SAE Toolbox

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June 24, 2025

Engineering 224

Project Description

Department of Mechanical Engineering

- NAU Baja SAE
- NAU Formula SAE
- Professor David Willy

Why?

Ongoing need for mobile tools and equipment at competition.

Figures 1, 2, 3: Project Background

Background – State of the Art

- 6-12 upper-level work-stations with two screens each
- Six lower-level seats with two monitors each
- All 15 seats with network, power, intercom and video access
- Integrated fuel rig and boom
- Toolbox storage
- Integrated canopy
- Seen at IndyCar and NASCAR

Figure 4: United Race Parts [1]

Benchmarking

Figure 5: Redline 75” Pit cart [2]

$4,999.50

Figure 6: Winter Pit Products [3]

$4,100.00

Figure 7: DK Hardware [4]

$7,406.27

Customer Requirements

Must haves:

- Required tooling
- Full set of racecar tires on rims
- Integrated steering and brake
- Built in power/battery
- Mounted fire extinguisher
- Driver equipment
- Locking drawers
- Built in shade

Bonuses:

- Bluetooth speaker system
- Charger station
- Solar power
- Hard mounted vice
- NAU logos
- Minimal trailer footprint
- Suspension system
- Enhanced trailer tailgate

Engineering Requirements

Table 1: Design Requirements Summary

Category	Requirement	Target / Specification
Mobility	Terrain-capable wheels	Rubber casters ≥8" OD (10" ideal), at least 6" minimum
	Steering system	Integrated manual steering mechanism (mandatory)
	Braking system	Self-braking or locking wheels (mandatory)
	Trailer footprint	Fits within trailer; max footprint to be defined in CAD
Storage	General tool storage	Secure drawers and bins with lock system for sloped terrain
	Equiptment & toolbox space	Compartment space for large toolbox and pit equipment
	Driver gear storage	3'x2'x1' internal volume minimum + helmet and fire suit compartments
	Fire extinguisher	External quick-access mount (interior optional if space permits)
Power & Electrical	Integrated power	120V system with X Amps (define per power tool requirement)
	Charging capability	Battery system with solar assist (optional)
	Powered tools	Wired vice, grinder, and arbor press (if feasible)
	Sound system (optional)	Bluetooth solar-powered speaker system
Work Features	Mounted vice	Fixed mounting locations with structural support
	Arbor press	Securely mounted with user access clearance
	Shade	Collapsible or integrated canopy system
Durability	Materials	Use 3/32", 1/16", 11/128" angle iron (as applicable)
	Construction	Welded steel/aluminum structure with bolted aluminum accessories
Safety & Identity	Safety features	Brake bleed kit, safety wire plier kit stored onboard
	Visual branding	NAU logos, Lumberjack Motorsports decals/stickers

QFD

Table 2: Full QFD

System QFD

Project: SAE Toolbox
Date: 6/10/2025

1	Stability						
2	Braking	6					
3	Frame rigidity and strength	3	3				
4	Casters	9	9	3			
5	Battery to power strip						
6							

Legend

A	Redline 75" Pit Cart
B	Winter Pit Products
C	DK Hardware

			Technical Requirements						Customer Opinion Survey				
	Customer Needs	Customer Weights	Stability	Braking	Frame rigidity and Strngth	Casters	Batter to Power Strip		1 Poor	2	3 Acceptable	4	5 Excellent
1	Large Toolbox	4	6	6	3	3					B		AC
2	Hold all of driver equipment/ spare wheels + rims	4	6	6	3	6					AC		B
3	Mounted items (arbor press, vice, grinding wheel,etc)	4	9	6			9			AC	B		
4	Price	5	6	6	6	6	6		ABC				
5	Brakes/ steering/ 6-10 inch casters	4	9	9		9					B		AC

	Stability	Braking	Frame rigidity and Strngth	Casters	Batter to Power Strip		
Technical Requirement Units	ft^3	ft^3	N/A	Years	12V DC to 120 AC		
Technical Requirement Targets	6ft^3	N/A	N/A	10	1		
Absolute Technical Importance	50	50	70	40	50	9	Total
Relative Technical Importance	0.185873606	0.185873606	0.260223048	0.148698885	0.185873606	0.033457249	269

QFD Close-Up

Table 3: QFD Enlarged

		Technical Requirements						Customer Opinion Survey				
Customer Needs	Customer Weights	Stability	Braking	Frame rigidity and Strngth	Casters	Batter to Power Strip		1 Poor	2	3 Acceptable	4	5 Excellent
Large Toolbox	4	6	6	3	3					B		AC
Hold all of driver equipment/ spare wheels + rims	4	6	6	3	6					AC		B
Mounted items (arbor press, vice, grinding wheel,etc)	4	9	6			9			AC	B		
Price	5	6	6	6	6	6		ABC				
Brakes/ steering/ 6-10 inch casters	4	9	9		9					B		AC

Literature Review: Stability

"Vehicle Static Stability Factor" (Technical Article) [5]

Explains the SSF equation (T/2H) to estimate rollover thresholds based on CG height and base width. Applicable to carts on slopes.

"Aircraft Design: A Systems Engineering Approach" (Book Chapter) [6]

Covers CG positioning and stability envelopes in vehicle systems. Helps in understanding cart stability during loading.

"Tip-Over Stability of Mobile Boom Cranes" (Engineering Thesis) [7]

Models tipping under swinging loads and sudden motion. Relevant if your cart carries tall/heavy items.

"Tip-Over Stability Using Dynamic Simulation" (Research Paper) [8]

Simulates orchard vehicles on uneven terrain using MATLAB/ADAMS. Provides multi-body model logic for your cart.

"Analytic Solutions for Wheeled Mobile Manipulators" (Research Paper) [9]

Solves wheel force loads and tipping conditions on slopes. Useful for stability under inclined transport or braking.

"Hamilton Whitepaper: Tipping Hazards in Tool Carts" (Industry Whitepaper) [10]

Describes real-world causes of tipping in mobile equipment. Gives safe CG height and load layout guidelines.

"Crane Tipping Theory Using CAD" (Design Case Study) [11]

Shows how to simulate tipping using CAD motion tools. Great for evaluating your design in SolidWorks or Fusion.

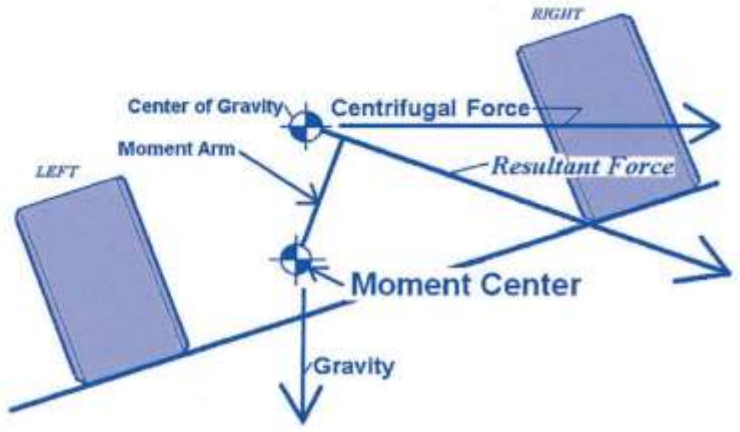


Figure 8: Moment Center Guide

Mathematical Modeling: Stability

Stability/Tipping Analysis

Base calculations from source [3] measurements

Critical Tipping Angle:

$$\emptyset = tan^{-1}\left(\frac{b}{h}\right) = 27.35° \qquad (1)$$

Meaning the cart will tip over if pushed onto a slope greater than 27.35°.

Force Required to Tip:

$$F_{Tip} = \frac{W*b}{h} = 310.34\ lb \qquad (2)$$

Variables Needed:

- *W*: Weight of fully loaded cart (600 lbf)
- *h*: Height of center of gravity (29 in)
- *b*: Half the width of the cart base (15 in)

This informs design criteria:

- Lowering the CG or increasing the wheelbase improves stability
- Heavy items low in the cart improves tipping resistance

Literature Review: Braking

"Braking of Road Vehicles" (Textbook chapter) [12]

This book focuses on the design and layout of brake systems in cars, trailers, and light vans, both mechanical and electric.

"Energy Storage for electric Vehicles" (Textbook chapter) [13]

This book focuses on electric vehicles and the energy storage within them (lithium-ion batteries).

"Model-Based Range Extension Control System for Electric Vehicles With Front and Rear Driving–Braking Force Distributions" (Research paper) [14]

Digital model that analyzes slip and motor losses to optimize front and rear braking force distributions.

"Optimal allocation method of electric/air braking force of high-speed train considering axle load transfer" (Research paper) [15]

Empirical and experimental analyses of how braking force is affected at different speeds based on wheel material.

"A New Model of Stopping Sight Distance of Curve Braking Based on Vehicle Dynamics" (Research paper) [16]

Analyzes how braking while cornering affects braking distance.

"Fuzzy Scheduled Optimal Control of Integrated Vehicle Braking and Steering Systems" (Research paper) [17]

Includes information and design on braking system that automatically adjusts to each wheel's road conditions.

Mathematical Modeling: Braking

Braking Force Equations:

- $W = F * d$ (3)
- $E_k = \frac{1}{2} * mv^2$ (4)
- $F_b = (\frac{1}{2} * mv^2)/\mathrm{d}$ (5)

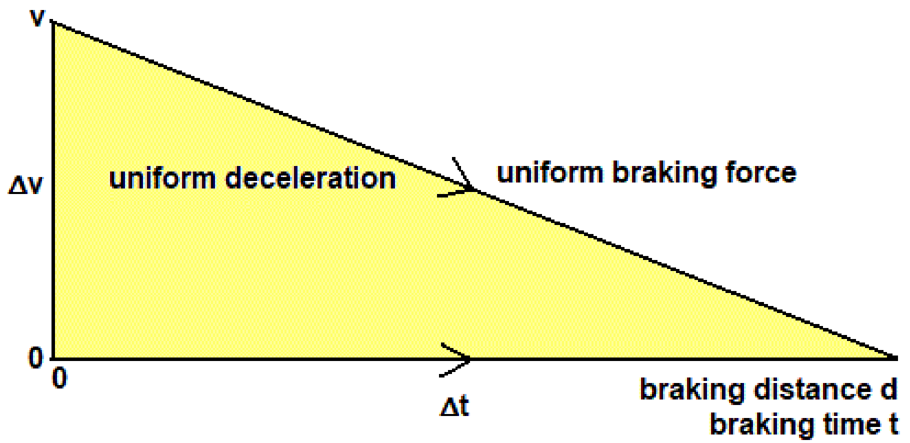


Figure 9: Physics of Braking

For braking force calculations, we will assume the maximum load for each casters to be 3000 lbs.

$$\frac{\frac{1}{2}(5443kg)\left(4.02\frac{m}{s}\right)^2}{3.05\ m} = 14.42\ kN\ or\ 3.2\ kips$$

Literature Review: Frame

“Mechanics of Materials” (Book Chapter) [18]

Covers beam bending theory and provides the second moment of area and section modulus equations for rectangular hollow sections. Used in our stress and deflection analysis.

“Mechanical Engineering Design” (Book Chapter) [19]

Outlines static strength theory and factor of safety methods. Informs our decision-making when checking frame stress against steel yield strength.

“Topology Optimization of Utility-Vehicle Chassis” (SAE Paper) [20]

Analyzes mass vs. stiffness tradeoffs for vehicle frames. Helped us justify keeping wall thickness moderate while still maintaining structural integrity.

“Fatigue Life Prediction for Welded RHS Beams” (*Int. J. Fatigue*) [21]

Presents S–N fatigue curves for common steel weld joints. Used to estimate whether our 4 mm corner welds meet a life of 1 million cycles.

“FEA of Box-Section Frames Under Combined Load” (*Engineering Structures*) [22]

Compares FEA results with hand calculations for RHS beams. Validates our simplified manual stress models with finite element trends.

“SkyCiv Beam Calculator” (Online Tool) [23]

Used to visualize shear and moment diagrams under different load conditions. Helpful for confirming our own bending calculations.

“MatWeb Materials Database” (Online Resource) [24]

Supplies mechanical properties (like 250 MPa yield stress) for mild steel. Ensures our material assumptions are realistic.

Mathematical Modeling: Frame

Second Moments of Area:

$$I_z = \frac{BH^3}{12} - \frac{bh^3}{12} \quad (6)$$

$$I_y = \frac{HB^3}{12} - \frac{hb^3}{12} \quad (7)$$

Section Modulus:

$$W_z = \frac{BH^3 - bh^3}{6H} \quad (8)$$

Bending Stress against material yield:

$$\sigma = \frac{M_{max}}{W_z} \quad (9)$$

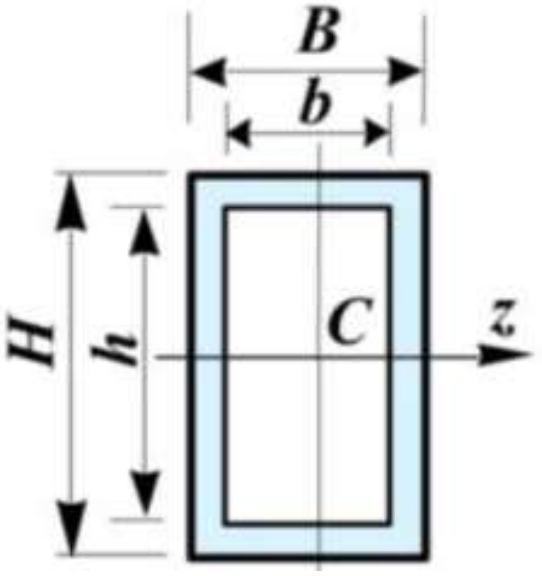


Figure 10: Cross-Section Geometry

Variables Needed:
B: Outer width
H: Height
b: Inner width
H: height

Design Insights:
-Increasing wall thickness (reducing *b*, *h*) sharply increases I and W.
-Lower overall height **H** reduces the bending lever arm *c*.
-Use these closed-form formulas for quick hand checks, then verify with FEA.

Literature Review: Casters

“Rolling Resistance and Energy Losses in Manual Wheelchairs” (Journal Article) [25]

Explores how surface texture and wheel material affect rolling resistance. Helps estimate manual force required for pushing carts with rubber wheels.

Shigley’s Mechanical Engineering Design by Budynas and Nisbett (Textbook Chapter) [26]

Provides foundational equations and example problems related to rolling resistance force. Useful for validating the $F_r = W * C_r$ model.

"Design and Analysis of Caster Wheels for Hospital Beds" (Engineering Paper) [27]

Discusses design constraints for caster systems under different weight loads. Relevant for selecting caster sizes and materials for heavy-duty carts.

***Fundamentals of Vehicle Dynamics* by Gillespie (Engineering Book) [28]**

Includes chapters on resistance forces acting on wheeled vehicles. Applies directly to predicting energy loss in mobile carts.

"Rolling Resistance Coefficient Reference Table" (*Engineering Toolbox*) [29]

Presents standard values for rubber, polyurethane, and steel wheels on various surfaces. Supports selection of design parameters.

"Caster Concepts: White Paper on Wheel Resistance" (Industry Whitepaper) [30]

Details empirical tests of wheel resistance over various surfaces. Helps justify selection of $W * C_r$ for rubber wheels on concrete.

"Wheelchair Propulsion and Surface Friction" (Thesis Study) [31]

Analyzes how surface slope and resistance coefficient affect rolling performance. Helps model user effort across non-ideal ground.

"Modeling Rolling Resistance in CAD Simulations" (Design Guide) [32]

Demonstrates how to include rolling friction in SolidWorks Motion or Fusion 360. Great for visualizing effort and torque requirement.

Mathematical Modeling: Casters

Drag Force on Casters:

$\sum F = 0$ and $F_r = W * C_r$ (10)

Example: W = 600, C_r = 0.015

F_r = 600×0.015 = 9 N

Variables Needed:

F_r = Total rolling resistance force (N)

C_r = Rolling resistance coefficient

W = Total weight or normal force (N)

We validated the result by comparing the estimated C_r with standard values from engineering handbooks and manufacturer specifications for rubber wheels on concrete.

The calculated rolling resistance force helped us:

- Ensure that the steering system and caster specifications can overcome the expected resistance
- Select appropriate wheel materials and diameters
- Estimate the effort required for users to manually move the cart over uneven surfaces

Schedule

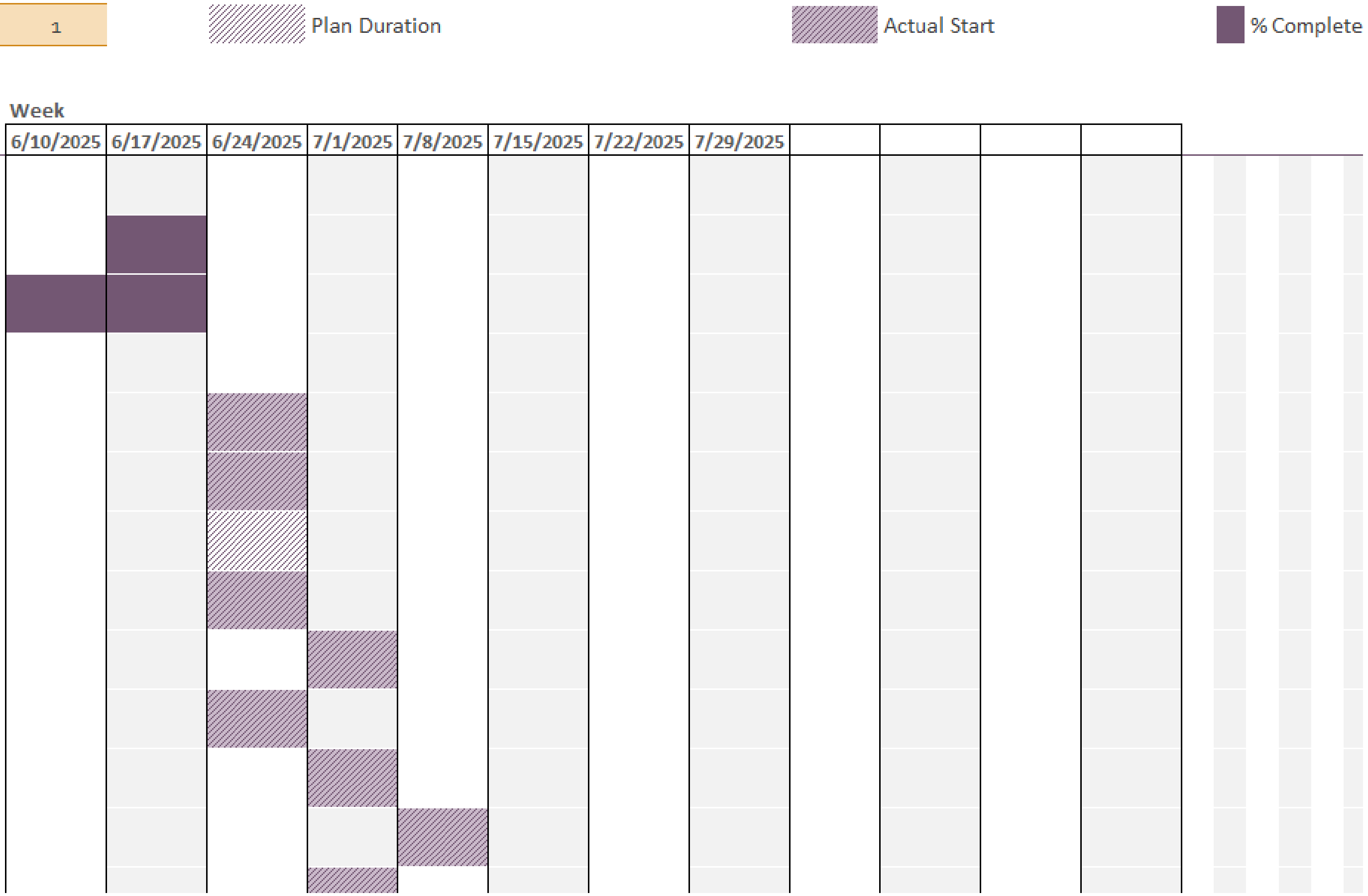
Table 4: SAE Toolbox Gantt Chart

Gantt Chart SAE Toolbox

Select a period to highlight at right. A legend describing the charting follows.

Period Highlight: 1

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Timecard Wk 2	11-Jun	6	11-Jun	6	100%
Staff Meeting #2	17-Jun	1	17-Jun	1	100%
Presentaion 1	10-Jun	14	10-Jun	14	100%
Peer Eval 1	19-Jun	1	19-Jun	1	0%
Staff Meeting #3	24-Jun	1	24-Jun	1	0%
Timecard Wk 3	19-Jun	6	19-Jun	6	0%
Team Analysis	24-Jun	4	20-Jun	4	0%
HW03 - Self Learning	20-Jun	7	20-Jun	7	0%
Staff Meeting #4	1-Jul	1	1-Jul	1	0%
Timecard Wk 4	24-Jun	5	24-Jun	5	0%
Report 1	1-Jul	7	1-Jul	7	0%
Staff Meeting #5	8-Jul	1	8-Jul	1	0%
	1-Jul	7	1-Jul	7	[illegible]



Budget

Total dollars available:

- $2,000 Available from sponsor
- Minimum $400 in fundraising

Anticipated expenses:

- Toolbox
- Wheels
- Power supply
- Framing

Expenses to Date:

No current expenses.

Remaining Expenses:

$2,000.00

Fundraising:

Sponsor requests sent for parts/tools/money etc.

What's Next

Concept Generation

➡ Concept Selection

➡ CAD Design

➡ FEA Structural Tests

Fall 2025:

- Final Design Manufacturing
- Design Testing

- Fundraising
- Budgeting
- House of Quality
- Prototyping
- Website Creation
- Bill of Materials

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Thank You

Questions?