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MECHANICAL ENGINEERING | RESEARCH ARTICLE

TRIZ method for innovation applied to an hoverboard

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Abstract: The aim of this work is to complete the QFD analysis carried out in a previous work that aimed to identify the main features that contribute to the success of a modern urban transport means: the hoverboard. Starting from this analysis, through the TRIZ methodology, resolutive principles have been identified for the realization of innovative solutions of the said urban transport means. In practice this analysis aims to manage the next phase of conceptual design realized with the QFD methodology and tries to guide the design process in its next phase. In this work was used the hill model, a characteristic model of the TRIZ methodology, and the technical innovative problems encountered were reformulated in terms of technical contradictions. Subsequently, general principles of inventive solutions were obtained using one of the tools of TRIZ: the matrix of contradiction. Finally, starting from these general principles of solution, innovative constructive solutions have been developed to be applied to the design of an innovative hoverboard.

Subjects: Industrial Engineering & Manufacturing; Mechanical Engineering; Engineering Management; Transport & Vehicle Engineering; Design

Keywords: TRIZ; QFD; urban transportation systems; innovative solution; contradictions; hill model

1. TRIZ for innovative architecture

The TOP-FLOP analysis implemented by L. Frizziero, *Conceptual design of an innovative electric transportation means with QFD, bench marking, top-flop analysis*, Far East Journal of Electronics and Communications, Volume 18 (1), 2018, (Francia, Caligiana, Liverani, Frizziero, & Donnici, 2018; Frizziero, 2018) (Meuli and Raghunath, 1997) allows the identification of 16 main performance features of an innovative electric transportation: the hoverboard. (read 4.1 Bench Marking Analysis: results).

Based on these features, an analysis will be conducted through a TRIZ methodology, that will lead to some innovative architecture of the system-hoverboard (Figure 1,Figure 43-46).

ABOUT THE AUTHOR

Leonardo Frizziero The research group of the authors is involved in Industrial and Mechanical Design. In particular, the research group studies innovative methodologies just like QFD, TRIZ, Design For Six Sigma, Bench Marking, Top-Flop Analysis, etc. Referring to the present paper, the method applied is TRIZ, that is an advanced methodology oriented to find innovation characteristics for new products.

PUBLIC INTEREST STATEMENT

The present paper describes an innovative methodology to design new products. In particular, the method applied, named TRIZ, is able to find new innovative solutions, overcoming technical contradictions, in order to propose new innovative products. TRIZ is a powerful instrument that enterprises and designer should improve in their process for making innovation.

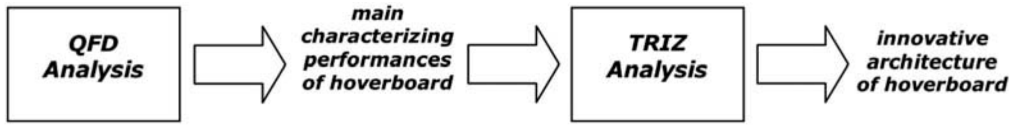


Figure 1. From the QFD analysis to the TRIZ analysis for innovative solutions.

Eight of these features have been preferred over the others because they have the ability to make the hoverboard more powerful (Caligiana, Liverani, Francia, Frizziero, & Donnici, 2017) (Frizziero, Francia, Donnici, Liverani, & Caligiana, 2018). The eight features identified are as follows:

1. Hoverboard speed (km/h)
2. Battery endurance (h)
3. Battery charge time (h)
4. Hoverboard weight (kg)
5. Hoverboard length (mm)
6. Hoverboard width (mm)
7. Hoverboard height (mm)
8. Hoverboard max power (W)

Starting from the features that improve the performance of the hoverboard identified through the QFD analysis, a TRIZ methodology will be applied to find some innovative solutions to improve the hoverboard overall performance (Freddi, 2005).

Improving the eight identified features will lead to the improvement of the hoverboard performance. However, this could lead to a "technical contradiction". A "technical contradiction" is defined as a situation in which the improvement of one feature brings on the deterioration of another feature within the same technical system.

Technical contradictions are a typical aspect of the evolution of a technical system.

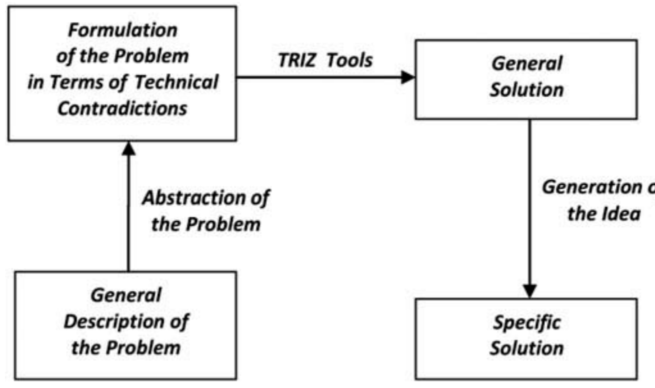
"Contradiction" is also one of the main postulates of TRIZ theory. This theory implies that a contradiction is the most important obstacle that limits the evolution of a technical system. As a consequence, the evolution of technical systems is strongly influenced by the resolution of contradictions.

The technical system analyzed in this study is the system-hoverboard. The goal of the study is to achieve a series of innovative architectures to be applied to the system-hoverboard through a resolution process that involves a series of steps.

The first step of the resolution process, in the TRIZ methodology, is to develop a general description of the problem and to identify the contradictions that prevent the achievement of the "more desirable result". The "more desirable result" is defined as the best possible solution among those achievable [3–5, 8].

The second step of the resolution process is a "good formulation" of the technical contradiction: this is necessary to identify the main problem and to reach an effective solution. It is important to

Figure 2. Hill model.



describe the problem in terms of technical contradiction: the more accurate the description, the more effective the solution.

The third step of the resolution process is to find a general solution for each physical contradiction within the system; the solution will be of a general nature. In this phase of the resolution process the tools developed for Triz by Altshuller (like a matrix of contradiction) will be very useful [6].

The fourth and last step of the resolution process is to translate the general solution into a specific innovative solution.

The resolution process therefore consists of four successive steps and can be represented graphically through the "Hill Model" in Figure 2.

2. The four steps of resolution process

The four steps of the resolution process can be defined as follows:

1. ***General description of the problem***

2. ***Formulation of the problem in terms of technical contradictions***

3. ***Find a general solution***

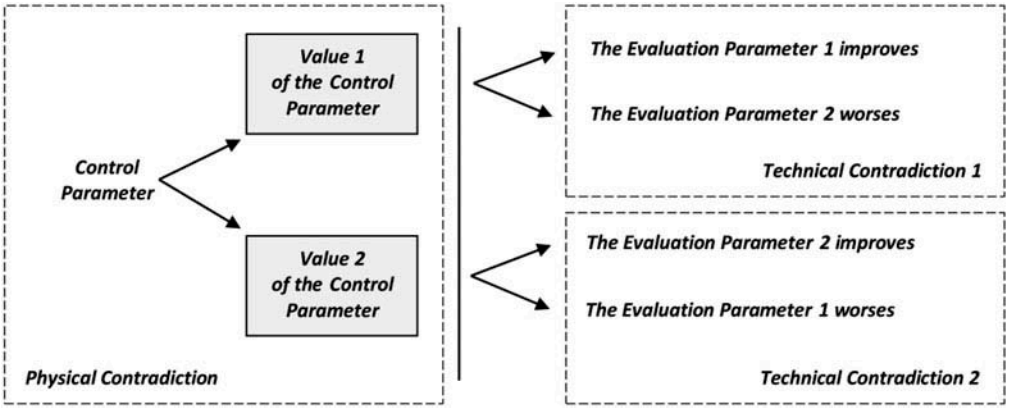
4. ***Translate into a specific innovative solution***

2.1. First step: general description of the problem

A well-defined problem is a problem half solved; at the beginning of the resolution process, it is necessary to create an accurate definition of the problem to be solved to achieve an optimal understanding of the system around the problem. This means that constraints will need to be highlighted to avoid the arising of the contradiction (Renzi, Leali, 2016) (Francia, Caligiana, & Liverani, 2016).

The improvement of the system-hoverboard overall performance involves the improvement of one or more of the following features: the hoverboard speed, the battery life, the charging time, the hoverboard weight, the hoverboard size (the length, the width and the height of the hoverboard) and the hoverboard maximum power. A technical contradiction arises if the process of improving one of the features leads to the detriment of another feature within the system-hoverboard. Solving the technical contradiction will then lead to the improvement of the overall performance of the system-hoverboard.

Figure 3. Model of technical contradiction in according to OTSM-TRIZ theory.



2.2. Second step: formulation of the problem in terms of technical contradiction

A general description of the problem to be solved and the context in which it develops will be followed by including the problem inside the terms of a technical contradiction. The easiest way to look for conflicting parameters is to formulate a series of questions such as

- What's improve ?

- What's worse ?

- Which aspect of the system improves ?

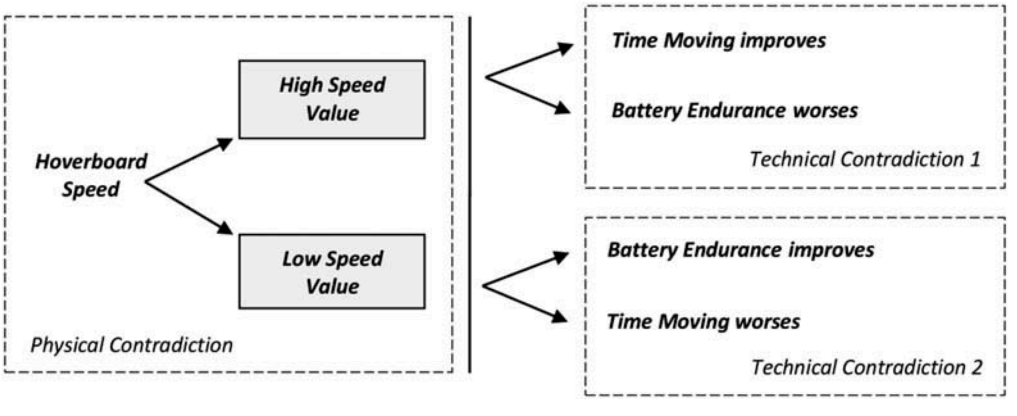
- Which aspect of the system worsens ?

According to OTSM-TRIZ theory (Altshuller, 1994), Figure 3 shows a general model of formulation of the problem in terms of technical contradiction:

Figures 4–9 represent the application of the theoretical model to the system-hoverboard. These diagrams represent each of the eight parameters identified at the beginning of this analysis (see "1.TRIZ for Innovative Architecture") and describe the technical contradictions that may arise by varying the values of such parameters.

The variation of the speed value of the hoverboard between a high value and a low value leads to Contradiction 1 as illustrated in Figure 4.

Figure 4. *Contradiction 1*: Contradiction that result from changing speed values of the hoverboard.



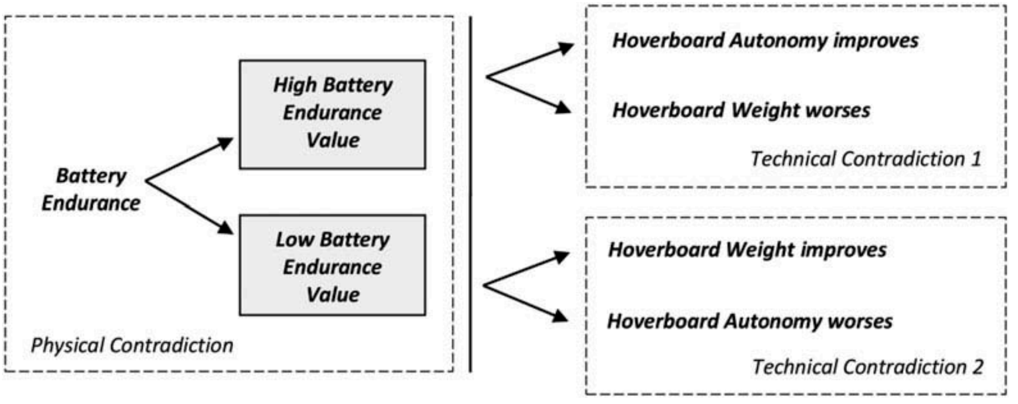


Figure 5. *Contradiction 2*: Contradiction that result from changing battery endurance values of the hoverboard.

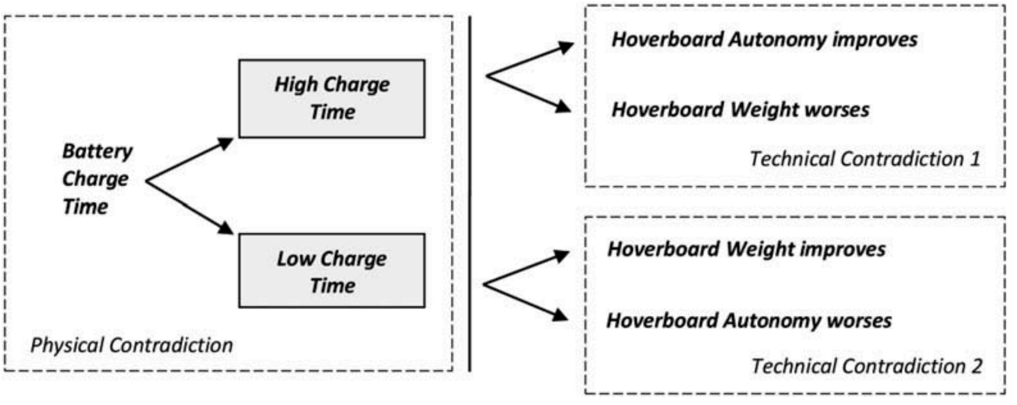


Figure 6. *Contradiction 3*: Contradiction that result from changing battery charge time values of the hoverboard.

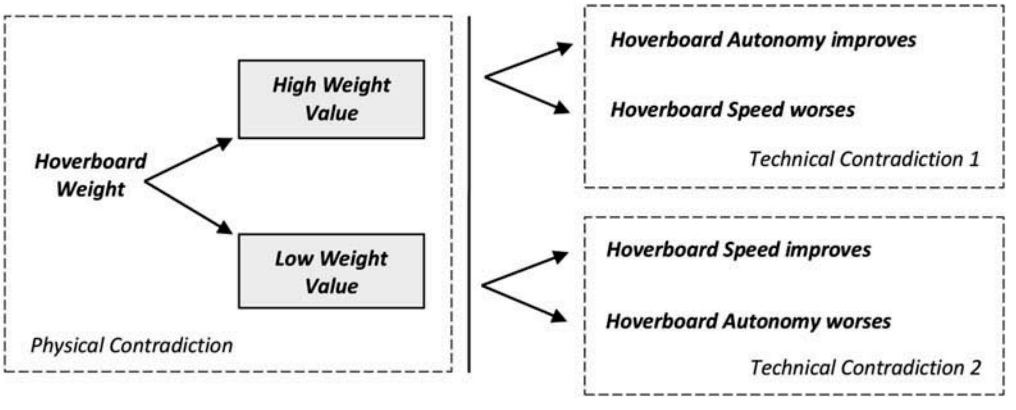


Figure 7. *Contradiction 4*: Contradiction that result from changing weight values of the hoverboard.

The variation of the system's battery life between a high endurance value (implementing a big battery in the hoverboard) and a low endurance value (implementing a small battery in the hoverboard), will lead to Contradiction 2 as illustrated in Figure 5.

The variation of the charge time value of the hoverboard battery between a high charge time value (implementing a big battery in the hoverboard) and a low charge time value (implementing a small battery in the hoverboard), will lead to Contradiction 3 as illustrated in Figure 6.

The variation of the weight value of the hoverboard between a high weight and a low weight value, will lead to Contradiction 4 as illustrated in Figure 7.

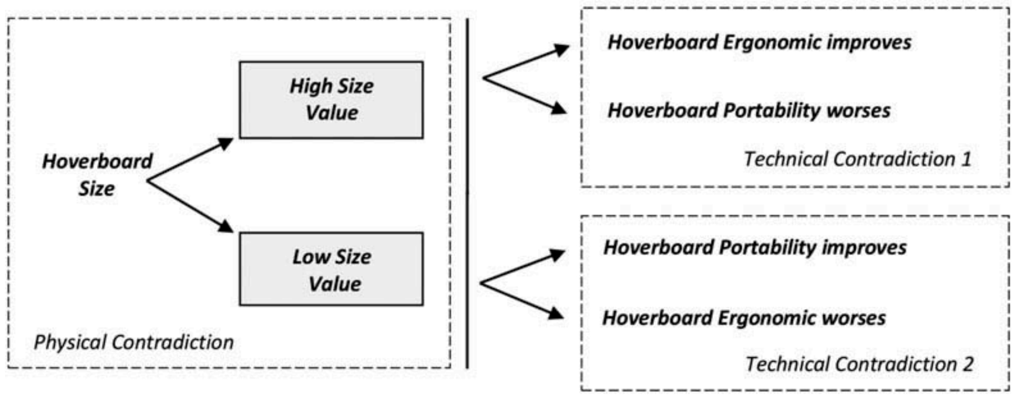


Figure 8. ***Contradiction 5*****: Contradiction that result from changing size values (length, width, height) of the hoverboard.**

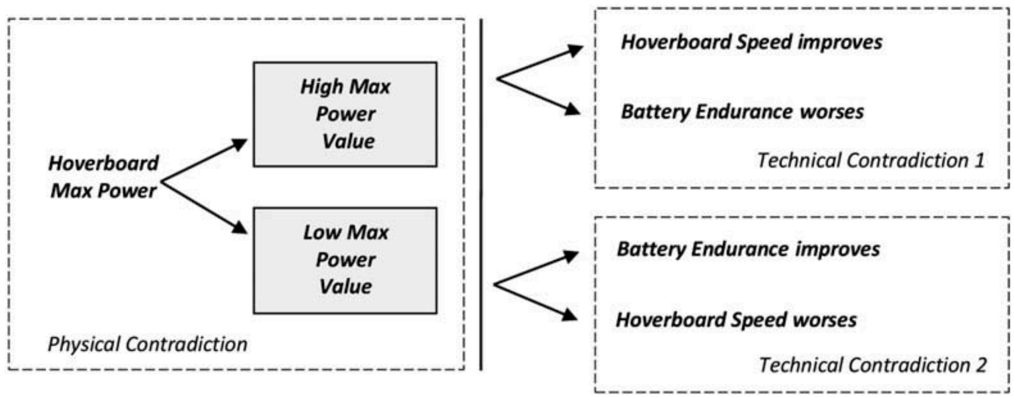


Figure 9. ***Contradiction 6*****: Contradiction that result from changing max power values of the hoverboard.**

The variation of the size value of the hoverboard between a high size and a low size value, will lead to Contradiction 5 as illustrated in Figure 8.

The variation of the max power value of the hoverboard between a high max power and a low max power value, will lead to Contradiction 6 illustrated in Figure 8.

2.3. Third and fourth step: translate into a specific innovative solution and find a general solution

Genrich Altshuller identified 39 technical parameters and 40 inventive principles that can be used to eliminate technical contradictions. The 39 technical parameters and the 40 inventive principles are related to each other through the Altshuller Matrix (or Matrix of Contradictions). The resolution process involves the translation of the technical contradictions, found in the previous steps, into the technical parameters of the Altshuller Matrix. The problem can be described using the 39 technical parameters and a general solution can be found using the 40 inventive principles implemented in the Altshuller Matrix. The 40 Inventive Principles have been formalized to facilitate the use of Altshuller Matrix (or Matrix of Contradictions) and are an important tool for seeking innovative ideas and for solving technical contradictions. The 39 Technical Parameters (or Technical Features) are represented in the 39 lines and in the 39 columns of the Altshuller Matrix and can be used to describe the technical contradictions of any inventive problem. There are other parameters that can be used but these 39 technical parameters are the most commonly used. The Hill Model scheme shown in Figure 2 can now be translated into the following scheme (Figure 10).

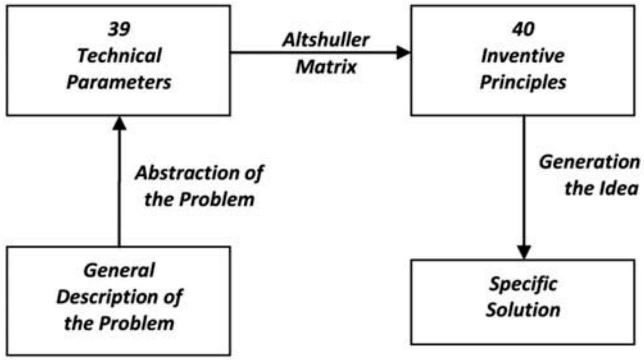


Figure 10. Hill model "modified".

The Altshuller Matrix or Matrix of Contradictions (Figure 11), shows the parameters that worsen the contradiction in the 39 lines while the parameters that improve the contradiction are shown in the 39 columns.

Every contradiction can now be analyzed; within the Altshuller Matrix it is important to consider both the parameters that worsen and the ones that improve the contradiction. The inventive principles that can solve the technical contradiction can be identified through the Matrix and a path toward a solution or problem solving ideas can be generated.

2.3.1. Contradiction 1 and first indication of solution

Contradiction 1 shows that there is a worsening of the parameter "loss of time" and an improvement of the parameter "usage of energy by a moving object" (Figure 12).

The inventive principles that can be derived from the Altshuller matrix (Figure 12) are as follows:

Principle 18—Mechanical Vibration

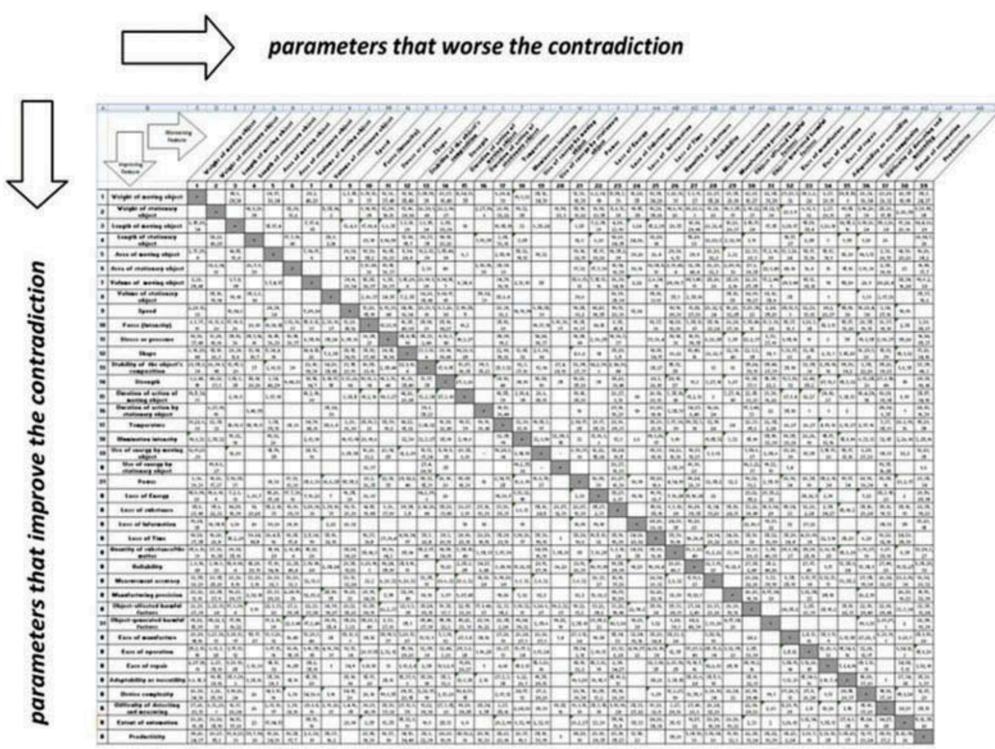


Figure 11. Matrix of contradictions.

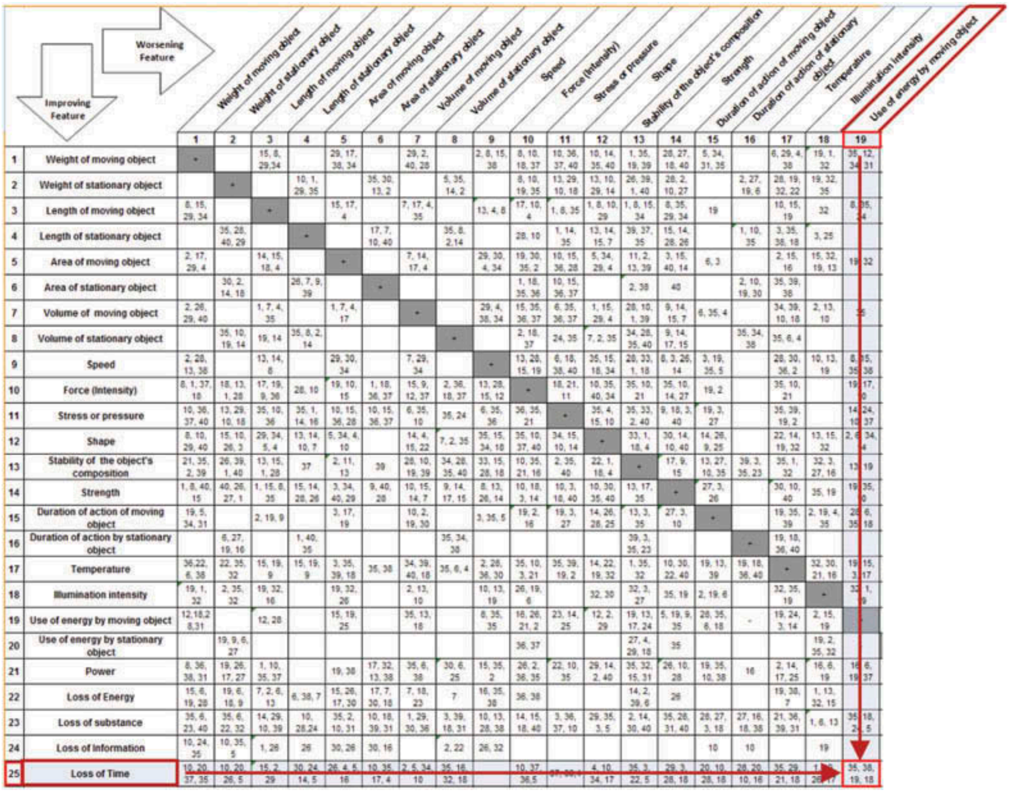


Figure 12. Contradiction 1 (first indication of solution).

Principle 19—Periodic Action

Principle 35—Parameter Changes

Principle 38—Strong Oxidant

If we consider Principles 18 (*Mechanical Vibration*), we might think to replace the DC electric motor with a piezoelectric motor (Figure 13).

The operating principle of a piezoelectric motor is shown in Figure 13(a–e).

According to Principles 19 (*Periodic Action)* and 35 (P*arameter Change*), it might be interesting to apply an AC electric motor to the moving object (Figure 14), instead of a DC electric motor (Figure 15); the change of current could be done by using an inverter.

Principle 38 (*Strong Oxidant*) does not suggest inventive principles in Contradiction 1.

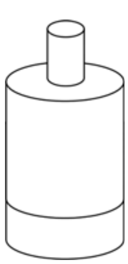


Figure 13. Piezoelectric Motor. (a) Piezoelectric motor—operating principle. (b) Piezoelectric Motor—operating principle. (c) Piezoelectric Motor—operating principle. (d) Piezoelectric Motor—operating principle. (e) Piezoelectric Motor—operating principle.

Figure 13. (Continued).

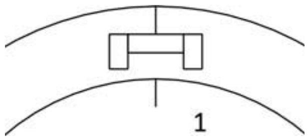


Figure 13. (Continued).

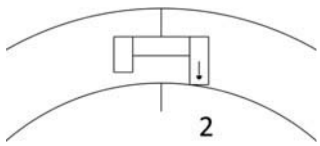


Figure 13. (Continued).

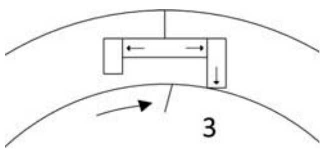


Figure 13. (Continued).

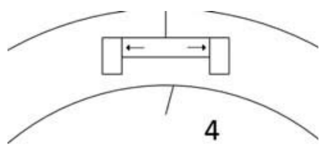


Figure 13. (Continued).

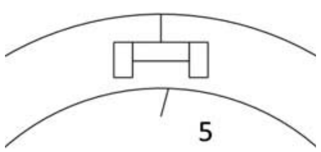


Figure 14. AC electric motor.

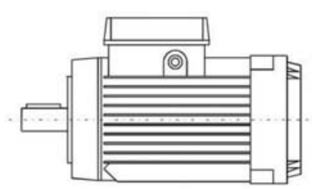
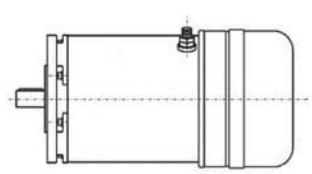


Figure 15. DC electric motor.



2.3.2. Contradiction 1 and second indication of solution

Contradiction 1 indicates parameter " Duration of action of moving object " tends to worsen while parameter "Usage of energy by a moving object" tends to improve (Figure 16).

The inventive principles that can be derived from the Altshuller matrix (Figure 16) are as follows:

Principle 6—Universality

Principle 18—Mechanical Vibration

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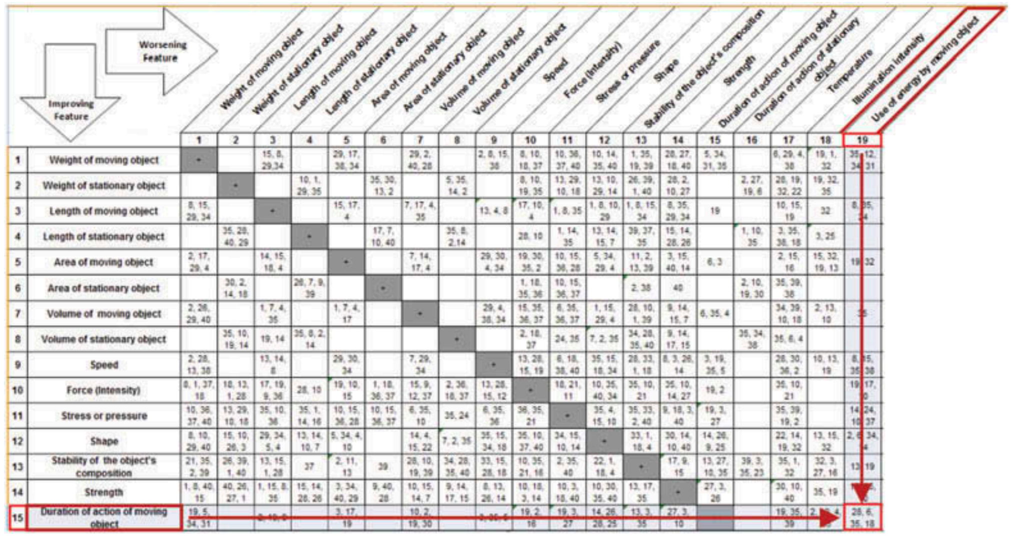
Figure 16. Contradiction 1 (second indication of solution).



Improving Feature ↓ / Worsening Feature →		1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	4 Length of stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object	8 Volume of stationary object	9 Speed	10 Force (Intensity)	11 Stress or Pressure	12 Shape	13 Stability of the object's composition	14 Strength	15 Duration of action of moving object	16 Duration of action of stationary object	17 Temperature	18 Illumination Intensity	19 Use of energy by moving object
1	Weight of moving object	-		15, 8, 29,34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, 38	8, 10, 18, 37	10, 36, 37, 40	10, 14, 35, 40	1, 35, 19, 39	28, 27, 18, 40	5, 34, 31, 35		6, 29, 4, 38	19, 1, 32	35, 12, 34, 31
2	Weight of stationary object		-		10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2		8, 10, 19, 35	13, 29, 10, 18	13, 10, 29, 14	26, 39, 1, 40	28, 2, 10, 27		2, 27, 19, 6	28, 19, 32, 22	19, 32, 35	
3	Length of moving object	8, 15, 29, 34		-		15, 17, 4		7, 17, 4, 35		13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 10, 29	1, 8, 15, 34	8, 35, 29, 34	19		10, 15, 19	32	8, 35, 24
4	Length of stationary object		35, 28, 40, 29		-		17, 7, 10, 40		35, 8, 2,14		28, 10	1, 14, 35	13, 14, 15, 7	39, 37, 35	15, 14, 28, 26		1, 10, 35	3, 35, 38, 18	3, 25	
5	Area of moving object	2, 17, 29, 4		14, 15, 18, 4		-		7, 14, 17, 4		29, 30, 4, 34	19, 30, 35, 2	10, 15, 36, 28	5, 34, 29, 4	11, 2, 13, 39	3, 15, 40, 14	6, 3		2, 15, 16	15, 32, 19, 13	19, 32
6	Area of stationary object		30, 2, 14, 18		26, 7, 9, 39		-				1, 18, 35, 36	10, 15, 36, 37		2, 38	40		2, 10, 19, 30	35, 39, 38		
7	Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17		-		29, 4, 38, 34	15, 35, 36, 37	6, 35, 36, 37	1, 15, 29, 4	28, 10, 1, 39	9, 14, 15, 7	6, 35, 4		34, 39, 10, 18	2, 13, 10	35
8	Volume of stationary object		35, 10, 19, 14	19, 14	35, 8, 2, 14				-		2, 18, 37	24, 35	7, 2, 35	34, 28, 35, 40	9, 14, 17, 15		35, 34, 38	35, 6, 4		
9	Speed	2, 28, 13, 38		13, 14, 8		29, 30, 34		7, 29, 34		-	13, 28, 15, 19	6, 18, 38, 40	35, 15, 18, 34	28, 33, 1, 18	8, 3, 26, 14	3, 19, 35, 5		28, 30, 36, 2	10, 13, 19	8, 15, 35, 38
10	Force (Intensity)	8, 1, 37, 18	18, 13, 1, 28	17, 19, 9, 36	28, 10	19, 10, 15	1, 18, 36, 37	15, 9, 12, 37	2, 36, 18, 37	13, 28, 15, 12	-	18, 21, 11	10, 35, 40, 34	35, 10, 21	35, 10, 14, 27	19, 2		35, 10, 21		19, 17, 10
11	Stress or pressure	10, 36, 37, 40	13, 29, 10, 18	35, 10, 36	35, 1, 14, 16	10, 15, 36, 28	10, 15, 36, 37	6, 35, 10	35, 24	6, 35, 36	36, 35, 21	-	35, 4, 15, 10	35, 33, 2, 40	9, 18, 3, 40	19, 3, 27		35, 39, 19, 2		14, 24, 10, 37
12	Shape	8, 10, 29, 40	15, 10, 26, 3	29, 34, 5, 4	13, 14, 10, 7	5, 34, 4, 10		14, 4, 15, 22	7, 2, 35	35, 15, 34, 18	35, 10, 37, 40	34, 15, 10, 14	-	33, 1, 18, 4	30, 14, 10, 40	14, 26, 9, 25		22, 14, 19, 32	13, 15, 32	2, 6, 34, 14
13	Stability of the object's composition	21, 35, 2, 39	26, 39, 1, 40	13, 15, 1, 28	37	2, 11, 13	39	28, 10, 19, 39	34, 28, 35, 40	33, 15, 28, 18	10, 35, 21, 16	2, 35, 40	22, 1, 18, 4	-	17, 9, 15	13, 27, 10, 35	39, 3, 35, 23	35, 1, 32	32, 3, 27, 16	13, 19
14	Strength	1, 8, 40, 15	40, 26, 27, 1	1, 15, 8, 35	15, 14, 28, 26	3, 34, 40, 29	9, 40, 28	10, 15, 14, 7	9, 14, 17, 15	8, 13, 26, 14	10, 18, 3, 14	10, 3, 18, 40	10, 30, 35, 40	13, 17, 35	-	27, 3, 26		30, 10, 40	35, 19	[illegible]
15	Duration of action of moving object	19, 5, 34, 31		2, 19, 9		3, 17, 19		10, 2, 19, 30		3, 35, 5	19, 2, 16	19, 3, 27	14, 26, 28, 25	13, 3, 35	27, 3, 10			19, 35, 39	2, 19, 4	28, 6, 35, 18

Principle 28—Mechanics Substitution

Principle 35—Parameter Changes

Principles 6 (*Universality*) and 28 (*Mechanics Substitution*), suggest the replacement of the mechanical motion system of the hoverboard with a magnetic levitation system (Figure 17).

Considering the principle of magnetic levitation trains (Figure 18) in which there is no contact between the monorail and the train itself, an innovative solution is represented by a system in which an "hoverboard table" (a change of a classical hoverboard with wheels) make the part of the train, and a rail, inserted in the urban paths, make the part of the monorail (Figure 19(a,b)).

This kind of solution would lead to the elimination of wheels, suspensions, engine and transmission of the hoverboard; the driving force is inserted directly into the monorail.

Principles 28 (Mechanics Substitution), shows that the mechanical motion system of the hoverboard can be replaced by the Propeller Motors system (Figure 20).

Principle 18 (*Mechanical Vibration) and Principle 35 (Parameter Changes)* do not suggest inventive principles in Contradiction 1.

2.3.3. Contradiction 2, Contradiction 3 and third indication of solution

Contradictions 2 and 3 are based on the same technical parameters. Parameter "Use of energy by moving object " tends to worsen, while parameter " Weight of moving object " tend to improve (Figure 21):

Figure 17. Magnetic levitation.

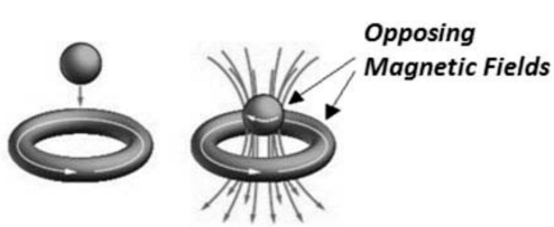


Figure 18. Magnetic levitation train.

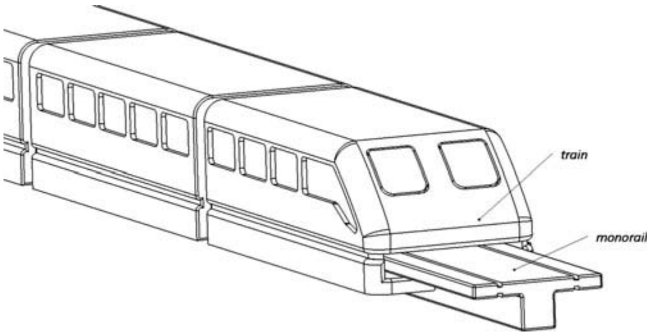


Figure 19. (a) Hoverboard table with magnetic levitation. (b) Hoverboard table with magnetic levitation.

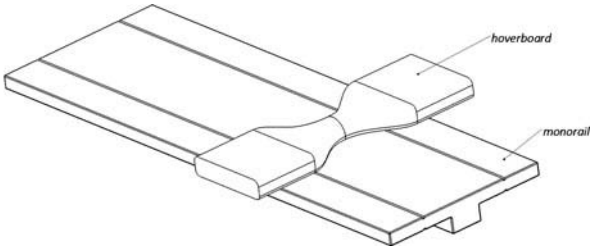


Figure 19. (Continued).

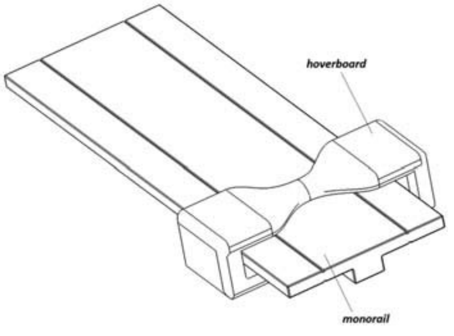
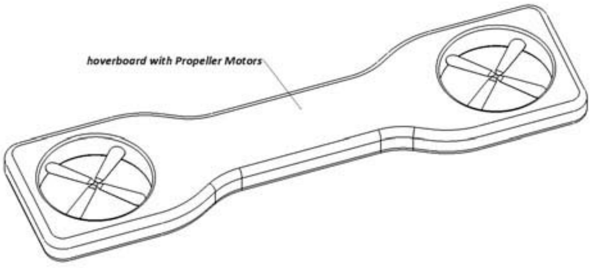


Figure 20. Hoverboard table with propeller motors.



The inventive principles that can be derived from the Altshuller matrix (Figure 21) are as follows:

Principle 2—Taking out

Principle 8—Anti-Weight

Principle 12—Equipotentiality, Remove Stress

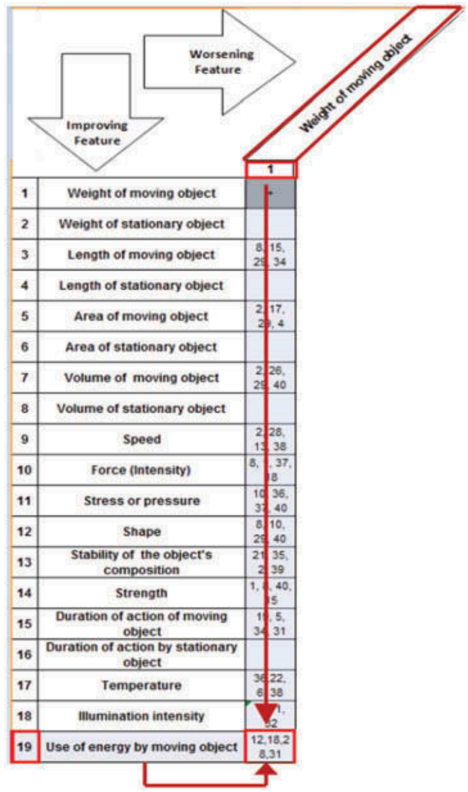


Figure 21. Contradictions 2 and 3 (third indication of solution).

Principle 18—Mechanical Vibration

Principle 31—Porous materials

Considering the Principles 2 (Taking out), we can think of extracting out of the hoverboard some of its parts, such as its source of energy (the battery) (Figure 22). "Urban paths" can be provided with "DC-powered binaries", and "hoverboard connected brushes" can be provided for passing current that will power the DC motor on the hoverboard (Figure 23). Once the battery is removed from the hoverboard, its weight is greatly reduced and its performance is therefore enhanced

Considering the Principles 8 (Anti-Weight), we might think to apply anti-weights to the hoverboard in order to make it lighter. The anti-weight principle can be applied for example with a power foils kite (Figure 24).

Considering combination of principles 2 and 8: after being removed, the battery can be carried inside a backpack for the comfort of the user (Figure 25).

and the anti-weight can be applied directly to the battery contained in the backpack (Figure 26).

It's possible to take a further step by combining the backpack and the anti-weight into a single object: an "inflatable backpack" with the ability to hold the battery in the air (Figure 27).

Principle 12 (Equipotentiality, Remove Stress) suggests the usage of a the gravitational field, that is, the weight of the hoverboard passenger (Figure 28), in order to activate the piezoelectric components considered under the Principle 18 (2.3.1 Contradiction 1 and first indication of solution—Figure 13).

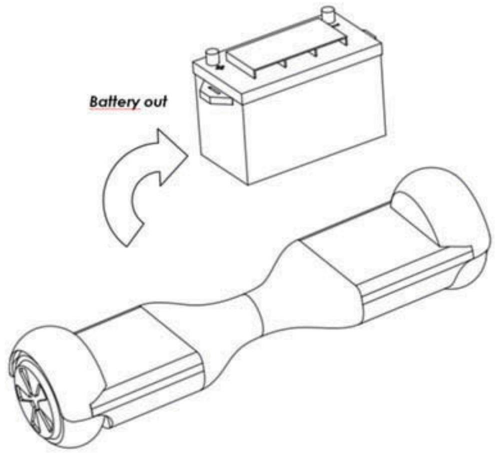


Figure 22. Hoverboard without battery.

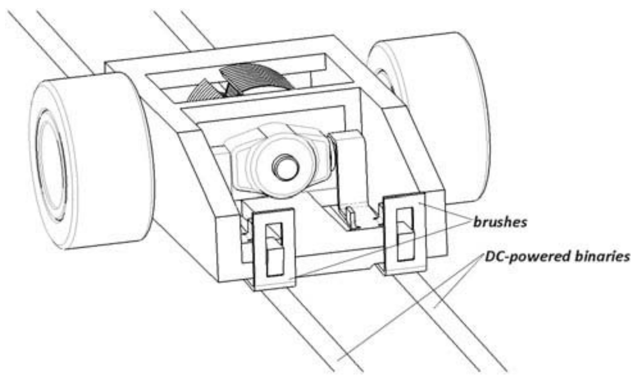


Figure 23. Hoverboard without battery and with brushes and DC-powered binaries.

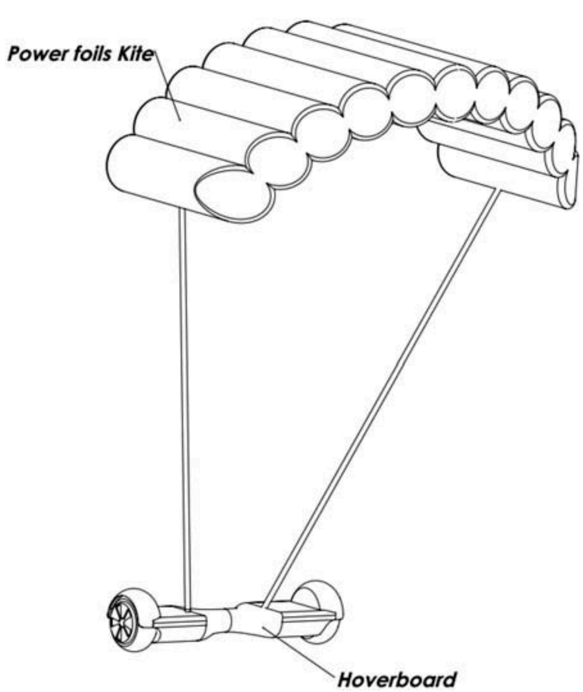


Figure 24. Hoverboard with anti-weights.

Figure 25. Hoverboard with the battery into a backpack.

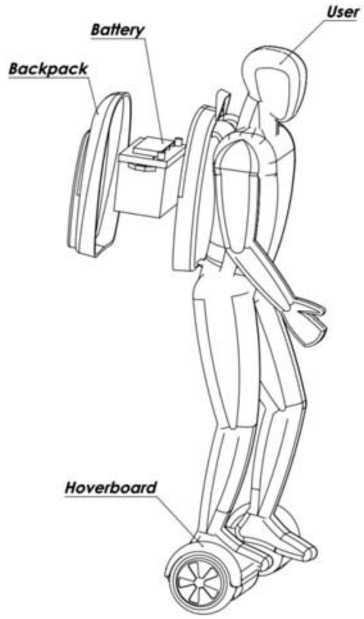
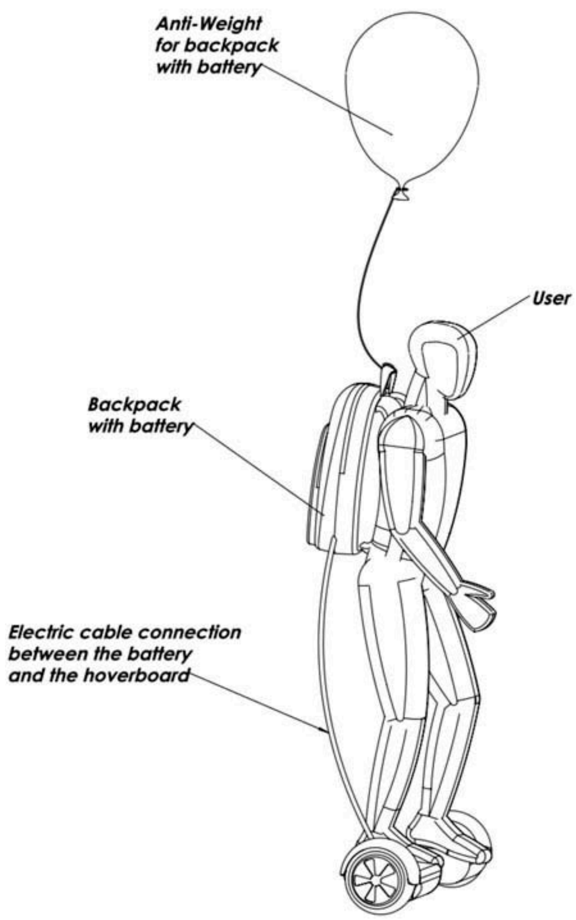


Figure 26. Hoverboard with the battery into a backpack and anti-weight.



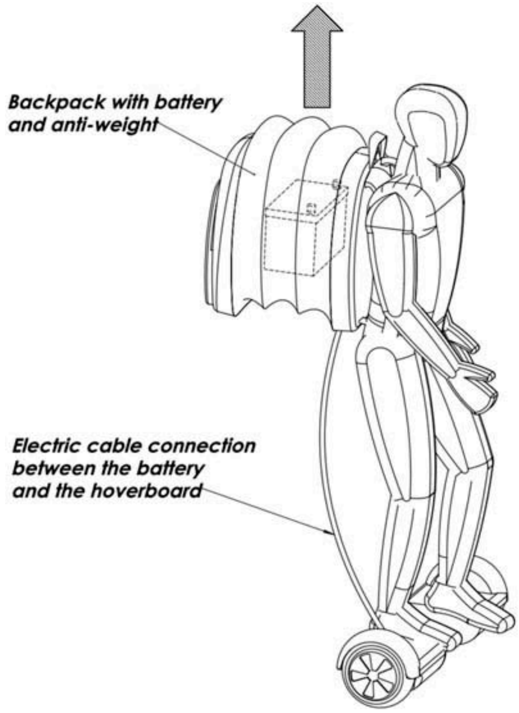


Figure 27. Hoverboard and Backpack with anti-weight and battery inside.

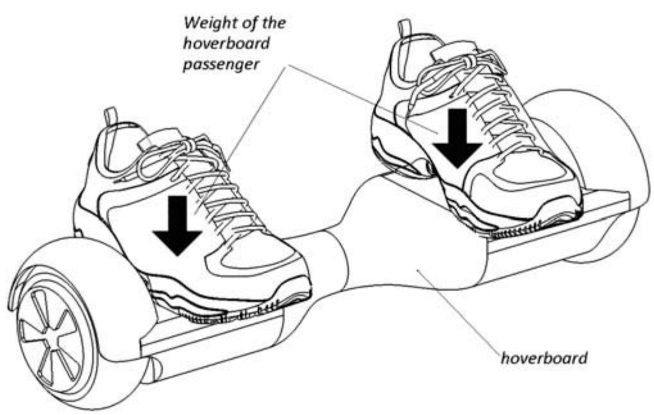


Figure 28. Hoverboard table with the passenger weight to activate the piezoelectric components.

Principles 31 (Porous materials), suggests a hoverboard with a porous material structure as shown in Figure 29. This allows you to get a very light hoverboard.

The combination of principles 31 and 6 (*Universality*), so we can think of replacing the hoverboard batteries with fuel cells (Figure 30).

and using the hoverboard's porous structure as a hydrogen tank (Figure 31).

2.3.4. Contradiction 4 and fourth indication of solution

Contradiction 4 suggests that parameter "Use of energy by moving object " tend to worsen, while parameter " Speed "tends to improve (Figure 32).

The inventive principles that can be derived from the Altshuller matrix (Figure 32) are as follows:

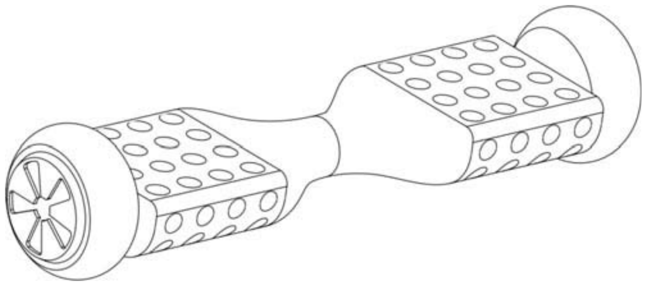


Figure 29. Hoverboard with a porous structure.

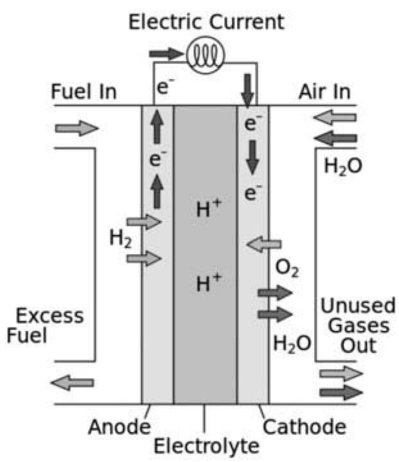


Figure 30. Fuel cells.

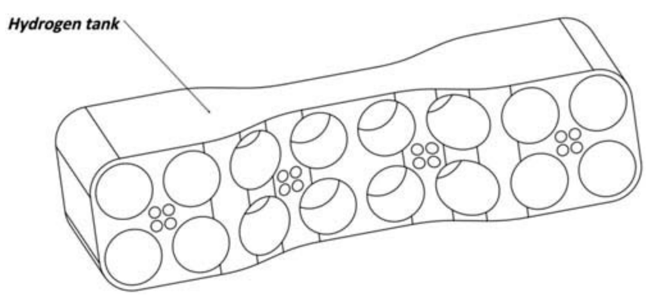


Figure 31. Hoverboard's porous structure as a hydrogen tank.

Principle 8—Anti-Weight

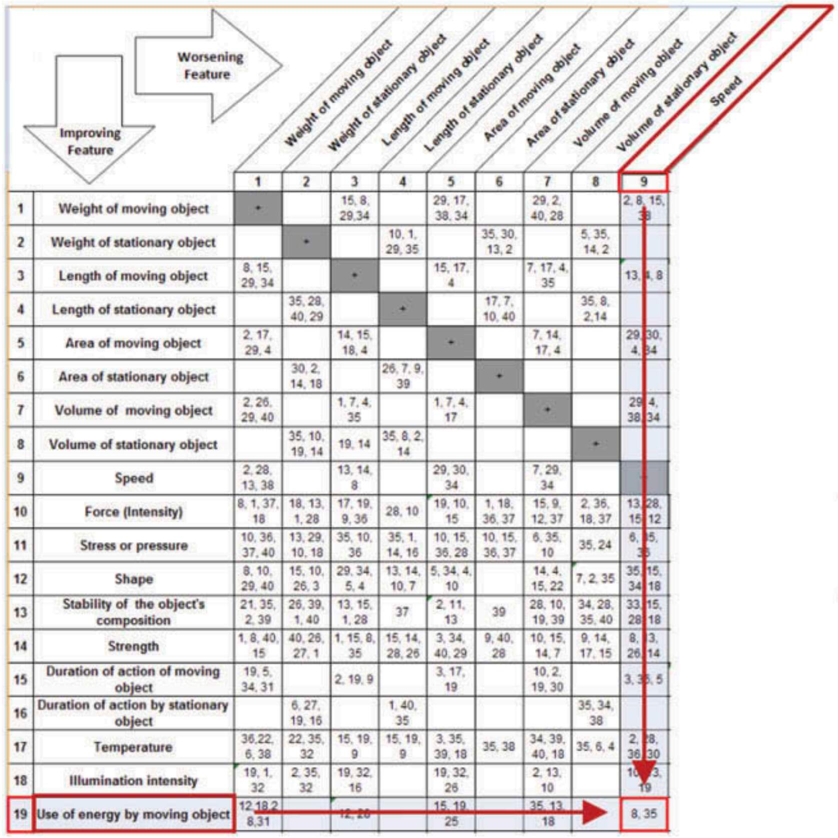
Principle 35—Parameter Changes

Principles 8 and 35 have been analyzed previously (Principles 8 in the paragraph 2.3.3 "Contradictions 2 and 3; third indication of solution"; Principles 35 in the paragraph 2.3.1 "Contradiction 1 and first indication of solution").

2.3.5. Contradiction 5 and fifth indication of solution

Contradiction 5 shown in Figure 8 suggests that parameter "Loss of Energy" tends to worsen, while parameter "Speed" tends to improve(Figure 33).

The inventive principles that can be derived from the Altshuller matrix (Figure 33) are as follows:



		1	2	3	4	5	6	7	8	9
1	Weight of moving object	*		15, 8, 29,34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, 38
2	Weight of stationary object		*		10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2	
3	Length of moving object	8, 15, 29, 34		*		15, 17, 4		7, 17, 4, 35		13, 4, 8
4	Length of stationary object		35, 28, 40, 29		*		17, 7, 10, 40		35, 8, 2,14	
5	Area of moving object	2, 17, 29, 4		14, 15, 18, 4		*		7, 14, 17, 4		29, 30, 4, 34
6	Area of stationary object		30, 2, 14, 18		26, 7, 9, 39		*			
7	Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17		*		29, 4, 38, 34
8	Volume of stationary object		35, 10, 19, 14	19, 14	35, 8, 2, 14				*	
9	Speed	2, 28, 13, 38		13, 14, 8		29, 30, 34		7, 29, 34		*
10	Force (Intensity)	8, 1, 37, 18	18, 13, 1, 28	17, 19, 9, 36	28, 10	19, 10, 15	1, 18, 36, 37	15, 9, 12, 37	2, 36, 18, 37	13, 28, 15, 12
11	Stress or pressure	10, 36, 37, 40	13, 29, 10, 18	35, 10, 36	35, 1, 14, 16	10, 15, 36, 28	10, 15, 36, 37	6, 35, 10	35, 24	6, 35, 36
12	Shape	8, 10, 29, 40	15, 10, 26, 3	29, 34, 5, 4	13, 14, 10, 7	5, 34, 4, 10		14, 4, 15, 22	7, 2, 35	35, 15, 34, 18
13	Stability of the object's composition	21, 35, 2, 39	26, 39, 1, 40	13, 15, 1, 28	37	2, 11, 13	39	28, 10, 19, 39	34, 28, 35, 40	33, 15, 28, 18
14	Strength	1, 8, 40, 15	40, 26, 27, 1	1, 15, 8, 35	15, 14, 28, 26	3, 34, 40, 29	9, 40, 28	10, 15, 14, 7	9, 14, 17, 15	8, 13, 26, 14
15	Duration of action of moving object	19, 5, 34, 31		2, 19, 9		3, 17, 19		10, 2, 19, 30		3, 35, 5
16	Duration of action by stationary object		6, 27, 19, 16		1, 40, 35				35, 34, 38	
17	Temperature	36,22, 6, 38	22, 35, 32	15, 19, 9	15, 19, 9	3, 35, 39, 18	35, 38	34, 39, 40, 18	35, 6, 4	2, 28, 36, 30
18	Illumination intensity	19, 1, 32	2, 35, 32	19, 32, 16		19, 32, 26		2, 13, 10		10, 13, 19
19	Use of energy by moving object	12,18,2 8,31		12, 28		15, 19, 25		35, 13, 18		8, 35

Figure 32. Contradiction 4 (fourth indication of solution).

Principle 16—Partial or excessive actions

Principle 35—Parameter Changes

Principle 38—Strong oxidants

Principles 16 (*Partial or excessive actions*), suggests a hoverboard with a modular structure (similar to the "LEGO" structure) with remarkable dimensions (hoverboard in over-size Figure 34) provided to the user.

The hoverboard is modular and adjustable to the size required for the user (hoverboard in minimum-size Figure 35).

Principle 35 and 38 have been analyzed previously in the paragraph 2.3.1 "Contradiction 1 and first indication of solution".

2.3.6. Contradiction 5 and sixth indication of solution

Contradiction 5 shown in Figure 8 suggests that parameter "Adaptability or Versatility" tends to worsen, while parameter "Ease of operation" tends to improve (Figure 36).

The inventive principles that can be derived from the Altshuller matrix (Figure 36) are as follows:

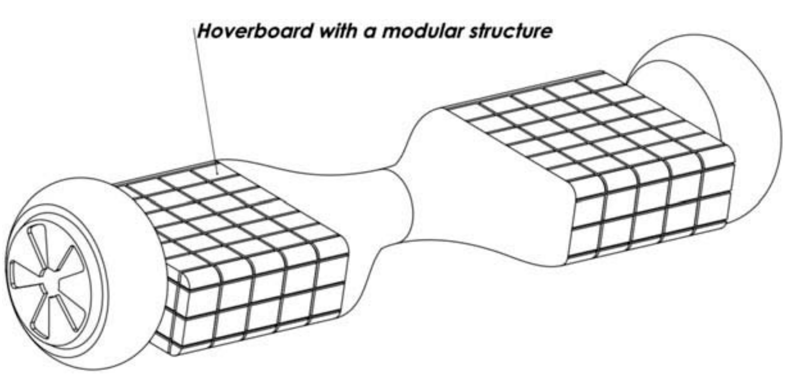
Principle 1—Segmentation

Principle 15—Dynamics

Figure 33. Contradiction 5 (fifth indication of solution).

	Improving Feature / Worsening Feature	1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	4 Length of stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object	8 Volume of stationary object	9 Speed
1	Weight of moving object	+		15, 8, 29,34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, [illegible]8
2	Weight of stationary object		+		10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2	
3	Length of moving object	8, 15, 29, 34		+		15, 17, 4		7, 17, 4, 35		13[illegible]4, 8
4	Length of stationary object		35, 28, 40, 29		+		17, 7, 10, 40		35, 8, 2,14	
5	Area of moving object	2, 17, 29, 4		14, 15, 18, 4		+		7, 14, 17, 4		29[illegible]30, 4[illegible]34
6	Area of stationary object		30, 2, 14, 18		26, 7, 9, 39		+			
7	Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17		+		2[illegible], 4, 38[illegible]34
8	Volume of stationary object		35, 10, 19, 14	19, 14	35, 8, 2, 14				+	
9	Speed	2, 28, 13, 38		13, 14, 8		29, 30, 34		7, 29, 34		+
10	Force (Intensity)	8, 1, 37, 18	18, 13, 1, 28	17, 19, 9, 36	28, 10	19, 10, 15	1, 18, 36, 37	15, 9, 12, 37	2, 36, 18, 37	13[illegible]28, 15[illegible]12
11	Stress or pressure	10, 36, 37, 40	13, 29, 10, 18	35, 10, 36	35, 1, 14, 16	10, 15, 36, 28	10, 15, 36, 37	6, 35, 10	35, 24	6,[illegible]35, [illegible]6
12	Shape	8, 10, 29, 40	15, 10, 26, 3	29, 34, 5, 4	13, 14, 10, 7	5, 34, 4, 10		14, 4, 15, 22	7, 2, 35	35[illegible]15, 34[illegible]18
13	Stability of the object's composition	21, 35, 2, 39	26, 39, 1, 40	13, 15, 1, 28	37	2, 11, 13	39	28, 10, 19, 39	34, 28, 35, 40	33[illegible]15, 28[illegible]18
14	Strength	1, 8, 40, 15	40, 26, 27, 1	1, 15, 8, 35	15, 14, 28, 26	3, 34, 40, 29	9, 40, 28	10, 15, 14, 7	9, 14, 17, 15	8,[illegible]13, 26[illegible]14
15	Duration of action of moving object	19, 5, 34, 31		2, 19, 9		3, 17, 19		10, 2, 19, 30		3,[illegible]5, 5
16	Duration of action by stationary object		6, 27, 19, 16		1, 40, 35				35, 34, 38	
17	Temperature	36,22, 6, 38	22, 35, 32	15, 19, 9	15, 19, 9	3, 35, 39, 18	35, 38	34, 39, 40, 18	35, 6, 4	2,[illegible]28, 36[illegible]30
18	Illumination intensity	19, 1, 32	2, 35, 32	19, 32, 16		19, 32, 26		2, 13, 10		10[illegible]13, [illegible]9
19	Use of energy by moving object	12,18,2 8,31		12, 28		15, 19, 25		35, 13, 18		8[illegible]35
20	Use of energy by stationary object		19, 9, 6, 27							
21	Power	8, 36, 38, 31	19, 26, 17, 27	1, 10, 35, 37		19, 38	17, 32, 13, 38	35, 6, 38	30, 6, 25	1[illegible]35, 2
22	Loss of Energy	15, 6, 19, 28	19, 6, 18, 9	7, 2, 6, 13	6, 38, 7	15, 26, 17, 30	17, 7, 30, 18	7, 18, 23		16, 35, 38

Figure 34. Modular hoverboard in over-size.



Principle 16—Partial or excessive actions

Principle 34—Discarding and recovering

A combination of Principle 1 (Segmentation) and Principle 15 (Dynamics), suggests building the hoverboard so that it can be disassembled into different parts (Figure 37). The different parts of the

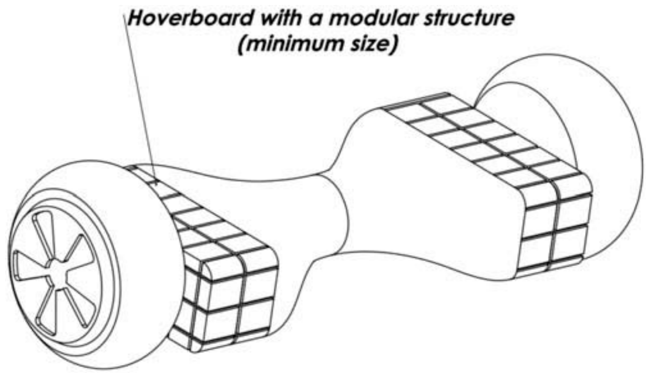


Figure 35. Modular hoverboard in minimum-size.

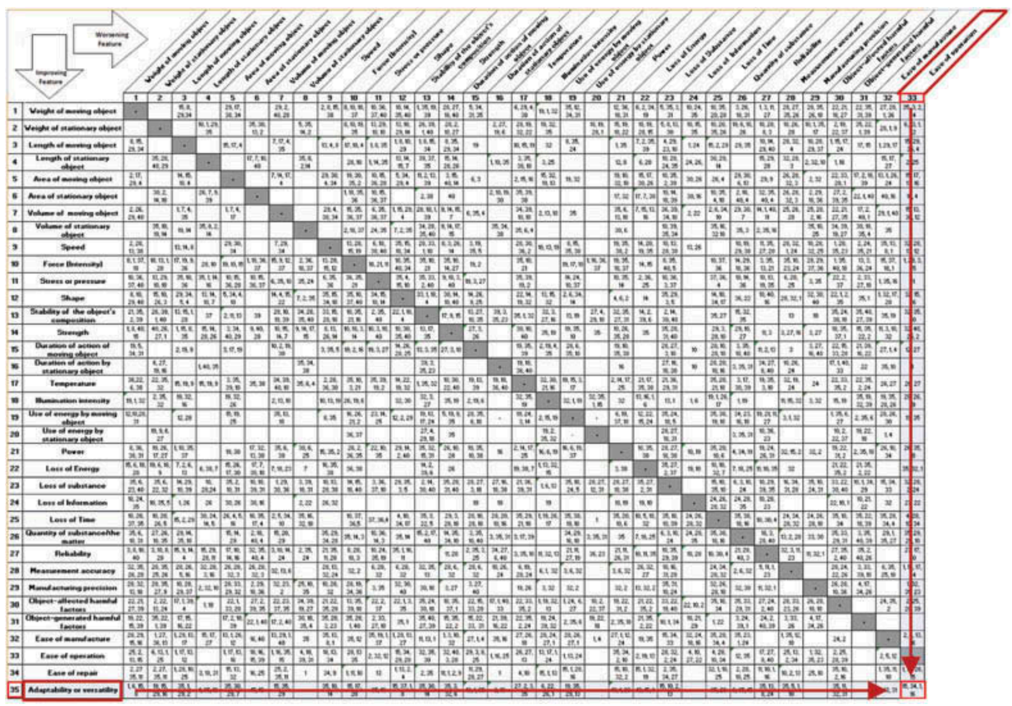


Figure 36. Contradiction 5 (sixth indication of solution).

hoverboard can be joined or disassembled through quick plugs to make the process faster and the hoverboard easily transportable.

Principle 16 (Partial or excessive actions) does not suggest inventive principles in Contradiction 5 [9].

Principle 34 (Discarding and recovering) suggests using rechargeable batteries that can be easily removed from the hoverboard and replaced by other rechargeable batteries in specific exchange and charging stations, placed in different locations within the urban network (Figure 38).

Again, Principle 34 (Discarding and recovering), suggests the installation of a battery charging system on the hoverboard; this system has the ability to self charge when moving downhill and when braking.

Finally, Principle 34 (Discarding and recovering), suggests to mount a battery charging system which works through solar panels placed over the hoverboard, so that it can be recharged at rest (Figure 39).

Figure 37. Hoverboard decomposed into different parts.

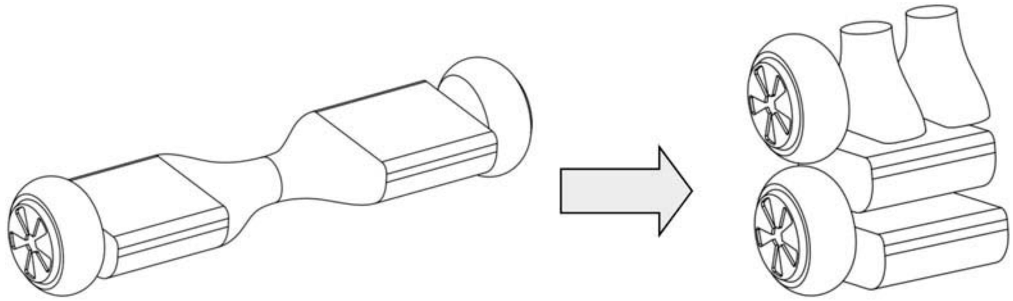


Figure 38. Hoverboard with rechargeable batteries and charging stations.

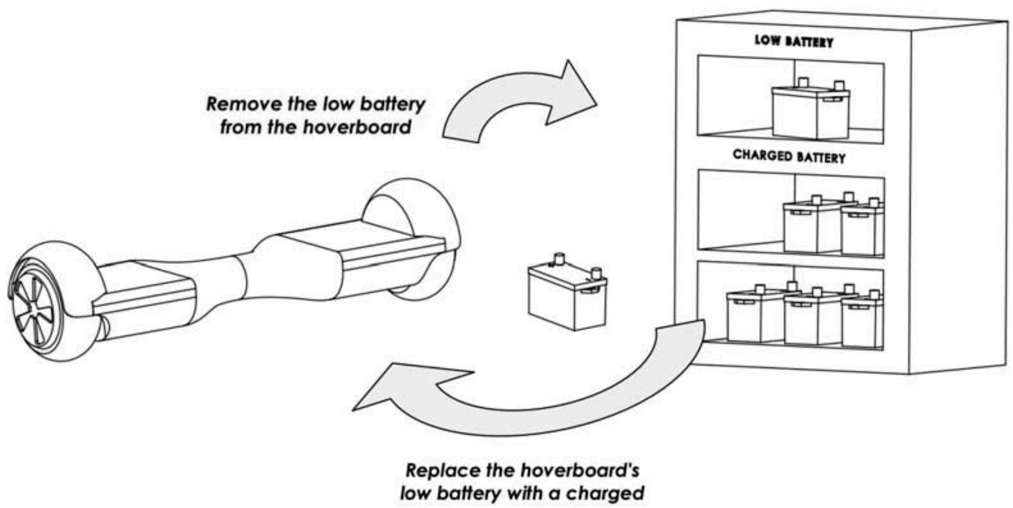
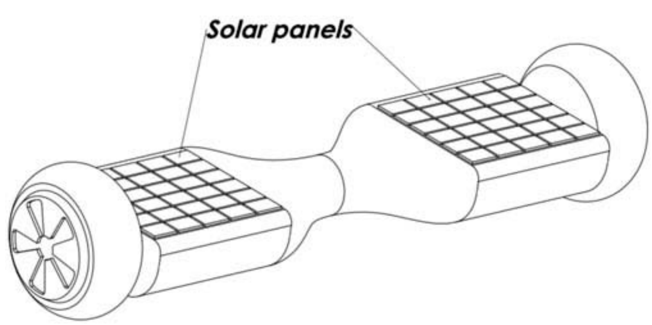


Figure 39. Hoverboard with solar panels.



2.3.7. Contradiction 6 and seventh indication of solution

Contradiction 6 suggests that parameter "Speed" tends to worsen, while parameter "Loss of Energy" tends to improve (Figure 40).

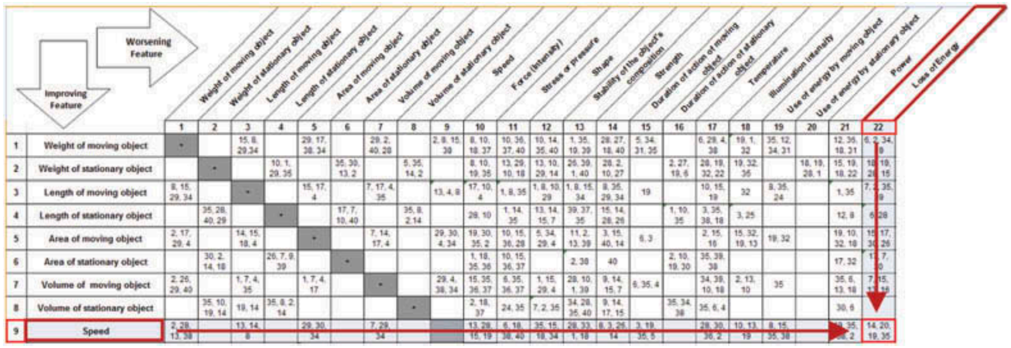
The inventive principles that can be derived from the Altshuller matrix (Figure 36) are as follows:

Principle 14—Spheroidality, Curvature

Principle 19—Periodic Action

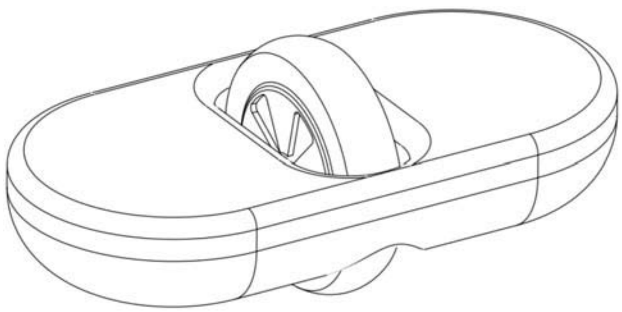
Principle 20—Continuity of Useful Action

Figure 40. Contradiction 6.



Improving Feature ↓ / Worsening Feature →		1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	4 Length of stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object	8 Volume of stationary object	9 Speed	10 Force (Intensity)	11 Stress or pressure	12 Shape	13 Stability of the object's composition	14 Strength	15 Duration of action of moving object	16 Duration of action of stationary object	17 Temperature	18 Illumination intensity	19 Use of energy by moving object	20 Use of energy by stationary object	21 Power	22 Loss of Energy
1	Weight of moving object	*		15, 8, 29,34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, 38	8, 10, 18, 37	10, 36, 37, 40	10, 14, 35, 40	1, 35, 19, 39	28, 27, 18, 40	5, 34, 31, 35		6, 29, 4, 38	19, 1, 32	35, 12, 34, 31		12, 36, 18, 31	6, 2, 34, [illegible]
2	Weight of stationary object		*		10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2		8, 10, 19, 35	13, 29, 10, 18	13, 10, 29, 14	26, 39, 1, 40	28, 2, 10, 27		2, 27, 19, 6	28, 19, 32, 22	19, 32, 35		18, 19, 28, 1	15, 19, 18, 22	18, 19, [illegible] 15
3	Length of moving object	8, 15, 29, 34		*		15, 17, 4		7, 17, 4, 35		13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 10, 29	1, 8, 15, 34	8, 35, 29, 34	19		10, 15, 19	32	8, 35, 24		1, 35	7, [illegible] 35, [illegible]
4	Length of stationary object		35, 28, 40, 29		*		17, 7, 10, 40		35, 8, 2,14		28, 10	1, 14, 35	13, 14, 15, 7	39, 37, 35	15, 14, 28, 26		1, 10, 35	3, 35, 38, 18	3, 25			12, 8	6, 28
5	Area of moving object	2, 17, 29, 4		14, 15, 18, 4		*		7, 14, 17, 4		29, 30, 4, 34	19, 30, 35, 2	10, 15, 36, 28	5, 34, 29, 4	11, 2, 13, 39	3, 15, 40, 14	6, 3		2, 15, 16	15, 32, 19, 13	19, 32		19, 10, 32, 18	15, 17, 30, 26
6	Area of stationary object		30, 2, 14, 18		26, 7, 9, 39		*				1, 18, 35, 36	10, 15, 36, 37		2, 38	40		2, 10, 19, 30	35, 39, 38				17, 32	17, 7, [illegible]
7	Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17		*		29, 4, 38, 34	15, 35, 36, 37	6, 35, 36, 37	1, 15, 29, 4	28, 10, 1, 39	9, 14, 15, 7	6, 35, 4		34, 39, 10, 18	2, 13, 10	35		35, 6, 13, 18	7, 15, [illegible]
8	Volume of stationary object		35, 10, 19, 14	19, 14	35, 8, 2, 14				*		2, 18, 37	24, 35	7, 2, 35	34, 28, 35, 40	9, 14, 17, 15		35, 34, 38	35, 6, 4				30, 6	
9	Speed	2, 28, 13, 38		13, 14, 8		29, 30, 34		7, 29, 34			13, 28, 15, 19	6, 18, 38, 40	35, 15, 18, 34	28, 33, 1, 18	8, 3, 26, 14	3, 19, 35, 5		28, 30, 36, 2	10, 13, 19	8, 15, 35, 38		[illegible] 35, [illegible] 2	14, 20, 19, 35

Figure 41. Hoverboard with one wheel.



Principle 35—Parameter Changes

Principle 14 (Spheroidality, Curvature) and Principle 35 (Parameter Changes) suggest to convert straight lines or flat surfaces into curved lines and curved surfaces, and also to change the number of wheels, for example from two wheels to one (Figure 41).

Principle 19 have been analyzed previously in the paragraph 2.3.1” Contradiction 1 and first indication of solution”.

Principle 20 does not suggest inventive principles in Contradiction 6 (Yang & Yan, 2017)).

2.4. Conclusions

The results obtained by the TRIZ analysis are shown in Figure 42.

Two important results have been achieved in the present study. Through the QFD analysis, the most successful features of this innovative means of transportations have been highlighted. The QFD analysis has taken into careful consideration the user’s needs, comfort and performance expectations. On the other hand, through the TRIZ analysis, innovative suggestions and principles aimed at problem solving have been achieved. It could be advantageous for all manufacturers of this innovative system to keep the results of this study in mind (Afshari, Peng, & Gu, 2016)).

TRIZ is a powerful method that open the mind of the designer to quite all the possible technical solutions in the state of the art. The answers given by the method are not all right to be used, but they serve to understand the problem looking at it from different points of view.

In the case study depicted, we could observe that for the same function, TRIZ method is able to give numerous and very different solutions, sometimes almost unpredictable. This is the power of the instrument.

Figure 42. Contradiction 1: schematization of the results of the triz analysis.

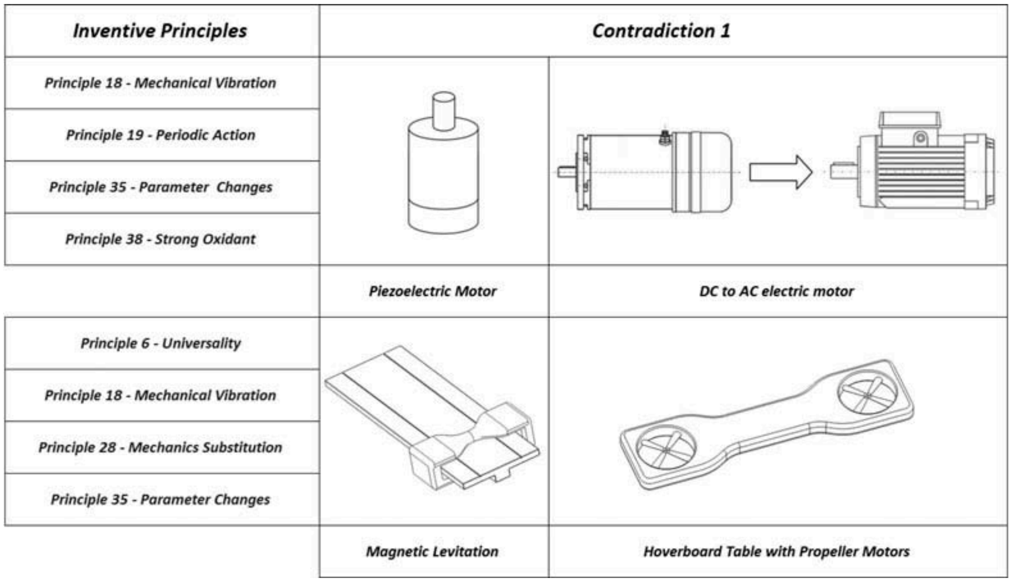


Figure 43. Contradictions 2 and 3: schematization of the results of the triz analysis.

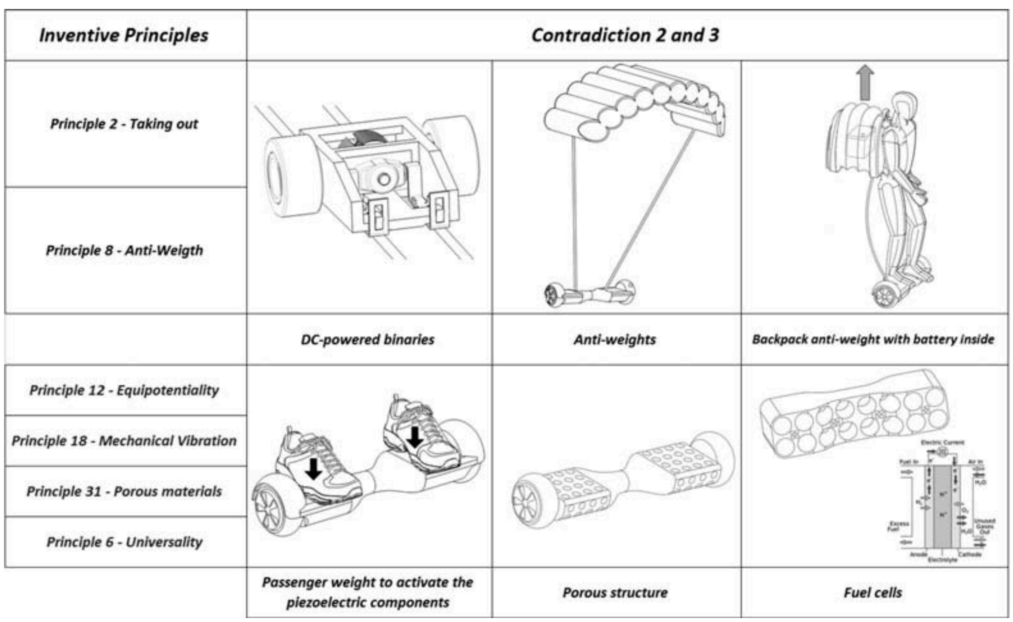


Figure 44. Contradiction 4: schematization of the results of the triz analysis.

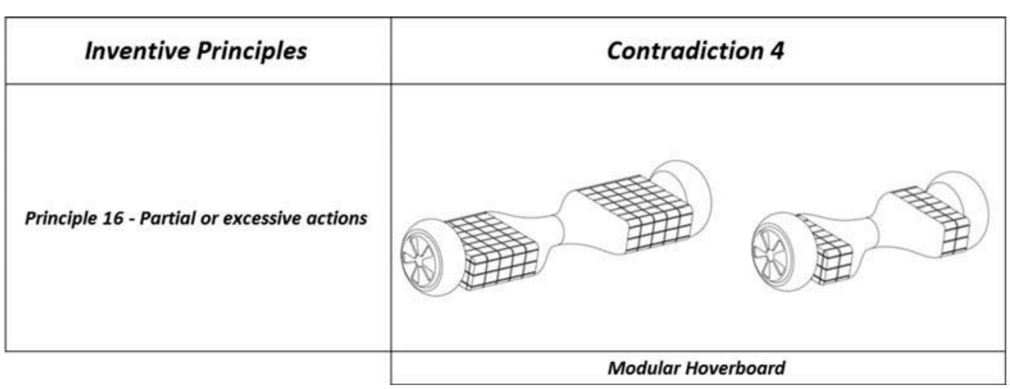


Figure 45. Contradiction 5: schematization of the results of the triz analysis.

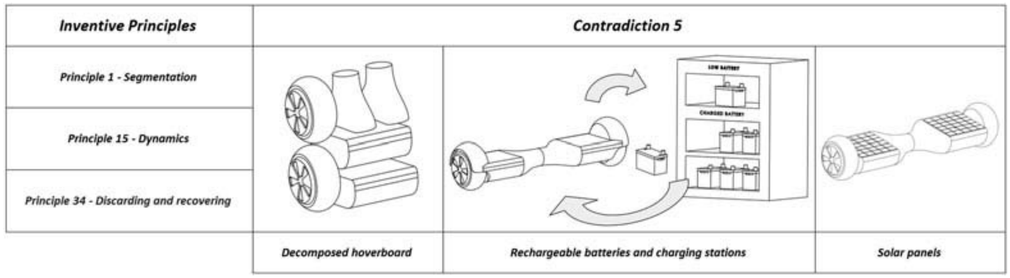
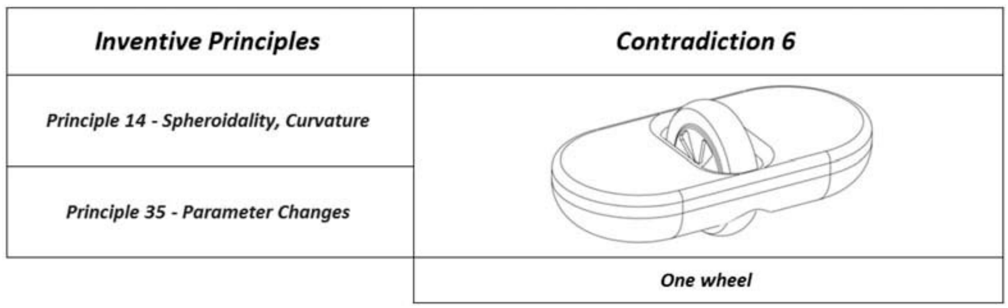


Figure 46. Contradiction 6: schematization of the results of the triz analysis.



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References

Afshari, H., Peng, Q., & Gu, P. (2016, December 31). Reducing effects of design uncertainties on product sustainability. *Cogent Engineering*, *3*(1). Article number 1231388 doi:10.1080/23311916.2016.1231388

Altshuller, H. 1994. *The art of inventing (and suddenly the inventor appeared)*. Shulyak L, translator. Worcester (MA): Technical Innovation Center.

Caligiana, G., Liverani, A., Francia, D., Frizziero, L., & Donnici, G. (2017). Integrating QFD and TRIZ for innovative design. *Journal of Advanced Mechanical Design, Systems and Manufacturing*, *11*(2). doi:10.1299/jamdsm.2017jamdsm0015

Francia, D., Caligiana, G., & Liverani, A. (2016). DFD evaluation for not automated products. *Research in Interactive Design*, *4*, 439–445.

Francia, D., Caligiana, G., Liverani, A., Frizziero, L., & Donnici, G. (2018, Feb). Printer CAD: A QFD and TRIZ integrated design solution for large size open moulding manufacturing. *International Journal on Interactive Design and Manufacturing*, *12*(1), 81-94..

Freddi, A. (2005). *Imparare a Progettare*. Bologna: Pitagora.

Frizziero, L. (2018). Conceptual design of an innovative electric transportation means with QFD, bench marking, top-flop analysis. *Far East Journal of Electronics and Communications*, *18*(1), Pushpa Publishing House, Allahabad, India. doi:10.17654/EC018010189

Frizziero, L., Francia, D., Donnici, G., Liverani, A., & Caligiana, G. (2018, Jan). Sustainable design of open molds with QFD and TRIZ combination. *Journal of Industrial and Production Engineering*, *35*(1), 21-31.

Meuli, M., & Raghunath, M. (1997). Tops and flops using cultured epithelial autografts in children. *Pediatric Surgery International*, *12*(7), 471–477.

Renzi, C., & Leali, F. (2016). A multicriteria decision-making application to the conceptual design of mechanical components. *Journal of Multi-Criteria Decision Analysis*, *23*(3–4), 87–111. doi:10.1002/mcda.v23.3-4

Yang, B., & Yan, W. (2017, January 1). Methods of obtaining, verifying, and reusing optimal biological solutions. *Cogent Engineering*, *4*(1). Article number 1306951 doi:10.1080/23311916.2017.1306951

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