Conceptual Design of a Bike Towing Trailer with Smart Towing Trailer

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Abstract. The roads in the rural places are narrow and bumpy. Hence, big vehicle such as a car, truck, and lorry have no access to the narrow roads. Therefore, most of the villagers choose light vehicles such as bicycles and motorcycles as the primary transportation method to deliver goods using a towing trailer. The towing trailer found in the many of the rural areas are very traditional and inconvenient. This paper focuses on the conceptual design of a smart bike towing trailer equipped with the multipurpose towing based on customer requirements. A total of 5 conceptual design is produced. The Pugh selection chart and weighted decision matrix is used and it is found that the conceptual concept 4 has the best design. A 3D detailed modelling of the concept 4 is developed for future testing and analysis of the design prior to fabrication.

1. Introduction

In the year 2017, there are approximately 75% of Malaysian lived in urban areas and cities while the remaining 25% lives in rural areas [1]. Roads are the ones of the main infrastructure in any civilization. In Malaysia, rural road falls under the state road category and it contributes the largest proportion of road in Malaysia. Rural road is one of the most effective approaches for local economy improvement [2].

Commonly the roads in rural area are narrow and not well maintained [3]. Large vehicle tends to face difficulty to operate on these kind of road. Hence, the primary mode of transportation used in the rural area are bicycles and motorcycles while towing trailer is used for goods transport. The common towing trailer is a coupling of a trailer to the vehicle. The towing trailer consist of wooden or thin metal platform equipped with two wheels and a connection module. The majority of the towing trailers used by the rural folks are fixed to the vehicle and not removable making it bulking and inconvenient. This type of towing trailer is found to be poorly design because it is inconvenient to use, difficult to store, low efficiency, unable support a heavy load, breakdown easily and require long-term maintenance.

This project aims to produce a better designed towing trailer by incorporating convenience, ease of use, durability, capacity, and efficiency into the towing trailer. The new design will be based on actual data of customer needs collected via questionnaires.
2. Benchmarking
Table 1 shows the benchmarking conducted of 4 available products with the specification. The operating characteristics of the benchmarking products served as the key performance metrics for the design product that will be measured and used for comparison.

| Product Name | Flatbed™ | Nomad™ | Travoy | Coho XC™ |
|--------------|----------|--------|--------|----------|
| Capacity     | 45.40 kg | 45.40 kg | 27.00 kg | 32.00 kg |
| Wheels       | 2        | 2      | 2      | 2        |
| Bike         | Rear Axle| Rear Axle | Rear Axle | Rear Axle |
| Attachment Point |        |        |        |          |
| Weight (kg)  | 6.42 kg  | 8.00 Kg | 4.50 kg | 10.00 kg |
| Wheel Size   | 16" Push Button | 16" Push Button | 12" Push Button | 16" Quick Release |
| Cover        | None     | Weatherproof Taraulin | Rain Cover | Cargo Bungee Net |
| Durability   | 3        | 3      | 4      | 4        |
| Cost         | RM 1180.00 | RM 1600.00 | RM 1300.00 | RM 1970.00 |
| Reliability  | 4        | 3      | 3      | 4        |
| Easy to attach | 3     | 3      | 3      | 3        |

3. Need Analysis
This survey was conducted using a set questionnaire to analyse customer needs and requirements and obtain accurate feedback regarding the product requirement. The questionnaire is divided into five parts, namely demographic profile, general overview, problem, solution, and respondents’ opinion. The structure of the questionnaire is made up of a combination of Likert scale types, multiple-choice question types, and open-ended questions.

A total of 50 feedbacks were collected from the population living in the rural area. 60% of the respondents are male and 40% female. The age group of respondents collected from 18-25, 26-40, 41-50, 51-60 and 61 above are 20%, 36%, 24%, 18% and 2% respectively. The respondent feedback on towing trailer requirement is as shown in the figure 1. From the questionnaire survey, the collected data of towing trailer requirement is used to obtain the importance weight factor of the house of quality.
4. House of quality (HOQ)

Table 2 shows the HOQ for decision making on the properties of the design. From table 2, it can be concluded that the importance of engineering characteristic is ranked in the order of type of material, material toughness, cost, capacity, size of trailer, durability and travel distance, weight and finally self-part assembly.

**Table 2. House of quality**

| Importance | Customer Requirement | Engineering Characteristic | Unit |
|------------|----------------------|---------------------------|------|
| Factor     |                      | Cost                      | KM   |
| 5          | Cheap                | 5                          |      |
| 2          | Light                | ▼                          |      |
| 2          | Easy to Maintenance  | ▼                          |      |
| 3          | Capable to support heavy load | ▼ |      |
| 4          | Life Span            | ▼                          |      |
| 4          | Capable to travel in Long Distance | ▼ |      |
| 4          | Large Storage Space  | ▼                          |      |
| 5          | Comfortable to Use   | ▼                          |      |

Raw Score (Importance factor x relationship) = (394)

| Engineering Requirements | Cost | Weight of Trailer | Self-Part Assembly | Durability | Type of Materials | Distance Travel | Size of Trailer | Capacity | Material Toughness at Attachment Areas |
|---------------------------|------|-------------------|---------------------|------------|-------------------|----------------|----------------|----------|----------------------------------------|
| Direction of Improvement  |      |                   |                     |            |                   |                |                |          |                                        |
| Unit                      | KM   | kg                | n/a                 | n/a        | n/a               | n/a            | n/a            | m^3      | kg/MPa                                 |
|                          |      |                   |                     |            |                   |                |                |          |                                        |
|                          |      |                   |                     |            |                   |                |                |          |                                        |

**Figure 1. Respondent feedback on trailer requirement**

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| Unit                      | KM   | kg                | n/a                 | n/a        | n/a               | n/a            | n/a            | m^3      | kg/MPa                                 |
|                          |      |                   |                     |            |                   |                |                |          |                                        |
5. Morphological chart
A morphological chart is a visual way to capture the necessary product functionality and explore alternative means and combinations of achieving that functionality [4]. Every element of product function may be solved with multiple solutions. Through the morphological chart, it enables these solutions to be expressed and provide a structure for considering alternative combinations. This can enable the early consideration of the product ‘architecture’ through the generation and consideration of different combinations of ‘sub-solutions’ that have not previously been identified. Used appropriately, it can help to encourage a user driven approach to the generation of potential solution. Table 3 shows the best solution concept generates for each sub-problem. All the sub-functions ideas are generated and combined into an overall solution to get the best solution.

Table 3. Morphological chart

| Function          | Option 1             | Option 2             | Option 3             |
|-------------------|----------------------|----------------------|----------------------|
| Tyre              | Road bike tyre       | Mountain bike tyre   | Hybrid tyre          |
| Power Supply      | Two stroke Engine    | Electric Driven Engine|
| Electric Supply   | Dynamo               | Battery              | Solar Plate          |
| Load Sensor       | Rectangular load cell| Load cell V105       | Load Cell SWARFX     |
| Connector (trailer to bike) | Chain and hook     | Hydraulic tow        | Classic tow bar      |
| Connector (Tyre to trailer) | Shaft with gear     | Shaft with bearing   |                      |
| Goods storage     | Open-top trailer     | Closed top double layer trailer | Closed top double layer trailer |

6. Conceptual Design
A total of 5 conceptual designs are produced by combining all the possible combinations of alternatives solution identified in Table 3 is as shown in figure 2. In the process of developing the concept design, 5 design constrains are considered, namely energy consumption, environmental friendliness, cost, safety and durability. Concepts generated are then evaluated on its feasibility and viability. The designs are dissected on its strength and weaknesses using the weighted decision matrix and Pugh concept selection. The methods will be applied in selecting the best conceptual design.
Figure 2. Concept designs
(a) Concept 1, (b) Concept 2, (c) Concept 3, (d) Concept 4, (e) Concept 5

7. Design Selection
The generated 5 conceptual designs are evaluated using the weighted decision matrix and Pugh chart for the selection process. A decision matrix is a tool to test competing concept by classifying the design criteria with variables of weighting and evaluating the degree to which each concept meets the criterion [5]. In order to determine this, the values obtained for different design criteria need to be converted into a consistent set of values. This criteria rating is integrated from the result of HOQ. Table 4 shows the
rating of each design tabulated in the decision matrix. It is observable that concept 4 obtained the highest rating of 7.97 while concept 2 received the worst rating of just 5.66.

In order to confirm the selection, the Pugh chart is deployed in Table 5. Pugh’s method compares each concept relative to a reference or datum concept and for each criterion determines whether the concept is better than (+), weaker than (-), or about the same (S) as the reference concept [6]. Flatbed has been chosen as the datum for the first Pugh chart selection as it is one of the competitive and benchmark products. The concept 4 and concept 5 have highest rating of 5 pluses rating. Hence, based on the rating of weight decision matrix and Pugh chart, concept 4 is chosen as the best design.

Table 4. Weighted decision matrix

| Design Criteria          | Cost  | Weight | Self-part assembly | Durability | Type of Material | Distance travel | Size of trailer | Capacity | Material toughness | Total Rating |
|--------------------------|-------|--------|--------------------|------------|------------------|-----------------|-----------------|----------|-------------------|--------------|
|                         | Factor | Score  | Score              | Score      | Score            | Score           | Score           | Score    | Score             |              |
| Concept 1                | 0.06  | 10     | 0.6                | 3          | 5                | 0.42            | 5               | 0.63     | 8.7              | 6.74         |
| Concept 2                | 0.06  | 9      | 0.54               | 2.7        | 5                | 0.45            | 2               | 0.3      | 6.66             | 5.66         |
| Concept 3                | 0.09  | 3      | 0.27               | 5          | 0.45             | 5               | 2               | 0.3      | 6.11             | 6.11         |
| Concept 4                | 0.4   | 5      | 2                  | 5          | 0.42             | 5               | 2               | 0.3      | 7.97             | 7.97         |
| Concept 5                | 0.09  | 8      | 0.72               | 7          | 0.63             | 7               | 0.63            | 0.3      | 7.7              | 7.7          |

Table 5. Pugh selection chart

| Selection Criteria         | Flatbed | Concepts |
|----------------------------|---------|----------|
| Cost                       | D       | 1        |
| Weight of trailer          | A       | 2        |
| Self-part assembly         | T       | 3        |
| Durability                 | U       | 4        |
| Type of material           | M       | 5        |
| Distance travel            | -       | +        |
| Size of trailer            | -       | +        |
| Capacity                   | +       | +        |
| Material toughness        | +       | +        |
| # of Pluses                | 7       | 5        |
| # of Minuscs               | 2       | 4        |
| Total Weight Score         | 5       | 1        |

It is observable that concept 4 obtained the highest rating of 7.97 while concept 2 received the worst rating of just 5.66.
8. 3D Modelling
The chosen concept design 4 is then being detailed in terms of dimension in a 3D modelling as shown in figure 3. The 3D modelling may be used for virtual simulation and analysis prior to fabrication of a prototype. Performing test and analysis virtually is more cost effective and less time.

Figure 3. 3D model of Concept 4

9. Conclusion
The conceptual design for the smart bike towing trailer were developed. The design process went through a detailed process of customer needs identification via market survey from 50 respondents, benchmarking of competitors, translating customer requirements into the design, and selecting the best design concept. A total of 5 concept design were produced based on the available solution obtained in the morphological chart. Each of the concept design were carefully evaluated and assessed based on the customer needs using the Pugh selection chart and weighted decision matrix. The concept 4 is found to be the best design that received the highest ranking based on the customer needs. The 3D modelling developed can be applied in various virtual testing to understand the properties of the design.

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