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EVALUATING THE CONCEPT VARIANTS OF AN ULTRA LIGHT ELECTRIC SCOOTER

Abstract: *The paper develops the conceptual design of a lightweight electric scooter with high pliability and portability characteristics. Primarily, the paper focuses on the development and virtual representation of the scooter concept through iterative improvements and the elimination of the weaknesses of design of the previous solution. After three successive iterations a final version is obtained that fully meets the requirements list. Secondly, during concept development, an evaluation of these concept variants is proposed, based on technical and economic criteria. Finally, a positioning matrix of the proposed product is obtained in relation to existing products on the market. A discussion of solutions based on the requirements list is offered also. Several conclusions distinguish the main points and results of the paper.*

Key words: *embodiment design, requirements list, functional structure, evaluation matrix, use-value analysis.*

1. INTRODUCTION

In this paper, we have developed several concept variants of a two-wheeled electric-powered scooter to address the personal transportation market (college students, workers in large factories and commuters).

We focused on evaluating own solutions that include multiple improvements compared to similar products on the market. This evaluation is used to determine the dominant concept that will be further developed in the embodiment design phase, taking into account the proposed original improvements, in compliance with the technical specifications imposed by the design theme.

In this case, the evaluation of the concept is based on virtual prototyping, because it involves the spatial representation of the new scooter concept.

2. FUNCTIONS OF ELECTRIC SCOOTER

The commercial success of most scooters depends on their ability to satisfy functional requirements and to meet consumers' needs: portability, appearance and low price. Achieving these goals is a product development problem involving the correct perception of a market opportunity, the development of a new scooter concept, its production, sale and distribution [1].

To define the physical shape of the scooter, it is first necessary to analyze the functions it needs to perform. In this context, the authors have to carefully analyze and identify the operational requirements and then decide upon the best solution from a functional and economical point of view.

For example, the scooter concept has to meet a set of specifications (requirements list) to describe what the scooter has to do, as follows:

- the product is a lightweight electric scooter that can be easily folded into a compact volume of small size (the scooter weigh about 10 kg);
- it travels at speeds up to 30 km per hour and can go about 25 km on a single charge;
- the scooter can be recharged in about two hours from a standard electric outlet;
- the scooter is easy to drive and has simple controls – just an accelerator button and a brake.

Relevant scenarios in scooter concept are shown in fig. 1. This diagram is elaborated in function of main design specifications.

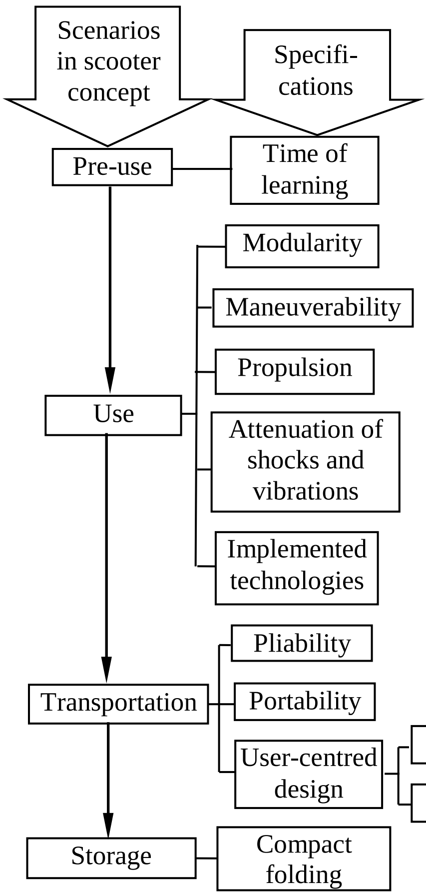


Fig. 1 Scenarios in scooter design.

The optimal function structure for the scooter is set according to the essential (obligatory) requirements of the requirements list and is the first important step of the conceptual design phase [2].

Figure 2 shows the function structure of an electric scooter. Determination of the function structure was based on establishing the main functions: generation of energy and management of this energy during the movement. Establishing the function structure facilitates the search for mechanical engineering solutions such as: arrangement of working surfaces and working motions (translation, rotation).

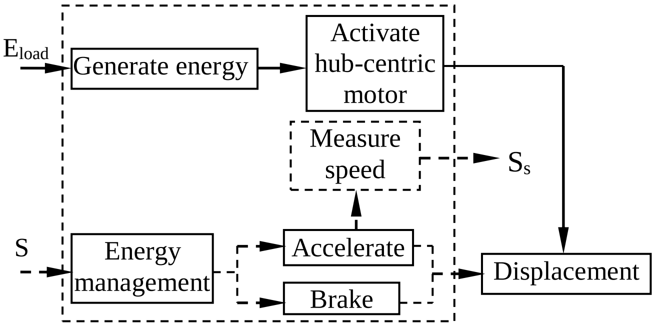


Fig. 2 Function structure of an electric scooter.

3. EMBODIMENT DESIGN

The embodiment design phase involves the determination of the scooter's architecture and its decomposition into constructive modules and components. This phase leads to the establishment of the general arrangement and spatial compatibility, the component shapes and materials and a functional specification of each of the scooter's subsystems.

The physical elements of the construction structure must lead to the fulfillment of the requirements list plus any other requirements necessary for the electric scooter to operate as it was intended.

The constructive solutions presented below have been iteratively developed. An iterative succession of principle sketches was made, which started from a first idea (first version) that was then modified and improved by eliminating the weak parts of conception. The iterative improvement continued until third version, which largely satisfies the requirements list [3].

3.1 First version

The purpose of the design was to exemplify how the platform folded, reducing the overall size. The front platform connects the handlebar to the rear platform. The total weight of the scooter is 18 kg, thanks to the DC motor that represents 35% of the total weight of the scooter, i.e. 6.3 kg (fig. 3).

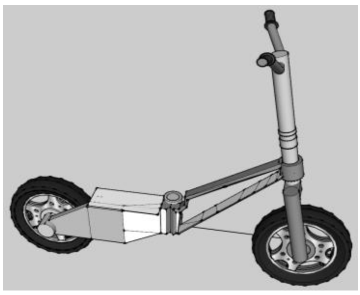


Fig. 3 First modeled version.

The scooter folds in the desired volume of 500x400x300 mm. In the design one can see a single folding axis of the platform, a folding axis for each handlebar handle, and a telescopic handlebar axis (fig. 4). In use, the design allows for a high degree of user comfort thanks to the front shock absorber, rear absorber and large wheels with inflatable tires that absorb shocks and the elements of discomfort of the running track.

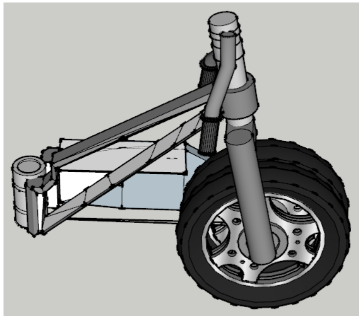


Fig. 4 First version of the folded scooter [3].

3.2 Second version

In this version the greatest improvement is the use of wheel-integrated motors. The folded scooter occupies a fairly small space of 400 x 250 x 120 mm, allowing storage in a backpack. There are 9 folding axes. Each handle can be folded down and the handlebars shaft is telescopic (fig. 5). Wheels are folded to 90 degrees. The hinge allows a folding axis of the wheel assembly at 180 degrees in the platform space. Thus full folding takes up much less space (fig. 6).

Fig. 5 Second modeled version.

The platforms are secured with 3 securing clamps, both to provide a safety factor and redundancy. In the later version, the clamps have been abandoned for other gripping methods that allow safe fastening.

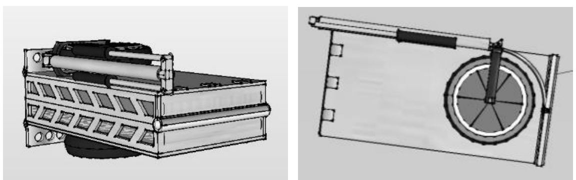


Fig. 6 Scooter completely folded [3].

3.3 Third version

The platform allows for 4 batteries (fig. 7). But the biggest feature that the scooter has is the ability to be folded. Currently on the market there are very few scooters that when not in use take up so little space, but they made compromises on functionality, simplicity, and aesthetics. The scooter presented here makes no such compromises, by relying on a simple yet robust design, mated to the latest technologies.

Fig. 7 Scooter which meet the requirements.

A series of images illustrate a temporal sequence of actions involving the scooter (fig. 8 – 14). It can be seen the advantages of the final scooter concept: it can be easily folded for storage and transport.

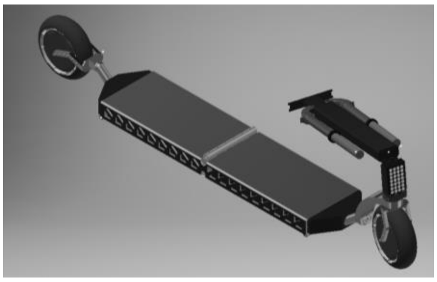


Fig. 8 Folded Handlebars.

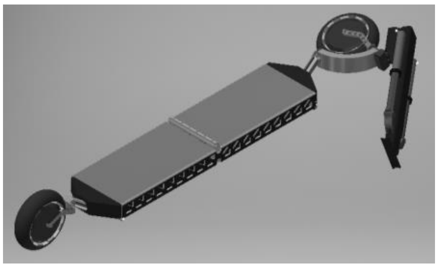


Fig. 9 Folded front wheel.

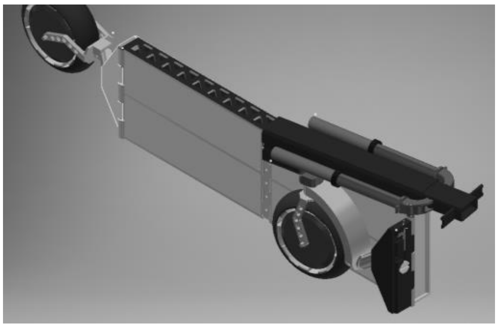


Fig. 10 Folded front scooter.

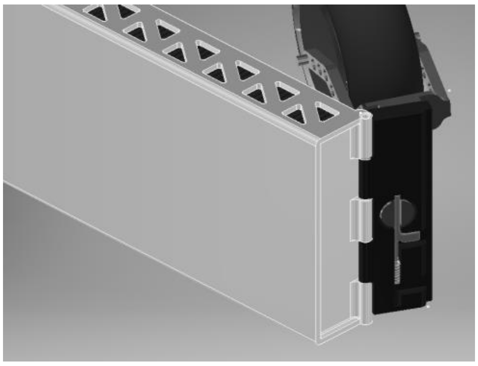


Fig. 11 Folding retention wheel mechanism.

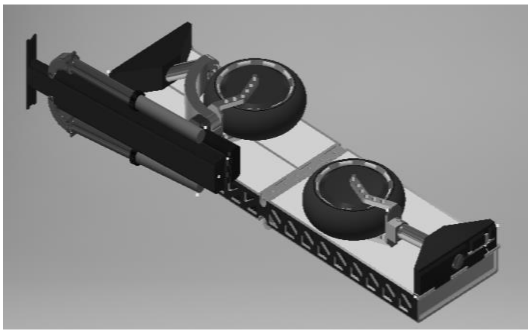


Fig. 12 Folded front and rear wheels.

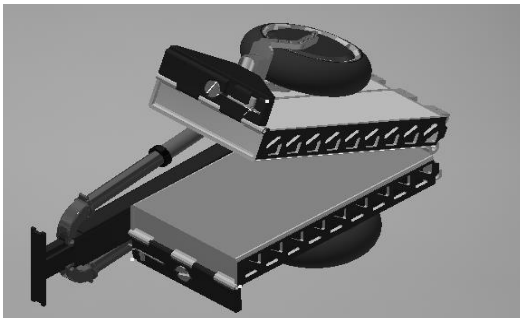


Fig. 13 Folded platform.

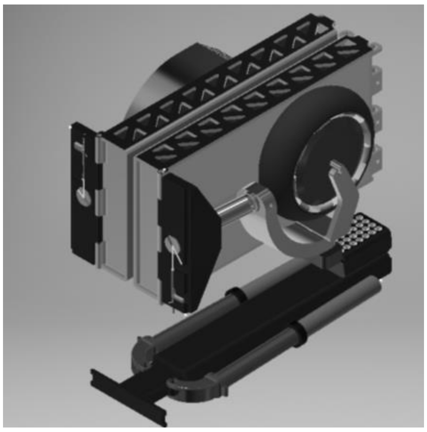


Fig. 14 Folded scooter [3].

It can be seen that the handlebars are exceeding the designated constraints. If space is limited, they can be easily removable, and deposited in other places. It is noted that the top of the handlebars is a platform to deposit a smart phone so that in transit, telemetry from the scooter can be displayed (speed, battery level, etc). The handlebars can potentially be used as a tripod or a monopod.

4. EVALUATION OF CONCEPT VARIANTS

The concept variants must be evaluated in function of technical, economic and aesthetic criteria. This evaluation is based on the comparison of two solutions proposed by the authors with the most interesting variants available on the market.

A method that covers a broad spectrum of objectives specified in the list of specific requirements and which allow the quantitative and qualitative assessment of the properties of the variants is the use-value analysis, based on the combined technical and economic evaluation technique specified in Guideline VDI (Verein Deutscher Ingenieure) 2225 [4]. Use-value analysis specifies the evaluation criteria by means of an objective system, in which the individual objectives are arranged in hierarchic order. Figure 15 illustrates the objective system for an electric scooter.

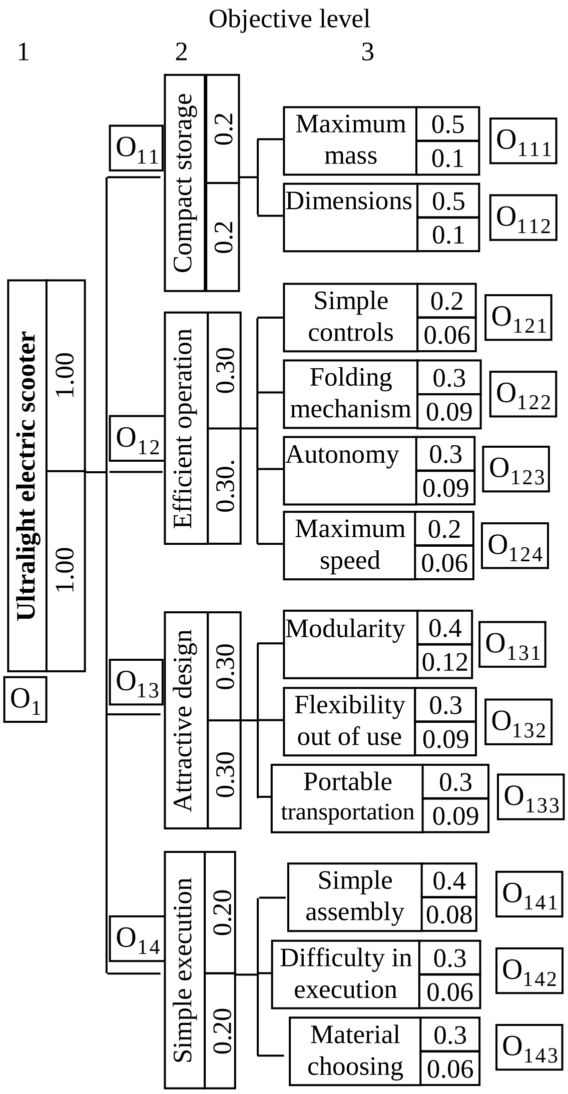


Fig. 15 Objectives tree and relative weights for choosing an electric scooter.

The sub-objectives are arranged horizontally into levels of decreasing complexity, and vertically into objective areas (for example, technical, economic, aesthetic). Sub- objectives of a higher level are connected with an objective of the next lower level.

The evaluation criteria (called objective criteria in use-value analysis) are based on sub-objectives of the level with the lowest complexity (level 4). For a more comprehensive evaluation, three intermediate objectives of the level 3 were correlated with sub-objectives on a lower level 4 (fig. 16).

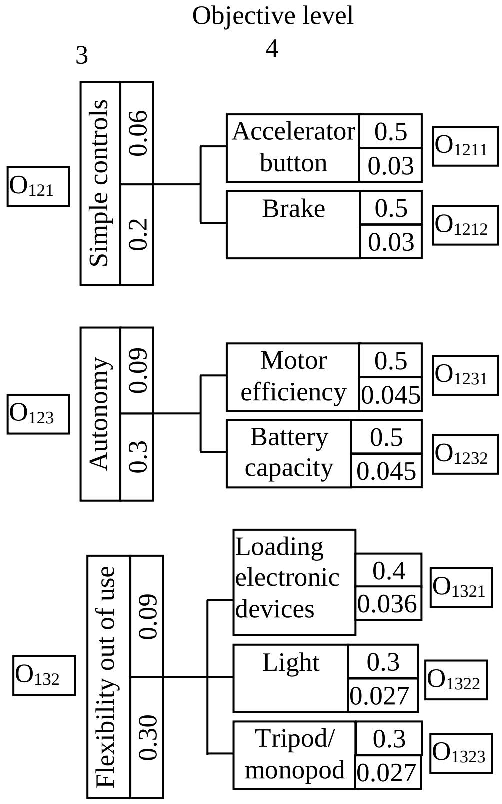


Fig. 16 Completing level 4 in the objectives tree.

4.1 Weighting evaluation criteria

The objective appreciation of the variants involves knowledge of the behavior, respectively of properties of the product considered. The expression of these properties in the form of characteristic sizes should be pursued, thus creating possibilities for quantification in the analysis of the variants.

The partial objectives, on the basis of which the appreciation is made, must be largely independent. This means that the measures taken to raise the use-value of a variant in order to achieve a partial objective must not influence the use-values in terms of the other partial objectives. It must, therefore, ensure that the achievement of a partial objective contributes to the use-value of the variant as a whole, without being conditioned on the achievement of other partial objectives.

The relative importance of a particular evaluation criterion (objective) is given by a “weighting factor” assigned to the objectives, defined by a real, positive number.

Such a weighting can occur either on a numerical scale, for example 0 = no importance and 10 = maximum importance, or in the form of a percentage indication, which allows reciprocally weighting of objectives. Experience shows that this latter approach leads to appreciations closer to reality, provided that the weighting factors are established step by step, based on the structured objectives system.

In four objective levels there are grouped objectives whose weighting factors are noted at each node:

a) to the left - the node weighting factor;

b) on the right - the relative weighting factor relative to nodes of the same level.

In use-value analysis, weightings are based on factors ranging from 0 to 1 so that a percentage weighting can be attached to all the sub-objectives.

The appreciation proceeds step by step from the higher complexity level to the next lower level. The estimation of the node weighting factors is as follows:

a) first are weighted the four nodes of the partial objectives O_{11}, O_{12}, O_{13}, O_{14} of the second level (with 0.2, 0.3, 0.3 and 0.2) in relation to the node of the upper objective O_1; the transverse sum of the weighting factors associated to a higher node is equal to 1;

b) next comes the weighting of the objectives of the 3rd level relative to the associated nodes of the 2nd level;

c) similarly, are weighted the objectives of the fourth level relative to the partial objectives associated with third level.

The weights of the nodes associated to a higher node are determined by taking into account the functional importance of the objectives. The sum of the weighting factors of all evaluation criteria must be equal to 1.

The relative weighting of a sub-objective at a particular level is found by multiplication of the weighting factor of the given objective level by the weighting factors of the higher objective levels [4]. Figure 15 illustrates this procedure.

Example of determining the weights relative to the first two nodes in level 4 associated with the first node in level 3: 0.03 = 0.06 x 0.5; 0.03 = 0.06 x 0.5.

The sum of the relative weights of nodes of the same level is equal to 1:

$$\sum_{Level\ 2} r_i = 1; \quad \sum_{Level\ 3} r_i = 1; \quad \sum_{Level\ 4} r_i = 1 \qquad (1)$$

Such weighting step by step allows, as a rule, for an appreciation in line with reality because it is easier to appreciate two or three partial objectives in relation to a higher objective, than to mutually appreciate all the partial objectives of a level, especially those of the lower levels.

4.2 Evaluation matrix

The sub-objectives thus established, that are the partial objectives of the inferior level of the objectives tree, constitute the basis for the next stages of appreciation. These are the criteria for appreciation, which are also referred to as objective criteria.

As a rule, an objective criterion and the corresponding sub-objective will be formulated the same. Objective sizes can be indicated by value and/or verbal. Under this aspect, objective sizes serve as a basis for information for the proper evaluation of the solutions. Such an evaluation is an objective stage, preceding the subjective stage of appreciation.

The next step is to draw a matrix in which the evaluation criteria are written in the first column of the matrix (fig. 17 and fig. 18). For each criterion, a value (expressed by points) is assigned that correlates the parameter magnitudes (the parameters resemble that of the verbal formulation of the evaluation criteria) with the value scale. Establishing this matrix is therefore a step towards the orderly representation of information useful in evaluating solutions.

To set the objective values, one possibility is to set and use a score. Such a rating scheme assigns points or quality numbers to relevant areas of values of objective sizes, or verbal formulations on the degree to which objective criteria are met. According to VDI 2225, the scale of points of appreciation is from 0 to 4 points. According to the use- value analysis method, objective values are scored from 0 to 10 points.

4.3 Determining overall value

The following overall value is used to evaluate solutions:

a) the unweighted overall value for all objective sizes:

$$v_{\Sigma} = \sum_{i=1}^{n} v_i \qquad (2)$$

b) the weighted overall value for all objective sizes:

$$(rv)_{\Sigma} = \sum_{i=1}^{n} r_i v_i \qquad (3)$$

It also calculates two relative overall values:

a) the non-dimensionally unweighted value for all objective sizes:

$$v_{\Sigma\ ad} = \frac{\sum_{i=1}^{n} v_i}{v_{\max}\, n} = \frac{v_{\Sigma}}{v_{\max}\, n} \qquad (4)$$

b) the non-dimensionally weighted value for all objective sizes:

$$(rv)_{\Sigma\ ad} = \frac{\sum_{i=1}^{n} r_i v_i}{v_{\max} \sum_{i=1}^{n} r_i} = \frac{(rv)_{\Sigma}}{v_{\max}} \qquad (5)$$

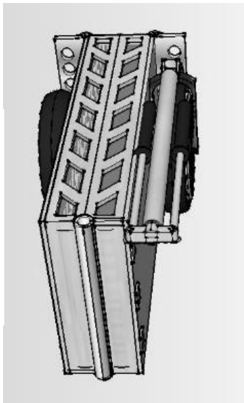
The above occurred: v_{max} - the maximum value of the rating scale (4 for VDI 2225, or 10 for use-value analysis [4]); n - the number of evaluation criteria considered when evaluating solutions (n=16).

It is also noticed that the sum of relative weights was rewritten in (5) in the form:

No.	Evaluation criteria	Weighting factor r_i	Parameters	Unit	MyWay Compact			Variant V_2		
					Magnitude	Value v	Weighted value	Magnitude	Value v	Weighted value
1.	Maximum mass	0.1	Weight	kg	13	7	0.7	12	8	0.8
2.	Dimensions	0.1	L x l x H	cm	107 x 35 x 114	6	0.6	40 x 25 x 12	8	0.8
3.	Accelerator button	0.03	Kick-assist system	-	incorporated	8	0.24	incorporated	8	0.24
4.	Brake	0.03	-	-	incorporated	6	0.18	incorporated	6	0.18
5.	Folding mechanism	0.09	Folding axes	no.	5	5	0.45	9	8	0.72
6.	Motor efficiency	0.045	Power	W	390	6	0.27	400	6	0.27
7.	Battery capacity	0.045	Capacity	Ah	32.5	7	0.315	32.5	7	0.315
8.	Maximum speed	0.06	Speed	km/h	25	5	0.3	30	6	0.36
9.	Modularity	0.12	Joints	-	high	8	0.96	average	6	0.72
10.	Loading electronic devices	0.036	-	-	unincorporated	0	0	unincorporated	0	0
11.	Light	0.027	-	-	incorporated	6	0.162	incorporated	6	0.162
12.	Tripod/ monopod	0.027	Handlebar	-	unincorporated	0	0	unincorporated	0	0
13.	Portable transportation	0.09	Compact storage	cm	65 x 25 x 26	6	0.54	40 x12 x 25	8	0.72
14.	Simple assembly	0.08	Simplicity of components	-	complicated	4	0.32	average	5	0.40
15.	Difficulty in execution	0.06	Simple production	-	complicated	4	0.24	average	5	0.30
16.	Material choosing	0.06	Material content	-	average	5	0.30	low	6	0.36
		$\sum_{i=1}^{n} r_i = 1$				$\Sigma v = 83$ $(\Sigma v)_{ad\,1} = 0.518$	$\Sigma rv = 5.577$ $(\Sigma rv)_{ad\,1} = 0.5577$		$\Sigma v = 93$ $(\Sigma v)_{ad\,2} = 0.581$	$\Sigma rv = 6.347$ $(\Sigma rv)_{ad\,2} = 0.6347$

Fig. 17 Evaluation matrix completed with values for two concept variants.

MyWay Compact scooter [7]

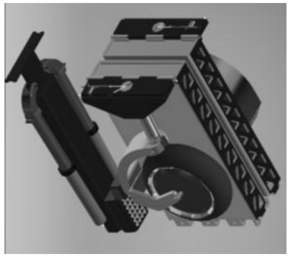


Variant V_2 [3]

No.	Evaluation criteria	Weighting factor r_i	Parameters	Unit	Hyundai iIoniq Scooter			Variant V_3		
					Magnitude	Value v	Weighted value	Magnitude	Value v	Weighted value
1.	Maximum mass	0.1	Weight	kg	14	6	0.6	11	9	0.9
2.	Dimensions	0.1	L x l x H	cm	80 x 10x 110	8	0.8	40 x 45 x 25	9	0.9
3.	Accelerator button	0.03	Kick-assist system	-	incorporated	8	0.24	incorporated	8	0.24
4.	Brake	0.03	-	-	incorporated	6	0.18	incorporated	6	0.18
5.	Folding mechanism	0.09	Folding axes	no.	9	8	0.72	10	9	0.81
6.	Motor efficiency	0.045	Power	kW	450	8	0.36	500	9	0.405
7.	Battery capacity	0.045	Capacity	Ah	32.5	7	0.315	32.5	7	0.315
8.	Maximum speed	0.06	Speed	km/h	25	5	0.30	35	7	0.42
9.	Modularity	0.12	Joints	-	high	8	0.96	high	8	0.96
10.	Loading electronic devices	0.036	-	-	incorporated	6	0.216	incorporated	7	0.252
11.	Light	0.027	-	-	incorporated	6	0.162	incorporated	6	0.162
12.	Tripod/ monopod	0.027	Handlebar	-	unincorporated	0	0	incorporated	8	0.216
13.	Portable transportation	0.09	Compact storage	cm	40 x 10 x 35	10	0.9	40 x 25 x 45	9	0.81
14.	Simple assembly	0.08	Simplicity of components	-	complicated	4	0.32	average	6	0.48
15.	Difficulty in execution	0.06	Simple production	-	complicated	4	0.24	average	6	0.36
16	Material choosing	0.06	Material content	-	average	5	0.30	low	6	0.36
		$\sum_{i=1}^{n} r_i = 1$				$\Sigma v = 99$ $(\Sigma v)_{ad\,HI} = 0.618$	$\Sigma rv = 6.613$ $(\Sigma rv)_{ad\,HI} = 0.6613$		$\Sigma v = 120$ $(\Sigma v)_{ad\,3} = 0.75$	$\Sigma rv = 7.77$ $(\Sigma rv)_{ad\,3} = 0.777$

Fig. 18 Evaluation matrix for other two concept variants.

Ryundai Ioniq scooter [6]



Variant V_3 [3]

$$\sum_{i=1}^{n} r_i = 1 \quad (6)$$

Comparison of concept variants is done by analyzing the overall values and relative overall values. The optimal solution is considered to have the maximum overall values, in our case variant 3.

Because the evaluation was made for variants of which three are in the concept phase (Hyundai Ioniq scooter is still a prototype not introduced in serial production - launched in 2017), the price was not entered as a differentiating element in the evaluation matrix.

Concept variant no. 3 was optimal because it proposes more improvements:

- The placement of the hub-centric motor on both wheels so that the space is saved for more batteries - having double the power allows for displacement on different terrain;
- The motor can act as a regenerative brake used for recharge the batteries;
- The kick-assist system that uses a circuit board linked to a set of accelerometers; this component make the scooter to augment the movements of the user (detects when the user pushes the scooter to increase speed or can reduce the speed if the user puts the foot on the gound to increase friction and to stop the scooter); with kick-assist feature, the motor develops 17.6 Nm of torque and a power of 390 watts per hour;
- The folding of the wheels on the side;
- Modularity – this aspect influences the fact that scooter is configurable by the user;
- Handlebars are telescopic to reach the user;
- The battery fits inside the platform and have a capacity of 33.5 Ah at 12 V (390 W); the battery is Li-Fe which is one of the least polluting and environmentally friendly battery, meaning that it can be easily recyclable.

5. CONCLUSION

Compared to the existing scooter versions on the market (Hyundai Motors Ioniq scooter, MyWay Compact, Courtesy of emPower Corporation [5]), proposed variant 3 has superior technical characteristics by using kick-assist feature and a larger number of batteries, but keeping weight in the area of tolerances.

The large number of folding axes leads to a reduction in size after folding, which makes it possible to store the scooter in a backpack and its use anywhere, from an airport runway to a mountain trail.

The solution adopted was developed using the discursive working method by iteratively improving the initial solution and adding changes that have led to increasing technical performances and reducing the weight of the electric scooter.

Identifying the important properties of the electric scooter and setting the objectives that characterize the realization of these properties is the first important step in the appreciation of the concept variants.

The evaluation of concept variants eliminated their subjective appreciation by using objective selection criteria (technical, economic and aesthetic), hierarchized in a weighted objectives tree according to their importance in achieving the objectives proposed by the list of requirements.

Use-value analysis implies a multidimensional appreciation because the objectives set out comprise the most diverse points of view (technical, economic and other), the cost of which must be correlated with their different weight in relation to all the functions offered by the product.

In conclusion, the concept proposed by the authors is a new one due to the use of several multifunctional components and folding capacity in a compact volume of small size, the use of space being done in a very efficient manner.

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