D8.3 - INITIAL SWARM LOGISTICS DEMONSTRATION

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Document History

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0.1	28-12-2018	Ángel Soriano (ROBOTNIK)	First draft
0.2	28-01-2019	Ángel Soriano (ROBOTNIK)	Updated draft
1.0	07-02-2019	Ángel Soriano (ROBOTNIK)	Minor changes related to reviewer's comments

Internal Review History

Review Date	Reviewer	Summary of Comments
01-02-2019	Judit Torma (SLAB)	Fixed a number of minor issues, added some suggestions about structure and content.
01-02-2019	Arthur Pitman (UNI-KLU)	Fixed a number of minor issues.

1 Executive summary

The present document is a deliverable of the CPSwarm project, funded by the European Commission's Directorate-General for Research and Innovation (DG RTD), under its Horizon 2020 Research and innovation program (H2020), reporting the results of the activities carried out in "Task 8.2 Swarm Logistics Scenario" at WP8 – Use Cases Implementation. The main objective of the CPSwarm project is to develop a workbench that aims to fully design, develop, validate and deploy engineered swarm solutions. More specifically, the project revolves around three vision scenarios; Swarm Drones, Swarm Logistics Assistant and Automotive CPS.

WP8 aims at investigating application scenarios for the complete toolchain developed in CPSwarm. The work of this WP is carried out in 4 tasks, one for each use case with a specific task dedicated to use case validation. Strongly driven by industrial needs, the work package focuses on three scenarios related to:

a) Swarms of drones and ground robots;

b) Swarm Logistics scenario;

c) Automotive use case.

The final use cases of these scenarios were described at the deliverable "*D2.2 Final Vision Scenarios and Use Case Definition*" led also by Robotnik. Each scenario belongs to a specific task defined within the work package. The swarm of drones and ground robots scenario is defined in the Task 8.1, the swarm logistics scenario at Task 8.2 and the automotive use case at Task 8.3. The fourth and last Task 8.4 includes the use cases outcomes tested and validated under an industrial standpoint.

The main objective of this deliverable namely "*D8.3 - Initial Swarm Logistics Demonstration*", is to describe the work carried out in "*Task 8.2 Swarm Logistics Scenario*" taking into account the results described in "*D2.2 Final Vision Scenarios and Use Case Definition*" and the demonstration carried out at the month 18 review of the project, where a swarm of three mobile robots was shown managing the movement of goods within a warehouse. Another deliverable called "*D8.4 Final Swarm Logistics demonstration*" will be released in M36 describing the final version of the use case and the implemented features.

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2 Introduction

Inside the project lifecycle of CPSwarm, shown in Figure 1, the experimental demonstration step is a key part of the final system delivery of the project, since it validates the viability of the CPSwarm's workbench. Experimental demonstration is covered by the Work Package 8, and is divided into three main scenarios or use case.

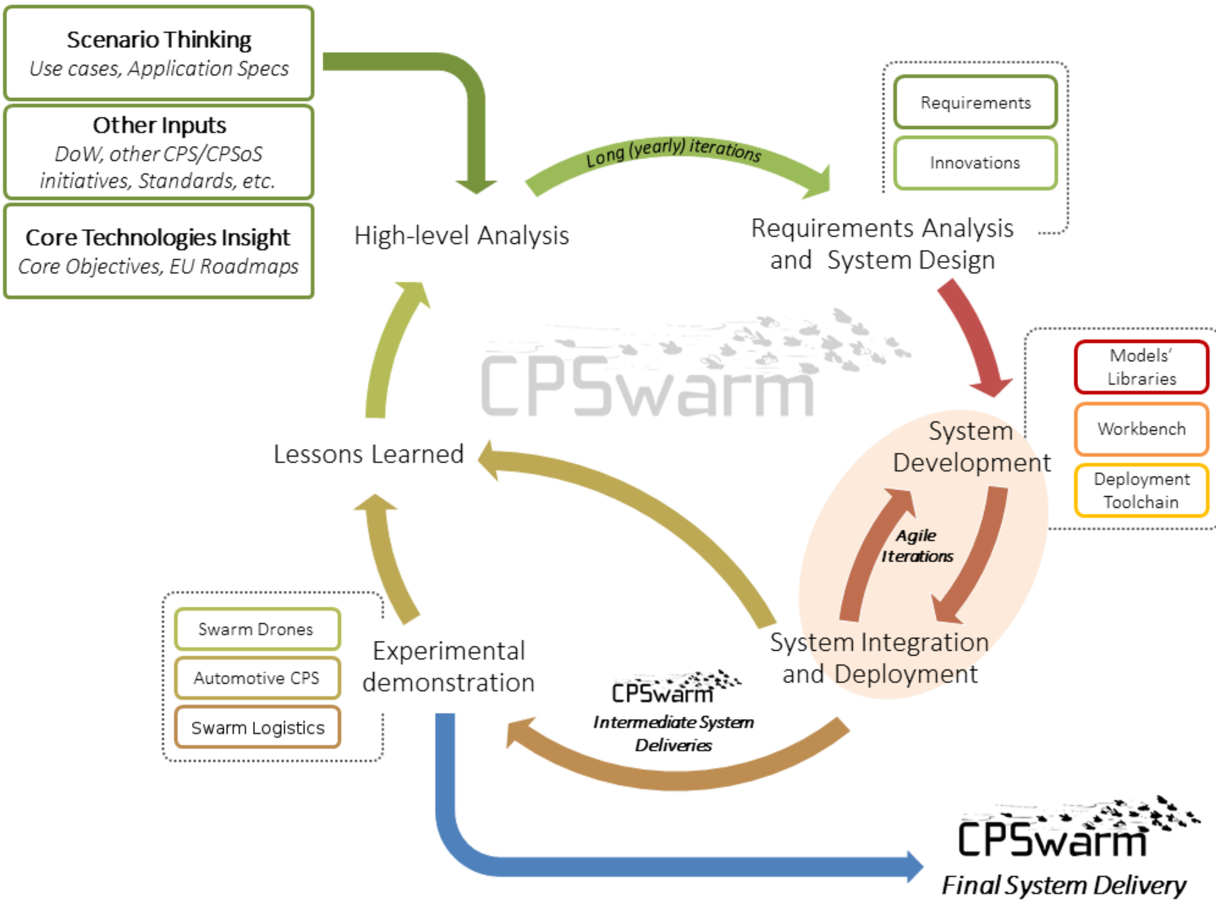

Figure 1 – CPSwarm project lifecycle.

This "**D8.3 - Initial Swarm Logistics Demonstration**" is a public deliverable focused on the results of *Task 8.2 Swarm Logistics Scenario* at M18 of the project.

2.1 Document organization

This document describes mainly the logistic scenario demonstration, as well as all related developments, not only about the coding or procedures but also the hardware itself that has been used during the swarm logistics scenario work.

Sections 3 and 4 present an overview of a typical logistic scenario and the use case selected to test our developments will be given.

After that, the specification of the system and its behavior will be presented, as well as the results shown in the live demonstration at the Month 18 Review.

Other related issues such as the relationship with the benchmark architecture and special comments on safety aspects are also included in this document.

2.2 Related documents

ID	Title	Reference	Version	Date
[RD1]	Final Vision Scenarios and Use Case Definition	D2.2	1.0	M16

3 Scenario overview

For this scenario, the robotics logistics concept is addressed combined with swarm behaviour and evolutionary algorithms.

The Swarm Logistics scenario involves robots, rovers and drones that collaboratively perform opportunistic scanning of the warehouse. The idea is to scan the entire area of the warehouse and share the acquired information to update the knowledge base on the go. In addition to collecting information about the maps of the entire area, the connected robots will also be used for collecting additional information implicitly e.g. room temperature, presence of humans, detection of in-path obstacles etc. Since all the connected robots of the swarm acquire the information collaboratively, the status of the area is always up to date and the effort is always divided among all members. As a starting point, each connected robot will be fed with some default information e.g. map of the area. This information is updated opportunistically on the go as the robots perform their main tasks. The main tasks of the robots are intended to assist humans in the logistics domain. These assistive tasks could include joining forces to move a heavy obstacle from one place to another.

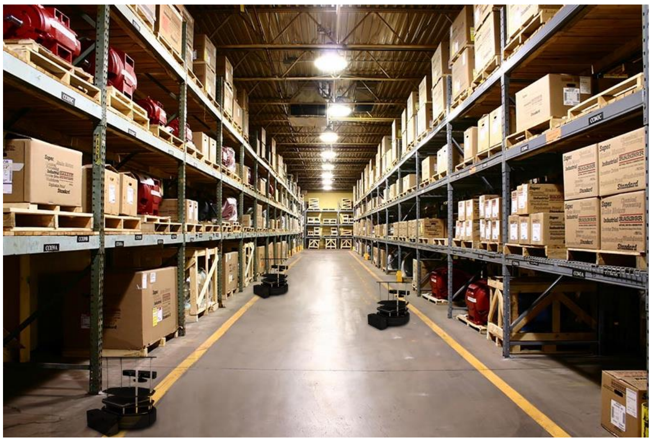

Figure 2: Impression on the Swarm Logistic scenario.

Additional sensors could be used to attain information regarding various aspects e.g. accelerometer for floor conditions, thermal sensor can detect the presence of any humans/animals in the vicinity, gas sensors can detect leakage of any harmful gases, temperature sensors can extract information about the current temperature of the entire area. For example, a warehouse is required to maintain a certain temperature to preserve the quality of fruits stored in it. While the robots are moving a fruit package from one point to another, they opportunistically detect the temperature of the area and in case, the temperature is higher/lower than the desired value, the respective personnel will be notified.

3.1 Swarm Logistic Scenario Description

Everyday a truck comes into a warehouse with a lot of packages that must be stored. The work of Alex is to put all the packages in tagged carts.

Figure 3: Alex needs to put the packages in tagged carts.

There is a storage area inside a warehouse where carts with goods are stored.
These tagged carts must be transported to a dedicated storage area. Alex always tries to make the carts occupy the minimum possible space to optimize the storage space in the warehouse.

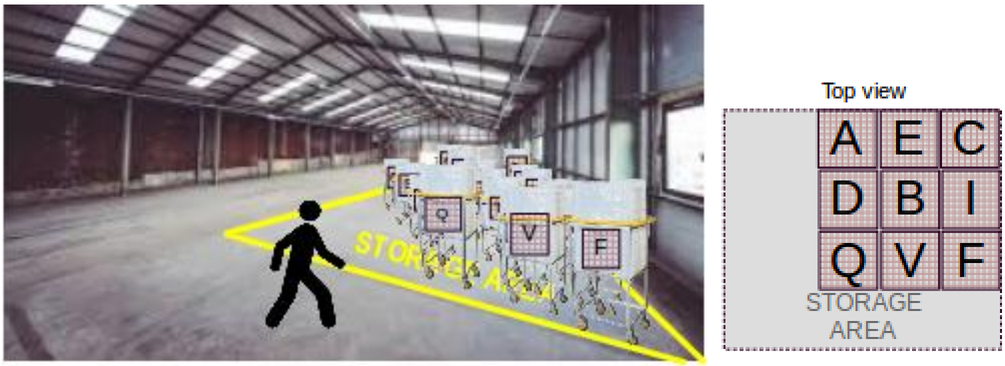

Figure 4: Dedicated storage area to store all the carts.

Periodically a specific cart is requested. Alex must look for it inside the area and transport it to another place.

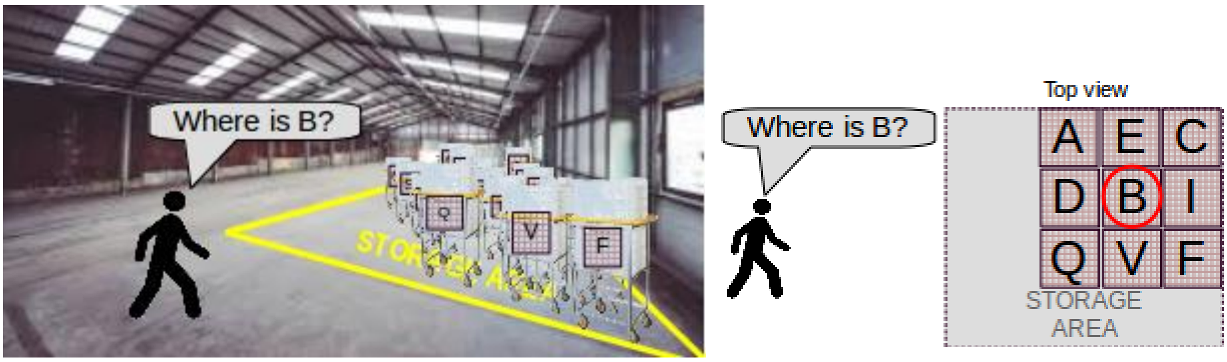

Figure 5: Alex needs to pick the cart B.

Usually the requested cart is surrounded by other carts so Alex has to spend a great deal of time moving around other carts to get it. In addition, usually more than one cart is requested at the same time, so sometimes there are multiple operators (Alex's colleagues) inside the storage area trying to access carts.

In addition, new carts come into the warehouse and they must be stored in the same area so ultimately many people are required to work within the storage area concurrently without any kind of organization.

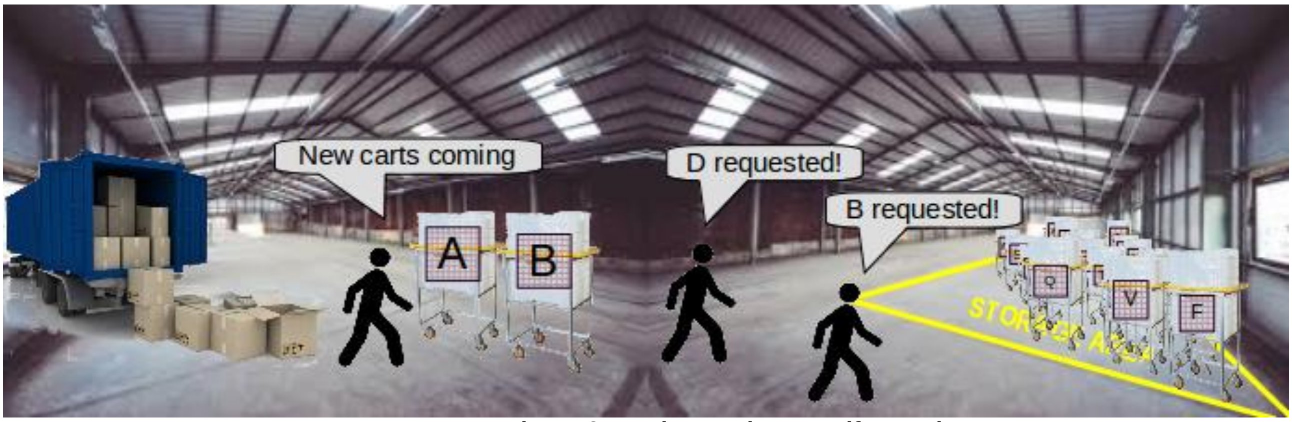

Figure 6: Workers trying to self-organize.

For this reason, the company installs a CPSwarm system to manage the storage area automatically and organize carts in an optimal way. The system is responsible of organizing the carts inside the warehouse and preparing the requested carts in a manual load area. This saves Alex a lot of work with respect to finding an optimal solution that needs to total overview of all stored carts as well as moving them. The system finds the optimal solution and the autonomously acting rovers move incoming or outgoing carts in or out of the manual load area where Alex can further handle them.

The robots recognize the legs of the carts through the measurements from a laser scanner and move under the selected cart. With an integrated elevator above the upper plate, the robots are able to lift, move and release carts.

The robots within the CPSwarm system must try to optimize the space occupied by the carts inside the warehouse and also try to serve the requested carts as soon as possible when they are required.

4 Hardware specification for the demonstration

To demonstrate the use case scenario, a robot model has been built from scratch. The base of the robot model is a iClebo Kobuki robot [1]. It is a low-cost mobile research base designed for education and research on state of art of robotics.

Three different levels of height with three hexagonal plates have been designed to be on the top of the Kobuki base as Figure 7 shows. On the first layer, an RPLidar A2 model has been integrated to have the ability to detect objects or obstacles. This laser has a range of 18 meters taking 4000 measures at 10 Hz frequency [2]. On the second layer, an Intel NUC i5 with 8 Gb of RAM and 128Gb of SSD has been installed to work as the brain of the platform (figure 8). This mini-computer offers Wi-Fi (802.11ac), Bluetooth 4.2 and Ethernet interfaces to interconnect the hardware elements and to communicate with the others CPS. On the third floor of the platform, the linear actuator CAHB-10 from SKF [3] has been integrated to move the top plate of the robot to move up and down the last plate and to pick up and place things.
Also, multicolor LED lights controlled by an Arduino board have been integrated to provide visual feedback about the state of the robot.

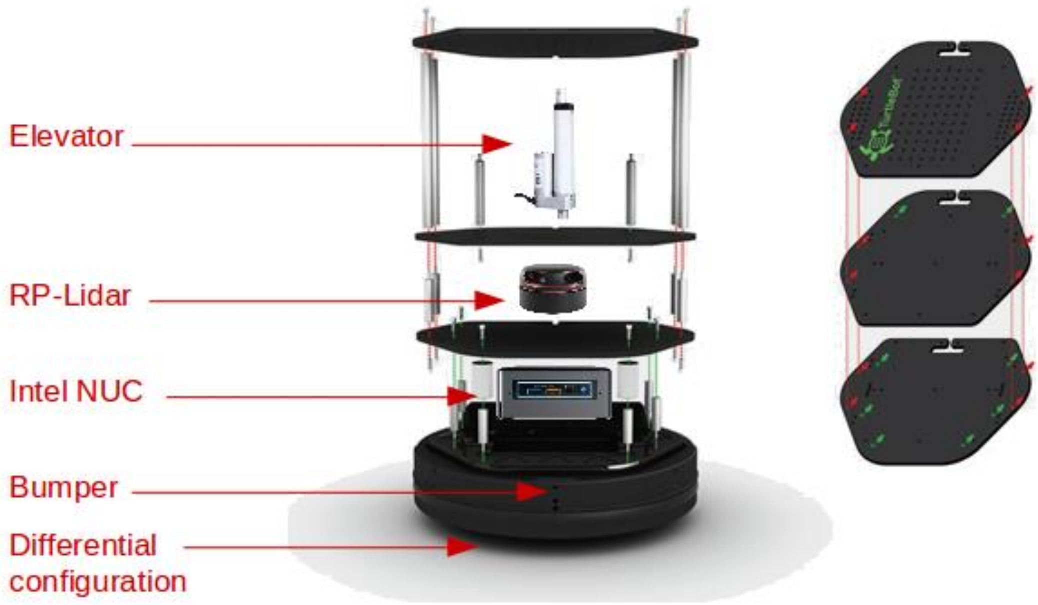

Figure 7: Robot designed for CPSwarm demonstration.

Figure 8: Architecture of components connections

5 Integrated Behaviors

Based on the final vision scenario described above, the following state machine has been designed in collaboration with LAKE.

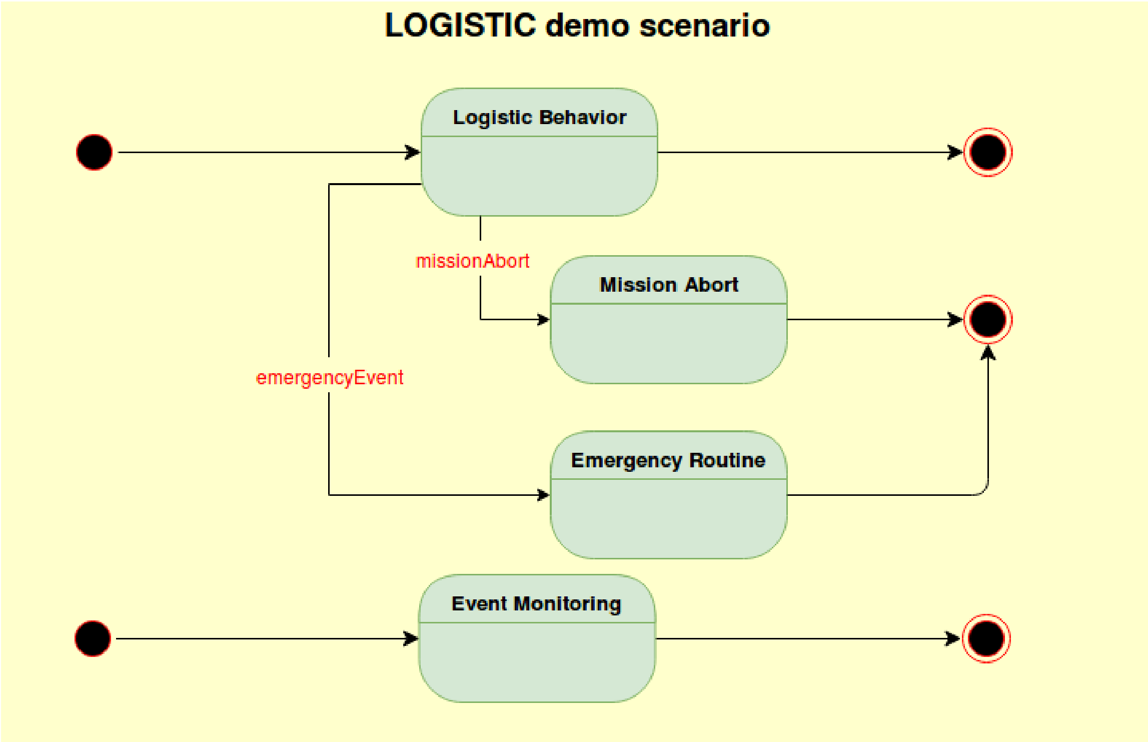

Figure 9: State Machine for Logistic Swarm Scenario

6 Description of demonstration at month 18th

6.1 History

Every day several tracks arrive into a warehouse with a lot of packages that must be stored. These packages are put in tagged carts manually by Alex.

Figure 10: Alex collecting the packages into boxes.

Then, when the truck is empty, Alex has to store the carts in a dedicated open space within the warehouse.

Figure 11: Alex transporting the carts into the storage area.

Naturally Alex should organize the carts to occupy the minimum possible space to optimize the storage space in the warehouse.

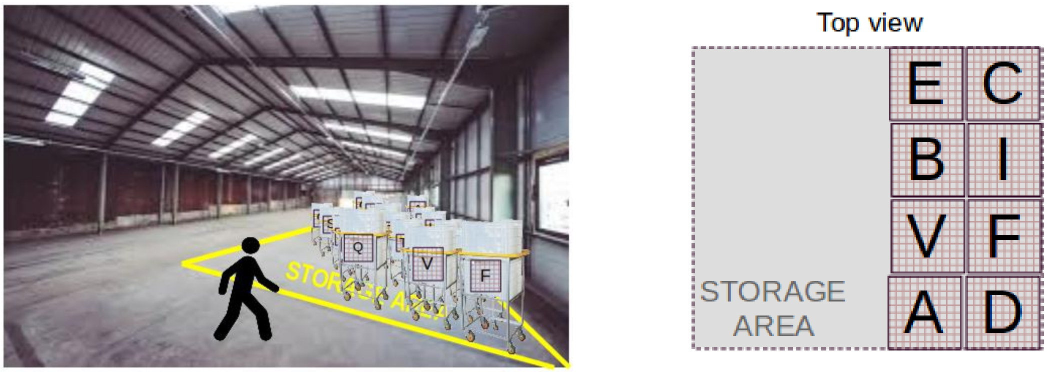

Figure 12: Alex organizing the packages into the storage area.

Fortunately, Alex's company is going to integrate the CPSwarm workbench to automate the management of storing the carts.

6.2 Starting Point of demo

Figure 13: Starting state of the real logistics demonstration scenario

Three robots, represented as turtle icons at Figure 14, are positioned in well-known positions at the beginning. The scenario is divided into two areas:

1. The area where the cars are located in a disorderly manner and where the robots must load them (*Load area*)

2. The area where the carts must be placed (*Unload area*).

In the starting point there are five tagged carts placed as the following image shows:

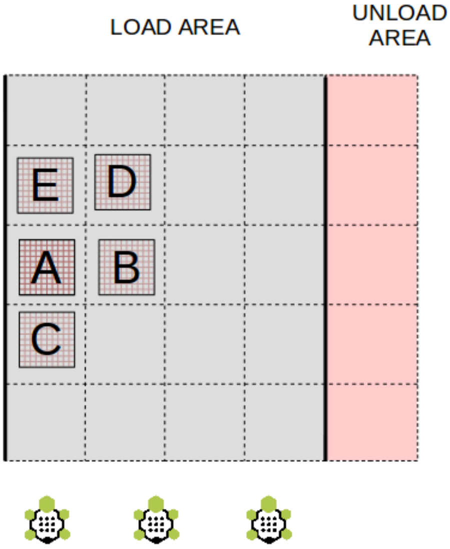

Figure 14: Starting state of the logistics demonstration scenario

Given a list of requirements defined by the position that each cart must occupy in the unloading area, the system auto-organizes the robots to bring each cart to its corresponding position in the unload area. For this, an interface has been developed to allow the user to choose which cart should be placed where. Figure 15 shows the operator graphical interface where the operator can choose in the unload area the ID of the cart assigned to each position. Then, by pushing the Run button, the system loads all the missions into the database. Each assignment between a cart and a position corresponds to a mission.

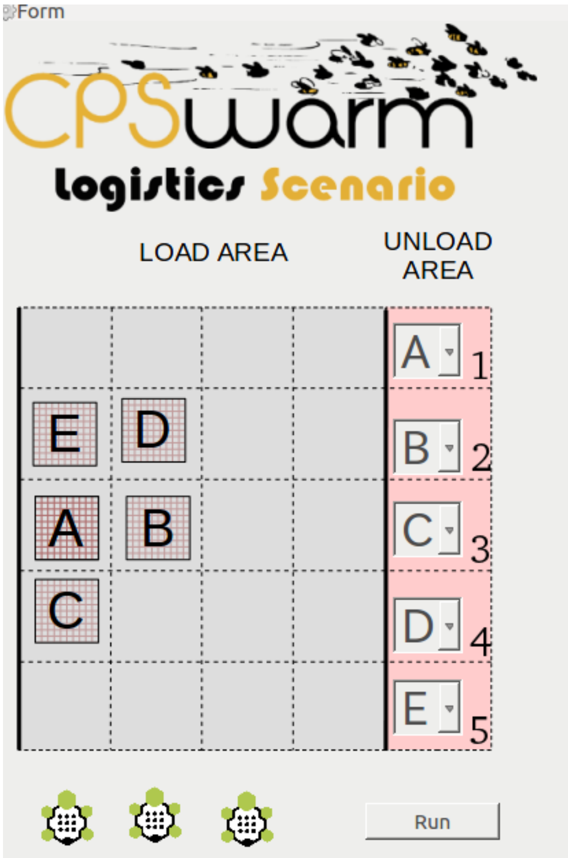

Figure 15: Graphical Operator Interface to configure the scenario

To manually interact with the entire system, a control box with three physical buttons has been built as shown in Figure 16.

Figure 16: Manual Control Box.

All the hardware devices, the three robots, the control box and the computer where the operator interface is launched, are connected to the same wireless network.

The flow of the demonstration is shown in Figure 17.

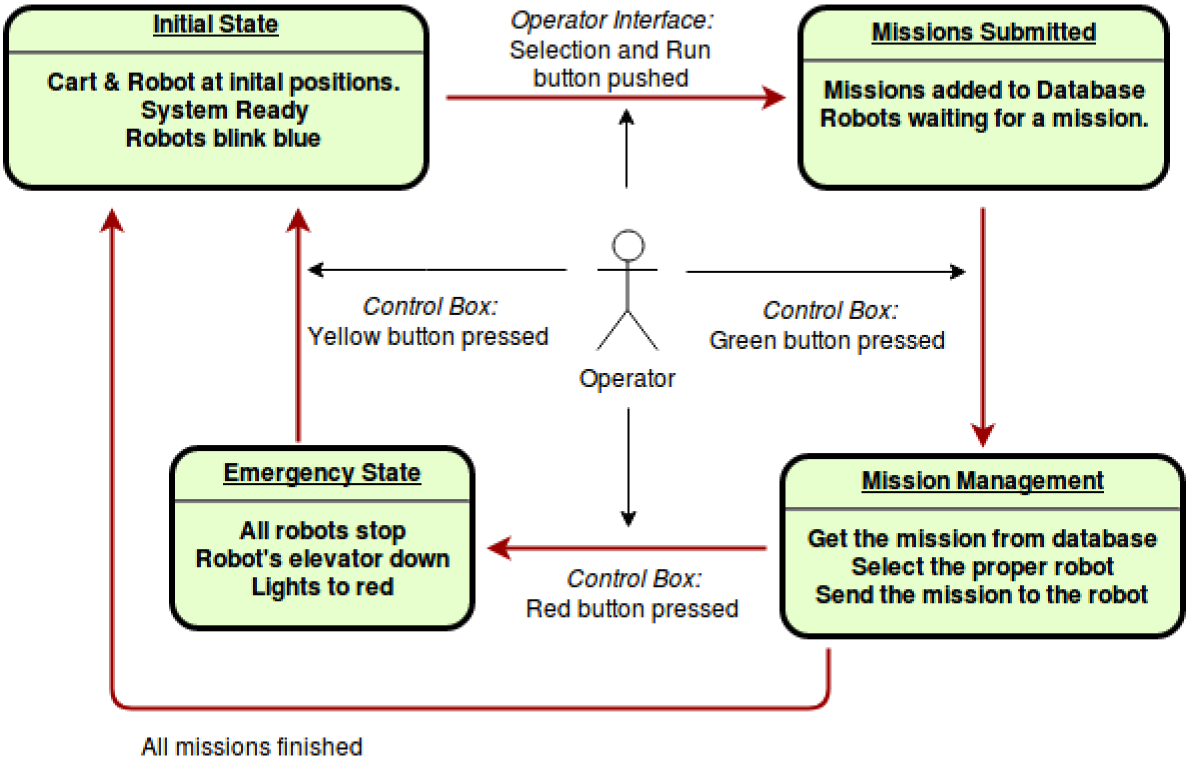

Figure 17: Flow of demonstration.

First of all, the carts and the robots are situated in the load area as Figure 13 shows. When the robots are ready to work their lights blink blue. Then the operator can choose the configuration using the interface described above where each position of the unload area is assigned to one cart. Then the operator pushes the run button to load the missions into the database.

When the missions have been submitted to the database, the operator can press the green button of the control box to order the system to start the first mission. Each time the green button is pressed the next mission is extracted from the database and sent to the server to be assigned to a robot. When a robot receives a mission, its lights switch to green.

To assign a mission, the system selects the closest free or idle robot to the cart of the mission. If no robots are available, the system waits until one robot is free or idle. Other missions can be added meanwhile.

When all the requirements are done (all the missions are finished) the robots return home (starting point) and the demonstration finishes.

The control box offers two more buttons, the green one and the red one. The red one can be used to cancel all the missions loaded at any time. If there are robots running missions when the button is pressed, the robots will stop immediately, they move down the elevator if it is up and the lights will blink red. In this case, the system is blocked by an emergency state and it needs to be rearmed by pushing the yellow button on the control box. The robots will change their lights to blue and will move to their home position. From this point, the robots are ready to accept new missions. If the operator requests a new mission and pushes the green button, the system will assign the mission to a robot.

The system assigns the mission taking into account the robots available at that point in time. Also some decision-making can be applied to choose which available robot will be chosen to pick the cart of each mission.

6.3 Challenges of the swarm logistics scenario

It is important to remark that the developments within this use case and demonstration respond to an actual need in the framework of mobile robotic logistics. The assignment of tasks according to different situations, the procedures and individual behavior that each robot is driven with, the interaction and commands received from an operator and the way the system handles all of these are an interesting exercise for common problematics in our day to day work.

And then not only for the operational layer but also for the overall picture, this kind of autonomous work for the robots (to continuously empty an area) is really interesting yet not fully developed as a whole in Robotnik's system. We could highlight here that normally, even if the common tools and subsystems are reused, there is always a need of some coding or development per case according to the user needs.

Our challenge here is not only to develop or use some tools that can be an advantage for some future cases, but also to speed up the whole process of in-house deployments by making the tools in the workbench available, including a modeling of the problem (which can then provide a straightforward solution), a deployment tool for the fleet, and of course all of the algorithms that may be scalable for other installations.

7 Safety

While safety regulations for collaborative robots have been a hot topic for the last decade, the first specific regulation has been published very recently. It must be highlighted here that the current norms such as the ISO/TS 15066 [4] are more focused on mobile manipulators and robotic arms, but the shared space problems are the same for mobile robots.
One important issue whenever addressing this matter is that, as per the regulation, the risk assessment must be done per case. Several features of the system must be revised for it to be compliant but always taking into account that a general requirement is not sufficient for every case.

In the case of mobile robotic bases, the most relevant dangers are related to running over, colliding with or entrapping a person or object during movement. For this to be solved a common approach is to provide the system with sensors in order to be aware of the environment and emergency stops (either onboard or remote) capable of disconnecting power and actuating brakes on the vehicle. It is also normal to include certified hardware that covers this function, such as safety lasers that not only cover 360º but also can be programed to lower the speed and then activate a safe stop (cat.1) if something is violating a programmed safe zone.

Once again, a study per case is needed, giving us for instance the chance to lower the safety requirements for a smaller robot that is not capable of pushing with a certain power and is equipped with a non-certified laser for obstacle avoidance, or just a physical bumper that stops the robot given any small collision (such as any kind of Roomba robot operating at home).

8 Next steps

Some ideas that the CPSwarm consortium plans to carry out in the future within the Swarm Logistics scenario are:

- Add cameras to the robots or to the environment to be able to discern between objects and humans and grant different behaviors in different cases.
- Add unique codes to the carts that allow a robot to identify them by computer vision.
- Distribute the intelligence more among the cyber-physical systems and reduce the involvement of the server in the demonstration use case.
- Add more robots to the scenario.

9 References

[1] Kobuki mobile robot: http://kobuki.yujinrobot.com/

[2] Slamtec RPLidar A2: https://www.slamtec.com/en/Lidar/A2Spec

[3] Skf Linal Actuator http://www.skf.com/binary/12-30013/CAHB-10Operatingmanual.pdf

[4] ISO/TS 15066:2016 Robotcs and robotics devices – Collaborative robots. https://www.iso.org/standard/62996.html