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A Novel Conceptual Design of a Stairlift for Elderly and Disabled People

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Abstract

The level of civilization of a society can be measured with the value and importance given to human. Developed and civilized countries offer many facilities for not only normal people but also disabled/elderly. Stairlifts are one of these facilities that will make daily life of the disabled/elderly people easier. Within the scope of this paper, a novel conceptual design of a stairlift is studied. This design process is based on the systematic design approach of Pahl and Beitz. The overall design process includes the problem definition, the establishment of function structure and the assessment of design variants. Future work is in progress for other design stages and prototype manufacturing.

1. INTRODUCTION

Integrating elderley people and those with disabilities into society by meeting their special or general needs is requirement for all social states. In USA ADA [1], the 21st and 26th articles of the EU Human Rights ‘Equality’ Division [2] and the UN Universal Declaration of Human Rights guarantee that people with disabilities and the elderly will participate in social life and benefit from all the oportunities [3]. Various physical obstacles or adverse conditions in private housing, generel or public buildings not only complicates the lives of the disabled/elderly people but also limits their participation in social life. Apart from the various international legal regulations mentioned, the Law on People with Disability was also introduced in Turkey, the authors home country, in 2005. As of 2012, it has been legally obligatory that all general/public buildings in Turkey have facilities including elevators to provide access to orthopedic and people with other disabilites due to article 2 of this law [4].

The World Health Organization (WHO) states that people are considered as elderley from 65 years old and on, and divides the elderness into thress stages: early old age (65-74 years), middle old age (75-84 years) and advanced old age (85 years and over). Depending on the advancing age, mental and physical abilities decrease, movement skills slow down, and the risk of illness increases [5, 6]. On the other hand, disability is examined in more detail. Disability status defined as; defectiveness (absence of psychological - physical functions), impairment (inability to work as compared to a healthy person) and disablement (inability to perform normal activities because of handicap) [7, 8]. Stairlifts situated in private or communal premises can make daily life of the disabled/elderly people easier. In this paper, a new and innovative stairlift conceptual design has been introduced with concerns of the ease and comfort of the elderly and disabled people easily reaching the upper floors of such buildings without help. The conceptual design of the novel stairlift is conducted based on the systematic design approach of Pahl and Beitz.

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2. A NOVEL DESIGN OF A STAIRLIFT

8.2% of population in Turkish society (6.495.239 people) are people over 65 years old. By 2050, this ratio is expected to reach 20.8% [9, 10]. According to the 2002 World Health Organization data, 12.9% of Turkey's population is expected to be disabled with the proportion of the population with orthopedic disabilities reaching 1,25% [9, 11]. In addition, 3,3% of the current population have difficulty at walking, stair climbing and descending [12]. There are various technologies for elderly / handicapped people live without the need of carers. The concept of assistive technologies covers all products and services that help individuals improve their functionality and independence [6, 13, 5]. In this context, there is an abvious need for a system that facilitates the climbing/descending of stairs, a problem that elderly/orthopedically disabled individuals face in their daily life. For this purpose stairlift systems are generally used and they carry people up and down the stairs safely. There are many types of technologically advanced stairlifts, especially in the developed countries, suitable for use by elderly / disabled people both indoors and outdoors [14, 15]. Stairlift systems can broadly be divided into three groups; (1) wheelchair only, (2) Seat only and (3) Wheelchair with seat. In general, the former option meets the needs of people with disability, the second one is for elderly, and the latter is for both groups. The latter option is considered within the scope of the current work as this system is not considered and manufactured much in the rest of the world. In addition, some new and innovative features are also introduced to the new conseptual design of this type of stairlift. Design study reported in this paper includes: (1) applying house of quality, (2) using TRIZ, (3) requirements list, (4) function structure, (5) sub and general designs, (6) preliminary evaluation, (7) promising design variants and (8) selection process. These steps are discussed individually in detail below [14, 15].

2.1. House of Quality (QFD)

QFD (Quality Function Deployment) provides opportunities such as determining customer requirements, converting these requirements into engineering parameters, determining importance / priority / interactions, comparing with other / competitors etc. In other words, it can be possible to design based solely on customer needs through QFD [16, 17, 18]. Thus, a house of quality belonging to the system to be developed was created and the relationship between customer requirements and engineering parameters was established (Table1). In the context of the survey, the expectations of the target customers (users) from a stairlift are briefly described; not taking up much space (small), easy to use and comfortable (ergonomic), aesthetically pleasing, allowing high mobility, robust, safe, easy and fast to install, attractive, etc. These customer wishes have been converted into the design parameters (DP). Then, the percentage of each parameter meeting the needs was calculated with numerical values, and the percentage significance level of DP (weight) was determined. The QFD provides guidance in the conceptual design phase in many research activities [19, 20].

The contradictions between DPs can be determined by the relation matrix on the roof of the quality house. Identification of these is important for making creative solution / problem identification easy [18]. The relationship matrix showing the contradictions between the DPs for design is shown in Figure 1. In the matrix, "+" means a positive relationship,"-" means a negative relationship (contradiction), and "o"means no relationship.

Table 1. *House of quality application to customer needs in stairlift design*

No	Importance rating 0~1 WGn	Fn=A, B, C, D A=9, B=5, C=3, D=1 $W_{TP}(n)=\prod_{n-1}^{n} w_{Gn}\cdot F_n$ $\%M_n=\frac{W_{TP}(n)}{\sum_{n-1}^{n} W_{TP}(n)}*100$ Design parameters Customer needs	Modularity DP 1	Weight DP 2	Capacity DP 3	Dimension measurements DP 4	Velocity DP 5	Climbing angle DP 6	System preparation speed DP 7	Energy consumption DP 8	Efficiency DP 9	Energy storage unit DP 10	Selecting materials DP 11	Control unit DP 12	Safety DP 13	Simplicity DP 14	Human and environmental compliance DP 15	Practicality DP 16
G1	0,75	Easy installation	A	B		C		C					C			B		
G2	0,6	Ergonomic				B								A		B	A	A
G3	0,9	Minimum weight	A	A						D	B		B			A		
G4	1	Carrying capacity			A		A			C			C				A	B
G5	1	Small size	B		A			B		B	A	B				B	B	A
G6	1	Climbing ability		A			A	A	A	A		C			B			
G7	1	Climbing speed		B	A	B		A							C	D		B
G8	0,6	System preparation speed				B	A		A							B		A
G9	0,9	Minimum energy consumption		B						A	A	C	C					D
G10	1	Energy loss		B						A	A	B					D	D
G11	1	Extra energy storage unit				B				B		A			B		C	A
G12	0,7	Outdoor suitable material		B									A	B	B		A	A
G13	0,9	Lightweight, durable material		A	A					C			A				B	B
G14	1	Movement control						A						A		B	A	A
G15	1	Emergency stop		C	C		B							A	A		B	A
G16	0,8	Durability	B	C									A				C	C
G17	0,5	Adjustable seat	B						B					B	A	B	A	A
G18	1	Easy production				B		A	B	B			B			A		
G19	0,8	Recycle											A			C	A	
G20	0,8	Mechanical design		D				C	B		A			B	A	A	B	
G21	0,8	Easy assambling/dismantling	B	A							C				A	A	A	
G22	1	Easy maintenance	B							C								A
G23	0,8	Cost of production											C				D	
Absolute importance			35,35	60,35	38,1	23,25	28,4	45,65	25,9	50,7	40,02	24,7	56,9	33,4	44,4	57,15	74,3	85,21
% Relative importance			4,88	8,34	5,26	3,22	3,93	6,31	3,57	7	5,52	3,41	7,87	4,62	6,13	7,9	10,27	11,77

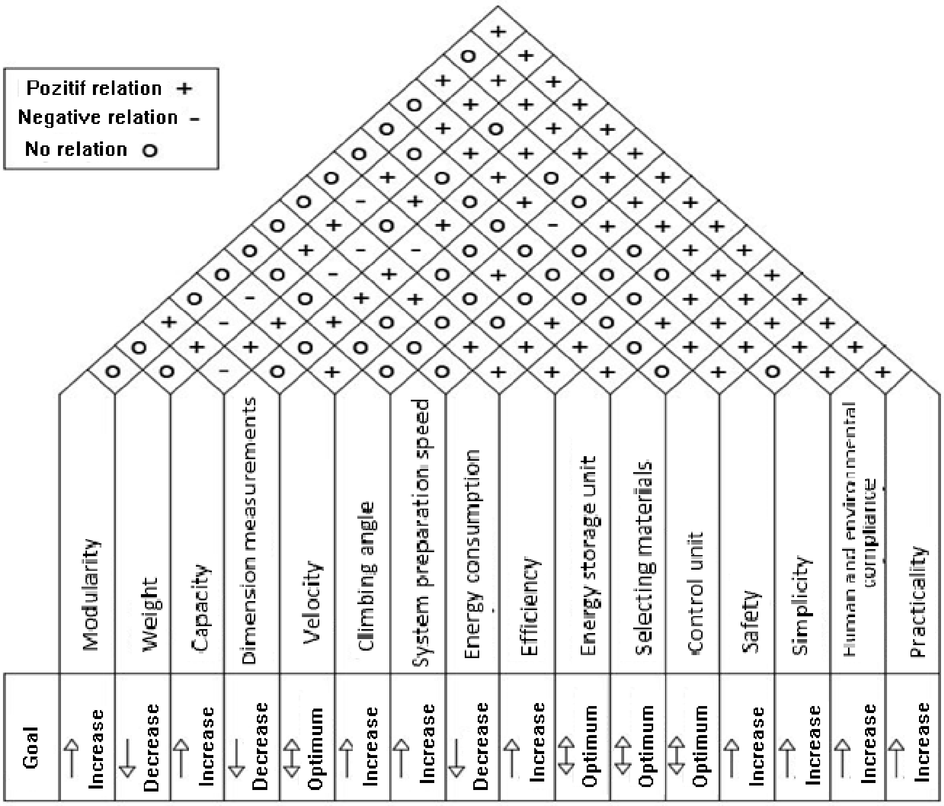

Figure 1. *Relations between engineering design parameters*

2.2. Theory of Inventive Problem Solving (TRIZ)

The relationship between the QFD and the design parameters we have transformed into customer requests has been presented by the help of a matrix. The contradictions between these DPs are indicated by "-" and have negative relations in the matrix. These contradictions were solved by using the contradiction matrix of TRIZ and 40 principles. For the solution, the contradictions were first turned into TRIZ engineering parameters. Then these parameters were intersected in the contradiction matrix and the principles of creative solution were found and they were evaluated. Optimum creative principles that would give a solution to the problem was selected after the evaluation process[17, 21]. The DP contradictions in the design and the corresponding TRIZ contradictions and the corresponding TRIZ solutions are given in Table 2.

Table 2. *DP contradictions, corresponding to TRIZ contradictions and solutions*

Contradictions in DP relationship matrix		TRIZ contradiction	TRIZ solution principles	The most appropriate principles	Problem number
1	Weight-Carrying speed	1-5	5, 34, 31, 35	34,31	P1
2	Weight-Climbing angle	2-20	18, 19, 28, 1	28,1	P2
3	Weight-Energy storage	1-7	29, 2, 40, 28	40,	P3
4	Capacity-Size measurements	7-7	7		P3
5	Capacity-Size measurements	5-7	7, 14, 17, 4	7,4	P4
6	Capacity-Energy consumption	1-19	35, 12, 34, 31	31	P5
7	Capacity-Efficiency	1-22	6, 2, 34, 19	19	P6
8	Size measurements-Energy storage	7-19	35		P6
9	Size measurements-Energy storage	7-36	26, 1	1	P4
10	Climbing angle-Safety	10-27	3, 35, 13, 21	3	P7

For the 1-5 contradiction expressed by P1 in Table 2, "particle removal and reconstruction" and "porous material" principles were adopted from the proposed solutions for the transport speed drop, depending on the system weight gain. Problem solving can be described as "avoid unnecessary parts and skeleton structure will be maximum strength / minimum material". Another example solution is the result of converting the same DP into two different TRIZ parameter contradictions (P3 and P4). It has been found suitable to increase the passenger carrying capacity and to use the principles of "nested structure" which is principle number 7 and "asymmetry" which is principle number 4, as a solution for increasing system volume. Thus, the platform can be designed asymmetrically intertwined and in a space-saving form [22]. Other problems and their creative solutions are given in Table 3.

Table 3. *Creative problem definitions or solutions for the solution of contradictions*

Problem no	Creative problem definition
P1	Avoid unnecessary parts and build up the skeleton structure with maximum strength / minimum material properties.
P2	Provide the necessary friction force with moving and multiple support rollers.
P3	The excess weight created by the additional power unit is compensated by using composite material in the subsystems or by using the subsystem (component) at the maximum level.
P4/P5	The seat unit folds to save volume. Nested structure of the disability platform and asymmetric parts are created to save volume.
P6	The problem of excess energy consumption caused by the heavy system can be eliminated by hollow structure designing of various components such as the seat and the platform
P7	Thanks to the gravitational force, sliding down should be made to consume less power and braking.
P8/P9	Additional power units must be placed in different locations, dividing capacity.
P10	The slip effect created by the large climbing angles must be prevented by increasing the friction force by changing the surface roughness values of the rollers.

2.3. Requirements List

A requirements list (design specification) prepared for the conceptual design of stairlift for elderly and disabled persons is given in Table 4. Here in the list CAD drawings, working principles, safety precautions, control features, adaptation to usage environment, production cost, etc. have been determined. The given requirements list is for conceptual design purposes only and can be extended for later stages of the design. Listed features are classified as demands and wishes. The design solutions must satisfy the demands (D), and the wishes (W) must be met to the extent that technical and economic conditions permit [19].

Table 4. *The requirements list fort the conceptual design of a stairlift*

Line	Requirements for Stairlift
1	The system weight should be between 250 - 300 kg.
2	Load capacity: Platform 225 kg, Seat 160 kg.
3	(W) The system should be as small as possible.
4	Inclination of climbing should be at most ≤ 30°.
5	Must be constant speed (0,12 m / s).
6	The materials used must be environmentally friendly and suitable for use indoors / outdoors.
7	The user must have the control with emergency buttons and call stations.
8	Must be comply with ISO EN 80-40 standarts.
9	(W) It must be partially demounted.
10	Standard parts must be used wherever possible.
11	System cost should be low.
12	The lift must be ergonomic.
13	Must have additional power unit (24 V battery).
14	Travel and user safety must be ensured (such as belt, voice warnings, etc.).
15	Control and use should be easy / simple.
16	(W) Can be turned off and locked when not in use.
17	Production cost should be ≤ 25.000,00 TL.

2.4. Function Structure

The functional structures of the stairlift were created for two separate scenarios. The first one was considered for handicapped person (Figure 2.a). The system consists of the initial signal, warning systems, drive unit and safety measures. Scenario 1 steps briefly include stairlift call and activation of visual and audible alert units of the call signal. There are some sub-functions (regulation of rotational speed, torque transmission, movement) that will make the system work. The stairlift going to the called location activates the platform opening mechanism and associated ramp for the passenger. After boarding the passenger, the protection bars are closed for possible security problems. The passenger selects the direction he / she wants to go and the corresponding subsystem operates. Thus, the stairlift moves in the desired direction according to the given signal. If there is a problem during the movement, it gives an audible signal again. When it comes to the desired stop location, the system opens the protection bars and the platform mechanism closes after the passenger got off. The second scenario is for elderly transportation. This scenario shown in Figure 2.b is very similar to the first one. The difference between the two is the passenger transport unit, which depends on the physical conditions of the passengers. The seat to be used by the elderly has been replaced by the carrying platform of the disabled person and the safety belt. The input energy (E) is electrical energy and the material is determined as the user in both scenarios. The energies leaving the system should be considered as lost energies.

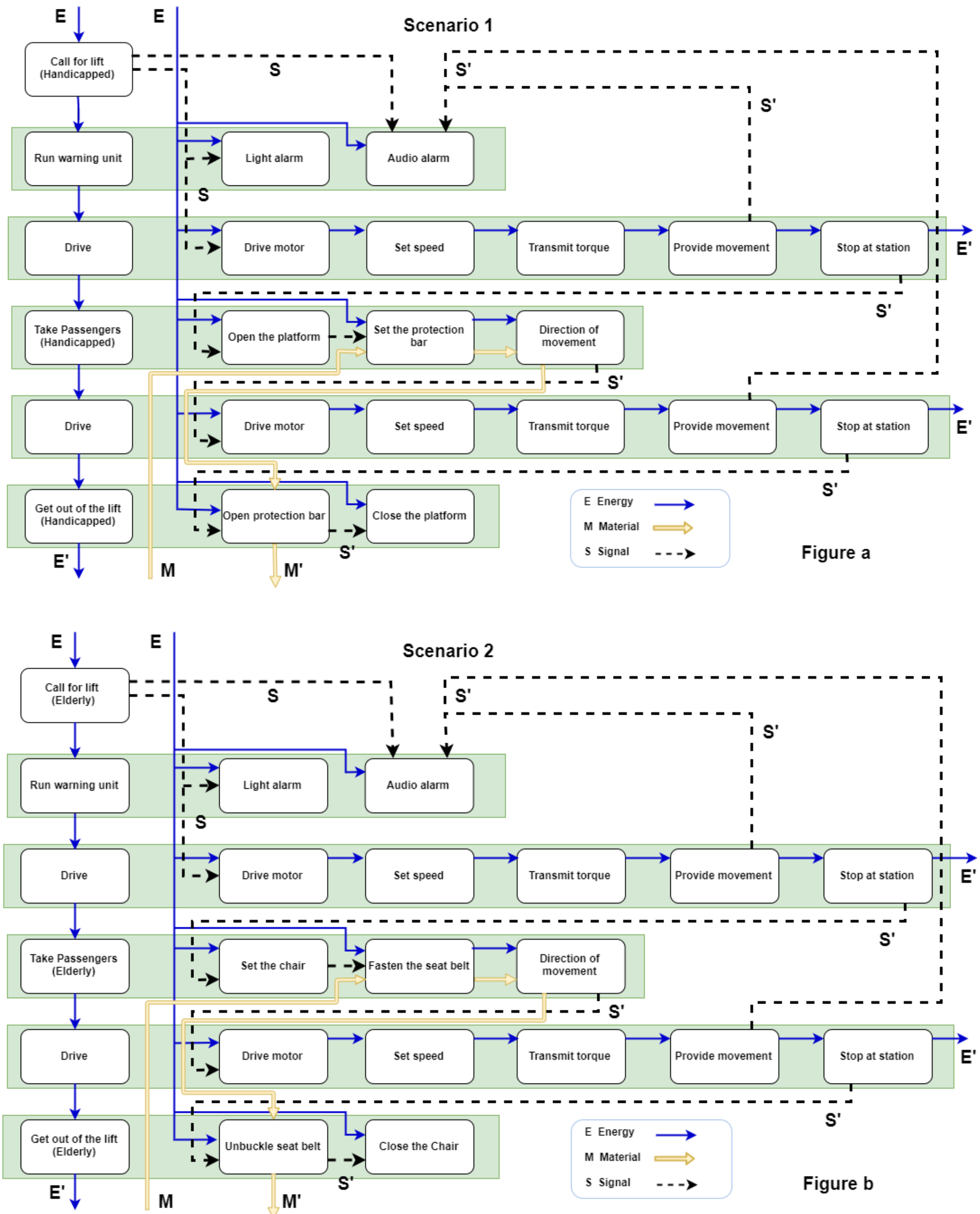

Figure 2. *Function structure of the stairlift design: (a) for Handicapped, (b) for Elderly*

2.5. Sub and General Designs

The function structure given in Figure 2 includes independent subfunctions of the stairlift. These subfunctions also specify the data flow and associations with respect to E, M, S. Here, the important sub-function blocks are determined and posibble solutions are put in a matrix (Fig. 3). Such representation is called a schematic morphological matrix / card [19]. There are different sub-solutions for each line function. These functions are; sitting (seat), carrying the handicapped (platform), power transmission (drive), system transpotation (rail), warning, stopping (brake) and passenger stabilization (seat belt).

Solution path		a	b	c	d
Important functions					
1	Seat	Full seat	Saddle type	Folding type	
2	Platform	Solid	Nested form		
3	Drive	Friction pulley	Sprocket	Rack and pinion gear	
4	Rail	Cylindrical	Extrude		
5	Warning	Reflective Band	LED	Warning lamp	Audible warning
6	Brake	Electro-mechanic	Hydraulic	Magnetic	
7	Control	Manual button	Joystik	Automatic button	
8	Seat belt	2 Points	5 Points		

Figure 3. *The morphological matrix for the conceptual design of stairlift*

The general design variants obtained by various combinations of some sub-solutions in the morphological matrix are shown in Table 5. Combinations (variants) were created by taking one specific sub-design from each line. For example, the seating function corresponding to the second column in Table 5 for S1 is taken from column c in Figure 3 and the platform function corresponding to the third column in Table 5 for S1 is taken from column b in Figure 3.

Table 5. *Possible design variants for the stairlift design*

Variants	Combined sub-designs							
S1	1.c	2.b	3.a	4.a	5.d	6.a	7.c	8.a
S2	1.a	2.a	3.b	4.a	5.c	6.a	7.c	8.a
S3	1.b	2.a	3.c	4.b	5.b	6.c	7.a	8.a
S4	1.c	2.a	3.c	4.a	5.a	6.a	7.b	8.b
S5	1.a	2.b	3.b	4.a	5.a	6.b	7.a	8.a

2.6. Preliminary Evaluation

The first stage and preliminary evaluation of the general designs composed by the sub-design combinations in the morphological matrix were performed with the selection card [19]. Here the criteria such as specification compliance, feasibility, reasonable cost, etc. were used (Figure 4).

Selection card of general solutions for stairlift

Selection criteria
(+) Yes
(–) No
(!) Check the requirement list
(?) missing information

DECISION
(+) Resume solution
(-) Not resume solution
(!) Check the require list for changes.
(?) Gather information and re-evaluate the solution.

SOLUTIONS	Specification compliance	Function compliance	Practicability	Meet safety requirements	Allowable production cost	Design simlicity	Working knowledge	Descriptions	DECISION
S1	+	+	+	+	+	+	+	Selected solution, geometry compatible.	+
S2	+	+	+	+	!	+	+	The selected solution space is insufficient.	+
S3	!	+	+	+	!	+	+	Special production, design requirement.	-
S4	+	+	+	+	+	+	+	Selected solution, similar products available.	+
S5	+	+	+	!	-	+	+	Relatively high cost, insufficient safety.	-

Figure 4. *The use of selection card for the conceptual design of stairlift*

Design variants (solutions) that meet the criteria were revised in accordance with the state evaluation keys (+, -, ?, ! etc.). If a design concept / variant is sufficient, then this variant should be selected and moved to the next stage [19]. And, after the preliminary evaluation, the design variants S1, S2 and S4 marked with +, which are seen in Figure 4, were selected as the promising design variants.

2.7. Promising Design Variants

The key / promising variants obtained via the pre-evaluation with the selection card are shown in Figure 5. Variant 1 offers a nested form handicap platform, foldable seat, cylindrical rail profile and friction drive system, and a two-point safety belt connection option. Variant 2 offers full seat, one-piece solid handicaped platform, drive system with sprocket, cylindrical rail profile, automatic button control options. Variant 4 offers the option of a one-piece solid handicaped platform, a folding seat, a cylindrical rail profile and a rack-pinion gear drive system.

a) Variant 1 b) Variant 2 c) Variant 4

Figure 5. *Promising design variants of stairlift: (a) Folding platform (b) Power transmission via sprocket, (c) One piece platform design*

2.8. Selection Process

In the design process carried out up to Stage 8, which is basically the stage involving a number of selection methods, some design variants have been created and the result of a preliminary selection process has been identified as three of these relatively more valuable and important concepual designs. Here, these three design variants will be evaluated more carefully and precisely, and the best variant will be determined. For this purpose, some criteria and their weights should be determined for the conceptual design of the stairlift. Criteria determination and weight distribution were made by the "objectives tree" shown in Figure 6 [19]. The evaluation criteria organized hierarchically in Figure 6 are divided into three groups as (1) ease of use, (2) simple production and (3) safety. The subgroups were defined as easy maintenance, easy handling (ease of movement and control), simple parts production (low number of parts / complexity, use of standard parts), simple assembly, mechanical safety, overload tolerance and vibration sensitivity.

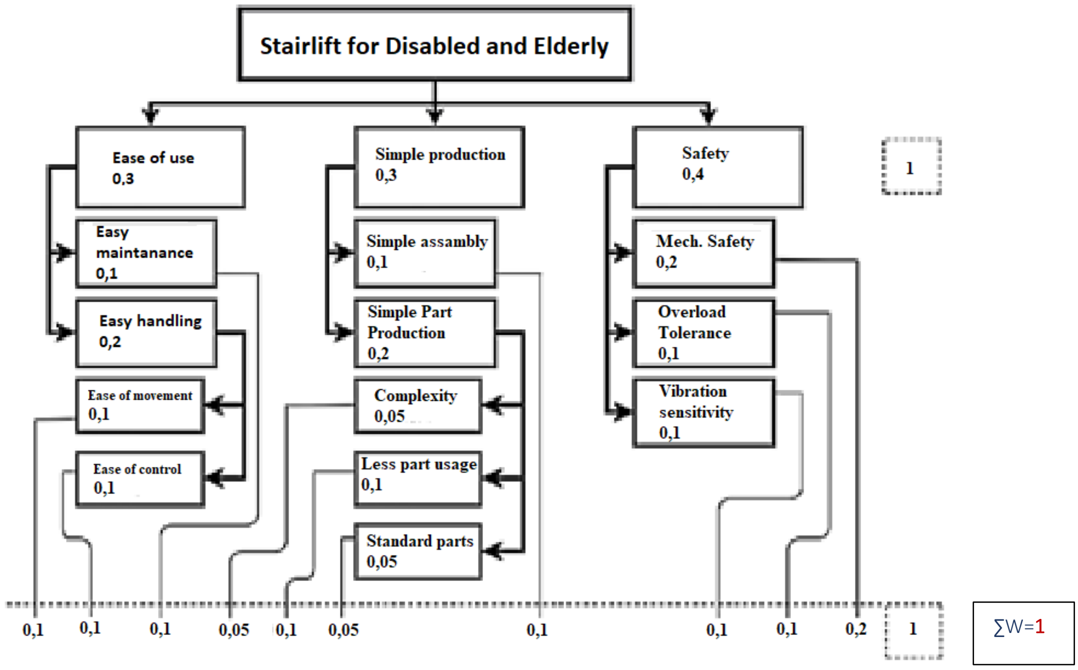

Figure 6. *Objectives tree for the conceptual design of stairlift.*

These criteria will then be converted to technical parameters, if possible, the units will be assigned, and finally the 3 design variants that pass the pre-evaluation will be graded according to these parameters (Table 6). Following this, a comparison was made between the variants with the highest two points in total, creating a value profile, and the variant that best meets these properties was chosen as the ideal design variant (Figure 7). The thickness of each bar in the figure describes the weigh of the corresponding criteria whilst the length of each bar describes the value it attains in this concept. Balanced distribution of the criteria for the evaluated design concept (variant) is preferred. Furthermore, the spaces represent the weak spots.

The conceptual design process conducted can be further developed with detailed design calculations as given in [23] and [24].

Table 6. *The evaluation chart for the three promising variants of stairlift design*

Value criteria	Weight (w)	Variant 1			Variant 2			Variant 4		
		Magnitude	Value	Weighted value	Magnitude	Value	Weighted value	Magnitude	Value	Weighted value
w1 Easy maintenance	0,1	Moderate	6	0,6	Moderate	4	0,4	Moderate	5	0,5
w2 Ease of movement	0,1	Moderate	6	0,6	Moderate	5	0,5	Moderate	5	0,5
w3 Ease of control	0,1	Moderate	6	0,6	Good	7	0,7	Good	7	0,7
w4 Low number of parts	0,1	Good	7	0,7	Moderate	5	0,5	Moderate	5	0,5
w5 Complexity	0,05	Good	7	0,35	Moderate	5	0,25	Moderate	5	0,25
w6 Standard parts	0,05	Moderate	6	0,3	Good	7	0,35	Good	7	0,35
w7 Simple assembly	0,1	Good	7	0,7	Moderate	6	0,6	Moderate	6	0,6
w8 Mechanical safety	0,2	Good	7	1,4	Good	7	1,4	Good	7	1,4
w9 Overload tolerance	0,1	Moderate	6	0,6	Moderate	6	0,6	Moderate	6	0,6
w10 Vibration sensitivity	0,1	Moderate	6	0,6	Moderate	5	0,4	Moderate	6	0,6
Wt = 1		∑v = 64			∑v = 57			∑v = 59		
		∑Wv = 6,45			∑Wv = 5,7			∑Wv = 6		

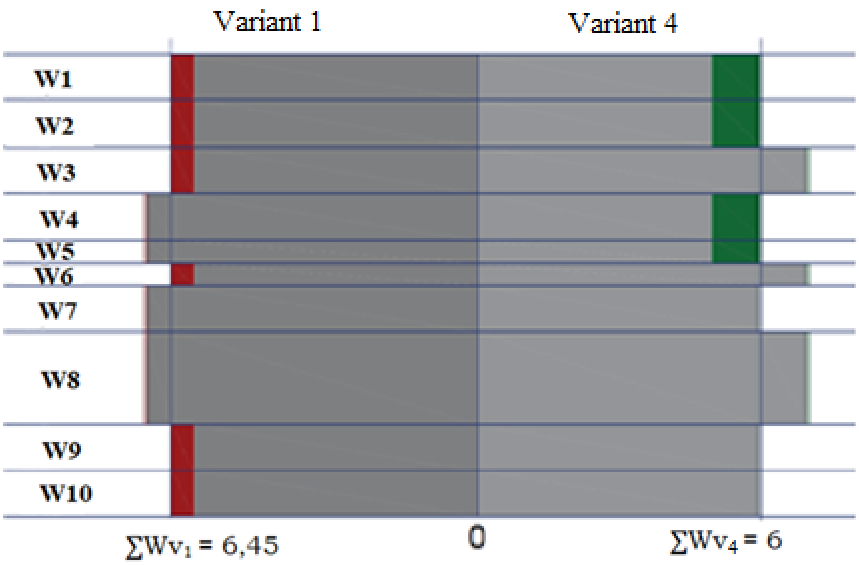

Figure 7. *Value profile diagram for the detection of weak spots*

2.9. Evaluation and Final Decision

As a result of the conceptual design process for the stairlift, the design variant 1 has been identified as the most appropriate design concept. Thus, a new and innovative system has been pre-designed for the elderly/disabled to do the best/comfortable transportation. The most important differences from the available commercial products are small system size (compact), appeal to elderly and disabled all in once, friction drive system, nested formed platform and foldable seat (Figure 8).

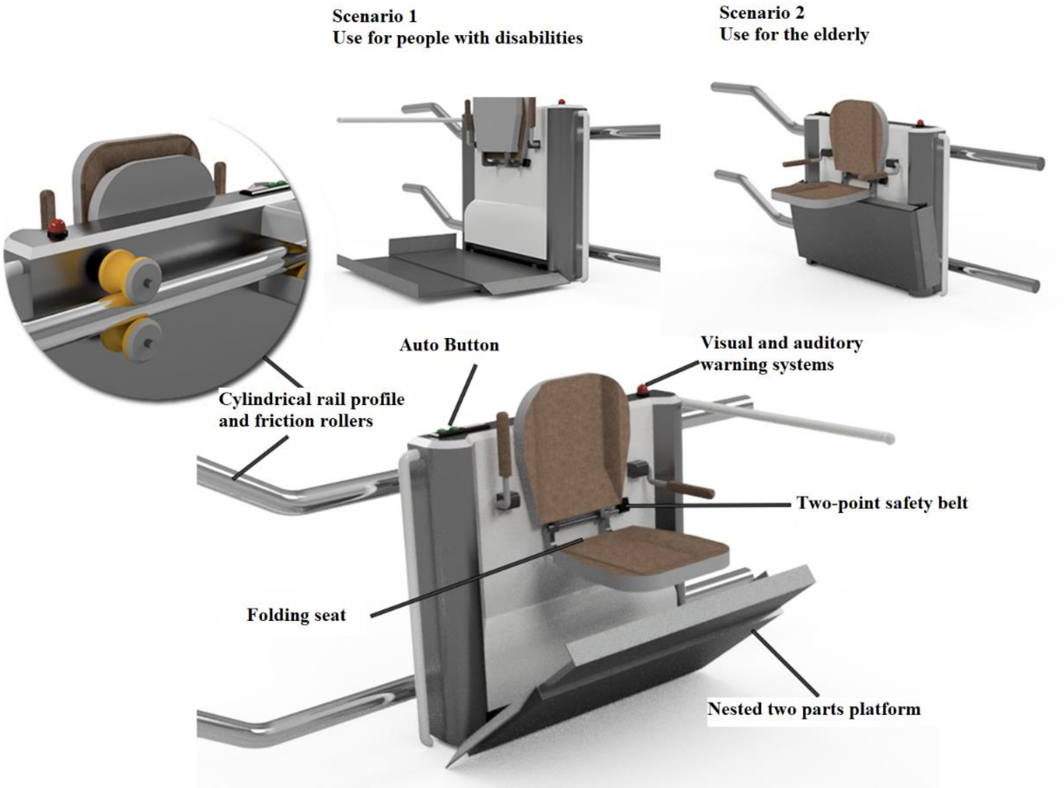

Figure 8. *The best conceptual design of stairlift development for elderly and disabled people*

3. CONCLUSION

Civilised societies attribute importance to people, especially elderley people and those with disabilities. An important part of the world society is composed by the elderly and the disabled. One essential need of these people is to use ancillary products to assist them in climbing and stepping down the stairs in buildings. There are currently no domestic commercial firms in Turkey manufacturing such products. To meet these needs, a SANTEZ project grant was awarded and an R & D program was initiated. In the first phase of this research work, a novel conceptual design of a stairlift was conducted. The study sets an example of design methods combination and optimization to be followed when designing a product or developing / modifying it. This work can provide a base and guide for those who work in the same field for further developments.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper.

REFERENCES

[1] Internet: https://en.wikipedia.org/wiki/Americans_with_Disabilities_Act_of_1990 (2017).
[2] Internet: https://www.hrw.org/news/2010/12/30/eu-commitment-disability-rights (2017).
[3] Internet: https://www.tbmm.gov.tr/komisyon/insanhaklari/pdf01/203-208.pdf (2017).
[4] Basic information handbook about accessibility for local governments, (2nd edition), Ankara: Republic of Turkey, Prime Ministry, Presidency of the Office for the Disabled, (2010).

[5] Tanju B., Hakan Y., İstanbul University Cerrahpaşa Medical Faculty Department of Internal Medicine Department of Geriatrics, Aging and Aging Epidemiology, Clinical Development, 25: 1-3, (2012).
[6] Loïc G., Chapal K., Lloyd W., Yukiko N., Jostacio L., Johan B., Alex R. and Adriana V. B., Medical and Assistive Health Technology: Meeting the Needs of Aging Populations, Gerontologist Oxford Journals, 56(S2), p.293–302, (2016).
[7] Canan K., World Disability Foundation Disability-Free City Planning Information Report, (2010).
[8] WHO World Report on Disability, WHO Library Cataloguing-in-Publication Data, (2011).
[9] Statistics on Disabled and Elderly Individuals, Statistics Bulletin, (2016).
[10] Ages by Statistics 2015, TÜİK Turkish Statistical Institute News Bulletin, Number 21520, (2016).
[11] Turkey Disability Survey 2002, State Statistics Press, (2004).
[12] İnternet: www.tuik.gov.tr/PreHaberBultenleri.do?id=18617 (2017).
[13] Assistive technology, WHO Fact sheet, (2016).
[14] Internet: http://stairlifts-review.toptenreviews.com/ (2017).
[15] Internet: http://www.lehner-lifttechnik.at/en/products (2017).
[16] Ivica V., Tonći G., Application of The Qualıty Function Deployment - QFD Method in A Product Design Stage, Advanced Technologies for Developing Countries – ATDC'03 (2003).
[17] Mayda, M. and Börklü, H.R., Development of an innovative conceptual design process by using Pahl and Beitz's systematic design, TRIZ and QFD, Journal of Advanced Mechanical Design, Systems, and Manufacturing, 8(3), (2014).
[18] http://www2.warwick.ac.uk/fac/sci/wmg/ftmsc/modules/modulelist/peuss/slides/section_6a_qfd_notes.pdf (2017).
[19] Börklü, H.R. (Türkçeye Çeviren), Pahl, G., Beitz, W., Feldhusen, G., Grote, K.H., Mühendislik Tasarımı: Sistematik Yaklaşım, Hatiboğlu Yayınları:152, Ankara (2010).
[20] Internet: http://www.fme.aegean.gr/sites/default/files/cn/quality_function_deployment.pdf (2017).
[21] Mayda, M. and Gultekin, N., Deterministic and probabilistic life assessment of a traditional car starter motor based on number of stop/start cycles, Journal of Advanced Mechanical Design, Systems and Manufacturing, 12(1): 1-8, (2018).
[22] Internet: https://www.triz.co.uk/files/oxfordtriz_contradictions_matrix.pdf (2017).
[23] Mayda, M., An Efficient Simulation-Based Search Method for Reliability-Based Robust Design Optimization of Mechanical Components, Mechanika, 23, 696-702, (2017).
[24] Mayda, M. and Choi, S.-K., A reliability-based design framework for early stages of design process, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 1-16, 10.1007/s40430-017-0731-y, (2017).