TRIZ and AHP in Early Design Stage of a Novel Reconfigurable Wheelchair

Sumit Desai, Shankar Mantha, Vikas Phalle*
Veermata Jijabai Technological Institute, Mumbai, India - 400019
**sumitdesai1234@gmail.com*

ABSTRACT

The Reconfigurable wheelchair incorporated with sit-to-stand and sit-to-sleep capabilities is the technological solution for extensive wheelchair users to promote their quality of life (QoL), safety and comfort. This paper presents the conceptual design of a reconfigurable wheelchair using the TRIZ and AHP integrated approach. The objective of this study was to develop optimal conceptual designs of a reconfigurable wheelchair by overcoming identified design conflicts. The TRIZ contradiction toolkit was employed in the early conceptual design phase. Based on the TRIZ inventive principles and developed design strategy, new reconfigurable wheelchair mechanism was modelled in SolidWorks environment, using a top-down modelling approach. Dimensions of a wheelchair were kept within the dimensions of a standard wheelchair. The newly modelled mechanism was refined using motion simulation capabilities of the SolidWorks software. The new mechanism was further integrated with different wheelchair design features by means of the morphological chart in order to get innovative conceptual designs. Further, Analytical Hierarchy Process (AHP) was utilized as a multi-criteria decision making technique for optimal conceptual design selection. Conceptual design-I (joystick controller with electric drive) received highest weight among all conceptual designs, hence selected as the optimal conceptual design. Consistency ratio (CR) for the pair-wise comparisons made throughout the AHP method was found less than 0.10. All AHP calculations were supported by Microsoft Excel Add-in for multi-criteria decision problems. For the purpose of functionality testing of newly modelled wheelchair, 3D printed wheelchair parts have been fabricated (using ABS material) and tested for desired mechanical movements. The methodology implemented in the present work can be utilized for upcoming applications in design of new assistive devices.

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Introduction

Wheelchairs as mobility devices are chosen by many lower limb disabled, elderly subjects due to their inability to stand and walk without support. One of the daily challenges is to transfer such subjects from the wheelchair to and from the bed/toilet seat. Generally, transfer support to such subjects is given by caregivers in both professional as well as private healthcare environments. Issues regarding caregiver transfer are caregiver dependency, lower back pain among caregivers, injury incidences due to the caregiver failing to properly apply strength during transfer [1]. Due to prolonged seated posture with being inactive in wheelchair, these subjects are exposed to many physical and psychological health problems e.g., fatigue, pain in the hip joint, pressure sores, etc [2].

Comprehensive needs assessment study of extensive wheelchair users [3] reported several common problems such as (1) difficulties in transfer from a wheelchair to and from bed (2) difficulties in stand from seating position (3) difficulties using commode without caregiver support and (4) risk of pressure sores due to extensive use of a wheelchair. A wheelchair with back seat adjustment can assist extensive wheelchair users in health preservation, balancing, trunk positioning, etc [4].

Table 1: Contributions in development of a reconfigurable wheelchair

Capabilities of developed model	***Year***	***References***
Wheelchair with swiveling, reclining, and lifting chair capabilities	*1991*	*[6]*
Wheelchair with hip-up capability	*1992*	*[7]*
Robot-assisted sit to stand transfer for lower limb prostheses	*2001*	*[8]*
Walking aid with feature to assist elders for Sit to Stand transfer	*2002*	*[9]*
Wheelchair with lifting and hip-up functions	*2004*	*[10]*
Chair to help in transformation from Sit to Stand for low seat	*2010*	*[11]*
Prototype of a reconfigurable wheelchair for sit to stand transfer	*2016*	*[12]*

Further, a wheelchair incorporated with standing feature enables users to have a better accessibility along with various health benefits such as enhanced blood circulation, reduced risk of pressure sores, etc [5] Both backrest adjustment as well as standing feature of the wheelchair allows the user to exercise so that physical damage prevention and physical rehabilitation can be attained. Thus, reconfigurable wheelchair built-in with sit-to-stand and sit-to-sleep capabilities can be a practical solution for such wheelchair user population to promote their quality of life (QoL), safety and comfort. In that regard, Table 1 summarizes contributions focusing on development of a reconfigurable wheelchair. Although reconfigurable wheelchairs was given a lot of attention either in research or through developing prototypes, none of the contributions were intended on studying and building a wheelchair model integrated with both sit-to-stand and sit-to-sleep capabilities.

Conceptual design is one of the essential phases in the new product development (NPD) where promising product concept alternatives are generated. Overall, the product conceptual design stage comprises conceptual designs generation and best conceptual design selection [13]. Various methodologies are available to support designer engineers in methodically generating and selecting best conceptual design. "Theory of Inventive Problem Solving" (TRIZ) for conceptual design is gaining higher interest as a support tool as it is derived from the study of inventions using patent database. Table 2 encapsulates examples of use of TRIZ for conceptual design. The designers can obtain a number of feasible conceptual designs through the use of the TRIZ approach. Accurate selection of conceptual design in the early product development stage has a significant role in deciding the product life cycle duration. The Analytical Hierarchy Process (AHP) is an effective multi-criteria decision making technique extensively utilized to solve industrial decision making problems. Adding TRIZ methodology to AHP has potential to improve effectiveness of the innovation.

In the present study, the integration of TRIZ and AHP approaches was employed in the conceptual design of the reconfigurable wheelchair. Based on the project requirements, the mechanism of the wheelchair was modeled in a smart way by solving design conflicts using TRIZ. Three major phases were involved during the concept design process which are: TRIZ application to eliminate design conflicts, top-down modeling approach in SolidWorks and AHP application in multi-criteria decision making problem. Feasible conceptual designs suggested by engineering methodology were compared with the AHP method for selection of the best conceptual design. In short, TRIZ and AHP were integrated to make use of strengths of both methods to quickly discover and resolve design conflicts, and develop most feasible wheelchair concept.

Table 2: Examples of the application of TRIZ for conceptual design

Application of TRIZ	*Application in product development*	*References*
TRIZ with QFD	*Notebook casing*	*[14]*
TRIZ with AHP	*Dual layer tread tire*	*[15]*
TRIZ with AHP and Eco-Design elements	*Bottle casing*	*[16]*
TRIZ with optimization tool	*Sheet metal snips*	*[17]*
TRIZ with FMEA and Eco-Design	*Vacuum cleaner*	*[18]*
TRIZ with axiomatic design and mixed integer programming	*Locomotive ballast*	*[19]*
TRIZ with axiomatic design	*Electrical switch*	*[20]*

Materials and Methods

The TRIZ–AHP integration procedure begins with the recognition of design conflicts present in wheelchair design project. The TRIZ contradiction toolkit was employed in the early concept generation phase in order to resolve recognized design conflicts.

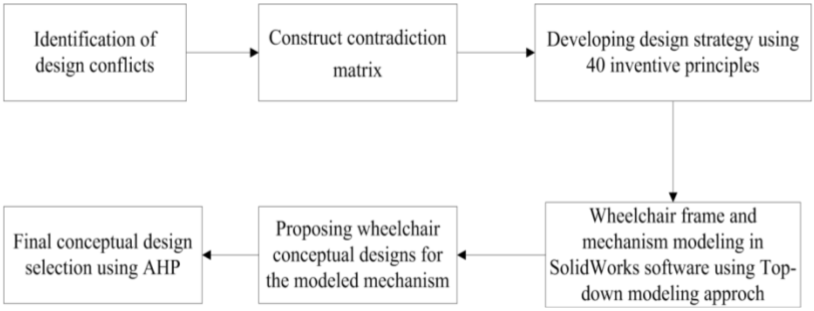

Figure 1: Framework of methodology adopted

Based on the TRIZ inventive principles and developed design strategy, new reconfigurable wheelchair mechanism was modeled with the help of SolidWorks using a top-down modeling approach. The newly modeled mechanism was further refined using motion simulation capabilities of the SolidWorks software. New mechanism concept was further integrated with different wheelchair features by means of a morphological chart. The AHP method was utilized as a multi-criteria decision making tool for design concept selection. The framework of methodology adopted in the present study illustrated in Figure 1

TRIZ contradiction toolkit

TRIZ tool is used to eliminate design conflicts instead of getting compromises among design parameters. TRIZ theory employs 40 inventive principles to propose a guideline for innovation [23].

The TRIZ methodology can be encapsulated in four steps [24-25]:

1. Understand the design problem and identify design conflicts.
2. Construct a contradiction matrix by mapping improving parameters (IP) and worsening parameters (WP) with list of 39 TRIZ engineering parameters.
3. Identify the TRIZ inventive principles from the contradiction matrix.
4. Develop design alternatives using TRIZ inventive principles.

AHP

The AHP method was proposed by Satty [28]. The AHP is an effective multi-criteria decision technique extensively used in design decision making problems. Initially, problem should be decomposed by defining goal, criteria, sub-criteria, alternatives. Further all these elements has to structure hierarchically with goal at first level, criteria at second level, sub-criteria at third level and alternatives at final level. Hieratical structure illustrates a comprehensive perspective of the relation between all elements associated with a decision making process. After the hierarchical decomposition stage, pair-wise comparison between the elements within every level should be made using comparison judgment value that indicates how many times one element is important over another element for the selected criterion for comparison. The relative scale for pair-wise comparison is as shown in Table 3. The matrix of weight is the outcome of the pair-wise comparison among two elements. The optimal alternative can be picked based on a global weight for each alternative.

The steps for AHP method can be summarized in [29-31]:

(1) Hierarchical decomposition of the problem.

(2) Pair-wise comparison between the elements within every level.

(3) Estimate the weight and check the consistency of judgment matrix.

If consistency ratio (CR) is less than 0.1, the consistency of the judgment matrix is permissible. If not, judgments need to be modified until the consistency is achieved. Consistency of the judgment matrix can be judged using Equation (1) and Equation (2) [28-30].

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Where λ_{max} is the principal Eigen value, n is the order of judgment matrix, RI is random index and CR is consistency ratio.

Table 3: One to nine comparison scale for pair-wise comparisons

Intensity of Importance	*Equal value*	*Slightly more*	*strong*	*Very strong*	*Extreme*	*Intermediate*	*Inverse comparisons*
Judgment values	*1*	*3*	*5*	*7*	*9*	*2,4,6,8*	*Reciprocals*

CAD modeling using top-down approach

In order to develop wheelchair mechanism concept, SolidWorks (Parametric CAD design software) by Dassault Systems was utilized. The top-down modeling approach implemented in the assembly modeling with keeping focus on inventive principles suggested by TRIZ. Basically, the top-down modeling approach is implemented to model assemblies where the parts are modeled in the assembly file, but saved as separate part files. In this approach, CAD modeling work starts in the assembly file and the geometry of one part can be used in defining the geometry of the another part. Top-down modeling approach allows to having a full observation of an assembly while changing dimensions of assembly in real time [26]. In present work, starting from a set of geometrical references of wheelchair frame, various mechanical links were modeled keeping focus on the relationship between all the mechanical links. Dimensions of a wheelchair were kept within the dimensions of a standard wheelchair [27]. The overall dimensions of wheelchair and a mechanical linkages kept in the range of dimensions of a standard wheelchair described in the IS 7454: 1991 [27]. SolidWorks motion simulation is a tool dedicated to simulating assembly motions was used to enhance wheelchair assembly design.

Results

Application of TRIZ methodology

The methodological TRIZ contradiction matrix approach was used in conceptual design of a reconfigurable wheelchair. The purpose was to clearly set the design strategies based on identified design conflicts which may arise while fulfilling the design requirements.

Identification of contradiction

Problems regarding caregiver transfer support are caregiver dependency, lower back pain among caregivers, injury incidences due to the caregiver failing to properly apply strength during transfer. Due to prolonged seated posture with being inactive in wheelchair, these subjects are exposed to many physical and psychological health problems e.g., fatigue, pain in the hip joint, bedsores, etc. Comprehensive needs assessment study of wheelchair users [3] reported several common problems such as (1) difficulties in transfer from a wheelchair to and from bed (2) problems to stand from seating position (3) problems in using commode without help and (4) risk of pressure sores due to extensive use of a wheelchair.

Aforementioned issues can be resolved by designing and developing a reconfigurable wheelchair, so that it can meet practical demands of the extensive wheelchair users. Thus, the main design intent was to design a reconfigurable wheelchair by improving versatility and automation level of the wheelchairs to fulfill needs of extensive wheelchair users. However, this will lead to a problem of weight increment of the wheelchair. In addition, improved automation level of the wheelchair will make the shape of the wheelchair more complicated. The first identified improving parameter (IP) is the versatility while the associated worsening parameter (WP) is weight increment of a wheelchair. The second identified improving parameter is the level of automation while the worsening parameters associated to it is shape of the wheelchair. Two kinds of conflict identified are shown in Figure 02.

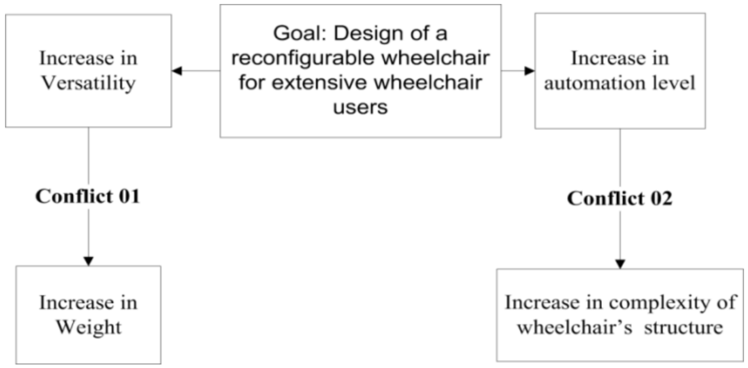

Figure 2: Two kinds of conflict identified

Construct contradiction matrix

After recognizing the design conflicts in fulfilling the design requirements, the improving parameters (IP) and worsening parameters (WP) were accurately mapped with the 39 TRIZ engineering parameters. The intent was to construct a contradiction matrix of improving parameters (IP) and worsening parameters (WP) to recognize suitable TRIZ inventive principles. Table 4 details the relation between selected TRIZ engineering parameters and the related inventive principles.

Table 4: Constructed contradiction matrix

TRIZ engineering parameters	***No.1 Weight of Moving Object***	***No.2 Weight of Static Object***	***No.12 Shape***
No. 01 : Weight of Moving Object	-	-	*#10,#14 #35,#40*
No. 35 : Applicability and versatility	*#1,#6 #15,#8*	*#19,#15 #29,#16*	*#15,#17 #1,#8*
No. 38 : Automation Degree	*#28,#26 #18,#35*	*#28,#26 #35,#10*	*#15,#32 #1,#13*

Developing design strategy using 40 inventive principles method

By checking the contradiction matrix, the inventive principle required for solving design conflicts were obtained. In order to achieve more versatile wheelchair design and to avoid the increase in the weight of system, selected inventive principles were segmentation (#1), multi-functionality (#6), anti-weight (#8), and dynamics (#15).

Table 5: Design strategy employed on basis of the selected TRIZ inventive principles

TRIZ Principles	***Description of TRIZ Inventive principles***	***Design strategy descriptions***
#6. Multi-functionality	*Make product to perform multiple functions and eliminate the need for other products/systems.*	*Increase the functionalities of a wheelchair to eliminate need of caregivers.*
#13. Inversion	*Reverse the action(s) used to solve the problem. Make movable parts stationary and stationary parts movable.*	*Keep caregivers in a stationary state (originally moving) while the wheelchair seat pan and backrest (originally stationary) moves at an appropriate speed.*
#15. Dynamicity	*If product is rigid or inflexible, make it movable or adaptive. Divide a device into parts which are capable of movement relative to each other.*	*Wheelchair capable of adjusting user postures dynamically according to the fatigue level and user needs.*

Further, in order to improve the automation level of the wheelchair and to avoid complexity of wheelchair structure, selected inventive principles were segmentation (#1), inversion (#13),color changes (#32), and dynamics (#15). The inventive principles suggested by the contradiction matrix were reviewed and most relevant principles i.e. universality (#6), inversion (#13), and dynamics (#15) were selected to serve as the guiding ideology for an innovative design of the reconfigurable wheelchair. Table 5 explains the design strategy employed based on the recognized inventive principles.

Kinematic concept and assembly modeling of a wheelchair frame and mechanism in SolidWorks

Selected TRIZ inventive principles were directly utilized into kinematic concept of wheelchair. The kinematic mechanism concept (Fig. 3) for a reconfigurable wheelchair consists of Watt's six-bar mechanism (attached twice at both sides of the wheelchair frame) and one slider crank mechanism (attached once at middle of wheelchair frame). Whole mechanism guides the motion of the parts of wheelchair for sit to stand and sit to sleep transformations. The link 1, seat (link 2), link 3 and frame form the first four-bar linkage of Watt's six-bar mechanism. The second four-bar of Watts six bar mechanism is formed by the link 3, link 4, link 5 and frame. Both four bar mechanism coupled with common link 3. Further, slider crank mechanism consists of the backrest (link6), slider (link 7), link 8 and frame where slider (link 7) reciprocates on the bar attached to the backrest (link 6) at the backside. The backrest (link 6) is must be locked with the link 5 during sit to stand transfer and unlocked during sit to sleep transfer. Note that seat (link 2), link 1, link 3 and link 5 are stationary during sit to sleep transfer. Link 10 (leg-rest) are connected with extended part of link 8 using link 9 in order to co-ordinate leg-rest and backrest motion.

The complete linkages arrangement accomplishes a planar motion and attached to wheelchair frame as shown in Figure3.Linkage structure of wheelchair mechanism at sit, stand and sleep configuration depicts in Figure 4, Figure 5, and Figure 6 respectively.

The top-down modeling approach was implemented in the assembly modeling with focus on inventive principles suggested by TRIZ. Dimensions of a wheelchair were kept within the dimensions of a standard wheelchair. The overall dimensions of wheelchair and a mechanical linkages kept in the range of dimensions of a standard wheelchair described in the IS 7454: 1991 [27]. CAD modeling work was started in the wheelchair assembly file and the geometry of one link was helped in defining the geometry of another link. Top-down modeling approach allowed having a full view of an assembly of wheelchair frame and mechanical links while making dimensional changes of assembly in real time. Starting from a set of geometrical references of wheelchair frame, several mechanical links were modeled keeping focus on the relationship between all the mechanical links. SolidWorks motion simulation was used to simulating assembly motions which helped to enhance wheelchair assembly. SolidWorks Motion simulations ensured that the leg-rest, sit and backrest were moving in a coordinated and safe way during sit to stand transformation, by using trajectories of motion. It also ensured the leg-rest and backrest move in a coordinated and safe way during sit to sleep transformations. Motion simulation also checked for interferences among modeled parts.

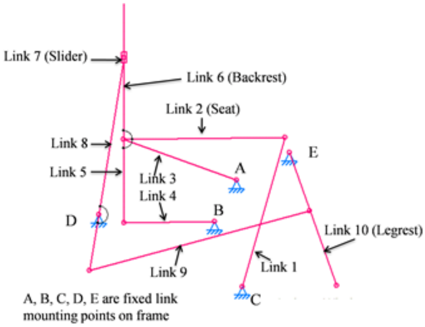

Figure 3: The kinematic concept of a reconfigurable wheelchair

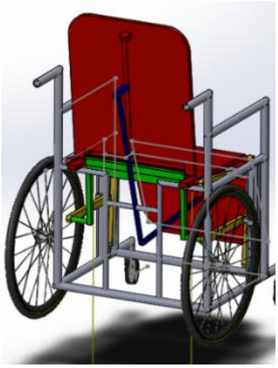

Figure 4: Linkage structure with frame for seat position

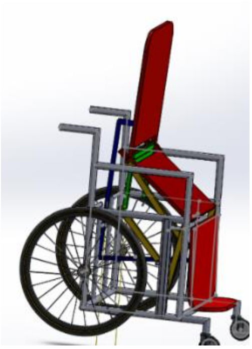

Figure 5: Wheelchair at standing configuration

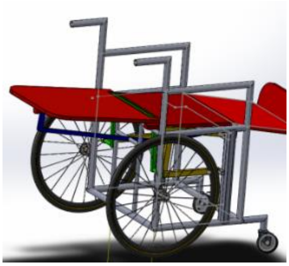

Figure 6: Wheelchair at sleeping configuration

Proposing wheelchair conceptual designs for the modeled mechanism

In this phase, proposed TRIZ inventive principles are further used to generate wheelchair system alternatives with help of a morphological chart. Based on product functional analysis, the morphological chart provided wheelchair design features during the concept generation process to help to recognize sub-solutions for respective sub-functions of the wheelchair design. Wheelchair conceptual designs were generated by selecting the individual sub-solutions of the wheelchair and merging them. The morphological chart was integrated with TRIZ method to quickly and systematically utilize the TRIZ principles. Using proposed TRIZ principles and the morphological chart, most feasible three conceptual designs were generated. All generated conceptual designs comprise same wheelchair frame and mechanism assembly.

Concept 1:

Conceptual design-I uses an easy accessible joy-stick controller with electric drive (servo-motor) to allow users to having control on the linkages motion as well as wheelchair propulsion. Placement of Joy-stick controller is done in such way that it is in within reach of any kind of user. With help of the joy-stick controller, user can easily control the backrest angle during seat to sleep transformation. Also, it can be used to control seat motion from sitting mode to standing mode. An electric propulsion capability is achieved by means of a long running battery set and two DC motors. This design uses a storage box between two wheels for battery and electronic parts (controller, motor drivers, etc.). The wheelchair wheels are fitted with electro-magnetic brakes (EMB) enabling the user to change velocity at will. Whole assembly is equipped with pin lock mechanism to lock the wheelchair mechanism at stopping points. In this design, adjustable armrest and leg rests are provided to suite any kind of user. Extend Casters are provided in order to avoid toppling issue.

Concept 2:

Conceptual design-II equipped with a hydraulic support system with complete functional capabilities allows a user to stand and sleep in safe manner. When user needs to stand or sleep, he/she can operate the handle to provide motion to mechanism with the help of a hydraulic system. In combination of chain drives, hydraulic system aids users to change to their desired position. The operating handle is placed in the side of the wheelchair, so that user can be easily accessible to the handle. A propulsion capability is achieved by means of manual operated push on wheels integrated with bicycle brakes to control speed. Small back wheels are used to stabilize the wheelchair during transformations, facilitating users to operate a wheelchair safely. Whole assembly is equipped with friction lock mechanism to lock the wheelchair mechanism at stopping points. The wheelchair is featured with adjustable leg rest and arm rest for users with different physical dimensions, spring suspensions, and H-shaped safety harness.

Concept 3:

Conceptual design-III applies pneumatic drive support system to provide motion to the mechanism. Whenever user needs to stand up, he/she need to press of a button at the armrest to adjust the speed of a seat. It can also enable users to shift to different beck-rest postures according to the fatigue degree. Wheelchair is provided with motion remote control arrangement so that caregiver can also contribute in change in postures. Jerking behavior of pneumatic system is overcome by using a shock absorber system, which makes transformation smoother to make a wheelchair more user-friendly. The solenoid valves controlled pneumatic tubes with the compressed air actuate all the movements of wheelchair parts. A propulsion capability is achieved by means of hand crank operated wheels integrated with bicycle brakes to control speed. Wheelie bars are provided to attain wheelchair stability during both transformations. The wheelchair is featured with adjustable leg length and seat depth to fit users with different leg length.

Final concept design selection using AHP

The AHP approach decomposed a problem into a goal, criteria, sub-criteria and alternatives. The overall goal of the AHP was to select the optimal conceptual design of a reconfigurable wheelchair. The main criteria were safety, weight and cost which were represented in the second level. The sub-criteria were represented in the third level. The last level was the conceptual designs labeled as conceptual design-I, II and III. The hierarchy of AHP was constructed as shown in Figure 7.

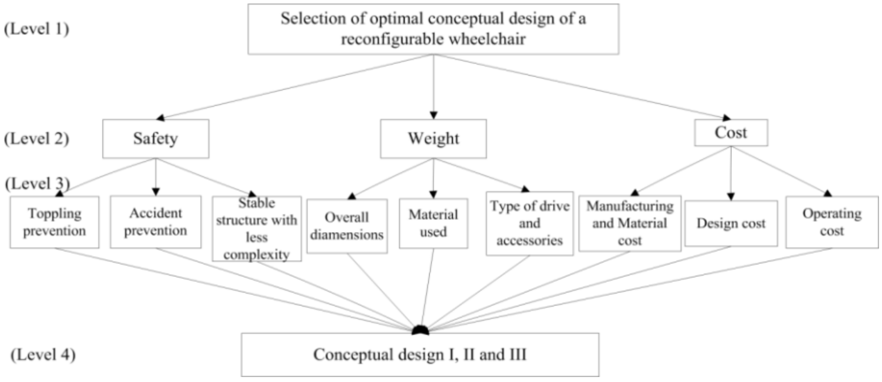

Figure 7: AHP hierarchy structure for the reconfigurable wheelchair concept design selection

After the hierarchical decomposition, pair-wise comparison between the elements in each level was made using comparison judgment values (from

Table 3) based on experience and knowledge of decision makers about a wheelchair. The process begins with a pair-wise comparison between the main criteria (safety, cost and weight) by design expertise (See Table 6). Then, the comparison matrices for each level with respect to the elements from the earlier level were obtained. All pair-wise comparisons were assisted by MS Excel adds-in for AHP based calculations.

Table 6: The comparison matrix for main criteria

Main criteria	***Safety***	***Weight***	***Cost***
Safety	*1*	*5*	*4*
Weight	*1/5*	*1*	*1/3*
Cost	*¼*	*3*	*1*
Total	*1.45*	*9*	*5.33*

For main criteria judgment matrix, λ max was calculated and found to be 3.086where random index, RI (3) is 6. The consistency index (CI) and the consistency ratio (CR) of the comparison matrix of main criteria were 0.043and 0.074 (See Table 7).

Table 7: Weight analysis among main criteria

Main Criteria	***Safety***	***Weight***	***Cost***	***Weights***	***Order***
Safety	*0.6896*	*0.5555*	*0.75*	*0.66507*	*1*
Weight	*0.1379*	*0.1111*	*0.0625*	*0.1038*	*3*
Cost	*0.1724*	*0.3333*	*0.1875*	*0.2310*	*2*

Where CI=0.043, CR= 0.074 and λ max = 3.086

Consistency index (CR) for the pair wise comparisons made throughout the AHP analysis was found to less than 0.10. From these calculations, it was assured that the consistency of the judgments made in all comparison matrices were permissible. Table 8 shows the comparison matrix of conceptual design alternatives for sub criterion safety.

Table 8: The comparison matrix for alternatives with respect to the first sub criteria safety

Alternatives	Conceptual design-I	Conceptual design-II	Conceptual design-III
Conceptual design-I	1	7	0.20
Conceptual design-II	0.14	1	0.13
Conceptual design-III	5	8	1

Further, the AHP calculations allowed the estimation of the criteria weights relative to the individual conceptual design as well as its global importance. The global weights for each criteria and sub criteria were summarized in Table 9.

The order of the three criteria was safety > cost > weight (See Table 9). Also, the ranking of sub criteria were accident prevention >stable structure with less complexity >Operating cost> …>design cost. It was clearly shown that accident prevention was the more significant sub criterion. Final aggregation of results was reported in Table 10. Based on the combined weights, three conceptual designs were ordered as Conceptual design I > Conceptual design III > Conceptual design II. Concept design I received highest weight compared to the other conceptual designs at the end of the AHP calculations and therefore chosen as the optimal conceptual design for the wheelchair development.

Table 9: Relative importance and ranking of criteria and sub- criteria

Main Criteria	Weight	Rank	Sub criteria	Relative Importance (%)	Weight	Rank
Safety	0.665	1	Toppling prevention	12.40	0.0668	7
			Accident prevention	52.99	0.2857	1
			Stable structure with less complexity	34.59	0.1865	2
Weight	0.1038	3	Overall wheelchair dimensions	33.84	0.0672	6
			Type and volume of material used	37.29	0.07404	5
			Types of drive and accessories incorporated	28.86	0.0573	8
Cost	0.2310	2	Manufacturing and material cost	42.14	0.1106	4
			Design cost	15.28	0.0401	9
			Operating cost	42.56	0.1117	3

Table 10: Final ranking of concepts alternatives

Criteria	*Sub criteria*	*Weight*	*Conceptual Design-I*	*Conceptual Design-II*	*Conceptual Design-III*	*CR*
Safety	***Toppling prevention***	*0.0668*	*0.162*	*0.3365*	*0.5015*	*0.085*
	Accident prevention	*0.2857*	*0.478*	*0.187*	*0.335*	*0.086*
	Stable structure with less complexity	*0.1865*	*0.451*	*0.314*	*0.235*	*0.025*
Weight	***Overall wheelchair dimensions***	*0.0672*	*0.426*	*0.2*	*0.374*	*0.013*
	Type and volume of material used	*0.07404*	*0.35*	*0.397*	*0.253*	*0.010*
	Types of drive and accessories incorporated	*0.0573*	*0.35*	*0.404*	*0.246*	*0.014*
Cost	***Manufacturing and material cost***	*0.1106*	*0.29*	*0.36*	*0.35*	*0.071*
	Design cost	*0.0401*	*0.43*	*0.277*	*0.293*	*0.042*
	Operating cost	*0.1117*	*0.33*	*0.328*	*0.342*	*0.043*
Evaluation of conceptual designs			***3.267***	***2.803***	***2.929***	

Product realization through 3D- Printing Technology

For the purpose of functionality testing of proposed mechanical movements of wheelchair, 3D printed wheelchair parts have been fabricated (3D printer (Fused Decomposition Modeling based Stratasys Dimension SST 1200)). It allowed constructing the physical model (using ABS material) for product realization. All the wheelchair parts were re-orientated to prevent the scaffolds during their 3D printing. Further, some transitions between surfaces redesigned to make them progressive by giving them certain slope, to make the layers self-supporting. After the printed parts were reprocessed using operations like drilling, cutting, using acetone primers, etc. All the printed and reprocessed parts were assembled in the final wheelchair model of the proposed wheelchair shown in Fig 8. At this stage, the wheelchair has been tested and it was shown to move as required with desired end configurations. The authors are in process of fabricating the actual prototype (using MS AISI

1018) to validate the efficiency of the proposed design, its configurability, and adaptability to various configurations.

Figure 8: 3D printed prototype with standing configuration

Conclusions

The present research implemented an integrated TRIZ–AHP approach in conceptual design phase of the reconfigurable wheelchair in order to get the optimal concept solution. From the TRIZ contradiction toolkit, Multi-functionality (#6), Inversion (#13) and Dynamicity (#15) inventive principles were employed in the early conceptual design phase to eliminate two identified design conflicts. Based on recognized TRIZ inventive principles, reconfigurable wheelchair mechanism was modeled in SolidWorks using a top-down modeling approach. The newly modeled mechanism was refined by using motion simulation capabilities of the SolidWorks software. The new mechanism concept was further integrated with different wheelchair design features by means of the morphological chart in order to get three innovative concept designs for the reconfigurable wheelchair. Concept design-I (Joystick controller with electric drive) received highest weight among all conceptual designs, hence selected as the best feasible design concept. Consistency ratio (CR) for the pair wise comparisons made throughout the AHP analysis was found less than 0.10. In future, the resulting wheelchair model will undergo structural and multi-body dynamics analyses and further product development phases. The methodology implemented in the present work can be utilized for upcoming applications in design of new assistive devices.

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