the ranking system and it acknowledged Concept 1 as the best. For the robust selection of solutions, VDI guidelines and Technical Economic Evaluations merged the best evaluation method for conceptual design selection.

Compliance with ethical standards

Disclosure of conflict of interest

Authors' declare that there is no competing conflict of interests

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