



## D8.4 - FINAL SWARM LOGISTICS DEMONSTRATION

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## 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 a final update about the results of the activities carried out in "Task 8.2 Swarm Logistics Scenario" at WP8 – Use Cases Implementation.

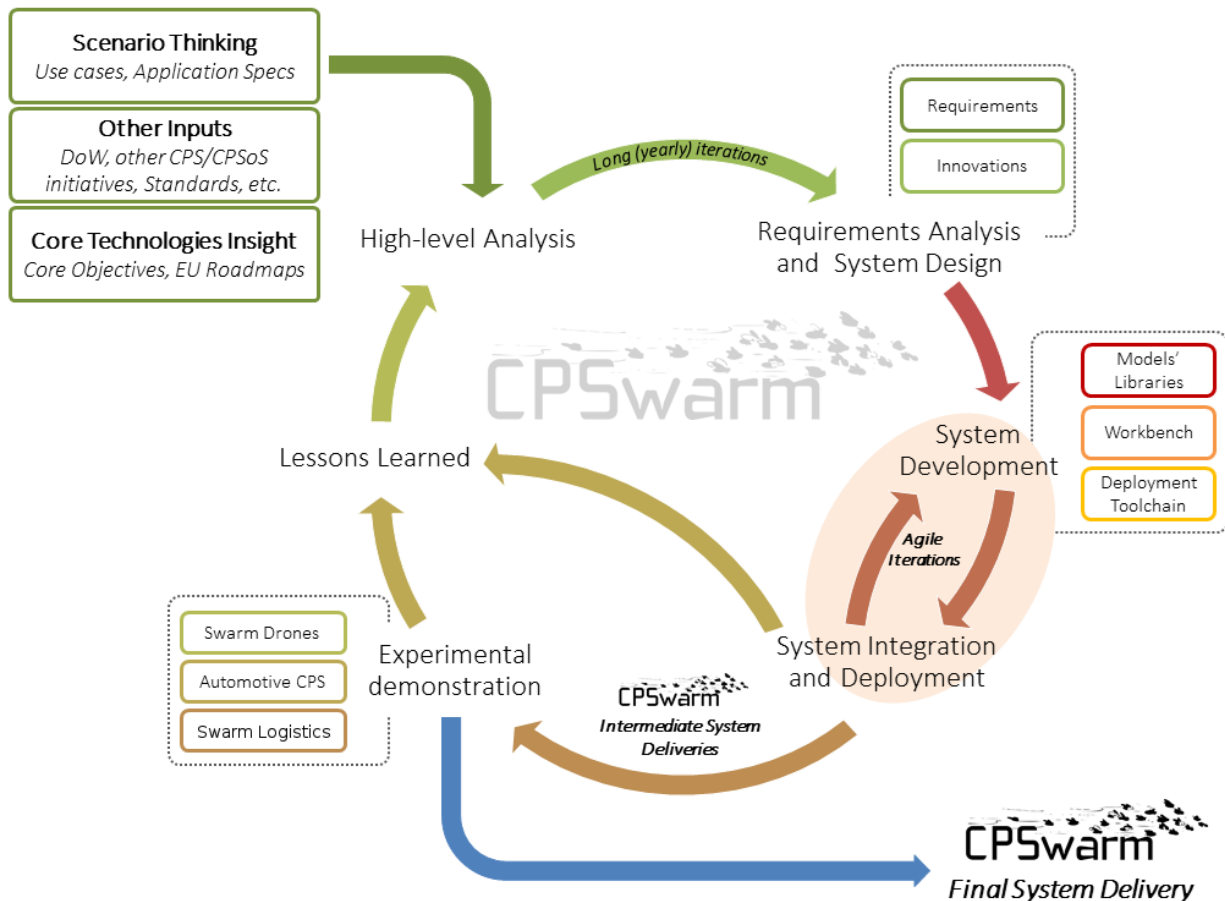
The deliverable namely "*D8.3 - Initial Swarm Logistics Demonstration*" described the work carried out in "*Task 8.2 Swarm Logistics Scenario*" taking into account the results described in "*D2.2 Final Vision Scenarios and Use Case Definition*" and the demonstration carried out at the month 18 review of the project. The main objective of this deliverable namely "*D8.4 Final Swarm Logistics demonstration*" is to describe the final version of the logistic use case, the last results of task 8.2 and the implemented features applied for the final demonstration at M36.

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## 1 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 cases.



This "**D8.4 - Final Swarm Logistics Demonstration**" is a public deliverable focused on the results of *Task 8.2 Swarm Logistics Scenario* at M36 of the project.

### 1.1 Document organization

This document describes mainly the final 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 the 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 36 review.

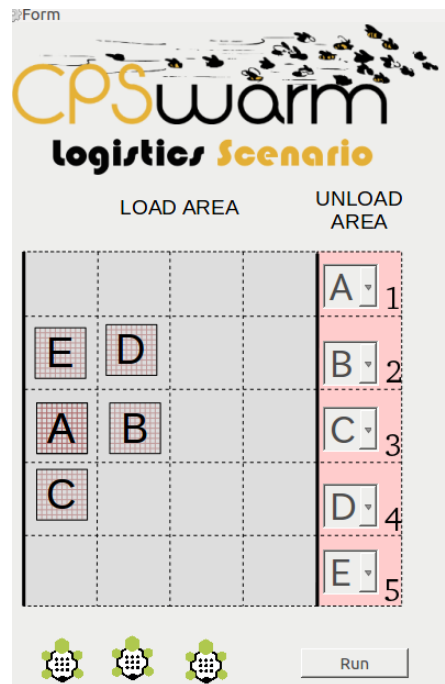
## 1.2 Related documents

ID	Title	Reference	Version	Date
[D2.2]	Final Vision Scenarios and Use Case Definition	D2.2	1.0	M16
[D4.6]	Final Swarm Modeling Library	D4.6	1.0	M34
[D7.6]	Final Monitoring and Configuration framework	D7.6	1.0	M36
[D8.3]	Initial Logistics Demonstration	D8.3	1.0	M24

## 2 Scenario Overview

The Swarm Logistic use case has been updated to increase the functionalities of the demonstration showed at M18 review.

In M18 demonstration the carts picked by robots were positioned around the scenario in some known positions. The three robots used were able to collaborate to pick them and to transport them to the storage area defined also like fixed positions inside the map of the warehouse. The flexibility of the system allowed to the operator to choose which cart should be in which position, as is shown in Figure 2 but the positions were always fixed.



This means that any cart (A, B, C, D or E) could be assigned to any position (1, 2, 3, 4 or 5) but both the position of the carts at load area and the final position at unload area were predefined and fixed inside the map of the scenario.

One of the new features for the final demonstration is that the position of the carts at the load area can be anywhere due to the fact that the robots will explore the load area searching and identifying autonomously the carts around and collaborate between them to bring the carts to the place positions, which can also be re-defined by the operator in real time.

To accomplish this, in this final scenario there are two types of robot configurations with different capacities. One of them is able to detect and identify the carts and the other is able to carry them. The details will be explained in the next sections.

In addition, the number of robots and carts has increased and the concept of human in the loop has been integrated in the scenario to detect the presence of humans around the robots.

This demonstration uses all the functionalities provided by CPSwarm workbench to develop easily an application that is oriented to logistic robotics assistance in real scenarios.

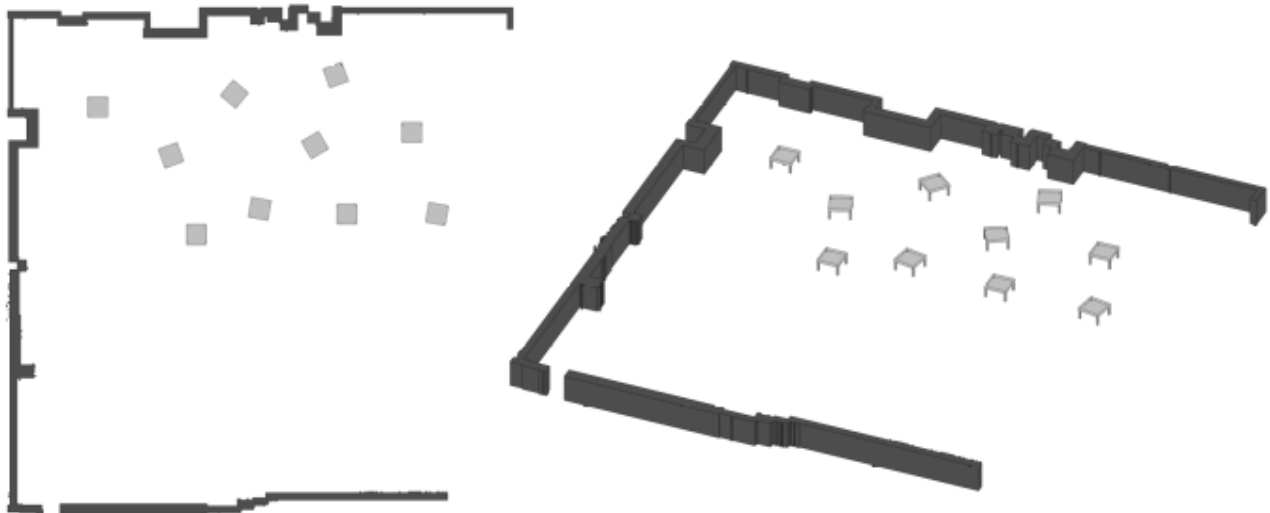
## 2.1 Final Swarm Logistic Scenario Description



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

Everyday a truck comes into a warehouse with a lot of packages that must be stored. The first task of Alex is to put all the packages in tagged carts as the Figure 3 shows.

Once the tagged carts are full of goods, the carts are scattered around the warehouse and Alex must transport and organize them to a storage area inside the warehouse. The Figure 4 shows the warehouse in Stage simulation environment.



**Figure 4: (Left) Top view of the warehouse with the scattered carts. (Right) Perspective view**

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.

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 offers an

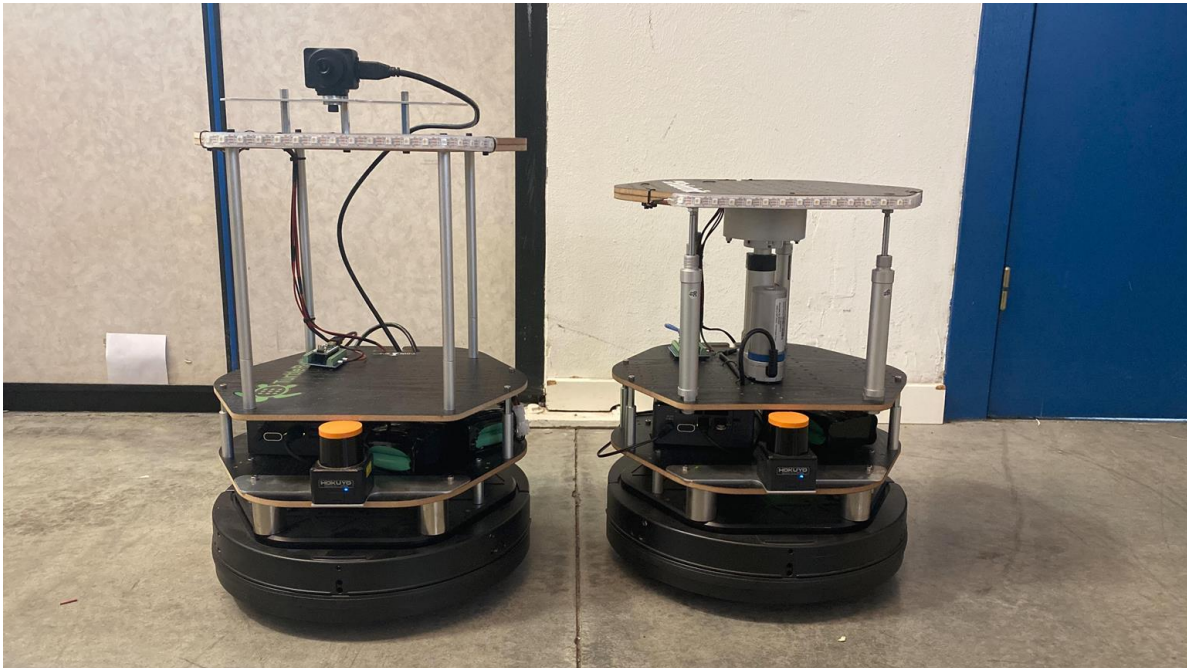


interface to interact with the entire swarm of robots. This saves Alex a lot of work and allows to find an optimal solution to the storage of carts, saving time and money.

The swarm of robots is able to search, find, identify and manage or transport the carts around the warehouse autonomously through the interaction between all of them, working together as a whole.

### 3 Updated Hardware Specification for the Demonstration

Unlike the demonstration at M18, in this final scenario, two robot models have been built from scratch. One named CPS\_scout and another one named CPS\_carrier. The base of both robot models is an iCLebo Kobuki robot [1] (also known as Turtlebot 2) which is a low-cost mobile research base designed for education and research on state-of-the-art of robotics. Both robots have three different levels of height with three hexagonal plates that have been designed to be on the top of the Kobuki base. The main difference between them is that CPS\_scout has a camera on board and CPS\_carrier has an elevator as Figure 5 shows.



The CPS\_carrier robots are the ones who can lift carts, thus they will keep the elevator installed between the two last wood stacks of the top on the robot. The structure of the elevator has been improved to win stability when the robot is transporting a cart.

The CPS\_scout robots do not need to lift carts, so the elevator has been removed. As innovation in the final scenario they have to identify QR codes from the carts thus a camera has been integrated. The camera model chosen is FLIR Chameleon CM3 (shown at figure 6). It has a resolution of 2048x1536 pixels, a rate frame of 55 fps and an interface USB 3.0. To integrate it with Ubuntu Operating System was necessary to increase the bandwidth of the USB ports in order to get the images at the rate of 55 fps.



In addition to the above, the laser sensor for both types of robots has been changed due to the problems experimented during the preparation of the demonstration at M18 with the laser RPLidar A2 from Slamtec [2]. The problem with this laser basically was that the natural sunlight from the windows of the hangar created invisible objects for the laser that were not really there. Due to this, the partners decided to change the sensor and integrate the laser Hokuyo UST-10LX [3] in all robots. This laser has a range of 10m, a wide detection angle of 270°, an angular resolution of 0.25° and a precision of 40mm. Like the previous laser, this model is oriented to indoor, but it supports better the light of the sun according to ROBOTNIK professional experience. The interface of the previous laser was USB but for the case of Hokuyo, it is connected to the computer by Ethernet and it needs to be fed between 10 to 30 V. Due to this some electrical modifications have been made to feed the laser directly from the battery of the robot.

From the point of view of software, the package used to integrate the new laser scan was the `urg_node` [4] from the official Robotic Operating System (ROS) distribution. And for the chameleon the package was the `flir_camera_driver` found at [5].

The carts have also been updated. The legs of the carts have been painted using white color, to facilitate their detection with the new laser, and a QR cubes have been created to put them on top of the carts to define the identification among them as the Figure 7 shows.



Another new hardware has been integrated in the logistic scenario for safety reasons. In the scenario there will be a fixed camera in a tripod which will be checking continuously that there is no person close to the scenario. For this mission the camera Rubedos VIPER [6] has been selected. This camera is a stereo camera with a depth range from 1 m to over 30m and a diagonal field of view up to 92 degrees. It also incorporates an NVIDIA® Jetson™ TX2 Module [7] to process on-board image processing. This device has an Ethernet interface so it has been connected to the main router and it is part of the scenario as another CPS that will notify the robots among the communication library if it detects one person around, it is the *CPS\_Camera*.



In addition, a LED light has been integrated in the scenario to give signals about the status of the demonstration. This light is connected to an Advantech ADAM module that supports Modbus protocol and is connected to the network by Ethernet. The software to manage the light is running in an external computer connected to the main network. The light takes into account the human detection from the camera and also the buttons actions from the manual control box. When the light is green means the demo is running, if it is yellow means a person has been detected and a red light means something is not going well and the demonstrations has been stopped.

Finally, the manual control box described at D8.3 has been also updated. Currently it includes the following list of devices:

- AC-DC converters and wiring:
  - Small converters will be powering the devices with 12V and 24V DC.
- Schneider ZBRRC and ZBRT buttons:
  - This module (shown at Figure 9) is receiving wireless signals from no-battery pushbuttons, resulting in a clean and easy infrastructure deployment.



- Advantech ADAM 6060 I/O module used to control the LED light (shown in Figure 10):
  - 6-ch DI, 6-ch RL, Ethernet-based smart I/O.
  - Remote monitoring and control with mobile devices.
  - Group configuration capability for multiple module setup.
  - Flexible user-defined Modbus address.
  - Intelligent control ability by Peer-to-Peer and GCL function.
  - Active I/O message by data stream or event trigger function.

- Multiple protocol support: Modbus/TCP, TCP/IP, UDP, HTTP, DHCP, SNMP, MQTT.



The router ASUS RT-N12 used for the demonstration at M18 has been also replaced to improve the communication between the CPS around the wireless network. For the final demonstration the model chosen has been Asus RT-AX88U (Figure 11). All the hardware devices, the seven robots, the wireless control box, the monitoring camera and the computer where the monitoring tool interface is launched, are connected to the same wireless network.

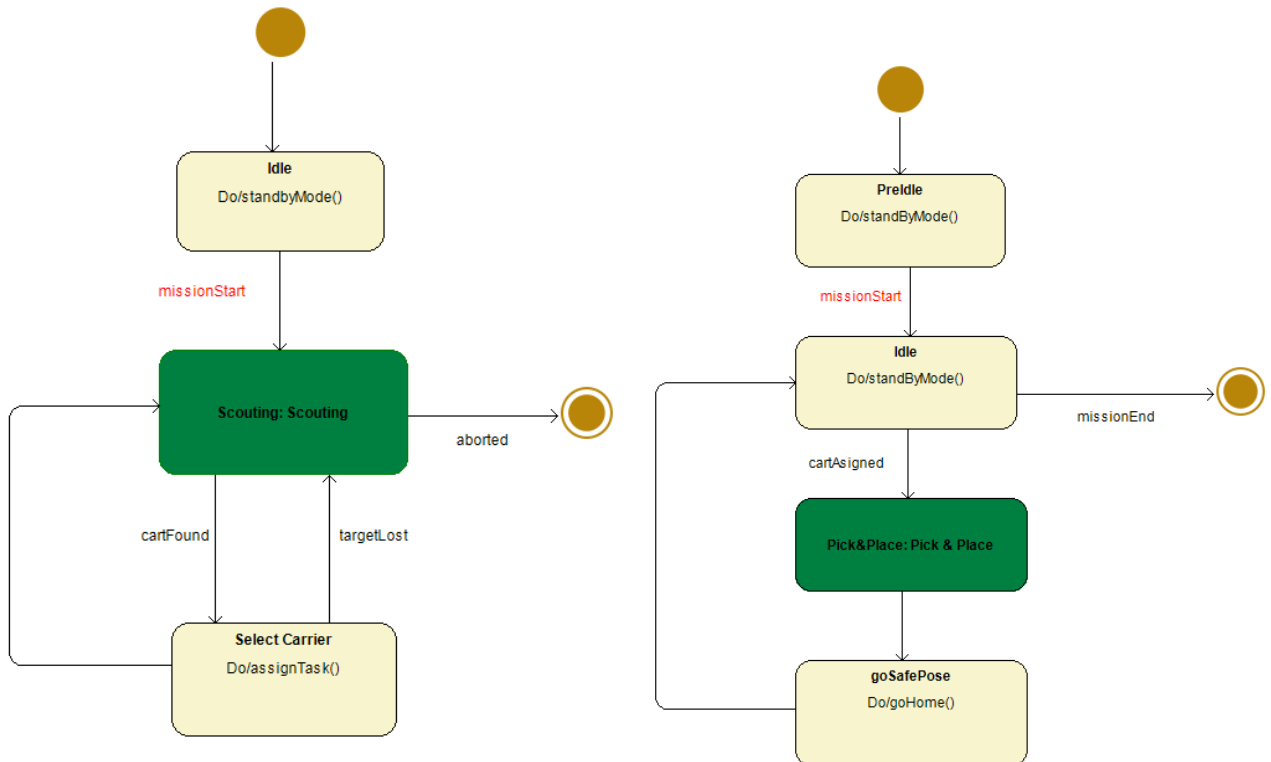
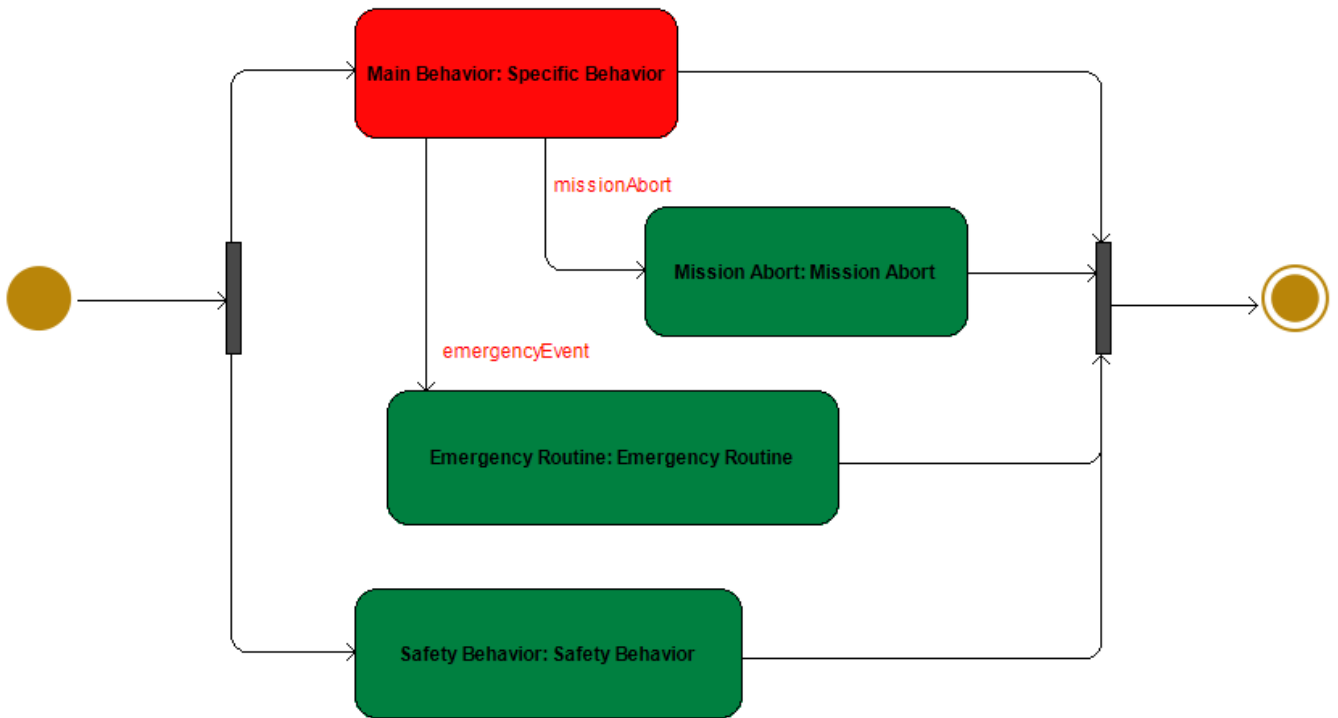


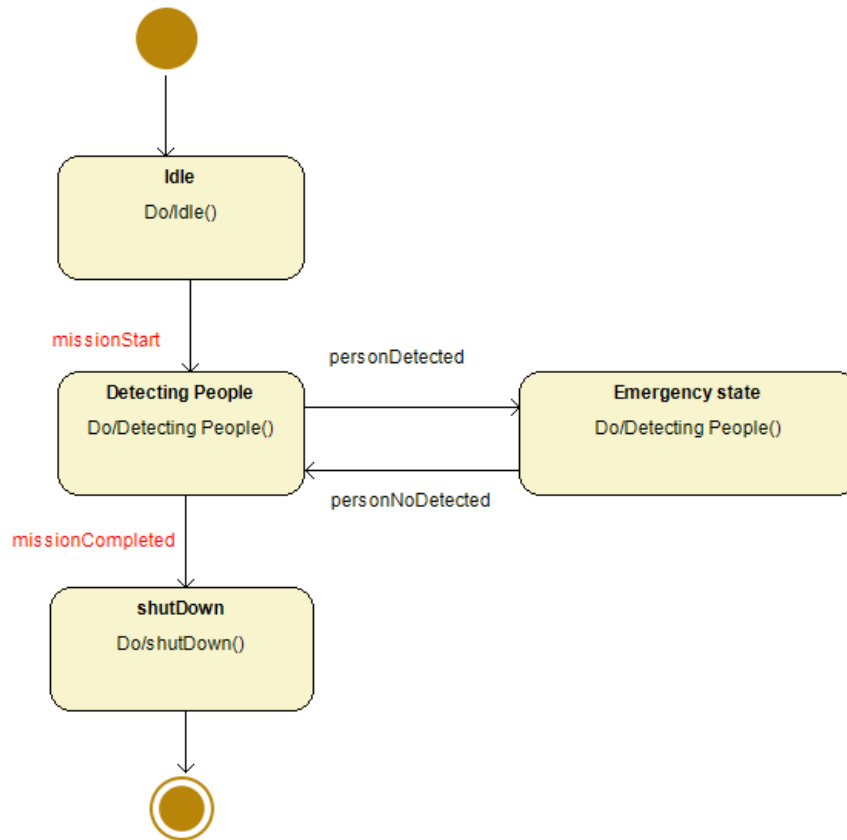
## 4 Final Integrated Behaviors

The specification of the final behaviors integrated is described at D4.6. Among these behaviors, to demonstrate the optimization components in the CPSwarm Workbench, a random walk algorithm is provided. While following this behavior, the *CPS\_Scout* robot picks a random direction and “walks” until it encounters a cart, the edge of the operating space or a distance threshold has been exceeded. It then picks a new random direction and continues walking as before. As the distance parameter affects the effectiveness of the Scout coverage behavior of operating space, it may be optimized for the specifics of the scenario as was described at D4.6.

In addition, the number of robots to manage the requested carts has been also optimized in order to save resources and minimize interlocks between robots.

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

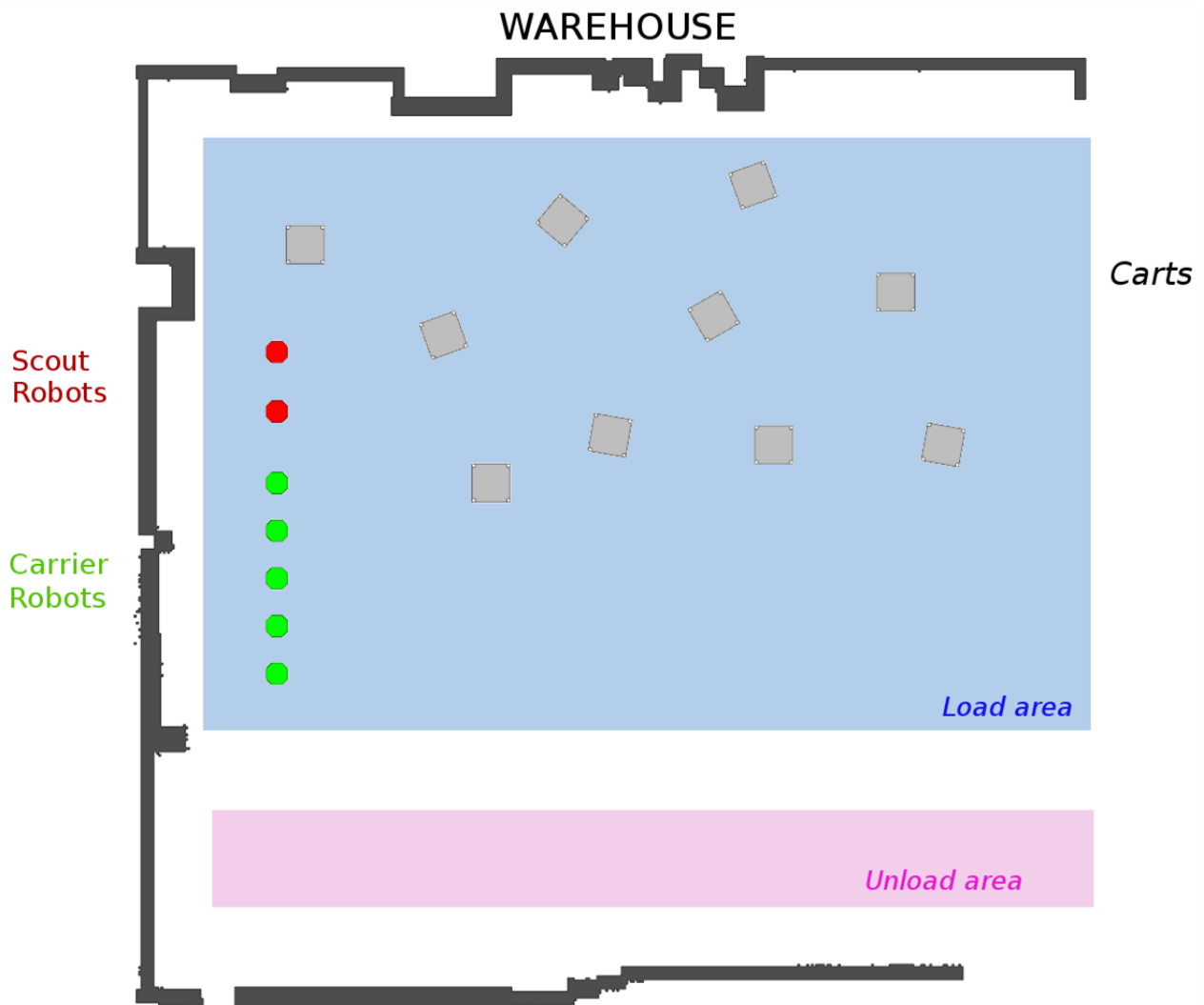






## 5 Final Description of Demonstration

The number of robots that has produced during the optimization phase the best results, has been represented as colored circles at Figure 15, are positioned in well-known positions at the beginning of the demonstration and ten carts are randomly scattered around the warehouse.



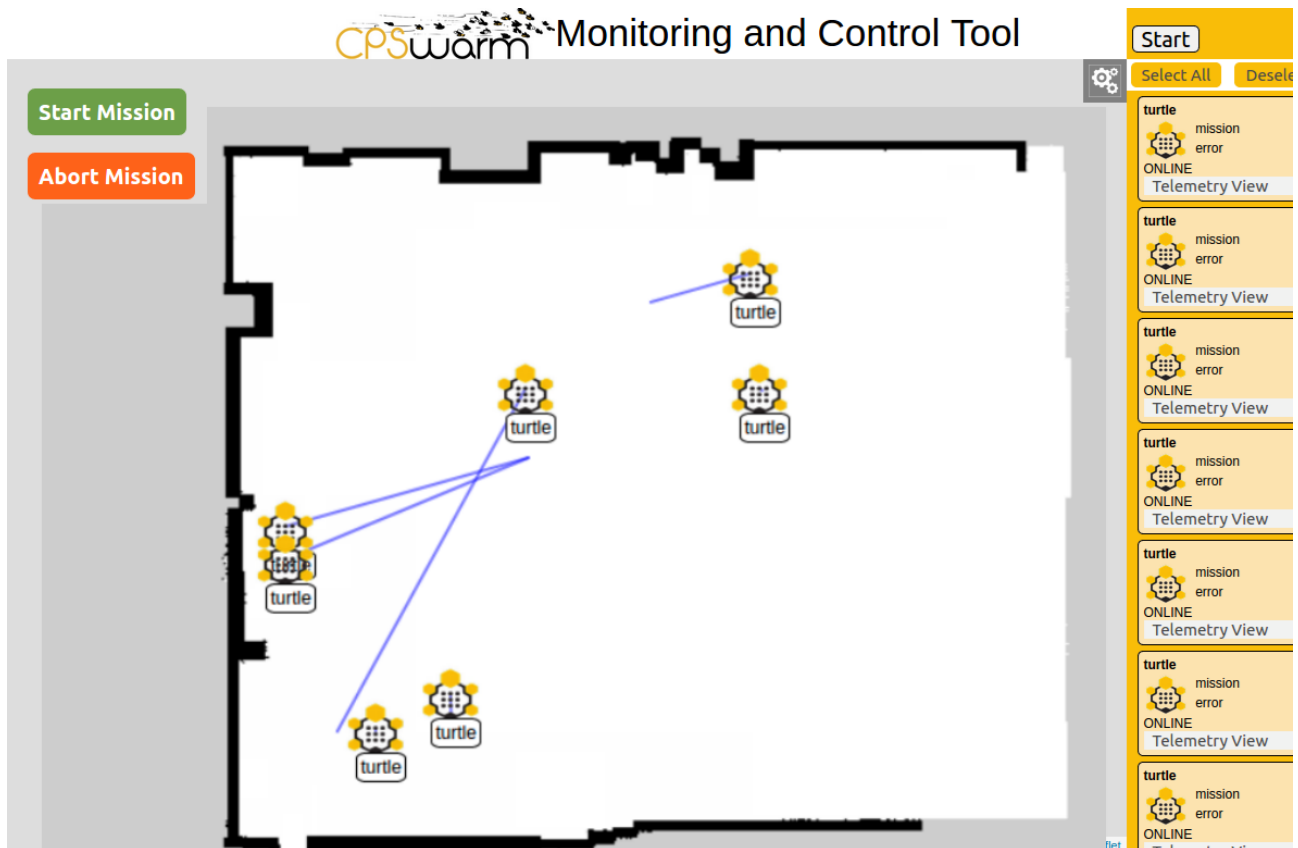
The scenario is divided into two main areas:

1. The area where the carts are located in a disorderly manner and where the robots must find and load them (*Load area*)
2. The area where the carts must be placed in an organized way (*Unload area*).

The ZBRT wireless buttons are used to control manually the execution of the demonstration remotely without wires. This allows the operator not to remain in a fixed and static place of work.


In addition, the Viper camera is located in a corner of the scenario focusing on the entire area where the robots are moving. If the camera detects a human presence, it notifies all robots and they move slowly until the detection of the human disappears.

In the starting point of the demonstration the ID of each cart is assigned to one default position where it must be placed. This assignment can be changed in real time using a *rosservice* through a console and also can be changed using the Monitoring and Command Tool developed in the project at WP7 and described at D7.6. In fact, the Monitoring and Command Tool has been slightly customized in order to add new features for this scenario like the icons of turtlebots (turtles) to represent the robots and icons of the carts as is shown at Figure 16.

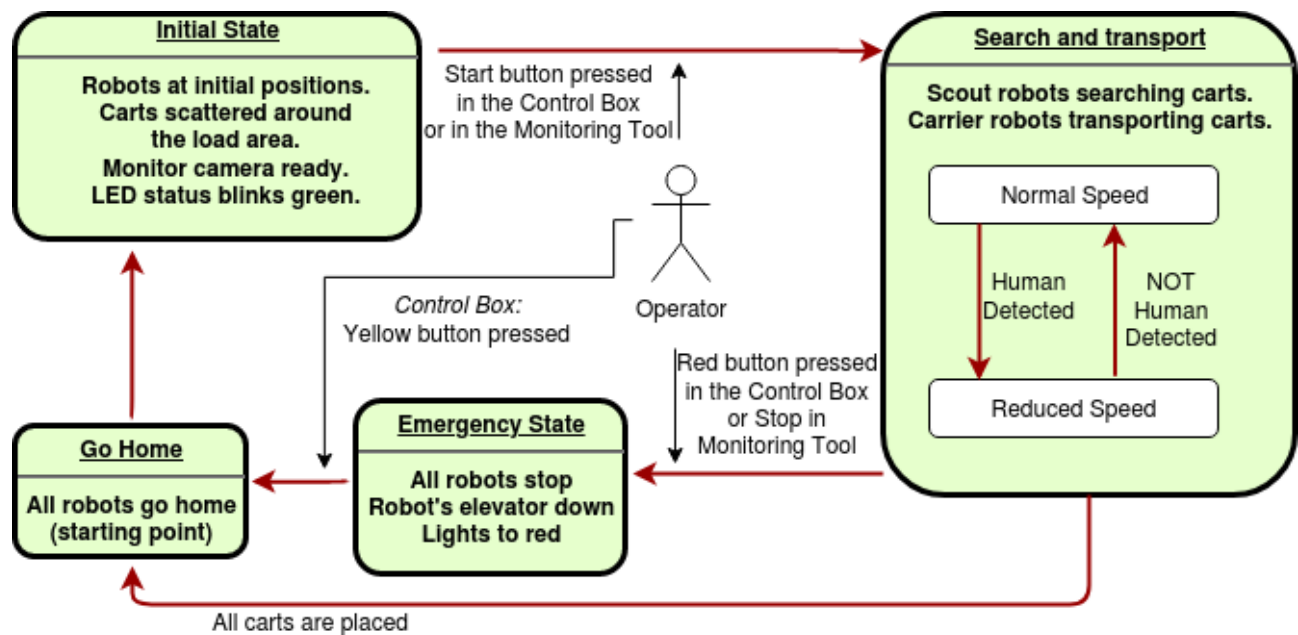


## 5.1 Flow of the demonstration

The flow of the demonstration is shown in Figure 17.

First of all, the carts and the robots are situated in the load area. When the robots are ready to work their lights blink blue. Then the operator can unload using the Monitoring and Command Tool interface or a *rosservice*. This action can be done anytime. Then, the operator  change the default position where the carts must be pushed the run button to start the demo and the *CPS\_scout* robots start to move around searching the carts.

When one *CPS\_scout* robot finds a cart, it reads the QR code with the camera and it starts an auction among all *CPS\_carrier* robots available (which are in Idle state) to select the one closest to the cart position. Each *CPS\_carrier* robot receives from the scout the ID of the cart and its position, and it replies with its euclidean distance from its position to the cart selected.



The *CPS\_scout* waits some seconds to receive all the bids from the *CPS\_carriers* and select the closest one. All the *CPS\_carrier* robots receive the name of the *CPS\_carrier* responsible for transporting finally the cart found. With the ID of the cart, the *CPS\_carrier* robots know in which location of the warehouse the carts must be placed.

When a *CPS\_scout* robot assigns a cart to a specific *CPS\_carrier* it starts looking for more carts.

The control box offers two more buttons, the yellow one and the red one. The red one can be used to cancel the demo 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 start again the demo. If the operator requests a new demo and pushes the green button, the system will start again.

If a person is detected inside the scenario during the execution of the demonstration by the monitor camera, the robots will continue moving but slower. Also, the monitor LED will change to yellow and it will remain in that state until the person disappears. If the person goes too close to any robot, the robot will stop immediately and it will start to move when the person walks away.

## 5.2 Challenges of the final 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.

## 6 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 [8] 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 to the system with sensors in order to be aware of the environment and emergency stops (either on board 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 360° but also can be programmed to lower the speed and then activate a safe stop cat.1 (defined at [9] and [10]) if something is violating a programmed safe zone.

Once again, a study per case is needed, giving, 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 cleaning robot operating at home).

In this use case, if a dynamic obstacle is too close to the robot it will try to avoid the collision with it but if that is not possible it will stop before it collide with it, thanks to the detection of the laser scan. Another related safety feature applied to the scenario is that all robots will reduce the velocity if some human is detected by the monitor camera.

## 7 Conclusions

This deliverable presents the work done in Task 8.2 of the project. It includes mainly the description of the updates carried on for the final demonstration of the Swarm Logistics use case for the final review at M36.

All the future objectives described at D.8.3 to improve the demonstration and to add new features have been integrated in the M36 demo. A camera has been added to be able to discern between objects and humans to grant different behaviors in different cases. Unique codes have been added to the carts to allow a robot to identify them by computer vision. The intelligence has been distributed more among the cyber-physical systems and the server has been totally removed. In addition, the number of robots has been increased from three to seven.

In conclusion, the whole CPSwarm Workbench has been integrated inside the use case helping and facilitating the development of the demonstration.

## Acronyms

Acronym	Explanation
LED	Light Emitting Diode
CPS	Cyber Physical System
ROS	Robot Operating System
ID	Identification
AC	Alternating Current
DC	Direct Current

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## References

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- [2] Slamtec Rplidar A2: <https://www.slamtec.com/en/Lidar/A2>
- [3] Hokuyo UST-10LX: <https://www.hokuyo-usa.com/products/scanning-laser-rangefinders/ust-10lx>
- [4] URG-Node package for ROS: [http://wiki.ros.org/urg\\_node](http://wiki.ros.org/urg_node)
- [5] FLIR Camera driver for ROS: [https://github.com/ros-drivers/flir\\_camera\\_driver](https://github.com/ros-drivers/flir_camera_driver)
- [6] Rubedos VIPER website: <https://www.rubedos.com/solutions/viper>
- [7] NVIDIA Jetson TX2: <https://www.nvidia.com/es-es/autonomous-machines/embedded-systems/jetson-tx2/>
- [8] ISO/TS 15066:2016 Robotcs and robotics devices – Collaborative robots.
- [9] ISO 13850, Safety of machinery – Emergency stop function
- [10] IEC 60204, Safety of machinery – Electrical equipment of machines