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FOLDABLE BICYCLE: EVALUATION OF EXISTING DESIGN AND NOVEL DESIGN PROPOSALS

Arunachalam M., Arun Prakash R. and Rajesh R.
PSG College of Technology, Coimbatore, India
E-Mail: muthiah_arunkaveri@yahoo.co.in

ABSTRACT

The Currently available Foldable bicycles in the Indian market are made up of heavy materials which make them difficult to carry. The prices of the bicycles are also generally not affordable to the common man. Many of them are not foldable in a configurable geometrical order, because of which their transportation becomes very difficult. It also leads to a lot of difficulty, when it is to be stored for future use. This paper aims at evaluating the existing foldable bicycles in the Indian market and proposing a compact foldable bicycle which is weightless and overcomes all the limitations in the currently available bicycles in the Indian market. The proposed bicycle is designed in such a way that it is foldable by providing fasteners at the joints. The design structure imparts stable bicycle geometry. This system meets different topography and environmental conditions which are not met by the existing foldable bicycles.

Keywords: foldable bicycle, conceptual design, morphological matrix.

1. INTRODUCTION

A product development process is the entire set of activities required to bring a new concept to a state market readiness. The design process are considered to be a set of technical activities within the product development process that work to meet the marketing and business case vision [1]. Various theories and methodologies used in a product design and development process along with their advantages and limitations have been reviewed by researchers [2]. The set of technical activities are performed in a sequential order.

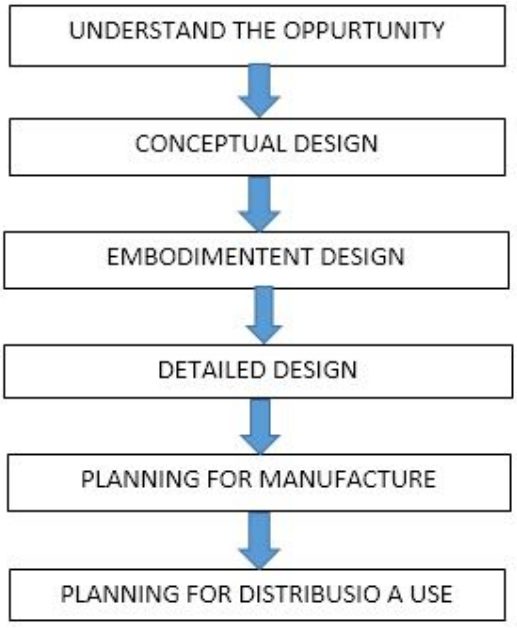

Figure-1. 1 sequences of phases in product development process.

The stages in the product development process are classified based on the type of technical activities performed in it. The flow chart in Figure-1 represents the sequence of activities performed in a typical product development process. The first phase, understanding the opportunity deals with developing a vision for new product.

It analyses the limitation in the existing product, from which the opportunity to develop a new design is created. The second phase, conceptual design deals with the generation of as many solutions as possible to evaluate it to select the best concepts. Generally the concept solutions are conceived as ideas which are represented by free-hand sketching.

Once the concept solutions are generated, the best concepts are selected by techniques like Pugh chart and weighted matrix which evaluate the concepts based on the specific criteria which the customer would consider while purchasing the product. The conceptual design stage is followed by the embodiment design stage which deals with the selection of suitable materials to the components, along with its dimensions.

The detail design stage, which follows the embodiment design stage deals with the detailed drawings and specifications of the components in the product. The CAD tools are extensively used in this stage. The analysis and optimization of the design concepts are done using various CAD/CAE packages. In the current study a few foldable bicycle concepts are proposed. [3] Some heuristics and line of thumb have also been developed by researchers to lighten the cognitive load that such design problems impose.

2. EXISTING DESIGN AND ITS EVALUATION

In this work, the existing foldable bicycles have been evaluated to understand the limitations in it. Generally, in a typical product development process, the product is evaluated based on a specific set of design criteria. The design criteria are framed with regard to cost, functionality, safety, maintenance, durability in addition to a specific set of criteria depending upon the product being

considered. In this study a specific set of criteria is formulated for the foldable bicycle and the existing bicycle designs are evaluated to understand their limitations. Depending upon the shortcoming of the existing product for the criteria, new designs are proposed to overcome the limitations. The formulated criteria for the foldable bicycle in this work for evaluation are based on: the folding methods, portability, ease of transportation, compactness (during travel and storage) material used, tire size, weight and quickness to fold etc. The shortcomings of the existing designs in satisfying the formulated set criteria have strengthened the need for a new design in foldable bicycle, to overcome the limitations.

The existing foldable bicycle designs are shown in Figures 2 and 3 [4]. The limitations in the existing foldable bicycles for the specific set of formulated design criteria are presented in this study. The weight of the currently existing foldable bicycles are found to be more than 15 kg., which is on the higher side considering the fact that it may be needed to be carried for long distances. The cost of the bicycle is also not affordable to average customers. The ease of fold ability is also found to be less because the existing bicycles can only be a folded into two fold. The proposed design in this study eliminates all the limitations in the existing ones by enhancing the design feature besides adding some additional features.

Figure-2. Existing alloy foldable bicycle.

Figure-3. Existing steel foldable bicycle.

3. CONCEPTUAL DESIGN

The conceptual design has the following stages in it as shown in Figure-4. The conceptual design is said to be a rough idea about the design to be proposed. It is considered to be a skeleton structure of the design, to which the flesh and body are added in the embodiment design stage which follows it.

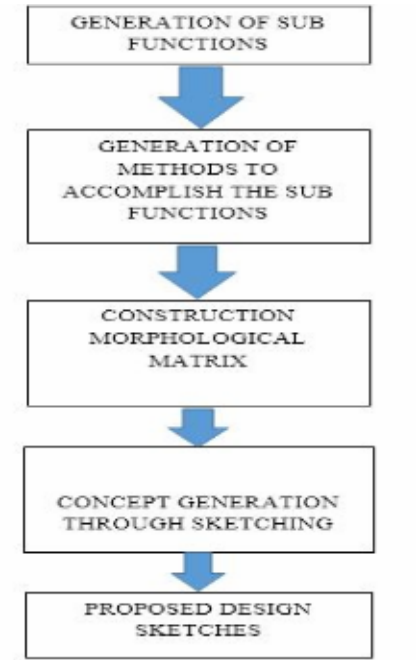

Figure-4. Conceptual design stages.

3.1. Generation of sub functions

In this stage of concept generation various sub functions that are needed to accomplish the overall function are identified. This is generally identified by function structure diagram. Each sub function can be accomplished by different ways which are called as concepts.

In the current study the following sub functions are identified based on the functional diagram. They are: **1.** Frame shape **2.** Frame, **3.** Drive mechanism, **4.** Front wheel/back wheel, **5.** Tube interfaces, **6.** Joints, **7.** Links, **8.** Dynamic interfaces, **9.** Forks and steering. The sub function identified is contributions to the accomplishment of the overall function of the product.

3.2. Generation of methods to accomplish the sub functions

The next stage in product design is to develop as many concepts as possible for each sub function. To accomplish each sub function a variety of options would be available. The available options for each sub function are then identified as real devices or sub components. These sub components which represent the sub functions are arranged in a logical manner to accomplish the main overall function. In the current study the subcomponents needed for the formulated sub functions like frame shape, drive mechanism, tube interface etc. have been determined. Figure-2 shows the number of sub components needed for the corresponding sub functions.

3.3. Construction morphological matrix

The representation of a variety of subcomponents for achieving each sub function is represented in a chart called morphological chart. The morphological chart

contains rows and columns which resemble a matrix form. Each row has a particular sub function and the different methods in which it can be accomplished. Once completed The morphological chart gives a variety of possible sub components that could be used to achieve each product sub function. Further, any sub component under a particular sub function could be combined with other sub components in the other rows by various combinations to result in a wide range of product configurations to accomplish the overall function of the product.

Figure-5 shows the different sub components which can possibly contribute to the sub functions mentioned above. For example as shown in Figure-5, to accomplish the sub function 'joining' the various methods like fasteners, welds and rivets could be used. Each sub component could be combined with other sub components under different sub functions like frame shape, frame structure, links, drive mechanism etc. to contribute to the overall function. Thus various foldable bicycle designs are proposed using the morphological chart.

Table-1 shows the combination of various sub components under various sub functions to contribute to the foldable bicycle designs. In this study using the morphological chart and the combination of sub components as shown in table 1 six new foldable bicycle concept design have been proposed. For example, as shown in Figure-6, concept sketch 1 is evolved by the combination:

(1,1)+(2,1)+(3,1)+(4,1)+(5,1)+(6,1)+(7,1)+(8,5)+(9,5).

The first number in the parenthesis represents the sub function number and the second letter represents the solution number in the morphological chart. For example, (1, 1) represents that for the sub function 1, the solution 1 in the chart is used. In Table-1, the sub function 1 represents the frame section and the solution 1 represents the circular type of section. Hence, it is inferred from notation (1, 1) that, circular section is used for the frame of the foldable bicycle. In similar manner (8, 5) represents that for the sub function 8, solution 5 is used. Thus a particular type of combination arranged in this method has nine sub components as there are nine sub functions to be accomplished. These nine sub components arranged in a logical order would be developed into the overall product under study. The combinations shown in table 1 lead to six different foldable bicycle concepts. The number of overall concepts are not only limited to six. They can be explored further to develop many more concept designs.

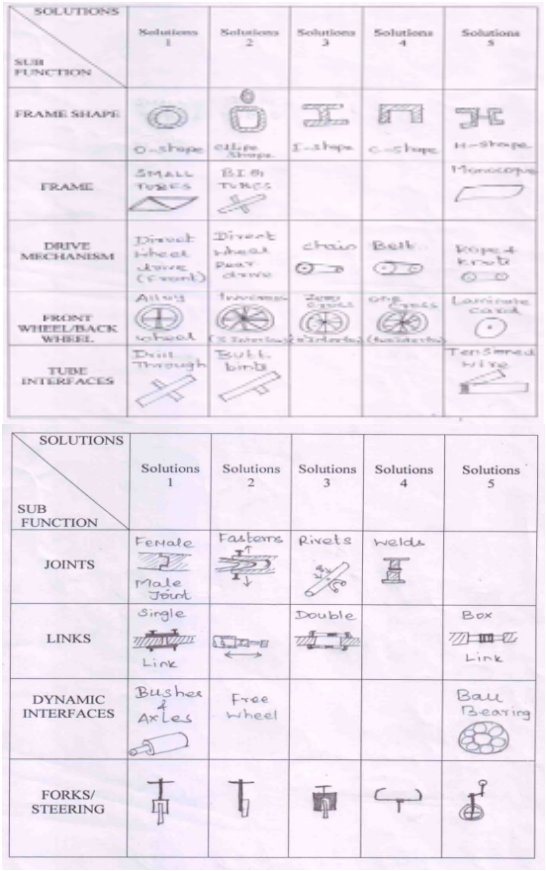

Figure-5. Morphological chart of foldable bicycle.

3.4. Concept generation through sketching

Generally in the conceptual design stage the product concepts are drawn in paper using pencil as free hand sketches. CAD systems are too rigid and not as flexible as freehand sketching. The initial free hand sketches roughly describe the possible numerous solution concepts for the identified problem. The paper and pencil work are intensively used in the conceptual design stage whereas CAD applications are used for detail design like modelling of parts, FEA, etc. The pencil work allows the flexibility of speed that is needed during the conceptual design stage.

Drawing and free hand sketching are the two efficient methods to develop an idea or thought to solve a definite problem and to express the ideas of the product that are to be designed. Drawing and free hand sketching can be considered as a symbolic language used by the designer during the conceptual design stage. Generally the sketches start as a valuable idea or a solution to a problem and it is continuously evolved by adding some minute details to enhance the features of design by successive iteration.

Concept sketches play an important role in product design and development process [5]. The initial sketches that are drawn may sometimes be used as a tool to generate new ideas. The sketching in the product development process acts as a bridge between an idea as a

thought and a physical representative of the idea as an object. The free hand sketch gives the flexibility in producing concepts and facilitates easy manipulation of the concepts, and they don't have any geometrical and topological constrains etc.

In this study, as many solutions as possible to a given design problem have been generated by means of sketching. Generally the CAD packages slow the ease and speed with which sketches can be created. The concept sketches provide quicker communication and retrieval at an early stage of design.

In this study, based on the combinations generated from table 1, six designs have been proposed in this section. The Figure-6, represents the conceptual sketch 1 evolved from combination:
(1,1)+(2,1)+(3,1)+(4,1)+(5,1)+(6,1)+(7,1)+(8,5)+(9,5).

It has to be noted that the combination matrix represents only the sub components chosen under a sub function and which may not necessarily be in the logical order or sequence in which each sub component is connected to the other.

Figure-6. Conceptual sketch 1.

Conceptual sketch 1 shows a foldable cycle, which is weightless because it doesn't have a chain drive and due to its reduction in material because of the decreased size of the rear wheel when compared to the front wheel.

Conceptual sketch 2 proposes a foldable bicycle, which has a simplified structure. It has been generated from the combination:
(1,1)+(2,1)+(3,3)+(4,1)+(5,1)+(6,2)+(7,2)+(8,1)+(9,1). It also follows the same principle as concept 1 with reduced rear wheel size which decreases the weight of the bicycle.

Table-1. Combination matrix for conceptual sketch.

Concept	Combination matrix for conceptual sketch
Concept sketch 1	(1,1)+(2,1) +(3,1)+(4,1)+(5,1)+(6,1)+(7,1)+(8,5)+(9,5)
Concept sketch 2	(1,1)+(2,1) +(3,3)+(4,1)+(5,1)+(6,2)+(7,2)+(8,1)+(9,1)
Concept sketch 3	(1,4)+(2,5) +(3,3)+(4,1)+(5,1)+(6,4)+(7,3)+(8,2)+(9,5)
Concept sketch 4	(1,1)+(2,2) +(3,3)+(4,4)+(5,5)+(6,2)+(7,4)+(8,2)+(9,4)
Concept sketch 5	(1,2)+(2,2) +(3,2)+(4,1)+(5,1)+(6,1)+(7,5)+(8,1)+(9,5)
Concept sketch 6	(1,1)+(2,1) +(3,3)+(4,1)+(5,2)+(6,3)+(7,4)+(8,5)+(9,2)

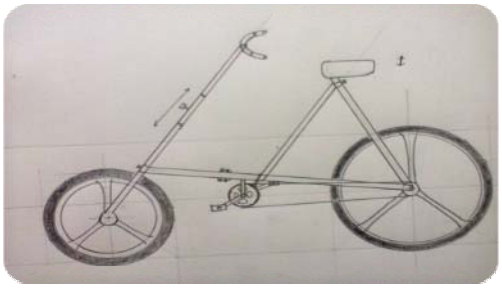

Figure-7. Conceptual sketch 2.

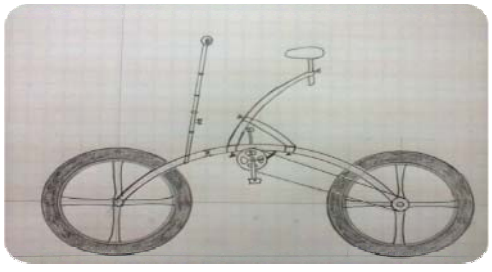

Figure-8. Conceptual sketch 3.

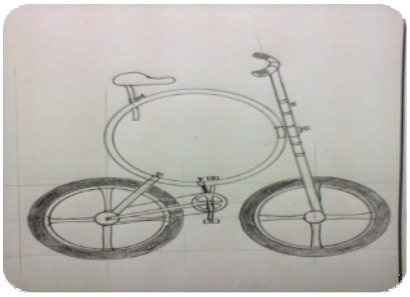

Figure-9. Conceptual sketch 4.

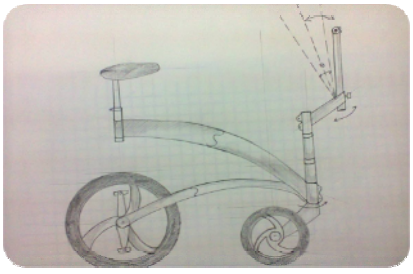

Figure-10. Conceptual sketch 5.

Figure-11. Conceptual sketch 6.

The proposed bicycle shown in Conceptual sketch 3 has a saddle seat that can be easily dissembled which leads to the ease of folding of the bicycle. The design has been developed from the combination:-

(1,4)+(2,5)+(3,3)+(4,1)+(5,1)+(6,4)+(7,3)+(8,2)+(9,5).

When removed easily, the saddle units facilitate the foldability of the frame which resembles the shape of a bow. The design resembles the design of the pi-cycle.

Conceptual sketch 4 proposes a design which is very compact and portable in nature. This design offers a lot of advantages with regard to compactness when it is folded. The design has been conceived by the combination:

(1,1)+(2,2)+(3,3)+(4,4)+(5,5)+(6,2)+(7,4)+(8,2)+(9,4).

Conceptual sketch 5 is adapted from the unicycle model. The bicycle uses the rear wheel drive. The front wheel size is lesser in size than the rear wheel. The chain drive is eliminated in this design which facilitates the design to be a weightless one when compared to the existing one. The handlebar proposed in this design is easily adjustable, which gives a very comfortable drive. The proposed design in concept sketch 5 has been obtained from combination:

(1,2)+(2,2)+(3,2)+(4,1)+(5,1)+(6,1)+(7,5)+(8,1)+(9,5).

The Conceptual sketch 6 proposes a design, which has very less number of members, which in turn reduces the weight substantially when compared to the existing design.

The proposed concepts in this study may offer some advantages like less weight, ease of foldability, less cost etc. A lot of designs could be generated further by effective use of morphological chart by combining various sub components in it.

4. CONCLUSIONS AND FUTURE WORK

In this study ,novel foldable bicycle designs have been proposed after evaluating the existing foldable bicycles in Indian market. By evaluating the existing designs, the limitations in the designs were found out which paved ways for exploring new foldable bicycle designs which overcome all those limitations. The sub functions which contribute to the overall product function are generated from functional diagram. To accomplish the different sub functions, possible sub components are identified and a morphological chart was generated. From the morphological chart, sub components under each product sub functions are combined to develop six new concept designs. The new designs thus developed have been represented using free hand concept sketching.

As for the future work, this study only deals with the evaluation of existing foldable bicycles in the Indian market. Hence further, the proposed concepts are to be evaluated to find out the best available concept using the typical concept selection methods like pugh chart and weighted matrix. The final concept design that has been selected by these methods would be considered for embodiment design in which the materials and dimensions are selected. The embodiment design stage is followed by analysis and optimisation.

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