# Grasping and Manipulation Competition: Manufacturing Track - Task Rules

## Background

We are entering a new manufacturing era where more and more small and medium sized enterprises (SMEs) are looking to implement robotic solutions into their production operations. SMEs represent the majority of manufacturers worldwide and they most often produce in batches with product variation from batch to batch, often called high-mix, low-volume production. To support production in such an environment where robot expertise is often limited, and cost is always a factor, robot systems must be easy to deploy and reconfigure with minimal retooling.

Assembly is one of the most difficult operations for robots, often relying on specialized tooling or jigs to ensure that a part can be positioned by a robot within the required assembly tolerances. These positioning tolerance requirements can also lead to time consuming robot programming strategies to precisely align a part for assembly. This competition challenges teams to develop robot systems that are easy to deploy and program with the goal of handling small batch assembly operations with part variations between batches. The robot systems will also be tested on their ability to assemble and disassemble parts.

Teams will compete with the goal of assembling and disassembling a manufacturing based task board containing a variety of insertion, meshing, screwing, and deformable material routing operations using an autonomous robot system. Less time spent fixturing and programming the system for operation will inevitably lead to more components being assembled and disassembled in the allotted time and possibly time bonus points upon full completion of the process. The main system components expected to achieve a truly autonomous system include one or more of the following: vision sensors, force sensors, robots, robot hands, flexible gripper systems and hand tools as well as the use of part and assembly CAD data.

Teams should design and test the operation of their systems prior to the competition using the practice task board provided. While we will attempt to ship practice boards to all registered teams, if you wish to purchase the components to build your own task boards, all details are listed on the website.

A new task board and parts to be assembled and disassembled will be distributed for final competition runs where part locations on the task boards and kit layout are different from the practice set. Most of the parts to be assembled/disassembled remain the same as the practice board but some parts may be replaced with similar but new “suprise” parts. The location of the task components will be randomized as described in the Setup section below. In addition, CAD data for the task board and kit layout in the same format provided with the practice materials will be supplied at competition start time. During the competition, the task boards must first be assembled and then disassembled by the competing robot systems per the following rules.

The manufacturing track is composed of two sub-tasks: assembly and disassembly. The assembly subtask 1 starts with an empty task board composed of four separate quadrants, where components are presented in kit form and assembled onto each of the four quadrants of the task board. The disassembly subtask 2 starts with a fully assembled task board where components are removed from each quadrant of the task board and placed in a kit. Team rankings will be determined by the results of these two sub-tasks. The task board presented with these rules closely resembles the practice and competition task boards. Figure 1 shows the practice board for which designs are distributed to teams several months before the competition.

The latest change to the rules, separates the tasks into four quadrants to test teams on their robot system’s ability in each quadrant separately: threading, insertion, belt drive, and cable. Teams should research improvements in all four sections to guarantee expertise in all quadrants. An award for “best-in-class” will be awarded to the best team that is able to complete a quadrant in full.

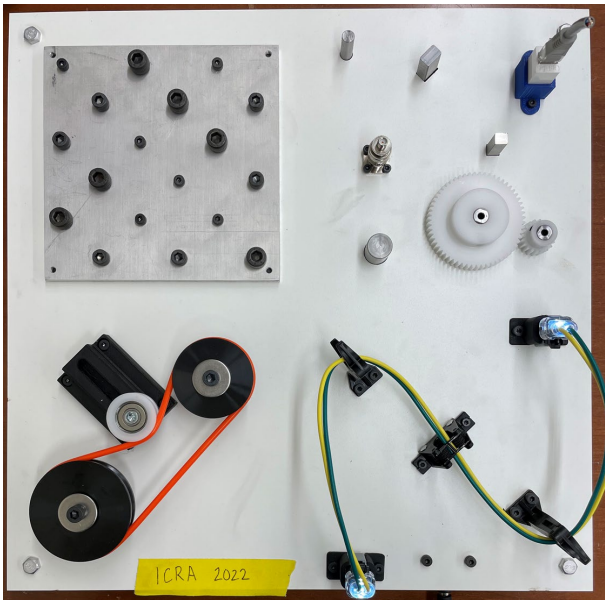

Figure 1: Fully assembled task board with quadrants.

Four task board quadrants (See Figure 1):

1. Threading
    a. Standard Socket Cap Screws (possible sizes M4, M8, M12, M16) to be threaded into an aluminum plate, nuts (possible sizes M4, M8, M12, M16) to be threaded onto bolts protruding from the board, and a possible alignment task.
2. Insertion
    a. Includes Metric pegs of various diameters and cross-sectional shapes, various male electrical connectors, and gear insertions
3. Belt Drive tensioning
    a. Track a flexible round belt on to a belt drive assembly and actuate a tensioner.
4. Cable routing
    a. Place and track wires along a specified path, through obstacles to create a wire harness

Components provided for practice board:

a. Practice task board with all parts for assembly/disassembly
b. Kit mat showing pre-determined start locations for parts
c. Computer Aided Design (CAD) data and .STL files for all parts, the task board, and the kit mat
d. *Optional use* fixtures (CAD files) for wire harness and screws

Components provided for competition board on the day of competition:

a. Competition task board with any new or replaced parts for assembly/disassembly
    i. Teams are expected to already have most of the parts from their practice board but parts may be replaced as needed
b. New kit mat showing pre-determined start locations for parts
c. Computer Aided Design (CAD) data and .STL files for all parts, the task board, and the kit mat
d. Kit tray for placing removed parts
e. Tape and velcro for marking the work area and stabilizing the board position and orientation

**Task Description:**

- Subtask 1: Board Assembly
- Subtask 2: Board Disassembly

*Setup*

Prior to the start of the competition, teams must define the planar workspace of their robot system on the table surface. Teams will be given a roll of black electrical tape to mark this work area that must be at minimum dimensions of 60 cm x 100 cm. Approximate locations for the task board, kit tray and kit mat are shown in Figure 2. Teams may set their preferred general object orientation (i.e. side of task board which faces a robot). Judge will then communicate to the teams as they place the task board and kit mat within the workspace to ensure random placement. The kit tray locations will be set by the teams. Methods for dispensing screws and wires to the robot system for assembly are at the discretion of the teams and this can be done outside of the defined work area. Optional fixtures are provided to the teams for the wires and screws. Figure 2 shows the initial setup.

Note: Practice task boards and associated parts must be stored to not interfere with the competition.

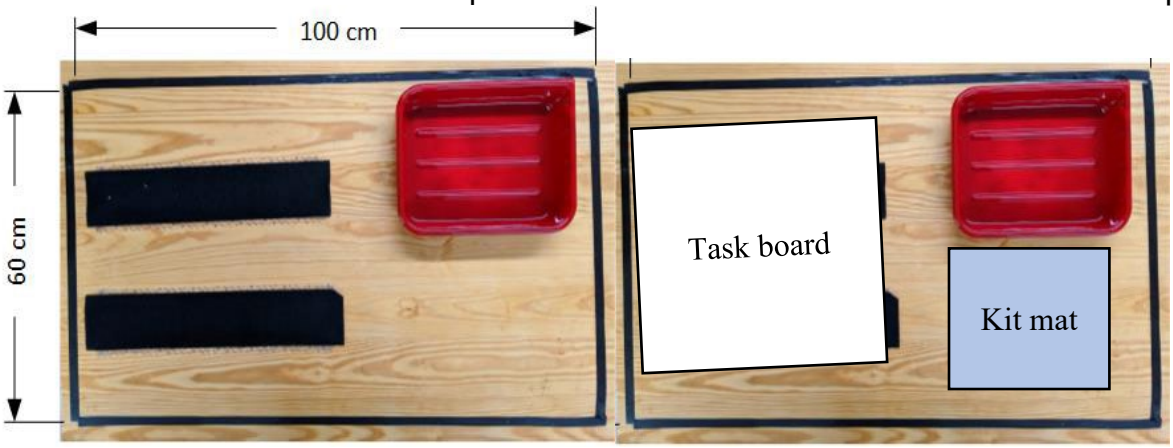


Figure 2: The initial layout where task board and kit layout are randomized. Teams use the electrical tape supplied to mark a 60 cm x 100 cm work area on a surface. General orientation of the task board and kit layout are specified by the teams and the judge ensures that final placement is random, **within +/- 10 cm and 10 degrees.**

**Subtask 1: Task Board Assembly**

*Description: Pegs, male electrical connectors, routed wires, screws and belt drive assembly components are placed on designated locations in the kit area by the team. The goal for the robot system is to pick all screws, pegs, gears, male electrical connectors, wires, and a belt from the kit layout/bolt dispenser and assemble them into their defined quadrants on the task board during each time frame. Points are assessed on a per part basis.*

*Setup:* Teams gather all components (from task board, table, and kit tray) and place them on kit layout. Belt is placed on the mat roughly centered on the concentric circle template. Wires are placed in a wire dispenser (either NIST provided or team design). Judges ensure that the task board is empty, and the layout is correct. A second set of screws and wires are provided so that teams can have the dispensing system already set up. Teams can remove the kit tray from the work area if desired.

*General steps per quadrant (Judge records start time):*

1. Expedient lead through programming methods applied if applicable. (Note: teams cannot change setup)
2. The robot picks a part from the kit layout.
3. The robot system assembles the part into its location on the board.
4. Repeat 2) and 3) for all parts in each quadrant.
5. Team informs judge to record end time and assess
6. After time is recorded and section is assessed, teams repeat the steps for the following quadrant

Time breakdown:

1. 30 minutes for general programming setup/time
2. 5 minutes to set up for quadrant 1 (threading)
3. 20 minutes for assembly of quadrant 1
4. 5 minutes to set up for quadrant 2 (insertion)
5. 20 minutes for assembly of quadrant 2
6. 5 minutes to set up for quadrant 3 (belt drive)
7. 20 minutes for assembly of quadrant 3
8. 5 minutes to set up for quadrant 4 (cable)
9. 20 minutes for assembly of quadrant 4

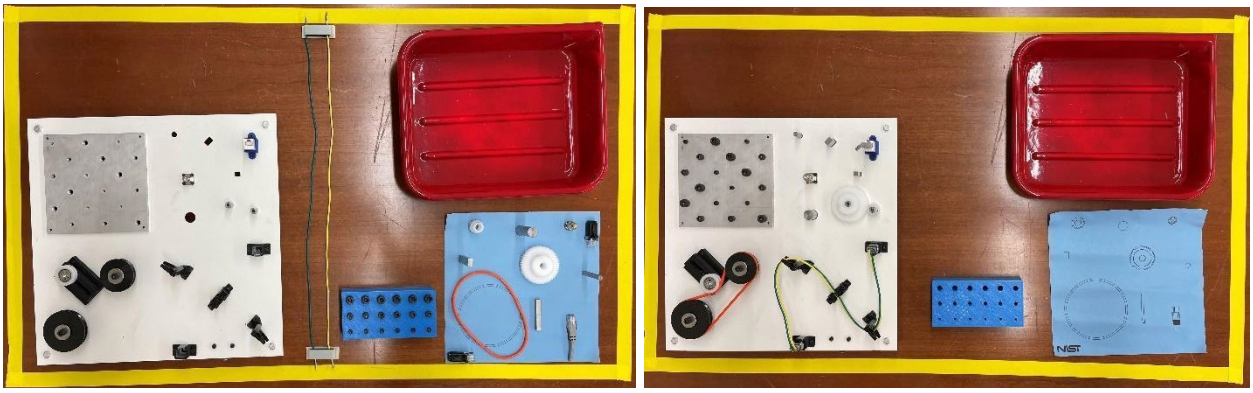

Figure 3: Subtask 1 – Assembly. This subtask starts with a fully disassembled task board with parts placed on kit layout template and fasteners and wires placed in a dispensing mechanism (a). Completion results in a fully assembled task board (b)

Note: kit layout and dispense mechanisms are previous designs and are subject to change.

*Rules:*

1. Time bonus points are only available if all parts are successfully assembled onto the applicable quadrant of the task board (maximum points achieved) as shown in Figure 1 and Figure 4(b).
2. No points earned for assembling something in the wrong quadrant other than the 1 point for getting the part to the board (see scoring section for complete point descriptions).
3. Points are only awarded for assembly of a part into its designated location. (e.g. no points for inserting 8mm peg into 16 mm hole)
4. No manual or teleoperated intervention by human operator (e.g., no manual tool changes)
5. No restriction on number of arms, grippers, sensors used
6. Use of hand tools (e.g., wrenches, electric drivers) is allowed provided the robot acquires these tools without human assistance.

7. Perception system markers (e.g., reflectors, AR tags, QR codes) may not be placed on the individual parts to be assembled but may be placed on the board, kit mat, or table.
8. Working area is the area within which the end-effector of the robot can move.
9. A reset is allowed in order to make program changes or repair/secure a task board. During a reset, teams must disassemble all parts from the current quadrant of the task board and reset in the kit area. All accumulated points are reset to zero. The clock continues to run throughout the reset.
10. Scoring is done after the completion of a quadrant.
11. While performing one quadrant of the task board, the other quadrants may be disassembled.

**Task Layout/scoring for each quadrant:**

Judge ensures teams understand the rules for the task as well as the rules for safe practices during the competition. All participating teams will have a personal judge (if enough are available) at their station. All teams will perform in parallel according to the schedule outlined for the competition.

****30 MINUTES GENERAL PROGRAMMING SETUP/TIME****

****5 MINUTES PREPARATION PERIOD FOR QUADRANT 1****

****20 MINUTES ASSEMBLY TIME****

Teams are welcome to use more time for programming and preparation but the 20 min start time and the end time will not change so they are cutting into their own time for scoring. Teams must inform the judge when they are ready to start their program. Teams must inform the judge when they need to intervene or stop their system for a reset. Teams must inform the judge when they are ready to start again after a reset.

**Quadrant 1 (threading):**
*Base Time Limit:* 20 minutes
*Number assembly parts:* 12
*Achievable Points:* 48 + Time bonus

| Operation | Points | Success measure |
|---|---|---|
| Fastener screwing | 2 | Screw cannot be lifted from hole and freely turns to tighten (threaded) |
| | 1 | Head of screw fully seated on board (washer test) |
| Nut securing | 2 | Nut cannot be lifted from screw and freely turns to tighten (threaded) |
| | 1 | Nut sits fully seated on board (washer test) |

Threading: Assembly Points
*Scoring:*
1. 1 point for each part that contacts any portion of the task board surface before the grasp is released or if the part is dropped and remains on the task board (total: 12 points)
2. Assembly points are based on the following criteria:
    a. 6 fastener screwing operations (total: 18 points)
    b. 6 nut securing operations (total: 18 points)

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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****5 MINUTES PREPARATION PERIOD FOR QUADRANT 2****

**Quadrant 2 (insertion):**
*Base Time Limit:* 20 minutes
*Number assembly parts:* 8
*Achievable Points:* 48 + Time bonus

Insertion: Assembly Points

| Operation | Points | Success measure |
|---|---|---|
| Insertion | 3 | Insertion into mating counterpart |
| | 2 | Fully seated and locked into place |
| Gear meshing | 3 | Gear is inserted onto the peg |
| | 2 | Fully seated and teeth mesh with the other gear |

*Scoring:*

3. 1 point for each part that contacts any portion of the task board surface before the grasp is released or if the part is dropped and remains on the task board (total: 8 points)
4. Assembly points are based on the following criteria:
    a. 6 insertion operations, 4 pegs and 2 connectors (total: 30 points)
    b. 2 gear meshing operations (total: 10 points)

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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****5 MINUTES PREPARATION PERIOD FOR QUADRANT 3****

**Quadrant 3 (belt tensioning):**
*Base Time Limit:* 20 minutes
*Number assembly parts:* 1
*Achievable Points:* 49 + Time bonus

Belt Drive: Assembly Points

| Operation | Points | Success measure |
|---|---|---|
| Belt threading | 12 | Belt sits in a pulley groove |
| Tensioning | 12 | Belt tensioned/screw tightened (seated in both pulley grooves) |

*Scoring:*

5. 1 point for each part that contacts any portion of the task board surface before the grasp is released or if the part is dropped and remains on the task board (total: 1 points)
6. Assembly points are based on the following criteria:
    a. 3 belt threading around pulleys (total: 36 points)

b. 1 tensioning operation (total: 12 points)

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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****5 MINUTES PREPARATION PERIOD FOR QUADRANT 4****

**Quadrant 4 (cable routing):**
*Base Time Limit:* 20 minutes
*Number assembly parts:* 2
*Achievable Points:* 51 + Time bonus

Cable: Assembly Points

| Operation | Points | Success measure |
|---|---|---|
| Pin insertions | 3 | pin inserted into connector |
| | 2 | pin locked into place (cannot be removed by tugging) |
| Wire routing | 4 | Wire is correctly routed through a latch |
| Wiring | 5 | Correct pin location according to wire diagram |

*Scoring:*

7. 1 point for each part that contacts any portion of the task board surface before the grasp is released or if the part is dropped and remains on the task board (total: 2 points)
8. Assembly points are based on the following criteria:
    a. 4 pin insertion operations (total: 20 points)
    b. 6 wire routing operations (total: 24 points)
    c. 1 wiring check (total: 5 points) *(connectors light when wired correctly)*

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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**Subtask 2: Task Board Disassembly**

*Description: Screws, nuts, pegs, gears, male electrical connectors, wire harness, and belt drive components are already assembled on the task board. The goal is for the competing robot system to remove all non-permanent components from each quadrant of the board and place them in the predefined kit space. Points are assessed on a per part basis. See Figure 4(a) for an example task board before disassembly and Figure 4(b) for an example task board after disassembly.*

Setup: board is fully assembled by hand and kit tray placed in the working area. Kit mat may be removed.

*General steps per quadrant (Judge records start time):*

1. Expedient lead through programming methods applied if applicable. (Note: teams cannot change setup)
2. The robot picks a part from the kit layout.
3. The robot system assembles the part into its location on the board.

4. Repeat 2) and 3) for all parts in each quadrant.
5. Team informs judge to record end time and assess
6. After time is recorded and section is assessed, teams repeat the steps for the following quadrant

Time breakdown:

1. 30 minutes for general programming setup/time
2. 5 minutes to set up for quadrant 1 (threading)
3. 10 minutes for assembly of quadrant 1
4. 5 minutes to set up for quadrant 2 (insertion)
5. 10 minutes for assembly of quadrant 2
6. 5 minutes to set up for quadrant 3 (belt drive)
7. 10 minutes for assembly of quadrant 3
8. 5 minutes to set up for quadrant 4 (cable)
9. 10 minutes for assembly of quadrant 4

*Rules:*

1. Time bonus points are only available if all parts are successfully assembled onto the applicable quadrant of the task board (maximum points achieved) as shown in Figure 1 and Figure 4(b).
2. Points awarded for the removal of the part from the board as well as the placement of the part into the kit tray.
3. No manual or teleoperated intervention by human operator (e.g., no manual tool changes)
4. No restriction on number of arms, grippers, sensors used
5. Use of hand tools (e.g., wrenches, electric drivers) is allowed provided the robot acquires these tools without human assistance.
6. Perception system markers (e.g., reflectors, AR tags, QR codes) may not be placed on the individual parts to be assembled but may be placed on the board, kit mat, or table.
7. Working area is the area within which the end-effector of the robot can move.
8. A reset is allowed in order to make program changes or repair/secure a task board. During a reset, teams must assemble all parts from the current quadrant of the task board. All accumulated points are reset to zero. The clock continues to run throughout the reset.
9. Scoring is done after the completion of a quadrant.
10. While performing one quadrant of the task board, the other quadrants remain assembled.

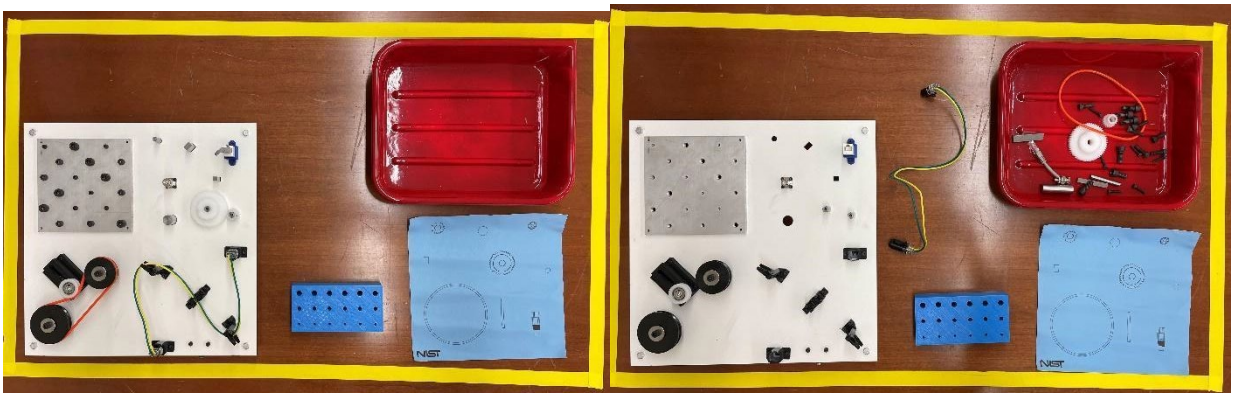

Figure 4: Subtask 2 – Disassembly. This subtask starts with a fully assembled task board (a). Completion results in a fully disassembled task board with all loose components placed in the tray. Note: Kit mat layout will change.

**Task Layout/scoring for each quadrant:**

Judge ensures teams understand the rules for the task as well as the rules for safe practices during the competition. All participating teams will have a personal judge (if enough are available) at their station. All teams will perform in parallel according to the schedule outlined for the competition.

****30 MINUTES GENERAL PROGRAMMING SETUP/TIME****

****5 MINUTES PREPARATION PERIOD FOR QUADRANT 1****

****10 MINUTES DISASSEMBLY TIME****

Teams are welcome to use more time for programming and preparation but the 10 min start time and the end time will not change so they are cutting into their own time for scoring. Teams must inform the judge when they are ready to start their program. Teams must inform the judge when they need to intervene or stop their system for a reset. Teams must inform the judge when they are ready to start again after a reset.

**Quadrant 1 (threading)**
*Base Time Limit:* 10 minutes
*Number of disassembly parts:* 12
*Achievable Points:* 36 + Time bonus

| Part name | Number of operations | Points | Success measure |
|---|---|---|---|
| Screws M4, M8, M12 | 6 | 12 | Screws unthreaded from the board and placed into kit tray |
| Nuts M4, M8, M12 | 6 | 12 | Bolts unthreaded from the board and placed into kit tray |

*Scoring:*

1. 2 points for each part removed from its position on the board (total: 24)
2. 1 point for each part placed into the kit tray (total: 12 points)

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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****5 MINUTES PREPARATION PERIOD FOR QUADRANT 2****

**Quadrant 2 (insertion)**
*Base Time Limit:* 10 minutes
*Number of disassembly parts:* 8
*Achievable Points:* 24 + Time bonus

| Part name | Number of operations | Points | Success measure |
|---|---|---|---|
| Pegs | 4 | 8 | Pegs removed from the board and placed into kit tray |

| | | | |
|---|---|---|---|
| Gears | 2 | 4 | Gears removed from the board and placed into kit tray |
| Ethernet connector | 1 | 2 | Ethernet removed from the board and placed into kit tray |
| USB connector | 1 | 2 | USB removed from the board and placed into kit tray |

*Scoring:*

1. 2 points for each part removed from its position on the board (total: 16)
2. 1 point for each part placed into the kit tray (total: 8 points)

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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****5 MINUTES PREPARATION PERIOD FOR QUADRANT 3****

**Quadrant 3 (belt drive)**
*Base Time Limit:* 10 minutes
*Number of disassembly parts:* 1
*Achievable Points:* 7 + Time bonus

| Part name | Number of operations | Points | Success measure |
|---|---|---|---|
| Belt | 3 | 6 | Belt removed from each pulley |

*Scoring:*

1. 2 points for each part removed from its position on the board (total: 6)
2. 1 point for the belt placed into the kit tray (total: 1 points)

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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****5 MINUTES PREPARATION PERIOD FOR QUADRANT 4****

**Quadrant 4 (cable)**
*Base Time Limit:* 10 minutes
*Number disassembly parts:* 1
*Achievable Points:* 11 + Time bonus

| Part name | Number of operations | Points | Success measure |
|---|---|---|---|
| Wires in harness | 3 | 6 | Completed harness removed from each post on the board |
| AT02 connectors (attached to wire harness) | 2 | 4 | Connector unclipped from female housing |

*Scoring:*

1. 2 points for each part removed from its position on the board (total: 10)
2. 1 point for completed wire harness placed into kit tray (total: 1 points)

Time Bonus: Time bonus = INT(total remaining time [min]) x 1 point

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**Time Shift**

220 (= 130 + 90) total minutes are allotted to each team including setup time for completing subtask 1 and subtask 2. At the 130-minute mark, all teams must start subtask 2 (disassembly). After 220 minutes, all task activities must be stopped.

Note: Judges can help set up the board for the transition from assembly to disassembly so that teams can focus on general programing

**Supporting material**

Teams will be asked to provide a short video of their system performing a run on the task board. Highlights showing their systems features and descriptions of assets that make their system unique are encouraged. Clarity of presentation is important as this will be shown on social media to an audience.

Additionally, teams are encouraged to attend a workshop following the competitions where they can present on their system and discuss/learn from other teams. This is an opportunity for teams to have input on the next year's competition changes.

Previous years have allowed teams to compete remotely, it’s important to note that this year the competition will be held in person only.