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DESIGN MODIFICATION AND SIMULATION OF A STAIR CLIMBING TROLLEY

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ABSTRACT

The project focuses on design modification and simulation of a new type of trolley with multifunctional ties. The device was redesigned to have three wheels in a triangular pattern that can be switched into three different working positions to aid in moving of heavy load through a desired vertical height. The project utilized concept generation and selection matrix to generate 30 possible design concepts. These concepts were pruned using concept scoring matrix to three (3) designs. Weighted Scoring Matrix was deployed to screen and rank three best designs. The project design was done using AutoCAD, SolidWorks and Ansys for load/stress analysis of each component. SolidWorks (SimXpress) was deployed for static analysis of the trolley components. Simulation result revealed a weight reduction from 200 kg to 15.3 kg and maximum stress of 7.13 x 108 N/m2 with a 1.5 factor of safety. The trolley design modification shows trolley as a viable option for stair-climbing with lesser physical energy, higher workload capacity and better efficiency.

Keywords: Analysis; Design modification; Simulation; SolidWorks; Trolley

INTRODUCTION

Trolley is an effective tool used to move heavy loads from one place to another. Stair climbing trolleys reduce human effort in transporting goods and services of various quantities through stairs; especially when alternative lifting facilities such as the escalators or lift systems are not available (Avinash et al., 2013). For example, in a factory or construction sites, workers must transport their equipment or jobs up and down the stairs. The trolley is essential since small construction sites generally do not have an elevator or escalators to move heavy package. In this case human labors are considered to be the only solution. It is very tiresome to manually lift heavy objects through flight of stairs without causing accidents or injuries (Jacovich, 2005). Labor is becoming costly, this problem can be solved if trolleys are deployed to lift loads while traveling through high flight of stairs (Siegwart et al., 1998). Pratik et al. (2017) designed and analyzed an automated staircase climbing load carriage taking speed and stability as design criteria when deployed on rough path. Additionally, Roshan et al. (2016) fabricated a stair climbing mechanism for transporting heavy load: it conceptualized a stepped path climbing trolley using tri-wheel tires. Ravindar et al., (2018) designed and fabricated staircase climbing trolley using finite element software with result revealing high load carrying capacity with little human effort by introducing ratchet mechanism. Kaviyarasu et al., (2018) conceptualized and simulated a tri-wheel stair climbing hand cart. The result revealed an improved and easy cart for handling large amount of load.

Chang Hsueh-Er developed a five wheeler trolley, which was driven by manual power (Praveen et al., 2016). Ashish Singh designed a robotic carrier incorporating a belt drive in place of wheels in his robotic carrier (Sayali et al., 2018). Earnesto Blanco developed a system which can carry heavy load throughout the stairs incorporating a mechanism from Galileo mobility Instruments to climb staircase using a reconfigurable caterpillar shape trolley (Mourikis et al., 2007; Shriwaskar & Choudary, 2013). Tighare et al., (2018) conducted a review study of stair climbing handling materials with results stating steel ANSI 4320 as better handle material for load range of 50 – 130 kg. Sonukumar et al., (2017) designed a semi-automatic stair climbing trolley over a smooth and rough surface with stability and high load lifting capacity

This project conceptualized a modified trolley that has several new features than the existing trolleys. Current study proposed a trolley system can be used in three different working positions with an embedded Tri-wheel that functions as an ordinary wheel on flat ground, having the ability to automatically climb an impediment during rolling. The wheel assembly moves using two wheels in contact with the ground. The modified trolley when used properly can protect people from having back injuries and other health problems that can result from lifting and carrying heavy loads.

MATERIAL AND METHOD

Concept Generation and Concept Selection

The new design went through two distinct reviews which are: concept generation and concept selection. In the concept generation, brainstorming was done in order to come up with many models that satisfied the objectives. Each generated design concept was analyzed against desired output and project objective. The analysis of generated designs was performed by analyzing the functional requirements of the project. Morphological chart was used as a systematic and analytical method to generate idea. Through this method, the concept generation was accomplished by creating a system with similar features from different parts.

Concept selection process allows the evaluation of generated concepts. The evaluation was done by using the concept scoring matrix to select the best generated design for the project. From the Morphological chart, 30 alternative designs were developed by all possible combinations of different components. Three (3) alternative designs were finally selected for evaluation from pool of 30 different designs as illustrated in Tables 1 - 2.

Table 1: Morphology chart for Alternative Designs

SUB FUNCTION	ALTERNATIVE DESIGN CONCEPTS		
	1	2	3
Handle Type	Continuous Arm	Projected Two Arms	T-Shaped Arm
Type of Wheel	Solid Rubber Tire	Pneumatic Tire	Rubber Tire
No. of Wheel	1	3	4
Strapping Material	Belt	Rubber	-
Axle Tray	Full Plated Tray	Pipe Tray	-

Table 2: Weighted Rating Evaluation of Final Selections

		SELECTION OF FINAL CONCEPT					
		ALTERNATIVE 1		ALTERNATIVE 2		ALTERNATIVE 3	
Criteria	Importance Weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Accuracy and Performance	15	2	0.3	4	0.6	1	0.15
Cost	10	3	0.3	3	0.3	2	0.2
Durability	10	4	0.4	5	0.5	3	0.3
Ease of Assembly	5	4	0.2	4	0.2	3	0.15
Ease of Manufacture	10	5	0.5	4	0.4	5	0.5
Ease of Operation	15	4	0.6	5	0.75	3	0.45
Portability	10	3	0.3	5	0.5	4	0.4
Reliability	10	4	0.4	5	0.5	4	0.4
Weight	15	2	0.3	2	0.3	2	0.3
Total			3.3		4.05		2.85

Table 3: Legend

Rating	Unsatisfactory	Just Tolerate	Adequate	Good	Very Good
Value	1	2	3	4	5

From Tables 2 and 3, alternative 2 scored 4.05 points as the best design concept. This design was chosen for further evaluation by simulating mhe concept against design criteria such as weight, stress/load analysis with result presented in discussion of result.

Materials for Component Selection

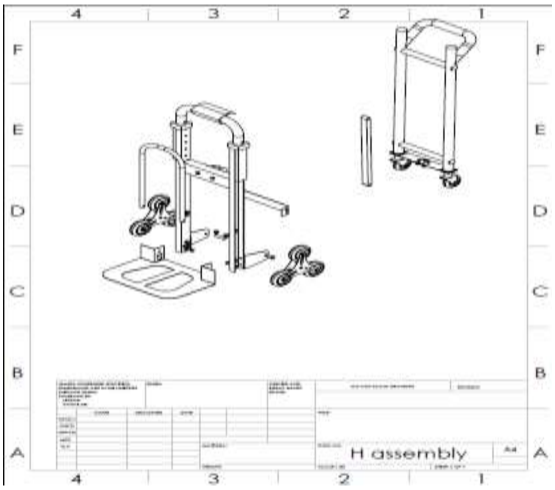
Unfit materials not required were screened out. Additionally, the materials not satisfying the functional requirements of the part were removed taking due consideration if the material can be functional and produced. Other screening criteria include: the nature of the applied loads and the operating environment. Ranking method together with material first approach was applied. Materials were rated according to application and the best materials were selected.

RESULTS AND DISCUSSION

RESULTS

Components of Trolley

Figures 1 and 2 show detailed information of the parts used in the assembly of the trolley capturing the weight, materials and quantity used.



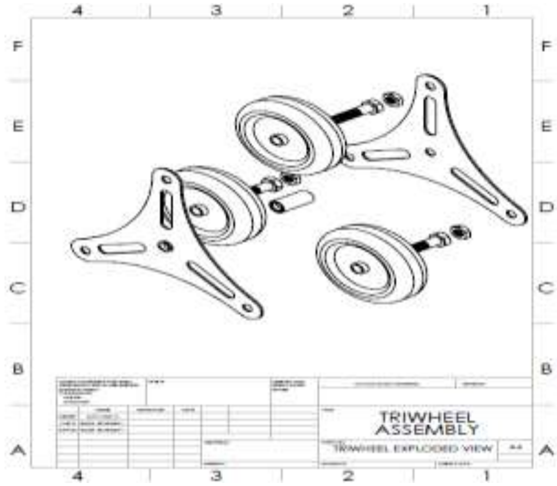


Figure 1: Handle System **Figure 2: Tri-wheel of the Trolley**

Table 4: CAD Model showing the multi-function positions of the trolley

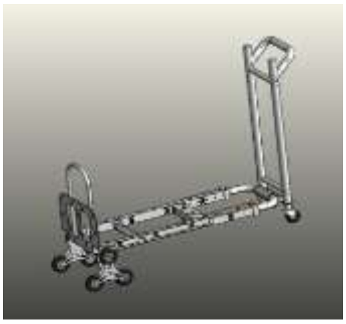
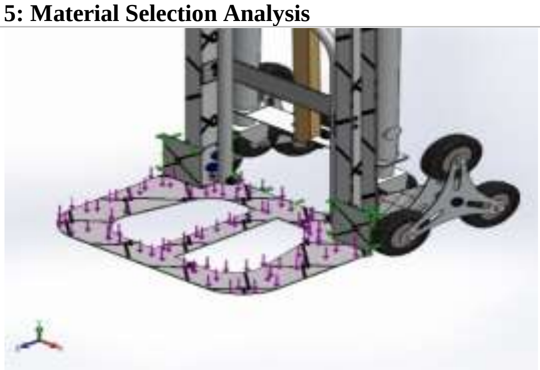
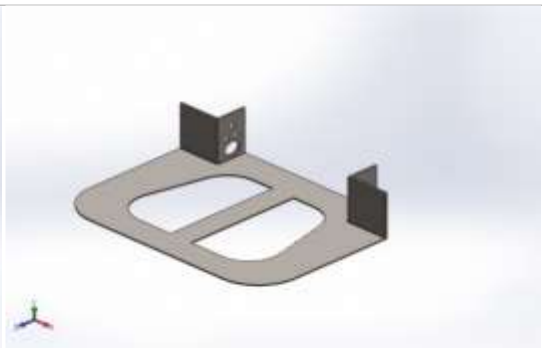
		
STANDING POSITION	**FLAT POSITION**	**INCLINED POSITION**

Table 4 shows the multifunctional positions of the proposed trolley system. It shows various positions the trolley can be manipulated to suit the different load capacities. The modification made it very convenient for fitting and lifting load up vertical stairways without causing backache to the handler.

Table 5 shows information on analyzed model. The nose plate is the load bearing part of the trolley which is subjected to continuous and repeated loading/stress. The forces acting on the nose plate are usually tensile stress and strain, although fatigue and impact loading can be encountered. Corrosion becomes a problem in aggressive environment, especially if the trolley handle and the nose plate are made of different materials. Details of the nose plate properties entail: AISI 4340 Steel, Density **of 7850 kg/m^3, Weight of 21.97kg,** Yield strength of 7.1x 10^8 N/m^2 and a Tensile strength of 1.11x109 N/m^2.

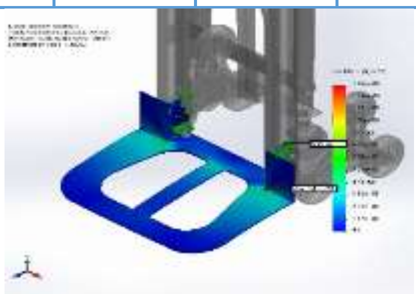
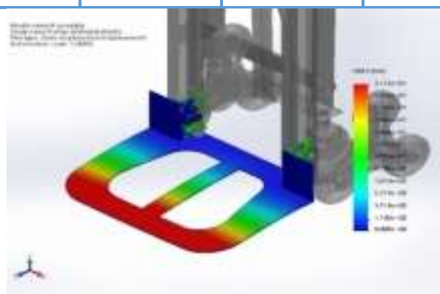
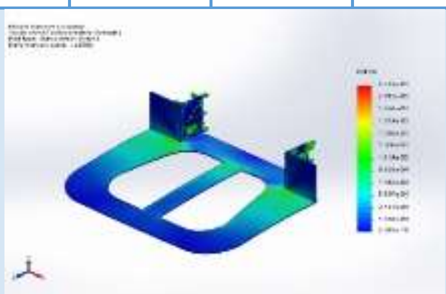
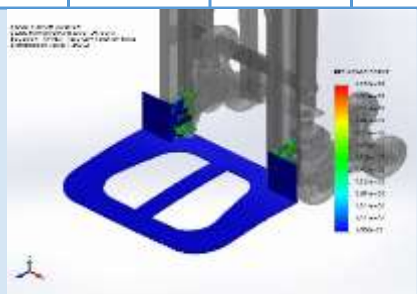
Table 5: Material Selection Analysis

	
ORIGINAL MODEL	ANALYZEDMODEL
Solid Bodies	

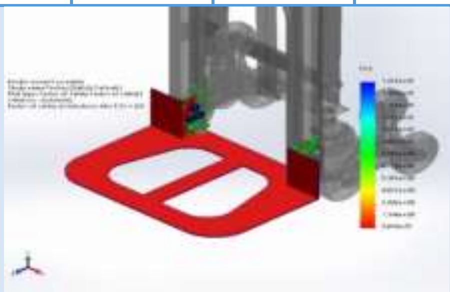
Nose Plate	**Treated As**	**Properties**
Material: Steel AISI 4340 Material: Steel AISI 4340 Model type: Linear Elastic Isotropic	**Solid Body** Failure criterion: Unknown Thermal expansion coefficient:1.2e-05 /K Poisson's ratio:0.32	**Density: 7850 kg/m^3** **Weight:21.9731 kg** Yield strength: 7.1e+08 N/m^2 Tensile strength: 1.11e+09 N/m^2 Elastic modulus: 2.05e+11 N/m^2

Table 6 shows the load/stress and strain concentration at the weld points of the nose plate. It shows maximum values of 7.13x10^8 N/m^2 and 1.69x10^3 N/m^2 for stress and strain (A and C) respectively. The nose plate of the trolley can accommodate a weight of 200 kg safely with little deformation for working hour of over 160,000 hours with a factor of safe (FOS) of 1.5.

Table 6: Load/Stress Analysis of loading Pad

Name	Type	Min	Max	Name	Type	Min	Max
Stress Analysis	**VON: von Mises Stress**	**38.1 N/m^2**	**7.13e+08 N/m^2**	**Displacement**	**URES: Resultant Displacement**	**0.000e+00 mm**	1.592e+01 mm
 A.Trolley (Static) 200kg-Stress				 B. Trolley (Static) 200kg-Displacement			
Name	**Type**	**Min**	**Max**	**Name**	**Type**	**Min**	Max
Strain	**ESTRN: Equivalent Strain**	**2.367e-10** **Element: 19**	**1.688e-03** **Element: 25522**	**Equation**	**"VON: von Mises Stress"**	**5.514e+01 SI** **Element: 19**	**3.933e+08 SI** **Element: 25522**
 C. Trolley (Static) 200kg-Strain				 D. Trolley (Static) 200kg-Equation			

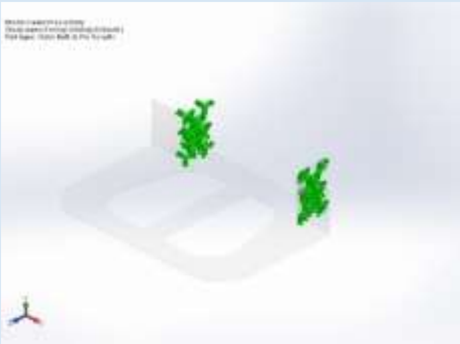
Name	Type	Min	Max	Name	Type
Factor of Safety	**Automatic 1.5**	**9.962e-01 Node: 59328**	**1.861e+07 Node: 59501**	**Fatigue Check**	**Fatigue Check Plot**



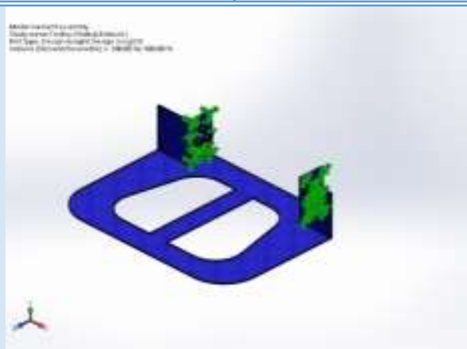
E. Trolley (Static) 200kg-Factor of Safety

F. Trolley (Static) 200kg-Fatigue Check

Name	Type	Name	Type
Pin/Bolt Check	**Static Bolt & Pin Results**	**Design Insight**	**Design Insight**



G. Trolley (Static) 200kg-Pin-Bolt Check



H. Trolley (Static)-Design Insight

CONCLUSION

From the static design simulations of the trolley it can be inferred that the redesigned trolley can suitably assume three working positions with a maximum payload of 200 kg or more. This result is further buttressed by the nose plate simulation result which revealed a maximum shear stress of 7.13×10^8 N/m^2 with a 1.5 factor of safety. Finally the simulated weight of the modified trolley was reduced to 15.3 kg from 25 kg.

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