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Mechanical Design and Analysis of New Staircase Climbing Hand Truck

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ABSTRACT

The transportation of goods on a staircase could give challenges to the users, especially those stay in a high-rise building particularly when the elevators are not in service. There is a variation of existing staircase climbing hand truck designs has been developed; however, some problems were identified. The existing designs have a limitation in terms of wheel system configuration to be used on different staircase sizes. Besides, the designs also possess limited supporting structure areas to accommodate the goods and are less ergonomic for handling and downsizing. The objective of the study was to design a new staircase climbing hand truck that was completed with new functional and ergonomic features to improve the climbing process. Primary and secondary data were collected via observation, interview, and journal articles, followed by design concept development, three-dimensional modelling and analysis, and usability testing. Our findings showed that the proposed design of the hand truck is satisfactory in terms of developed features such as an adjustable wheel frame, foldable nose plate, safety compartments and cables, and adjustable handle. Further improvements might be necessary to enhance the design functionality of the hand truck for the transportation of goods on a staircase.

Keywords: Climbing, Design, Hand Truck, Staircase, Trolley

1. INTRODUCTION

Transporting materials or goods in a high-rise building from one floor to another is important so the next corresponding works can be executed adequately [1]. There are several ways the goods can be transferred in a building using facilitating technologies in which, one of them is by using the escalator. An escalator is a moving staircase that transports people or goods between levels through a revolving belt of steps operated by a motor. Besides, the crane is another option used as towering equipment, suspending heavy things from a projecting arm to move them. However, the application of both the escalator and crane is not practical in a building with few levels because they require high cost and space. Alternatively, a staircase climbing hand truck could be a better choice [2-4].

The hand truck is generally used to facilitate carrying heavy goods with less effort [1, 3]. The tool can be used on even and uneven surfaces. Sometimes, the hand truck is also called an extended version of a trolley due to its unique function, which can be used on a staircase and uneven surfaces (holes). The hand truck is also interpreted as a straightforward operating vehicle that minimises time and effort without any external electrical power input [2]. The hand truck started as a relatively simple piece of equipment, carrying several boxes or a large part of equipment simply by leaning back on two wheels [4]. Constant evolution has led the hand truck to take on a

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wide variety of forms, from basic models to those capable of converting to different shapes and handling significant appliances.

Literature reported that staircase-climbing hand trucks could be categorised into basic hand trolleys, convertible hand trucks, and appliance hand trucks [5]. The basic hand truck is a few feet tall and has either a shallow or deep platform on the floor. This type of hand truck has evolved a bit on their own, at least in terms of the materials used. Models are available today in aluminium and stainless steel, and they come with slightly different looks based on their capacity and their intended function within the workplace. The convertible hand truck, on the other hand, serves as an upright hand truck and flat, platform-style cart that can transport equipment throughout a facility [5]. These hand trucks were developed to support equipment on both sides and give business owners more peace of mind throughout the day. Although these trucks often have very high weight capacities and represent a significant improvement over their more basic counterparts, they can merely be a stepping-stone to larger and more powerful models currently in use worldwide [5]. The appliance hand trucks represent the largest and most improved hand truck model currently on the market. Their massive size and heavyweight capacity make them perfect for moving huge appliances, retail store shelves, and certain types of power equipment within an industrial facility. These models are fully evolved to meet today's most challenging requirements [5].

One of the drawbacks of the existing hand truck designs, regardless of their type, is the fixed or limited wheel frame configuration to be adjusted to suit specific dimensions of the staircase. This situation requires the users to put more effort into lifting the hand truck on the staircase, resulting in fatigue and tiredness. Moreover, the conventional hand truck has a small base or platform to place the goods. Unstable placement or position of the things on the platform could cause them to fall or have accidents. A wider platform is desired to cover well and stabilise the position of the goods. The existing designs are heavy and possess complex structural body frames, making it difficult to downsize for storage. Other than that, less ergonomic features shown in the conventional designs may lead to the users to fatigue in handling the hand truck.

Considering the aforementioned disadvantages can affect the performance of a hand truck, it is thus necessary to design and develop a new staircase climbing hand truck. The main focus is given to the development of updated features and related mechanisms to highly improve functionality, secure user safety, and reduce any possible harm to the users.

2. MATERIAL AND METHODS

2.1 User Needs Identification

The determination of user needs is essential before the progress of design concepts of the hand truck can be made. To execute this, two major approaches were implemented, which are through observation and interview. For the observation study, the session was performed at a 7-storey student hostel to further understand the characteristics of goods transportation on the staircase. The dimensions of the staircase at the venue are 17 cm and 24 cm in height and width, respectively. Our results showed that the students claimed difficulty transferring goods, especially those heavy on the staircase if the elevators are not in service. They also reported that there were a few hand trolleys available to use; however, the provided models were inadequate to carry the goods climbing the staircase due to the condition of the wheel structure, which was stiff and inflexible. The condition of the staircase itself was also poor, with uneven surfaces and holes appeared in many places. The students needed to be careful in bringing the things so they would not fall. Some of the students also complained of experiencing fatigue and tiredness while carrying the goods without using any assistive devices. The types of goods that are commonly transported at the hostel are large volumes of water bottles, tangible project tasks, clothes, large parcels, and many more.

The interview sessions were conducted by phone or face-to-face based on the interviewees' preferences. There were five interviewees chosen, in which all of them are students that commonly use the staircase in daily activities. A number of questions were asked to the interviewees associated with the problems investigated, such as frequency of using the staircase in a day, type of the goods to be carried, experiences using the hand truck, difficulty in handling the hand truck, the possibility of having an injury while using the hand truck, and recommendations to improve the current hand truck design. The interviewees stated that they tended to use the staircase at least four times a day (go and return) with or without carrying a significant number of things. Some of them claimed they had no experience using any kind of hand truck, which gave us challenges in obtaining the required data. To those who have experience utilising the hand truck, there was a problem when lifting the equipment on the staircase related to the movement of the wheels. The existing wheel configuration has a limitation in terms of rotation and anchorage on the staircase steps. The wheel frame is developed to be fixed at a certain position without can be adjusted. Thus, the users have to increase their effort to lift the hand truck for the staircase with a larger width and height. This may also result in fatigue and tiredness during a longer working operation. Furthermore, the hand truck should be lightweight, safe, and ergonomic but must still retain the optimum strength in its operation.

2.2 Product Design Specifications

After considering all the collected data from the observation and interview sessions, the proposed design of hand truck should attain the following specifications: 1) adjustable wheel frame: the opening of the wheel can be adjusted in specific lengths to cope with different staircase sizes; 2) extended portion of the platform or nose plate: the coverage area of the platform to support the goods is widen; 3) adjustable height of the handle: the height of the handle can be adjusted in several different lengths; 4) safety compartment and cable: the placement of the goods can more be secured and reducing the tendency of falling down; 5) lightweight materials for the main body frame: the bulky and heavy body frame may lead to the difficulty in handling and downsizing; 6) operating system of the hand truck: the climbing mechanism of the hand truck could be in manual mode in order to reduce the overall weight; and 7) overall dimension of the hand truck: the hand truck should not be too large or small, but it must be adequate to carry the loads with acceptable strength. All these criteria were then considered for functional analysis, which was performed through a morphological chart. In the morphological chart, several functions related to the product specifications were suggested and further interpreted in a brainstorming session. As a result, a total of eight groups of functions had been developed for the proposed design, which are handle design, main body frame design, platform or nose plate design, wheel frame configuration, safety elements, operating system, downsizing mechanism, and main materials of the structure. Each function was then transformed into at least three detailed ideas to yield a variety of possible solutions. Several combinations of ideas from every function were made to produce five different design concepts. Figure 1 exhibits the four design concepts in sketching mode.

In brief, concept A has a retractable handle that can be adjusted in several lengths. The main body frame can be horizontally folded for downsizing. In terms of the climbing mechanism, this concept is completed with three wheels to support heavy-duty work. The wheel frame can be adjusted manually using bolts and nuts in three different levels. An additional safety compartment or bag can be attached and detached from the body frame to store the things. On the other hand, Concept B has an additional handle to enhance the grip while handling the hand truck. The main body frame was developed with a straight lattice design to hold heavy goods, and it can be vertically folded for storage. Similar to concept A, concept B also imposes an adjustable three-wheel system for climbing. However, the length of the wheel frame is adjusted using locking pins instead bolt and nut. This concept was embedded with safety straps to keep the goods in place. Concept C has a curve-back cross brace for holding a high quantity of weights. Compared to concepts A and B, the platform plate for this concept is slightly longer and wider and can be folded. The three-wheel system is still applied in this concept for climbing purposes, and it can be extended up to three levels using bolt and nut fastening type. A larger size and double layer of safety compartment is installed on the body frame to accommodate many goods. For concept D, the length of the handle can be adjusted in a way similar to concept B. The body frame can be folded vertically for downsizing. It has a single-wheel system with two extra small wheels to guide the movement in a straight lane. The extra wheels could also help to anchor on the steps during climbing the staircase. The wheel frame can be lengthened or shortened by adjusting the locking system using bolts and nuts. Double straps are installed on the body frame to secure the placement of the goods.

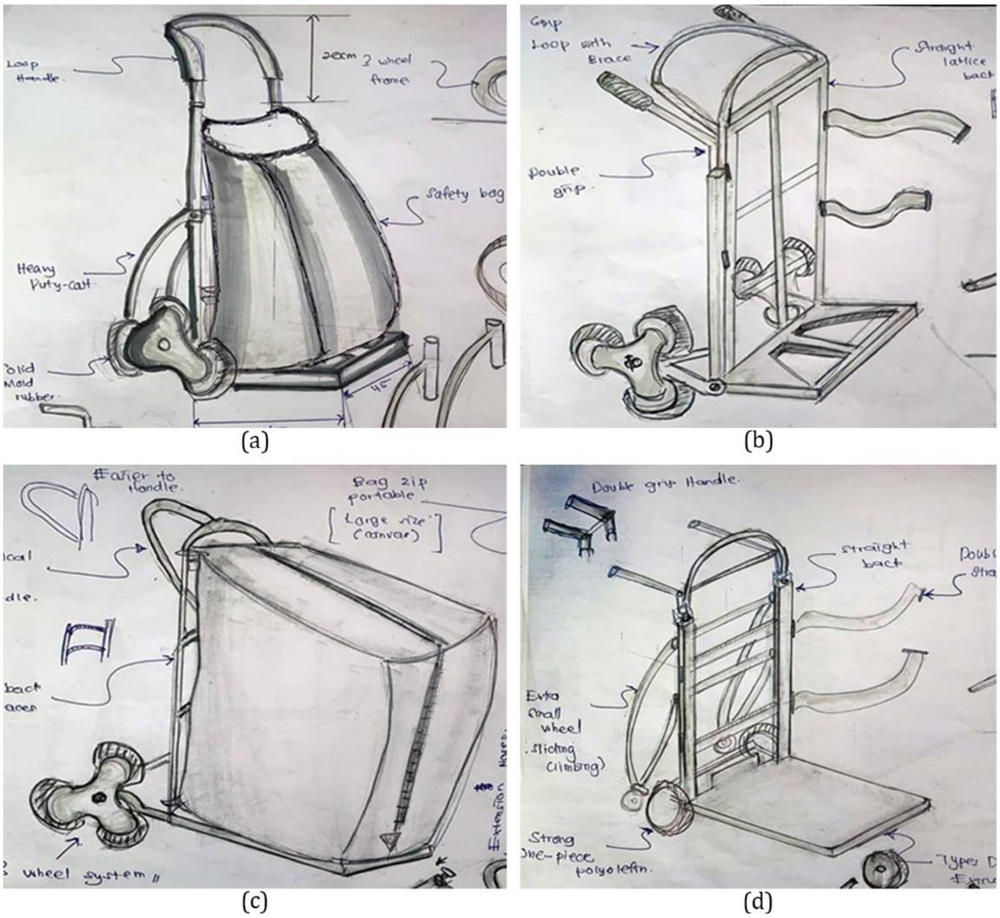


Figure 1: Four different design concepts of the proposed hand truck.

All the proposed design concepts were then examined in accordance with the finalized user needs. Comparison among design concepts was made in terms of several selection criteria in order to select the best one using concept screening and concept scoring methods. Through the concept of the screening method, a selection matrix was created based on the user's needs. Besides, an existing product as a benchmark had also been set. Each concept was evaluated using "+", "−", and "0" symbols for each selection criterion that indicated better, worse, and equal in comparison to the benchmarked product, respectively. Then, the ranking of the design concepts was determined by computing the net score based on the sum of "+". The concept that showed the greatest net score will secure the first place, and the one that showed the least being the last. Also, an additional evaluation was performed on all concepts to identify the need for revision. Table 1 depicts the data evaluation in the concept screening for all concepts of the proposed product. It was shown that concept A, concept B, and concept C had been chosen for further assessment.

Table 1: Concept screening of all design concepts.

No.	Selection Criteria	Concept A	Concept B	Concept C	Concept D	Competitor (Reference)
1	Adjustable Wheel Frame	+	+	+	0	0
2	Easy Handling	0	+	+	+	0
3	Easy to Carry	+	0	0	+	0
4	Lightweight	+	+	+	0	0
5	Durable	+	0	0	0	0
6	Safety Features	+	0	+	0	0
7	Ergonomic Design	0	0	+	+	0
	Sum 0's	5	3	5	3	0
	Sum –'s	0	0	1	1	0
	Sum +'s	2	4	1	3	0
	Net Score	5	3	4	2	
	Rank	1	3	2	4	
	Continue?	Yes	Yes	Yes	No	

All three concepts were then evaluated in detail in the concept scoring stage to select the best design. Rating scale values were given to each selection criterion to distinguish its significance or importance level. The rating scale ranges from 1 to 5, where 1: Poor, 2: Ok, 3: Fair, 4: Good, and 5: Excellent. Furthermore, each selection criterion was set to a weightage value (%) by considering its contribution preferences in product function. Table 2 shows the concept scoring method performed on concept A, concept B, and concept C. Concept A recorded the highest total score compared to concept B and concept C; therefore, concept A was selected as the final design to be developed further. A few related modifications were also made to concept A to improve some features.

Table 2: Concept scoring data for concept A, concept B, and concept C.

No.	Parameter		Concept A		Concept B		Concept C	
	Selection Criteria	Weightage (%)	Rating	Score (%)	Rating	Score (%)	Rating	Score (%)
1	Adjustable Wheel Frame	10	5	1.25	4	1.00	5	1.25
2	Easy Handling	10	3	0.75	5	1.25	5	1.25
3	Easy to Carry	10	4	1.00	4	1.00	5	1.25
4	Lightweight	20	5	1.25	3	0.75	4	1.00
5	Durable	20	5	1.25	3	0.75	3	0.75
6	Safety Features	15	4	1.00	4	1.00	3	0.75
7	Ergonomic Design	15	3	0.75	4	1.00	3	0.75
	Total Score		7.25		6.75		7.00	
	Rank		1		3		2	
	Develop?		Yes		No		No	

2.3 Three-Dimensional Modelling and Prototype Fabrication

A complete three-dimensional (3-D) model of the finalized design was created using the computer-aided design (CAD) software CATIA. The 3-D model parts were constructed using suitable modelling features available in the software, such as revolved, extruded cut, extruded, mirrored, and shell. As all the individual parts of the design were completely built, they have assembled accordingly. The general or standard dimensions of a hand truck were referred to available data in the literatures so that the proposed design was still within the ergonomic scope. Figure 2 illustrates the 3-D model of the hand truck design in full assembly and downsizing configurations. Generally, our proposed design consists of a three-wheel system where the wheel frame can be adjusted in three different levels or extended to 2 cm, 4 cm, and 6 cm. The design also comprises an adjustable handle where the length can be varied depending on the user preferences to achieve ergonomic configuration. The outer surface of the handle is covered with rubber to secure good gripping while handling the hand truck. For safety purposes, the hand truck is equipped with a detachable compartment or bag to place the goods. This is also to ensure that the goods are safely carried. To improve the safety elements, safety cables are also included in the design, where they are attached to the body frame to hold the goods. The main body frame is made of aluminium alloy, whilst the wheel structures are made of mild steel. Some of the internal parts of the wheel system are made of acrylonitrile butadiene styrene (ABS) through the 3-D printing method. In terms of downsizing, the body frame is vertically folded, and the wheel frames on both sides are inwardly folded. The selection of lightweight material (aluminium alloy) for the main body frame helps the users to easily carry and store the hand truck. Overall, the proposed hand truck model has a dimension of 557 mm, 524 mm, and 1078 mm in width, length, and height, respectively.

All 3-D model files were saved in the appropriate format in CATIA software. The model files were thoroughly checked before the mock-up of the product was prepared for initial functional inspection. The process was then followed by prototype fabrication through metalworking and 3-D printing. The prototype fabrication processes and the finished prototype are shown in Figure 3.

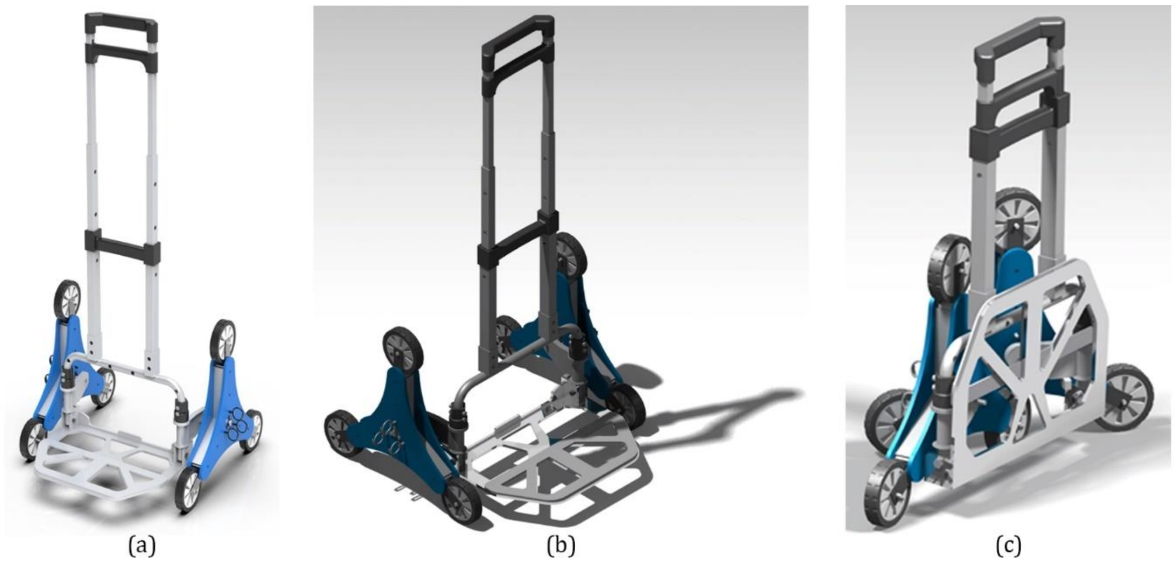
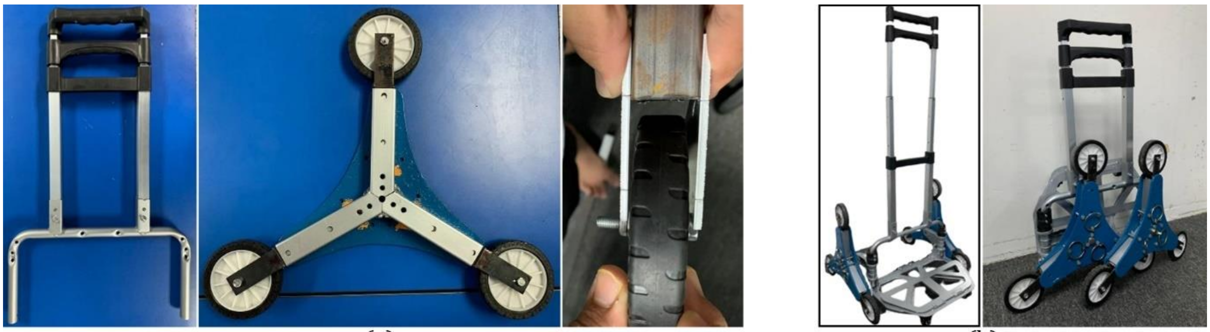


Figure 2: (a) and (b) The isometric views of the 3-D hand truck model. (c) The downsizing configuration of the hand truck model.

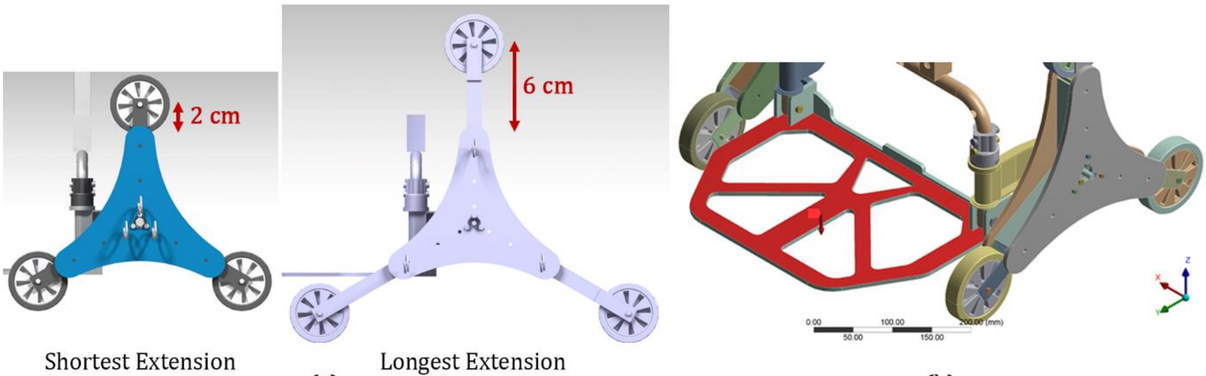


(a) (b)

Figure 3: (a) Some of the prototype fabrication processes. (b) Finished prototype.

2.4 Computational Analysis and Usability Testing

To estimate the structural strength of the proposed hand truck, a 3-D linear static finite element analysis (FEA) was conducted. Since the main focus of the invention is on the adjustable wheel frame for usage in different staircase sizes; thus, two different wheel extension configurations – shortest and longest extension lengths – were evaluated in the computational structural analysis (Figure 4a). FEA is a well-accepted numerical method that is widely used to probe the problems related to mathematical modelling in the area of science and technology [6-10]. All geometrical models of the hand truck design were exported into an FEA software, ANSYS, in IGS file format (.igs). The material properties assigned to the models were assumed to be isotropic, linearly elastic, and homogenous. Table 3 shows the value of elastic modulus, *E* and Poisson's ratio, *v* was considered for each material in the analysis. For the loading, a force of 294.3 N, representing a 30-kg load, was applied on the nose plate surface (Figure 4b). This force indicates the weight of the goods placed on the hand truck. As for the support, all the surfaces of the wheels that touch the ground or flat surface were fixed in all directions in terms of translation and rotation. The four-node solid tetrahedral element was used as the mesh type assigned to all part models. A similar size of the mesh (3.0 mm) was applied to all models to ensure the reliability of mesh construction at critical locations. All contact surfaces in the assembly model were considered as bonded type.



(a) (b)

Figure 4: (a) Comparison of shortest (2 cm) and longest (6 cm) extension lengths. (b) The location (red area) of the force (294.3 N) applied on the nose plate surface.

Table 3: Material properties used in the analysis.

Material	Elastic Modulus (GPa)	Poisson's Ratio	References
Aluminium Alloy	70	0.33	Soleimany et al. (2013) [11]
Mild Steel	200	0.30	Ghaidan (2013) [12]
Polylactic Acid	2.9	0.37	Farah et al. (2016) [13]
Nylon	0.42	0.40	Polyzos et al. (2022) [14]
Polyethylene	1.09	0.32	Jordan et al. (2021) [15]

The finished prototype was tested to evaluate its usability and functionality in climbing the staircase through three different wheel frame extension lengths – shortest (2 cm), medium (4 cm), and longest (6 cm) extensions. The prototype usability testing was performed at a 7-storey student hostel where the dimension of the staircase used is 17 cm and 24 cm for height and width, respectively. All three case conditions were set with a similar loading weight (10 kg) on the top surface of the hand truck nose plate while climbing the staircase. Besides, the person performing the usability testing was kept the same to avoid unnecessary variations in the results obtained. The hand truck was set to climb the staircase at one level only in one way.

3. RESULTS AND DISCUSSION

3.1 Structural Analysis Results

The results of 3-D linear static FEA were presented in the maximum magnitude and distribution of equivalent von Mises stress and total deformation. The visualization of the stress and deformation distributions in the models was executed using a colour contour plot by which the most and least critical regions are indicated by the red and blue colours, respectively. Our findings showed that the model with the minimum extension recorded a lower maximum stress value (396.4 MPa) than the model with the maximum extension length (411.1 MPa). The percentage difference was about 3.6%. Figure 5 exhibits that the critical stress region was located at the connecting rod between the wheel frame and nose plate bar for the shortest and longest extension cases. The surrounding areas covering the wheel frame itself and the upper horizontal bar of the nose plate sustained minimal stress levels. The rationale behind why the longest extension led to the greater stress magnitude compared to the shortest one is possible because of the increased bending retention of the structure in resisting the loading. Compared to the shortest extension case, the configuration of the wheel frame is more stable and rigid in bearing the loading. This is also supported by the calculation of the Factor of Safety (FOS), where the minimum extension (1.01) resulted in a slightly higher FOS relative to the maximum extension length (0.97). Since the longest extension of the wheel frame recorded the value of FOS slightly lower than 1.0, expecting a greater tendency to fail, several possible improvements or precautions can be imposed on that configuration. As an example, the placement and weight of the goods must be considered carefully to avoid any unwanted failures. Besides, the selection of a more appropriate locking system for the adjustable wheel frame parts, which is stiffer and more promising, could be suggested.

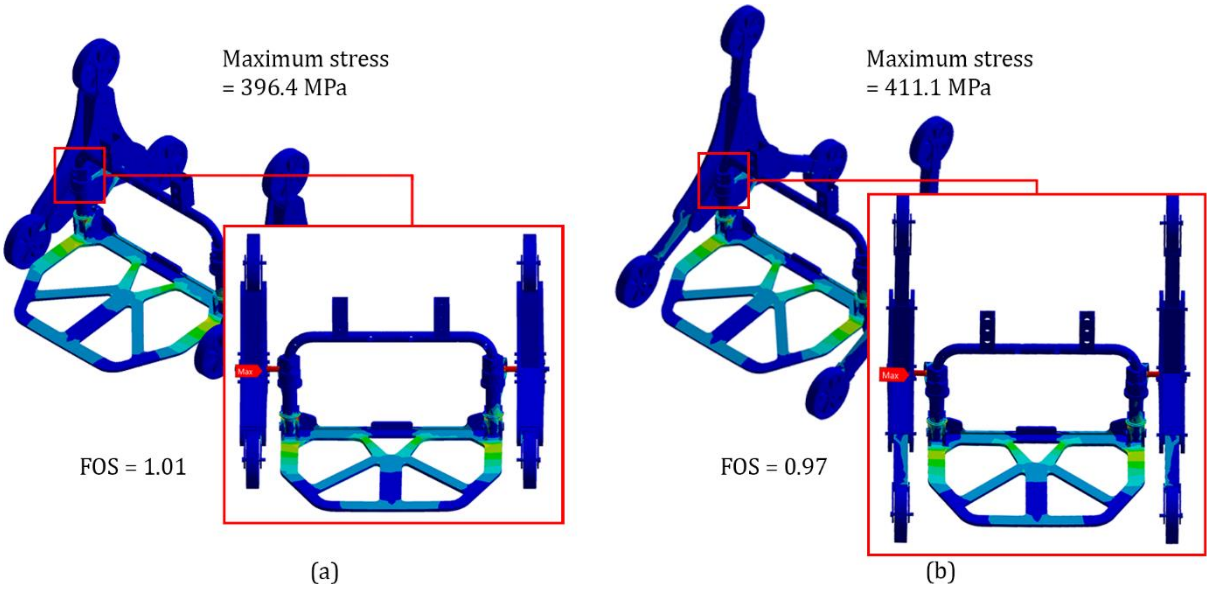


Figure 5: The critical stress region of the hand truck model for the (a) shortest and (b) longest wheel frame extensions.

For the total deformation results, it is important to note that the shortest wheel frame extension exhibited the maximum displacement value of 9.11 mm, marginally greater than the longest (9.00 mm), with a percentage difference of merely 1.2%. Figure 6 depicts the distribution of total deformation within the climbing part model where the highly affected region was recorded at the tip of the nose plate for both extension length cases. The configuration of the nose plate considered in the analysis was before it was folded out to provide additional support space. It is thus expected that the maximum total deformation at the tip of the nose plate will be increased due to the increase in the bending stress from the loading. To reduce the chance of having a significant deformation that leading to failure, an additional small support can be added at the bottom surface of the nose plate.

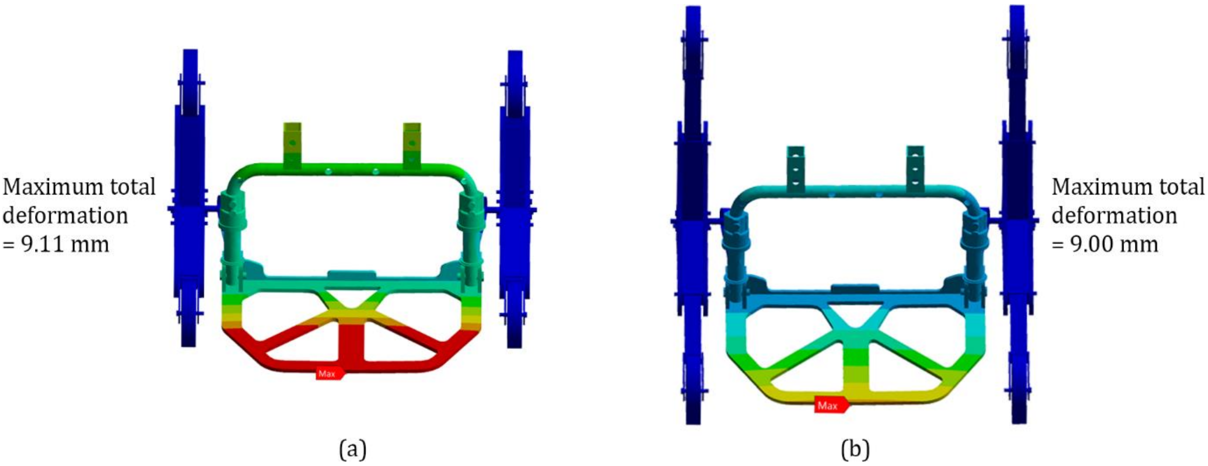


Figure 6: The critical deformation region of the hand truck model for the (a) shortest and (b) longest wheel frame extensions.

3.2 Usability Testing Results

Prior to the usability testing, the user needs to know how to upsize the hand truck prototype so that it is ready to use. Firstly, the wheel frame of the hand truck had to be flipped out at 90° from its original position. Then, the safety pin must be pulled out, and the extension length of the wheel frame was adjusted either at the shortest, medium, or longest extension. Next, the safety pin was inserted back to lock or secure the position of the wheel frame. If necessary, the extended part of the nose plate could be flipped out for additional support space. The goods could then be placed on the nose plate and secured using the safety cables. The height of the handle was adjusted to the desired position, and the hand truck could start being pulled on the staircase. Figure 7 shows the three-wheel frame extensions considered in the usability testing. The results of the testing showed that the medium extension length (4 cm) of the wheel opening led to an adequate climbing process compared to the shortest (2 cm) and longest (6 cm) extensions. More efforts were needed to lift the goods if the shortest extension was used. This could be due to the length of the extension being quite limited to cover or anchor to the next step on the staircase tested. The longest wheel extension, on the other hand, could save more time because that configuration could cover two staircase steps at only one complete wheel rotation as compared to others. Therefore, the variations in the wheel frame extension length were seen to be advantageous for the application at different staircase sizes.

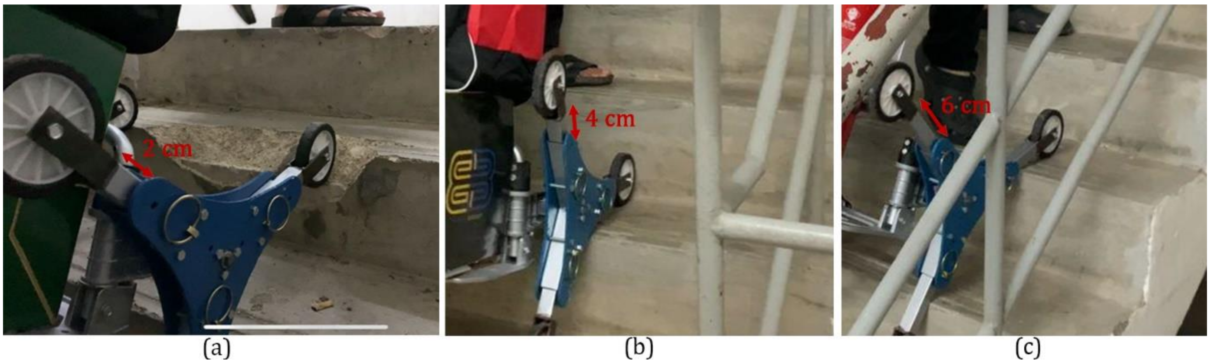


Figure 7: The usability testing of the prototype for (a) shortest, (b) medium, and (c) longest extensions.

4. CONCLUSION

Based on the design development processes, computational structural analysis, and usability testing performed, it can be concluded that the proposed hand truck design provided satisfactory results. The mechanical stress and total deformation generated in the design were acceptable in tolerating the loading imposed. The improved working mechanism of the hand truck that focuses on handling different staircase sizes, safety elements, and ergonomic features can reduce or even prevent unfavourable situations. Thus, this new hand truck design is perceived to tackle the drawbacks of the existing hand trucks.

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REFERENCES

[1] Kilari, S., Praneetha, V., Deep, V., Ajay, T., Veda, M., Brahmmam, S., & Krishna, S. Design & fabrication of tri-wheel staircase climbing hand trolley. International Journal of Engineering Trends and Technology, vol 67, issue (2019) pp. 54-57.

[2] Chodankar, O., Dharne, D., Ibrampurkar, P., Salave, N., & Lanjekar, S. Design of stair climbing trolley. International Journal for Scientific Research & Development, vol 7, issue 2 (2019) pp. 907-909.

[3] Gaikwad, A.V., & Kadam, S.J. Design and fabrication of a stair climbing hand truck. Research & Reviews: Journal of Engineering and Technology, vol 2, issue 2 (2013) pp. 1-6.

[4] Chhabra, S., Srivastava, V.K., Singh, S., Tiwari, V., Samaniya, U.K., & Sangwan, S. A new design of staircase climbing trolley. International Research Journal of Modernization in Engineering Technology and Science, vol 4, issue 3 (2022) pp. 2634-2640.

[5] https://www.douglasequipment.com/hand-trucks/the-evolution-of-hand-trucks/

[6] Rosli, M.U., Ishak, M.I., Jamalludin, M.R., Khor, C.Y., Nawi, M.A.M., & Mohamad Syafiq, A.K. Simulation-based optimization of plastic injection molding parameter for aircraft part fabrication using response surface methodology (RSM). IOP Conference Series: Materials Science and Engineering, vol 551, issue 1 (2019) p. 012108.

[7] Ibrahim, M.I.F., Rosli, M.U., Ishak, M.I., Zakaria, M.S., Jamalludin, M.R., Khor, C.Y., Rahim, W.M.F.W.A., Nawi, M.A.M., & Shahrin, S. Simulation based optimization of injection molding parameter for meso-scale product of dental component fabrication using response surface methodology (RSM). AIP Conference Proceedings, vol 2030, issue 1 (2018) p. 020078.

[8] Rosli, M.U., Termizi, S.N.A.A., Khor, C.Y., Nawi, M.A.M., Omar, A.A., & Ishak, M.I. Optimisation of process parameters in plastic injection moulding simulation for blower impeller's fan using response surface methodology. Intelligent Manufacturing and Mechatronics (2021) pp. 309-318.

[9] Nawi, M.A.M., Ishak, M.I., Rosli, M.U., Musa, N.M., Ahmad Termizi, S.N.A., Khor, C.Y., & Faris, M.A. The effect of multi-staged swirling fluidized bed on air flow distribution. IOP Conference Series: Materials Science and Engineering, vol 864, issue 1 (2020) pp. 012194.

[10] Ahmad Termizi, S.N.A., Khor, C.Y., Nawi, M.A.M., Ahmad, N., Ishak, M.I., Rosli, M.U., & Jamalludin, M.R. Computational fluid dynamics (CFD) simulation on mixing in T-shaped micromixer. IOP Conference Series: Materials Science and Engineering, vol 932, issue 1 (2020) p. 012006.

[11] Soleimany, M.R., Moharami, R., & Zadeh, M.R. Study on effects of mechanical properties of aluminum alloys on residual stresses distribution in cold rolling process on the cylindrical specimen using FEM simulation. Journal of Basic and Applied Scientific Research, vol 3, issue 1 (2013) pp. 492-498.

[12] Ghaidan, A.A. The effect of heat treatment on elastic-plastic behavior and absorbing energy for L-shaped mild steel under compressive axial load. Al-Rafidain Engineering, vol 21, issue 5 (2013) pp. 115-126.

[13] Farah, S., Anderson, D.G., & Langer, R. Physical and mechanical properties of PLA, and their functions in widespread applications — A comprehensive review. Advanced Drug Delivery Reviews, vol 107 (2016) pp. 367-392.

[14] Polyzos, E., & Pyl, L. Effect of printing direction on the elastic properties of 3D-printed nylon materials Physical Sciences Forum, vol 4, issue 1 (2022) pp. 1-8.

[15] Jordan, J.L., Rowland, R.L., Greenhall, J., Moss, E.K., Huber, R.C., Willis, E.C., Hrubiak, R., Kenney-Benson, C., Bartram, B., & Sturtevant, B.T. Elastic properties of polyethylene from high pressure sound speed measurements. Polymer, vol 212 (2021) p. 123164.