Designation: F3244 – 17

Standard Test Method for Navigation: Defined Area[1]

This standard is issued under the fixed designation F3244; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *Purpose:*

1.1.1 The purpose of this test method is to evaluate an A-unmanned ground vehicle's (A-UGV) capability of traversing through a defined space with limited A-UGV clearance. This test method is intended for use by A-UGV manufacturers, installers, and users. This test method defines a set of generic 2D area shapes representative of user applications and for different A-UGV types.

1.1.2 A-UGVs shall possess a certain set of navigation capabilities appropriate to A-UGV operations such as A-UGV movement between structures that define the vehicle path. A navigation system is the monitoring and controlling functions of the A-UGV, providing frequent A-UGV updates of vehicle movement from one place to another. A-UGV environments often include various constraints to A-UGV mobility. In this test method, apparatuses, procedures, tasks, and metrics are specified that apply constraints and thereby, standard test methods for determining an A-UGV's navigation capabilities are defined.

1.1.3 This test method is scalable to provide a range of dimensions to constrain the A-UGV mobility during task performance.

1.1.4 A-UGVs shall be able to handle many types of open and defined area complexities with appropriate precision and accuracy to perform a particular task.

1.1.5 The required mobility capabilities include preprogrammed or autonomous movement or both from a start point to an end point. Further mobility requirements may include: sustained speeds, vehicle reconfiguration to pass through defined spaces, payload, A-UGV movement within constrained volumes, or other vehicle capabilities, or combinations thereof. This test method is designed such that a candidate A-UGV can be evaluated as to whether or not it meets a set of user application requirements.

1.1.6 *Performing Location*—This test method shall be performed in a location where the apparatus and environmental test conditions can be fully implemented. Environmental conditions are specified and recorded.

1.1.7 Additional test methods within Committee F45 are anticipated to be developed to address additional or advanced mobility capability requirements.

1.2 *Units*—The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversions to inch-pound units. They are close approximate equivalents for the purpose of specifying material dimensions or quantities that are readily available to avoid excessive fabrication costs of test apparatuses while maintaining repeatability and reproducibility of the test method results. These values given in parentheses are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. Safety standards such as ANSI/ITSDF B56.5, BS EN 1525, or other safety standards should be followed. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F3200 Terminology for Driverless Automatic Guided Industrial Vehicles

F3218 Practice for Recording Environmental Effects for Utilization with A-UGV Test Methods

2.2 *ANSI/ITSDF Standard:*[3]

ANSI/ITSDF B56.5 Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles

[1] This test method is under the jurisdiction of ASTM Committee F45 on Driverless Automatic Guided Industrial Vehicles and is the direct responsibility of Subcommittee F45.02 on Docking and Navigation.

Current edition approved July 1, 2017. Published October 2017. DOI: 10.1520/F3244-17.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Industrial Truck Standards Development Foundation (ITSDF), 1750 K St. NW, Suite 460, Washington, DC 20006.

2.3 *BS Standard:*[4]

BS EN 1525 Safety of Industrial Trucks. Driverless Trucks and Their Systems

3. Terminology

3.1 *Definitions*—In Terminology F3200, additional definitions relevant to this test method are given.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *end goal, n*—location at which a task will be completed and is defined by a line perpendicular to vehicle movement.

3.2.2 *goal(s), n*—location(s) the vehicle will pass through as a task is progressed.

3.2.3 *start, n*—location at which the A-UGV will begin the test and is defined by a line perpendicular to vehicle movement.

3.2.4 *task, n*—see Terminology F3200 definition.

3.2.4.1 *Discussion*—For this test method, one task is defined as when the A-UGV moves from the specified start location (Point A) to the goal location (Point B or C), as shown in Figs. 1-7, traversing in a specified direction (forward or reverse). Where possible the A-UGV should return to the start line using autonomous control without operator intervention.

4. Summary of Test Method

4.1 *Area Definition*—This test method consists of traversing multiple repetitions of a single task within a specified navigation area defined by physical barriers, virtual barriers, or floor markings, or combinations thereof. Further details are given in Section 6. Figs. 1-7 show possible defined area navigation constraints and references to locations within the apparatus (A, B, and C) and start and goal lines. Using these shapes, the test method can be used to determine an A-UGV's capability at traversing through an area of specified dimensions. The test method could also be used to determine the minimum space in which the A-UGV is able to traverse.

4.2 *Navigation Test Method:*

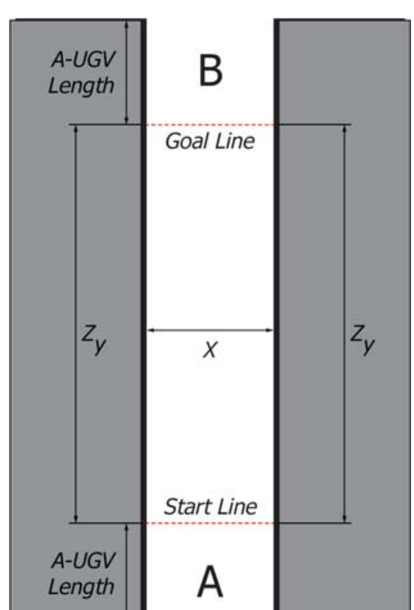
4.2.1 The A-UGV shall drive through the apparatus (examples are shown in Fig. 9 and Fig. 10). The completion of one of the repetitions is when the A-UGV traverses from the specified start location (A) across an end goal line (B or C). The A-UGV shall not make contact with any barrier (unless with only a contact-sensing device that is used to navigate) nor deviate from the defined area during a task. If the A-UGV makes contact with any barrier or crosses a virtual barrier during a repetition, the result is a test failure. The test requestor has the authority to select defined path width(s) (x or y, or both, in Figs. 1-7) for the test event. The defined path width may be altered by the test requestor prior to a test with the aim of identifying the minimum space that can be traversed by the A-UGV, if desired.

4.2.2 A task is successfully completed when the entire A-UGV crosses the specified start line at the start location (A), traverses within the defined area, and crosses the specified goal line at the end goal (B or C) without crossing or impacting the physical barriers, virtual barriers, or floor markers.

4.2.3 The A-UGV's navigation capability is defined by its ability to repeatedly travel through a defined area from start to end goal. The test does not require a specific route to be followed by the A-UGV. The route definition is not part of the standard test, nor the line that may be followed, to a certain repeatability. The test is set out to identify the area required for A-UGV movement.

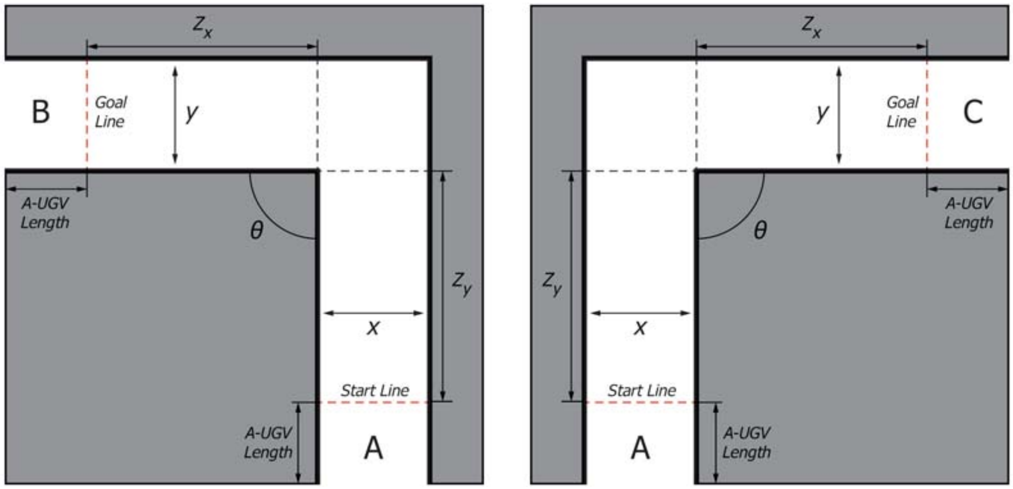
4.2.4 The test supervisor will inform the test requestor of the number of task repetitions to be made, corresponding to the statistical reliability and confidence levels shown in Table 1.

[4] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.



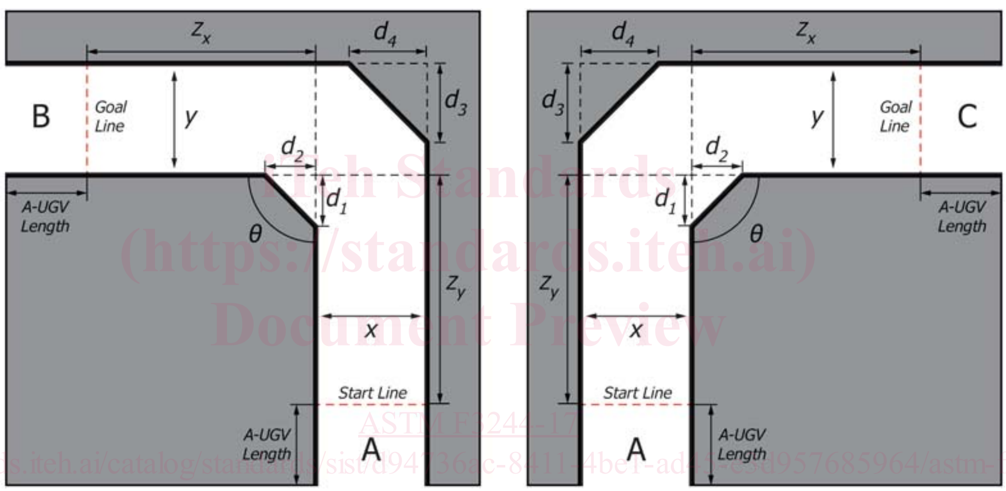
NOTE 1—The thick black lines indicate the physical barriers or lines along which virtual barriers or floor markings are set.

FIG. 1 Diagram of Test Method for Navigation through a Straight Aisle



NOTE 1—The thick black lines indicate the physical barriers or lines along which virtual barriers or floor markings are set.

FIG. 2 Diagrams of Test Method for Navigation through a Single Intersection with No Chamfers, Showing Both Possible A-UGV Turn Directions



NOTE 1—The thick black lines indicate the physical barriers or lines along which virtual barriers or floor markings are set.

FIG. 3 Diagrams of Test Method for Navigation through a Single Intersection, Showing Interior Chamfer Defined by d_1 and d_2 and Exterior Chamfer Defined by d_3 and d_4, Showing Both Possible A-UGV Turn Directions

4.2.5 The test supervisor is responsible for setting up the apparatus and instrumentation, directing the test, and reporting results of the test to the test requestor.

4.2.6 The test supervisor will be responsible for directing the test technician and the A-UGV operator.

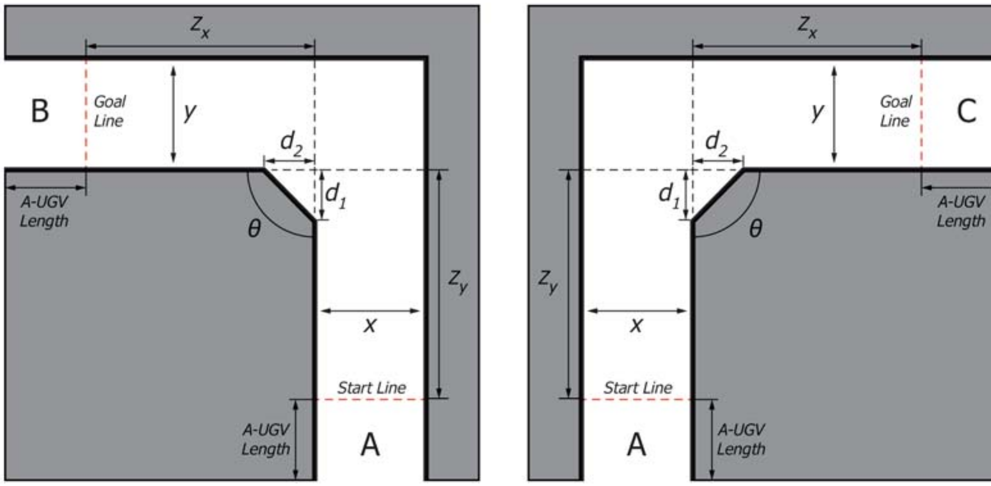
4.3 *Metrics*—Derived from Figs. 1-7. All measurements shown in the figures related to a 2D space with a flat, horizontal floor. Measurements between boundaries are perpendicular to the boundary being measured.

4.3.1 *Straight Aisle Width (*Fig. 1*)*—The value, *x*, is the distance between boundaries representing the area needed by the A-UGV to traverse through a straight aisle.

4.3.2 *Intersecting Aisles Widths (Single and Dual,* Figs. 2-7*)*—The same discussion of aisle width described in 4.3.1 applies here. However, there are two measured widths to be determined: the initial aisle width, *x*, and the final aisle width, *y*. The combination of these metrics describes the dimensions of traversable 2D space by an A-UGV through an intersection of θ degrees. The default value of θ is 90° for a perpendicular intersection, but angles other than 90° may be selected by the test requestor.

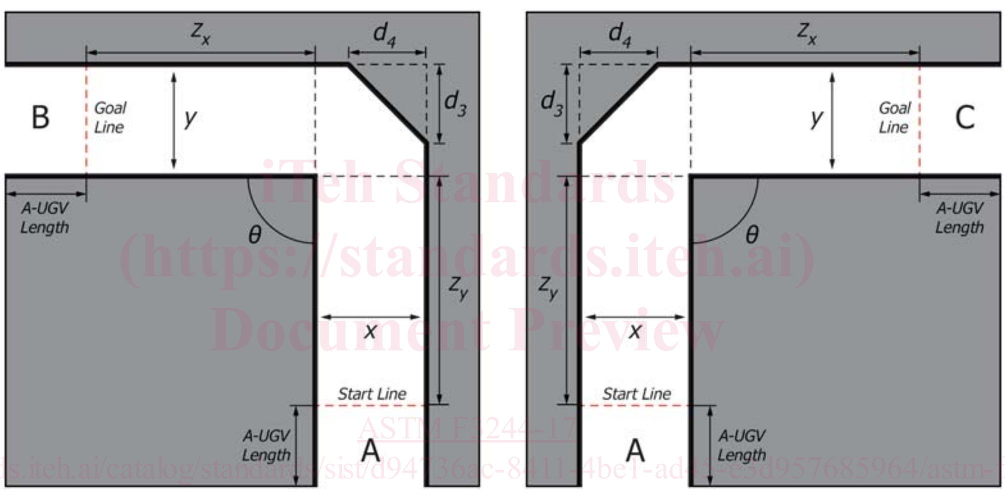
4.3.3 *Chamfered Corners*—These enable the test requestor to further specify the shape of the corners of an area. Chamfers are defined by setback distances for the interior chamfer (d_1 and d_2) see Fig. 4 and the exterior chamfer (d_3 and d_4), see Fig. 5. The setback distance is that distance between the virtual corner and the start of the chamfer identifying the interior space. The interior chamfer enables the width of the aisle intersection to be increased from that identified in the single intersection (see Fig. 4) or dual intersection (see Fig. 7). The exterior chamfer enables the width of the aisle intersection to be decreased from that identified in the single intersection (see Fig. 5). Both interior and exterior chamfers can be used in the single intersection (see Fig. 3).

4.3.4 *Completion Time*—The start time of a task is considered the moment the entire body of the A-UGV crosses the start



NOTE 1—The thick black lines indicate the physical barriers or lines along which virtual barriers or floor markings are set.

FIG. 4 Diagrams of Test Method for Navigation through a Single Intersection with Interior Chamfer Only, Defined by d_1 and d_2, Showing Both Possible A-UGV Turn Directions



NOTE 1—The thick black lines indicate the physical barriers or lines along which virtual barriers or floor markings are set.

FIG. 5 Diagram of Test Method for Navigation through a Single Intersection with Exterior Chamfer Only, Defined by d_3 and d_4, Showing Both Possible A-UGV Turn Directions

line, exiting the start location (A). The end time of a task is considered the moment the entire body of the A-UGV crosses the goal line entering the end goal location (B or C) (see Figs. 1-7). Task completion time is recorded to an accuracy of 1 s for each repetition, and test completion time is recorded as an average of all completed task repetitions.

4.3.5 *Path Length*—The path length is defined for its use in the calculation of the Average Traversal Speed. It is the measurement of a path down the center of the defined area. Curved traversal distances are not measured.

4.3.5.1 For the Straight Aisle, Path Length is z_y (see Fig. 1).

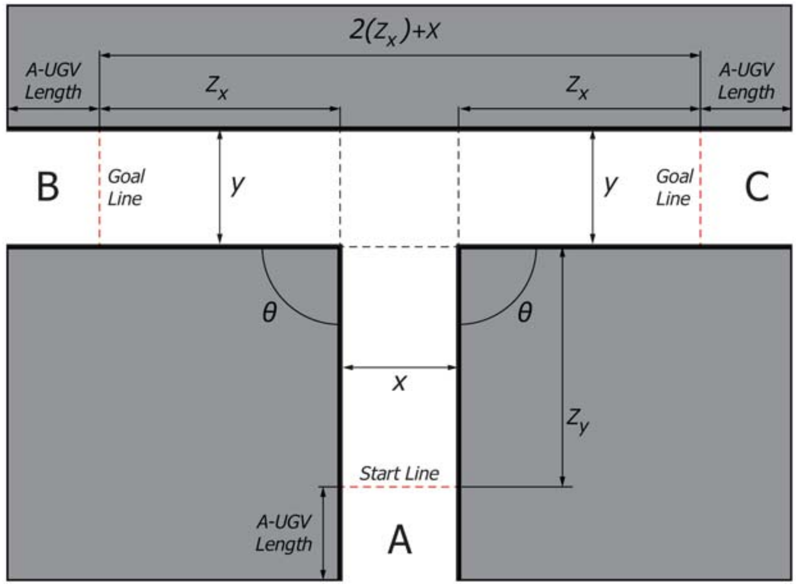
4.3.5.2 For the Intersecting Aisles where θ is 90°, Path Length is $(z_y - y/2) + (z_x - x/2)$ (see Figs. 2-7). For intersecting aisles where θ is not 90°, a similar calculation using the defined area's center line should be made.

4.3.6 *Traversal Speed*—The speed, measured in meters per second, determined by dividing the Path Length by the completion time for a single repetition. Average Traversal Speed is calculated by dividing the Path Length by the Average Time, where average time is the Total Duration for n repetitions, divided by n.

4.3.7 *A-UGV Aisle Heading/Direction*—In straight aisles, the A-UGV may be commanded to use a particular heading moving forward or in reverse. The heading and direction that is used by the A-UGV will be recorded for each test.

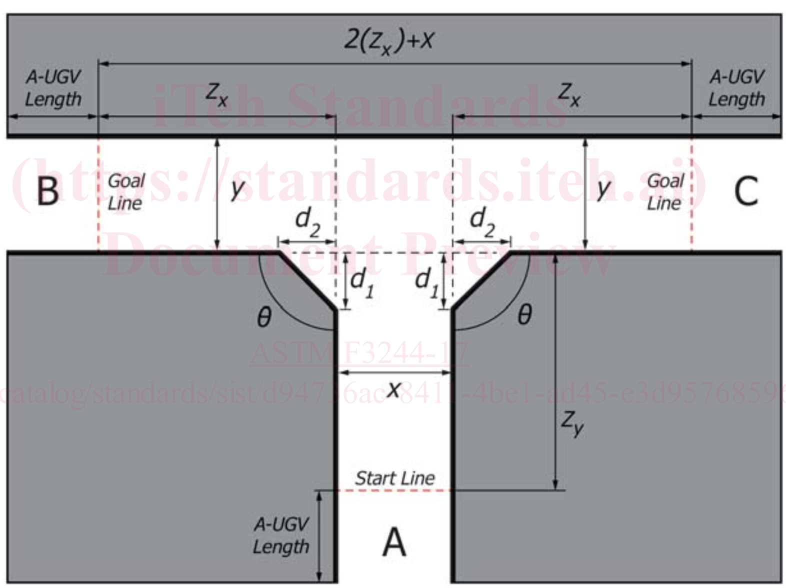
4.3.8 *A-UGV Turn Direction*—In turning between intersecting aisles (see Figs. 2-7), the A-UGV can be commanded to traverse between the start line (A) and either of the two possible goal lines (B or C), each of which result in a different route. The test requestor can test both routes with both vehicle orientations to determine the symmetry of A-UGV operation, which would encompass two separate tests.

4.3.9 *Test Flexibility*—Under some circumstances, a test requestor may request a test be carried out using the intersection shape described in 4.3.2 but with different intersection angle at a value other than 90°. Such a test is allowed when requested by the test requestor prior to beginning a test,



NOTE 1—The thick black lines indicate the physical barriers or lines along which virtual barriers or floor markings are set.

FIG. 6 Diagram of Test Method for Navigation through a Dual Intersection with No Chamfers



NOTE 1—The thick black lines indicate the physical barriers or lines along which virtual barriers or floor markings are set.

FIG. 7 Diagram of Test Method for Navigation through a Dual Intersection with Interior Chamfers Defined by d_1 and d_2

although with the provision that the area definition and test completion follow the methods set out in 4.3.

4.3.10 *Multiple Areas*—The tests described in this test method anticipate only a single area route will be chosen for the test. Future standard test methods may be developed that combine multiple areas or apparatuses to define more complex areas and routes.

5. Significance and Use

5.1 A-UGVs operate in a wide range of applications such as manufacturing facilities and warehouses. Fig. 8 shows three example A-UGV types and test apparatus sizes to test A-UGVs intended for different vehicle tasks, types, sizes, and capabilities. Such sites can have both defined and undefined areas that are structured and unstructured. The testing results of the candidate A-UGV shall describe, in a statistically significant way, the ability of the A-UGV to traverse the commanded path. Whether or not an A-UGV is able to deviate from its path, or uses features of the local environment as input to its navigation method or both, should not result in a different test method. Rather, the capabilities of the A-UGV to adapt its navigation method in a given environment will be objectively determined by its performance in the test method.

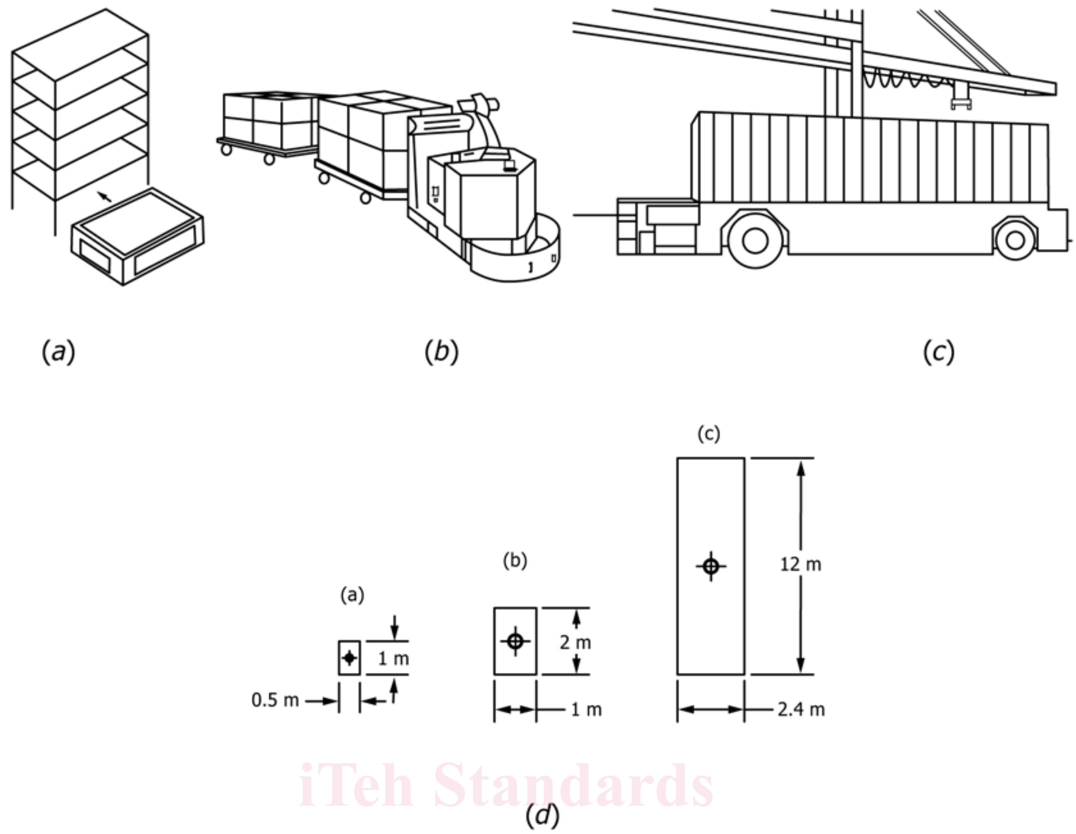


FIG. 8 Example A-UGV Size Variability (a) Low Profile, (b) Industrial Tug, (c) Container A-UGV, and (d) Size Variability Values

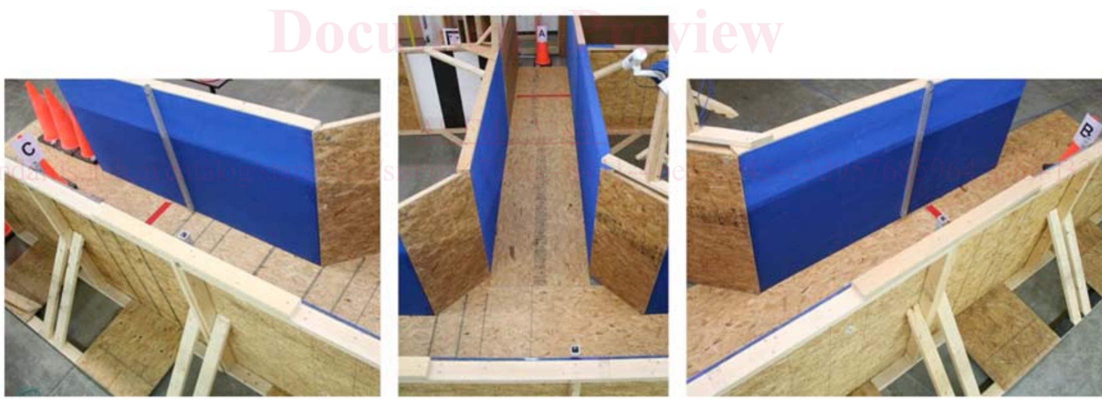


FIG. 9 Example: Dual Intersection with Interior Chamfers Apparatus with Physical Barriers

5.2 Three different manners in which a test method can be rendered are specified for use: physical boundaries, virtual boundaries, and floor markings (see Section 6 for apparatus specifics). The test method(s) chosen shall be appropriate to the application and environment in which the A-UGV will be used.

5.3 These test methods address A-UGV performance requirements expressed by A-UGV manufacturers and potential A-UGV users. The performance data captured by these test methods are indicative of the capabilities of the A-UGV and the application represented by the test.

5.4 The test apparatuses are scalable to constrain A-UGV sizes in defined areas to meet current and advanced next generation manufacturing and distribution facility operations.

5.5 The standard apparatuses are specified to be easily fabricated to facilitate self-evaluation by A-UGV developers and users and provide practice tasks for A-UGV developers, users, and potential users that exercise A-UGV actuators, sensors, and controls.

5.6 Although the test methods were developed first for A-UGVs, they may also be applicable to mobile manipulators and other types of industrial automated mobility equipment, as well as in other domains.

6. Apparatus

NOTE 1—Boundaries for the test methods can be created physically, by virtual lines, or with floor markers.