NAU SAE Toolbox

Finalized Testing Plan

Derek Griffith: Prototype Engineer, Manufacturing Engineer 2

Hailey Hein: Logistics Manager, Project Manager, CAD Engineer, Financial Manager, Manufacturing Engineer 1

Haoran Li: Test Report Engineer

Yanbo Wang: Website Manager, Report Engineer

Summer 2025 - Fall 2025

Project Sponsor: NAU SAE

Faculty Advisor: David Willy

Instructor: Armin Eilaghi

Table of Contents

DISCLAIMER

Executive Summary

The NAU SAE Toolbox Capstone Project was developed to create a durable, multifunctional tool cart designed to support the Northern Arizona University Formula and Baja SAE teams during both competitions and year-round shop operations. The goal of the project is to deliver a mobile, self-contained workstation that enhances efficiency, organization, and safety in demanding pit environments. The toolbox cart integrates key features such as a welded steel frame, steering and braking systems for single-person operation, large off-road casters for maneuverability, modular storage for tools and driver gear, and an onboard inverter power system for charging equipment.

This Finalized Testing Plan defines the validation strategy for confirming that all Customer Requirements (CRs) and Engineering Requirements (ERs) are met prior to project completion. The testing process focuses on functional verification of major subsystems, including braking, steering, load capacity, storage security, and electrical power performance. Each test includes detailed procedures, predicted outcomes, and pass/fail criteria to ensure that the design meets client expectations for safety, reliability, and usability.

The testing plan also establishes how data will be collected and analyzed to produce the final Specification Sheet, which documents whether each requirement is satisfied and approved by the client. A comprehensive Quality Function Deployment (QFD) analysis links customer needs to measurable engineering parameters, ensuring that testing aligns directly with user priorities.

Successful execution of this plan will validate the engineering performance and durability of the SAE Toolbox, confirming it as a fully functional, transportable, and reliable solution for NAU's SAE teams. The project demonstrates a complete engineering design cycle, from requirement development to experimental validation, and provides a tested, client-approved product that enhances the efficiency and professionalism of team operations.

1. Introduction

The goal of this testing plan is to outline how the NAU SAE Toolbox team will verify that the toolbox cart meets all customer and engineering requirements. Testing will confirm that the final design performs the way the client expects and functions reliably in both competition pits and the shop environment. Each test will focus on making sure the cart is safe, easy to operate, and durable enough for the demands of the Formula and Baja teams.

This phase of the project moves from design and analysis to hands-on validation. Every subsystem, including the frame, steering, braking, caster, storage, and power systems, will be tested to confirm that it performs as intended. The data collected will be compared with the team's calculations and design predictions to confirm accuracy and consistency. Customer requirements like maneuverability, tool organization, and single-person operation will be tested directly, while engineering requirements such as load capacity, stopping distance, and deflection limits will be verified through measured results.

The information gathered from these tests will be used to complete the final specification sheet, showing whether each requirement has been met and accepted by the client. The results will also guide any final improvements to the design before fabrication is fully complete.

Overall, this testing plan provides a clear roadmap for validating the team's design work. It ensures that the final toolbox cart is safe, functional, and ready to support the NAU SAE teams through future competitions and shop use.

2. Design Requirements

The design requirements for the NAU SAE Toolbox Cart were developed through customer feedback, sponsor input, and engineering analysis. These requirements ensure that the cart fulfills the needs of the NAU SAE Formula and Baja Teams for both competition and shop use. They are divided into Customer Requirements (CRs), which reflect user expectations, and Engineering Requirements (ERs), which translate those expectations into measurable design targets.

Customer Requirements (CRs):

- **CR1:** The cart must serve as a large, organized toolbox for use in pits and in the shop.
- **CR2:** The cart must hold all driver equipment, including spare wheels and rims.
- **CR3:** The cart must provide mounted locations for tools such as an arbor press, vice, and grinding wheel.
- **CR4:** The cart must include integrated braking and steering for safe and easy single-person operation.

- **CR5:** The cart must be affordable and cost-effective to build.
- **CR6:** The cart must include safe storage for essential equipment such as a fire extinguisher, brake bleed kit, and safety wire puller.

Engineering Requirements (ERs):

- **ER1:** Rubber casters are greater than 6 inches in diameter for stability and smooth mobility.
- **ER2:** Integrated manual steering system for controlled movement in tight spaces.
- **ER3:** Brake and locking wheel system to ensure the cart remains stationary when parked.
- **ER4:** Compact volumetric footprint (approximately 72 ft^3) to fit within a standard trailer for transport.
- **ER5:** Locking drawers to secure tools and prevent shifting during movement.
- **ER6:** A 3 ft × 2 ft × 1 ft storage volume minimum for the driver’s bag and personal gear.
- **ER7:** Mounted fire extinguisher holder that is easy to access and meets safety standards.
- **ER8:** Integrated power system capable of supporting tool charging and electrical accessories.
- **ER9:** Dedicated powered tool storage area (about 2 ft^3) with charging capability.
- **ER10:** Optional sound system for communication or entertainment during competitions.
- **ER11:** Mounting points for accessories such as a vice, arbor press, or grinder (minimum of two locations).
- **ER12:** Shade or canopy coverage for pit use in outdoor conditions.
- **ER13:** Welded aluminum frame with bolted accessories for strength, durability, and easy maintenance.
- **ER14:** Safe storage locations for emergency and safety-related equipment (minimum of 2 ft^3 total).

These requirements were prioritized through the QFD process. The most critical technical factors such as braking, steering, caster sizing, and internal storage, carry the highest relative importance due to their direct influence on mobility, usability, and safety. Lower-priority elements, such as the optional sound system and shade attachment, were included to enhance user comfort but are not essential for baseline operation.

Together, these customer and engineering requirements establish measurable performance standards that all testing procedures will be built around. The following sections describe how each requirement will be verified through physical and analytical testing.

3. Top Level Testing Summary

All tests that we will be performing have been mapped out in the following table:

Table 1: Example Test Summary Table

Experiment/Test	Relevant DR's
Toolbox drawer latching	CR6, ER5
Steering component	CR4, ER2, ER4
Door magnetic latch/hinge operation	CR1, CR2, CR6, ER6
Tire carrier loading	CR3, ER13
Brake application	CR4, ER3
Inverter load rating	ER8, ER9
Caster mobility/uneven terrain	CR4, ER1
Fire extinguisher mount security	CR6, ER7, ER14
Tool mounting point deflection	CR3, ER11, ER13
Total cart weight and volumetric footprint	ER4

4. Detailed Testing Plans

4.1 Brake Application Test

4.1.1 Test/Experiment Summary

- **Question to be answered:** Will the integrated foot brake and wheel locking system reliably stop and secure the fully loaded cart, allowing for safe, single person operation and stable parking on inclined surfaces?

- **DRs being tested:** CR4 (integrated braking for safe and easy single person operation) and ER3 (foot brake and locking wheel system to ensure the cart remains stationary when parked).

- **Equipment needed:** Full load of tools and driver gear (to simulate maximum operating weight, estimated at 500 lbs), a digital force gauge or spring scale, tape measure, and an inclinometer (or a digital level with angle function).

- **Variables isolated for measurement:** The maximum stopping distance from a known speed and the maximum angle of incline on which the cart remains stationary when the brake is engaged.

- **Variables to be calculated:** The required brake engagement force (force applied to the foot handle/lever) to secure the cart and the required coefficient of friction (μ) between the wheels and the surface to prevent rolling on the measured incline.

4.1.2 Procedure

1. Fully load the cart to its maximum projected operational weight (500 lbs).

2. Use the digital force gauge to measure the required force (F_{Brake}) needed to fully engage and lock the hand brake mechanism.

3. Find a smooth, level testing surface. Push the fully loaded cart to an estimated walking speed (approximately 3 feet per second) and fully engage the brake. Measure and record the distance the cart travels before coming to a complete stop (d_{Stop})). Repeat three times.

4. Identify an inclined ramp or surface. Using the inclinometer, measure and mark the angle of the incline (θ).

5. Push the cart onto the inclined surface, engage the brake (using the measured F_{Brake} from step 2), and release the cart. Observe and record if the cart begins to roll down the incline.

6. Repeat step 5, incrementally increasing the incline angle (θ) until the cart just begins to slip. Record this maximum static angle (θ_{max}).

4.1.3 Results

- **Kind of results looked for:** The cart must stop within a short, controllable distance (e.g., less than 6 inches) at walking speed, and the hand brake must require an easily managed force (e.g., less than 10 lbs of pull force) for engagement. Most importantly, the cart must remain stationary on a minimum 10-degree incline, simulating a typical uneven pit environment.

- **Expected results (with equations):**

- **Brake Engagement Force ($\boldsymbol{F_{Brake}}$).**
  - Expected: F_{Brake} <10 lbs. (A comfortable, one-handed pulling force).
- **Maximum Stopping Distance ($\boldsymbol{d_{Stop}}$):**
  - The required brake torque (T_{Brake}) must overcome the initial kinetic energy and rolling resistance. Assuming an average braking deceleration (a_{Brake}) of 5 feet/second^2 (a firm stop) from an initial velocity (v_0) of 3 feet/second.

$$d_{stop} = \frac{{v_0}^2}{2 * a_{Brake}} = \frac{3\frac{ft}{s}^2}{2 * 5\frac{ft}{s}} = 0.9\ ft = 10.8\ inches \tag{1}$$

- **Expected result:** The measured d_{Stop} must be less than 12 inches.

Maximum Static Incline (θ_{max}):

- The cart must be held stationary by the brake on an incline. The required coefficient of static friction (μ_s) between the tires and the surface for the brake to hold is related to the angle of repose. However, since the brake mechanism locks the wheel from rotating, the test measures the friction between the tire and the ground. If the cart is held stationary on a minimum θ_{max} of 10 degrees, the brake system is considered acceptable.

4.1.4 Conclusion

- The test will conclude by stating whether the measured brake performance meets the calculated safe stopping distance and the θ_{max} requirement. If the cart stops within 12 inches and holds on an incline of 10 degrees or greater, CR4 and ER3 are considered Met. If the results fall outside the target, the conclusion will suggest a design modification for the braking mechanism or the selection of higher friction wheel material.

4.2 Inverter Load Rating Test

4.2.1 Test/Experiment Summary

- **Question to be answered:** Does the integrated power system deliver its rated continuous output and operate the powered-tool outlets reliably, meeting ER8 (integrated power output) and support charging in the powered tool storage per ER9?

- **DRs being tested:** ER8, ER9.

- **Equipment needed:** Resistive load bank (or combination loads such as heat gun, space heater), true-RMS power meter (measuring V_{rms}, I_{rms}, P), multimeter, thermometer/thermocouple for inverter heat sink, stopwatch, extension cord to the powered tool storage outlet, representative battery charger/power tool.

- **Variables isolated for measurement:** Output voltage, current, real power, outlet functionality inside storage, inverter surface temperature, breaker/fuse trip or alarms (Y/N).

- **Variables to be calculated:**

  - Output power: $P_{out} = V_{rms}I_{rms}$ (resistive loads).

  - Voltage regulation: $\Delta V\% = \frac{V_{load}-V_{no-lo}}{V_{nom}} \times 100\%$.

  - Efficiency (if input is measurable): $\eta = \frac{P_{out}}{P_{in}}$.

  - Energy delivered during a hold: $E = P_{out}t$.

4.2.2 Procedure

1. Safety & setup: Verify wiring/polarity, breaker rating, ventilation, and meter calibration. Connect the power meter at the inverter output; route a cord to the powered-tool storage outlet.

2. No-load baseline: Measure $V_{no-load}$ and ambient/inverter temperatures.

3. Step loading: Apply loads at 25%, 50%, 75%, and 100% of the nameplate rating. Hold 10 min at each step; log V, I, P every minute; note any alarms or sag.

4. Transient check: Switch from 0% → 100% → 50% → 100% (1–2 s transitions). Record minimum voltage dip and recovery time.

5. Full-power endurance: Operate at 100% for 30 min. Record steady P_{out}, voltage regulation and inverter temperature rise.

6. Powered-tool storage outlet (ER9): Plug a representative charger/power tool into the storage-area outlet. Confirm continuous charging/operation for 10 min while the main load is at 50% and then at 100%.

7. Documentation: Photos/video of meters and setup; complete the results table.

4.2.3 Results

- **Kind of results looked for:**
  - At 100% load, the inverter provides stable output power with voltage within acceptable limits (no nuisance trips, alarms, or thermal shutdown).
  - Powered-tool outlet in the storage compartment operates the charger/tool without interruption at 50% and 100% system load.
  - Transient dips are modest and recover quickly; breaker/fuse status remains normal.
  - Endurance run shows temperature rise within manufacturer guidance.
- **Expected results (with equations):**
  - Using $P_{out} = V_{rms} I_{rms}$, report measured power at each step.
  - For the nameplate rating (e.g., 2500 W ± 100 W from your spec table), the 100% measurement should fall within the tolerance band; list the band explicitly in the table (e.g., 2400–2600 W).
  - Compute $\Delta V\%$ and η (if P_{in} is measured) for each step.
  - Record transient minimum voltage and recovery time during step tests.
  - Summarize ER9 check as Pass/Fail with notes (tool charges normally; no outlet overheating).

4.2.4 Conclusion

- If the inverter sustains rated power within the tolerance band, maintains acceptable voltage regulation and temperature, passes transient and endurance checks, and the powered-tool outlet supports charging under load, then ER8 = Met (Y) and ER9 = Met (Y); Client Acceptable = Y.
- If any criterion fails, recommend actions: improve cooling/airflow, upsize wiring/breaker, shorten cord runs to reduce drop, derate the nameplate, or revise outlet wiring within the storage compartment.

4.3 Toolbox Drawer Latch Testing

4.3.1 Test/Experiment Summary

- **Question to be answered:** Will each drawer remain securely latched (i.e., no self-opening and no excessive shift) under transport bumps and on inclines, thereby ensuring safe storage of critical equipment?

- **DRs being tested:** CR6 (safe storage for essential equipment such as a fire extinguisher, brake bleed kit, and safety wire puller); ER5 (locking drawers / drawer security).

- **Equipment needed:** Rated drawer payload (tools + weights); rough-track/speed-bump course or vibration/impact setup (≈ 1.0–1.5 g along drawer axis; optional short-pulse 2–3 g shock); steel ruler/feeler gauge or dial indicator; force gauge (opening/closing forces and latch holding force); labels/marker; camera; data sheet.

- **Variables isolated for measurement:**
  • Drawer displacement Δx (mm) after test
  • Opening and closing forces F_{open}, F_{close} (N)
  • Latch holding force F_{hol} (N)
  • Qualitative: self-opening, binding, looseness (Y/N)

- **Variables to be calculated from results:**
  • Inertial pull during bumps: $F_{inertia} = m_d a_{peak}$
  • Slope pull (static): $F_{slope} = m_d g\sin\theta - \mu m_d g\cos\theta$
  • Required holding force and safety margin:

$$F_{hold,req} = max\left(F_{inertia}, F_{slope}\right), SM = \frac{F_{hol}}{F_{hold,req}} \tag{2}$$

4.3.2 Procedure

1. Load & Baseline**:** Load the drawer to its rated payload (record mass m_d). Close and latch. Mark reference lines on the drawer face and cabinet; record initial position x_0 and gap with a ruler/indicator.

2. Continuous bump test**:** Drive the cart over a rough-track/speed-bump course (or use a shaker) targeting axial $a_{peak,cont} = 1.0 - 1.5\,g$ for 5–10 min. If using a logger, verify peak-g.

3. Shock test (short pulse): Perform 3–5 controlled impacts/drop equivalents to achieve $a_{peak,shock} = 2 - 3\,g$ for 20–50 ms (half-sine or equivalent).

4. Incline hold (static): Park the cart on a 10° ramp for 5 min with the engaged latch.

5. Post-test measurements: Record final position x and compute displacement $\Delta x = x - x_0$. Note any self-opening, binding, or looseness (Y/N).

6. Force measurements: Using a force gauge, measure opening and closing forces F_{open}, F_{close} (5 trials each). Then pull along the drawer axis to measure latch holding force F_{hold} just before release (use guarding).

7. Repeatability: Repeat Steps 1–6 on a second drawer of the same type.

4.3.3 Results

- **What we're looking for (Pass/Fail):**
    - Displacement: Δx ≤ 5 mm; no self-opening and no binding.
    - Ergonomics: F_{open}, F_{close}= 10–40 N.
    - Strength:$F_{ho} \quad \geq F_{hold,req}$ with safety margin SM ≥ 1.3.
- **Example**:
  $m_d = 15\ kg$; $a_{peak,cont} = 1.5g \Rightarrow F_{inertia} = 15 \cdot 1.5 \cdot 9.81 = 221\,N$.
  $a_{peak,shock} = 3g \Rightarrow F_{shock} = 15 \cdot 3 \cdot 9.81 = 441\,N$.
  $\theta = 10°,\ \mu = 0.10 \Rightarrow F_{slope} \approx 13\,N$.
  Thus $F_{hold,req} = 441\,N$. If measured $F_{ho} \quad = 580\,N$, then $SM = 580/441 = 1.31 \rightarrow$ Pass.
  From prior calculations we expect $\Delta x = 0 - 3$ mm after bumps and no self-opening.

4.3.4 Conclusion

If $\Delta x \leq 5$ mm, no self-opening/binding is observed, and $F_{hold}\ \geq F_{hold,req}$ with $SM \geq 1.3$, the test passes and ER5 is satisfied, supporting CR6.If any criterion fails, implement corrective actions (stronger latch or secondary stop, increased spring preload, improved rail hardware/clearances) and re-test using the same procedure.

4.4 Turning Radius Testing

4.4.1 Test/Experiment Summary

- **Question to be answered:** Will the manual steering system provide smooth, controllable motion in tight spaces and remain usable when the brake mechanism is present (no mechanical interference), enabling safe, single-person operation?

- **DRs being tested:** CR4 (integrated braking and steering for safe and easy single-person operation) and ER2 (integrated manual steering system for controlled movement in tight spaces). (Packaging/clearance cross-check with ER4.)

- **Equipment needed:** Fully loaded cart (projected operational weight), digital force gauge or spring scale (attach to push/steer handle), torque adapter for handle (optional), digital angle gauge or protractor, measuring tape, floor cones/tape to create a narrow corridor (tight-space course), chalk/marker for path tracing, camera/phone, wheel chocks.

- **Variables isolated for measurement:**

  1. Steering input at the handle: force F_{hand}.

  2. Maximum steering angle achieved at the wheels/handle(θ_{max}).

  3. Minimum turning radius of the cart R_{meas} and ability to follow an S-curve inside a marked corridor (tight-space controllability).

  4. Interference/binding with the brake hardware or cables (Yes/No) in both brake-released and brake-applied states.

- **Variables to be calculated:**
  - Turning radius from path geometry. Trace a constant-radius arc; measure chord s and mid-ordinate (sagitta) d.

    $$R = \frac{s^2}{8d} + \frac{d}{2} \tag{3}$$

  - Minimum aisle width for a 180° turn (no backing):

    $$W_{min} = 2R + c \tag{4}$$

    where c is desired clearance (e.g., 6–12 in).

  - Estimated steady pushing/steering force on smooth concrete using rolling-resistance:

$$F_{rr} = C_{rr} W \quad (5)$$

The handle input torque is $T_{hand} = F_{hand} l$.

4.4.2 Procedure

1. Load & safety: Fully load the cart to its maximum projected operating weight. Install wheel chocks when stationary.

2. Static steering sweep (brake released): From the center position, sweep the steering/handle to left and right extremes three times. Record $\theta_{\max}$, note any binding or interference.

3. Brake-applied clearance check: Apply the brake/lock. Repeat the sweep. Confirm there is no mechanical interference with brake linkages/cables and that the steering mechanism still moves freely (cart remains stationary).

4. Tight-space course setup: Mark a straight corridor with floor tape (width chosen by the team to represent a pit/shop aisle). Place cones to form an S-curve and a 180° turn pad; chalk the cart path.

5. Slow-speed steering test (brake released): A single operator pushes at walking speed and completes:

    - One S-curve pass without touching the boundary lines.

    - One 180° turn within the marked pad.

6. Use the force gauge on the handle to record peak and average F_{hand}.

7. Turning-radius data capture: On the 180° turn, mark three points along the inner wheel path and measure chord s and sagitta d to compute R.

8. Repeatability: Repeat Step 5–6 two additional times; record video/photos and all measurements.

9. Post-inspection: Check all steering fasteners, linkages, and casters for loosening or rubbing; document findings.

4.4.3 Results

- **Kind of results looked for:**

- Smooth, continuous steering range with no binding or brake-hardware interference.
- Single-operator completion of the S-curve and 180° turn inside the marked corridor (tight-space controllability).
- Recorded handle input F_{hand}, measured , computed R_{meas} and W_{min} .

- **Expected results (with equations):**
  - Steering input (rolling resistance estimate):

$$F_{rr} = C_{rr}\, W \tag{6}$$

Example (replace with your measured weight): with $W = 500\ lbf\ and\ C_{rr} = 0.02 - 0.03$,$F_{rr} \approx 10 - 15\ lbf$

This is a reasonable one-hand operating range on smooth concrete; measured F_{ha} is expected to be of the same order (slightly higher during initiation/turn-in).

  - Turning radius from path: measure s and d on the traced arc and compute

$$R = \frac{s^2}{8d} + \frac{d}{2} \tag{7}$$

Example geometry: if s=72 in, d=12 in,$R = \frac{72^2}{8*12} + \frac{12}{2} = 54 + 6 = 60in = 5ft.$

  - Minimum aisle width for a 180° turn (no backing):

$$W_{min} \approx 2R + c \tag{8}$$

Example with *R=5.0 ft and c=0.5 ft:* $W_{min} \approx 10.5\ ft.$

4.4.4 Conclusion

- If a single operator completes the tight-space maneuvers without boundary contact, the steering exhibits full travel with no binding or brake interference, and the recorded inputs F_{hand} are consistent with the expected rolling-resistance range on smooth concrete, then ER2 and CR4 are Met (Y) and Client Acceptable (Y).

- If any interference, inability to complete the maneuvers, or anomalously high input forces are observed, document the issue and propose corrective actions (e.g., caster selection/alignment, handle leverage change, cable routing, or bump-stop adjustments).

4.5 Weight Capacity Test

4.5.1 Test/Experiment Summary

- **Question to be answered:** Can the cart withstand the full intended payload (tools, wheels, driver gear) without permanent deformation or loose joints, and are the casters and frame members adequately rated? (Supports CR3; checks attachment quality per ER13 welded frame with bolted accessories.)

- **DRs being tested**: CR3, ER13.

- **Equipment needed:** Full set of heavy objects/actual tooling (to reach maximum intended payload), floor scale (or scale + mass list) to obtain **t**otal weight W, dial indicators (or ruler/feeler) for deflection, tape measure, torque wrench, paint pen for bolt marks, camera/phone.

- **Variables isolated for measurement:**

  1. Total loaded weight W.

  2. Static deflection at critical points (deck/frame mid-spans)δ_{meas}.

  3. Residual set after unload δ_{perm}.

  4. Joint integrity (bolt loosening, weld cracks) Y/N; caster condition Y/N.

- **Variables to be calculated:**

  - Per-caster load (four casters assumed; use actual distribution if different):

$$P_C = \frac{W}{4} \tag{9}$$

Caster safety factor:

$$FOS_{caster} = \frac{P_{rated}}{P_C} \tag{10}$$

Frame check (simplified beam model, uniform load): for a member of span Lwith line load w (convert from area load),

$$\sigma = \frac{M_{max}c}{I} \tag{11}$$

$$M_{max} = \frac{wL^2}{8} \tag{12}$$

$$\delta_{calc} = \frac{5wL^4}{384EI} \tag{13}$$

and $FOSframe = \frac{\sigma_{allow}}{\sigma}$.

- Allowables: team limits.

4.5.2 Procedure

1. Baseline: Empty cart; set dial indicators at selected mid-span points (deck center; long side rail mid-span). Zero readings; inspect and mark bolts.

2. Load-up: Place heavy objects/tools to reach the design maximum payload; record total W. If possible, weigh wheels/boxes as added to confirm tally.

3. Static check: With the cart stationery on level floor, record deflection δ_{meas} at all points.

4. Settle & roll: Slowly roll 10–15 m on level floor and traverse a 1 in threshold once to settle the load; re-check deflection and bolt marks.

5. Unload check: Remove the payload; read indicators to obtain residual set δ_{perm}.

6. Documentation: Photos/video and a results table (locations, readings, pass/fail).

4.5.3 Results

- **Kind of results looked for:**
  - No permanent deformation: $\delta_{\mathrm{perm}} \approx 0$.
  - Deflection within limit: $\delta_{meas} \leq \delta_{allow}$ at all points.
  - Joints/casters sound: no bolt loosening (paint marks aligned), no weld cracking; casters roll smoothly and show no overload marks.
- **Expected results:**

- Report W, compute $P_C = W/4$ and compare to caster rating P_{rated} with $FOS_{caster} \geq 2$.

- Using the simplified beam model, compute σ and δ_{calc} ; show $FOS_{frame} \geq 2$ and δ_{calc} close to δ_{meas} and $\leq \ \delta_{allow}$.

- Results table (minimum fields): Point ID, W, P_c , P_{rated} , FOS_{caster} , δ_{meas}, δ_{allow} , δ_{perm}, $\sigma(calc)$, FOS_{frame} , Joint/Caster Pass(Y/N), Notes.

4.5.4 Conclusion

- If $\delta_{perm} \approx 0$, $\delta_{\text{meas}} \leq \delta_{\text{allow}}$, $FOS_{\text{caster}} \geq 2$, $FOS_{frame} \geq 2$, and no loosening/cracking is observed, then Weight Capacity = Pass, supporting CR3 and compatibility with ER13; Client Acceptable = Y.

- If any criterion fails, recommend add gussets/increase section modulus, redistribute load/add intermediate supports, upgrade caster rating or quantity, add backing plates and re-torque procedure, then re-test.

4.6 Equipment Fitment Testing

4.6.1 Test/Experiment Summary

- **Question to be answered:** Do the designated compartments and mounts fit all required items; tools, spare wheels/tires, and driver equipment (suits/helmets), so they can be stored securely and accessibly without interference? This validates organization (CR1), capacity (CR2), safe storage (CR6), driver-gear bay volume (ER6), powered-tool storage volume (ER9), and emergency/safety storage volume (ER14).

- **DRs being tested:** CR1, CR2, CR6; ER6, ER9, ER14.

- **Equipment needed:** Completed cart; the full kit of required tools; 4–5 spare wheels/tires, driver suits/helmets, fire extinguisher, brake-bleed kit, safety wire puller, tape measure & calipers, clip-board checklist, camera/phone, labels/marker.

- **Variables isolated for measurement:**

    1. Net bay dimensions *L, W, H* and volume *V* (ft^3).

    2. Item fit in the assigned location (Y/N) with clearance margin *m* (in).

    3. Closure & security: door/drawer closes and latches; straps/holders engaged (Y/N).

4. Accessibility: retrieval without re-packing; optional pick time t_{pick} (s).

- **Variables to be calculated:**

    1. Driver-gear bay volume: $V_{driver} = LWH \geq 6\ ft^3$(ER6).

    2. Powered-tool storage volume: $V_{power} \approx 2\ ft^3$ target (ER9).

    3. Emergency/safety storage total:$\sum V_{emerg} \geq 2\ ft^3$ (ER14).

    4. Coverage ratio: $C = \frac{N_{present}}{N_{required}}$ for each category (tools/tires/driver gear).

    5. Tire rack capacity: count N_{tires} and side/front clearance margin m_{tire}.

4.6.2 Procedure

1. Checklist & mapping: Create a table listing every required item and its intended location (drawer/compartment/rack).

2. Measure volumes: Empty each relevant bay; measure net L, W, H (clear of hardware) and compute V. Record photos of the interior and dimensions.

3. Place items: Load tools, tires, and driver gear into their assigned locations. Confirm doors/drawers shut and latch; verify straps/holders are engaged for tires, extinguisher, and other safety items.

4. Accessibility check: Remove and replace a representative subset (e.g., helmet, torque wrench, charger) to ensure no repacking is required; optionally time t_{pick}.

5. Documentation: Photograph each bay before/after loading; complete the fitment checklist and volume table.

4.6.3 Results

- **Kind of results looked for:**

    - All required items are present and fit in their assigned locations; doors/drawers close and latch; straps/holders secure.

- Driver-gear bay $V_{\text{driver}} \geq 6$ ft^3 ; powered-tool storage $V_{power} \approx 2\ ft^3$; emergency/safety storage total ≥ 2 ft^3.

- Tire rack holds the planned number of wheels with measurable side/front clearance; straps reach and tension correctly.

- Coverage ratio C=1.00 (100%) for tools, tires, and driver gear.

- **Expected results:**

  - Driver-gear bay (ER6):

$$V_{driver} = \frac{L(in)}{12} \cdot \frac{W(in)}{12} \cdot \frac{H(in)}{12} = \frac{36}{12} \cdot \frac{24}{12} \cdot \frac{12}{12} = 3 * 2 * 1 = 6\ ft^3 \text{ (Meets ER6)} \quad (14)$$

  - Powered-tool storage (ER9 target ≈ 2 ft^3):

$$V_{power} = \frac{24}{12} \cdot \frac{12}{12} \cdot \frac{12}{12} = 2.0\ \ ft^3\ \ (Meets) \quad (15)$$

  - Emergency/safety storage total (ER14 ≥ 2 ft^3):
    Box A 18×12×12 in → 1.5·1·1=1.5 ft^3;*Box B* 12×12×12 in → 1·1·1=1.0 ft^3.

    $\sum V_{emerg} = 1.5 + 1.0 = 2.5\ ft^3\ \ (Meets\ ER14)$

  - Tire rack capacity & clearance:

$$N_{tires} = \frac{L_r}{t} = \frac{40in}{8in} = 5 \quad (16)$$

$$m_{side} = \frac{W_r - D}{2} = \frac{(26 - 24)}{2} = 1in(pass) \quad (17)$$

  - Coverage ratio per category:

$$C_{tools} = \frac{N_{required}}{N_{present}} = \frac{85}{85} = 1.00 \quad (18)$$

$$C_{tires} = \frac{5}{5} = 1.00 \quad (19)$$

$$C_{driver} = \frac{4}{4} = 1.00 \quad (20)$$

4.6.4 Conclusion

- If all volumes meet targets, every item fits with positive clearance and secure closure/retention, and coverage ratios C=1.00 for all categories, then CR1/CR2/CR6 = Met (Y) and ER6/ER9/ER14 = Met (Y); Client Acceptable = Y.

- If any bay misses its target or any item lacks clearance/retention, propose adjustments (move dividers, add holders/straps, resize or re-locate a bay, revise packing list) and re-test using the same checklist and calculations.

4.7 Correct Tools Testing

4.7.1 Test/Experiment Summary

- **Question to be answered:** With only the tools on the cart, can the team complete SAE tech inspection and routine pit work without borrowing tools, and can a single operator locate & return critical tool quickly?

- **DRs tested:** CR1 (organized toolbox), CR6 (safe storage).

- **Equipment needed:** Official/team tech-inspection tool checklist; toolbox, labels/foam cutouts, stopwatch, camera, calibration references (for torque wrench, calipers).

- **Variables isolated for measurement:**

    1. Presence & condition of each required tool (Y/N).
    2. Labeling/organization (slot/foam present) (Y/N).
    3. Retrieval time t_{pick} for critical tools (s).
    4. Calibration/accuracy status (Y/N).
    5. Consumables stock vs minimum list (Y/N).

- **Variables to be calculated from results:**

    - Overall coverage: $C_{total} = \frac{N_{present}}{N_{required}}$.
    - Critical-set coverage: $C_{crit} = \frac{N_{crit,present}}{N_{crit,req}}$.

- Labeling completeness: $C_{label} = \frac{N_{labeled\, slots}}{N_{tool\, slots}}$.

- Spare ratio: $Rspare = \frac{Q_{on-ha}}{Q_{min}}$.

- Time metrics: median retrieval time t_{med} and 95th-percentile t95 .

4.7.2 Procedure

1. Prepare the inspection checklist and map each tool to a labeled slot/foam.

2. Inventory drawers: verify presence, condition, and labels; photograph.

3. Retrieval drill: One operator retrieves and returns 5 critical tools (e.g., torque wrench, 10–19 mm sockets, calipers, multimeter, safety-wire pliers) three times each; record t_{pick}.

4. Verify calibration/accuracy (certificate date or quick check).

5. Count consumables vs minimum list.

6. Compute $C_{total}, C_{crit}, C_{label}, R_{spare}, t_{med}, t_{95}$.

4.7.3 Results

- **Kind of results looked for:** All required and critical tools present, labeled, functional drawers close/lock, retrieval is fast, consumables meet minimums.

- **Expected results:**

  - $C_{total} = \frac{85}{85} = 1.00$, $C_{crit} = \frac{20}{20} = 1.00$, $C_{label} = \frac{90}{90} = 1.00$.

  - Consumables: $R_{spare} = 200/100 = 2.0\ (\geq 1\ Pass)$.

  - Retrieval drill: t_{med}=11 s, t_{95}=19 s(targets: t_{med}≤15t, t_{95}≤25 s).

  - Table fields: Item, Req Qty, Present, Condition, Slot/Label, t_{pick}, notes, photo ID; plus, summary line with the metrics above.

4.7.4 Conclusion

- If $C_{crit} = 1.00, C_{total} = 1.00, C_{label} = 1.00, R_{spare} \geq 1$and $t_{med} \leq 15$t, $t_{95} \leq 25$s, then Correct Tools = Pass, satisfying CR1/CR6; Client Acceptable = Y.

- Otherwise, provide a purchase/placement/calibration action list, implement, and re-test with the same drill.

4.8 Door Magnetic Latch / Hinge Operation Test

4.8.1 Test/Experiment Summary

- **Question to be answered:** Do the doors open/close smoothly and stay closed during motion, keeping compartments organized (CR1, CR2, CR6), and does the driver-gear bay meet the minimum storage volume requirement (ER6)?

- **DRs being tested:** CR1 (organized toolbox use), CR2 (holds all driver equipment), CR6 (safe storage), ER6 (≥ 3 ft × 2 ft × 1 ft driver-gear storage minimum).

- **Equipment needed:** Full representative load in each compartment, tape measure, calipers (as needed), digital pull gauge or spring scale for magnetic latch force, painter's tape/chalk for marking, stopwatch (for cycle timing), camera/phone.

- **Variables isolated for measurement:**

    1. Door motion quality (bind/rub/clearance, Y/N) and hinge free play.

    2. Magnetic latch holding force F_{mag}(lbf).

    3. Compartment net interior dimensions L, W, H and computed volume V.

    4. Door closed integrity during accelerations/bumps (self-opening Y/N).

- **Variables to be calculated:**

    - Driver-gear Bay volume: V = L×W×H (ft^3). Requirement: V ≥ 3×2×1=6 ft^3 (ER6).

    - Opening tendency under deceleration**:** inertial pull on door contents $F_i = am_{drawer/door}$. Safety factor for the latch:

$$SF = \frac{F_{mag}}{F_i}(expect\ SF > 1;\ aim\ 1.5 \sim 2\ for\ margin) \qquad (21)$$

where a is the representative deceleration during push-stop/bumps.

4.8.2 Procedure

1. Dimensional check (ER6): Empty the driver-gear compartment, measure net L, W, H clear of hardware; compute and record V.

2. Functional open/close: Slowly open each door to full travel and close it 10 times; note hinge smoothness, interference, and magnet engagement.

3. Latch force measurement: Attach the pull gauge perpendicular to the door at the latch location; record the peak detent/pull-off force F_{mag} (repeat 3× and average).

4. Loaded road-handling simulation: Load compartments with representative gear. Push the cart at walking speed and perform three firm stops and three bump crossings (door thresholds/wood strip). Observe whether any door self-opens; record Yes/No.

4.8.3 Results

- **Kind of results looked for:**
  - Doors open and close smoothly with no rubbing or binding.
  - No self-opening in stops/bumps; latch fully re-engages after each close.
  - Driver-gear Bay volume V meets or exceeds 6 ft^3.
- **Expected results (with equations):**
  - Volume (ER6):

    V = L×W×H (ft3) ⇒ V≥6 ft^3

    Example: L=36 in=3 ft, W=24 in=2 ft, H=12 in=1 ft ⇒V= 6 ft^3 → Pass.
  - Latch safety factor: choose a representative deceleration a (e.g., 0.3~0.5 g) and estimate the effective door/contents mass acting to pull the door:

$$F_i = m\,a, SF = \frac{F_{mag}}{F_i} \quad (22)$$

Example (replace with your measurements): for m = 8 lbm and a = 0.4g ⇒ Fi ≈ 3.2 lbf. If measured F_{mag} = 8 lbf, then $SF = 2.5$ → expected to remain closed in tests.

4.8.4 Conclusion

- If V ≥ 6 ft^3 for the driver-gear bay (ER6 met), all doors close smoothly with no self-opening during the dynamic maneuvers, and measured SF > 1 with comfortable margin, then CR1/CR2/CR6 = Met (Y) and Client Acceptable = Y.

- If any door self-opens, binds, or the computed $SF \leq 1$, document the door and failure condition, and recommend corrective actions (magnet upgrade, strike alignment, secondary latch, hinge adjustment, or gasket friction tuning).

4.9 Top-Mounted Tire Rack Loading Testing

4.9.1 Test/Experiment Summary

- **Question to be answered:** Will the roof-mounted tire rack (tray, side rails/brackets, and bolted joints) safely support stacked wheels during operation without loosening, slipping, or permanent deformation, so that the cart still provides a reliable mounted location for accessories (CR3) and the attachment method remains compatible with the welded frame and bolted accessories (ER13)?

- **DRs being tested:** CR3 (mounted locations for tools/attachments); ER13 (welded frame with bolted accessories).

- **Equipment needed:** Stacked wheels or equivalent masses (full load), tape/calipers and scale, dial indicator (or ruler with feeler), torque wrench, 1–1.5 in wood strip or curb, paint pen for bolt-marking, camera/phone, the actual straps/retainers used on the rack.

- **Variables isolated for measurement:**

    1. Vertical deflection at rack mid-span/critical points (δ).

    2. Joint integrity (bolt loosening, hole ovaling, weld cracks) Y/N.

    3. Retention performance (wheel slip or vertical uplift; strap relaxation) Y/N.

- **Variables to be calculated:**
  Model each side rail as a simply supported beam carrying half the stack weight. Let total stack weight W_{stack}, span L, rail section I and outer fiber c, modulus E.

$$F_{slide} = \frac{W_{\text{stack}}}{2} \tag{23}$$

$$M_{\max} = \frac{F_{slide}L}{4} \tag{24}$$

$$\sigma = \frac{\mathrm{M}_{max}\mathrm{c}}{I} \tag{25}$$

$$\delta_{calc} = \frac{F_{slide}L^3}{48EI} \tag{26}$$

  Bolted joints:$\tau = \frac{V}{nA_s}, \sigma_b = \frac{V}{n_t d}\ with\ V \approx Fside$
  Strap preload to prevent uplift under vertical bump a_v (0.3–0.5 g) with two straps and safety factor $SF = 1.5 - 2$:

$$T_{req} \geq \frac{W_{\text{stack}}\, a_v}{2} * SF \tag{27}$$

4.9.2 Procedure

1. Weigh & measure: Record W_{stack}; measure L and rail section to obtain I,c. Log bolt size/grade/count and rack-to-frame locations.

2. Install & mark: Load wheels as intended; apply production straps; torque all bolts to spec and mark with paint.

3. Static deflection: With full load, measure mid-span vertical deflection δ_{meas} (subtract no-load reference).

4. Bump & stop: Push the fully loaded cart over a 1–1.5 in wood strip/curb three times and perform three firm stops; observe slip/uplift and strap relaxation.

5. Documentation: Capture photos/video and complete a results table.

4.9.3 Results

- **Kind of results looked for:**

  - No wheel slip/uplift; straps intact and not relaxed.

  - No bolt loosening (paint marks aligned), no hole ovaling, no weld cracking.

  - Measured deflection δmeas small and consistent with calculation.

- **Expected results (with equations):**

- Use measured geometry and weight in:

$$M_{\max} = \frac{F_{slide}L}{4} \tag{28}$$

$$\sigma = \frac{\mathrm{M}_{max}\mathrm{c}}{I} \tag{29}$$

$$\delta_{calc} = \frac{F_{slide}L^3}{48EI} \tag{30}$$

- Compute safety factors:

$$FOS_\sigma = \frac{\sigma_{allow}}{\sigma} \tag{31}$$

$$FOS_\tau = \frac{\tau_{allow}}{\tau} \tag{32}$$

$$FOS_b = \frac{\sigma_{b,allow}}{\sigma_b} \tag{33}$$

Verify actual strap preload ≥ T_{req} .
Example: with W_{stack}=120 lbf, $a_v = 0.4g$, $SF = 2 \rightarrow T_{req} \geq 120 \times 0.4/2 \times 2 =$ $48\ lbf\ per\ strap$.

4.9.4 Conclusion

- If there is no slip/uplift and no loosening/cracking, δ_{meas} agrees with δ_{calc} within acceptable range, FOS ≥ 2 for bending and joints (per team standard), and strap preload ≥ T_{req}, then CR3 = Met (Y) and ER13 = Met (Y); Client Acceptable = Y.

- If any criterion is not met, recommend design actions (increase rail section modulus/add gussets, shorten span or add a center support, upgrade/ add bolts with backing plates, increase strap rating and add side/front stops).

5. Specification Sheet Preparation

Table 2 breaks down the customer requirements by category and whether we have implemented them correctly, and if the client has approved of the methods.

Table 2: Example CR Summary Table

Customer Requirement	CR Met (Y/N)	Client Acceptable (Y/N)
CR1: The cart must serve as a large, organized toolbox for use in SAE pits.	Y	Y
CR2: The cart must hold all driver equipment, including spare wheels and rims.	Y	Y

CR3: The cart must provide mounted locations for tools such as an arbor press, vice, and grinding wheel.	Y	Y
CR4: The cart must include integrated braking and steering for safe and easy single person operation.	Y	Y
CR5: The cart must be affordable and cost effective to build.	Y	Y
CR6: The cart must include safe storage for essential equipment such as a fire extinguisher, brake bleed kit, and safety wire puller.	Y	Y

Table 3 presents a template to prepare for our upcoming testing results. The measured/calculated column will be filled in with corresponding values as we document our testing.

Table 3: Example ER Summary Table

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER Met (Y/N)	Client Acceptable (Y/N)
ER1: Caster diameter	>6 in	N/A		Y	Y
ER2: Steering system	Manual Steering	N/A		Y	Y
ER3:	>10 degree incline	-2 degrees		Y	Y
ER4: Volumetric footprint	<72 ft^3	Max 100 ft^3		Y	Y
ER5: Drawer security	Locking drawers	N/A		Y	Y
ER6: Driver gear storage volume	>3 x 2 x 1 ft^3	N/A		Y	Y
ER7: Fire extinguisher holder	Meets NFPA 10 access	N/A		Y	Y
ER8: Integrated power output	2500 W	+- 100 Watts		Y	Y
ER9: Powered tool storage volume	>2 ft^3	N/A		Y	Y
ER10: Sound system	Optional	N/A		N	Y
ER11: Accessory mount points	>2 locations	N/A		Y	Y

ER12: Shade/canopy coverage	Optional	N/A		N	Y
ER13: Frame material	Welded A36 Steel	N/A		Y	Y
ER14: Emergency storage volume	>2 ft^3	N/A		Y	Y

6. QFD

The completed QFD chart, shown in Appendix A, illustrates the relationship between customer and engineering requirements and guided the development of the testing plan. A copy of the full QFD matrix has been attached to this submission for reference.

7. Conclusion

This Finalized Testing Plan provides the critical, detailed roadmap for the final validation phase of the NAU SAE Toolbox project. All customer and engineering requirements have been translated into a set of measurable tests focusing on safety, usability, and durability. The structured approach, from the Top-Level Testing Summary that links requirements to specific experiments, to the Detailed Testing Plans that predict results using engineering principles, ensures a rigorous and comprehensive evaluation of the final prototype. By executing these procedures, the team will generate the necessary data to complete the Specification Sheet, confirming that the toolbox cart meets or exceeds client expectations for competition pit and shop use. The integration of the Quality Function Deployment (QFD) analysis further ensures that testing efforts are prioritized toward the requirements that provide the greatest value and satisfaction to the NAU SAE client. Successfully completing this plan will validate the design and deliver a highly functional and reliable asset to the NAU SAE teams.

8. References

[1] J. J. Cristiano, J. K. Liker, and C. C. White, "Key factors in the successful application of Quality Function Deployment (QFD)," *IEEE Transactions on Engineering Management*, vol. 48, no. 1, pp. 81–95, Feb. 2001. DOI: 10.1109/17.913168. [Online]. Available: https://doi.org/10.1109/17.913168. (Accessed: 17-Oct-2025)

[2] K. Miyashita and M. Wada, "Study on Self-Position Estimation and Control of Active Caster Type Omnidirectional Cart with Automatic/Manual Driving Modes," in *Proceedings of the 2020 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2020)*, Boston, MA, Jul. 2020, pp. 1798–1803. [Online]. Available: https://ieeexplore.ieee.org/document/9158854. (Accessed: 17-Oct-2025)

[3] IEEE, *IEEE Recommended Practice for Battery Management Systems in Stationary Energy Storage Applications*, IEEE Std P2686-2024. (Recommended practice published 2024/2025). [Online]. Available (summary/purchase): https://standards.ieee.org/standard/2686-2024.html and https://webstore.ansi.org/standards/ieee/ieee26862024. (Accessed: 17-Oct-2025)

[4] M. Wada et al., "Mechanical design of an active-caster robotic drive with dual-wheel and differential mechanism," in *Proceedings of the 2019 IEEE/SICE International Symposium on System Integration (SII 2019)* / related IEEE/IECON/IECON references on active-caster drives. (See IEEE conference proceedings for active-caster design and implementation examples). [Online]. Example conference record: https://dl.acm.org/doi/proceedings/10.5555/978-1-7281-6794-7. (Accessed: 17-Oct-2025)

[5] "Universal tool transport cart," U.S. Patent US 6,315,376 B1, filed by (inventor/assignee listed on patent), issued Nov. 13, 2001. [Online]. Available: https://patents.google.com/patent/US6315376B1/en. (Accessed: 17-Oct-2025)

[6] NFPA, *NFPA 10: Standard for Portable Fire Extinguishers* (relevant sections on mounting and accessibility). Background/guidance summary and access: NFPA web resources (NFPA 10 overview and guides). [Online]. Available: https://www.nfpa.org/ (see NFPA 10 resources) and a summary article: https://blog.ansi.org/ansi/nfpa-10-2018-standard-portable-fire-extinguisher/. (Accessed: 17-Oct-2025)

9. Appendix

Appendix A: QFD

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

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 pulle	1 Poor	2	3 Acceptable	4	5 Excellent
		Technical Requirements															Customer Opinion Survey				
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				