**Robot Cycle Analysis**

Once we defined the type of main game element to use, we analyzed robot cycle times in Deep Space to determine the maximum number of Flare scoring opportunities needed. For the following cycle analysis, we measured the cycle times of top-level teams playing Deep Space, then considered how Linked Together would shift those cycle times. We chose to compare Linked Together with Deep Space for three reasons:

1. Both are pick-and-place games with game objects scored in fairly tight tolerances
2. If dropped on the field, the hatch panel requires a re-orientation within the robot
3. The time to summit the Mountain will likely be similar to that of the 2019 Habitat Climb.

Of Deep Space’s full 2:30 game duration, top-level teams spent approximately 2:05 (125 sec) driver cycling, in which they performed 12-14 cycles. Since Flares require more precision and robots will likely cross the field to score and retrieve their Camping Gear, Linked Together will have slower cycle times, so we estimate that the field should definitely be able to handle at least 12 equivalent Deep Space cycles. 12 Deep Space cycles yields $\approx 10.4$ seconds per cycle, but we expect the extra time to pick up and deposit two Flares will cause Linked Together cycle times to increase to 11.5 seconds. Thus, our field equivalent number of cycles is $10.8$ cycles per robot, meaning one top-tier robot running at full capacity for all of its cycles will interact with $\approx 22$ Flares. Thus, each alliance needs 66 Flare scoring opportunities, and the entire field needs 132 objects (which we deemed the upper bound of reasonable).

**Robot Scoring Overview**

Linked Together needs to be easy for the audience to follow, which means having a simple arithmetic scoring system that influences desired robot strategy. During the Blizzard, alliances receive a 2 point bonus when scoring Flares, and robots receive 3 points for exiting the base of their Mountain. Alliances receive 3 point(s) for each Flare on a Pole, and 2 points for each Flare ending in the Collecting Station. At the end of the match, alliances receive 6 points per Camping Gear on the field, 12 points per Camping Gear at the base of the Mountain, and 16 points per Camping Gear with a summited robot. Summiting the Mountain returns 18 points per climbed robot.

In qualification matches, alliances have the opportunity to earn three ranking points for the following actions:

1. All robots exit the base of the Mountain during the Blizzard
2. All robots climb at the end of the match
3. Both Camping Gear end on the field

**Robot Scoring Numbers**

We can analyze a single alliance in a vacuum because robots may not descore their opponents’ Flares, there will be no game-wide shortage of Flares, and defense was accounted for in the cycle times.

$$54 \text{ flares on Communication Array} \times \frac{3 \text{ pts}}{\text{ Flare}} = 162 \text{ pts from Communication Arrays}$$

$$12 \text{ flares used in retrieving Camping Gear} \times \frac{2 \text{ pts}}{\text{ Collected Flare}} = 24 \text{ pts from Collecting} \hspace{1cm} \text{*a net opportunity cost of 12 points}$$

"Collecting Flares is a rookie-friendly game mechanism, but it has a low enough quantity cap to where a rookie team could finish both Collecting Stations in a match. Collecting should not provide the same initial value as Arranging; however, once completed, the ability to throw in a Camping Gear yields a profit. Since the Collecting Stations acts as a sort of exchange, the value of a Camping Gear on the field must offset the net opportunity cost from choosing to Collect instead of Arrange the required 6 Flares. Thus, a single Camping Gear on the field is worth 6 points.

To determine endgame scoring, we analyzed prior FIRST games to determine what percentage increase the endgame can return given the theoretical maximum autonomous and driver score. We found that the endgame bonus should never yield more than a 50% increase, and that it usually hovers around 40%.

Including the Camping Gear as part of traditional gameplay–except for when at the SUMMIT BASE or with a climbed robot–allows us to see that the theoretical maximum driver score is 198 points/alliance. If all robots scored their two preloads during the Blizzard and successfully exited their Mountain base, the theoretical maximum Driver and Blizzard score then increases to 219 points/alliance. We then proceeded to derive our endgame values, which lead to a maximum possible endgame return of 80 points (39% increase).

$$18 \times 3 \hspace{1cm} \text{← For three climbed robots}$$

$$+ 16 \times 2 \hspace{1cm} \text{← For both camping gear being on a climbed robot}$$

Endgame valued at 80 points
Pole and Depot placements centered around the core idea that each robot on an alliance performs slightly different tasks optimized for lower cycle times. While there are many different cycling paths robots could take depending on their unique capabilities, we designed the field setup so the three dominant routes reward slightly different robot designs.

- **Route A** (top left) rewards a maneuverable robot that can do 9 cycles while facing defense, can get past the Neutral Depots early in the match, and can catch the Camping Gear to race back to their side for the endgame.

- **Route B** (bottom middle) rewards a robot that can extend high to score on the tallest Communication Array Poles. While a robot running route B has the added safety of their protected zone, driving over the SUMMIT BASE corner can pose a tipping risk for a taller type of robot.

- **Route C** (Bottom right) is protected because it is deep in alliance territory, and opponents have no reason to visit that corner of the field except to play defense. While Route C is ideal for rookie teams, it provides a challenge for robots trying to cycle it quickly. Teams looking to speed up their cycle times on Route C must have a maneuverable drivebase to manage the tight spaces and a dexterous intake that can pick up Flares from a random orientation.

* In higher-level matches, expect there to be more crossplay between routes B and C, as robots that finish route C early will provide assistance to help their B partner finish.

**Rookie Accessibility in the Kit Of Parts**

Along with having rookie-friendly aspects to its gameplay, Linked Together was designed so most of its Kit Of Parts and field elements have simple substitutes for rookies and teams with less funding. The Flare can be made from a 10" segment of 8 in. diameter PVC tubing from a local hardware store. Communication Array Poles can be made out of a flange bracket and 3.5 in. PVC. While the Camping Gear has no cheaper alternative, teams can hold a piece of plywood on a staircase for the Mountain structure. Teams also have the option to create a 2-in-1 Mountain and Low Pole Practice Element, pictured at the right.

**Why we revived the Sandstorm (the Blizzard)**

Choosing to allow vision during the Blizzard was extremely difficult, but we believe it increases the contribution a rookie team can make while better engaging the audience for the first 15 seconds. However, adding vision targets to each goal should lead more teams to prefer autonomous code. These vision targets provide a unique challenge: curving the retro-reflective tape around the base causes a camera’s 2D perspective to perceive reflected light falloff towards the apparent sides of the tape, but tracking the targets is easier as their proximity to the dark playing floor increases the image’s contrast.
Field Reset & Indicator Lights

The tallest of the six-Flare capacity Poles (the three with the indicator lights) stand 5 ft. 5 in. tall, allowing the field crew to safely and efficiently remove scored Flares during field reset. Additionally, since there are more game objects than normal, the Alliance-Side Depot sees Flares starting in a random configuration to quicken field reset.

Three of each alliance’s 6-capacity Poles act as the mounting point for the field’s six indicator lights, raising those Poles’ total height up 1 inch. These lights will turn green to indicate that a team may enter the field to set up or retrieve their robot. Each light will turn on to the alliance’s color to indicate the earning of one of each ranking point. At the end of the match, while final scores are loading on screen the lights can pulse to show the arrival of a helicopter.

Audience Display

Linked Together’s focus on engaging the audience extends to the Audience Display as well. Since all game elements are easily visible due to their size, little extra match data needs to be provided. However, we expect the audience will have a hard time tracking how many Flares have been Collected. To resolve this issue, the Audience Display includes two circles for each Collecting station, that fill up as more Flares are Collected. When a circle is full, the corresponding Collecting Station’s human player is ready to throw their Camping Gear on the field.

To emphasize the ticking clock, we moved the “Time Remaining” readout so it protrudes out of the main audience display. Connecting to Linked Together’s theme, the “Time Remaining” readout is connected to the main body by two triangles that subtly represent the Mountain structure.

Collecting Station Port Safety

As mentioned briefly in the description of expected robot actions, we believe that reorienting Flares will prove to be challenging for rookie teams. Pictured at the left is a closeup of the Collecting Station wall that illustrates how teams can push Flares over a small bump to be returned to them in a vertical orientation via the Upper Port. The Collecting Station employs a few design tricks to reduce the risk of injury to the human player:

1) The entire wall is clear to allow improved visibility and better coordination with robot actions.
2) The robot-side of the Upper Port is shielded so that no intaking mechanism can reach towards the human player’s hands.
3) The small bump before the Lower Port keeps robots from ramming the wall to push Flares in at full driving speed.
4) Flares’ edges are beveled to avoid scraping human players.

Linked Together and COVID

As much as we would have liked to skip straight to the Moving Forward section of this summary, COVID is still a part of our daily lives. And while we have all reason to believe that the world will have largely returned to normal come 2022, Linked Together has a few features that help it be more COVID safe:

1) Driver Stations are separated by removable acrylic shielding (see image on next page).
2) All game objects are hard surfaces to permit ease of cleaning.
3) When robots are being placed and removed, alliances’ 65° Communication Array Poles force circular walking traffic, keeping teams from doubling back on each other.
Moving Forward

While we hope that Linked Together inspires future elements of FIRST games, we acknowledge our lack of implementation experience that the FIRST design team has amassed. Having spent hours analyzing trends in past game concepts and searching for possibly unpredicted aspects of real gameplay, here are the most significant areas of Linked Together where we believe further development is needed.

1. If climbing without the chain is deemed unnecessary, the Mountain surface can be made of a low-traction material. This would have the secondary benefit of keeping robots from tipping backwards if they disengage from the chain, as frictional torquing is reduced.

2. A prescribed amount of Flares in the Alliance-Side Depot could start with vision targets to encourage teams to score on the 2-capacity Poles and engage with that Depot during the Blizzard.

3. Addition of a pressure pad system atop the summit to reduce the need for referee judgment calls.

4. A small railing could be added on the edges of the summit to keep the robots from falling off sideways.

5. The Human-player side of each Collecting Station’s Lower Port may need an protective mechanism like FIRST Power Up’s shielded rollers to further protect human players.

6. Scoring values and the Camping Gear exchange ratio can be altered to achieve different gameplay.

*An example of how a Neutral Depot becomes easier to traverse once Flares are scored*