

ISSN : 0973 - 8355

www.ijmmsa.com



IJMMSA

INTERNATIONAL JOURNAL OF

MATHEMATICAL, MODELLING, SIMULATIONS AND APPLICATIONS

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Design and Static Structural Analysis of a Convertible Material Handling Trolley for Academic Support Staff

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Abstract

Academic support staff routinely relocate furniture, equipment and supplies during examinations, events and maintenance. A manually operated trolley can support these activities, provided that its structural response and handling requirements are evaluated. This study presents the design and preliminary static structural assessment of a convertible steel trolley with upright and horizontal configurations. The concept incorporates an extendable frame, a load plate, a handle, two 152.4 mm wheels and two 76.2 mm wheels. A static stress analysis was performed in Autodesk Fusion using a 300 N resultant load, fixed translational constraints, and a parabolic solid mesh containing 804,688 nodes and 389,473 elements. The assigned steel yield strength was 207 MPa. The numerical results gave a maximum von Mises stress of 67.472 MPa, a maximum total displacement of 1.16 mm and a minimum safety factor of 3.068. The peak stress corresponds to 32.60% of the assigned yield strength. The itemized project cost was INR 5,618. These results support further development under the evaluated static condition. Mesh convergence, physical load testing, connection behavior and user trials remain necessary to establish operating capacity and ergonomic performance. The study provides a documented design baseline for an institutional material-handling aid.

Keywords: Material handling trolley, convertible frame, finite element analysis, static stress, support staff, cost analysis

1. Introduction

Moving desks, chairs, laboratory equipment and supplies is a recurring task in academic institutions. Examination arrangements, technical events and classroom maintenance require repeated relocation of these items. A handling device intended for this setting must accommodate different

load shapes while remaining practical to move, store and maintain within the institution.

Replacing part of a carrying task with wheeled transport changes the physical demands on the operator. It does not by itself establish acceptable handling effort. Snook and Ciriello [1] investigated manual

handling tasks using psychophysical methods and considered variables such as task frequency, distance, height and duration. Their work provides a basis for evaluating handling demands against the conditions of a specific task.

Wheel selection also affects usability. Al-Eisawi et al. [2] measured the forces required to initiate movement of four-wheel carts while varying cart weight, wheel characteristics, orientation and floor material. These variables are relevant to institutional routes that include corridors, turns and changes in floor condition. The Health and Safety Executive RAPP tool [3] provides a structured method for assessing pushing and pulling operations, including wheeled loads.

The present study addresses a local design requirement at Nagesh Karajagi Orchid College of Engineering and Technology, Solapur. Its objectives are to develop a convertible trolley configuration, assess the modeled structure under a defined static load and organize the associated project cost. The contribution is an application-specific design and numerical baseline. The scope does not include measured reductions in handling time, user effort or injury occurrence.

2. Trolley Design and Configuration

The proposed device combines an upright hand-truck arrangement with a horizontal trolley arrangement. The upright configuration provides a load plate for supporting an item near its base. In the horizontal configuration, the longitudinal members form an extended support frame. Figure 1 illustrates the horizontal arrangement, while Figure 2 shows the upright arrangement.



Figure 1. CAD view of the horizontal trolley configuration.



Figure 2. CAD view of the upright configuration.

The principal components are a tubular steel frame, a handle, an extendable support platform, a load plate and wheel as-

semblies. The handle provides the operator interface for steering and applying force. The extendable arrangement is intended to accommodate bulky objects. The proposed wheel set comprises two 6 in wheels and two 3 in wheels, equivalent to diameters of 152.4 mm and 76.2 mm, respectively.

The combination of larger wheels and smaller steering wheels is intended to support movement and direction changes. Its performance depends on wheel ratings, bearings, floor condition and load position. The suitability of the chosen diameters must therefore be established through testing along the intended routes [2]. No rolling-resistance measurement is used in the present structural assessment.

Conversion between configurations introduces additional design requirements at joints, sliding interfaces and locking features. These regions must retain their position during handling and preserve sufficient clearance under load. The static analysis reported here evaluates the horizontal configuration. The upright configuration is presented as part of the design concept and requires a separate load case before its performance can be compared.

3. Materials and Numerical Methodology

3.1 Material definition

The three-dimensional model was assessed using the Static Stress study in Autodesk Fusion, version 2.0.20476. The analyzed model was identified as MATERIAL HANDLING DEVICE v3. A steel material definition was assigned using the mechanical properties in Table 1. Density is converted from the model value of $7.850 \times 10^{-6} \text{ kg/mm}^3$ to SI units.

Table 1. Steel properties assigned in the model.

Property	Value
Density	7,850 kg/m ³
Young's modulus	210,000 MPa
Poisson's ratio	0.30
Yield strength	207 MPa
Ultimate tensile strength	345 MPa

The assessment uses a linear elastic interpretation of the static stress results. This interpretation assumes small deformation and loading for which inertial effects are insignificant [4]. The yield strength is used to assess the numerical margin against the onset of yielding. The assigned properties require confirmation against the material selected for fabrication; no experimentally measured material properties are used.

3.2 Loads and constraints

A total resultant force of 300 N was applied to the selected frame entities. The

recorded components were $F_x = 0$ N, $F_y = -299.973$ N and $F_z = -4.024$ N. These components give a resultant of approximately 300 N. The force-per-entity option was disabled, so the specified magnitude represents the total applied force across the selected entities.

The fixed constraint restrained translation in the X, Y and Z directions at the selected support entities. Figure 3 shows the restraint locations, and Figure 4 shows the load application. A contact tolerance of 0.10 mm was specified. The assessment uses the restraints represented in the model; it does not reproduce rolling wheel contact or operator steering forces.

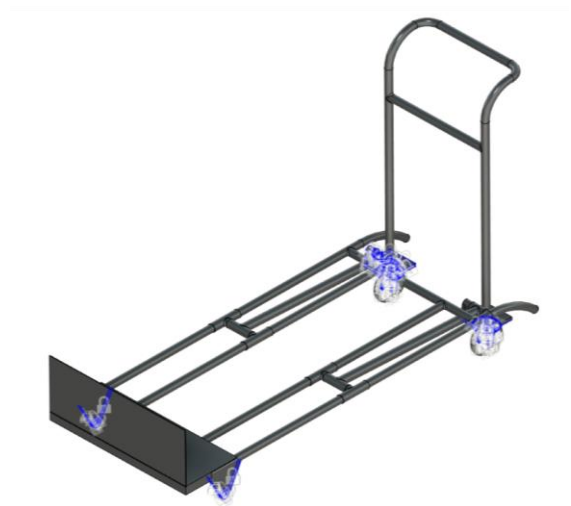


Figure 3. Fixed support entities in the static model.

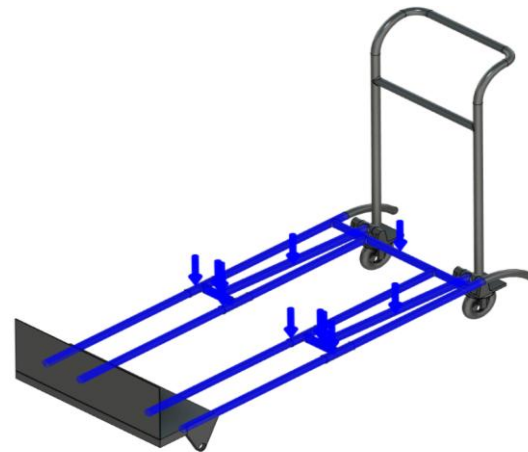


Figure 4. Force application on the horizontal frame.

For reference, the applied force is equivalent to the gravitational force of approximately 30.58 kg when $g = 9.81$ m/s². This conversion describes the analyzed force only. It does not establish the trolley payload rating because self-weight contribution, load distribution, component ratings and operating conditions require separate confirmation.

3.3 Mesh settings

The model used parabolic solid elements with a nominal average element size of 10 mm. The resulting mesh contained 804,688 nodes and 389,473 elements. The main settings are summarized in Table 2. The minimum element-size setting was 20% of the average size; this is a meshing input rather than a measured minimum edge length.

Table 2. Finite element mesh and refinement settings.

Parameter	Setting
Average element size	10.00 mm

Parameter	Setting
Element order	Parabolic
Nodes	804,688
Elements	389,473
Minimum size setting	20% of average
Adjacent size ratio	1.5
Maximum aspect ratio	10
Adaptive refinement steps	0
Configured convergence tolerance	20%

No adaptive refinement steps were performed. Consequently, the configured convergence tolerance does not demonstrate that the stress solution converged. Mesh independence should be checked by repeating the analysis with progressively finer discretization and comparing results at consistent geometric locations [5]. The present values are therefore treated as preliminary numerical estimates.

3.4 Assessment parameters

The principal response measures were von Mises stress, total displacement and yield-based safety factor. The minimum factor was checked independently using the assigned yield strength and maximum equivalent stress. Equation (1) gives the corresponding ratio, where n is the safety factor.

$$n = \frac{207}{67.472} = 3.068 \quad (1)$$

The result agrees with the minimum safety factor in the simulation summary. Safety factor is a model response to the selected

material definition, geometry, constraints and loading [6]. Stress utilization was calculated as the maximum von Mises stress divided by the assigned yield strength and expressed as a percentage. This provides a second way to interpret the same static result.

4. Results and Discussion

4.1 Static stress response

The static solution produced a maximum von Mises stress of 67.472 MPa. Relative to the assigned yield strength of 207 MPa, this represents 32.60% stress utilization. Thus, the reported solution remains below the material yield threshold for the evaluated load case. Table 3 summarizes the principal outputs.

Table 3. Results for the 300 N static load case.

Response	Value
Maximum von Mises stress	67.472 MPa
Maximum total displacement	1.16 mm
Minimum safety factor	3.068
First principal stress range	−24.699 to 28.741 MPa
Third principal stress range	−90.169 to 5.029 MPa
Stress utilization ¹	32.60%

¹ Calculated from $67.472/207 \times 100$.

Figure 5 shows the von Mises stress distribution. The contour indicates a nonuniform response along the frame members. Local verification should focus on load transfer

through the rails, interfaces and wheel-support regions. The principal stress ranges in Table 3 also show the presence of both tensile and compressive components within the modeled structure.

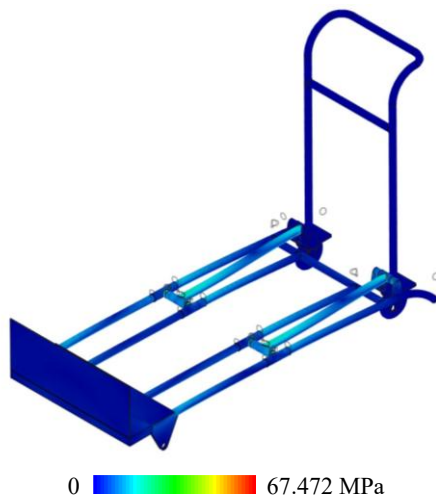


Figure 5. Von Mises stress contour under the applied load.

The reported safety-factor summary extends from 3.068 to 15.00. The minimum value governs the yield comparison. Other failure mechanisms are addressed in the validation scope in Section 6.

4.2 Displacement response

The maximum total displacement was 1.16 mm. Figure 6 presents the displacement contour. This result describes the modeled response at the stated load and support condition. Its acceptability depends on the clearances and alignment requirements of the telescoping and conversion mechanisms. A displacement limit cannot be established from the absolute value alone.

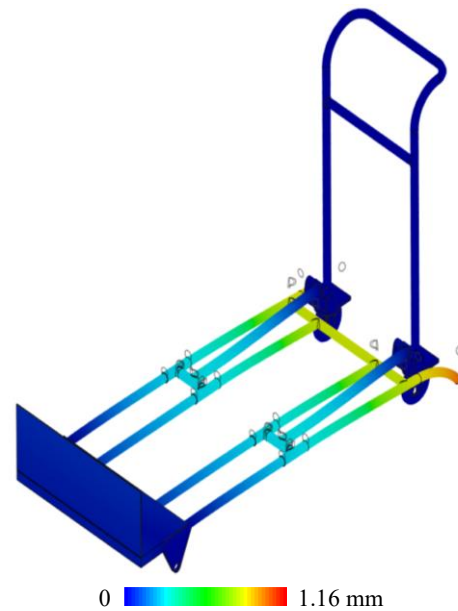


Figure 6. Total displacement contour under the applied load.

Actual wheel contact, bearing flexibility and uneven floors can change the load path relative to the fixed-support model. Physical measurements are needed to establish prediction accuracy.

4.3 Implications for design

The combined stress and displacement results support continued development of the horizontal configuration at the evaluated static condition. They provide a starting point for identifying regions that need more detailed analysis. The results do not establish an optimum frame or prove superiority over a conventional trolley because no alternative design was analyzed under matching conditions.

The convertible arrangement may reduce the need to keep separate devices for different handling tasks. However, this potential benefit must be balanced against the

additional joints and locking features required for conversion. Future design comparisons should use the same load, support assumptions and acceptance criteria so that differences in mass, stiffness and cost can be assessed consistently.

5. Project Cost Analysis

The itemized cost for the proposed trolley is presented in Table 4. The entries include structural material, wheels, workshop consumables, a shaft, coating, a prototype item and transportation. Each amount is the cost of the complete line item, rather than the cost per unit. The arithmetic total is INR 5,618.

Table 4. Itemized project cost.

Item	Qty.	INR
Circular pipe	2	2,100
Wheels, 6 in	2	1,400
Wheels, 3 in	2	700
Grinding wheels	3	90
Welding rods	30	150
Shaft	1	100
Paint / coating	1	250
Prototype item	—	328
Transportation	—	500
Total		5,618

The pipe and wheel entries together account for INR 4,200, or approximately 74.76% of the listed total. These items are therefore important cost contributors when selecting the frame and running gear. Low-

er-cost substitutions should be evaluated against structural properties and wheel ratings before any saving is treated as a design improvement.

Labor, electricity, depreciation, taxes and maintenance are not separately itemized in this project estimate. A full production cost and operational savings require additional cost, time and maintenance data.

6. Limitations and Further Validation

The investigation is limited to one reported static load case and one analyzed configuration. Geometry dimensions, tube wall thickness, joint details and wheel load ratings need to be documented with the fabrication drawings to support independent replication. Gravity loading, contact definitions and load placement should be verified in the retained simulation model before additional capacity claims are made.

The next numerical stage should compare successively refined meshes and examine sensitivity to support and contact assumptions. The upright arrangement, eccentric loading and the most extended frame position require their own cases. Connection checks should address telescoping engagement, locking elements and welds. Buckling, repeated loading and dynamic events during starts, stops and threshold crossings also require assessment.

Physical validation should measure frame displacement under controlled loads, check residual deformation after unloading and inspect joints and wheels. These measurements would allow the numerical predictions to be compared with the built device. Stability and load-retention checks are also necessary because a stress-based safety factor does not evaluate the possibility of overturning or load movement.

User trials should record starting and sustained push forces, travel time, task frequency, route condition and operator feedback. Comparisons with the existing handling method should use the same load and route. A structured pushing and pulling assessment, such as RAPP [3], can organize this evaluation. Until such observations are available, reduced effort, faster work and improved comfort remain expected benefits rather than demonstrated results.

7. Conclusion

A convertible material-handling trolley was developed at the CAD and preliminary structural-assessment level for academic support tasks. The design combines upright and horizontal configurations with an extendable steel frame and two-wheel sizes. The horizontal model was assessed under a total applied force of 300 N using the specified fixed supports.

The analysis yielded a maximum von Mises stress of 67.472 MPa, a maximum total displacement of 1.16 mm and a minimum safety factor of 3.068 for an assigned yield strength of 207 MPa. The cost items sum to INR 5,618. Together, these results provide a quantitative baseline for further design development under the evaluated condition.

The findings support progressing to mesh verification, connection assessment and physical testing. They do not establish a rated payload or measured ergonomic improvement. Completing these steps will allow the numerical assessment to be connected to actual handling performance and to a defensible operating specification.

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