RoboCup Logistics League

Rules and Regulations 2023

The Technical Committee 2012–2023

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1 Introduction

The future of industrial production is to utilize smarter and more flexible systems. Manufacturing industries are on the brink of widely accepting a new paradigm for organizing production by introducing perceiving, active, context-aware autonomous systems. This paradigm is often referred to as Industry 4.0 [1], a move from static process chains towards more automation and autonomy. One of its corner stones are so called *smart factories* which are flexible facilities in which manufacturing steps are considered as services. This means that various production steps, machines and sub-facilities can be combined in (almost) arbitrary ways allowing for the production of various product types and variants cost-effectively, even in small quantities. This is in contrast To traditional production chains which produce only a small number of varieties of a product at high quantities [3]. To realize such factories and make use of their full potential, more capable logistics systems are needed, of which the most flexible form are autonomous mobile robots.

The RoboCup Logistics League (RCLL) is determined to develop into a state-of-the-art platform for mobile robotics education and research tackling the problem of flexible and efficient production logistics at a comprehensible size. Being an industry motivated league, it focuses on challenges promoting precise actions and robust long-enduring execution, and further encourages external data supported autonomy. By providing feedback and competition hardware, industrial partner Festo transfers insights into future factory concepts to help uncover relevant future topics for education and research.

This year's competition is laid out in the following pages. It ensures the same and fair conditions for all participants. It neither dictates nor suggests how to fulfill the task, but is meant to encourage new developments in the RCLL through restrictions and tasks. Smart Factory environments require new concepts of flexibility, awareness and optimization from autonomous entities working in an environment with specified, yet to some degree uncertain and dynamic, agency. This includes current challenges of developing industry-wide standards for Cyber Physical Systems for production processes like designing plug-and-produce capable systems.

1.1 History and Recent Development

After exciting competitions in the previous years, we look forward to a new scale of competition that will emerge from initiatives around the globe. In 2012 we had our first Logistics League World Champion. In 2013 we introduced the Referee Box (refbox) [4] changing the competition at its core by introducing a flow of information. This allowed for more dynamic games and the automatic tracking of scores. In 2014, we merged the formerly separate playing fields into a single field on which both teams compete simultaneously, introducing the need for self-localization, collision avoidance, and increased spatial coordination complexity. Additionally, the production schedules became more dynamic in that orders were posted dynamically and less frequently. In 2015 we introduced actual physical processing machines based on the Festo Modular Production System (MPS) requiring more complex machine handling [2]. The production schedule has again become more flexible and dynamic, by introducing color-coded rings of which a varying number can be requested to be mounted in a specific order for a certain product. This increased the number of products from 3 to about 240. After three years of constant and tremendous changes, 2016 was a year to consolidate our league as a whole by increasing the number of participating teams and allowing existing teams to excel in their capabilities. In 2017, we changed the field size and zone layout and we shifted the focus from the exploration to the production phase. In 2018, we saw more and more teams successfully delivering orders, even of higher complexity. For 2019, the Technical Committee (TC) integrated a barcode recognition system to track products, which allows to automate scoring and to grant partial points for production steps. Additionally, the communication with the MPS stations got improved through a switch to new hardware and to the OPC Unified Architecture.[1] The introduction of competitive orders aimed to increase the competition aspect by giving a bonus to the team that delivered first, thereby promoting strategic reasoning to gain an advantage over the other team. Also, teams were allowed to purchase additional robot maintenance, which increases overall game activity while posing an additional strategic challenge to the teams. In 2020 the TC reworked the storage station integration and the rules regarding storage station usage. The storage station became fully functional. In 2021 an online format was introduced to allow competitions around the world without being required to gather at the same location or even having a full field setup. The online format consists of different challenges with varying difficulty. While some of the complexity of the regular RCLL game could not be projected to the challenge format, it allowed to introduce new ideas to the league, that can be tested in isolated tasks before the final integration into the regular game rules. New teams also benefit from the challenge format as they can explore the different aspects of the RCLL without having to worry about the full scope yet.[2]

In 2022 the TC reworked the online format to become a challenge track for real competitions which is suitable for upcoming teams to solve individual challenges of the RCLL. Seasoned teams continue to compete against each other in regular RCLL games in the main track of the competition. The league also relaxed the hardware restrictions to allow the use of alternative robotic platforms other than the Festo robotino for teams competing in the new challenge track. This enables interested teams to explore the different tasks of the RCLL before committing to the standard platform of the league. Given recent developments in the object classification field, the decision was made to rework the exploration in the main track. Firstly, the exploration and production phase are merged to allow machine usage as soon as they are correctly reported. Secondly, the deprecated ALVAR tags got replaced by ARUCO tags as markers for machines. ARUCO tags are widely supported. Thirdly, teams can now chose to play without markers. While currently being an optional choice, the TC decided to establish the use of markerless machine detecting methods in the future by rewarding the play without markers in the games directly, instead of relying on a separate technical challenge for this (as it was the case previously). Lastly, the order schedule within RCLL games in the main track got modified to be less predictable while following simpler generation rules to dispatch orders. Building upon these advances, the 2023 rule update focused on including and codifying common practices during competitions and making rules more specific and clear. Additionally, the point scoring for delivery in a main track game were changed such that a bigger emphasis is put on the delivery of products within the delivery-windows.

1.2 The Task

Our aim is to provide a simplified Smart Factory environment, where teams of autonomous robots must operate a flexible production plant without human interference and against the clock. The Logistics League's core task is to fulfill placed product orders by executing multi-stage production cycles, before delivering the finished products within the requested time frame. This is achieved by transporting small pieces of material between assembly machines (MPS stations, see Section 4), which can be instructed to perform different refinement steps, such as mounting a colored ring on a cylindrical base product. Efficient handling of the material logistics and utilization of the available machines are core requirements to succeed in the RCLL. Depending on the game format (see Section 8.1 and Section 8.2), the machine positions might be unknown in the beginning, such that they need to be correctly discovered (see Section 5.2.1).

[1]We gratefully thank the RoboCup Federation for supporting the work on workpiece tracking and network robustness.

[2]A list of rule changes can be found at `https://github.com/robocup-logistics/rcll-rulebook`

The RCLL supports different competition tracks:

- Production logistic scenarios where two teams compete against each other on the same playing field and need to serve multiple dynamically dispatched orders. This game mode is referred to as the *main track*.
- Individual challenges carried on a field, where only one team competes at a time. The challenges are designed to reflect the individual tasks that are required to solve complex production scenarios from the main track. This game mode is referred to as the *challenge track*.

A RCLL tournament is divided, such that entry-level teams participate in the challenge track and advanced teams compete in the main track separately.

This work flow is controlled by a Referee Box (refbox) [4][3] broadcasting information via wifi (see Section 7.2). It is a software system that runs on a system provided by the Organizing Committee and controls the overall game, monitors feedback from the robots, and awards points. The work flow itself is divided into phases: During a setup phase (see Section 5.1) the field setup is prepared and the robots are started. Within the production phase (see Section 5.2) the refbox dynamically announces the tasks that the robots must fulfill automatically. During the first part of the production phase, no machine information will be announced. Robots need to discover the positions of their machines and report them to the refbox (see Section 5.2.1). The main production scenario utilizes all of the above phases, some of the individual challenges skip the exploration phase, see Section 8.2 for details.

1.3 Agreements & Regulations

Standardized Robotic Platform In the RCLL, the Robotino robotic system from Festo Didactic SE is used as the common base platform. It can be used with certain freedoms and limitations regarding hardware and software modifications and additions, which will be outlined in Section 6. This includes the current version, Robotino 4, as well as the phased-out Robotino 3 and 2. Entry-level teams can explore the league with other robotic platforms as participation in the challenge track does not require the usage of the Robotino platform. However, the general hardware constraints outlined in Section 6 still apply.

Rules Philosophy Each team should act within the meaning of a cooperative and fair behavior, even if the goal of each team is to be the best. Teams should not search for gaps or inconsistencies in the rulebook to achieve advantages in the competition. Instead, we ask explicitly to bring such gaps to our attention. Since the rulebook cannot cover all possible cases, we consider a general gentleman agreement: "One should treat others as one would like others to treat oneself".

The factory area has to be treated in the best possible way. Any possible damage to the field, opposing robots or the machines will be penalized by the referee.

The general development of the rules loosely follows a tick-tock rhythm, where years of larger rule modifications are followed by a year of stabilization and conservative changes.

2 League Administration

2.1 Technical Committee 2022

The Technical Committee (TC) is responsible to update and publish the rulebook, to decide on technical questions during the tournament, and to communicate with the league stake holders on technical

[3]Code and documentation available at `https://github.com/robocup-logistics/rcll-refbox`

advancements. Current members of the TC are (in alphabetical order):

Lukas Knoflach, Graz University of Technology, Graz, Austria
Peter Kohout, Graz University of Technology, Graz, Austria
Sven Imhof, HFTM Technical Institute of Applied Science Mittelland, Biel, Switzerland
Alain Rohr, HFTM Technical Institute of Applied Science Mittelland, Biel, Switzerland
Daniel Swoboda, RWTH Aachen University, Aachen, Germany
Tarik Viehmann, RWTH Aachen University, Aachen, Germany

To get into contact with the TC use the mailing list
`robocup-logistics-tc@lists.kbsg.rwth-aachen.de`

2.2 Organizing Committee 2022

The Organizational Committee (OC) is responsible for organizing the RoboCup competitions, to communicate to the RoboCup Federation trustees and chairs the requirements of the league, and to inform and attract new teams to the league. Current members of the OC are (in alphabetical order):

Stefan Brandenberger, HFTM Technical Institute of Applied Science Mittelland, Biel, Switzerland
Vanessa Egger, Graz University of Technology, Graz, Austria
Wataru Uemura, Ryukoku University, Kyoto, Japan

To get into contact with the OC use the mailing list
`robocup-logistics-oc@lists.kbsg.rwth-aachen.de`

2.3 Executive Committee

Executive Committee members are responsible for the long term goals of the league and thus have also contact to other leagues as well as to the RoboCup federation. The Executive Committee presents the league and its achievements to the RoboCup federation every year and gets feedback to organize the league. All committee members are also members of the Technical Committee. Executive Committee members are elected by the Board of Trustees and appointed by the President of the RoboCup Federation; they serve 3-year terms.

Alexander Ferrein, FH Aachen, Aachen, Germany
Christian Deppe, Festo Didactic SE, Denkendorf, Germany

2.4 Website and Contact

The website of the RoboCup Logistics League is available at
`https://ll.robocup.org/`

A mailing list for general announcements and discussion about the league is available at
`https://lists.kbsg.rwth-aachen.de/listinfo/robocup-logistics`

We also have a Slack workspace, which anyone is welcome to join.[4]

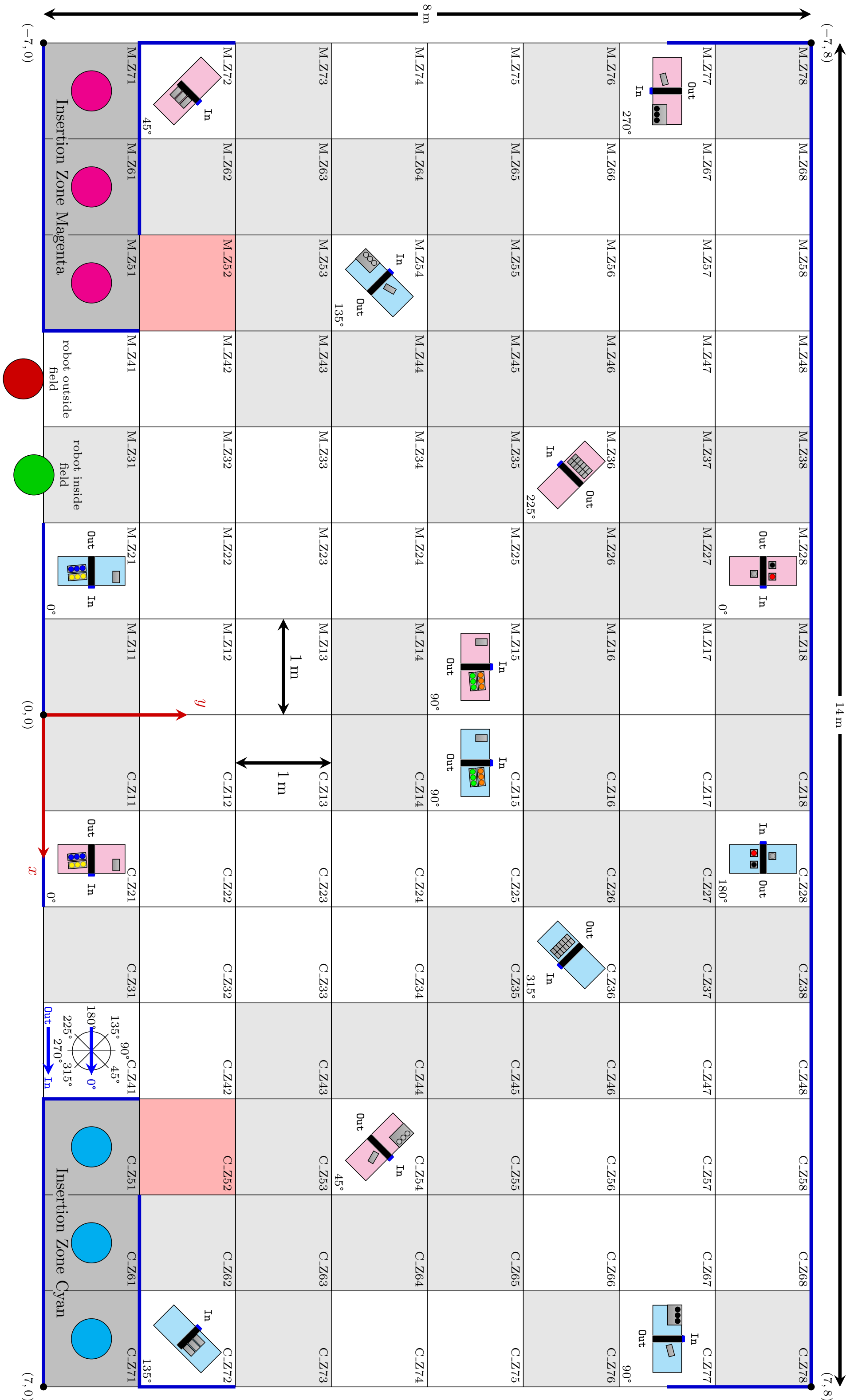


Figure 1: Competition area for two teams: Squares indicate zones for possible machine placements, circles denote robots. Cyan and magenta are team assignment colors. Thick blue lines are wall elements. Dark gray areas are insertion areas where robots start. No machines may be placed in the vicinity of other machines (light gray areas) or at the insertion zone entrance (light red area).

3 Competition Area

The competition area of the RCLL has a rectangular shape. The field is divided in square zones of $1\,\mathrm{m} \times 1\,\mathrm{m}$. The zones of each field are named according to the following scheme: A team prefix ("C-" for cyan at the positive half of the X-axis, "M-" for magenta at the negative half of the X-axs), "Z" to distinguish zone names, and a grid coordinate form the name of a zone. For example, The zone C-Z23 is a zone on the cyan primary half, which is the second along the positive half of the X-axis and the third along the Y-axis. Zones will not be physically represented or visible on the field. They cannot be used for any other purpose than machine positioning.

The field is partially surrounded (at least 50% but not more than 70%) by wall elements of at least $0.5\,\mathrm{m}$ height. Different machines are placed within the area, the constraints for positioning them are given in Section 4.0.2. The RCLL supports two kind of field layouts: Firstly, a symmetrical one with aspect ratio 1:2 intended for two teams to compete simultaneously on the same area. Secondly, a field with a squared layout that is intended for tasks, where only one team is on the field at a time. Fields also contain designated robot insertion areas, that are used as a starting position for the robots when a game starts or a robot is inserted into a running game. A team's insertion zone is always placed on the far side along the X-axis of the side it is playing on, i.e. for a field side with dimensions $m \times n$, the insertion zone will occupy the zones $\{(m-2,1),(m-1,1),(m,1)\}$, with the robots entering through $(m-2,1)$ and $(m-2,2)$. The usage of these areas is restricted to these purposes, unless stated otherwise. The insertion area is also partially surrounded by wall segments as shown in Figure 1 and Figure 2. In the following, the different field layouts are presented. The depicted field layouts are examples only, the actual distribution and alignment of machines on the competition area will change before the actual game starts and will be different for each game. Thus, teams should focus on a generic approach for production, allowing for dynamic adaptation of machine positions and alignments.

3.1 Fields with Aspect Ratio 2:1 (Main Track Field)

An example of a competition area for games on the main track is shown in Figure 1, it features the reference standard size of $14\,\mathrm{m} \times 8\,\mathrm{m}$ large arena with 112 square zones and with 14 randomly distributed machines (an identical set of 7 machines for each team exclusively). Alternatively, the field may be reduced in size symmetrically by the local organizers to accomodate local limitations. In case of a field size reduction, it must be guaranteed that all machines can still be placed according to the rules in Section 4.0.2.

The distribution and alignment of all machines is axially symmetrical on the y-axis. Thus, each team has similar conditions on both halves of the competition field. For details, see Section 4.0.2. The entire area is shared among both teams on the field and any robot may travel anywhere at any time (while not obstructing for an extended period of time or pushing other robots or machines). However, there are primary sides (split along the y-axis) for each team where a team's *robot insertion area* is located. We will refer to the side with positive coordinates on the x-axis as the (primary) half of team cyan, and the side with negative coordinates on the x-axis as the (primary) half of team magenta.

[4] https://join.slack.com/t/robocuplogist-ewg8659/shared_invite/zt-11rvzswk5-AuV0isGO3Log1soa5_dwmg

3.2 Fields with Aspect Ratio 1:1 (Challenge Track Field)

An example of a competition area with aspect ratio 1 is shown in Figure 2, it spans a $5\,\mathrm{m} \times 5\,\mathrm{m}$ large arena with 25 square zones, where 3 machines are placed.

Only one team at a time competes on the area, the chosen team-color does not matter. However, the field coordinates resemble the magenta halve of the field, hence the coordinates on the x-axis of all zones are negative. Teams can play as either cyan or magenta, as machine positions published by the refbox place the machines of both teams on the same location (e.g., M-BS and C-BS are both placed at M-Z12 in the field of Figure 2).

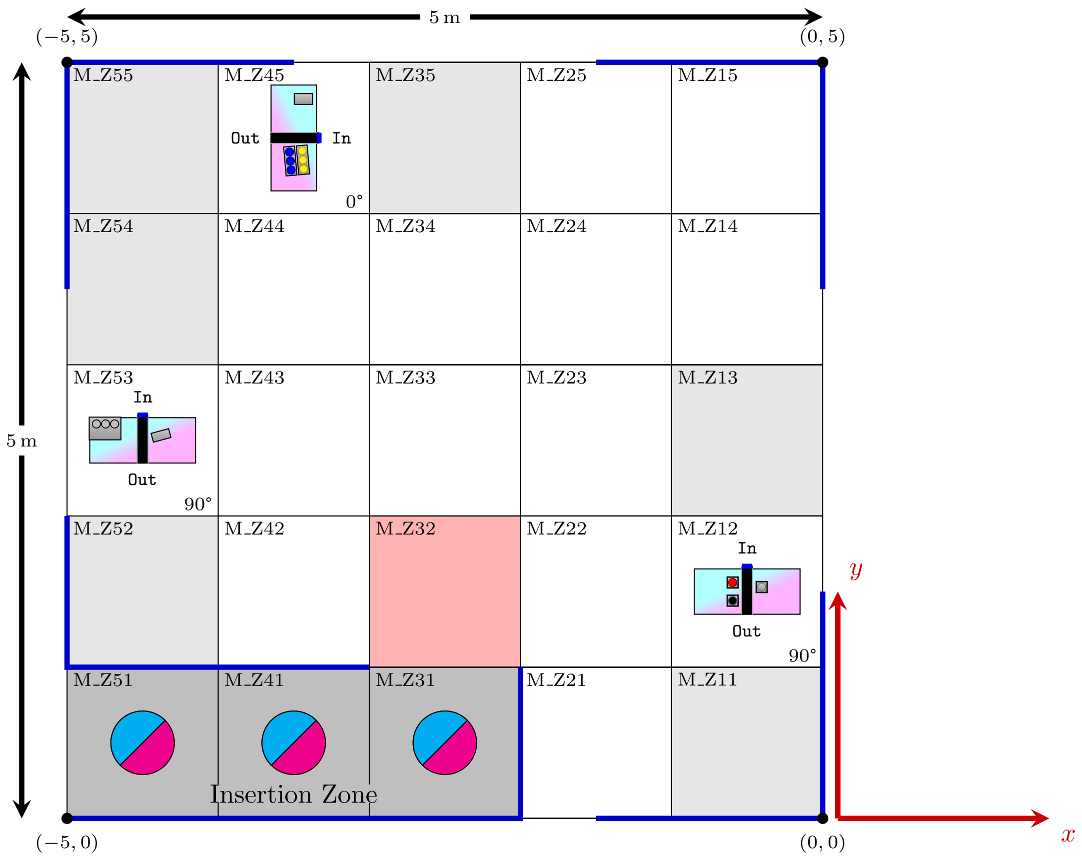


Figure 2: Competition area for a field of the challenge track.

3.3 Moving on the Field

The robots are free to move on the field. However, robots may not leave the competition area (surrounded by the partial walls). That is, when connecting all wall segments with the shortest possible edges, robots may not move such that the base is fully outside this area. For example, in Figure 1, the red robot is outside the intended area and thus in an illegal position.

Robots that leave the competition area illegally are considered as *misbehaving robot* and punished accordingly (cf. Section 9.3.1).

4 Machines

In the RCLL 5 different types of production machines are in use, each fulfilling a different role in the production process. Machines are based on the Modular Production System (MPS)[5] by Festo Didactic SE. We use the terms *MPS* and *machine* interchangeably throughout this rulebook.

Each MPS shares the same basic layout as highlighted in Figure 4. A movable rectangular trolley makes up the base of the machine. A conveyer belt connecting the two short sides of the machine is the main interaction point for robots. Three colored signal lights are used to visually indicate the current state of the machine. Each machine type has additional individual application modules which provide the different functionalities.

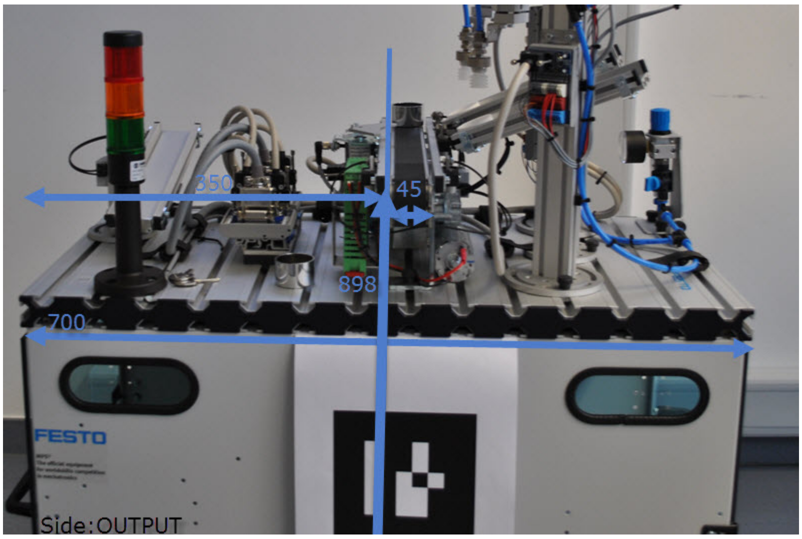


Figure 3: General Machine Layout

Based on these shared properties, there are five kinds of machines:

Base Station (BS) acts as dispenser of base elements (Figure 4(a)). The application modules are three magazines of base elements.

Cap Station (CS) mounts a cap as the final step in production on an intermediate product (Figure 4(b)). The application module is a vacuum pick & place module. There is a slide to store at most one cap piece at a time. At the beginning this slide is empty and has to be filled in the following way. A base element with a cap must be taken to the machine and is then unmounted and buffered in the slide. The cap is then mounted on the next intermediate product taken to the machine.

Ring Station (RS) mounts one colored ring out of two available colors on an intermediate product (Figure 4(c)). Each RS has two vacuum pick & place units as application modules with separate unique colors which are determined by the refbox. There is an additional pre-fill slide which is used for some colors (specified anew for each game) to add base elements.

Storage Station (SS) provides 48 slots of storage divided into 6 layers (Figure 4(d)). The Storage Station initially provides one pre-stored sample of each possible C_0 configuration (one per layer), according to Table 1.

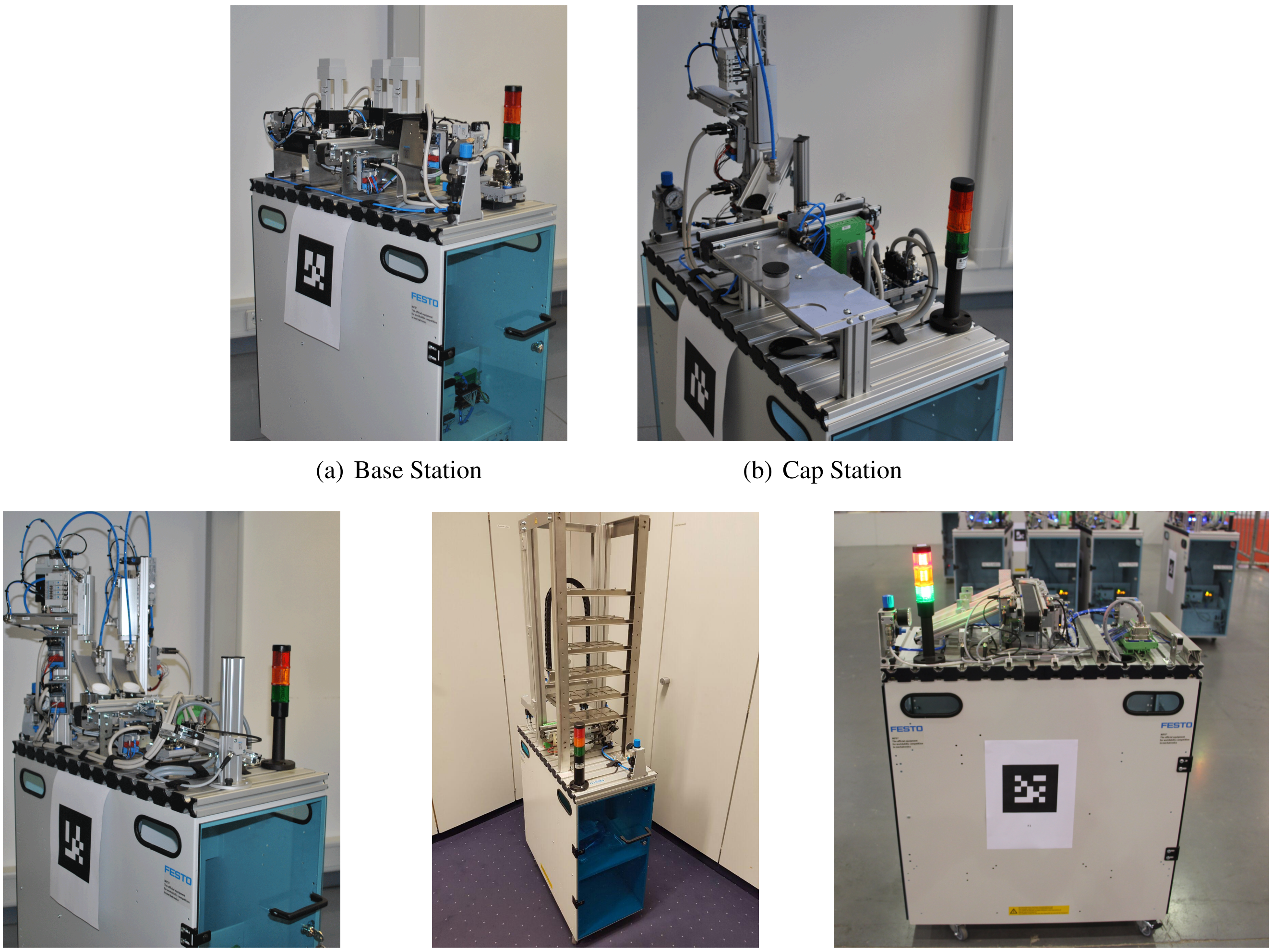
[5]For more information see `http://www.robocup-logistics.org/links/festo-mps`.

Product		Position
Base Color	Cap Color	
RED	GREY	(0,1)
RED	BLACK	(1,1)
SILVER	GREY	(2,1)
SILVER	BLACK	(3,1)
BLACK	GREY	(4,1)
BLACK	BLACK	(5,1)

Table 1: Pre-stored C0 products at the SS, the positions are labeled according to Figure 10.

Delivery Station (DS) Accepts completed products. The stations contains three slides (Figure 4(e)). The delivered products are verified by either the referees or an automated external vision system.

Machines of type CS and RS are called production machines as they perform refinement steps on a workpiece during the production phase. Processing times are outlined in Table 2.



(a) Base Station

(b) Cap Station

(c) Ring Station

(d) Storage Station

(e) Delivery Station

Figure 4: The different MPS stations

Type	Distribution	(Final) processing time[s]
Base Station (BS)	1 per team	minimum physical time
Cap Station (CS)	2 per team	$t_2 = 15$ to $25\,\mathrm{sec}$
Ring Station (RS)	2 per team	$t_3 = 40$ to $60\,\mathrm{sec}$
Storage Station (SS)	1 per team	minimum physical time
Delivery Station (DS)	1 per team	$t_5 = 20$ to $40\,\mathrm{sec}$

Table 2: MPS type, distribution and processing times

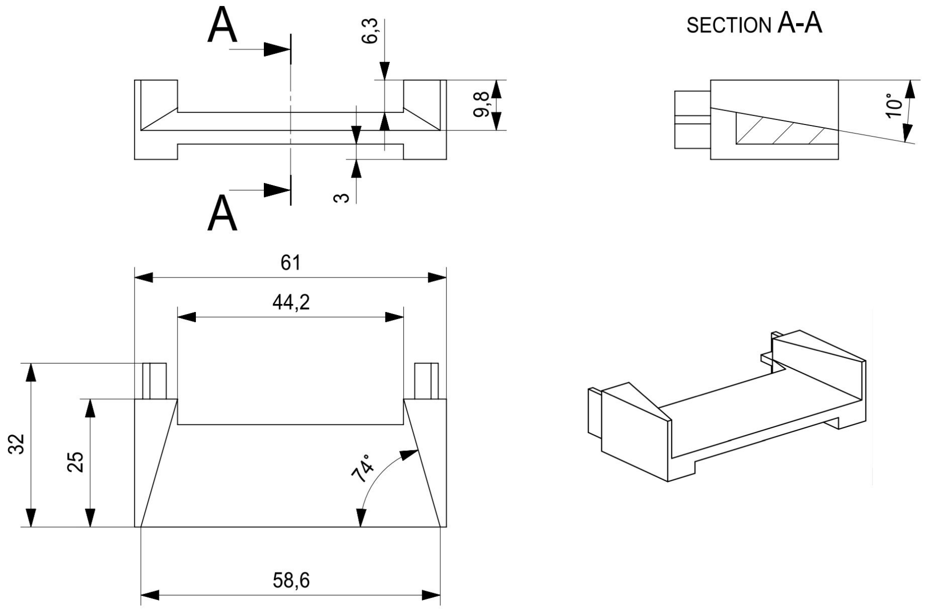


Figure 5: Narrowing cone

4.0.1 Physical Description of Machines

The stations have a rectangular base shape of $0.35\,\mathrm{m} \times 0.7\,\mathrm{m}$with a height of about $1\,\mathrm{m}$ depending on machine type. A machine is movable by four wheels with $0.1\,\mathrm{m}$ clearance. Both narrow sides of the trolley are closed by plexiglas and have a handle. All physical interfaces like conveyor belt inputs and outputs, shelves, and slides for additional bases on ring stations are accessible at $89.8\,\mathrm{cm}$ height.[6] Working space between guiding lanes is $4.5\,\mathrm{cm}$. Setup lanes and shelves feature approximately the same space for handling and adjusting. All diffuse sensors (input side) have been removed to allow for infrared-emitting cameras. To simplify the delivery on the belt, each machine will be equipped with a narrowing cone on its input side (Figure 5). You can order them from Festo Didactic SE (C. Deppe) or download the STL model file from the RCLL site.

4.0.2 Machine Positioning

The zones and rotations for the MPS will be randomly chosen by the refbox.[7] Each game will have a new randomly generated field layout, the referees will place the MPS in the middle of the zone with given rotation at there best effort but errors of the positioning should be expected.

[6]Note however, that due to small variances and unevenness in the floor there may likewise be small variances in the working height of some or all parts of a station.

[7]It is also possible to store and retrieve field layouts with the refbox, which is useful for testing purposes or if a game needs to be restarted. See the refbox configuration options in the wiki for details.

A MPS can generally be placed in any zones except those at the entrance of the insertion area (the light red areas in Figure 1 and Figure 2). These zones are needed to enter the field. Each MPS has one out of 8 possible orientations, starting at $0°$ with steps of $45°$ Intuitively, the different orientations are shown in the pictogram in zone C_Z41 of Figure 1, where the tip of the blue arrow represents the input side of a machine and points towards the respective rotation ($0°$ in that figure). Formally, to denote the orientation we assign a local right-handed coordinate system to each MPS station. The x-axis is given by the conveyor pointing from the output to the input. The origin is the center point of the conveyor. The orientation is then the relative rotation of the local MPS system compared to the fixed field coordinate system. For example, at an MPS orientation of $0°$, its local coordinate system is aligned with the field (in terms of orientation). Furthermore, an MPS at an orientation of $90°$ will be rotated counter-clockwise a quarter turn compared to the field system.

To ensure fairness, positions and orientations of the machines are mirrored along the field's y-axis. There are two cases that need to be handled separately. First, machines in a cell not adjacent to the wall, and machines of types BS, DS, and SS (even when adjacent to the wall) are mirrored according to Table 3. Second, CS and RS stations must be handled slightly different, if oriented next to a wall or field border (e.g., zones C-Z*1, C-Z*8, C-Z7*, M-Z*1, M-Z*8 and M-Z7* in Figure 1). The reason being, that the shelf and slide of these stations are offset sideways at the input side. This might lead to the situation that for one team the shelf is close to the wall, and for the other it is not. To remedy this problem, the RS and CS machines adjacent to a wall will always be placed such that the shelf or slide is on the farther end with respect to the wall. For example, in Figure 1, the magenta CS in M-Z77 with a rotation of $270°$. Were this setup mirrored, the shelf on the cyan CS in C-Z77 would be close to the wall. Instead, it has a different orientation violating the y-symmetry but allowing for easier access to the shelf.

For placing of machines, the refbox will take care of the necessary constraints to ensure that all in- and output sides, shelves and slides are reachable. That is, a path to each blocked zone (see Figure 6) must exist from any unoccupied or blocked zone of the field. If a machine is rotated with $0°$, $90°$, $180°$ or $270°$ the zones in front the input and output side are blocked as well (Figure 6(a)). For machines with rotations $45°$, $135°$, $225°$ and $315°$ three zones in front of each input and output side are blocked (Figure 6(b)). No MPS nor blocked zones for another MPS may be placed in a blocked zone. All blocked zones of any MPS must be located within the competition area. Furthermore, only two machines will ever be placed next to each other, a third machine will only be placed with at least one empty zone in-between.

Cyan	Magenta
$0°$	$180°$
$45°$	$135°$
$90°$	$90°$
$135°$	$45°$
$180°$	$0°$
$225°$	$315°$
$270°$	$270°$
$315°$	$225°$

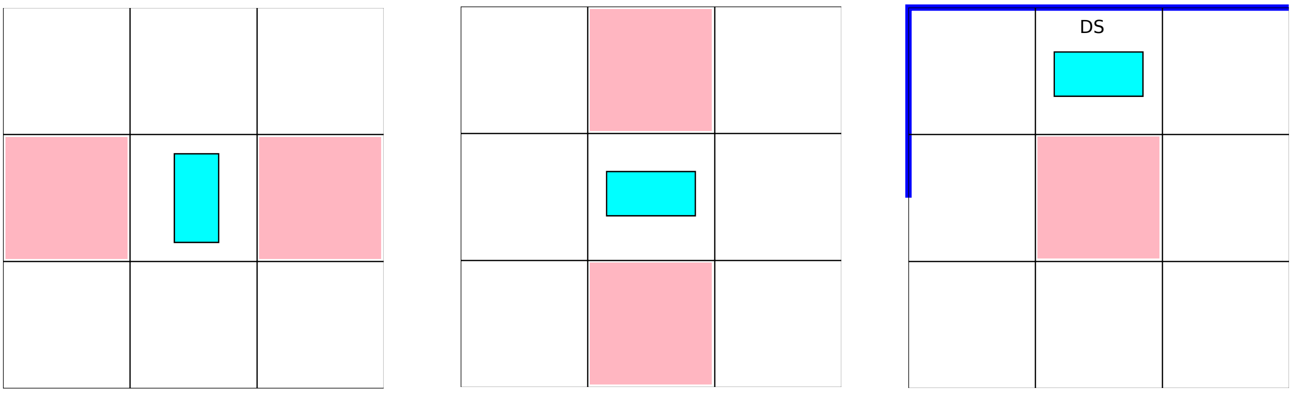
Table 3: MPS orientation mapping during mirroring

4.0.3 Markers

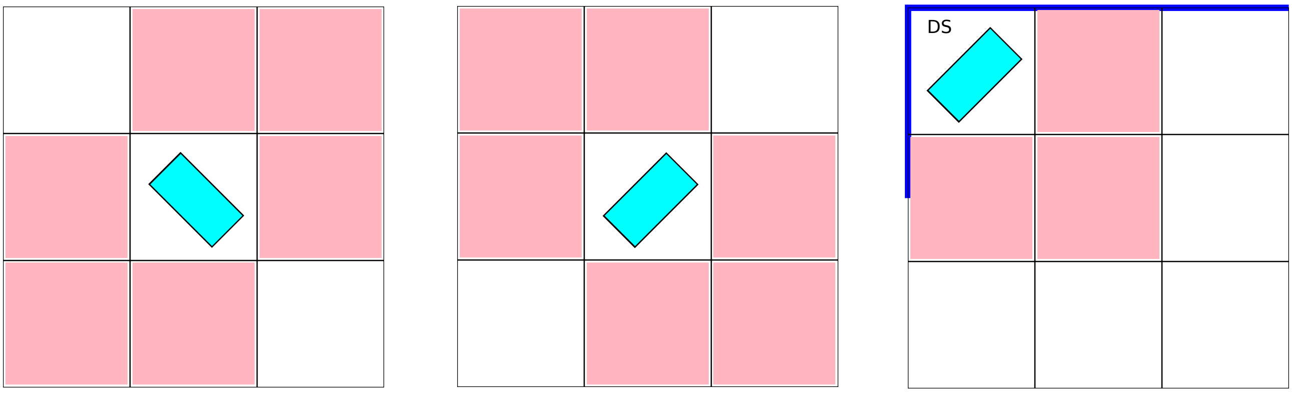
Each machine can be equipped with two *markers* based on ARUCO AR tags, one placed on the input, another one on the output side. Teams can choose whether uniquely identifying markers should be added to their machines or not. In the main track of the RCLL, where two teams compete on the same playing field, Unmarked MPS markers may be used for machines of a team that does not require markers, if the opposing team relies o the presence of markers.

Markers will be horizontally centered below the conveyor belt. The vertical distance between the tag's upper edge and the conveyor belt will be about $35\,\mathrm{cm}$. The markers will be mounted at the same position on all machines in a best effort fashion, but teams should expect slight deviations to their exact position. The markers are available for printing on the rulebook github.[8]

[8] https://github.com/robocup-logistics/rcll-rulebook/tree/master/markers/



(a) For rotations with 0°, 90°, 180° or 270°. BS, CS, RS, and SS block the zones close to the input as well as the output. DS blocks the zones close to the input.



(b) For rotations with 45°, 135°, 225° and 315°. BS, CS, RS, and SS block the zones close to the input as well as the output. DS blocks the zones close to the input.

Figure 6: Blocked zones regarding the MPS rotation (red zones must not be used as position for other machines and must be located inside the competition area).

4.1 Mockup Machines

In case no real MPS stations are available, replications (so called *mockup machines*) may be used, that do not need to physically perform the respective production steps. Instead, that work may be carried out by a human supervisor (see Section 5.4). The minimum requirements for a mockup machine are specified in the following.

Mockup machines are required to have the same box-like base shape as specified in the RCLL rulebook. Additionally, the following parts need to be mounted:

- a model of the conveyor belt
- a shelf on the front right side of the box on stations replicating a CS
- either a shelf, a slide or a conveyor belt on the front right side of the box, such that it is accessible from the front on stations replicating a RS

Models for a conveyor belt, shelf and slides can be found in the RCLL rulebook repository.[9]

The building materials for the models must be opaque, but may have any color.

`numbered_markers.pdf`

[9] `https://github.com/robocup-logistics/rcll-rulebook/tree/master/mock_up_models`

5 Game Play

At the beginning of each match, the refbox must be configured according to the game mode specification. To guide the match, the refbox utilizes different phases, which are outlined in the following sections. Within the different game modes in the RCLL (see Section 8.1 and Section 8.2), different phases might be utilized. Regardless of the game mode, all matches will start at the exact time scheduled by the Organizing Committee in the setup phase (cf. Section 5.1).

5.1 Setup Phase

Once the refbox is initialized, it switches to the setup phase. All robots which are to participate in the game need to be in the insertion area during the setup phase (not in the game area where the machines are located). During the setup phase, the refbox announces the layout of the competition area, including the ring colors assigned to the ring stations to the referees. Machine positions are not communicated to the robots yet. The competing team(s) may use the setup phase to start up their robots and to fill their machines (see Section 5.4.4). Once the setup phase ends, no more interference (physically or remotely) with the robot is allowed. The robot(s) must react to the refbox game state messages and start the game play autonomously. The refbox will automatically end the setup phase

		Input		Output	
	Machine	ID	Tag	ID	Tag
Cyan	CS 1	102		101	
	CS 2	104		103	
	RS 1	112		111	
	RS 2	114		113	
	BS	122		121	
	DS	132		131	
	SS	142		141	

		Input		Output	
	Machine	ID	Tag	ID	Tag
Magenta	CS 1	202		201	
	CS 2	204		203	
	RS 1	212		211	
	RS 2	214		213	
	BS	222		221	
	DS	232		231	
	SS	242		241	

Machine	ID	Tag
Unmarked MPS (UMPS)	301	

Table 4: Machine tags are ARUCO tags (from the original ARUCO dictionary, 5×5 bits, 1024 markers) with the given IDs.

after 5 minutes. Production phase follows.

5.2 Production Phase

During the production phase machines can be used to assemble products according to dynamically arriving orders. The refbox publishes information regarding products and machines. This includes configured colors at the ring stations and their prices. Depending on the played format, machine zones and orientations may be announced as well. A minimum of zero points will be accounted for the production phase.

5.2.1 Exploration Period

The refbox is tasked with distributing machine information (including position) during the game to the robots of each team. Depending on the game mode, complexity might be increased by using an *exploration period* at the beginning of the production phase. During this period, the positions of the machines won't be announced and the robots of both teams can roam the environment and report their (and only their) machines to the refbox. Correctly reported machines will be rewarded with points and can be used for production. Machines can be identified through two different ways: either by relying on the provided unique tags, or by using visual object classification methods. Teams are free to choose which method they will use, but the decision needs to be announced to the judges before the machine setup begins. Depending on the team's choice, the machines of a team will either be equipped with unique tags (should the tag based approach be chosen) or UMPS tags. Points will be awarded for correct discoveries regardless of the chosen difficulty. The scoring is shown in Table 6.

Moving or processing workpieces at an MPS is explicitely allowed during the exploration period. As soon es the necessary machines have been correctly identified and reported to the refbox, production of announced orders or machine preparation can immediately begin.

Reports are issued to the refbox using a *MachineReport message*. For each machine, identified by its name, both its zone and its orientation (in degrees) can be explored. Both properties can be submitted at the same time in one message or be split up into multiple messages. The refbox accepts only the first submitted value for each property. For a detailed description of the message please refer to the refbox wiki.[10]

The exploration period ends automatically after the time span has passed. Its end is marked by the distribution of machine position information from the refbox to the robots.

5.2.2 Workpieces

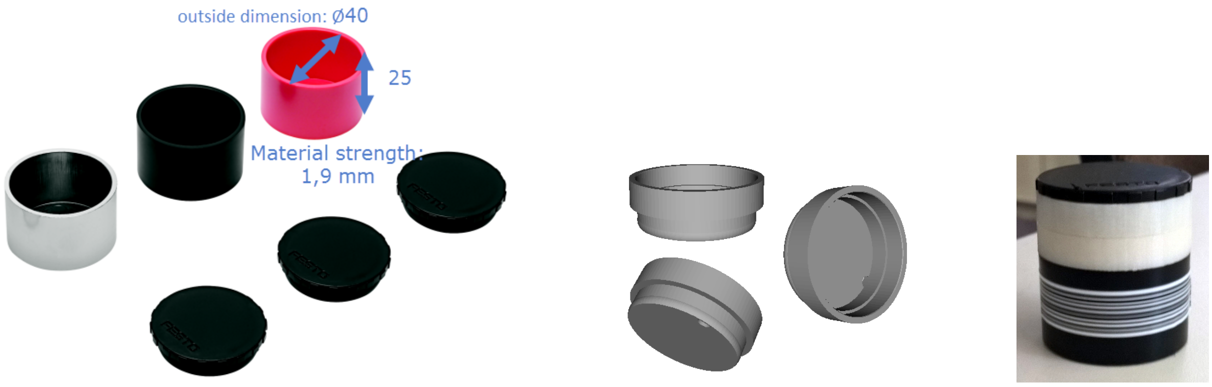
Workpieces denote raw materials that need to be refined through production steps. They consist of the following elements:

Base The base is the lowermost element of each workpiece. Bases are dispensed by the Base Station (BS) and bases with mounted caps are available on the Cap Station (CS). Bases are available in the colors red, black, silver, and transparent. Transparent bases are to be used and only used on CS shelves (cf. Section 5.2.4), they cannot be used as a workpiece for production. They may, however, be used to provide additional bases required by an RS, stored on a team's CS shelf, or recycled at the DS.

Ring Rings are mounted in intermediate production steps at the Ring Station (RS).

[10] `https://github.com/robocup-logistics/rcll-refbox/wiki/Communication-Protocol`

Cap Caps are the topmost element of each workpiece. They are obtained by taking pre-assembled base-cap combinations available on the shelf to the Cap Station (CS). Caps can be black or gray.



(a) Workpiece base elements and caps.

(b) Renderings of intermediate rings (rings are colored in competition).

(c) Prototype base barcode

Figure 7: Workpiece elements and product example.

Barcodes. All bases are labeled with a horizontally encircling, white glossy tag containing a white reference area as well as an identifying UPC-E barcode. Each base is equipped with a unique ID. Figure 7(c) shows a prototype of a barcode labeled workpiece.

The barcodes can be scanned at each station via attached barcode scanners and communicated to the refbox. The refbox can use this information to track assembly processes, i.e., to determine the state of a workpiece. However, this feature is only available, if the scanners are attached to the machines, which may not be the case as this system is still under evaluation.

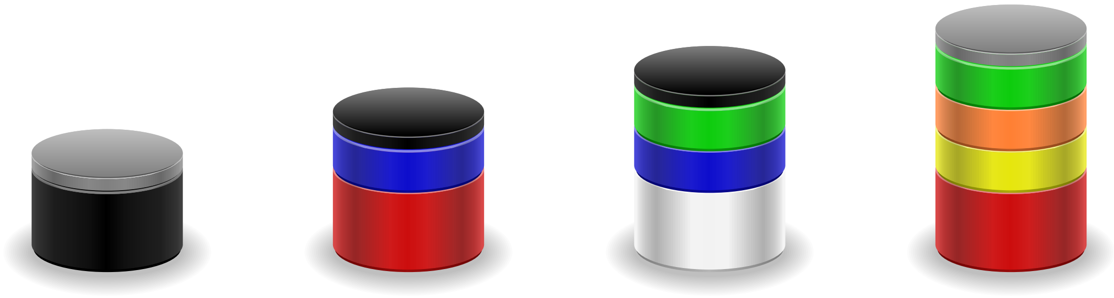
5.2.3 Production, Color Complexities, and Additional Bases

The product portfolio comprises many different variants and is categorized by the four available *product complexity* levels shown in Figure 8. The lowest complexity C_0 consists of just a base and a cap and requires to load the CS with the proper cap color and then processing a properly colored base at that machine. The highest complexity C_3 requires a base with three mounted rings and a cap. For a product, the colors of base, rings, and cap as well as the order of the rings are of importance.

Depending on the ring color, the robot may need to deliver one or more *additional bases* to a RS first in order to enable it to mount the ring. We therefore distinguish *color complexities* as CC_0, CC_1, and CC_2 depending on whether zero, one, or two additional bases are required for a color.

Each order will consist of the product variant to produce, the amount thereof, and a delivery time slot. An order therefore specifies a production chain to be accomplished for fulfillment. Figure 9 shows some example production chains of the four different complexities (cf. Figure 8).

Products retrieved from the Storage Station may be used only for C_0 orders with a requested quantity equal to or greater than two. An order can be *competitive* or *non-competitive*. For a competitive order, the team that delivers it first will get extra points (cf. Section 5.3). For a non-competitive order, each team scores independently of the other team.



(a) C_0 (b) C_1 (c) C_2 (d) C_3

Figure 8: Products are composed of a base element and a cap with zero, one, two, or three intermediate rings representing the product complexity. The complexity level is stated as the number of required intermediate rings. The base element colors are red, black, and silver, the ring colors are blue, green, yellow, and orange, and the cap colors are either gray or black.

5.2.4 MPS — During Production Phase

In the production phase a production machine performs refinement steps on a product such as mounting an additional ring or a cap. Machines operate in a transaction style. That is, before using a machine it must be prepared for a specific mode. Then the input products can be fed into the machine and the refinement step commences. Eventually, after the production period is completed, the resulting product is delivered on the output lane.

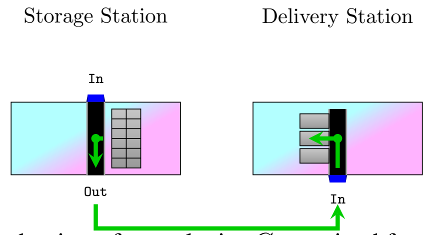
A light signal mounted near the output lane (cf. Section 4) indicates the state of the machine. The light signals are summarized in Table 5.

In the production phase, machines must be prepared to be used by instructing the refbox. This applies to all machine types. If a product from the input is required for the processing step (DS, CS, RS and a storage operation at the SS), then the conveyor belt is started after receiving a prepare message. If no workpiece reaches the machine operating point (indicated through the middle belt sensor) within $45\,\mathrm{s}$, the machine goes to a temporary out-of-order state (cf. Section 5.2.5). The BS and the retrieval operation at the SS cause the requested workpiece to be dispensed upon receiving a prepare message. After performing an operation at the BS, CS, RS or the SS (in case of a retrieval) the conveyor belt is started. If no workpiece reaches the destination point (indicated through the output belt sensor, or in case of the BS either the input or output belt sensor) within $90\,\mathrm{s}$, the machine goes in a temporary out-of-order state (cf. Section 5.2.5). The workpiece may remain on the machine for an arbitrary time after the operation is completed.

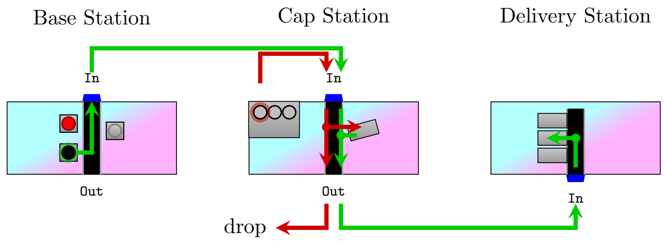
The following describes the communication and reactions of the machines during the production phase. For the actual messages we refer to the refbox documentation (see Section 1.2).

Base Station The BS prepare message denotes the color of the base element that should be dispensed. After receiving the message, the refbox will instruct the MPS to immediately provide a base of the desired color.

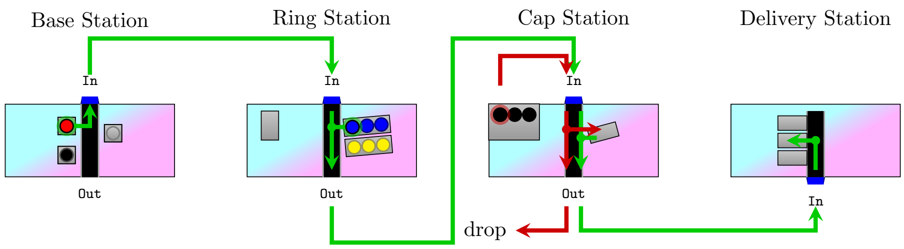
Ring Station The RS prepare message must state which of the two colors to prepare and retrieve. Each RS is responsible for two specific colors. Some colors require loading the RS with additional bases (cf. Section 5.2.3). If the desired color requires additional bases, the machine expects to receive them first. It is required to wait at least 5 seconds between subsequently loading bases into a RS slide as the sensor may trigger multiple times during a loading attempt, which is why the read data must be filtered. Once the required number of additional bases has been received, the intermediate product can be fed into the machine. It receives a ring of the desired color and moves the processed product to the output.



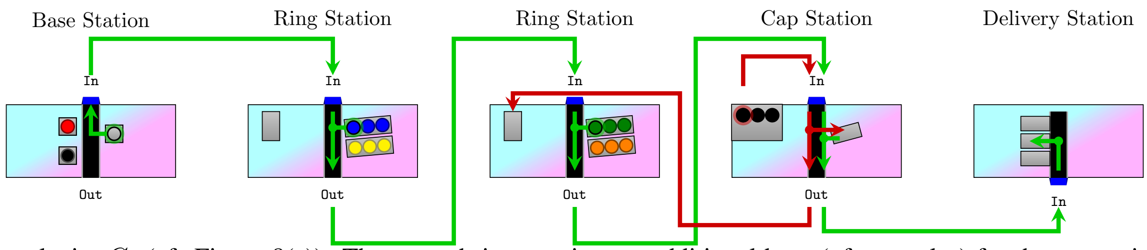
(a) Production of complexity C_0 received from a SS.



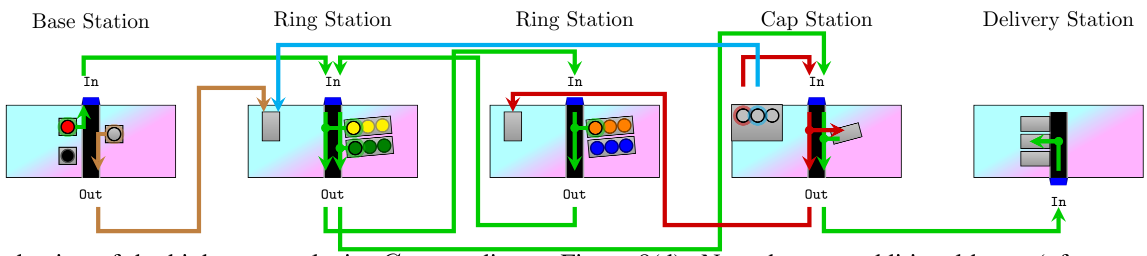
(b) Production of complexity C_0 as shown in Figure 8(a). A cup must be buffered at the CS (red path) before a cap can be mounted on the product (green path). The remaining cap-less carrier is not needed for the product.



(c) Production of complexity C_1 according to Figure 8(b).



(d) Complexity C_2 (cf. Figure 8(c)). The second ring requires an additional base (of any color) for the green ring. The cap-less carrier is used as payment in this example.



(e) Production of the highest complexity C_3 according to Figure 8(d). Note that two additional bases (of any color) are required to pay for the green ring and another one is needed for for the orange ring. A cap-less carrier (red arrow), a capcarrier (blue arrow) and a fresh base from the BS (brown arrow) are used in this example to fulfill the payments.

Figure 9: Production Chains of four example products (cf. Figure 8). Green arrows show the product path from start to delivery, red arrows show the path of a capcarrier that is used to buffer the CS. *Note that this is a particular example. The actual production chains and requirements for additional BEs are determined randomly by the refbox for each game and steps such paying BEs can be accomplished in different ways.*

Cap Station The CS prepare message initiates either the retrieval or the mounting of a cap. For retrieving a prepared base (with a cap mounted on top) from the machine's shelf must be fed into the machine. All base elements prepared on the shelf are specially colored workpieces (clear). The machine will take the cap off the base and buffer it on the slide, releasing the decapped base to the output side. This base can only be used for providing an additional base to an RS (see below), reuse by placing it back on the shelf, or discarding it at the DS. For mounting a cap, a workpiece (without cap) must be provided onto which the cap is mounted.
Delivery Station The DS prepare message denotes the order ID of the product that is delivered. The DS will consume any workpiece provided, but points can only be scored if the delivered workpiece fulfills the requirements of the provided order ID (see Table 6). The special order with ID 0 can be used to remove (partial) workpieces from the field through the delivery station. If the delivery window of the supplied order ID has not started yet, then the machine will wait until the delivery start time is crossed before processing the consumption.
Storage Station The SS prepare message denotes the storage place (shelf and slot number) and the type of the operation that should be performed. The SS consists of six shelves with eight slots each. Figure 10 depicts how positions are mapped to their respective shelf and slot numbers $(x, y), x \in [0, 5], y \in [0, 7]$. Accessing a slot $(x, y), y \in \{1, 3, 5, 7\}$ in the back of a shelf while slot $(x, y-1)$ is occupied causes the SS to relocate the product at $(x, y-1)$ to a randomly chosen accessible position before processing the instruction. If all other free positions are located in the back and are also blocked by products stored in front of them, then one of those free positions (x', y') is chosen and $(x', y'-1)$ is relocated to (x', y'), before relocating $(x, y-1)$ to (x', y'). Descriptions can be added to the prepare messages when storing workpieces. These descriptions are attached to the position of the workpiece and updated automatically when relocating operations happen. Each team receives the storage status for their respective SS periodically, including the corresponding descriptions at each position. Positions and configurations of pre-stored products are also announced through storage status messages. Note the costs for using the SS outlined in Section 5.3.

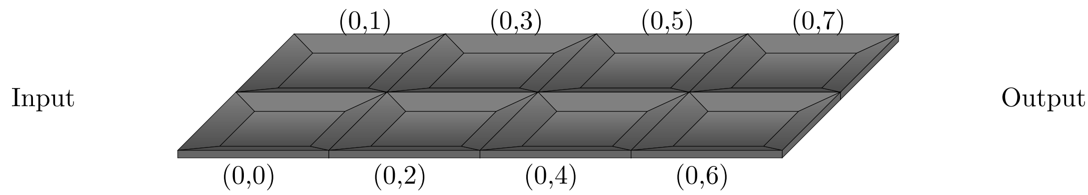


Figure 10: The bottom-most SS shelf. Position (x, y) consists of shelf number x and slot number y. Shelves are numbered in ascending order from bottom to top.

The preparation and use of a machine follows a transaction style. Once the machine has been prepared, the full cycle can be completed (committed). There may be only one transaction running at a time. If a second preparation is performed the machine will be temporarily broken, which causes it to recover to a determined state. An MPS may be reset by a team at any time by a dedicated msg. This causes the MPS to go into the broken state as well.

5.2.5 Broken Machine Downtime

If a machine is improperly instructed or used, or a reset message has been sent, the machine will go into a failure state. The machine cannot be used for 30 seconds and until repaired. This includes interactions with shelves, conveyor belts, or slides. That is, if damage was inflicted on the machine or the referee needs longer to repair the machine the game continues and the machine will be offline

Light Signals			Description
RED	YELLOW	GREEN	
ON			Machine is DOWN, temporarily unavailable
	ON		Report received, not processed yet
		ON	Machine is IDLE and usable
		BLINK	Machine is PREPARED
	BLINK		Zone reported correctly
ON	ON		Zone reported wrongly
	ON	ON	Machine is processing
ON	BLINK		Rotation reported wrongly
	ON	BLINK	Machine is READY-AT-OUTPUT
BLINK	BLINK		Machine was wrongly instructed, it is currently BROKEN
	BLINK	BLINK	Machine is WAIT-IDLE, soon to be IDLE again

Table 5: Light codes for each machine status during the production phase.

for a longer time. Any production that was running will be aborted and any product which was being processed or placed into the machine's input or output is no longer available and will be removed by the referee. Any additional bases or caps buffered at the machine will be void and the points gained removed. For storage stations, no slot is refilled, the load status remains exactly as before the broken state. The downtime is indicated by a flashing red light.

5.2.6 Scheduled Machine Downtime

Depending on the game format, the refbox may take down RS and CS machines at random. If two teams play at the same time, then the same machines for both teams are affected in the same time window. The machines affected will remain out of order for 30 to 60 seconds. Every machine can only be forced out of order once per match. If a machine turns offline during processing of a product it will afterwards resume the process (extending the overall processing time by the duration of the time spent offline). The downtime is indicated by a steady red light. Base elements fed into the machine while out-of-order are accepted when the machine gets back online, with the same constraints mentioned in Section 5.2.4.

5.3 Task Fulfillment and Scoring

During the production phase, points are awarded for intermediate production steps and final delivery of goods according to Table 6. Points for production steps are awarded as soon as they are verified. This depends on weather the barcode tracking system is deployed on the stations or not.

If the tracking system is used, the refbox automatically can verify that issued machine instructions actually belong to an active order. Therefore, points are only awarded if there is an order for which the performed step is required and which has not yet expired (the end of the order time window has not yet passed) and for which the step has not been performed for as often as products have been requested. For example, consider a C_1 order with a single ring of which two products have been requested. When the appropriate ring of that C_1 product is mounted, the appropriate points (for finishing a C_1 pre-cap) are awarded if and only if the end time of the delivery window of that order has not passed and the step has not been completed more than two times (including the just performed step). Therefore, only production steps which can be determined to belong to an upcoming (and announced) or on-going order can be awarded. Performing a step for a later order which has not yet been announced cannot be awarded.

If the tracking system is not available, then the production steps are verified manually by the referee upon delivery. Products, which are not delivered, do not score. That includes half-finished products at the end of the game in particular. Production points are also awarded for later deliveries, that is, points for steps like mounting the cap are awarded in full for as long as there was or is an order active for that specific product if there are still items in the order remaining, i.e., not the full amount of ordered products has been delivered.

Competitive Order Scoring For a competitive order, the same scoring scheme for in-time, delayed, and late delivery applies, with additional points for the successful first delivery and a point deduction for the second delivery (cf. Table 6). The deduction may not exceed the points given for the delivery.[11] Points for production steps are given in the same way as for non-competitive orders. In particular, production points are also given if a team delivers the product after the other team.

Storage Station Costs Storage Station usage is associated with different costs. However, exploration points gained during the exploration can not be used for this. If the team has not yet received sufficient points, the payment can be performed on "(partial) credit". Points that were missing upon preparation will be subtracted later from points scored. Only retrieving and storing induces costs per operation. Points are deducted as soon as the respective operation finishes. All costs are listed in Table 6.

Exploration Period Scoring If the game mode includes an exploration period, machines can be reported to the refbox during the entirety of the duration of the period. Machines cannot be instructed during the exploration period, unless they were correctly reported (meaning, both the zone and rotation were correct). Machine positions will be announced after the end of the period.

For each machine,identified by its name, both its zone and its orientation (in degrees) can be explored. Both properties can be submitted at the same time in one message or be split up into multiple messages. The refbox accepts only the first submitted value for each property. It also sends a *MachineReportInfo* that provides general feedback, but does not contain information about the outcome of the received reports. For a detailed description of the message please refer to the refbox wiki.[12]

The name of a machine can be determined in two ways:

- If the machine has an identifying marker, then the machine name can be retrieved by correctly reading the marker.
- The machine name can alternatively be requested from the refbox, given its zone and type are known. If a *MachineReport* is sent without a specified machine name, but with a machine type and a belonging zone, then the *MachineReportInfo* will contain a corresponding *MachineTypeFeedback* with the name and of the belonging team at that location. If there is no machine of the given type at the specified zone, then this counts as a wrong zone exploration and one machine of that type cannot be reported anymore.

This means that in order to provide a report that scores points, in the case that no markers are used, two reports must be submitted. In the first one, zone and type a specified, to which the refbox replies

[11] As an example, if a team delivers late and scores only 5 points for the delivery, only 5 points will be deducted.

[12] `https://github.com/robocup-logistics/rcll-refbox/wiki/Communication-Protocol`

Exploration Points

Report Type	Description	Points
Machine Name Report	Machine zone and rotation reported correctly.	$+2$
	Machine zone reported correctly, rotation not specified.	$+1$
	Machine zone reported correctly but orientation wrongly ($1-1=0$)	0
	Machine zone reported wrongly (orientation irrelevant)	-1
Machine Type Report	Machine type and zone reported correctly (machine name is revealed)	0
	Machine type and zone reported wrongly	-1
Round Total	A maximum of 14 points can be achieved by correctly reporting all 7 production machines.	0 to 14

Production Points

Sub-task	Production Phase	Points
Additional base	Feed an additional base into a ring station	$+2$
Finish CC_0 step	Finish the work order for a color requiring no additional base	$+5$
Finish CC_1 step	Finish the work order for a color requiring one additional base	$+10$
Finish CC_2 step	Finish the work order for a color requiring two additional bases	$+20$
Mount cap	Mount the cap on a product	$+10$
Retrieve cap	Buffer a cap into a cap station	$+2$
Retrieve from SS	A workpiece has been requested from storage and is ready for retrieval	-5
Store at SS	A workpiece is stored into the SS	-5
Delivery C0	Deliver a product of complexity C0 to the designated loading zone	$+20$
Delivery C1	Deliver a product of complexity C1 to the designated loading zone	$+30$
Delivery C2	Deliver a product of complexity C2 to the designated loading zone	$+50$
Delivery C3	Deliver a product of complexity C3 to the designated loading zone	$+100$
Delayed Delivery	An order delivered after its delivery deadline is penalized. The penalty is a fraction of the points P_d scored upon delivery and it depends on the actual delivery time T_d and the delivery window $[T_s, T_e]$. Starting with a penalty of 15%, it increases by the same amount for every $\frac{T_e - T_s}{5}$ seconds passed since the delivery window end T_e up to the actual delivery time T_d. However, the penalty is capped at a maximum of -75% of P_d.	$-15\% \cdot P_d$ $-30\% \cdot P_d$ $-45\% \cdot P_d$ $-60\% \cdot P_d$ $-75\% \cdot P_d$

Wrong delivery	Deliver one of the final product variants after all products requested have already been delivered or deliver a unrequested or unfinished product	0
1st competitive delivery	Points for the first delivery for a competitive order. The score is given in addition to the points for the regular delivery.	$+10$
2nd competitive delivery	Point deduction for the second delivery for a competitive order. The points are deducted from the delivery points, the total cannot be less than 0 points.	-10
Dropping a workpiece by a robot	Dropping a workpiece on the floor of the field intentionally or through failed grasping attempts. Cases in which the workpiece falls after it was properly handed over to a machine are not considered intentional (e.g. a workpiece overshooting on a slide or an output sensor malfunctioning).	-10
Obstruction	Deliver a workpiece to a machine of the opposing team	-20
Round Total	A minimum of 0 points is awarded.	≥ 0
Commentary Points		
Task	Game Commentary	Points
Accepted Commentary	Commentate at least one half of the game continuously on microphone in English (or the local language of the venue) to the public	+10

Table 6: Scoring Schemes

with the machine name. The information can be used to create a partial or full report for the machine name to claim points. The scoring is shown in Table 6.

5.4 Human Responsibilities During a Match

During a match and while the robot is active on the field no manual interference or manipulation of the robot in hardware, software, configuration, instructions, or whatsoever, is allowed. Teams may visualize robot data on computers at the field, but existing input devices must be covered with a sheet of paper in order to assert a fair game without manual interference.

While the game tasks must be handled by autonomously acting robots, there are cicumstances, where human interference is allowed or even required. This section describes which rights and obligations teams, referees and refbox operators have during a running games.

No team member is allowed to enter the competition area prior to or during a match, except in cases of robot maintenance (cf. Section 5.4.3) or machine refill (cf. Section 5.4.4).

5.4.1 Referee Box Operator

The refbox operator runs and oversees the refbox. The operator is responsible to

- properly configure the refbox to the current game format,
- observe the refbox status to ensure the correctness of the digital representation and automatic scoring,

- manually confirm delivered orders (if workpiece tracking is disabled),
- manually score interactions that can not be automatically tracked (e.g., dropping workpieces),
- announce critical situations to the field referees (e.g., if a machine that is mocked up as described in Section 4.1 is instructed and needs manual operation),
- start and stop the game on request of the field referees,
- manage robot maintenances: They confirm with the field referees that the maintenance is granted, enter them into the refbox, observe the time remaining to bring back a robot, or announce if a robot may no longer participate in the game.

5.4.2 Field Referees

Field referees observe the field, announce rule violations (cf. Section 9), and communicate with the teams and refbox operator. There are always two field referees per game, announced through the schedule by the Organizing Committee. The referee named first on the schedule is the head referee and has the upper hand when there is a referee disagreement and then announces the final decision. If two teams compete on the same field, one field referee is assigned to a particular field half. The head referee is assigned to the primary side of team cyan, while the secondary field referee is responsible for the primary side of team magenta.

Field Observation The field referees observe the game from the side of the field or from any position on the field (e.g., to better understand the game situation). They shall avoid robots spatially on the field, but ultimately robots are expected to avoid collision with human referees. Field referees also need to observe machine processing steps, validate that the machines work as intended or correct minor operation failures manually. Operation failures may only be corrected if they are not caused by the robots. It is up to the referees to decide wether an operation failure was caused by a robot or the machine. In case a machine is mocked up through the refbox, the field referees are responsible to manually perform the assembly steps as announced by the refbox operator. Field referees are also responsible for removing fallen products from the playing-ground and observing the correct refill procedure for machines (see Section 5.4.4).

Robot Maintenance Field referees are responsible for making the decision whether a team may take out a robot for maintenance. They should judge the game situation carefully and should allow the robot to be taken out for maintenance, if the calling team would not have any advantage in the current game situation from taking out the robot. An advantage would be, for instance, to take out a robot, if two robots of the same team are hindering each other. It is up to the discretion of the referee when to allow the robot maintenance.

Another reason for maintenance is a *misbehaving robot* (see Section 9.3.1). Several infringements in this rulebook demand that the robot be taken out, e.g., leaving the field (cf. Section 3.3). If a robot needs to be taken out for the third time, either on request or as decided by the referee, it is disqualified from the current game. It may no longer communicate with the still active robots and must be taken out of the competition area.

Any workpiece carried carried by a robot that is put in maintenance is to be removed from the game by the field referees.

Game Pause Each referee may call a pause of the game at any time, e.g., if robots must be penalized or disentangled after a collision. Referees may explicitly pause the game to convene and discuss an unclear situation as to avoid hasty decisions. Such pauses shall be short-lived as to follow the competition schedule.

After the game is paused, all robots have 3 seconds to stop any movement. Robots that do not stop within the time limit are considered misbehaving robots and are punished accordingly (see Section 9.3.1). The match time will be paused during the interruption.

5.4.3 Performing Robot Maintenance

Each team is allowed to maintain each robot twice per game. The first maintenance per robot is free, while the second maintenance for any robot needs to be purchased costing 5 points. If a team has not yet received sufficient points, maintenances can also be purchased on (partial) credit. The remaining points can be deducted from points that are scored later in the game. The score for both exploration- and production-phase cannot become negative due to using additional maintenances.

Teams have to call upon the field referees for *robot maintenance*. Up to two team members are allowed to remove a robot from the field. Or the robots may be driven out manually by remote control using a joystick, gamepad or similar. Human commands must be mapped directly to motion commands, no autonomous driving is allowed. In both cases (driving out and taking out) the robot must leave the field through the closest opening in the wall unless this would interfere with the game. In that case, the next closest exit may be chosen (referee decides). The robot need to be carried to the insertion area for re-participation.

The repair time may take at most 120 seconds, starting from the moment of driving or taking out the robot. After a robot has been taken out for the first time, the team can perform any repairs to the robot and/or the robot's software. To return the robot into the game, the team asks the referee to place back the robot onto the field. After the referee accepts the motion, the team has 15 seconds quick setup time, which is limited to basic instructions like initial localization or software start-up. The robot may leave the insertion area onto the field (autonomous driving). If the robot is not returned to the field in time, it is disqualified from the ongoing game.

5.4.4 Machine Refill

The teams are responsible for restocking all materials (base elements, rings, prepared caps on shelves, and C_0 in the SS) before and during matches. Each team has to designate one team-member as a *"replenisher"* who must be specified to the corresponding referees ahead of each game. Only this team member will be allowed to access the field area in case of a refill procedure. The replenisher must not obstruct other robots and should interfere as little as possible. The machines can only be refilled when a magazine or shelf is empty. In this case the replenisher may enter the competition-area without asking the referee. Shelves have to be (re-)filled in all three reachable slots. The replenisher may restock only caps if transparent base elements have been put back to the shelf, once no cap is remaining on this shelf. Ring station slides must be emptied once three payments are inserted to avoid overflowing slides.

The teams are partly free to choose their assembly and placement of products. For example, teams can fill any number of bases into a BS or are free to choose the color of caps for a CS. However teams are only allowed to fill the CS if the whole shelf is empty and then it has to be filled completely. The color assignment of bases on the BS and SS must be obeyed, as otherwise they will deliver the wrong bases. Similarly, ring color assignments at the RS must be respected according to the refbox announcement.

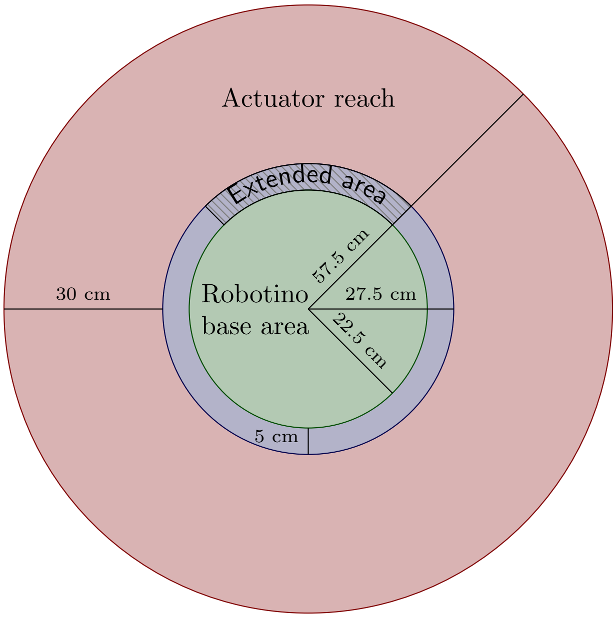


Figure 11: Robot dimensional constraints (top down view).

6 Hardware Specification

All participants have to design their competition robots within the following specifications.

6.1 Robot Dimensions

The robots dimensions (including sensors, computing equipment, etc.) must be within a cylindrical bounding box with maximum total height of $1.6\,\mathrm{m}$ (relative to the ground) and a diameter of $0.55\,\mathrm{m}$ (centered at the robot's rotational center-point, green *Robotino base area* plus blue *Extended area* of Figure 11) during regular operation. While in front of a machine and during a production process, the gripper may be extended up to $30\,\mathrm{cm}$ beyond the bounding box (red *Actuator reach* of Figure 11). But it is only allowed to reach a maximum of $15\,\mathrm{cm}$ into the machine area.

There are no set weight limitations, however teams must be able to manually carry their robots from the field with at most 2 people in case of major failures.

6.2 Sensors and Actuators

Any kind of sensors can be changed or added to the robot platform. However, it is not possible to implement sensors that require modifications outside the Robotino area (e.g., Northstar, indoor GPS). The only additional actuator allowed is one gripping device for workpieces which can be the original or a modified one. In the resting position and while driving it also must not exceed the robot diameter by more than this 5cm, including workpiece. Only one workpiece or a composite product must be grasped and transported per robot at once. Storage magazines on the robot or similar are prohibited. All products will incorporate exactly one base unit allowing a single unified handling device to be used for all operations involving workpieces.

The gripper is allowed to transport one workpiece at a time. And it must release the workpiece for safety whenever the referee wants to take out it.

6.3 Additional Computing Devices

It is allowed to install additional computing power on the Robotino. This may either be in form of a notebook/laptop device or any other computing device that suits the size requirement of the Robotino competition system. Furthermore, it is allowed to communicate with an additional computing device off-field. This device may be used for team coordination and/or other purposes. However, communication among the robots and the off-field device is not guaranteed during the competition.

6.4 Robotino-Specific Regulations

The following regulations are only applied to robots participating in the main track of the RCLL, those are required to use the robotino platform. For a detailed technical description of the basic robotino hardware, refer to the robotino website.[13]

There must be no changes to the controller or mechanical system. Past the diameter of $45\,\mathrm{cm}$ (the width of the Robotino), additional hardware may only occupy up to 25% of this additional $5\,\mathrm{cm}$ wide ring around the robot (e.g., the dashed part of the *Extended area* of Figure 11).

6.5 Open-Platform Regulations

The following regulations are only applied to robots participating in the challenge track of the RCLL and that are not utilizing the robotino with its original controller and mechanical system.

All robots are restricted to operate with a maximum speed of $1\,\mathrm{m/s}$ to be comparable with the capabilities of the Robotino.

6.6 Markings

All field robots must be assigned a single unique number out of the set $\{1, 2, 3\}$. The number must be written on the robot in one or more places and clearly visible from all directions, e.g., printed adhesive labels placed on top or the sides of the robot. The number must be the same as is announced in the beacon signal to the referee box (cf. Section 7.2).

7 Communication

Robots have to operate autonomously, that is, without any human interference during the game. Communication among robots and to off-board computing units is in principle only allowed using wifi (cf. Section 7.7). If the event regulations set by the venue organizers, organizing committee and technical committee allow it, other wireless communication methods (e.g., broadband cellular) might be used after explicit approval is granted. Communication is not guaranteed and may be unavailable during parts of the game. Interruptions must be expected and are no reason to pause or abort a game, even if they endure for long periods of the game.

7.1 Bandwidth Allocation

No minimum bandwidth is guaranteed. The amount of communicated data over the wifi connection shall not exceed $2\,\mathrm{Mbit/s}$. Even though the lower layers could provide for more bandwidth, the overall available frequency spectrum and wifi channels have to be shared, not only within our own

[13] robotino.com by Festo Didactics.

league. Generally, a conservative use of bandwidth resources is advised. Should a frequently or endured exceedance of the bandwidth limit become known, or if the overall bandwidth limit must be reduced due to outer circumstances, the TC can monitor the network traffic and demand reduction in communicated data as necessary.

7.2 Referee Box Instructions

The refbox is the single point of instruction for robots during the game. After game setup has finished, game state information and orders are announced by the refbox.

The communication from the refbox to the robot is a datagram-oriented broadcast protocol based on Google protocol buffers[14] (protobuf). The protocol definition and technical parameters are described in detail in the refbox documentation (see Section 1.2).

7.3 Remote Control

Remote operation or instruction of any kind of the robots is forbidden at all times during a game. The only allowed interaction is for the start-up (cf. Section 5.1). Any failure to comply with this rule will lead to immediate disqualification of the infringing team.

7.4 Monitoring

Passive monitoring, i.e., receive-only communication from a base station of the robots' performance is allowed. However, the overall bandwidth limit may not be exceeded. If the referee has any reason to belief that a monitoring application might be used for instruction, he can demand the shutdown of the monitoring software (also refer to previous section on Remote Control).

7.5 Inter-robot Communication

Robots currently active on the field can freely exchange any information that supports a coordinated team play. Robots not actively participating in the game, for example because they have been irrevocably removed from the current game, may not communicate with the other robots. It is forbidden to communicate with any sensors that are not physically attached to a robot, including, for example, but not limited to a camera aside the field. Likewise any off-robot actuator is forbidden.

7.6 Communication Eavesdropping and Interference

Communication of another team may neither be eavesdropped on nor be interfered with. Teams not currently active shall disconnect from the field access points.

Monitoring of bandwidth used or of possible misbehavior may only be performed by members of the TC or an appointed delegate. Any indication of misbehavior will be discussed by the team leader convention and may result in penalties or disqualification from the tournament.

7.7 Wifi Regulations

In order to provide the optimal possible solution for wireless communication during the event, all teams are required to use the 5 GHz wifi equipment. They are furthermore required to connect their

[14] Available at `https://code.google.com/p/protobuf/`

Robotinos wifi unit to the access point provided. All teams can also rely on wifi clients supplied by Festo but are not required to. A detailed description concerning the infrastructure can be found in Appendix **??**.

8 Tournament Setup

A tournament in the RCLL is divided into two different tracks. While in the challenge track (see Section 8.2) teams need to complete challenges without direct opposition in order to accumulate points, the main track consists of matches, where two teams directly compete against each other in a full production scenario.

Each tournament starts with a qualification day, where teams can attempt the production challenge (see Section 8.2.10) from the challenge track in order to prove that they have the required prerequisites to participate in the main track. The schedule for each team on the qualification day will be provided by the OC at the beginning of the tournament.

Teams that complete the production challenge can chose the track that they want to participate in, the other teams will compete in the challenge track.

The same field is used for both competition tracks, the OC will provide a schedule for the remaining tournament once the qualification phase is over, where the time slots of both tracks are specified.

In addition to the two competition track, there is also an open challenge, where teams can showcase ideas and innovations that go beyond the scope of the tournament track (See Section 8.3).

8.1 Main Track

Objective of a match is to score the most points according to the scoring described in Section 5.3. Each match is 20 minutes long. The first 3 minute are the exploration period. During this period, machine locations are not shared with the team's robots. After the exploration period is over, the information will be shared through the refbox. With the switch to the production phase, the machine locations (zone position and rotation) are announced.

8.1.1 Field Layout

Games are played on a symmetrical fields, the competition area spans $14\,\mathrm{m} \times 8\,\mathrm{m}$ and each team has one BS, SS and DS as well as two CS and two RS available, so a total of 14 machines are placed on the field. The field shown in Figure 1 is an exemplary field for a game in the main competition.

The machines will be placed mostly on the primary half of a team (cf. Section 3.1). However, some machines will be swapped, that is, some machines will not be located in the primary half: For each game, one CS and one RS of each team will be chosen randomly and swapped with the corresponding machine of the other team on the non-primary half — that is two machines in total per team. The CS and RS will be swapped with the symmetrically positioned machine of the same type of the other team.

8.1.2 Order Schedule

The refbox will announce orders throughout the game in an incremental fashion. The ring colors which require additional bases are randomized per game and announced by the refbox. There will be one color requiring 2 additional bases, one requiring 1 base, and two colors requiring no additional base at all. The ring colors are assigned to the ring stations according to Table 7.

Ring Station	Color 1	Color 2
RS1	ORANGE	GREEN
RS2	BLUE	YELLOW

Table 7: Assignments of ring colors to ring stations.

Complexity	Production Window	Delivery Window
C0	$[\ 60, 120]$s	$[\ 90, 180]$s
C1	$[120, 300]$s	$[\ 90, 180]$s
C2	$[300, 400]$s	$[150, 210]$s
C3	$[400, 500]$s	$[150, 210]$s

Table 8: Order time randomization ranges.

In each regular game, up to 10 orders will be posted. Each order will require one product of a specified product type to be delivered. The product is specified in terms of base color, rings (color and order) and cap color. 3 time points are attached to each order: At its *activation time*, the refbox announces the order to each team along with a *delivery start time* and a *delivery end time* (deadline).

At the beginning of the game, 2 orders are announced, one with complexity C0 or C1, the other with complexity C2 or C3. In any case, the first ring (if any) of either of this two orders is of color complexity CC_0 (costs no additional bases to mount).

The remaining 8 orders are dispatched throughout the game according to the following criteria:

- 50% are of complexity C2 or C3, the other 50% are of complexity C0 or C1. Hence the complexities of orders will be similar for all games within a tournament phase. But the actual production chains are randomized.
- Exactly one order is competitive, while the remaining orders will be *non-competitive*.
- The activation times are roughly evenly spaced between minute 3 and minute 16 (every $120\,\mathrm{s}$ with deviations of up to $90\,\mathrm{s}$, but always between minute 3 and 16).
- The time between activation and delivery start (production window) is randomized and based on the complexity of the product. Similarly the time between delivery start and end (delivery window) is randomized as indicated in Table 8.
- Color combinations of bases and rings are unique across orders, so it is not possible to have a started product with a ring that could belong to multiple orders.
- Consecutive rings do not have the same ring color. This helps to easily distinguish products from distance.

In case of overtime, an additional competitive order of complexity C0 will be placed.

In each game each team is allowed to fulfill a single order of complexity C0 by utilizing a pre-stored C0 from the storage station. However, the overtime order can not be fulfilled using pre-stored products.

Teams playing on the field at the same time will get the same production plan. However, each game will use a new randomized order schedule.

8.1.3 Scheduled Machine Downtime

There will be exactly two occurrences of scheduled machine downtime for each game in the main track according to the rules in Section 5.2.6.

8.1.4 Overview — Main Track

There will be up to three stages in the main track, a (optional) round-robin phase for all participating teams, playoffs for the best four teams from the round-robin phase, and the finals. The best two teams of the playoffs play the grand finale to decide which team will become the winner of the main track in the RCLL, whereas the other two teams compete in the small final for the third place.

Scoring Scheme The scoring scheme in the round-robin phase and the playoffs is based on a ranking score per won games. As each team in this phase directly competes with an opposing team, a ranking score will be determined as follows. In each *game*, the winning team gets 3 ranking points, the loosing team gets 0. A team wins if it achieves more points in the game than the other team (cf. 5.2). In the case of a non-zero draw, see Section 8.1.5 for overtime. If, after overtime, a draw is not resolved, both teams get 1 ranking point. If both team end with a zero score, each team gets 0 ranking points. Points awarded for commentary are not considered in this decision.

Ranking The *overall ranking* is determined by the sum of the ranking scores of each team in descending order, highest first. If two teams have the same score, the overall total in-game points are summarized and the team with more game points ranks higher. If there still is a draw, the direct comparison of the games of the two teams is used to break the tie. If this still is unsuccessful, a coin toss determines the higher ranked team.

Round-Robin phase If more than 6 teams participate in the main track, a preliminary round-robin phase will be played. The ranking points will be accumulated and the teams will be ranked according to the accumulated points in descending order. Depending on this order, only the first 6 teams are qualified for the Playoffs. In case of a tie, the scored in-game points across the played games are accumulated and used as tie-breaker. As a last resort a coin flip decides about the order.

Playoffs The play-offs can be played in one out of two modes, depending on the number of qualified teams.

- 6 Qualified Teams

  Qualified teams will be divided into two groups of three teams each. The first group will be composed of the teams that ranked first, fourth, and fifth in the Round-Robin phase respectively. The second group contains the teams that ranked second, third, and sixth. Within each group, each teams plays against all other teams (round-robin).

- Less than 6 Qualified Teams

  All qualified for the Playoffs are added to a single group and play in round-robin fashion each team against all other teams. Depending on the number of teams each encounter may be decided through multiple matches, such as best-of-3 or best-of-5 formats.

Finals The best teams of the two playoff groups (or the two best teams in case of one group) will advance to the grand finale, the remaining two teams will compete in the small finals for the third place. The team that scores more points after the regular game time wins. If there is no winner after the regular time, refer to Section Section 8.1.5. If after this there is still no winner, a coin toss will decide.

The detailed seeding will be created at the event. Although the idea is to allow each participant to challenge each other team, the league can be adjusted to meet time requirements.

8.1.5 Overtime

Starting with the play-offs phase of the tournament the game must be won by one of the teams by a higher score. If after the regular game time there is a draw, the game will automatically and without interruption be extended by 5 more minutes, unless both teams scored zero points (points awarded for commentary are not considered in this decision). If after five minutes there is still no winner, the team scoring the first points during the extension will win.

8.1.6 Game Commentary

In addition to scoring the production phase, points are also awarded if a team provides an commentary on microphone to the public throughout the game as stated in Table 6. The commentary should communicate the overall problems to be solved within this league, the actual events taking place, but also give an insight on the own team and how they solved certain tasks. It does neither have to be perfect, nor to be a flawless stream of information. The commentary should be continuous, but short pauses are acceptable. At the end of the game the referees decide if the commentary duties were met. If both teams are willing to commentate on the game, the game time is shared according to the team specification (e.g., team 1 commentates the first half, team 2 the second half). However, the teams can also make custom arrangements to split the overall time.

8.2 Challenge Track

This track is organized as a competition on a pool of challenges, where teams can decide to participate in any number of those.

The objectives of this tournament format are:

- to provide a framework that allows teams to show and evaluate their progress in the individual tasks of the RCLL,
- to ease the preparation for the main track through providing a simplified cost- and space-efficient setup suitable for replication in local labs,
- and to be attractive for both RoboCup live events and online competitions, where teams can participate remotely from all over the world.

8.2.1 Field Layout

Challenges are played on fields, where the competition area spans $5\,\mathrm{m} \times 5\,\mathrm{m}$ and only one team participates at a time. The field depicted in Figure 2 depicts a valid competition area for a match. Up to four MPS may be placed on a field, depending on the chosen challenge.

8.2.2 Remote Setup

In case a competition is carried out remotely, a rule-compliant local setup has to be established. Requirements include a camera setup that covers the field sufficiently such that external viewers can verify the integrity of each of the challenges, a screen recording of the corresponding refbox frontend, as well as an approval for every mockup machine and robot that is used. To ease the setup, rules regarding required wall segments at the field borders are suspended in remote competitions. When challenges are played remotely, a recording of each run (which includes the logs from the refbox, the video of the field and the screenrecording of the refbox frontend) must be submitted to the OC. The video proof should be sufficient in quality such that general game integrity can be verified.

After registration the OC will verify the field setup in a video call. The validation call will be scheduled individually for each team to account for timezones. Remote participation is only allowed after the setup has been approved and only with the approved setup.

8.2.3 Overview — Challenge Track

The challenge track offers a set of individual challenges that need to be solved throughout the official competition days. The available challenges are defined in Section 8.2. Points can be earned by solving challenges, where the amount of points varies depending on the difficulty and task of the challenge. The team with the most points by the end of the last competition day wins the tournament.

8.2.4 Online Format

For the online competitions each team can book official attempts by announcing a 30 minute time slot along with the attempted challenge in advance of the respective competition day. The booking procedure is managed by the OC. Each slot can be used to do at most one challenge and the corresponding challenge is carried out according to the following procedure:

1. The refbox is configured for the respective challenge and in case the challenge is carried out remotely, the live stream is started. The `SETUP` phase begins, see Section 5.1.
2. Then the `PRODUCTION` phase starts by instructing the referee box accordingly. During the production phase the team has 20 minutes to solve the challenge. The challenge must be terminated before the 30 minutes of the time slot end, otherwise the attempt will be counted as a failure.

A team may retry the challenge by

1. setting the refbox back to the setup phase
2. resetting the field setup accordingly
3. and then starting the production phase again.

Only the last attempt in each slot can be counted. A team may decide to count no attempt at all. Once a challenge is counted, it may not be retried again, unless the difficulty is increased. In order to complete an attempt, the refbox needs to be set to phase `POST_GAME`.

All challenges are conducted while measuring the execution time of the corresponding attempt, starting from the begin of the `PRODUCTION` phase and ending at the begin of `POST_GAME`.

Bonus Points for Fastest Challenge Completion The fastest team to complete a challenge on the selected difficulty gains 5 additional points. A challenge is only completed if the full score is achieved, so getting only partial credits for a challenge disqualifies from getting the bonus points for the fastest completion.

8.2.5 Changes compared to the Main Competition

The tasks covered in the various challenges of Section 8.2.6 have to be executed following the regular rules for the RCLL. However, some aspects are altered to simplify the setup.

Product Delivery To reduce the amount of machines required for participation, it is possible to bring the finished product to the insertion area and drop it there, instead of bringing it to a delivery station. A team has to specify the type of delivery before the challenge starts.

Ring Color Assignment The cost for mounting each ring color are fixed, the assignment of ring colors is semi-fixed as teams can choose between two different options for each challenge (`option1` or `option2` according to Table 9). The refbox settings default to `option1`, but teams may change this accordingly.

	Ring Costs				Color Assignment	
	Color	Price	Color	Price		
	Yellow	0	Green	0	RS1: $\mathcal{RC}_1$	RS1: $\mathcal{RC}_2$
	Blue	1	Orange	2	RS2: $\mathcal{RC}_2$	RS2: $\mathcal{RC}_1$
Configuration	$\mathcal{RC}_1$		$\mathcal{RC}_2$		`option1`	`option2`

Table 9: Fixed ring costs.

Materials The available material that can be used per challenge is restricted (unless stated otherwise) per machine according to the information in Table 10.

Machine	Available Material
BS	2 bases of each color
CS	3 cap-carriers (cap color choices up to each team)
RS	4 rings of each assigned color (8 in total)

Table 10: Materials

Orders Orders to be fulfilled in challenges can be chosen by the competing team by either ordering them through the webshop[15] or by configuring them in the refbox directly.

In challenges where only one RS is present, teams are responsible to order products which can be assembled using the available stations only.

Scoring While the refbox may assign points during challenges according to the regular RCLL rules, those points do not count towards this competition. Instead, the point scoring for each challenge is listed in Section 8.2.

[15] `https://github.com/robocup-logistics/rcll-webshop`

8.2.6 Challenges Overview

Challenges have different types and variations (difficulty levels). The overall score of the competition is calculated by summing up the score in the highest difficulty achieved in each of the challenge types. The challenge types of the competition are described in Section 8.2.7-8.2.13.

8.2.7 Navigation Challenge

Basic navigation task with known obstacles.
Task: Drive to 12 randomly generated target zones. A target zone is reached, if any robot remains in that zone for at least 5 consecutive seconds. The pose of each robot must be set in the beacon message for the refbox to properly register the zones as visited. The robot may move within the zone during the 5 second period.
Variations of this challenge depend on the number of available machines (see Table 11). An unknown machine may be added as a further variation. The placement of this machine is decided by the referee in the setup phase but must be in accordance with the general rules for placing machines. Multiple robots may be used to simultaneously to reach multiple target zones. Partial points may be awarded in case only a subset of target zones were reached, which are accumulated if the challenge is completed fully.

Machines (Unknown)	Scoring			
	$\geq$ 4 zones	$\geq$ 8 zones	all 12 zones	combined
2	+4	+3	+3	10
3	+5	+4	+3	12
4	+6	+5	+4	15
4 (+1)	+7	+6	+5	18

Table 11: Navigation Challenge

8.2.8 Exploration Challenge

Replicate the RCLL exploration phase from previous seasons. Machine Marker detection as well as navigational skills are required to solve this challenge.
Task: Find and report all machines on the field (type and orientation) according to the rules of a regular exploration phase.
Variable in the number of machines (see Table 12). This challenge needs to be run by setting the

Machines	Scoring
2	10
3	12
4	15

Table 12: Exploration Challenge

refbox to phase `EXPLORATION`.

8.2.9 Grasping Challenge

Simple grasping task. Each Machine has a base at output. Robots start at the zone in front of a machine output.

Task: A robot brings a base from one machine's output back to its input. A human supervisor places it back to the output. Repeat until all products were placed at the respective machines input 3 times and all robots returned to their starting positions.
Variations differ by number of machines, see Table 13. The i-th repetition is considered to be successful, once all bases were placed at the respective machine input at least i times. The placement of the machines on the field is fixed according to the field shown in Figure 2, where the BS is placed at M-Z12, CS1 is placed at M-Z53 and RS1 is placed at M-Z25. In order to load this layout into the refbox follow the instructions from the wiki.[16]

Machines	Scoring	
	first repetition	each subsequent repetiton
1	+4	+2
2	+6	+2
3	+9	+2

Table 13: Grasping Challenge

8.2.10 Product Challenges

A team is only able to do one Production challenge. Each challenge corresponds to the production of a product with one of the available complexities (C0, C1, C2, C3) in the RCLL using either one or two RS.
For complexities C1, C2 and C3 the accumulated cost for mounting the required rings must be equal to 1, 2 and 3, respectively. **Task:** Produce all posted orders.

Machines	Challenge type	Scoring
2	C0	10
3	C1	12
3	C2	15
4	C2	15
3	C3	20
4	C3	20

Table 14: CX Challenge

8.2.11 Exploration + Production Challenges

The same challenge as in Section 8.2.10 but without receiving the machine positions. Hence exploration and production takes place concurrently. The challenge reflects the exploration period of the standard game. The same point scores as in Figure 15 apply with an additional $+5$ per challenge.

8.2.12 Simulation Challenge

In this Challenge a full game has to be played using the the RCLL Simulator .[17] The goal is to deliver a C3. Either two or three robots have to be used, each of them has to perform at least one retrieve and

[16] `https://github.com/robocup-logistics/rcll-refbox/wiki/Configuration#game`
[17] `https://github.com/robocup-logistics/rcll-simulator`

one deliver task.

Robots	Scoring
2	10
3	15

Table 15: CX Challenge

8.2.13 Markerless Detection Challenge

Image recognition challenge to classify different machine types.
Task: Autonomously label the machines shown in a set of pictures by their type. A picture may contain more than one machine, which all count towards the total number of machines to detect. Labels must be placed on the machines within the picture. Machines are distinguished by their types (BS, CS, RS, DS, SS).
As a preparation for this challenge, a data set will be supplied to all participants which may be used for training and testing purposes.[18] The evaluation set for the challenge consists of a set of separate images that is encrypted and distributed in advance of attempting the challenge. The password to decrypt the evaluation set is given out when the challenge is attempted. This challenge can only be attempted once to avoid improper use of the evaluation set. The points scored are calculated based on the relative amount of correctly and wrongly classified machines (across all types) according to Table 16. So a total amount of 30 points can be scored if all machines of all types are correctly classified.

% Correctly Classified	% Wrongly Classified	% Not Classified	Scoring
x	y	z	$(x-y)\cdot 30$

Table 16: Machine Detection Challenge

In order to verify the labeling, each team must presents the labeled data within the time slot (e.g., via screen-sharing when participating remotely). Additionally, the labeled data has to be sent to the OC.

8.3 Open Challenge

Each team will be given 5 minutes to showcase their robot team, e.g., show some new robotics developments. This may involve any task as long as it is performed with at most three Robotino robots within the competition area. For the time of the free challenge, any software or hardware modification is allowed, even though otherwise disallowed in the regular competition. This may be used to motivate ideas for future developments of the league and to highlight particular advances in the system of the presenting team.

The team leaders of non-presenting team will judge the performance and rate it with points between 0–10. The team with the highest sum of points will win this challenge. The other teams are ranked in decreasing point order.

[18] `https://fh-aachen.sciebo.de/s/mICiBMFyHV5GkxN`

9 Rule Enforcement

Referees manage the overall game, make sure that the rules of the game are followed, and instruct and monitor the refbox as described in Section 5.4.

9.1 Referee Delegation

Each participating team of the tournament must provide at least two team members which act as referees. These referees must be announced at the beginning of the tournament and are fixed throughout the whole competition (unless the participant drops out of the tournament, e.g., because of illness). The referees must meet the following criteria. They must

- be available for each game that they are assigned to and appear 5 minutes prior to the game start time (schedule to be announced by Organizing Committee at beginning of the tournament)
- have good knowledge of the rulebook and the applied rules
- participate in the referee briefings (organized by Organization and Technical Committees)
- be able to lead a game and communicate with the teams in English.

9.2 Liability Waiver

Referees cannot be held liable for:

- any kind of injury suffered by a player, official or spectator
- any damage to property of any kind
- any other loss suffered by any individual, club, company, association or other body, which is due or which may be due to any decision, which he may take under the terms of the rules of the game or in respect of the normal procedures required to hold, play and control a match.

9.3 Punishable Offenses

The league reserves its right to disqualify clearly malicious teams.

9.3.1 Misbehaving Robot

A misbehaving robot is punished by forcing a maintenance on it (see Section 5.4). Any workpieces carried by a misbehaving robot are to me removed during maintenance.

The following situations may cause a robot to be considered misbehaving:

- Leaving the competition area illegally (see Section 3.3)
- Movements not stopping 3 seconds after a game is paused
- Obstructing opponents (cf. Section 9.3.2)

9.3.2 Obstruction Penalty

As the Logistics League follows the idea of having active teams compete alongside each other, instead of directly against each other, we punish intentional obstruction of the opposing team.

This applies in particular to the input and output area in front of any MPS. All robots are allowed to enter this space, but robots must not obstruct opposing robots which intend to approach their MPS. Concretely, that robot must give way and release an approachable path to the MPS within a time window of 10 seconds. If a robot cannot follow this rule, it is considered a misbehaving robot and punished accordingly (cf. 9.3.1).

Furthermore, teams are penalized for obstruction according to Table 6 when delivering a workpiece to a machine of the opposing team. In this case, the workpiece gets removed and cannot be used afterwards.

A robot moving a workpiece of the opposing team at their MPS is considered a misbehaving robot. The referee will move the workpiece back to its original position.

9.3.3 Pushing Rules

With multiple teams on the field at the same time, robots must implement ways for collision avoidance. At the same time, they shall not interfere with the goods of the other team. The case where a robot of one team bumps into or moves a robot of another team we call “pushing”.

The following rules shall be obeyed by the robots and provide the guidelines for referees to call for improper behavior of a robot due to pushing.

1. Pushing occurs only between robots of different teams.

2. Robots must drive such that they try to avoid physical contact with robots from the opposing team. However, physical contact per se does not represent an offense.

3. All robots should be equipped with appropriate sensors to detect situations of physical contact with other robots (direct pushing situations).

4. If physical contact with other robots cannot be avoided, it must be soft, i.e., at slow speed and with as small physical impact as possible, in order to avoid damage to itself and other robots. Robots moving at high speed must significantly decelerate before a collision occurs with another robot.

5. If a destruction collision is immediate and the robots do not react, the referee should use the refbox to send a stop command to all robots. Every team has to react to the stop command by immediately stopping their robots.

6. Whenever a robot produces direct physical contact with another robot while moving, it must stop movement immediately in that direction (and choose a new direction for movement).

7. If pushing occurs between a moving and a standing robot, the moving robot causes the pushing situation and is responsible for resolving it. If it is not able to do so, a pushing foul will be called.

8. If pushing occurs between two moving robots, both robots are responsible for resolving the pushing situation. If one robot continues pushing by moving in its initial direction, while the other robot is recognizably reacting and trying to take another direction, the foul will be called on the pushing robot.

9. If two robots encounter physical contact and cannot resolve the situation because they get entangled, the referee may issue a pushing foul on both robots.

10. If, in the opinion of the referee, physical contact between two robots is not soft, or if one or both of the robots do not change direction after encountering physical contact, a pushing foul will be called.

11. When a pushing foul is detected the offending robot is considered misbehaving (cf. Section 9.3.1). The other team can decide within 10 seconds to restart their involved robot in the insertion zone without it counting as a penalty restart.

12. If a robot loses its workpiece during collision avoidance or in case of a collision, the workpiece will not be replaced and is removed by the referee.

9.4 Complaint Procedure

Rule issues are not to be discussed during a game. Referee decisions are binding for the game. A team may protest and challenge a game by executing the following complaint procedure. The procedure is also automatically invoked if a referee decides to abort a game for any reason (e.g., field damage, lighting failures, burning robots).

To initiate the complaint procedure, the team leader of the challenging team is to contact a member of the Technical Committee within 10 minutes after the respective game has ended. The member of the Technical Committee then invokes a team leader conference in cooperation with the Organizing Committee. In this conference, the following parties participate: the referees of the game in question, not less than half of all registered team leaders, and the Technical Committee (counseling). The situation shall be resolved by unanimous consent or by vote of the team leaders (majority of team leaders participating in the conference is sufficient).

All teams are reminded that while this is a competition, the league is also about *cooperative* research and evaluation and complaints should be handled in a fair and forthcoming way.

9.5 Penalties

The catalog in Table 17 represents the decision basis for the referees not being exhaustive or binding. Refer to Section 1.3 for the general league agreements, hardware restrictions can be found in Section 6 and in Section 7 regulations regarding communication during games are described.

Issue	Sanction
Premature movement	No robot is allowed to move until the referee announced the start of the match. The faulty robot will be grounded for 2 minutes.
Damaging factory equipment	Theoretical damage to the real factory equipment as a result of collisions and negligent actions. This behavior will be punished as a minor rule break.
Not showing up	A team not showing up at all. The team will be removed from the tournament unless the team leader can provide a sincere explanation.
Manual Interference	A manual interference of a team, i.e., touching a robot without the referee's permission, during the game will be punished as a major rule break.
Breaking a minor rule	A rule infringement with minor impact on the team performance or competition mechanics. Upon decision of the referee, 25 % of the scored points of the team at the time of the infringement will be deducted, at least 1 point.
Breaking a major rule	A rule infringement with considerable impact on the team performance or competition mechanics. Upon decision of the referee, 50 % of the scored points of the team at the time of the infringement will be deducted, at least 5 points.
Arguing with the referee	There will be no discussions during a match. Each team can make a motion to protest a certain match and its result which will be dealt with after the match. There will be a warning. Continued disregard will result in a time punishment to the team's current or next match.
Disregarding rules of conduct	Following the rules of conduct should be self-explanatory. Upon disregard, the referee will impose sanctions ranged from time punishments to the team's complete removal from the tournament.

Table 17: Infringements

References

[1] Henning Kagermann, Wolfgang Wahlster, and Johannes Helbig. *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*. Final Report. Platform Industrie 4.0, 2013.

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[3] Tim Niemueller, Gerhard Lakemeyer, Sebastian Reuter, Sabina Jeschke, and Alexander Ferrein. "Benchmarking of Cyber-Physical Systems in Industrial Robotics". In: *Cyber-Physical Systems: Foundations, Principles and Applications*. Ed. by Houbing Song, Danda B. Rawat, Sabina Jeschke, and Christian Brecher. Amsterdam: Elsevier, 2016 (in press).

[4] Tim Niemueller, Sebastian Zug, Sven Schneider, and Ulrich Karras. "Knowledge-Based Instrumentation and Control for Competitive Industry-Inspired Robotic Domains". In: *KI - Künstliche Intelligenz* 30 (2016).