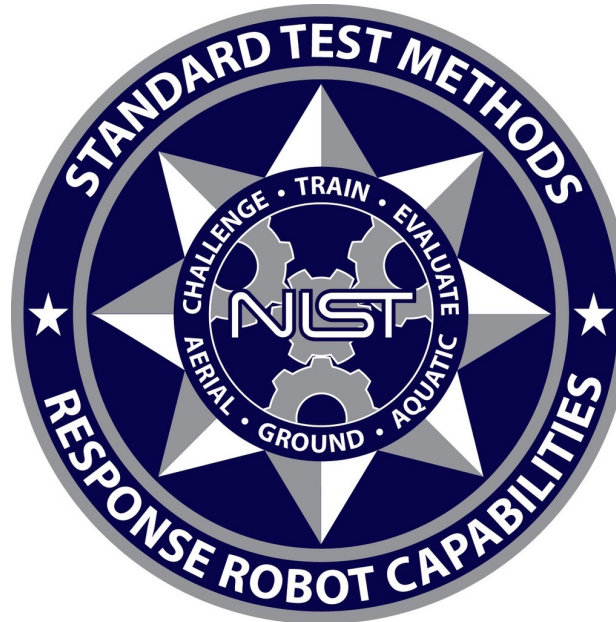


ASTM E54.09 Homeland Security Applications; Response Robots Ground Tests: Maneuvering and Mobility

Version 2022A



**STARTS AT 11:00 AM EST
WASHINGTON, DC TIME**

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U.S. Department of Homeland Security

Internet
RobotTestMethods.nist.gov



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RobotTestMethods@nist.gov

39 Ground Tests

STANDARDS **BALLOTING** PROTOTYPE
20 11 8

Logistics

- E2521-16 Terminology
- E3132-17 System Configuration
- E2592-16 Packaging for Equipment Caches

Sensing

- E2566-17 Visual Acuity
- WK42364 Visual Dynamic Range
- WK54755 Visual Color Acuity
- WK57967 Thermal Image Acuity
- WK49478 Latency of Video and Control
- WK33261 Point and Zoom Cameras
- WK60783 Audio Speech Intelligibility

Radio Comms

- E2854-21 Line-of-Sight Range
- E2855.21- Non-Line-of-Sight Range
- WK60731 Attenuated Range (APC)

Mobility

- E2829-20 Sustained Speed
- E2991-17 Terrains: Gravel
- E2992-17 Terrains: Sand
- E2826-20 Terrains: Continuous Pitch/Roll Ramps
- E2827-20 Terrains: Crossing Pitch/Roll Ramps
- E2828-20 Terrains: Symmetric Stepfields
- WK##### Terrains: Reconfigurable Pallets
- WK##### Terrains: Reconfigurable Crates
- E2803-20 Obstacles: Variable Inclined Planes
- E2801-20 Obstacles: Variable Gaps
- E2802-20 Obstacles: Variable Hurdles
- E2804-20 Obstacles: Variable Stairs/Landings
- E3310-21 Obstacles: Variable Parallel Rails
- E3311-21 Obstacles: Variable Diagonal Rails

Dexterity

- E2830-20 Tow Grasped Sleds
- WK54271 Inspect
- WK54272 Touch/Insert Tools
- WK54273 Rotate
- WK54274 Extract and Place
- WK54276 Grasp, Carry, and Place
- WK54290 Break/Bore Panels
- WK54278 Cut Straps and Ropes
- WK54287 Inspect Underbody
- WK54289 Inspect Cab Interior

Situational Awareness

- E2853-21 Search Tasks

Energy/Power

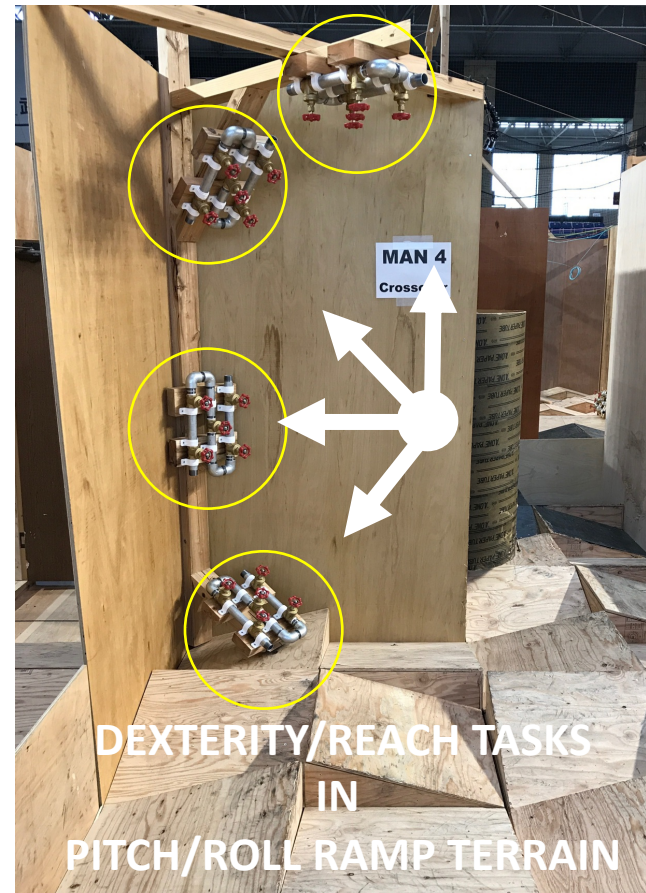
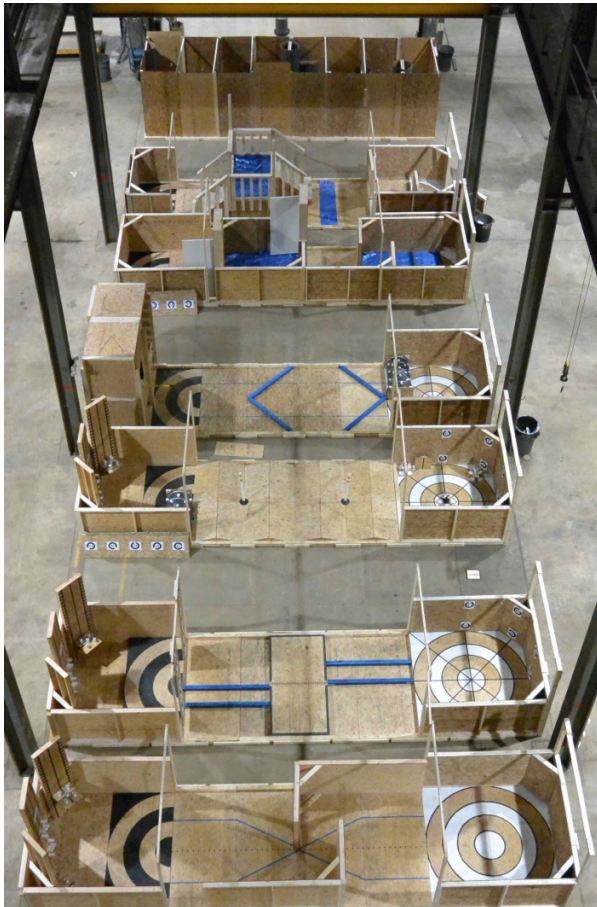
- WK55025 Endurance

Scale for Outdoor Environments

Ground Tests

120 cm (48 in) Lateral Clearance

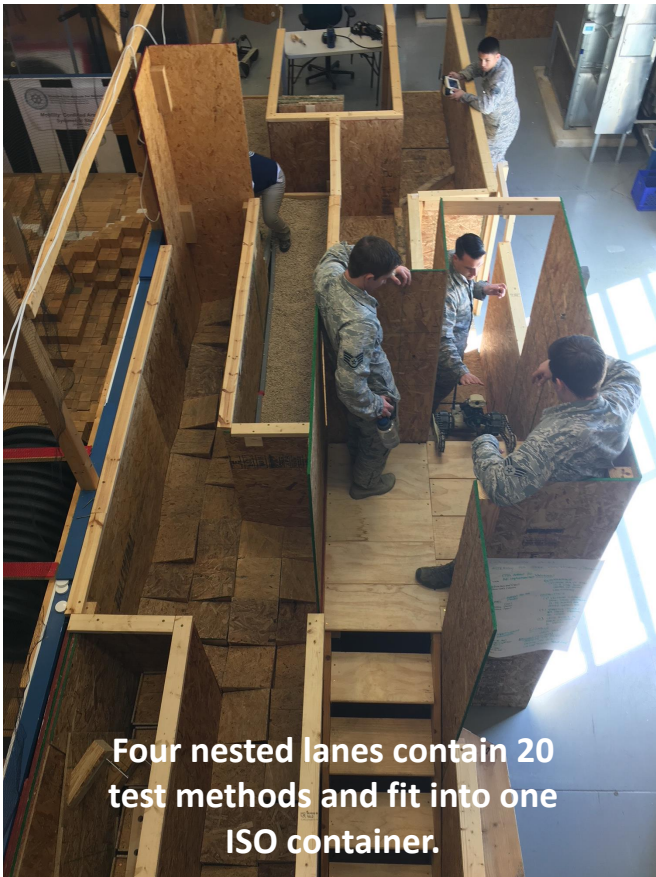
Individual Maneuvering, Terrain and Obstacle Lanes, with Dexterity Tasks in the Terrains



Scale for Indoor/Outdoor Environments

Ground Tests

60 cm (24 in) Lateral Clearance
Trains, Busses, Planes, Dwellings, Parked Cars, etc.



Scale for Confined Access Environments

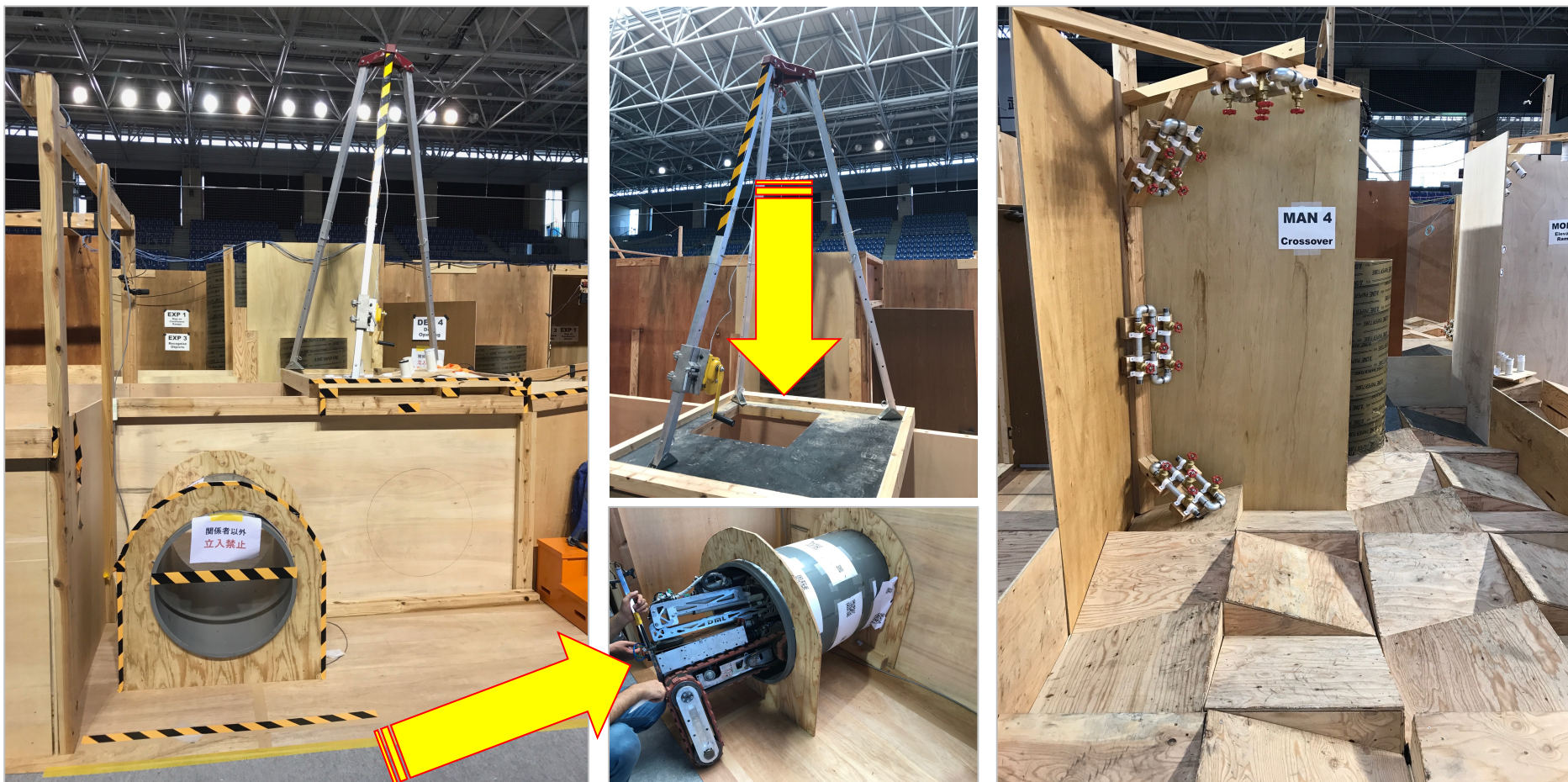
Ground Tests

30 cm (12 in) Lateral Clearance
Robots Deployed Through Access Holes, Throwable, Disposable



Smaller Robots Fit Through Confined Access into Larger Tests

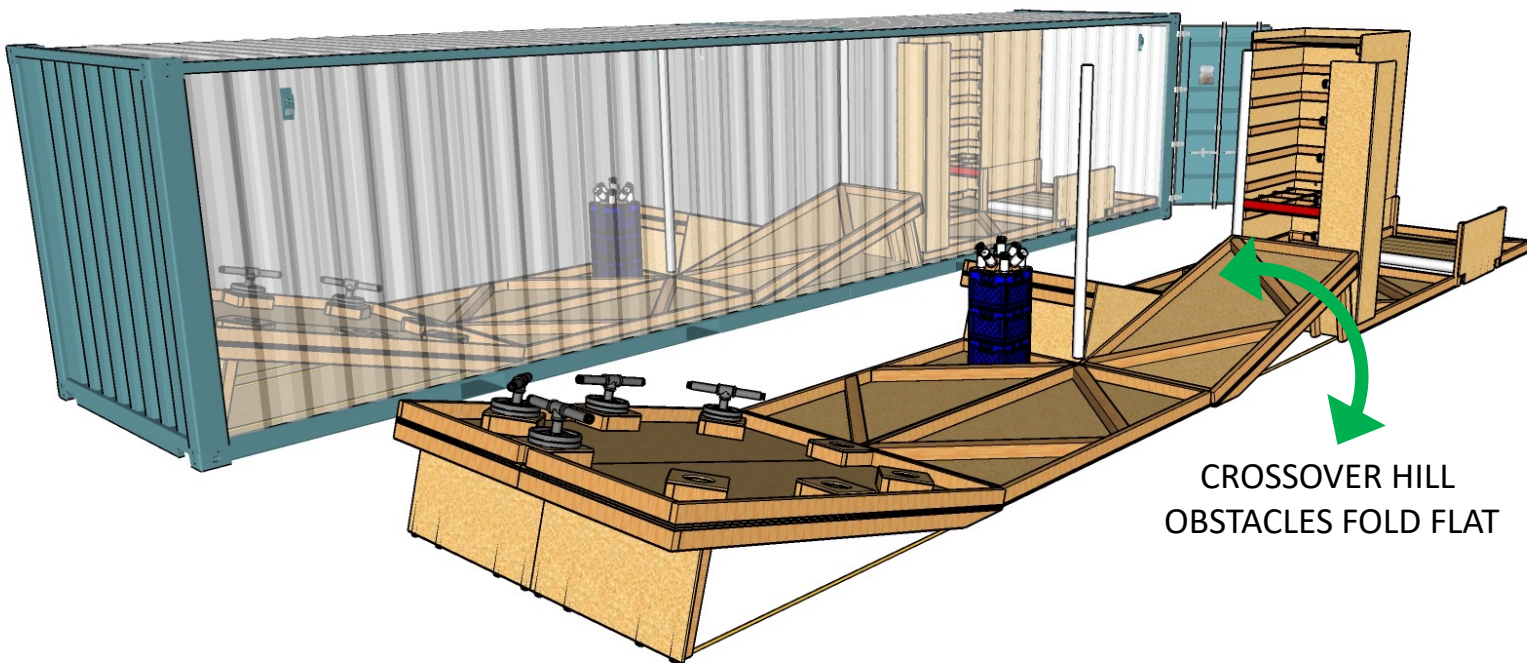
Ground Tests



Parking Lot ISO Container Facilities (Rent or Buy)

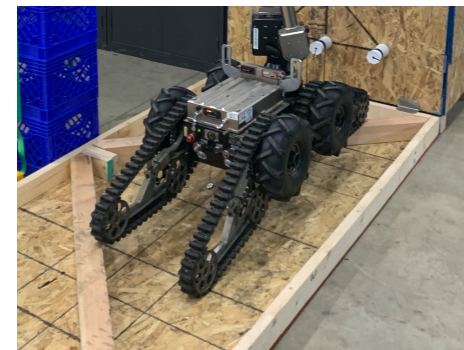
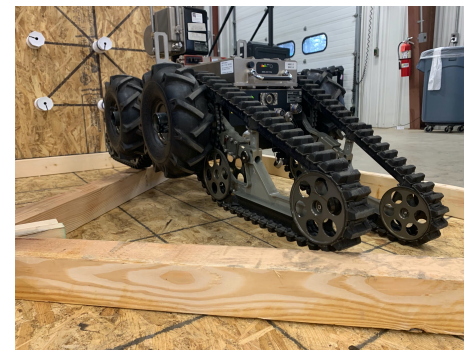
Ground Tests

ALL DEXTERITY TESTS AND MORE IN ONE SHIPPING CONTAINER



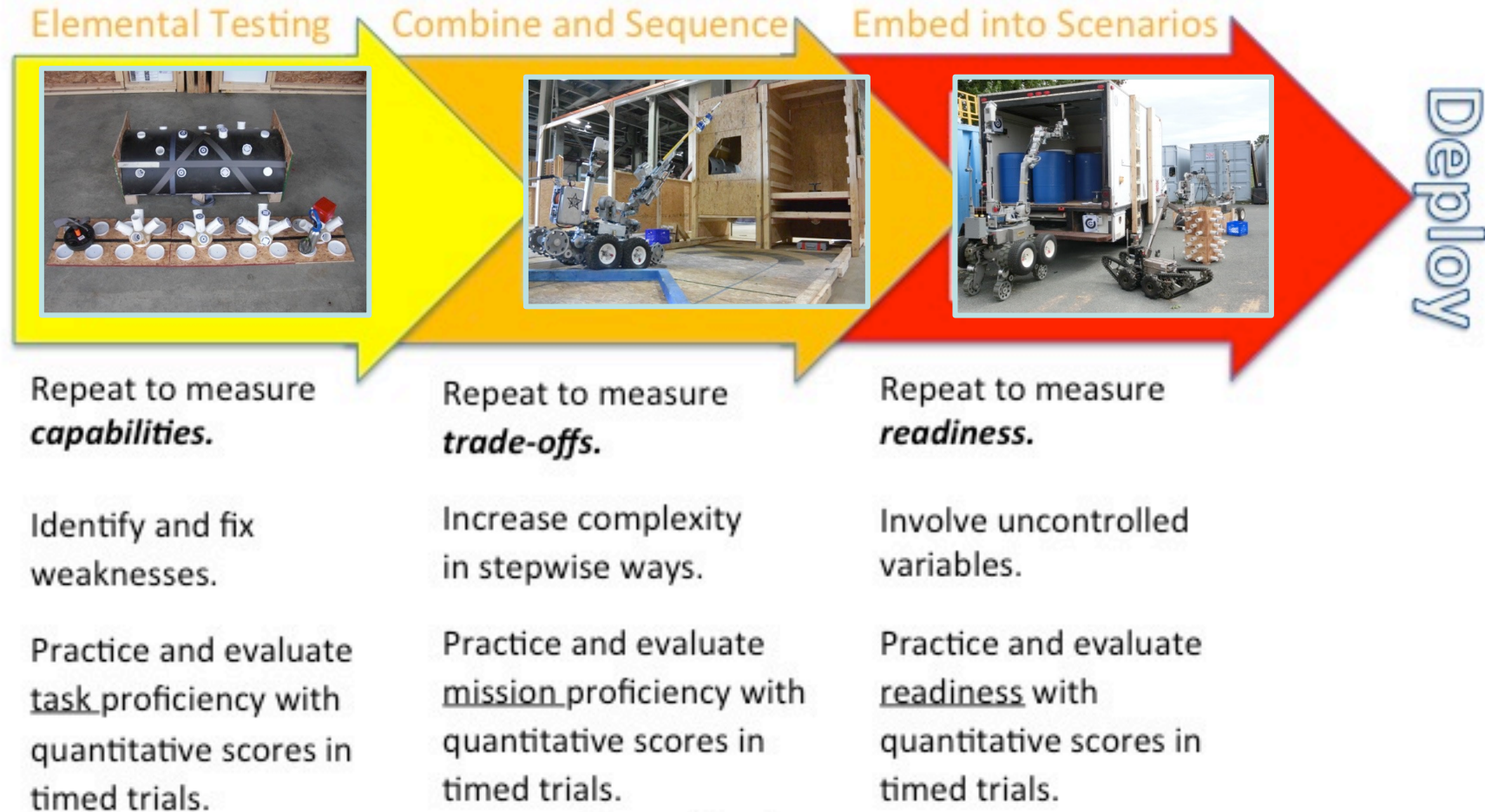
CROSSOVER HILL
OBSTACLES FOLD FLAT

DIAGONAL RAILS ADD SOME TERRAIN COMPLEXITY TO
DEXERITY, STRENGTH, AND GRASP-STOW-CARRY-PLACE TASKS



Standard Test Trials Lead to Deployments

Safety | Capabilities | Proficiency



Maneuvering

Ground Tests

Common Features of Maneuvering Tests

Maneuvering Tests

- Essentially flat with minimal discontinuities to deal with.
- Isolated speed control, steering, situational awareness, etc.
- Easy enough to require FORWARD and REVERSE driving.

SUITE OF TESTS ([Standard](#) | [Validating](#))

E2829-20 Maneuvering: Sustained Speed

E3310-21 Maneuvering: Parallel Rails

E2801-20 Maneuvering : Gaps

E2803-20 Maneuvering: Inclined Planes

WK##### Maneuvering: Centering Tasks

WK##### Maneuvering: Leaning Obstacles

WK##### Maneuvering: Underbody Inspection

WK##### Maneuvering: Avoid Holes

Sustain Speed on a Line (Forward Only or Forward/Reverse)

Maneuvering Tests

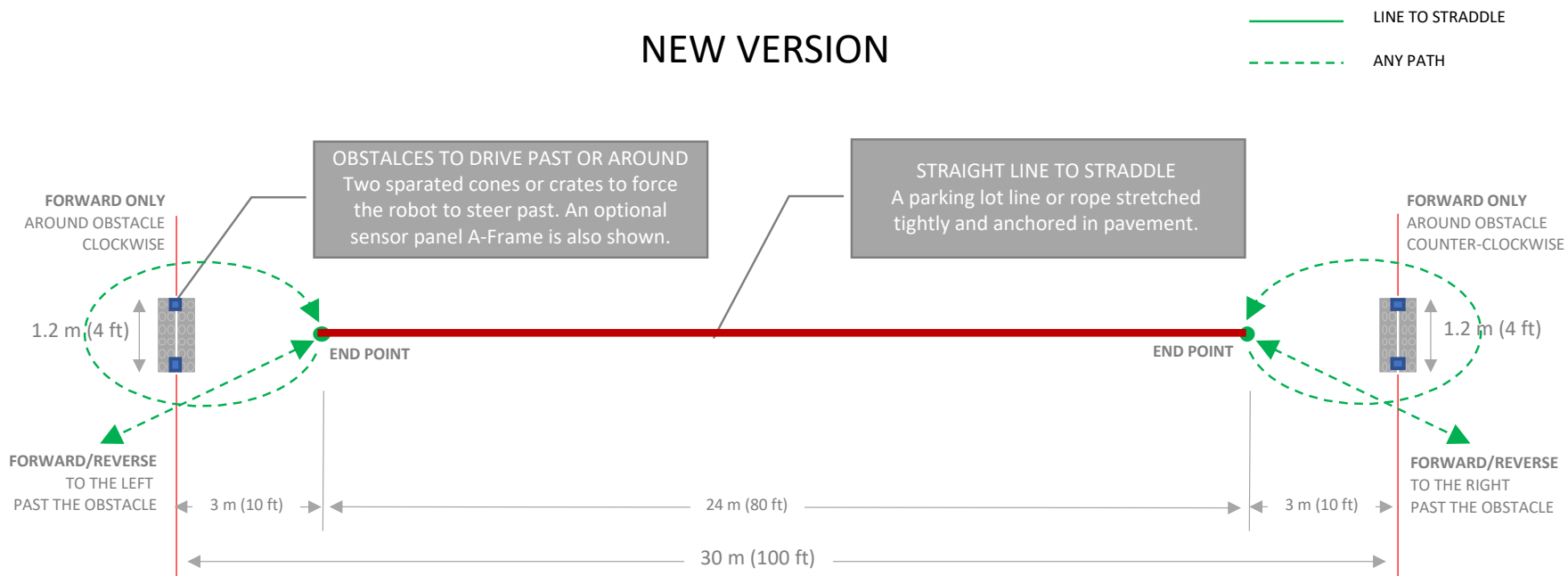
ORIGINAL VERSION (2012)



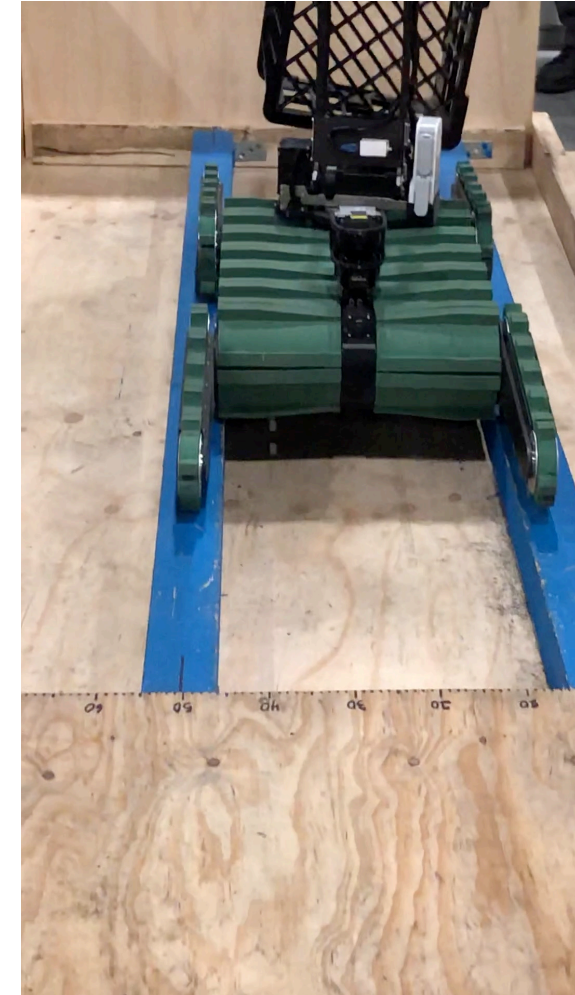
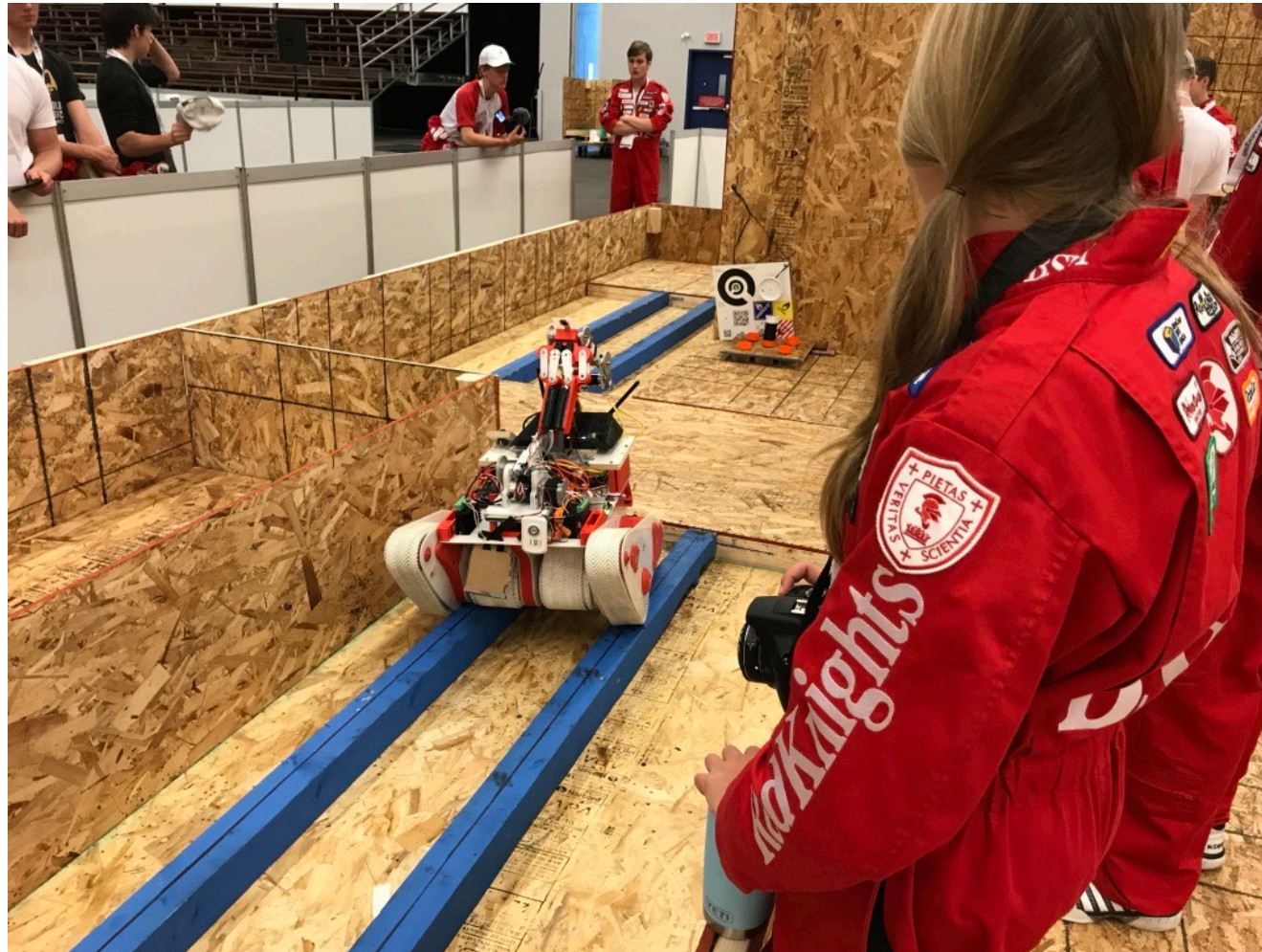
NEW VERSION (2020)



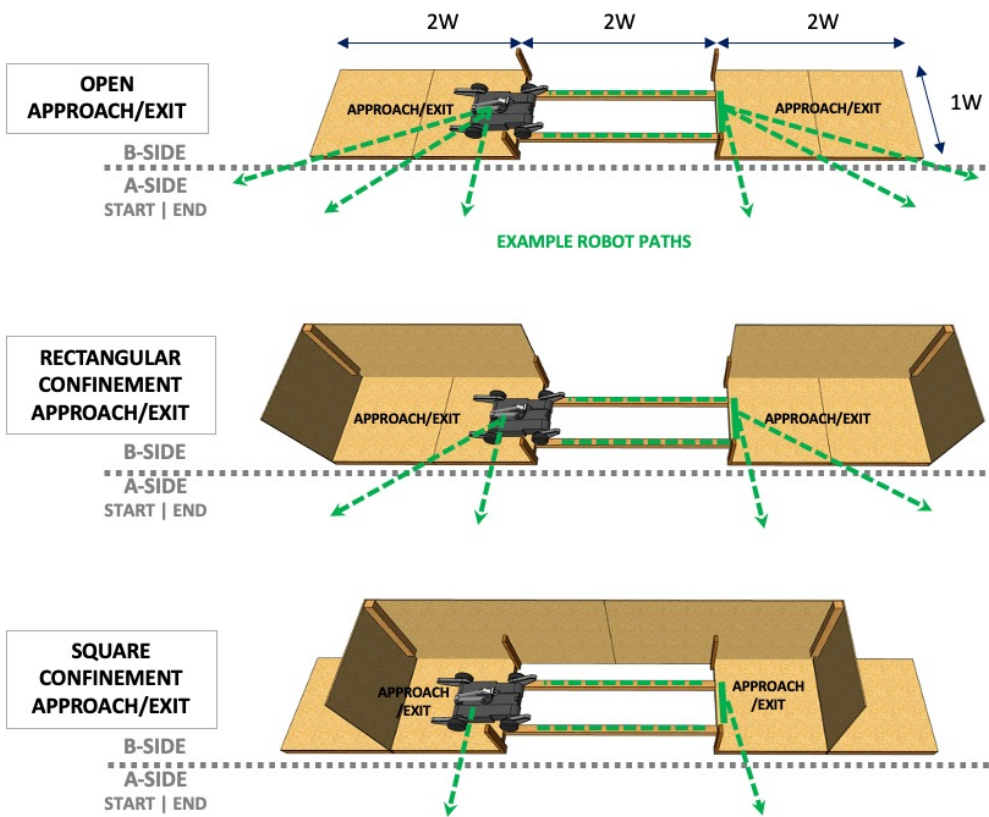
NEW VERSION



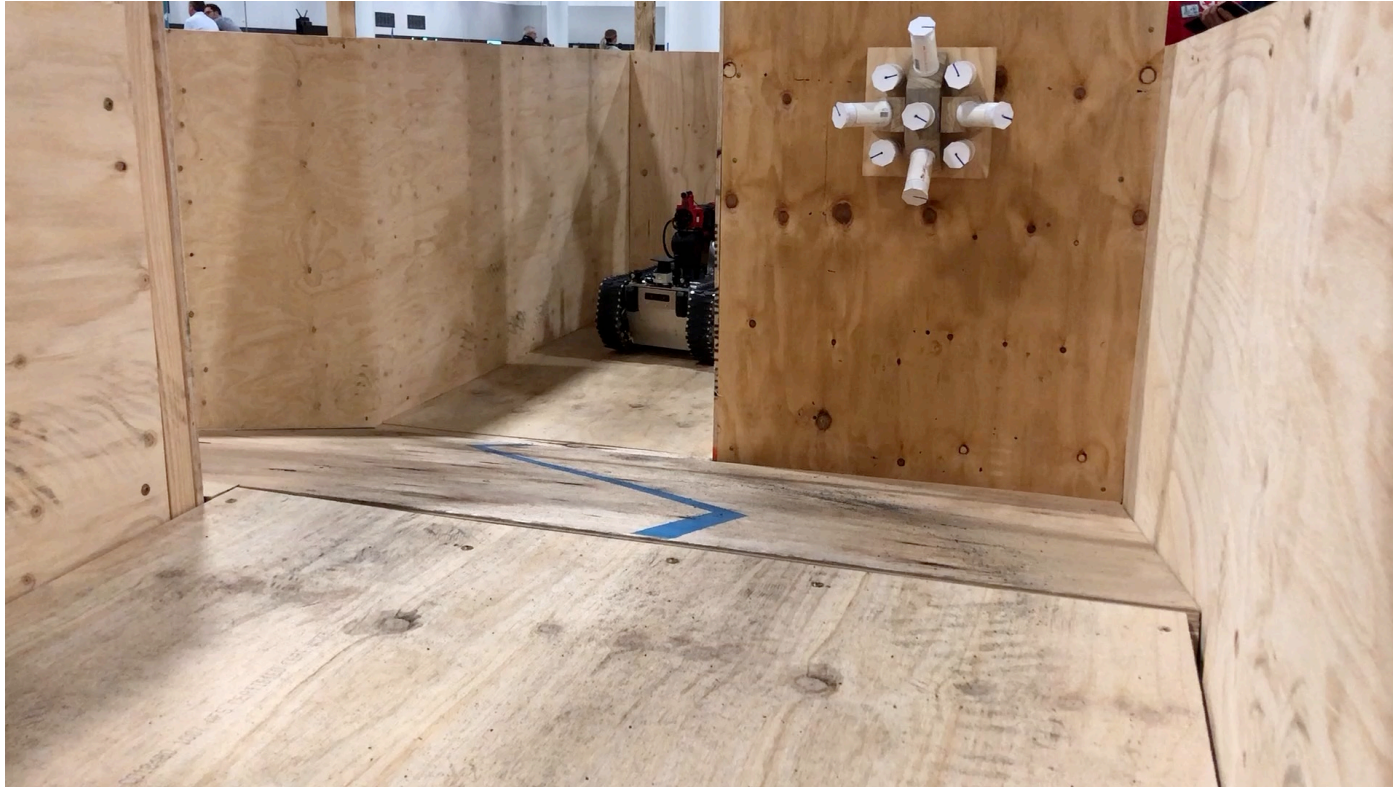
Parallel Rails (Forward/Reverse) Maneuvering Tests



Parallel Rails (Forward/Reverse) Maneuvering Tests



Incline Maneuvering Tests (Forward/Reverse)

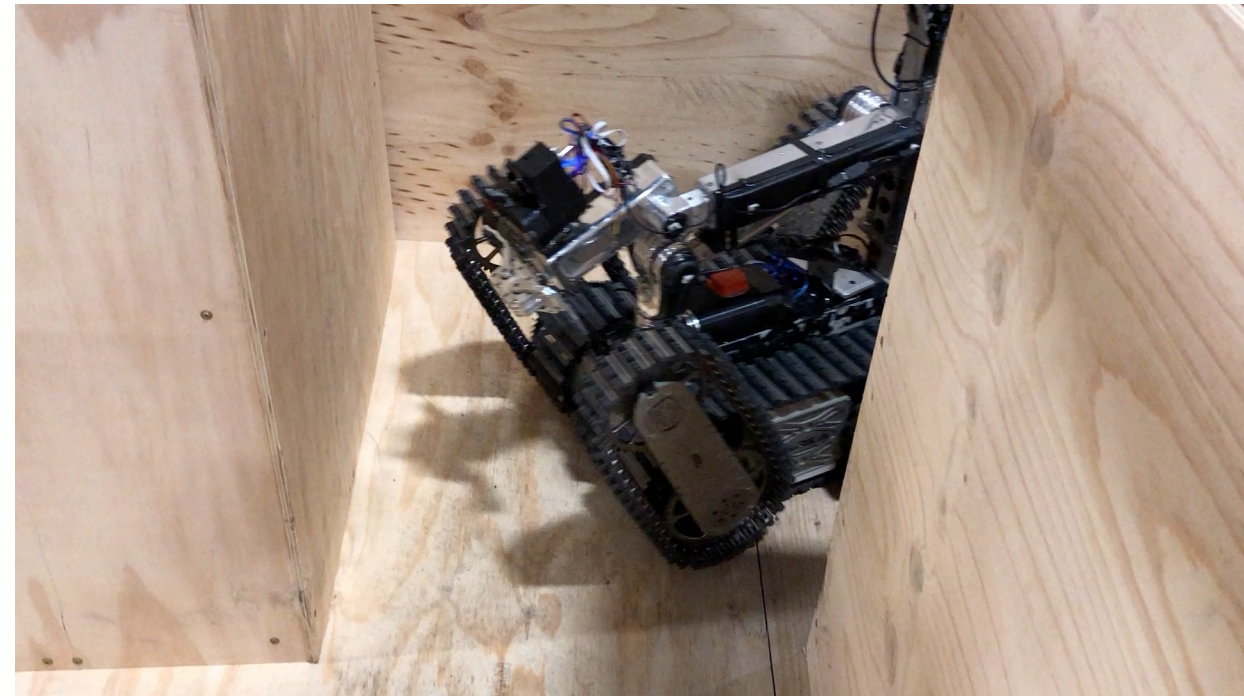
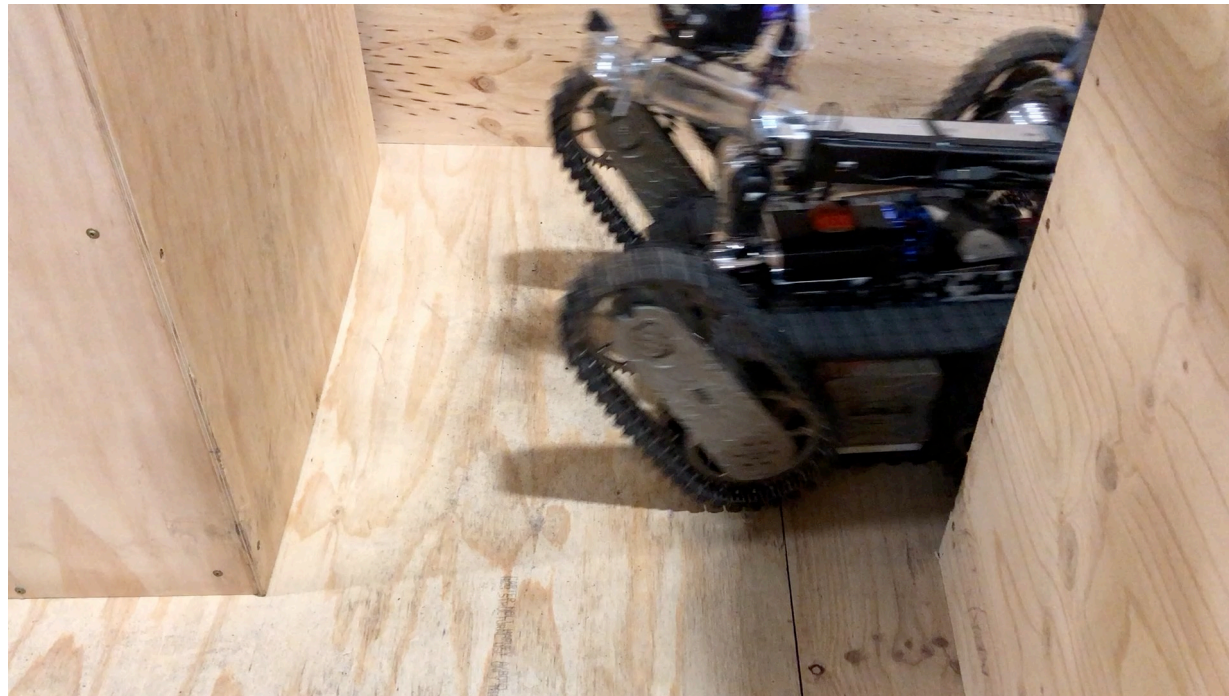


Centering (Forward/Reverse)

Maneuvering Tests (Forward/Reverse)

SPACE = ROBOT DIAGONAL
(GROUND PROJECTION)

SPACE = 120% ROBOT WIDTH
(ENCOURAGING AUTONOMY)

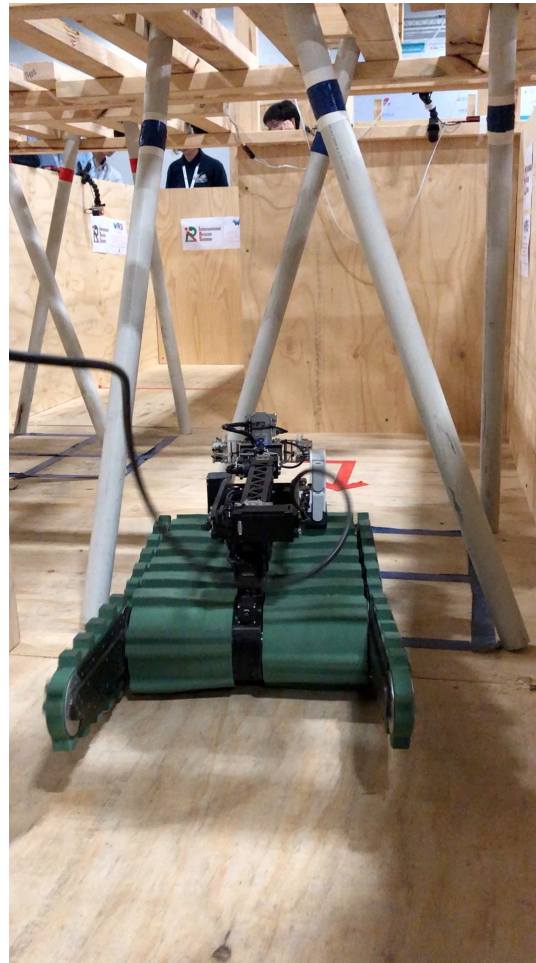


Centering (Forward/Reverse)

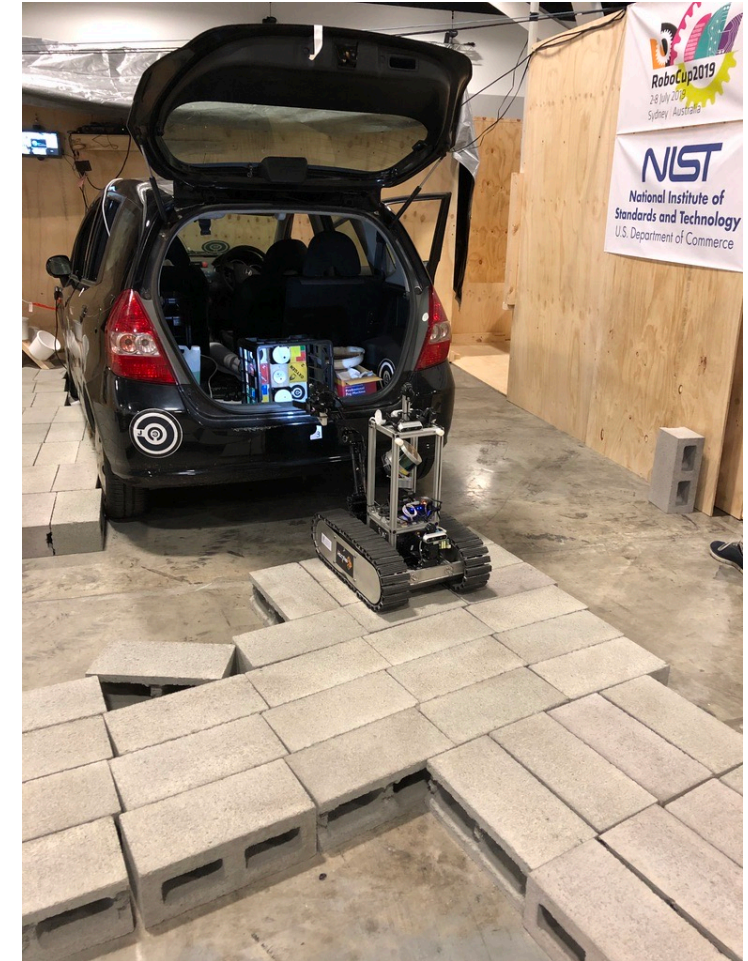
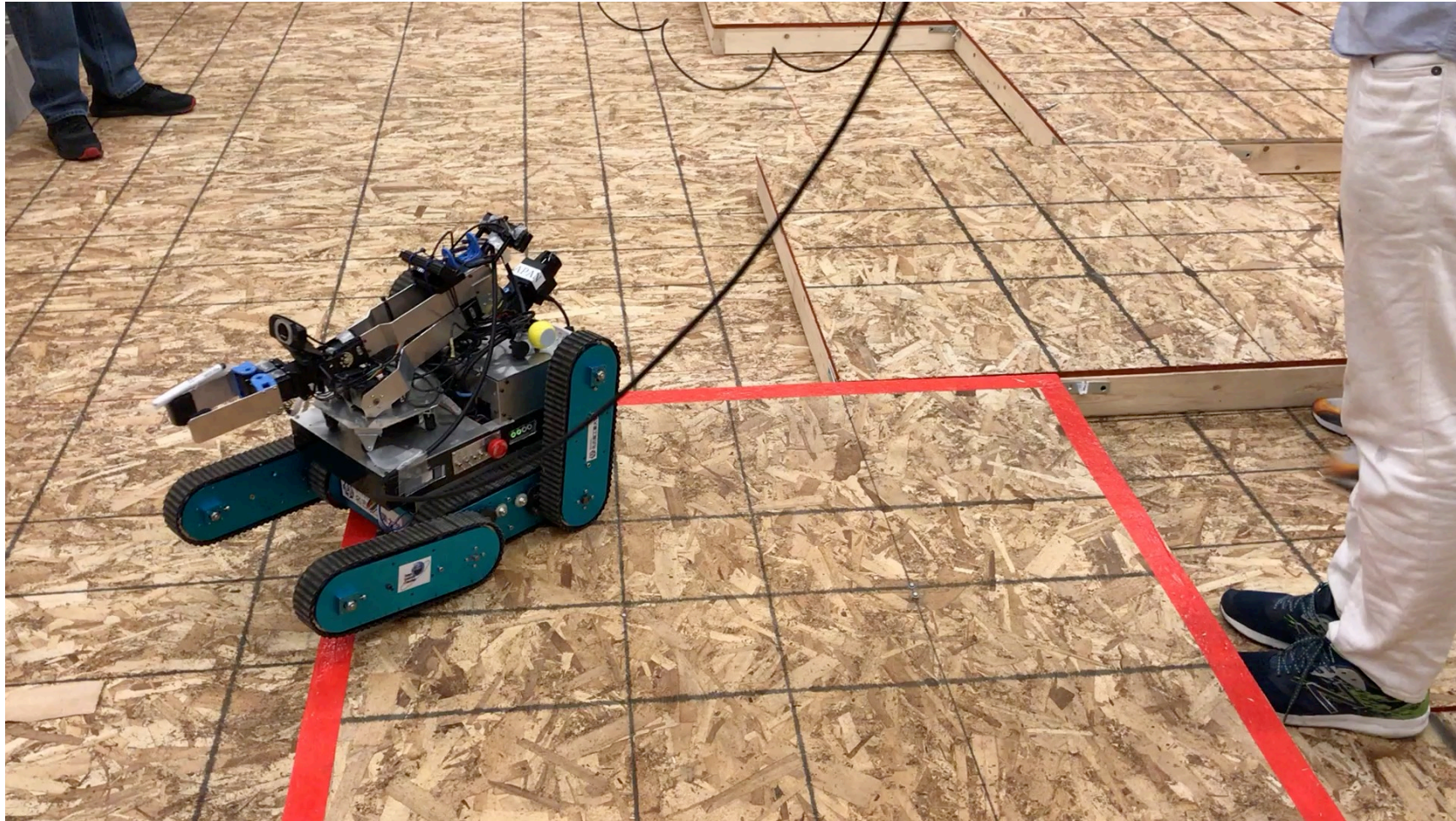
Maneuvering Tests

(Forward/Reverse)

Leaning Objects Maneuvering Tests (Forward/Reverse)



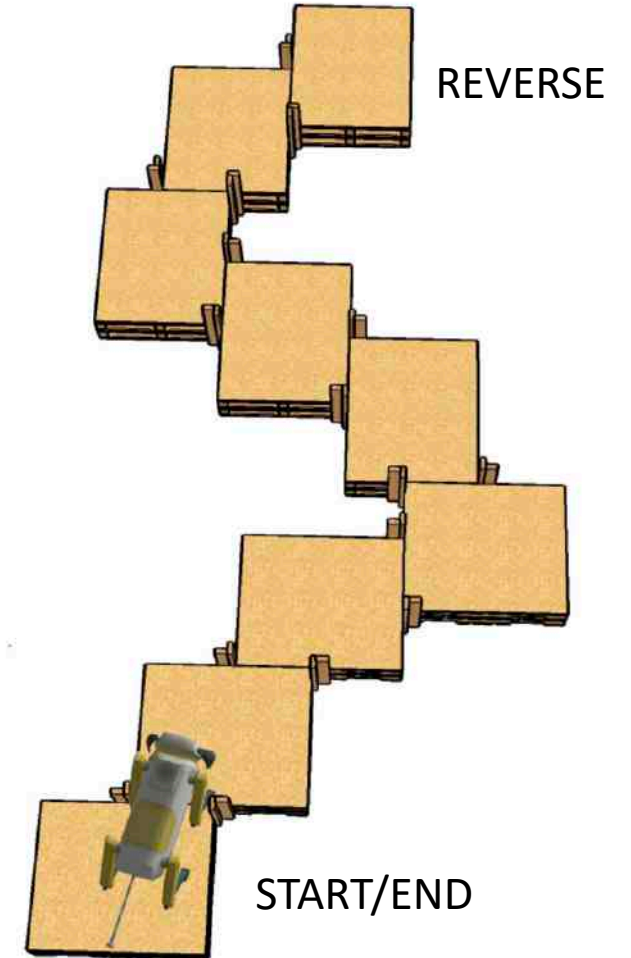
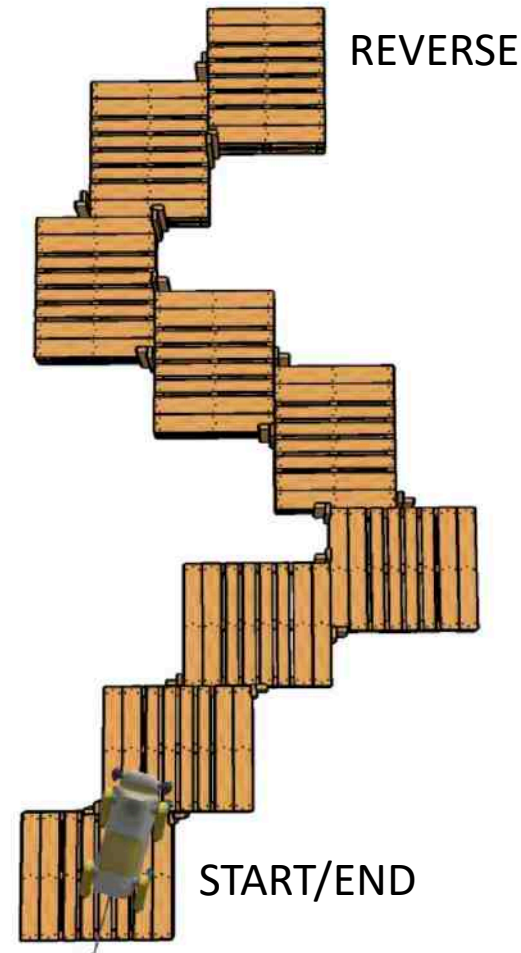
Avoid Holes (Autonomous) Maneuvering Tests



Avoid Holes (Autonomous)

Maneuvering Tests

- Variable doorway widths (120% robot width)
- Negative obstacles (don't fall off)
- Steps up/down at any point (different stacks)
- Solid or slatted surfaces

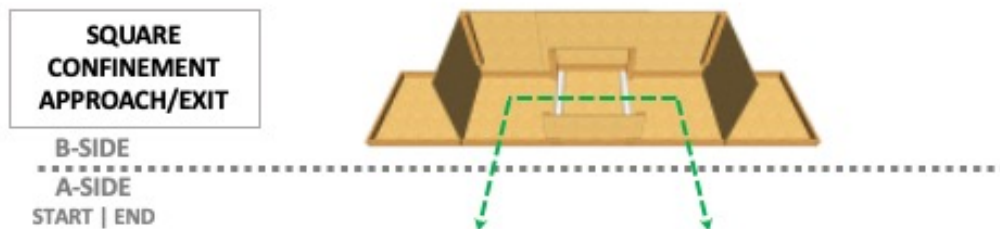
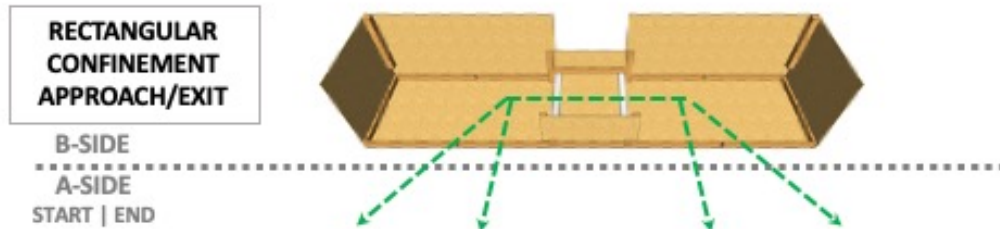
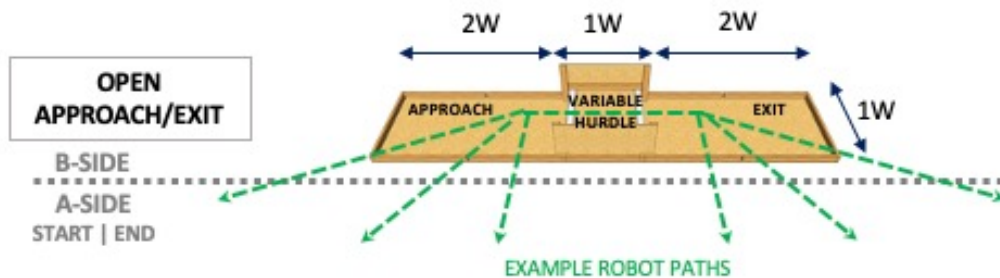


Obstacles

Ground Tests

Common Features of Obstacle Tests

Obstacle Tests



Variable obstacle difficulties using incremental settings.

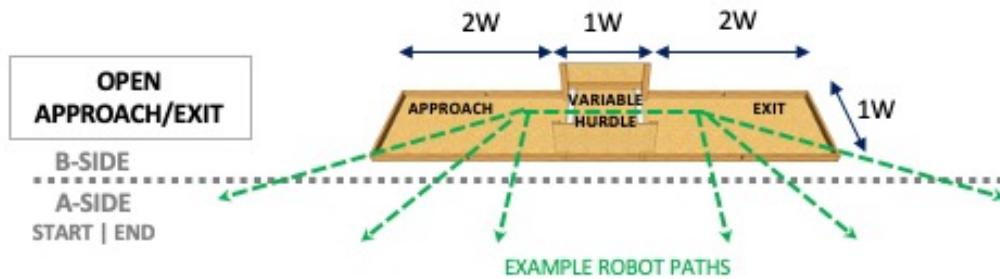
Procedures are based on A/B side offsets from the obstacle at the start and end positions.

Three different confinements around the obstacle approach and exit:

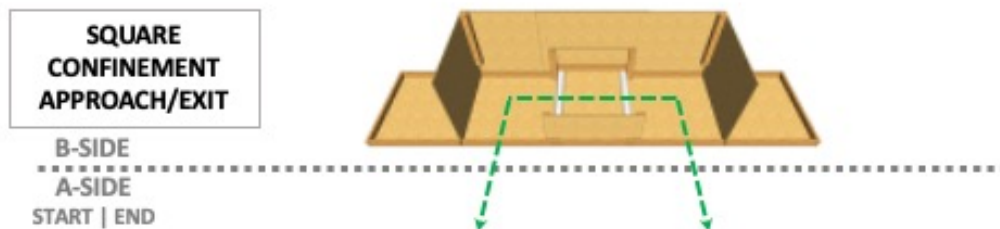
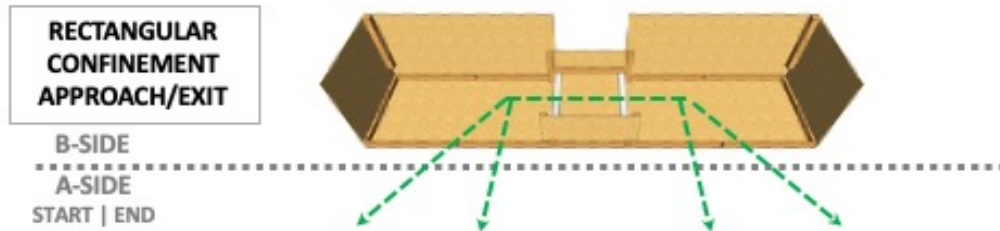
- Open (no walls)
- Rectangular (1:2 ratio landings)
- Square (1:2 ratio landings)

Standard Tests | Validating Prototypes

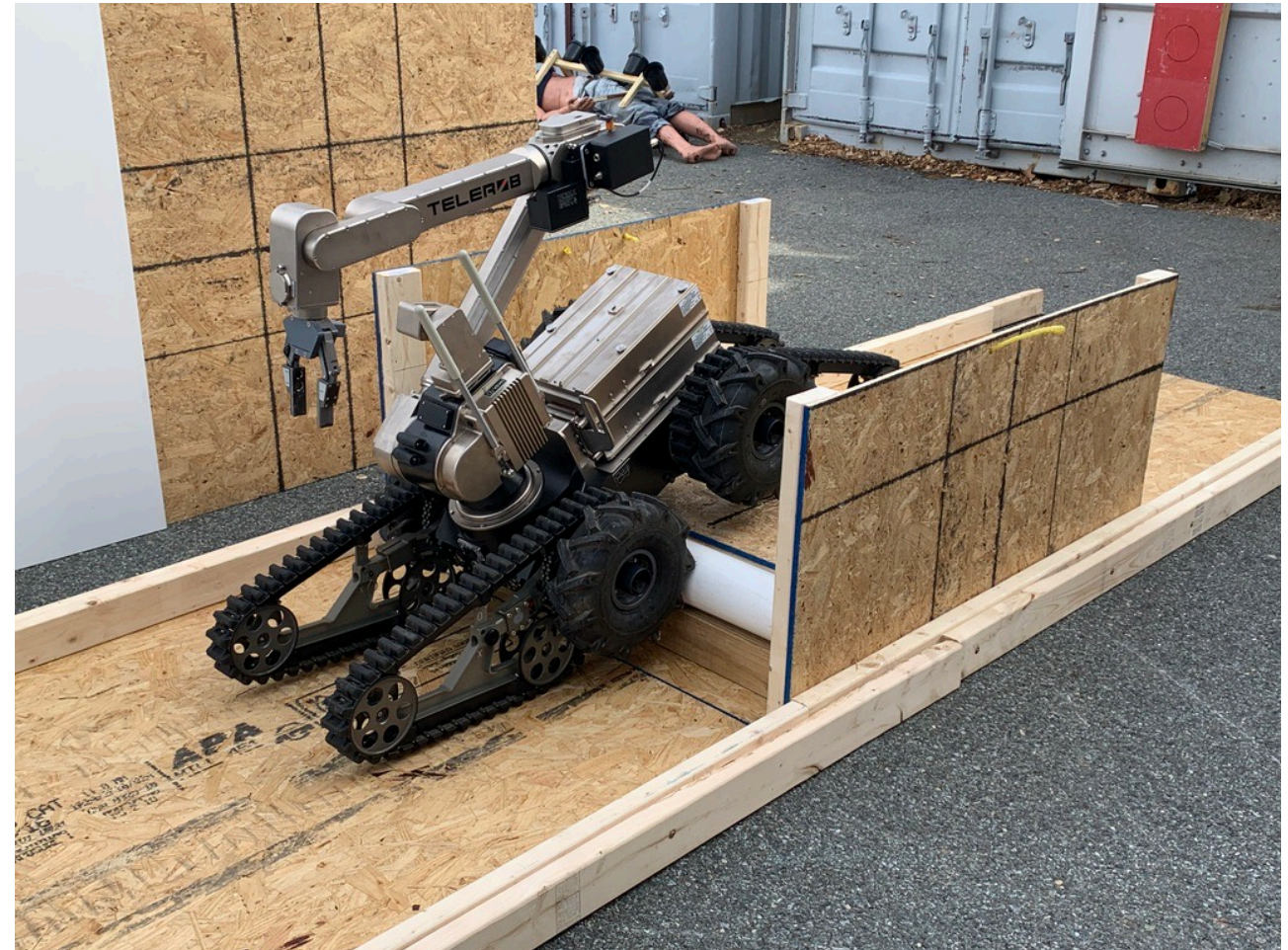
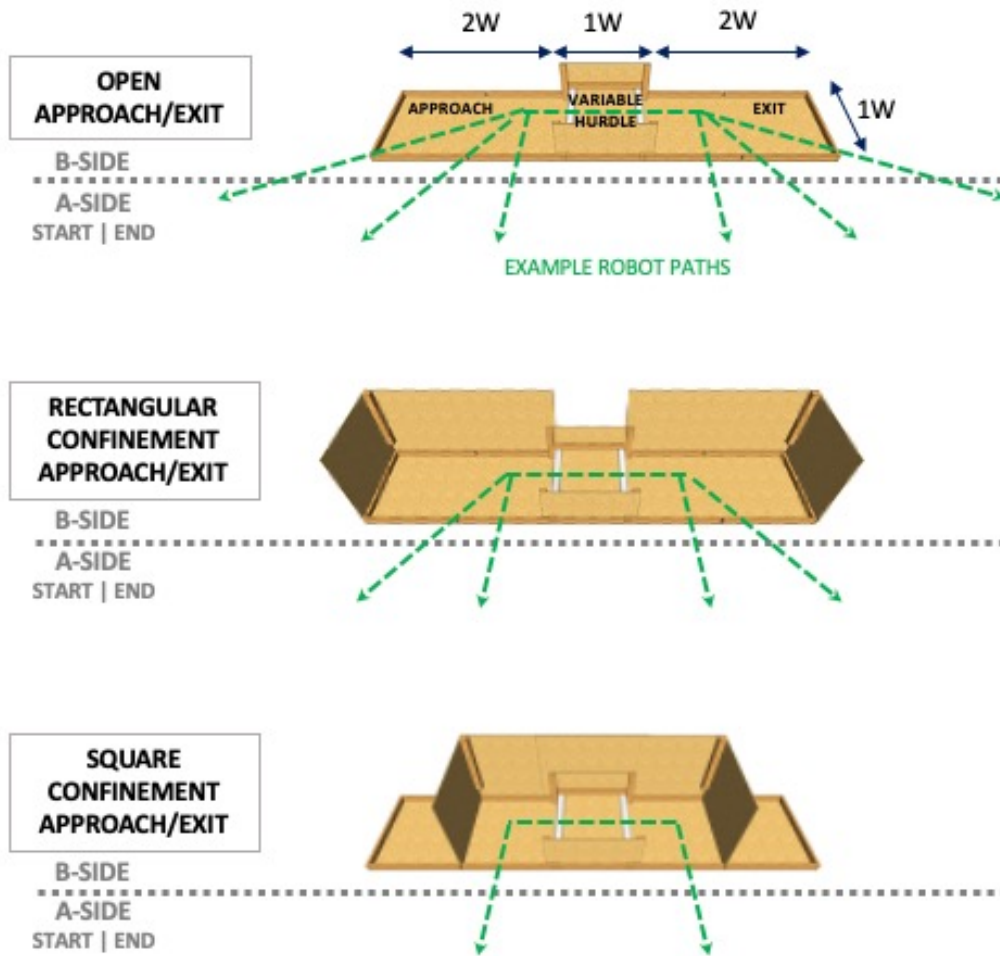
Obstacle Tests



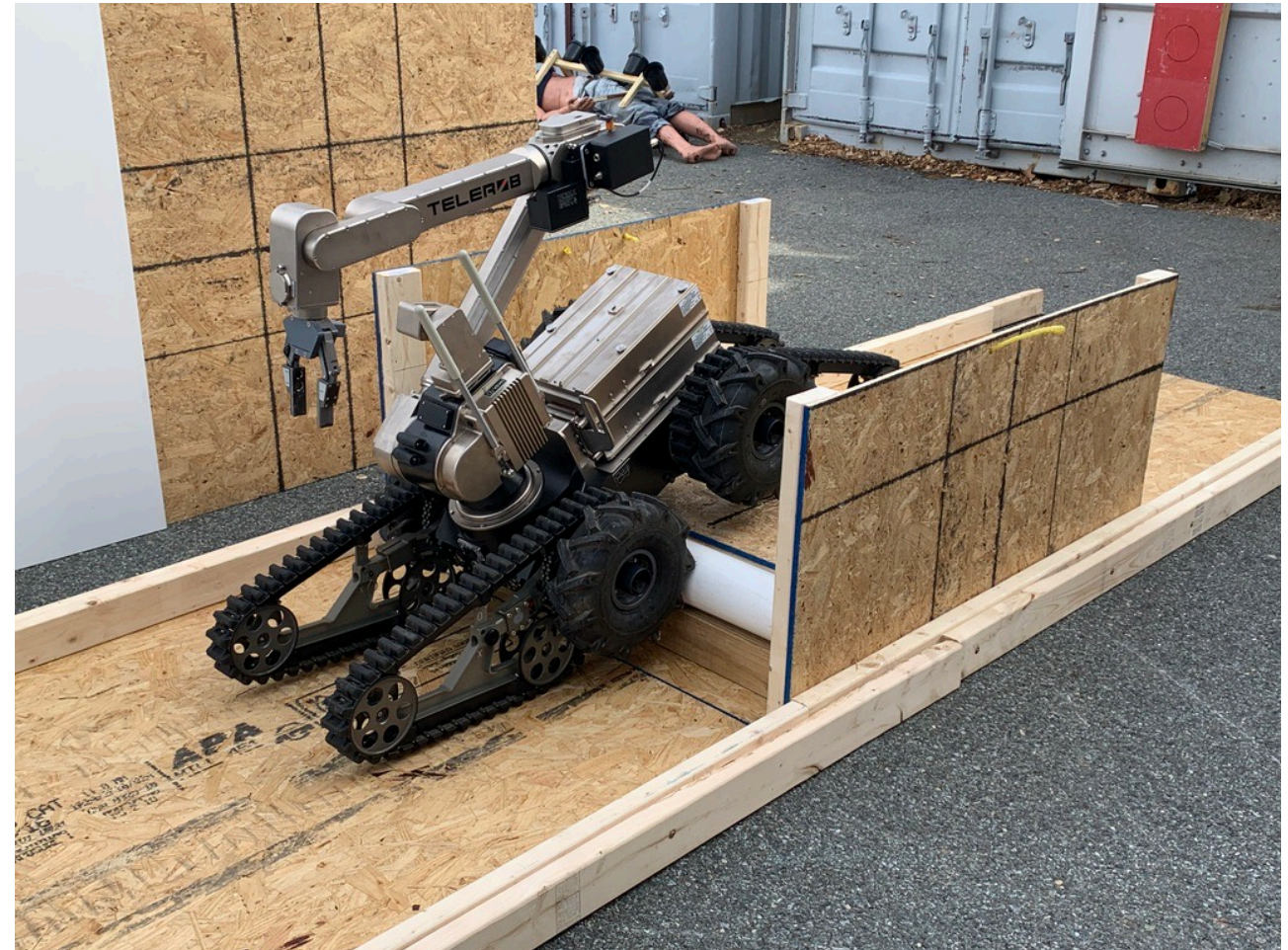
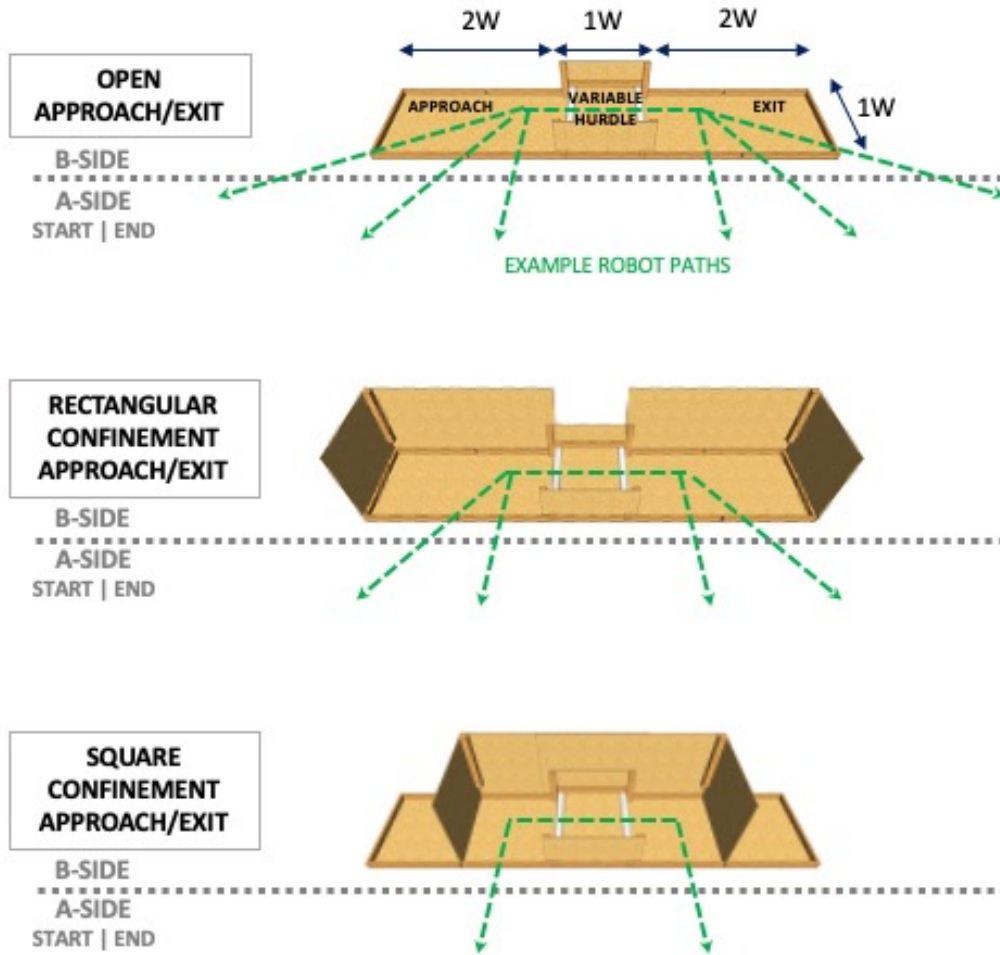
- E2802-20 Obstacles: Variable Hurdles
- E3311-21 Obstacles: Variable Diagonal Rails
- E2804-20 Obstacles: Variable Stairs/Landings



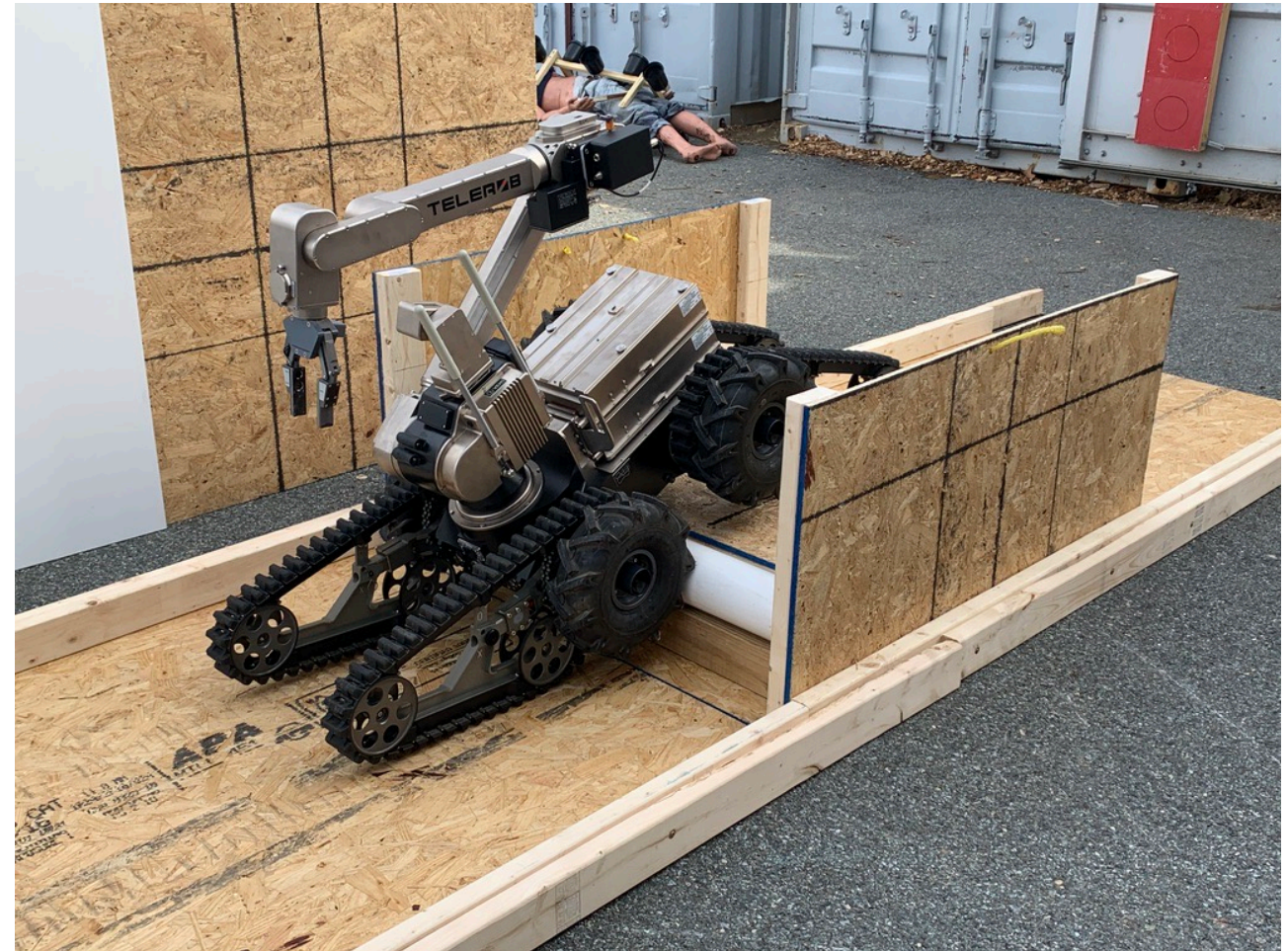
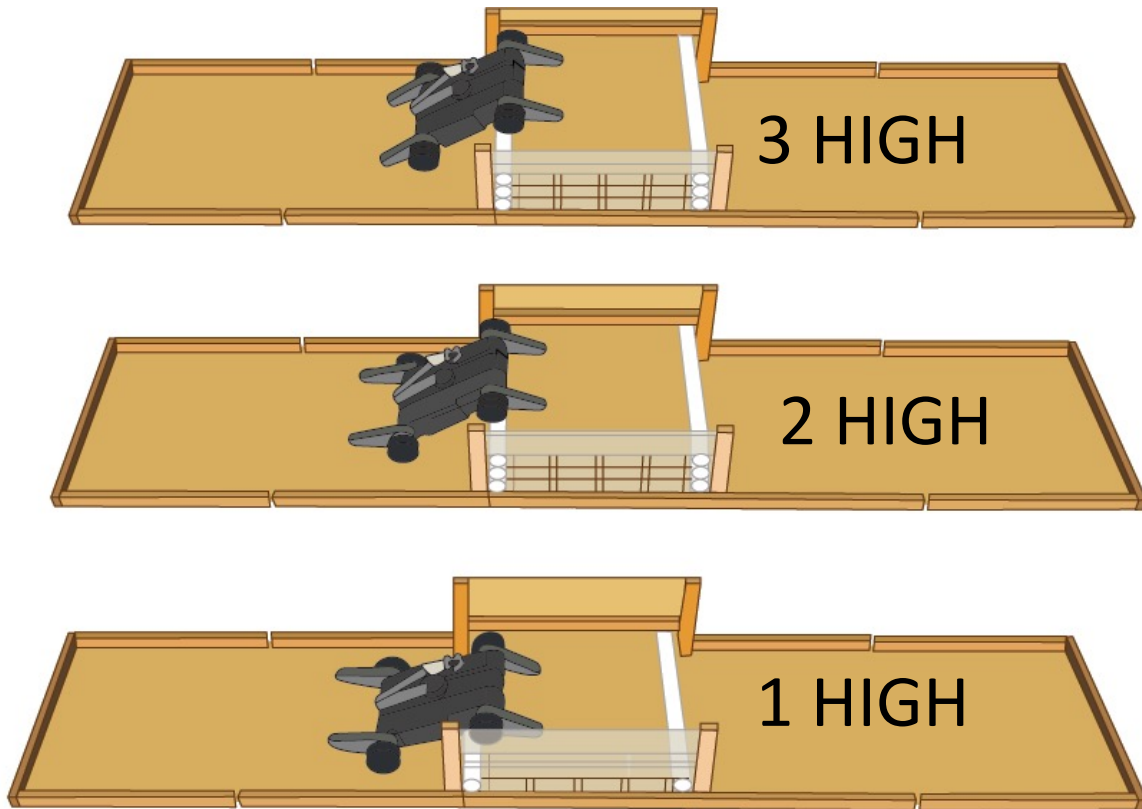
Variable Hurdle Obstacle Tests



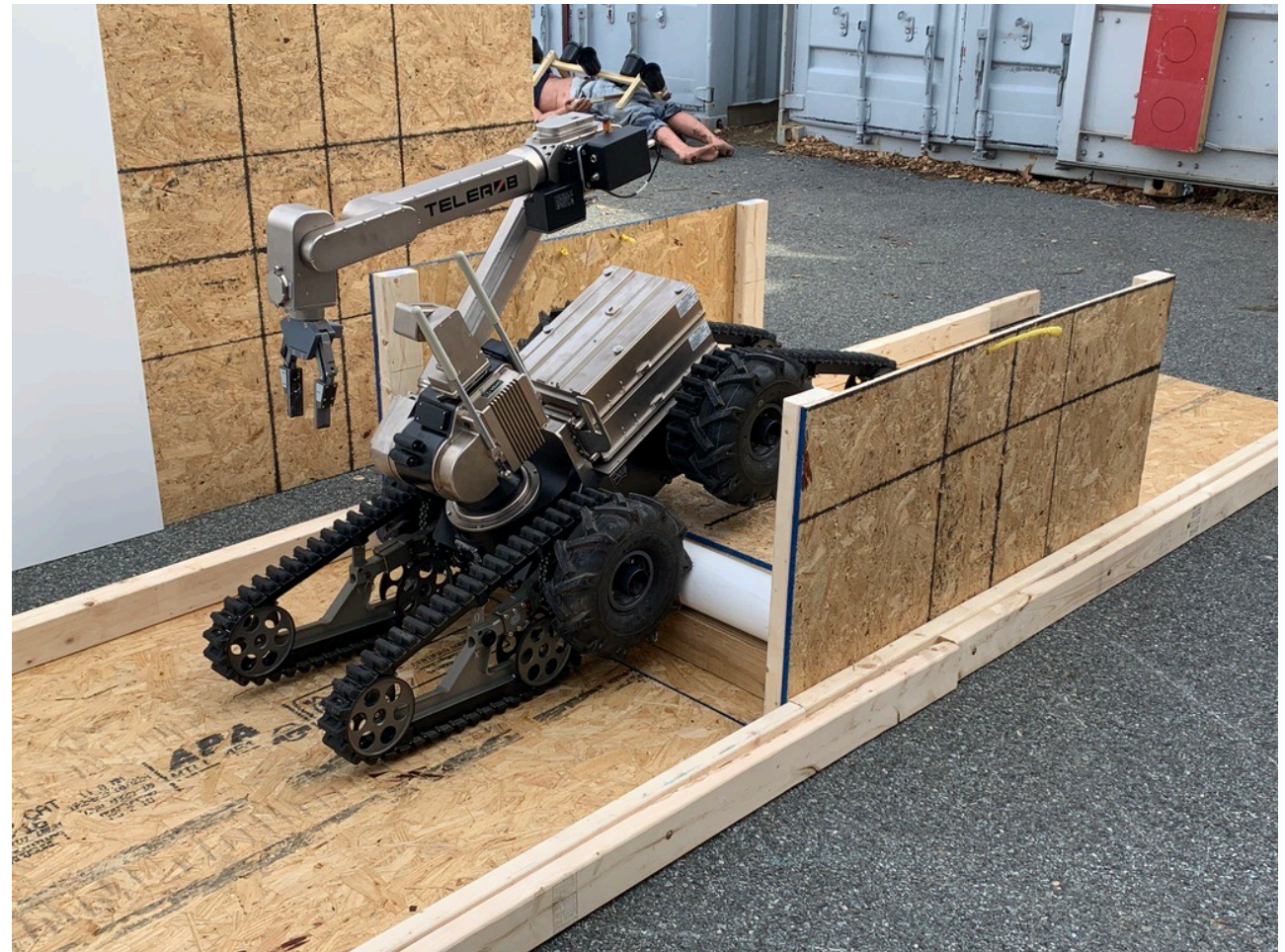
Variable Hurdle Obstacle Tests



Variable Hurdle Obstacle Tests

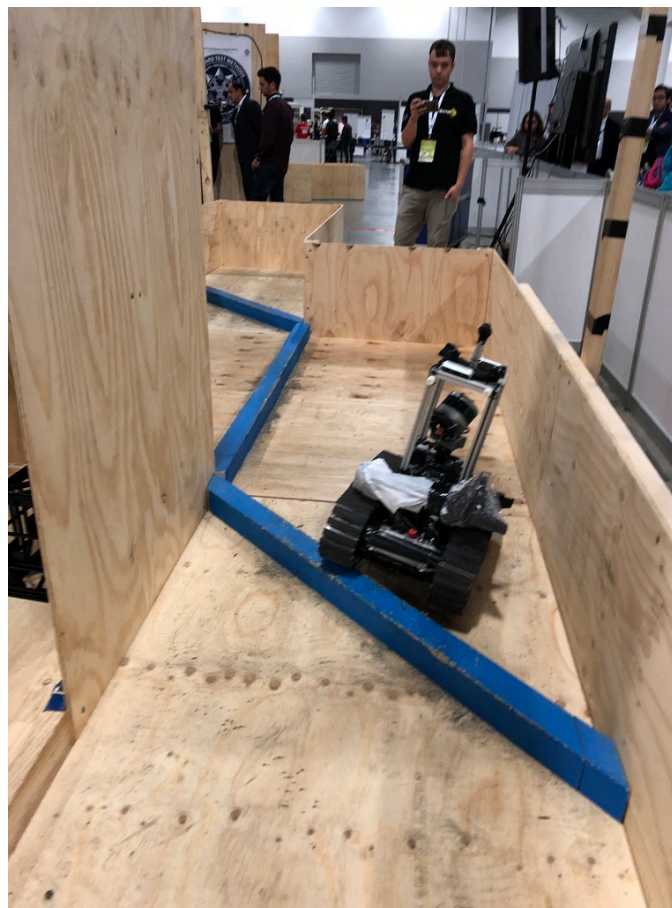
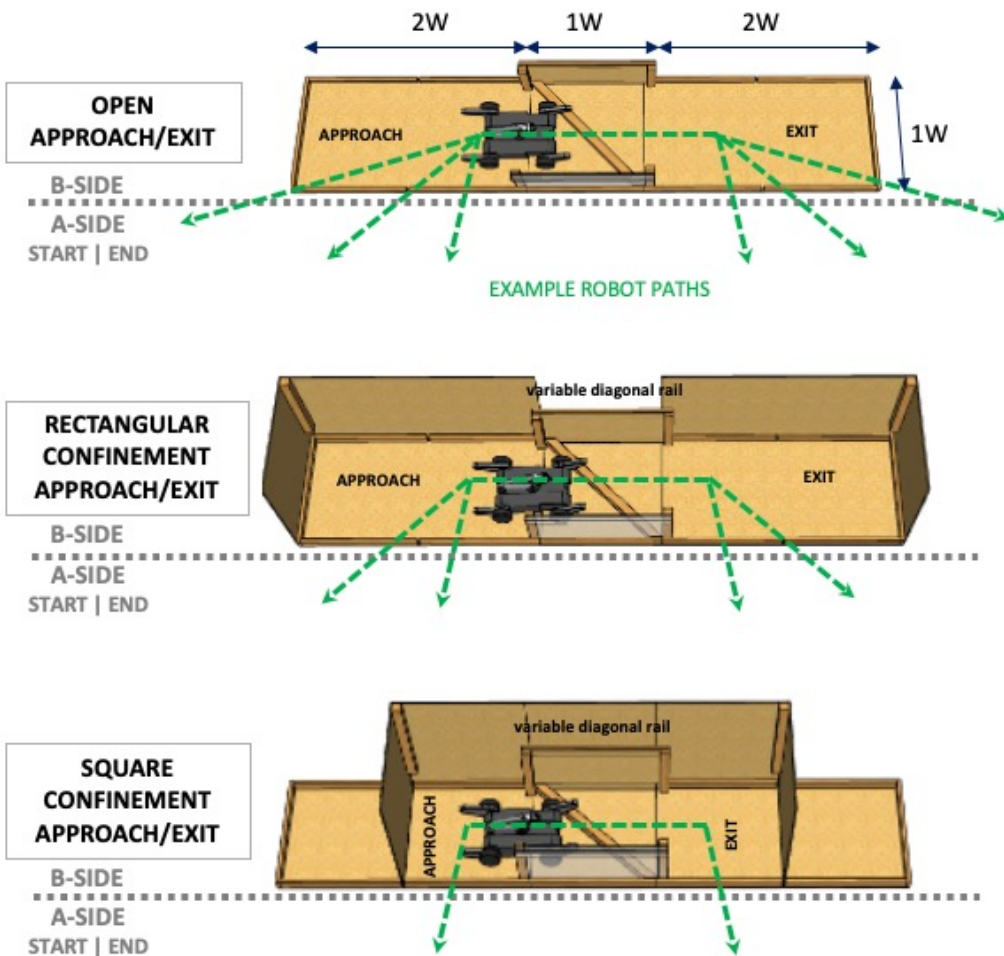


Variable Hurdle Obstacle Tests



Variable Diagonal Rails Obstacle Tests

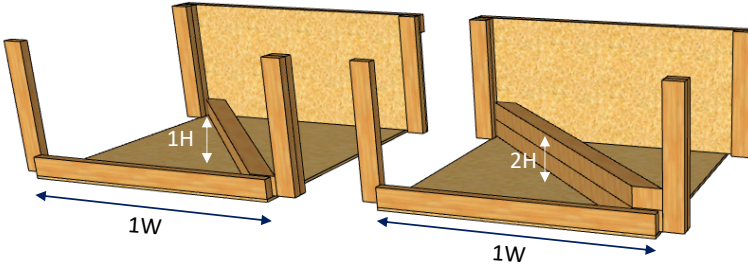
Started as Diagonal Curbs



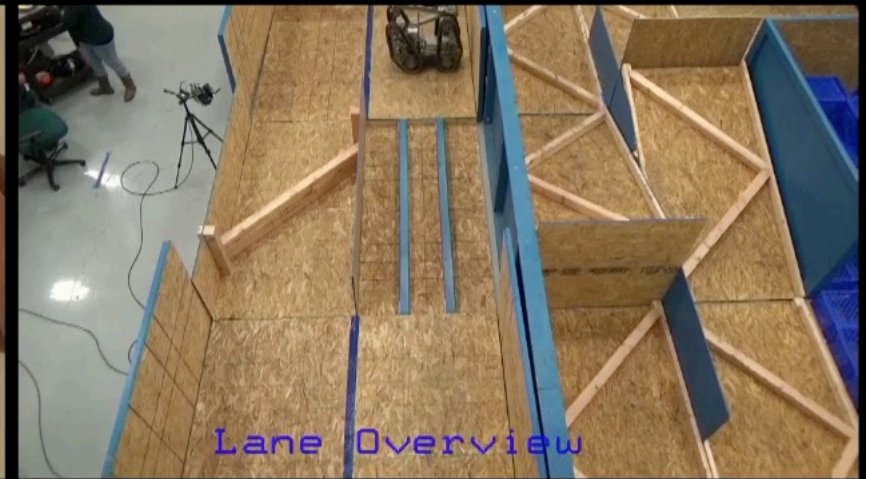
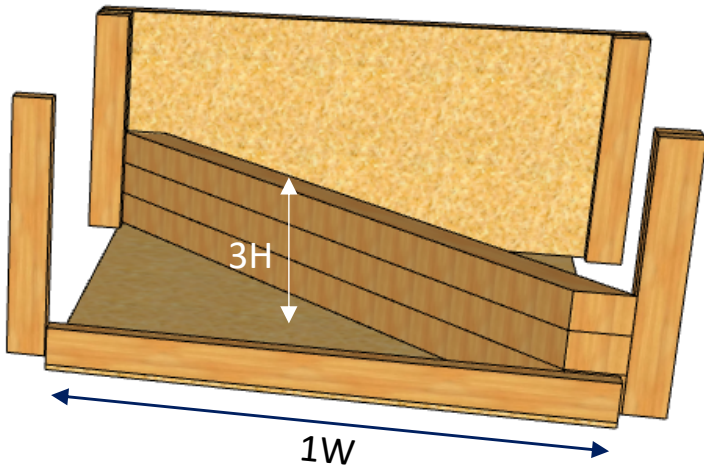
Variable Diagonal Rails Obstacle Tests

1 HIGH

2 HIGH



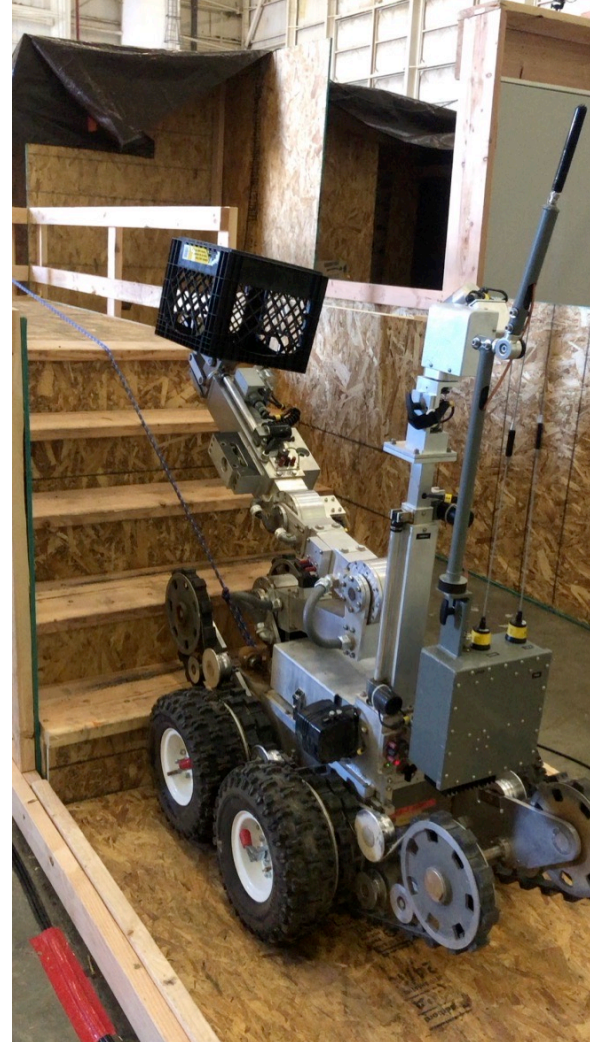
3 HIGH



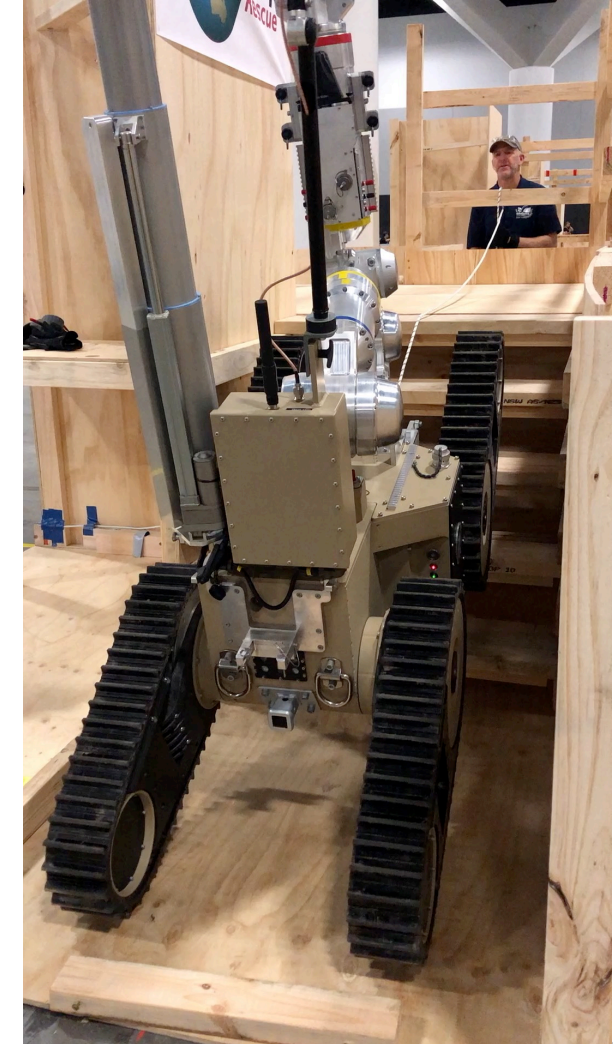
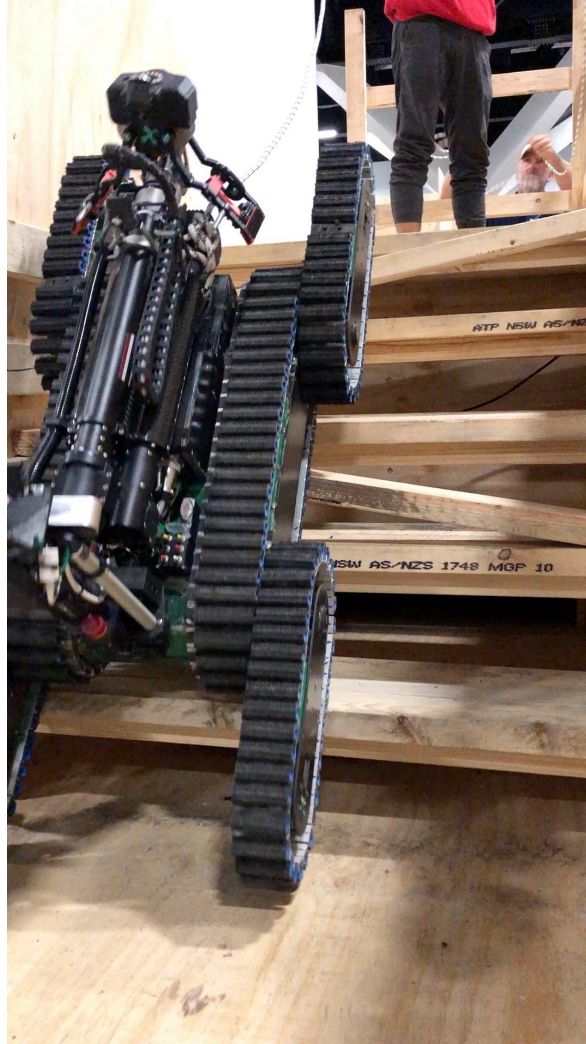
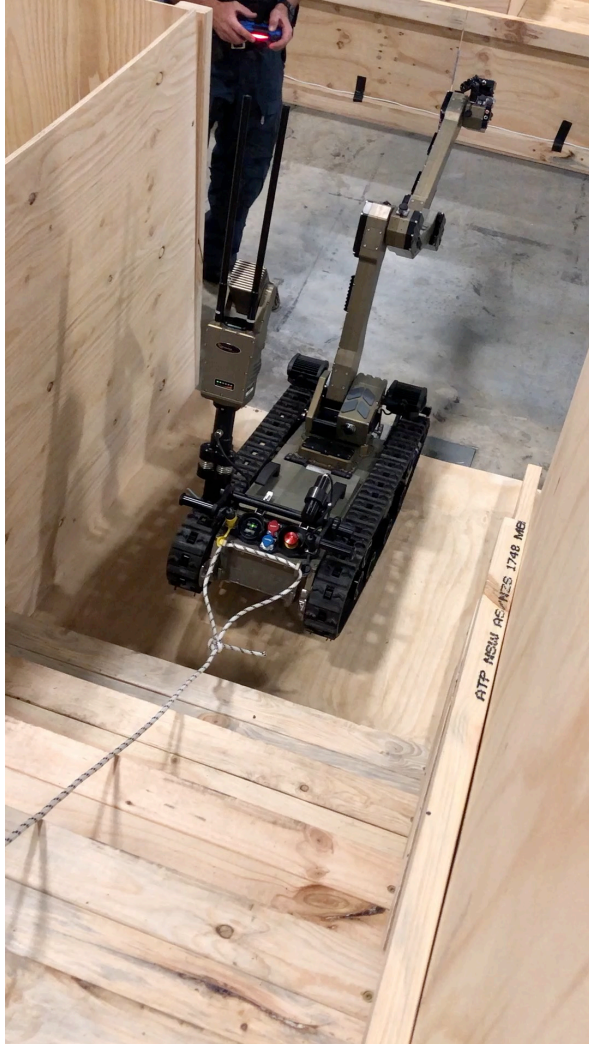
Variable Stairs Obstacle Tests



Variable Stairs Obstacle Tests



Variable Stairs with Debris Option Obstacle Tests



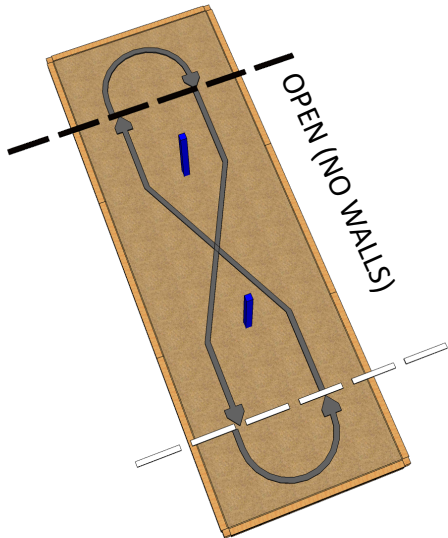
Terrains

Ground Tests

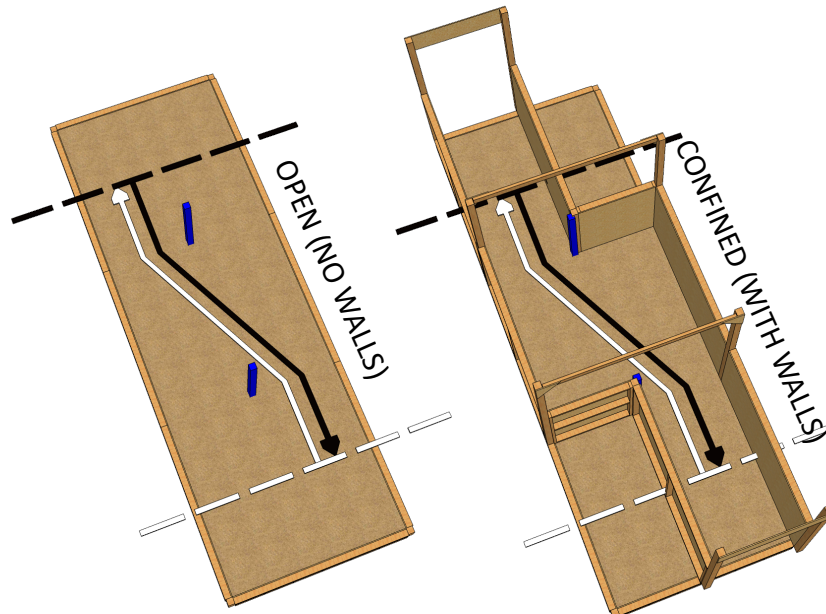
Common Features of Terrain Tests

Terrain Tests

**FIGURE-8 PATH
(CONTINUOUS)**
ALWAYS FORWARD
(2012)



**ZIG-ZAG PATH
(END TO END)**
FORWARD and REVERSE
(2019)



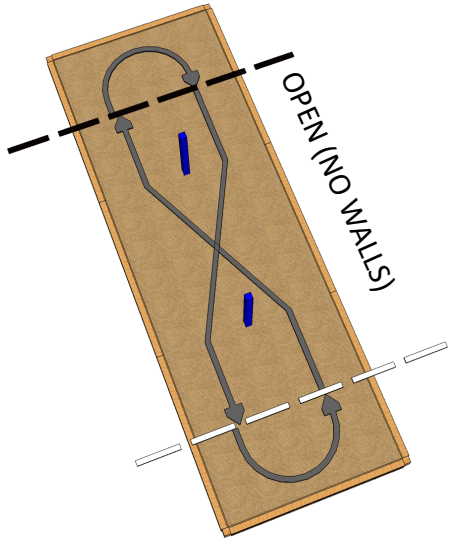
Three different driving paths and levels of difficulty:

- Figure-8 Path (Forward Only)
- Zig-Zag Path (Forward/Reverse)
- **NEW Crossover Slopes Obstacle (Any Orientation)**

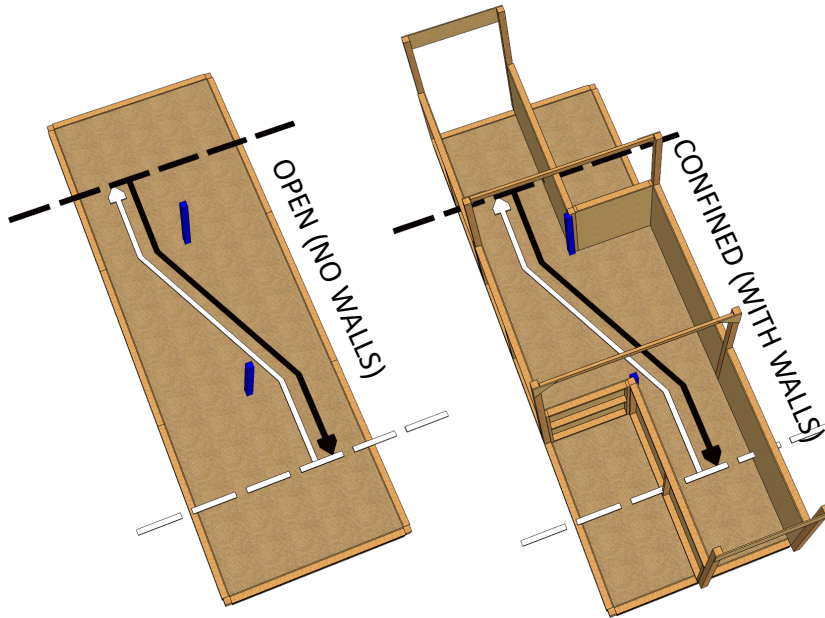
Standards | Prototypes

Terrain Tests

**FIGURE-8 PATH
(CONTINUOUS)**
ALWAYS FORWARD
(2012)



**ZIG-ZAG PATH
(END TO END)**
FORWARD and REVERSE
(2019)



E2826-20 Terrains: Continuous Pitch/Roll Ramps

E2827-20 Terrains: Crossing Pitch/Roll Ramps

E2991-17 Terrains: Gravel

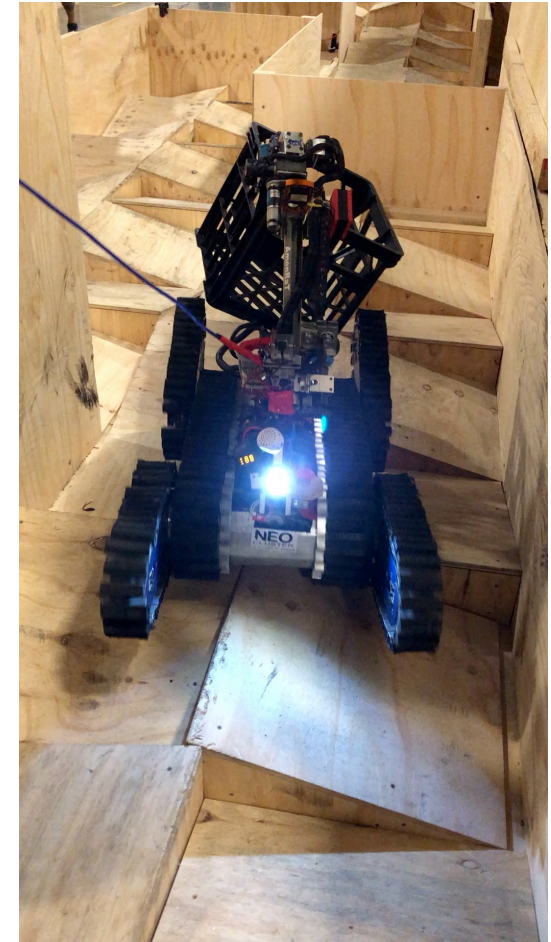
E2992-17 Terrains: Sand

E2828-20 Terrains: Symmetric Stepfields

WK##### Terrains: Reconfigurable Pallets

WK##### Terrains: Reconfigurable Crates

Continuous and Crossing Pitch/Roll Ramps Terrain Tests



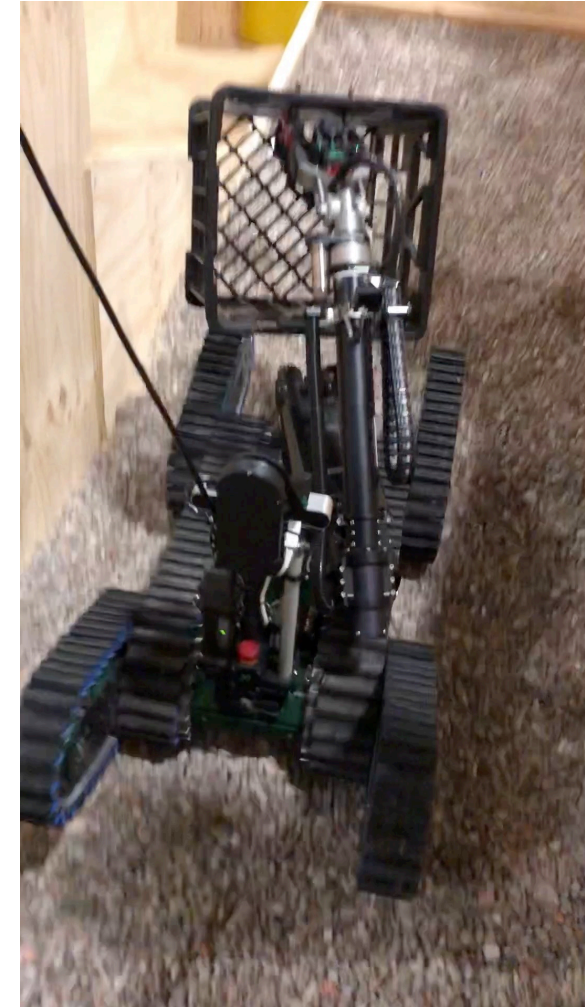
Elevated Crossing Ramps

Terrain Tests

These were too difficult to fabricate and didn't provide the intended challenge.



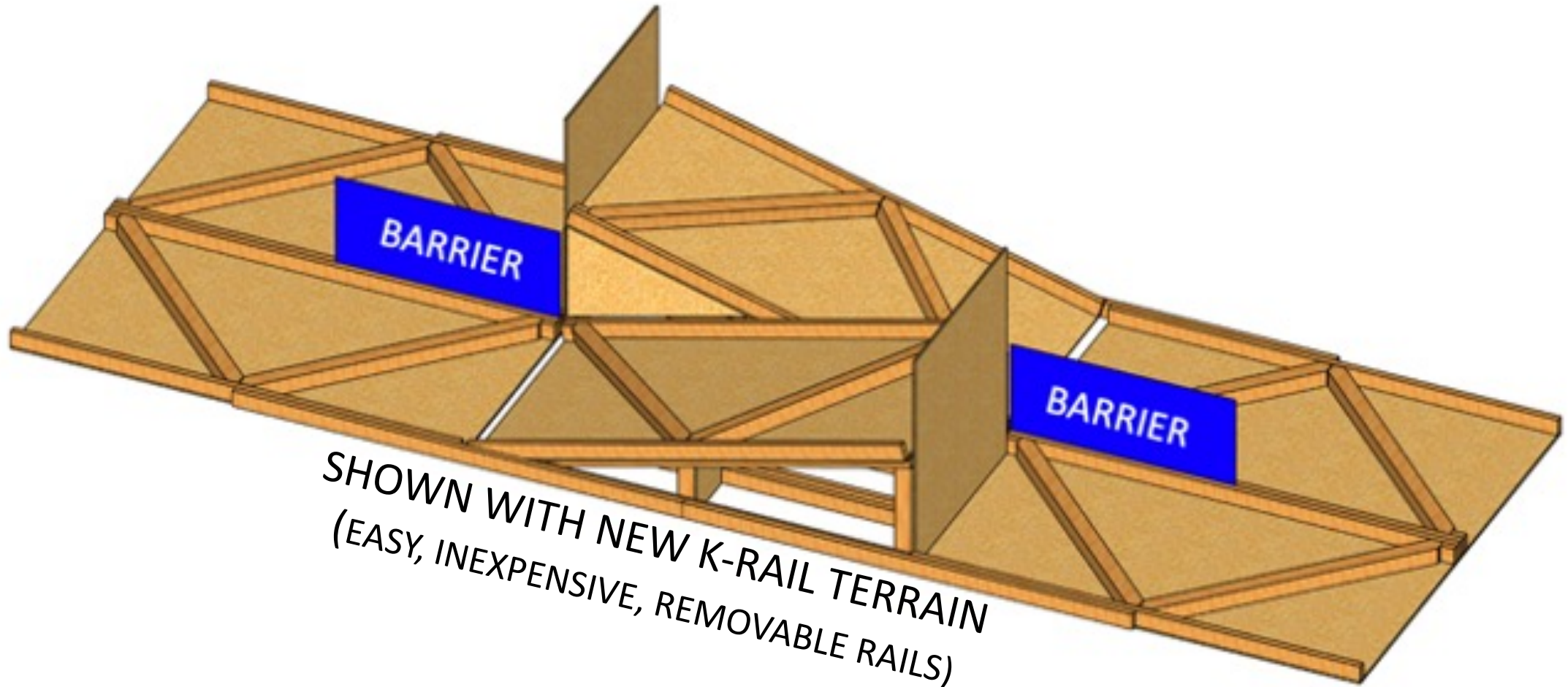
Crossover Slopes (Sand, Gravel, Low Friction, High Friction) Obstacle Tests



New Crossover Slopes Option for Terrains

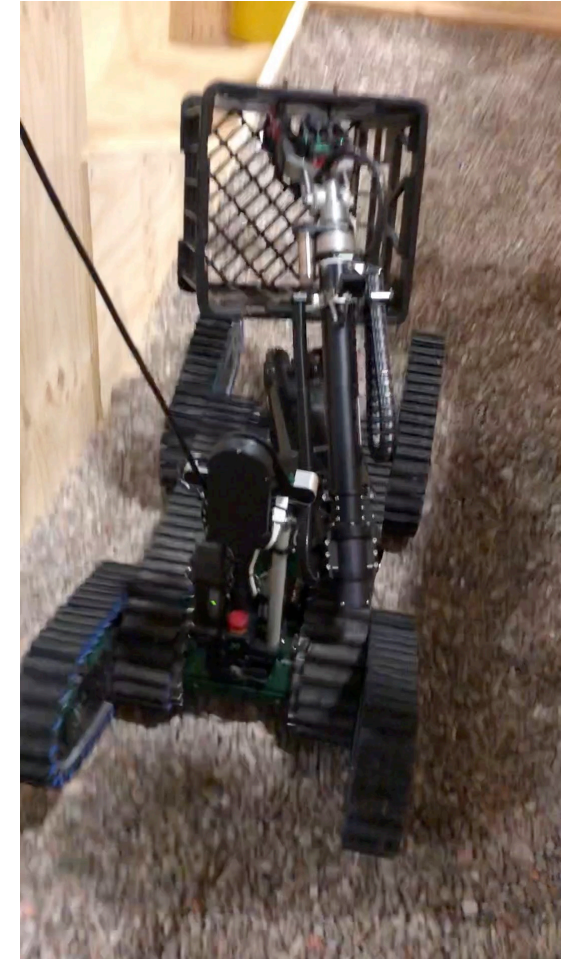
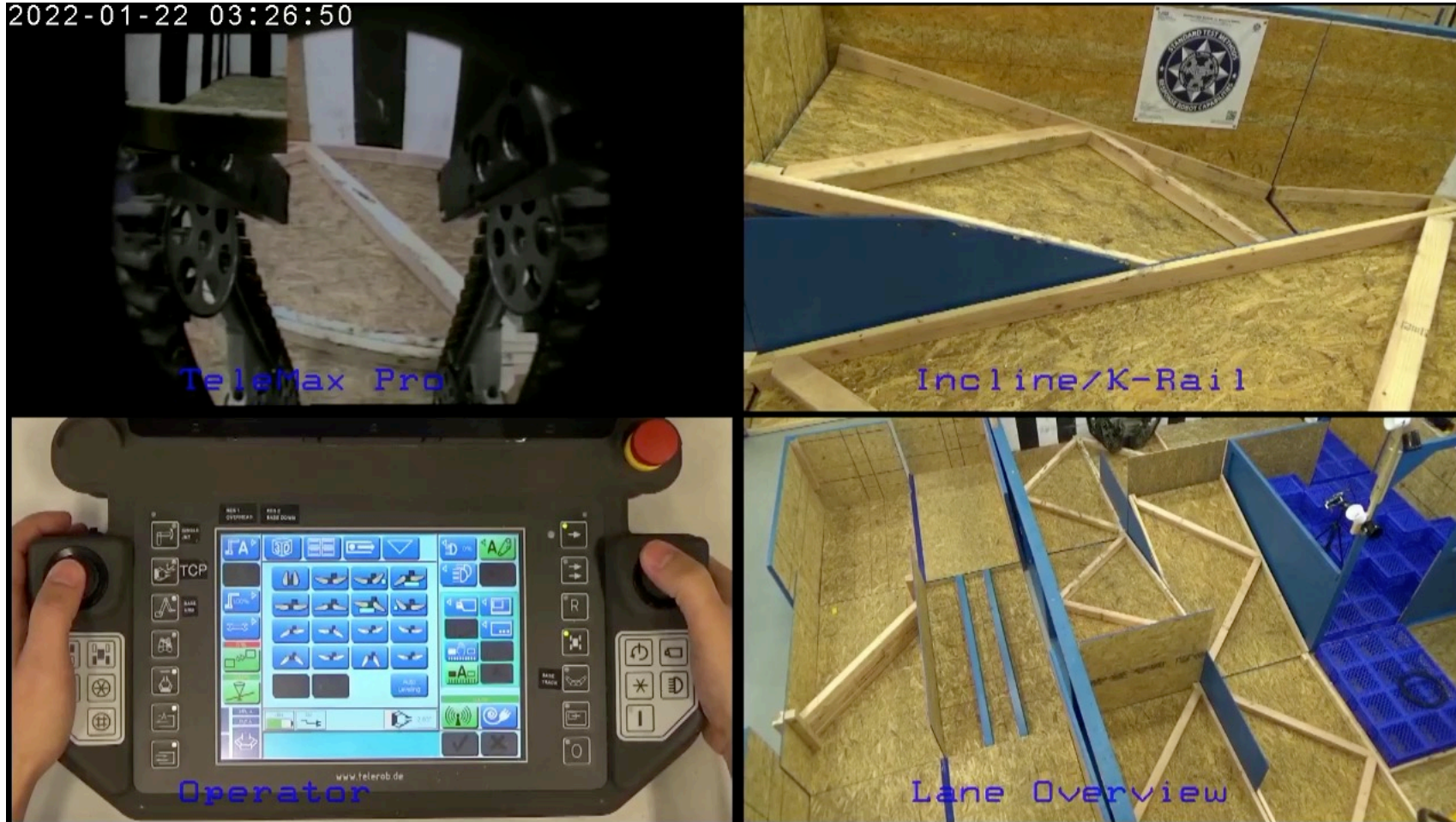
Terrain Tests

38



Crossover Slopes Option for All Terrains

Terrain Tests



Reconfigurable Pallets

Terrain Tests

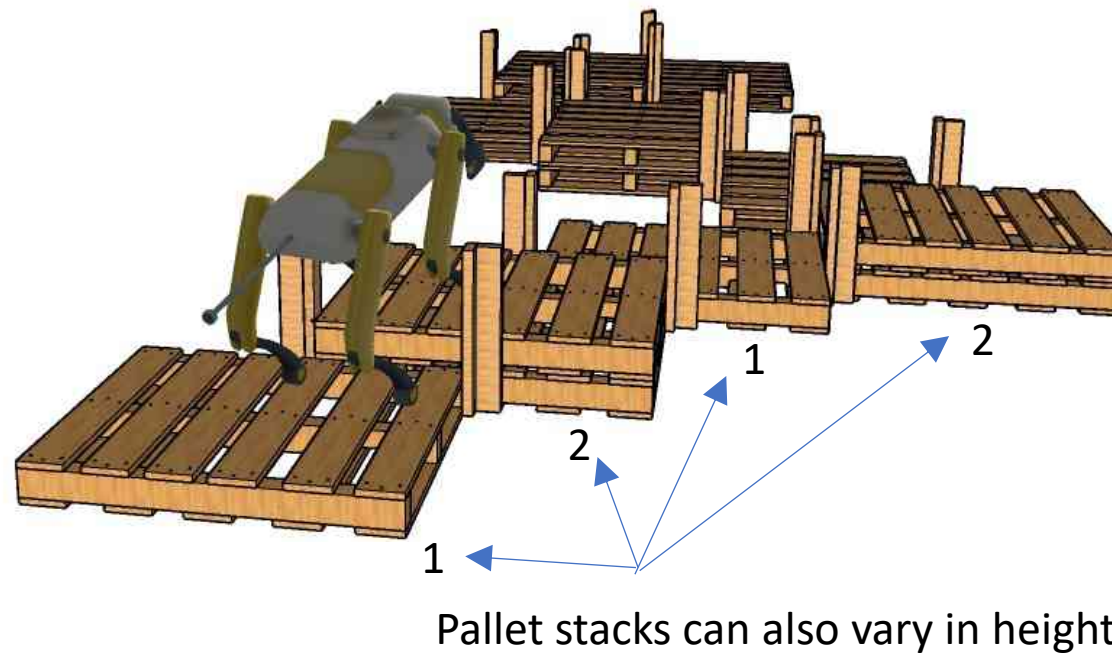
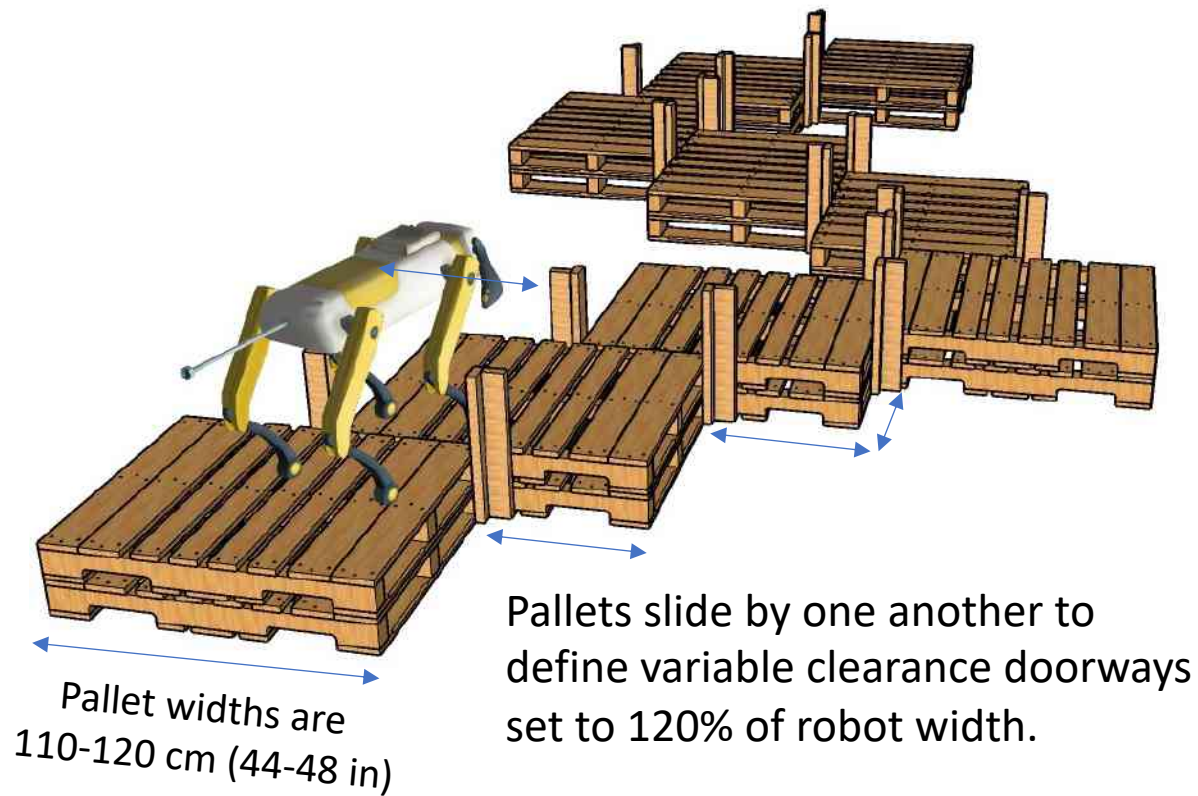
These are especially cheap and easy to source and build.

They provide of different incremental elevations for autonomous robots starting to negotiate terrains.



Reconfigurable Pallets

Terrain Tests

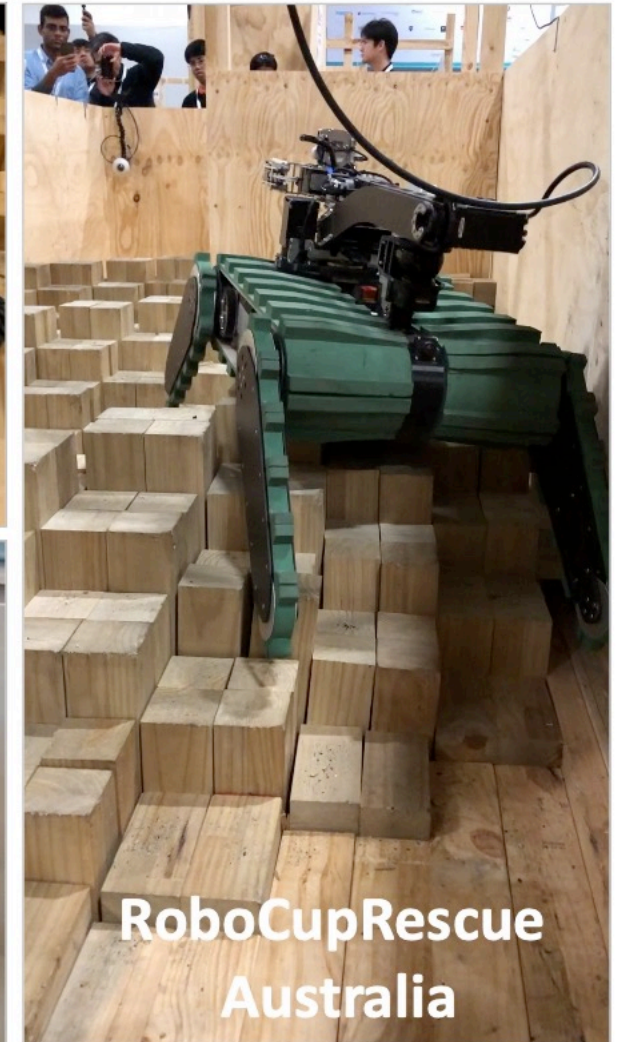


Stepfields Terrain Tests

These are classic, of course!

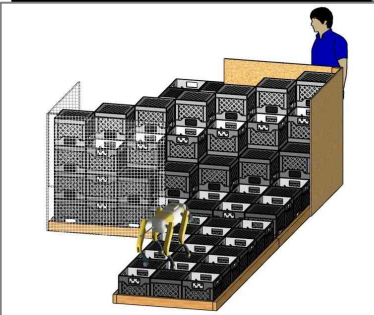
But they are the most expensive test we build, and difficult to fabricate. They were just the first idea in (2003!)

We need a an easier discretized terrain that's more reconfigurable. Especially for legged robots.

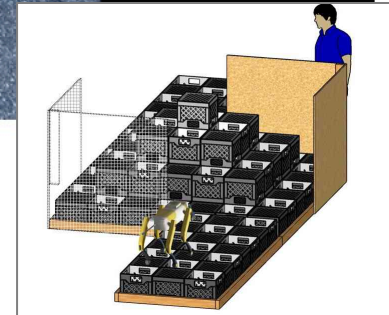
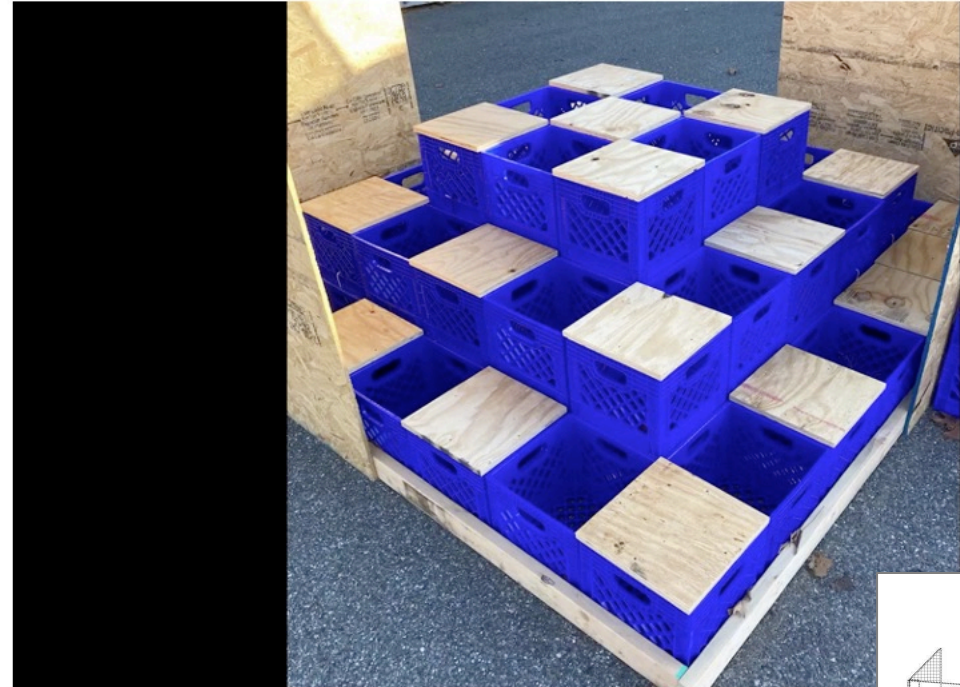


Comparing Emerging Capabilities

DIAGONAL HILL (SOLID or GRATED STEPS)



PYRAMID HILL (CHECKERED STEPS)



Reconfigurable Crates

Terrain Tests



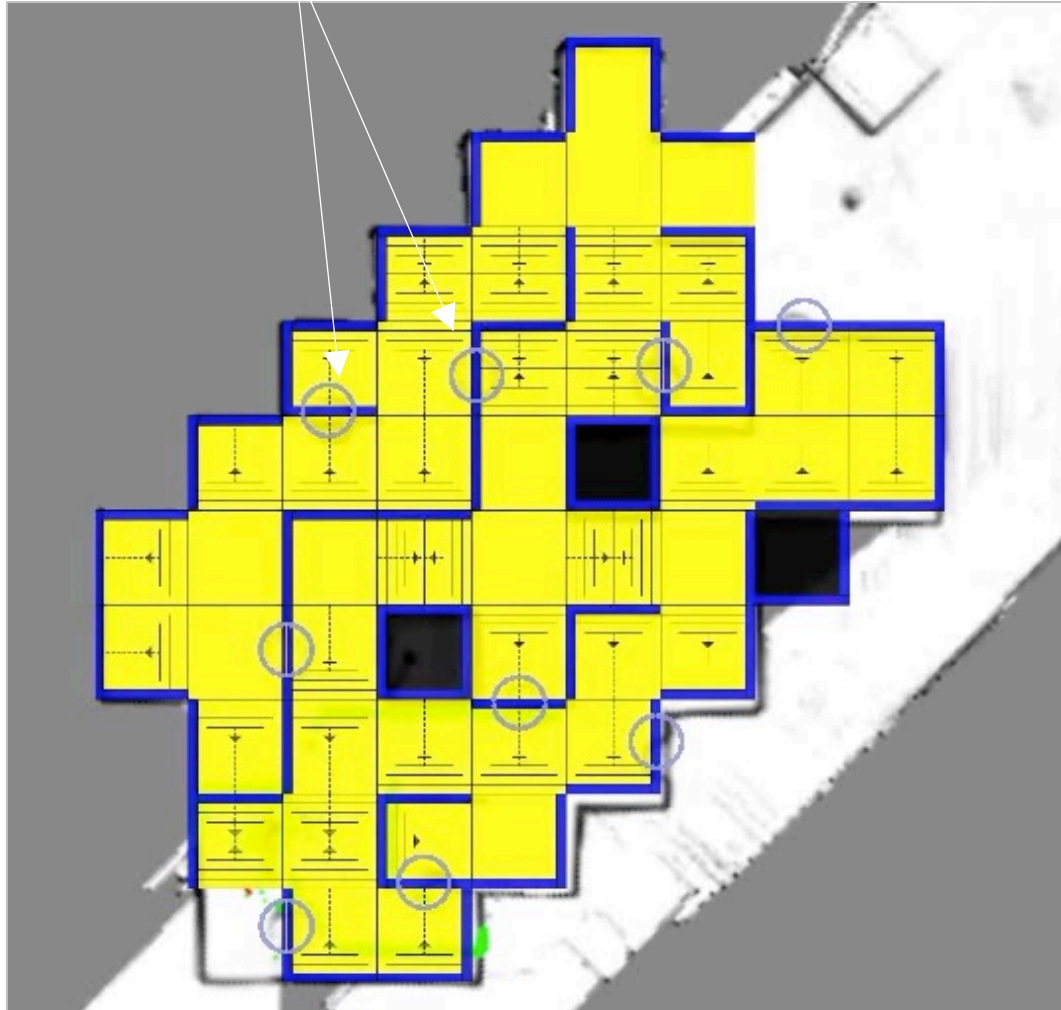
Reconfigurable Crates

Terrain Tests

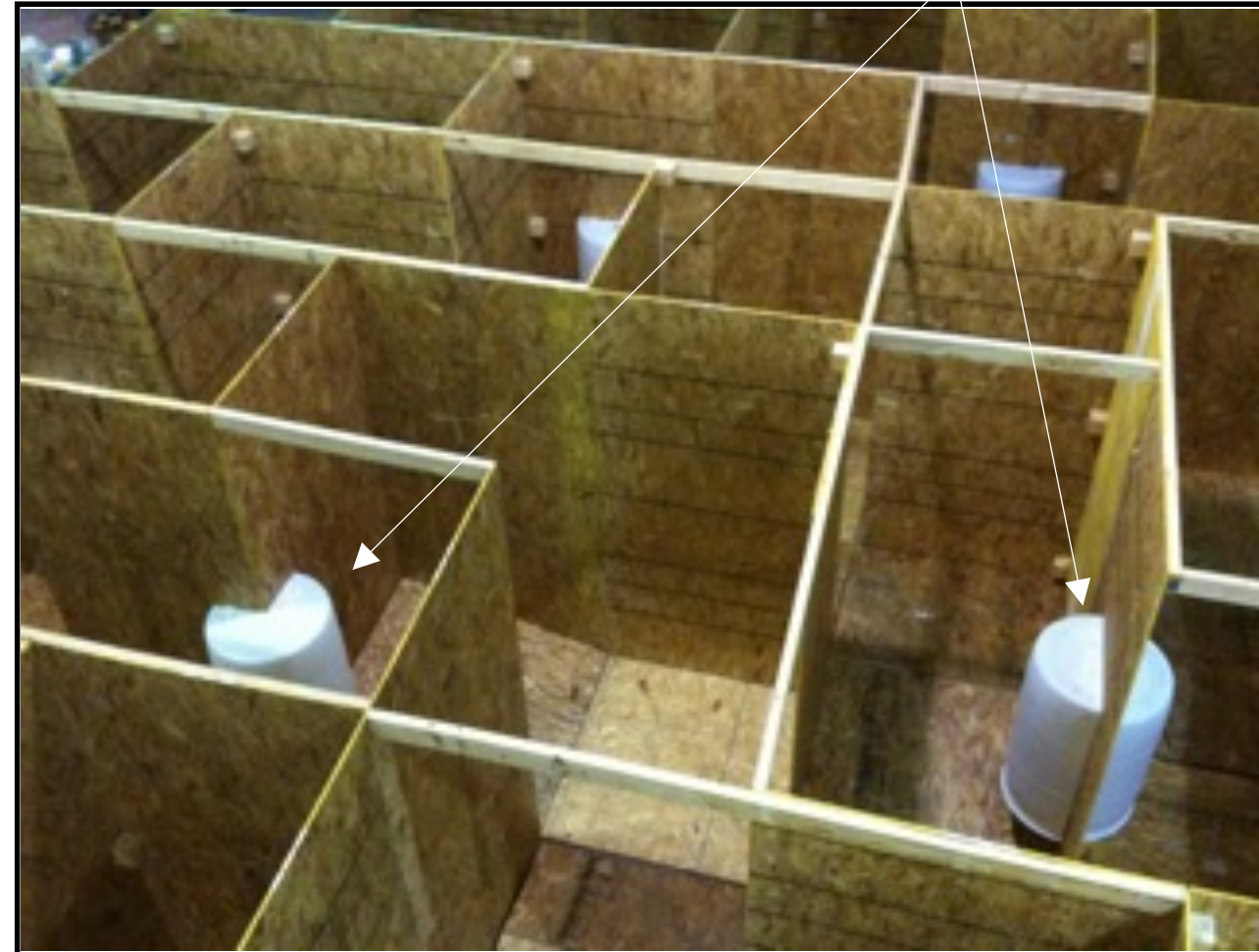


Labyrinth/Maze Navigation Maneuvering Tests

Mapping Fiducials (Half Barrels)



Mapping Fiducials (Half Barrels)



Mission Essential Tasks

C-IED/EOD



Open Doors



Surmount Hurdle



**Ascend/Descend
Stairs**



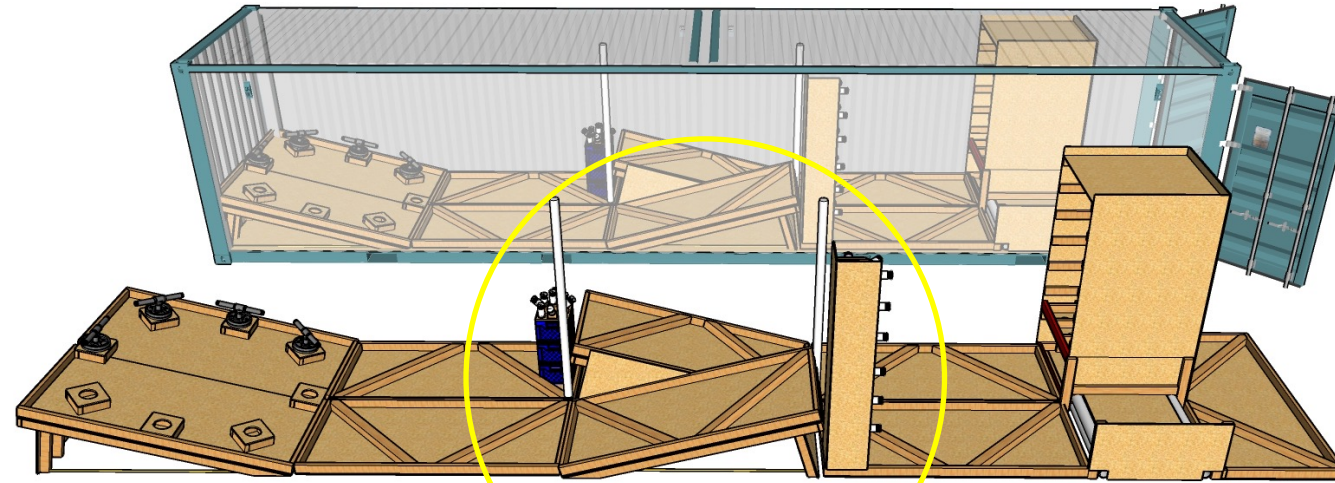
Entangle Obstacles



Negotiate Hallways

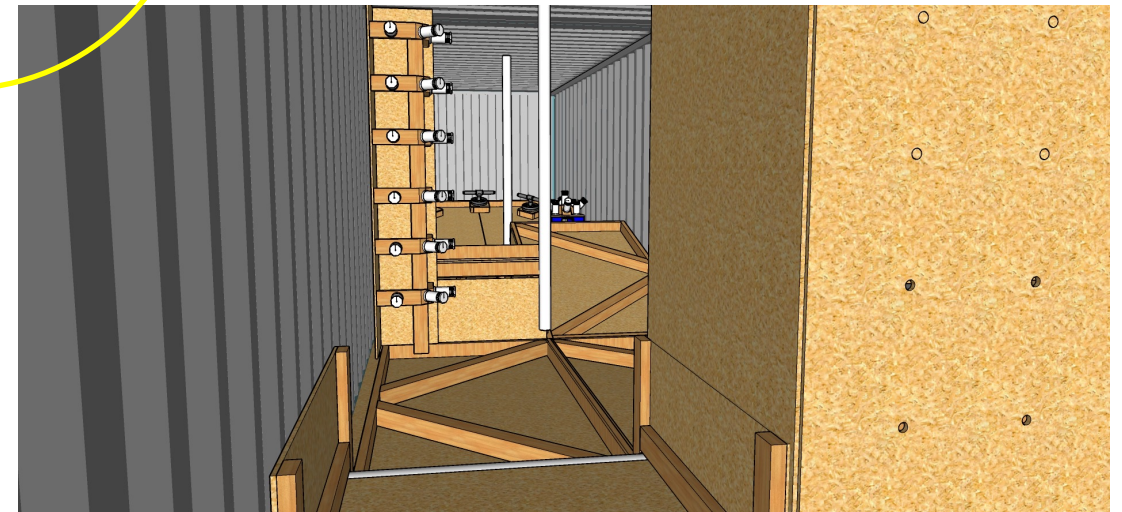
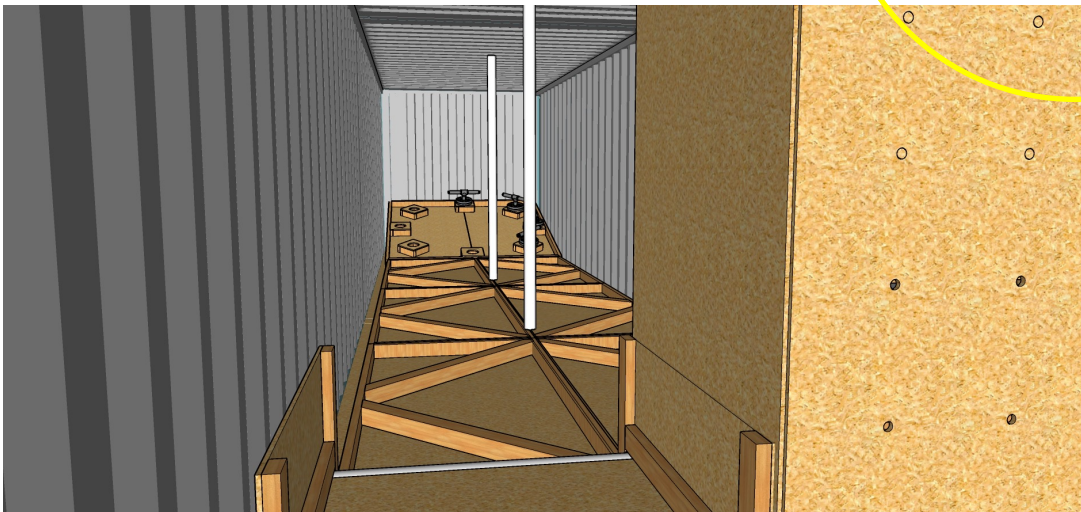
Shipping Container Facilities (Buy or Rent)

Maneuvering and Dexterity



FLAT FIGURE-8

CROSSOVER SLOPES



NEED TO BE UPDATED (2016/2017)

39 Ground Tests

STANDARDS **BALLOTING** PROTOTYPE
20 11 8

Logistics

- E2521-16 Terminology
- E3132-17 System Configuration
- E2592-16 Packaging for Equipment Caches

Sensing

- E2566-17 Visual Acuity
- WK42364 Visual Dynamic Range
- WK54755 Visual Color Acuity
- WK57967 Thermal Image Acuity
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- WK33261 Point and Zoom Cameras
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- WK##### Terrains: Reconfigurable Pallets
- WK##### Terrains: Reconfigurable Crates
- E2803-20 Obstacles: Variable Inclined Planes
- E2801-20 Obstacles: Variable Gaps
- E2802-20 Obstacles: Variable Hurdles
- E2804-20 Obstacles: Variable Stairs/Landings
- E3310-21 Obstacles: Variable Parallel Rails
- E3311-21 Obstacles: Variable Diagonal Rails

Dexterity

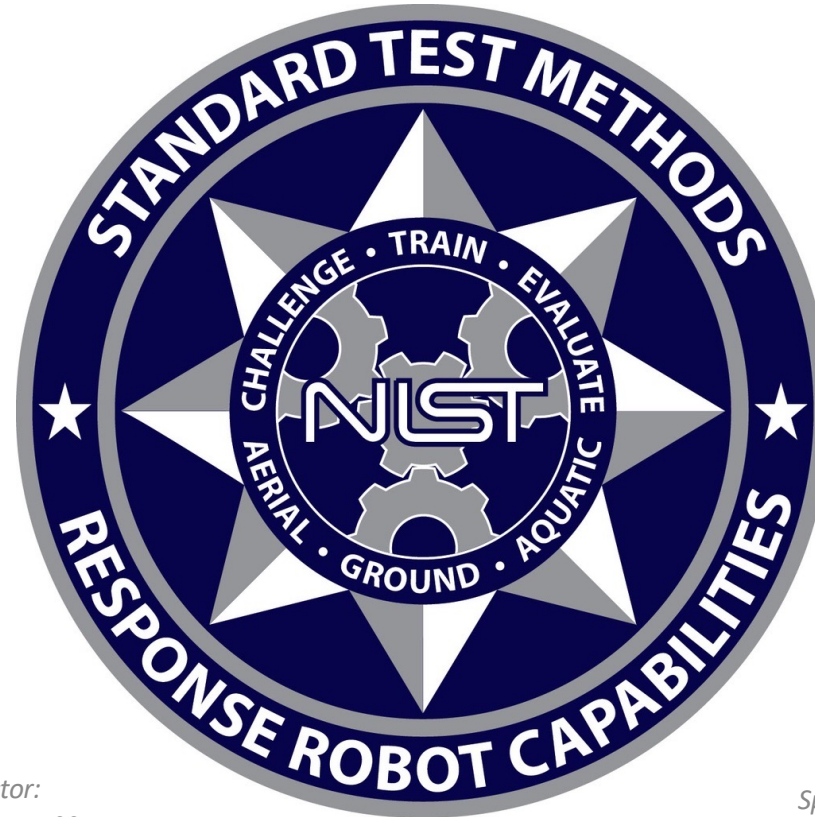
- E2830-20 Tow Grasped Sleds
- WK54271 Inspect
- WK54272 Touch/Insert Tools
- WK54273 Rotate
- WK54274 Extract and Place
- WK54276 Grasp, Carry, and Place
- WK54290 Break/Bore Panels
- WK54278 Cut Straps and Ropes
- WK54287 Inspect Underbody
- WK54289 Inspect Cab Interior

Situational Awareness

- E2853-21 Search Tasks

Energy/Power

- WK55025 Endurance



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