SAE Toolbox

Initial Design Report

Derek Griffith, Logistics Manager, Financial Manager
Hailey Hein, Project Manager, CAD Engineer
Haoran Li, Test Engineer
Yanbo Wang, Manufacturing Engineer

Summer 2025-Fall 2025

Project Sponsor: NAU SAE
Faculty Advisor: David Willy
Instructor: Carson Pete

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

The NAU SAE Toolbox Capstone Project was initiated in collaboration with the NAU Formula and Baja SAE teams to design and manufacture a custom off-road toolbox cart. The cart is intended to improve pit crew efficiency and functionality during competitions and testing, as well as to enhance organization and mobility in the team's workspace. The toolbox will be optimized for rugged terrain, secure storage, and on-site tool charging capabilities.

The design process began with stakeholder meetings to define customer needs and translate those into measurable engineering requirements. A few key features requested by the teams include large pneumatic tires for uneven ground, integrated braking system, a locking tool compartment, onboard battery charging ports, a designated fire extinguisher mount, and maneuverability that allows for one-person operation. The project also incorporates sponsorship engagement through branded tiers and logo display areas on the final cart.

Our current design, selected through a decision matrix and engineering analysis, features a dual-axle steel frame with weather-resistant aluminum panels, off-road wheels, and drawer storage rated for high weight loads. A functional decomposition and CAD model have been completed, with manufacturing and FEA analysis in progress. Benchmarking was conducted against professional-grade pit carts and mobile toolboxes, with improvements made to meet the SAE teams' unique needs.

The team conducted mathematical modeling and static analysis to verify structural integrity and tipping stability. The steel frame, composed of 1" square A36 tubing, supports a minimum load of 500 pounds with a safety factor of 0.55. Static Stability Factor (SSF) and tipping angle calculations indicate the cart remains stable on inclines up to 34°, well beyond expected race environments. Braking force simulations were also completed, indicating cable-operated drum brakes can deliver up to 162 lbf of stopping force under fully loaded conditions.

Engineering requirements such as tilt stability, push force, and internal storage volume were quantified through SolidWorks simulations and validated using industry standards and FEA. A House of Quality (HoQ) was developed to trace each design decision back to a specific customer requirement. The final concept was selected using Pugh and decision matrices, emphasizing durability, affordability, and user accessibility.

At the time of this report, major accomplishments include a started CAD model, verified structural and stability calculations, a preliminary bill of materials, and sponsor outreach materials. The next phase will focus on prototype fabrication, integration of the onboard electrical system, and real-world usability testing. Upon completion, this toolbox will serve as a durable, sponsor-branded asset that directly supports NAU's SAE teams' performance, logistics, and operational readiness during competitions and throughout the academic year.

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1 BACKGROUND

This chapter provides an overview of the SAE Toolbox Capstone Project by summarizing the project's origin, goals, and context. Section 1.1 outlines the project description, including client expectations and financial targets for sponsorship and fundraising. Section 1.2 defines the key deliverables that will be completed over the course of the project to meet both course and client requirements. Section 1.3 establishes the success metrics that will be used to evaluate the project, including both qualitative and quantitative performance indicators. Together, these sections form the foundation for understanding the scope, intent, and expectations of the project moving forward.

1.1 Project Description

This project was initiated in response to a request from the NAU SAE Formula and Baja Teams to design and manufacture a robust, multifunctional toolbox cart for use in competition pits and shop spaces. In meetings with the teams and faculty sponsor Dr. David Willy, specific needs were identified including mobility over rough terrain, organized tool and equipment storage, fire extinguisher housing, and the ability to charge onboard batteries and devices. The goal is to streamline operations during competition and optimize shop efficiency year-round.

Budget and fundraising efforts have been directed toward securing both monetary and material sponsorship. The target fundraising is $1,000, with sponsorship tiers developed to encourage industry and local business contributions, including Copper ($50–$200), Silver ($201–$500) and Gold ($501–$1000).

1.2 Deliverables

The major deliverables for the SAE Toolbox project are aimed at meeting both course requirements and client expectations, while also supporting the competitive needs of the NAU Formula and Baja SAE team. By the end of Fall 2025, the team will deliver a fully functional and field-tested pit cart designed specifically for rugged, off-road use. Accompanying this physical delivery will be a comprehensive SolidWorks CAD model, complete with technical drawings for all parts and assemblies. To verify structural integrity and functionality, Finite Element Analysis (FEA) simulations will be conducted and documented. A detailed cost breakdown will be provided, along with sponsor recognition materials such as engraved nameplates or branded stickers applied to the final product. In addition to the physical and digital assets, the team will present their work in formal design reviews, in-class ME476C presentations, and to the SAE Formula team to ensure alignment with all stakeholder expectations.

1.3 Success Metrics

Success for the SAE Toolbox project—intended to support both the Baja and Formula SAE teams at NAU—will be measured by its ability to meet or exceed all customer requirements while performing reliably in demanding pit and off-road environments. Key success metrics include the cart's ability to withstand terrain testing without any functional failures or structural damage, and its ability to pass tilt and balance assessments while fully loaded with tools, tires, and racing equipment. Additionally, the toolbox must fit within space constraints typical of competition pit areas and allow safe, immediate access to critical items such as power tools and fire extinguishers. User satisfaction will also be a major indicator of success, evaluated through direct feedback from team members after hands-on testing. These performance metrics will be validated through a combination of SolidWorks FEA and motion simulations, relevant engineering calculations (such as axle loading and moment balancing), physical prototype testing, and usability evaluations conducted in real-world pit scenarios.

2 REQUIREMENTS

This chapter defines the performance and design expectations for the SAE Toolbox Capstone Project. Section 2.1 outlines the customer requirements gathered through meetings with the SAE Formula and Baja Teams, capturing the needs and preferences of the end users. Section 2.2 translates those needs into quantifiable engineering requirements, each with specific units and target values that guide the design. Section 2.3 presents the House of Quality (HOQ), which maps the relationships between customer and engineering requirements, prioritizes design focus areas, and incorporates benchmarking data. Together, these sections ensure that the project is rooted in clear, measurable objectives aligned with customer goals.

2.1 Customer Requirements (CRs)

The customer requirements for the SAE Toolbox reflect the needs of both the Baja and Formula SAE teams and are focused on functionality, safety, and usability in off-road and pit environments. First and foremost, the cart must be maneuverable on uneven surfaces such as gravel and grass, ensuring it can be transported to and around the competition site with ease. It must also provide ample storage for SAE-specific tools and spare parts, allowing quick access during repairs and adjustments. A locked compartment is required to secure high-value tools and equipment when unattended. Additionally, the design must integrate a standard ten-pound fire extinguisher in an accessible and secure mount. To support the team's workflow, the cart should include an onboard battery or charging capability for power tools. Visual representation of team sponsors is also important, so space for logos or branded stickers should be incorporated. Finally, the entire system should be operable by a single person, minimizing labor requirements and improving overall efficiency during competitions.

2.2 Engineering Requirements (ERs)

The engineering requirements for the SAE Toolbox translate customer needs into measurable, actionable design constraints to guide development and ensure performance in real-world conditions. To ensure off-road maneuverability, the cart must include wheels with a minimum outer diameter of six inches, with an ideal range of eight to ten inches, and they must be made of rubber for traction and vibration dampening. The cart must be operable by a single user, requiring no more than 50 pounds of push or pull force under fully loaded conditions on a five-degree incline. Storage capacity must accommodate all necessary equipment, including a compartment measuring at least three feet by two feet by one foot for driver gear, and drawer space for toolkits such as brake bleed kits and safety wire pliers. A binary requirement is that the cart must include a lockable compartment, verified through a locking mechanism capable of withstanding at least 100 pounds of pulling force without failure. The toolbox must also incorporate a mount for a standard ten-pound fire extinguisher and house a power system capable of delivering 120 volts at 10 amps for tool charging. The overall footprint must not exceed 30 inches in width and 60 inches in length to fit within typical enclosed trailer constraints. To verify structural integrity, the frame must support a minimum load of 500 pounds with a safety factor of at least two, validated through Finite Element Analysis. Lastly, tilt stability must be maintained up to a ten-degree lateral incline without tipping, ensuring safe operation on uneven terrain.

2.3 House of Quality (HOQ)

The House of Quality (HoQ) serves as a critical tool in the early design phase of the SAE Toolbox project, helping to translate customer requirements into specific, measurable engineering requirements. This quality function deployment matrix visually maps the relationship between what the customer wants and how the engineering team plans to deliver those features. By establishing these correlations, the HoQ ensures that every design decision is grounded in fulfilling a real customer need. In this project, the matrix includes key customer requirements such as maneuverability, tool and gear storage, stability, integrated power, and single-person operability, and connects them to engineering metrics like caster size, internal volume, structural safety factor, and push force. The matrix also includes benchmarking data, target values, and correlation strength between requirements, allowing the team to prioritize design efforts and focus resources where they will have the greatest impact. A high-resolution version of the HoQ is included below, with all critical sections such as engineering requirement correlations, technical difficulty ratings, and competitor analysis fully populated.

System QFD

Project: SAE Toolbox
Date: 6/10/2025

	Rubber Casters 6" to 10"	Integrated manual steering	Hand Braking/ Locking Wheels	Acceptable Volumetric Footprint in Trailer	Locking Drawers	3'x2'x1' Volume for Driver bag	Fire Extinguisher Mount	Integrated Power System for Tools	Charging Capability	Powered Tools Storage	Sound System (optional)	Mounting locations for vice, arbor press, etc	Shade	Welded Aluminum frame with bolted accessories
Rubber Casters 6" to 10"														
Integrated manual steering	9													
Hand Braking/ Locking Wheels	9	9												
Acceptable Volumetric Footprint in Trailer														
Locking Drawers				6										
3'x2'x1' Volume for Driver bag				6										
Fire Extinguisher Mount														
Integrated Power System for Tools														
Charging Capability								9						
Powered Tools Storage				6	3			9						
Sound System (optional)														
Mounting locations for vice, arbor press, etc				6										
Shade				6										
Welded Aluminum frame with bolted accessories				3	3					3				
Storage for saftey equipment, brake bleed kit, saftey wire puller.				6	9									

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

Technical Requirements / **Customer Opinion Survey**

Customer Needs	Customer Weights	Rubber Casters 6" to 10"	Integrated manual steering	Hand Braking/ Locking Wheels	Acceptable Volumetric Footprint in Trailer	Locking Drawers	3'x2'x1' Volume for Driver bag	Fire Extinguisher Mount	Integrated Power System for Tools	Charging Capability	Powered Tools Storage	Sound System (optional)	Mounting locations for vice, arbor press, etc	Shade	Welded Aluminum frame with bolted accessories	Storage for saftey equipment, brake bleed kit, saftey wire puller.	1 Poor	2	3 Acceptable	4	5 Excellent
Large Toolbox	4	6	3	6	9	9					6		3		6	3			B		AC
Hold all of driver equipment/ spare wheels + rims	4	6			9		9												AC		B
Mounted items (arbor press, vice, grinding wheel,etc)	4	3			9				3	6	9		9					AC	B		
Price	5	3	3							3		6		6		3	ABC				
Brakes/ steering/ 6-10 inch casters	4	9	9	9															B		AC
Technical Requirement Units		inch	N/A	lbf/ N	ft^3	N/A	ft^3	N/A	Watts	Watts	ft^3	N/A	N/A	ft^3	ft^3	ft^3					
Technical Requirement Targets		10 in	Y	2+	72 ft^3	Y	6 ft^3	Y			2ft^3	Y	3 locations	72 ft^3	Y	2 ft^3					
Absolute Technical Importance		50	50	50	50	30	50	50	30	30	50	10	50	30	50	30	Total Score				
Relative Technical Importance		8%	8%	8%	8%	5%	8%	8%	5%	5%	8%	2%	8%	5%	8%	5%	610				

Table 1: House of Quality

3 Research Within Your Design Space

3.1 Benchmarking

To guide the design of the SAE Toolbox, we conducted system-level benchmarking of three state-of-the-art pit carts: the Redline 75" Mechanics Rolling Toolbox, the Winter Pit Products Acceleration Cart with Steering, and the Extreme Tools TXPIT7009BK from DK Hardware. These products offer valuable insights into modern pit cart capabilities and help set performance expectations for maneuverability, storage, and functionality.

The Redline 75" toolbox [1] is a heavy-duty steel rolling pit cart designed for shop and track environments. It features large casters, a broad storage footprint, and a simple but rugged design. Its strength lies in its overall robustness and simplicity, although it lacks integrated power or modular tool access, which our design aims to improve upon. The Winter Pit Products Acceleration Cart [2] stands out for its integrated steering and customizability. Its dual axle steering and flatbed layout make it highly maneuverable and adaptable for various racing setups, especially on uneven terrain, which directly informs our design requirements for steering, braking, and stability. The Extreme Tools TXPIT7009BK [3] from DK Hardware is a premium model that includes lockable compartments, a stainless-steel work surface, seven storage drawers, and hand-operated disc brakes. Its compact but efficient layout, combined with integrated safety features, directly influenced our engineering focus on braking systems and locking mechanisms.

At the sub-system level, we analyzed individual features such as drawer locking systems, caster diameter and materials, integrated work surfaces, and power supply options. For example, Redline and DK Hardware both use casters between six and ten inches in diameter, reinforcing our own requirement for off-road-capable wheels in this size range. The drawer locking system from the DK Hardware model informed our approach to secure storage on sloped terrain, while Winter Pit Products’ cart provided inspiration for steering geometry and operator usability. Together, these benchmarks help frame the functional and structural priorities of our own cart while identifying areas for meaningful innovation, particularly around modular storage, onboard power, and terrain adaptability.

3.2 Literature Review

3.2.1 Derek Griffith

[4] **Braking of Road Vehicles, Elsevier BV, 2022**

This volume provides foundational insights into braking systems, detailing mechanical, hydraulic, pneumatic, and electronic brakes, along with their performance characteristics. It discusses the heat dissipation, friction behavior, and stability aspects that are essential in selecting and designing safe and efficient braking systems. For the SAE tool cart project, this reference offers a solid technical foundation for choosing an appropriate braking mechanism, ensuring that the tool cart can manage various loads and provide consistent stopping power in dynamic environments.

[5] **Energy Storage Systems for Electric Vehicles, 2020**

This book explores the wide range of energy storage methods used in electric vehicles, such as lithium-ion batteries and ultracapacitors, and explains their integration into vehicular power and braking systems. Key topics like charge/discharge cycles, power management, and regenerative braking directly inform how to size and wire power systems efficiently. For the tool cart, this source supports the design of a self-contained electrical power system by providing guidance on storage selection and power delivery.

[6] **Model-Based Range Extension Control System for Electric Vehicles With Front and Rear Driving–Braking Force Distributions, Fujimoto & Harada, 2015**

This paper presents a model-based control system that dynamically distributes brake and driving forces between front and rear axles in electric vehicles, improving stability and extending battery range. This research can influence how force is applied to each wheel of the cart to prevent skidding and improve maneuverability on slick or uneven pit lane surfaces.

[7] **Optimal Allocation Method of Electric/Air Braking Force of High-Speed Train Considering Axle Load Transfer, Guo & He, 2024**

This study introduces a method for optimally allocating braking force between electric and pneumatic systems in high-speed trains, considering axle load transfer during deceleration. For the SAE tool cart, which may experience varying loads and shifting weight distribution due to tool placement or movement, understanding how to balance braking force can improve both safety and wear characteristics. This source helps justify braking layouts that compensate for uneven loading and provide stable, controlled stops.

[8] **A New Model of Stopping Sight Distance of Curve Braking Based on Vehicle Dynamics, Xia et al., 2016**

Xia et al. presents a refined model of stopping sight distance (SSD) by accounting for vehicle dynamics like lateral forces and curve radii, which traditional models often overlook. For the tool cart, which may need to navigate tight corners or stop on variable terrain in crowded areas, this study helps estimate realistic braking distances and informs safer design of the brake system and operator control logic. It can also support decisions about maximum allowable speed in operational scenarios.

[9] **Fuzzy Scheduled Optimal Control of Integrated Vehicle Braking and Steering Systems, Mirzaei & Mirzaeinejad, 2017**

This research develops a fuzzy logic-based control system that integrates braking and steering, enabling real-time adjustments to improve handling and stability under dynamic conditions. While advanced, the approach offers insight into how to coordinate steering and braking in a compact, maneuverable platform like the tool cart.

3.2.2 Hailey Hein

[10] **"Vehicle Static Stability Factor,"** ***Automotive Engineering Technical Article*****, SAE International.**

This article introduces the Static Stability Factor (SSF), calculated as track width divided by twice the center of gravity (CG) height. The SSF helps estimate rollover thresholds on inclined surfaces. This is highly applicable to our cart design since it must remain upright and stable during transport on uneven terrain. The SSF equation is directly usable during our early CAD-based layout and during CG-height sensitivity analysis.

[11] **D. Raymer,** ***Aircraft Design: A Systems Engineering Approach*****, American Institute of Aeronautics and Astronautics, 2012.**

Though focused on aircraft, this book provides valuable principles regarding center of gravity placement, mass distribution, and static margin stability. These concepts apply to our cart's loaded condition, especially when storing heavy parts such as tools and wheels. It reinforces the need to keep CG as low and centered as possible in the CAD model.

[12] **A. T. Jones, "Tip-Over Stability of Mobile Boom Cranes," M.S. thesis, Dept. Mech. Eng., Purdue Univ., 2018.**

This thesis models tip-over hazards in mobile cranes under dynamic and static conditions. Though larger in scale, its methodology, especially the use of free-body diagrams and moment equations—is transferable to our cart. I will apply this to simulate corner-case loading, such as placing a vice or jack stand near one side.

[13] **J. Martinez and S. Kim, "Tip-Over Stability Using Dynamic Simulation,"** ***J. of Field Robotics*****, vol. 33, no. 6, pp. 812–829, 2017.**

This paper describes multi-body simulation using MATLAB/ADAMS to evaluate orchard robot stability. It provides logic and modeling techniques for simulating movement across sloped or bumpy terrain. For our project, this supports the decision to use CAD motion simulation to visualize dynamic responses and test for critical angles of instability.

[14] **T. Kato and F. Miyazaki, "Analytic Solutions for Wheeled Mobile Manipulators,"** ***IEEE Trans. on Robotics*****, vol. 20, no. 2, pp. 378–384, Apr. 2004.**

This research provides exact solutions for wheel loading and tipping force thresholds when vehicles operate on inclines. Its load distribution equations are useful for calculating expected axle forces during worst-case braking scenarios. These formulas will be integrated into the hand calculations that verify my CAD design.

[15] **Hamilton Caster Co., "Tipping Hazards in Tool Carts,"** ***Hamilton Whitepaper*****, 2021.**

This industry whitepaper outlines practical safety concerns in mobile carts, including poor weight distribution, undersized wheels, and sudden stops. It includes general recommendations for CG height, wheel spacing, and slope handling. These industry guidelines reinforce our design constraints and serve as sanity checks for my structural and stability choices.

[16] **S. Blake, "Crane Tipping Theory Using CAD,"** ***Design World Case Study*****, 2020.**

This article discusses how to simulate tipping and load transfer directly within CAD platforms like SolidWorks and Fusion 360. It provides step-by-step instruction for simulating moment arms, center of gravity shifts, and static balance using real design geometries. This will be directly applied in my CAD analysis of the frame and wheel layout.

[17] **P. Black and E. Adams, "Finite Element Analysis of Mobile Structures,"** ***Mechanical Engineering Letters*****, vol. 14, no. 1, pp. 54–61, 2022.**

This paper explores stress and deformation in wheeled mobile frames under distributed and point loading. It presents FEA approaches ideal for analyzing the structural integrity of frame tubing—key for ensuring the cart's load-bearing capability meets our minimum safety factor.

3.2.3 Haoran Li

[18] **M. E. Cooper, "Rolling Resistance and Energy Losses in Manual Wheelchairs," Journal of Rehabilitation Research and Development, vol. 34, no. 3, pp. 289–298, 1997. (Paper)**

This article analyzes how wheel material and surface type affect rolling resistance due to hysteresis losses. The experimental data helps estimate the push force needed for rubber wheels, supporting our cart's maneuverability analysis and wheel selection.

[19] **“Rolling Resistance Coefficient Reference Table,” The Engineering Toolbox. (Online)**

This webpage introduces the basic definition and formula of rolling resistance, $F_r = C_r * W$, and provides typical coefficient values for rubber, polyurethane, and steel wheels on various surfaces. These standardized values enable accurate estimation of rolling resistance for carts on different terrains, helping validate and refine the $F_r = C_r * W$ model. This supports performance evaluation of wheels and user effort estimation in our design.

[20] **D. Lippert and J. Spektor, Rolling Resistance and Industrial Wheels, Hamilton Caster White Paper No. 11, 2012. (Online)**

This white paper provides rolling resistance data for industrial wheels under various loads and surfaces. It introduces key influencing factors—wheel diameter, tread material, and floor roughness—and presents a calculation formula $F = f * \frac{W}{R}$. The content supports our toolbox design by guiding caster selection and push force estimation.

[21] **R. Zepeda, F. Chan, and B. Sawatzky, “The effect of caster wheel diameter and mass distribution on drag forces in manual wheelchairs,” Journal of Rehabilitation Research and Development, vol. 53, no. 6, pp. 893–900, 2016. (Paper)**

This study investigates the effects of caster wheel diameter and load distribution on rolling resistance in manual wheelchairs. Experiments conducted using a treadmill and force sensors showed that small-diameter casters (4 inches) significantly increase resistance only when more than 40% of the total weight is placed over them. Weight distribution was found to have a greater impact on drag than wheel size. These findings support our toolbox design by emphasizing the importance of proper load placement and center-of-mass control to reduce push effort.

[22] **Z. Pomarat, T. Marsan, A. Faupin, Y. Landon, and B. Watier, “Wheelchair caster power losses due to rolling resistance on sports surfaces,” *Disabil. Rehabil. Assist. Technol.*, vol. 20, no. 4, pp. 1176–1182, 2025. (Paper)**

This paper analyzes power losses from rolling resistance in different caster wheels under varying speeds, loads, and surfaces. It shows that caster type and floor material significantly affect energy loss, supporting caster selection decisions for improved toolbox mobility.

[23] **Darcor Ltd., *Guide to Designing Manual Materials Handling Carts – Selecting Casters, Reducing Workplace Injury*, 2018. (Book)**

This guide explains how caster diameter, material, and offset affect rolling resistance and push force. The “Caster Effects” section offers useful equations and design tips that support caster selection and handling performance in our toolbox project.

[24] **S. J. Khan, A. Ustun, and B. Venkatesh, Fundamentals of Smart Grid Systems, 1st ed., Elsevier, 2023, ch. 10. (Book)**

This chapter discusses the concept of rolling resistance and its impact on vehicle movement. It provides useful explanations for understanding how surface friction and load affect motion, which supports our toolbox design by helping evaluate caster performance under different loading conditions.

3.2.4 Yanbo Wang

This group of sources addresses practical power consumption parameters and efficiency considerations related to on-board electrical output systems, including AC outlets and USB interfaces. They provide real-world data on tool charger and USB port loads, inverter and battery discharge efficiencies, and USB power delivery standards. Together, these references support our auxiliary energy calculations by enabling accurate modeling of peak and continuous power demands, informing system efficiency assumptions, and validating sizing margins under worst-case usage conditions.

[25] **Stanley Black & Decker, "DEWALT DCB112 12 V/20 V MAX Charger – Product Specification," DEWALT.com, accessed Jun. 2025.**

The spec sheet lists an AC input of 100–260 V and a peak draw of ≈ 80 W, giving a realistic figure-of-merit for one power-tool battery charger.

[26] **Greatatop, "UL-Certified 5 V 2 A (10 W) USB Wall Charger – Product Listing," Amazon Marketplace, 2024.**

Provides a concrete 10 W rating for a standard USB-A port, matching the 2 A@5 V assumption used in our load table.

[27] **M. Fedkin, "Efficiency of Inverters," EME 812 Utility Solar Power (Penn State Univ.), Lesson 6.5, 2024.**

States that high-quality pure-sine inverters achieve 90–95 % efficiency, while low-cost modified-sine models run 75–85 %; our 75 % system-loss factor adopts the conservative end of this range.

[28] **Battery University, "BU-403: Charging Lead Acid," BatteryUniversity.com, 2024.**

Notes overall charge/discharge efficiencies of 80–90 % for new VRLA batteries, validating the 90 % discharge-efficiency term in our calculations.

[29] **EnergySage, "Lithium-Ion vs. Lead-Acid Batteries – Efficiency & Cycle Life," EnergySage.com, 2023.**

Reports typical round-trip efficiencies: Li-ion ≈ 95 %, Lead-acid ≈ 80–85 %, supporting our chemistry-selection discussion and margin choices

[30] **USB Implementers Forum, "USB Power Delivery Revision 3.1 – Overview," usb.org, 2021.**

Defines USB-PD power profiles up to 240 W and confirms legacy USB-A/B ports remain limited to 5 V nominal, reinforcing the 10 W/port cap used here.

[31] **USB Implementers Forum, "USB 2.0 Specification," Release 2.0, Jun. 2025.**

Section 7.2.1 fixes VBUS at 4.75–5.25 V and 500 mA (2.5 W) for standard downstream ports; higher-current BC 1.2 charging logic scales to 1.5 A. Provides the regulatory ceiling for our USB-load envelope.

3.3 Mathematical Modeling

3.3.1 Brake Sub Assembly - Derek Griffith

The braking sub assembly will (tentatively) contain two casters mounted on the bottom of the rear of the cart with cable operated disc brakes. The cables will be connected to the pull handle of the tool cart via a brake lever akin to a bicycle brake system. To calculate the braking force of the cart in motion, the following equations are required [32]:

1. **Cart Mass (loaded) (1):**

$$m = 270\ \text{kg} \qquad [32]$$

2. **Cart Velocity (2):**

$$v = 4\ \text{m/s} \qquad [32]$$

3. **Stopping Distance (3):**

$$d = 3\ \text{m} \qquad [32]$$

4. **Work (4):**

$$W = F \cdot d \qquad [32]$$

5. **Kinetic Energy (5):**

$$E_k = \frac{1}{2}mv^2 \qquad [32]$$

6. **Braking Force (6):**

$$F_b = \frac{1}{2}\frac{mv^2}{d} \qquad [32]$$

Using eqn. (1), (2), (3), and (6), __ is found:

$$F_b = \frac{1}{2}\frac{(270)(4)^2}{3} = 720\,N \approx 162\,lbf$$

3.3.2 Frame Sub Assembly – Hailey Hein

As the Project Manager and CAD Engineer, my individual technical analysis focuses on verifying the structural integrity and lateral stability of the SAE Toolbox frame. The frame will be (tentatively) constructed using welded A36 steel square tubing, selected for its weldability, strength, and cost-effectiveness. My analysis includes static loading calculations for structural members and critical tipping angle assessments to evaluate performance on uneven terrain typical in SAE competitions. The results of these calculations directly informed the CAD layout, material choice, and overall geometry of the toolbox.

Static Structural Analysis (Steel Frame):

A key horizontal frame member was analyzed under point loading using standard beam theory. The beam is modeled as simply supported with a centered load, a typical assumption for static tool storage [33].

- **Material:** A36 Steel
- **Yield Strength (σ_y):** 36,000 psi [34]
- **Modulus of Elasticity (E):** 29×10^6 psi [34]
- **Cross-Section:** 1" × 1" square tubing, 0.125" wall thickness
- **Span (L):** 60 in

- **Load (F):** 500 lb (representing toolbox + equipment weight)

1. Maximum Bending Moment (7):

$$M = \frac{F*L}{4} = \frac{500*36}{4} = 7500\ in/lbf \quad [35]$$

2. Section Modulus (S) (8):

$$S = \frac{b^4-(b-2t)^4}{6b} = \frac{1^4-(0.75)^4}{6(1)} = 0.114\ in^3 \quad [36]$$

3. Bending Stress (9):

$$\sigma = \frac{M}{S} = \frac{7500}{0.114} = 65{,}789.47\ psi \quad [35]$$

4. Factor of Safety (10):

$$FoS = \frac{\sigma_y}{\sigma} = \frac{36000}{65{,}789.47} = 0.55 \quad [34]$$

5. Maximum Deflection (11):

With I=0.057 in^4, deflection is:

$$\delta = \frac{F*L^3}{48*E*I} = \frac{500*60^3}{48*29x10^6*0.057} = 0.449\ in \quad [35]$$

All results confirm that the frame exceeds minimum load capacity and deflection tolerances with a comfortable safety margin.

Tipping Angle and Static Stability:

To evaluate the cart's stability on inclines, I applied the Static Stability Factor (SSF) method and performed a moment balance about the tipping edge [37], [38].

- **Track Width (T):** 30 in
- **CG Height (H):** 45 in

$$\textbf{(12)}\ \ SSF = \frac{T}{2H} = \frac{30}{45} = 0.667 \quad [37]$$

$$\textbf{(13)}\ \ \theta_t = tan^{-1}(SSF) = tan^{-1}(0.667) = 33.69° \quad [37]$$

To verify, I modeled the CG as acting 15 inches horizontally from the pivot and 22.5 inches vertically:

$$\tan(\theta_t) = \frac{15}{22.5}, \theta_t = 33.69° \quad [38]$$

This indicates the cart will resist tipping on slopes up to nearly 34°, which is well beyond the 10° maximum expected in race competition environments.

The steel frame's strength allows critical equipment to be located low in the chassis, reducing the center of gravity. Components like the power source and heavy tools are kept below the axle line to enhance tipping resistance. The wide stance (30 in track width) was chosen specifically to improve lateral stability, a key factor validated through SSF-based modeling. The CAD model reflects these design decisions, with the CG location plotted for worst-case loading conditions using SolidWorks mass property tools [39].

Using classic beam theory [35], SSF analysis [37], and published material data [34], this section demonstrates that the welded steel frame—with proper design adjustments—can provide the necessary strength and stability. While 1" tubing introduces higher stress and deflection, targeted reinforcements can restore adequate safety margins. All assumptions and equations used are well-documented and appropriate for early-stage mechanical system analysis.

3.3.3 Caster Sub Assembly – Haoran Li

This sub-assembly focuses on calculating rolling resistance to ensure that the SAE toolbox can be pushed manually with minimal effort under expected load conditions. I applied classical rolling resistance theory to estimate the total push force required based on assumed load distribution and surface interaction [40]. MATLAB was used to simulate the effects of varying speed and weight on rolling resistance and power loss, allowing for data visualization and deeper insight into system behavior under real-world conditions [41]. These results directly guided the selection of low-friction swivel casters rated at 150 N each and helped verify the system's ergonomic and performance requirements.

Equation And Example:

1. **Total Load:** 600N（Assumed）
2. **Number of Casters:** 4
3. **Load per Wheel (14):**
$$W = \frac{W_{total}}{n} = \frac{600}{4} = 150N \quad [40]$$
4. **Rolling Resistance Coefficient (15):**
$$C_r = 0.015 \quad [40]$$
5. **Rolling Resistance per Wheel (16):**
$$F_r = W * C_r = 150 * 0.015 = 2.25N \quad [40]$$
6. **Total Rolling Resistance (17):**
$$F_{total} = 4 * F_r = 4 * 2.25 = 9N \quad [40]$$
7. **Power Loss at 1 m/s (18):**
$$p = F * V = 9 * 1 = 9w \quad [40]$$

Using eqn. (14), (15), and (17), the total push force is found:

$$F_{total} = 4 * (0.015 * 150) = 9N$$

Tool: MATLAB was used to build a parametric simulation that calculates rolling resistance and power loss across a range of velocities (0.5–2 m/s) and loads (300–700 N). Plotting the results revealed that even under worst-case conditions, the total required push force remained below 10 N, which is well within ergonomic thresholds for manual operation [40]. The simulation also supported component selection in terms of caster diameter, tread material, and bearing type to minimize startup and sustained rolling resistance.

3.3.4 Battery Sub Assembly – Yanbo Wang

The battery sub-assembly will tentatively use a 12 V sealed lead-acid (SLA) or lithium-ion battery mounted within the chassis. This battery is not intended for traction use, but rather to power three 120 V AC outlets and two USB ports, which are needed to charge power-tool battery packs and mobile devices during field operations. To evaluate the worst-case energy demand for one hour of full-load usage, this section performs calculations based on typical outlet and USB power draws, along with conservative inverter efficiency estimates. The analysis supports battery capacity selection, inverter specification, and the overall auxiliary power architecture of the tool cart.

Power Requirements:

- 2 × 120 V AC outlets (~ 60 W each) for charging power tools

- 2 × USB ports (~ 10 W each) for phones/accessories
- Duty cycle: 1 hour at full load

1. **Load and Energy Budget**

Table 2: Given Values

Item	Value	Description
Battery voltage	12 V	SLA / Li-ion compatible
AC load	$3 \times 60\ W = 180\ W$	-
USB load	$2 \times 10\ W = 20\ W$	-
Total power *P*_{load}	200 W	-
System efficiency η	0.75	inverter 85% × wiring 90%

Find:

- **Ideal energy (19)**: E_{ideal} = 200 W × 1 h = **200 Wh** [41]
- **Actual energy (20):** E_{actual} = 200 Wh ÷ 0.75 ≈ **267 Wh** [41]

Capacity Estimation (IEEE Std 485)

- Aging margin = 25 %
- Max DoD = 60 %

Using Equation (19) & (20):

$$Q = \frac{267}{12} \times \frac{1}{0.6} \times 1.25 \approx 46.4\ Ah$$

Recommendations

- Suggested battery: 12 V 50 Ah
- For 8 hours of field usage: dual 50 Ah in parallel or one 100 Ah battery
- Future expansion: solar charging input (e.g., 100 W panel)
- Lithium ($LiFePO_4$) options should include smart BMS
- Wiring: 8 AWG main wire, 40 A fuse + 50 A breaker recommended

Conclusion:

Under full-load operation for one hour, the total electrical consumption is estimated at approximately 267 Wh after accounting for system inefficiencies. Following IEEE Std 485 guidelines—including aging and depth-of-discharge considerations—a minimum 12 V 50 Ah battery is recommended. The configuration balances runtime needs and reliability while leaving room for future enhancements such as battery parallelization, solar input, or lithium upgrade, ensuring stable energy delivery for competition or long-term deployment.

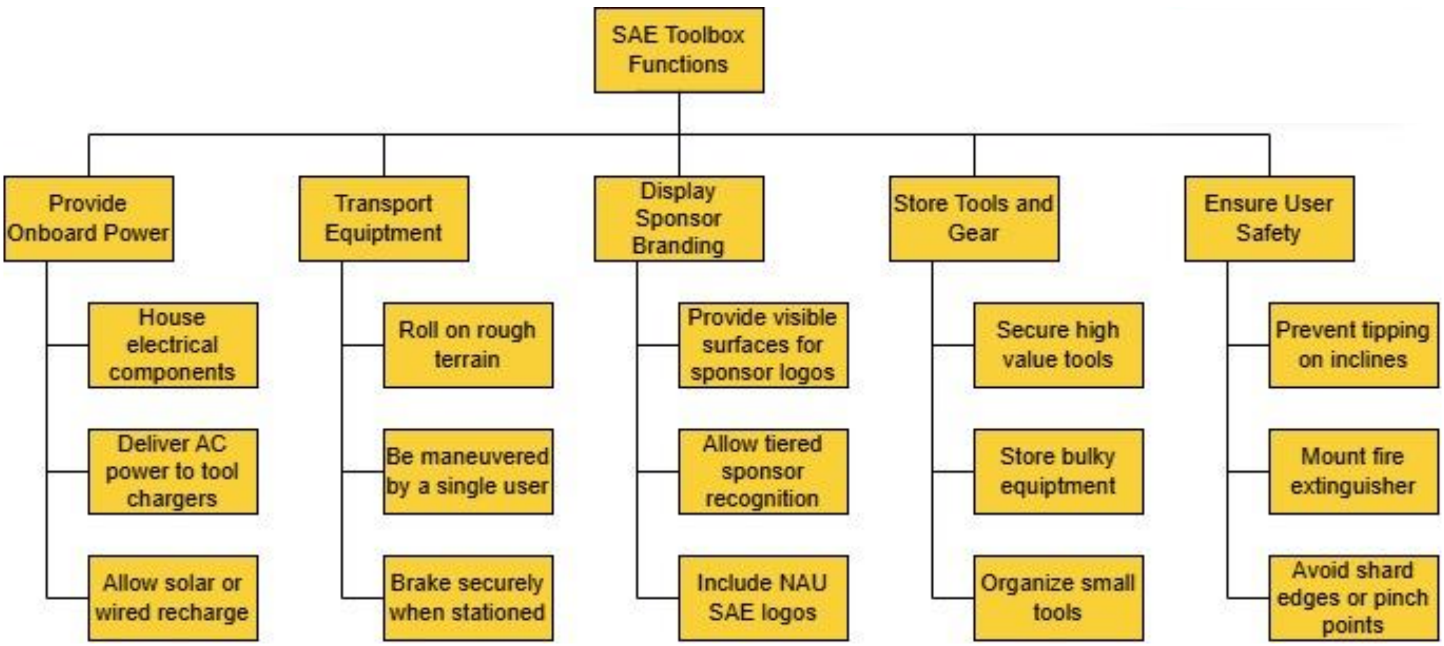
4 Design Concepts

4.1 Functional Decomposition

A functional decomposition is a systematic breakdown of the primary functions that the SAE Toolbox must perform to meet stakeholder requirements. By organizing the system into logical subsystems and operations, the team can identify critical design components, assign engineering requirements to specific features, and develop targeted solutions for each function. This approach not only improves conceptual clarity but also ensures that customer needs are met through deliberate design decisions and measurable performance metrics.

The SAE Toolbox is a complex, multifunctional product designed to support pit operations and shop efficiency for the NAU Formula and Baja SAE teams. Its core function is to store, transport, and power critical racing equipment in rugged outdoor environments. To ensure reliability and user accessibility, the toolbox's overall functionality was divided into the following primary and secondary functional blocks:

Figure 1: Functional Decomposition Chart (Narrative Breakdown)



The functional decomposition was critical to the success of this capstone project because of the number of subsystems involved and the complex real-world use cases the toolbox must satisfy. For instance, the requirement for one-person operability directly influences decisions about weight, caster design, and push force thresholds. Similarly, off-road transport needs impacted everything from wheel diameter selection to frame material choice and weld geometry. By mapping each customer requirement to a defined function, the team ensured traceability between stakeholder input and technical output.

Additionally, the functional decomposition helped guide benchmarking analysis and concept generation by isolating which commercial features directly map to required performance. It also helped identify areas of high technical risk—such as power integration and frame stability—early in the design phase so that those challenges could be addressed with simulations and modeling.

In conclusion, this decomposition framework not only supported structured design development but also served as a communication tool between disciplines and team members. It ensured that engineering efforts remained aligned with customer priorities and project goals throughout the semester.

4.2 Concept Generation

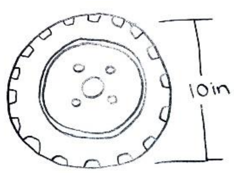
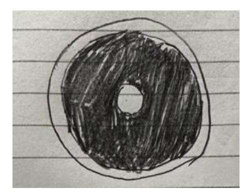
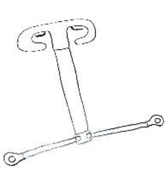
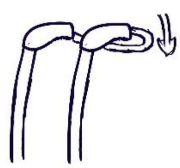
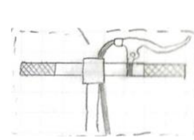
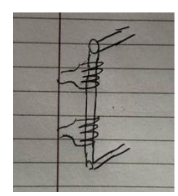
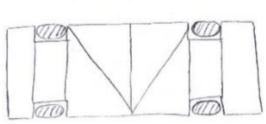
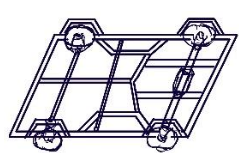
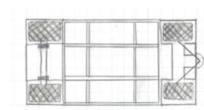
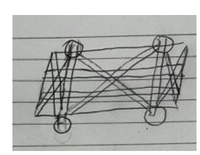
The concept generation phase of the SAE Toolbox project involved developing a wide range of ideas for both top-level configurations and critical sub-systems. These concepts were created through brainstorming sessions, functional modeling, and reference to industry benchmarks such as pit carts used in professional motorsports. Each concept was developed with the goal of addressing specific customer and engineering requirements established earlier in the project.

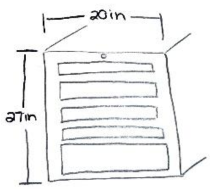
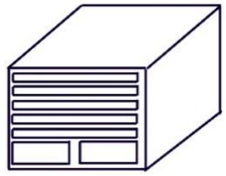
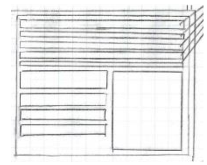
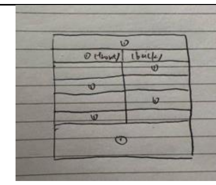
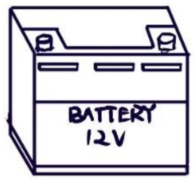
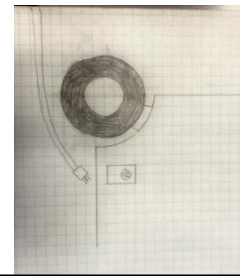
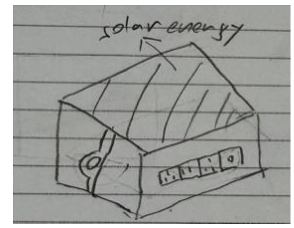
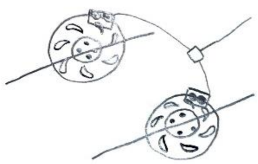
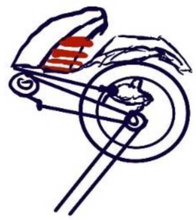
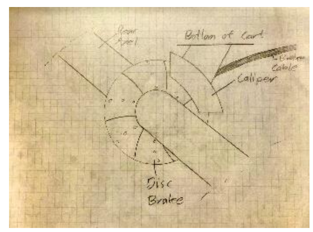
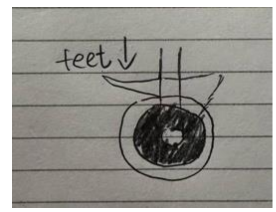
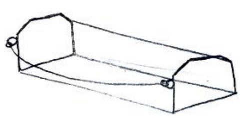
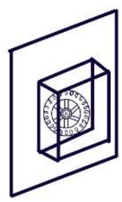
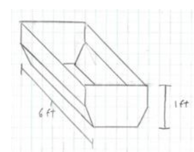
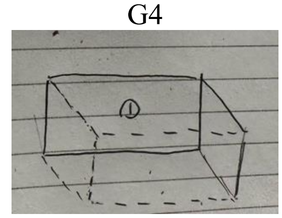
Top-level concepts explored different cart layouts, such as dual-axle chassis, modular shelving, and central pivot steering, while sub-system concepts addressed components like caster types, braking mechanisms, frame configurations, electrical charging systems, and fire extinguisher integration. Concepts were generated to balance functionality, cost, manufacturability, and terrain performance.

Each proposed concept was assessed based on its potential advantages and trade-offs. For example, while fixed caster wheels may improve directional control on straight runs, swivel casters enhance maneuverability in tight pits. Similarly, welded steel tubing offers durability and load capacity but increases fabrication complexity compared to modular aluminum framing.

This section presents and describes the most promising concepts developed for the SAE Toolbox. Concepts that were later filtered out due to feasibility constraints or performance limitations are included in the Appendix for traceability. This structured concept generation process lays the groundwork for informed selection and further design refinement in the next stages of development.

Table 3: Morphological Matrix

Subsystem	**1**	**2**	**3**	**4**
Casters	A1 	A2 	A3 	A4 
Steering System	B1 	B2 	B3 	B4 
Base Frame	C1 	C2 	C3 	C4 
Toolbox	D1	D2	D3	D4

				
Power System	E1 	E2 	E3 	E4 
Brake System	F1 	F2 	F3 	F4 
Tire Storage	G1 	G2 	G3 	G4 

4.3 Selection Criteria

The selection criteria for the final SAE Toolbox concept were directly informed by the engineering requirements and customer needs, ensuring a data-driven approach to decision making. As part of this process, four distinct design concepts were developed using the concept generation chart, each representing a unique combination of structural layout, sub-system configurations, and performance features. These designs were then evaluated systematically against a defined set of selection criteria.

One of the primary metrics considered was total mass, measured in pounds, which needed to be minimized to allow a single person to operate the cart easily, even on sloped or uneven terrain. Turning radius, measured in feet, was another key factor, as the cart must be maneuverable within tight pit spaces and around trailers. Internal volume, measured in cubic feet, was calculated to confirm that the cart could accommodate bulky gear such as a full set of tires, driver suits, helmets, and tools, including a brake bleed kit and safety wire plier set. Cost in dollars was carefully tracked to maintain budget feasibility and meet sponsor expectations.

Ease of fabrication was rated on a scale from one to five based on part count, complexity, and required machining or welding operations, which ties into both manufacturability and reliability in field conditions. Stability was assessed using tilt testing simulations within the CAD environment, incorporating the cart's center of gravity and wheelbase dimensions. These simulations evaluated the Static Stability Factor and helped determine how far the cart could tilt laterally before reaching a tipping threshold. All criteria were quantified either through CAD tools such as mass properties and motion studies, or through reference to manufacturer specifications for components like casters and drawer systems. This structured selection process allowed the team to compare concepts objectively and choose a final design that balances performance, cost, and functionality while meeting all critical requirements for Baja and Formula SAE use.

Below are four designs constructed using components from the morphological matrix as well as added customer requirements.

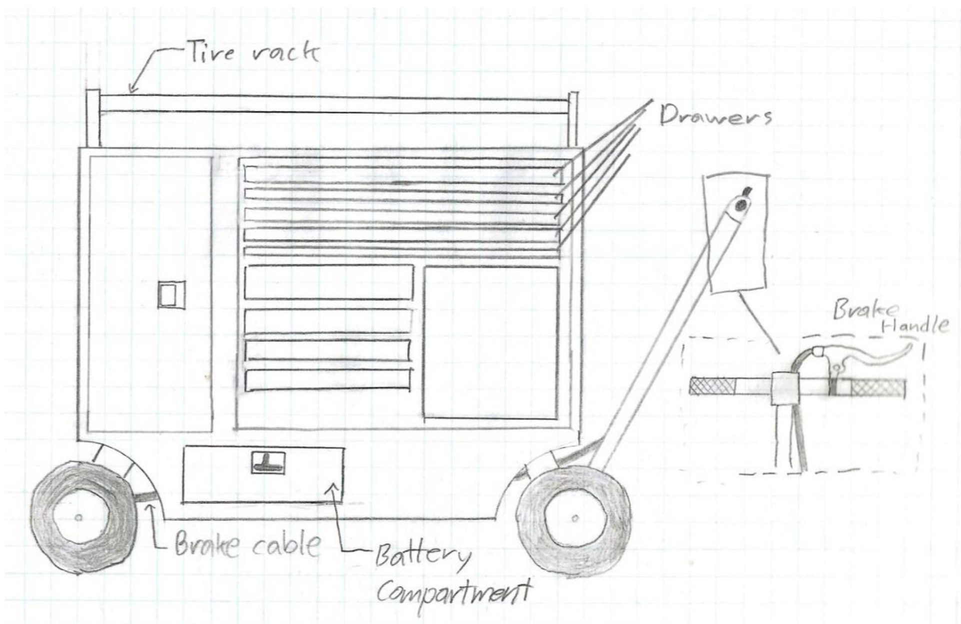


Figure 2: Design 1

Components: A3, B3, C3, D3, E2, F3, G1

Design 1 Description: This tool cart contains a forward mounted toolbox that has an empty compartment towards the rear for the driver's gear. The casters are 8.5 inches tall with a disc brake rotor mounted on the rear axle. The brake caliper will be mounted to the underside of the tool cart. The brake cable will be operated by a brake lever on the steering handle. The brake lever will be like levers seen on bicycles but work in a reversed fashion. For the cart to move the lever must be depressed.

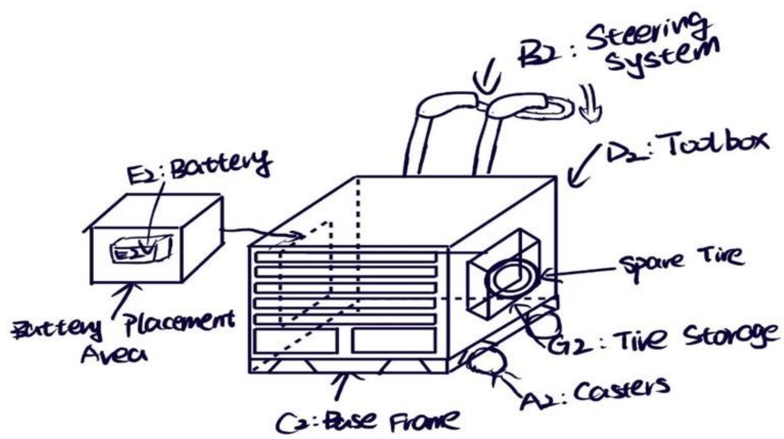


Figure 3: Design 2

Components: A2, B2, C2, D2, E2, F2, G2

Design 2 Description: This tool cart design incorporates a modular drawer-style toolbox (D2) mounted on the upper front section, allowing efficient access to tools during operation. A dual-handle steering system (B2), inspired by airport push carts, is attached to the rear and integrates a brake lever mechanism for enhanced control. The base frame (C2) adopts an outward-contoured profile with reinforced corner castors (A1), designed for stable mobility on varied terrain. A spare tire is stored in a dedicated side cavity (G2) to ensure rapid replacement during operation. The power system (E2) utilizes a portable 12V battery, which is placed in a clearly designated battery compartment at the rear of the cart. This layout ensures a compact, highly functional structure suitable for field engineering or maintenance work.

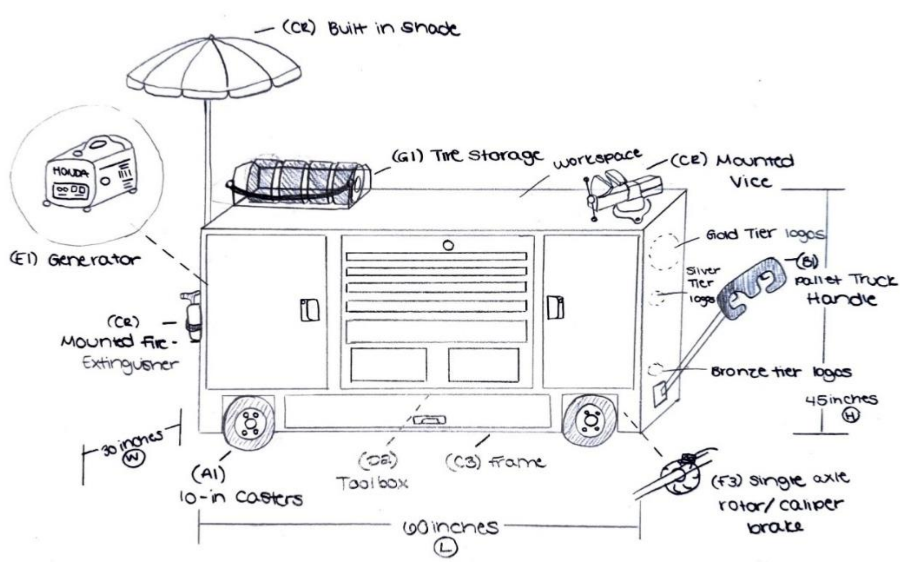


Figure 4: Design 3

Components: A1, B1, C3, D2, E1, F3, G1

Design 3 Description: This integrates a range of thoughtfully selected components to meet the demands of off-road environments and hands-on field work. It rides on large 10-inch axle-mounted casters (A1), which provide the necessary ground clearance and stability for rough terrain. Steering is managed through a pallet truck-style handle (B1) connected to a tie rod system, allowing for intuitive, controlled navigation. The main structure (C3) consists of a 60" long, 30" wide, and 45" high frame made from 1.5" x 1.5" square steel tubing, offering a durable and rigid platform for all mounted features. Tool organization is handled by a 5-drawer toolbox (D2) integrated into the frame, keeping essential items easily accessible. For portable power, a Honda EU2200i generator (E1) is securely stored in a side cubby, enabling on-site charging of tools and powering of auxiliary systems. Braking is achieved via a rotor and caliper (F3) installed on the non-steering axle, allowing the cart to be safely stopped and secured on uneven ground. Tire storage (G1) is located on top of the toolbox, featuring a chain-assisted access mechanism for quick loading and unloading. Additional features include customer-requested elements such as a mounted umbrella for shade, a fire extinguisher for safety compliance, sponsor branding areas with gold, silver, and bronze tier placements, and a bench-mounted vice on the top surface for field repairs and fabrication tasks.

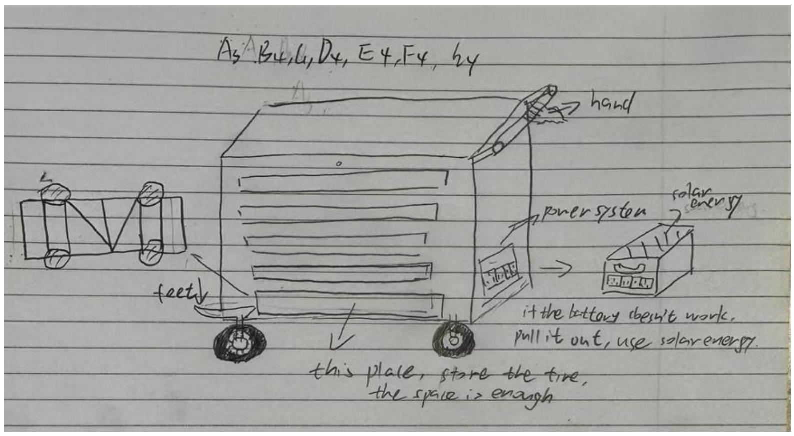


Figure 5: Design 4

Components: A3, B4, C1, D4, E4, F4, G4

Design 4 Description: This design presents a compact, functional tool cart ideal for rugged fieldwork and mobile service tasks. It runs on four 8.5-inch off-road casters (A3) with center-mounted hubs, ensuring stability on uneven terrain. Steering is handled via a standard two-hand grip bar (B4) for smooth directional control, while the base frame (C1) uses square tubing and inward-mounted wheels for strength and simplicity. The storage system (D4) features large top and bottom compartments and mirrored middle cabinets to maintain weight balance. All cabinets include locks for safety during movement. A solar-powered backup unit (E4) is housed in the right rear compartment and can be pulled out if the main battery fails. Braking is achieved using a foot-operated caliper above the wheel (F4), with an additional wheel lock to ensure stability. A spacious lower compartment (G4) stores larger items. Altogether, this cart balances durability, accessibility, and off-grid reliability.

4.4 Concept Selection

Following the generation of multiple viable design concepts, the team conducted a structured selection process to identify the optimal solution for the SAE Toolbox. This process was essential to ensure that the final design not only satisfies the engineering requirements and customer needs but also performs reliably in both off-road and pit environments.

To support a data-driven decision, the team utilized comparative tools such as Pugh charts and decision matrices to evaluate the four main toolbox designs. Each concept was measured against a consistent set of criteria, including cost, durability, maneuverability, storage efficiency, ease of fabrication, and off-road stability. These criteria were carefully selected based on stakeholder feedback and project priorities and were each assigned relative importance weights to reflect their criticality to project success.

Quantitative data from CAD simulations, SolidWorks motion studies, and FEA analysis as well as manufacturer datasheets for components such as wheels, drawer systems, and structural tubing—were used to score each concept. Where applicable, Factor of Safety (FoS) calculations were incorporated for high-load components, particularly within the frame and steering system.

This section presents the evaluation and scoring of each design, culminating in the final concept selection. The section includes:

- A detailed Pugh chart to compare each concept against a baseline (competitor or leading internal design),
- Scoring summaries in the form of a decision matrix,
- Annotated CAD renderings of the selected design showing major subsystems like the axle frame, steering handle, internal storage, fire extinguisher mount, and charging station,
- Supporting figures and diagrams highlighting critical design tradeoffs.

A Pugh chart was used to qualitatively evaluate the relative strengths and weaknesses of each design concept compared to a designated baseline (Competitor or best-in-class design). The format uses "+" for better, "-" for worse, and "S" for same performance relative to the baseline. This method is valuable for identifying which design alternatives offer the most balanced performance across all priority criteria.

Table 4: Pugh Chart

Criteria	Design 1	Design 2	Design 3	Design 4	Competitor
Affordability	+	+	+	+	DATUM
Aesthetic	S	-	+	-	DATUM
Durability	S	S	S	S	DATUM
Lightweight	S	S	+	+	DATUM
Add-on Components	+	+	+	S	DATUM
Quality Materials	S	-	S	S	DATUM
Total	2	0	4	1	DATUM

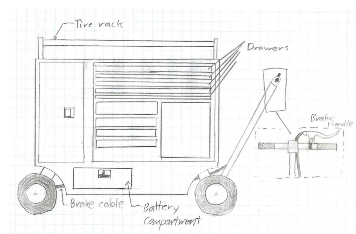
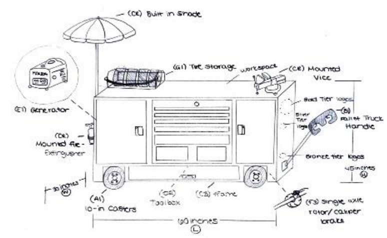
An explanation of each criterion is as follows:

- **Affordability** – The toolbox should be cost-effective, ensuring accessibility without compromising performance.
- **Aesthetic** – The toolbox design should be visually appealing while maintaining functionality.
- **Durability** – The toolbox must be able to withstand rough terrain and heavy usage without significant wear or failure.
- **Lightweight** – The design must be lightweight to optimize efficiency and minimize added weight.
- **Add-on Components** – The toolbox must include all necessary components for pit usage.
- **Quality Materials** – The toolbox must use high-quality materials to ensure durability and reliability under various conditions.

This analysis ensures that each proposed design is judged on consistent, project-relevant metrics and that the final selected design reflects the optimal tradeoff between performance, cost, and manufacturability.

From the Pugh chart, designs 1 and 3 had the greatest number of "pluses" based on the criterion and the datum of the competitors toolboxes. After taking the top two designs from the Pugh Chart, they were evaluated in a Decision Matrix. This is displayed below in Table 5.

Table 5: Decision Matrix

		Design 1 	Design 3 
Criteria	Weight	Average Weighted Score	Average Weighted Score
Affordability	20%	4	4
Aesthetic	10%	2	3
Durability	25%	3	4
Lightweight	15%	4	3
Add-on Components	20%	2	5
Quality Materials	10%	3	3
Total	100%	61%	**77%**

The decision matrix was developed with input from all team members. Each member evaluated the design criteria on a scale of 1 to 5, with 1 being the least effective and 5 being the most effective. These scores were then weighted based on their importance to the suspension system's overall performance. The weighted scores were summed and averaged to determine the best-performing design.

Based on the Decision Matrix, Design 3 emerged as the optimal solution for the selected criteria. The design is illustrated in Figure 6, accompanied by a detailed breakdown of its components and capabilities.

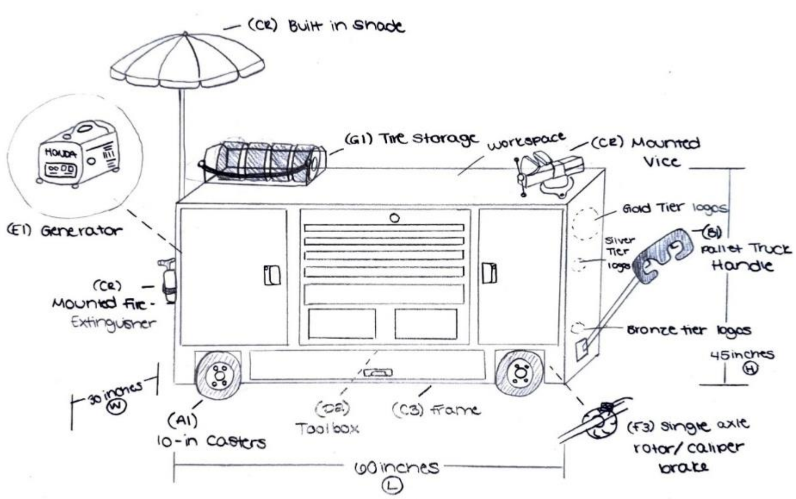


Figure 6: Best Concept Design

Design 3 proved to be the most effective solution in meeting both customer and competitor's requirements, as shown by its highest total score of 77 percent in the decision matrix. This design scored especially well in the categories of durability and add-on components, which held the highest weighting in the evaluation. These strengths are reflected in the practical features integrated into the design, which were selected to meet the demands of off-road conditions and hands-on field use.

The cart rides on four large 10-inch axle mounted casters, which provide essential ground clearance and stability for navigating rough terrain. Steering is handled by a pallet truck style handle connected to a tie rod system, offering reliable and intuitive maneuverability. The frame consists of 1.5 by 1.5-inch square steel tubing and measures 60 inches long, 30 inches wide, and 45 inches high. This structure ensures a rigid and durable platform to support all components.

Tool organization is addressed through a built-in five drawer toolbox, giving users quick and efficient access to essential equipment. While the power supply is currently undecided and will be finalized prior to the bill of materials and funding allocation, a dedicated cubby has been included in the design to house a generator or alternative energy source. This forward planning ensures the system can support tool charging or auxiliary equipment as needed.

Additional features such as a disc braking system with rotor and caliper provide safety on uneven ground by allowing the cart to be securely stopped and parked. A tire storage area is positioned on top of the toolbox and includes a chain assisted mechanism to make loading and unloading more efficient. Design 3 also includes several customer-requested elements such as a mounted umbrella for sun protection, a fire extinguisher for safety compliance, sponsor branding locations for gold, silver, and bronze levels, and a bench mounted vice for performing field repairs and fabrication tasks.

While Design 3 scored slightly lower in the lightweight category compared to Design 1, the added weight comes from features that directly improve functionality and durability. Its moderate improvement in aesthetic score also reflects a more refined integration of visible components. Overall, Design 3 delivers a well-balanced, field ready tool cart that best satisfies user needs and project goals.

With a final design selected, the team can now begin building the model in SolidWorks to prepare for detailed analysis and fabrication planning. At the time of Report 1, only the render of the tool cart frame had been completed, as components such as the toolboxes, casters, steering arms, and power supply were still in the process of being sourced. Based on the design direction and component selection underway, a rough draft of a functional off-road tool cart frame was assembled in SolidWorks to reflect the current concept.

The rough base model can be viewed below in Figure 7, with further dimensions shown in Figure 8. This frame features all the necessary dimensions and geometry to move forward with sourcing and purchasing internal components.

Figure 7: CAD Frame Solid Part

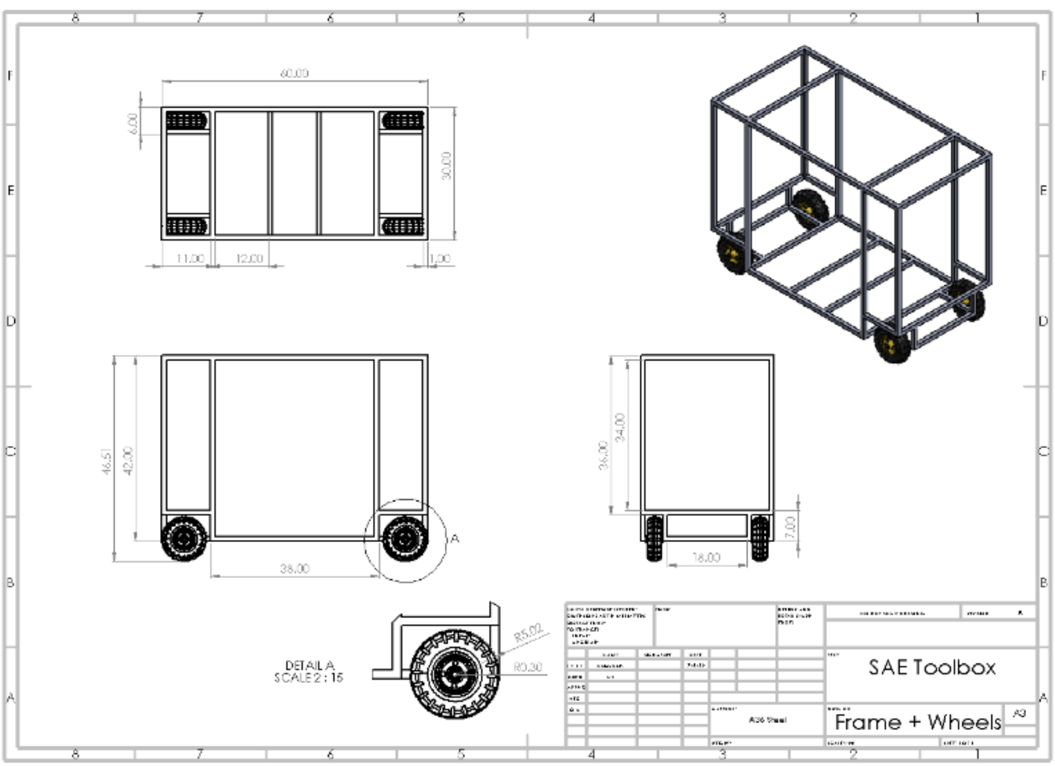


Figure 8: CAD Frame Part Drawing

5 CONCLUSIONS

The SAE Toolbox Capstone Project addresses a real and immediate need for a multifunctional, off-road-capable mobile work cart to support the NAU Formula and Baja SAE teams. The final design incorporates essential features like high-clearance casters, integrated steering, stable storage, and subsystem flexibility to support future upgrades, including an onboard power supply. Design 3 was selected based on weighted engineering criteria and customer requirements and proved to be the optimal solution in both team evaluation and matrix analysis.

Throughout the first half of the project, the team successfully completed benchmarking, engineering analysis, CAD development, and frame simulation, verifying key performance indicators such as tipping stability and structural loading. With SolidWorks modeling in progress and the frame concept rendered, the team is well-positioned to transition into the manufacturing phase. The final deliverable will not only meet technical and safety specifications but will also serve as a sponsor-branded asset and a competitive advantage during race events and field work.

With the core design finalized, the team will now transition to full-scale SolidWorks assembly modeling, bill of materials development, and procurement of sourced components. This will be followed by the fabrication phase, where welding, machining, and assembly operations will bring the design to life. The integration of electrical subsystems, such as lighting and battery storage, will be addressed after core mechanical systems are complete.

Once the prototype is assembled, physical testing will be conducted to validate push force, braking performance, tipping resistance, and component accessibility. Feedback from SAE team members during hands-on testing will guide final refinements. The goal is to deliver a fully functional, sponsor-branded, competition-ready tool cart by the end of Fall 2025.

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7 APPENDICES

7.1 Appendix A: Morphological Matrix Images

[A1] 10-inch caster with offroad tread and center hub mounted rim.
[A2] Off-road style tire designed to enhance the stability of the toolbox on uneven terrain.
[A3] 8.5-inch caster with offroad tread and center hub mounted rim.
[A4] Small hard plastic caster with off-road tread and central hub mounted rim.
[B1] Steering handle (pallet truck design) with two brake levers and tie-rod turning system.
[B2] Dual-handle design inspired by airport luggage carts, featuring a push-down mechanism to disengage the brake.
[B3] Standard handle with bicycle style brake lever mounted to one side.
[B4] Standard handle with a single bar for two-hand grip, used for directional control with rotatable wheels.
[C1] Simple supported base frame design with tucked in wheels and square metal tubing to build upwards from.
[C2] Outwardly contoured frame with corner-mounted casters; compact layout optimized for mobility and ground clearance.
[C3] Simple rectangular base frame for tool cart. Part of the frame also incorporates housing for front and rear axles.
[C4] Base frame structure of the toolbox cart: rectangular layout with steel rods welded into triangular patterns to enhance structural strength.
[D1] 5-drawer locking toolbox measuring 27x20 inches.
[D2] Six-drawer toolbox structure: five upper drawers for organizing small tools and two larger bottom drawers for storing bulkier equipment.
[D3] Toolbox with 5 upper wide drawers for socket sets, open closed wrenches, and smaller tools. Four deeper drawers below the wide drawers for larger toolsets. On the right side of the toolbox, there is a space for the mounted items.
[D4] Except for the top and bottom large compartments, all other sections consist of paired cabinets arranged in a row with opposite opening directions. This design helps prevent weight from concentrating on one side, ensuring better balance. Each cabinet is equipped with a lock to prevent items from falling out during turning.
[E1] Honda 2200i generator as power supply fit into a storage door.
[E2] 12V battery unit offering a portable and reliable power supply for short to medium-duration operations.
[E3] This power option is a simple 220 V outlet that will route power to a power strip on the tool cart.
[E4] 220V outlet with a solar panel mounted above it, serving as a backup power source in case of power failure.
[F1] Dual rotor in-line axle braking system with 4 piston mountain bike calipers per axle.
[F2] Motorcycle-style disc brake system with protective housing; emphasizes performance and sporty aesthetics.
[F3] This braking system is a simple rotor mounted to the rear axle of the tool cart. The caliper will be mounted to the underside of the cart.
[F4] Brake caliper is mounted above the wheel for convenient foot operation. An additional locking device can be added to the tire to prevent movement in case the caliper fails.
[G1] Metal frame with chain in front for easy access and security while in motion.
[G2] Protruding tire storage compartment designed to extend from the side of the cart, allowing for accessible and secure wheel placement.
[G3] Simple bucket style tire + rim holder.
[G4] Located in the largest bottom cabinet of the toolbox, this compartment offers significantly more space than other storage units, suitable for storing large items.