

# On the application of a Cyber-Physical Systems framework for Industry 4.0 in Aerospace and Automotive Industries

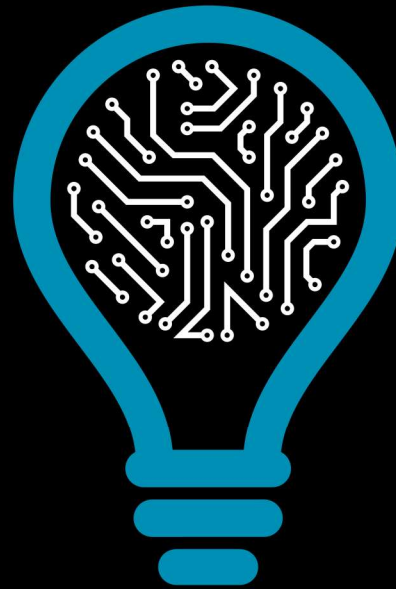
Rafael Arrais, César Toscano, Germano Veiga  
(presented by Roberto Vita)

9<sup>th</sup> EASN International Conference on Innovation in Aviation & Space

03-06/09/2019



INSTITUTE FOR SYSTEMS  
AND COMPUTER ENGINEERING,  
TECHNOLOGY AND SCIENCE



## On the application of a Cyber-Physical Systems framework for Industry 4.0 in Aerospace and Automotive Industries

1. Addressed Problem
2. Open Scalable Production System
3. Industrial Application Examples
4. Conclusion and Future Work

## 1. Addressed Problem

### 1.1. The Fourth Industrial Revolution



### 1st

Mechanisation,  
Steam and  
Water Power



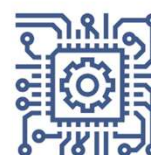
### 2nd

Mass  
production,  
Assembly lines,  
electricity



### 3rd

Computer &  
Automation



### 4th

Cyber Physical  
Systems,  
networks, AI

In <https://www.celaton.com/news/item/the-fourth-industrial-revolution-the-future-of-work.html> (Accessed in 2019-03-28)

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## 1. Addressed Problem

### 1.2. Open Challenges and Opportunities of CPS in Manufacturing



Programming abstractions, hardware  
and software architectures



Trust and usability



Robustness, predictability and  
reliability



Fault Tolerance and Safety




Cybersecurity

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## 1. Addressed Problem


### 1.3. Motivation for a Digital Manufacturing Stack for Robotic Applications





Complex Robotic Applications often require the **INTEGRATION** of several software modules.







The **ORCHESTRATION** of Robotic Applications is not a trivial problem, even if interfaces are well defined.



Usually, strategies rely on **PROBLEM SPECIFIC** orchestrators.  
(monolithic conditional cascading structures, nested switch statements, or ad hoc task planning)

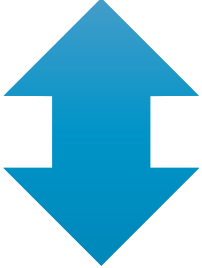





<sup>1</sup> [https://en.wikipedia.org/wiki/Spaghetti\\_code](https://en.wikipedia.org/wiki/Spaghetti_code)

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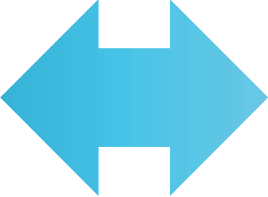
## 1. Addressed Problem

### 1.3. Motivation for a Digital Manufacturing Stack for Robotic Applications





### VERTICAL INTEGRATION





Ensure **BI-DIRECTIONAL** communication between robots and higher vertical systems in the architecture (*MES, ERP, ...*)



### HORIZONTAL INTEGRATION

Provide **INTEROPERABILITY** between robots and industrial equipment (*Automated Warehouses, 3D printers, ...*)

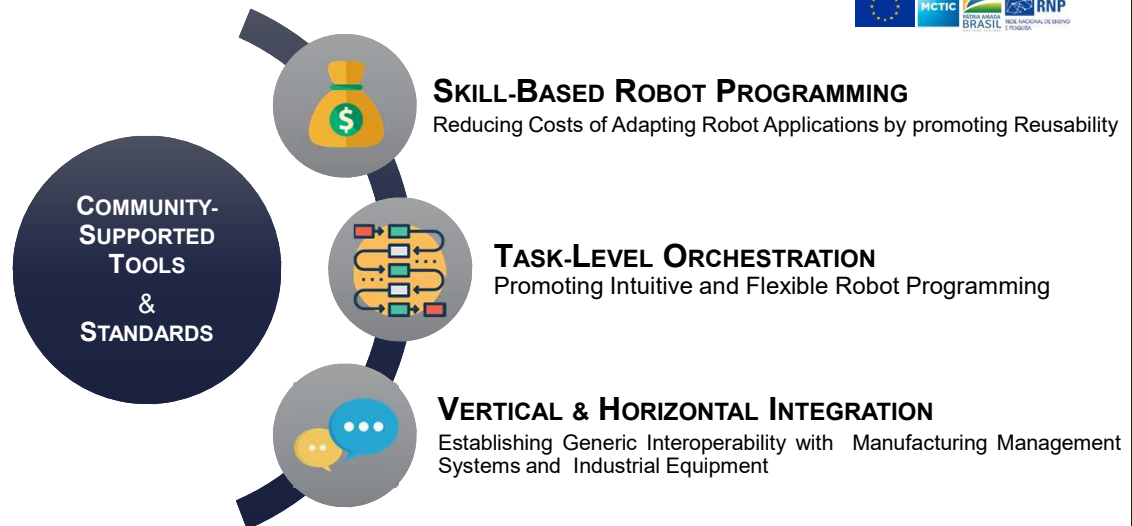



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## 2. Open Scalable Production System

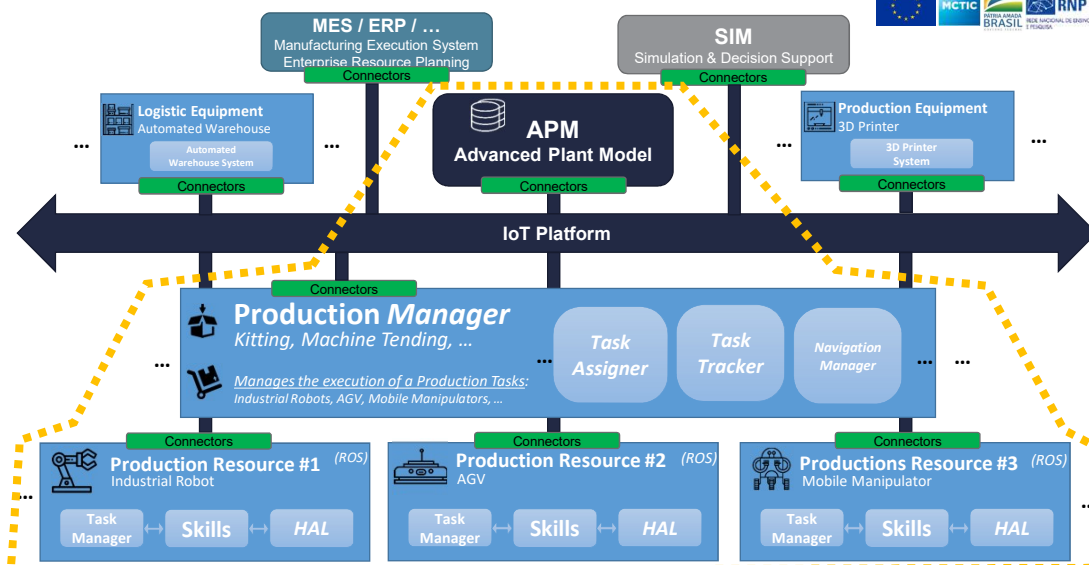
### 2.1. Objectives



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## 2. Open Scalable Production System

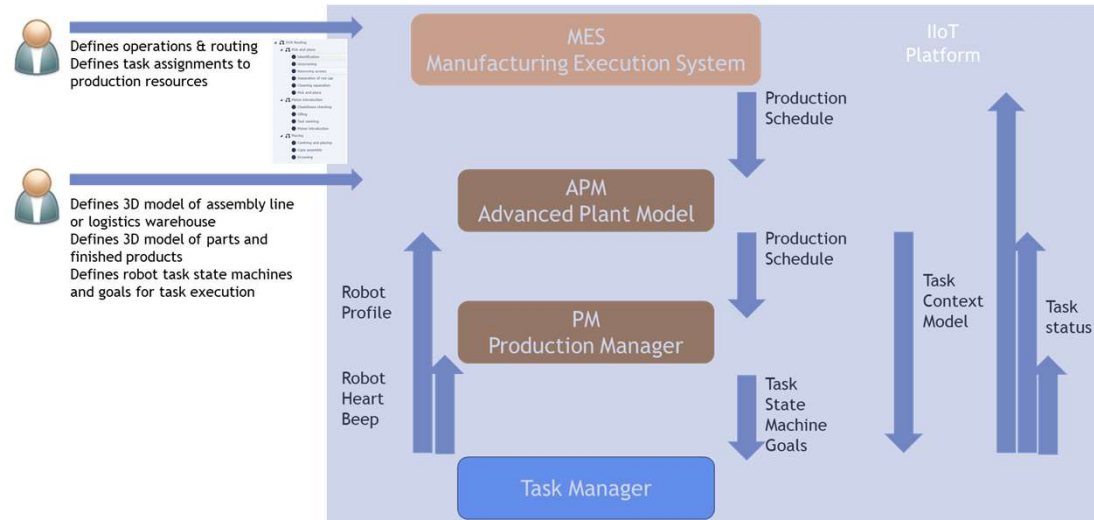
### 2.2. Proposed Architecture



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## 2. Open Scalable Production System

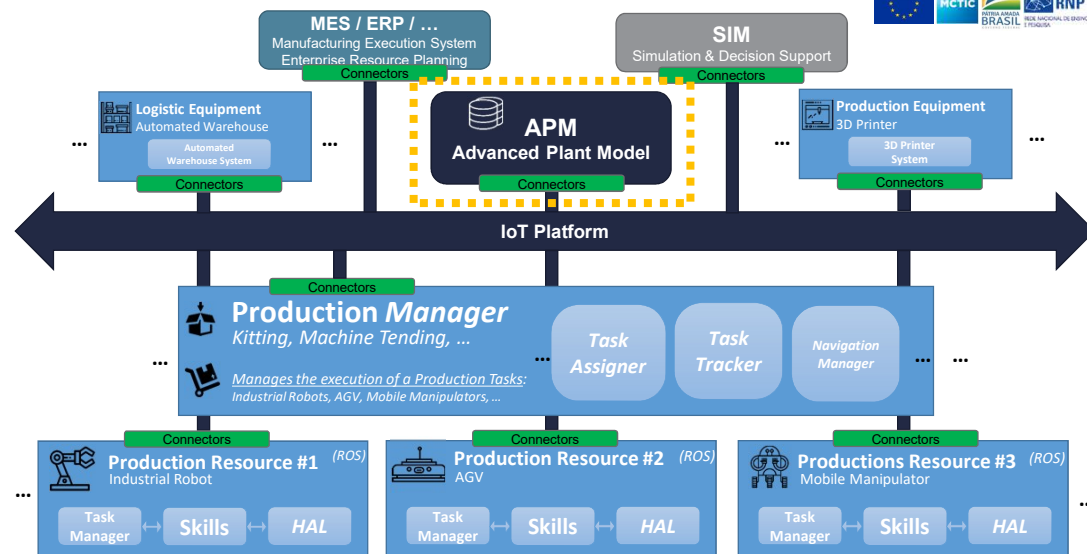
### 2.2. Proposed Architecture



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## 2. Open Scalable Production System

### 2.3. Proposed Architecture: **Advanced Plant Model (APM)**

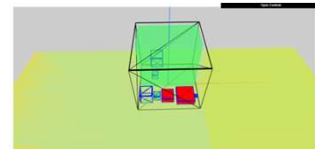
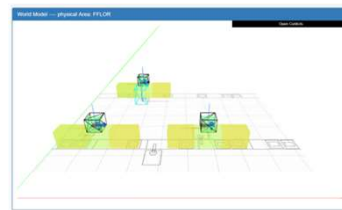
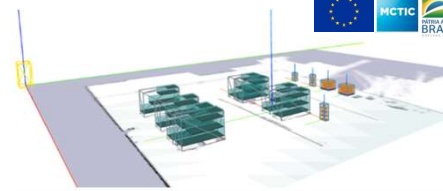


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## 2. Open Scalable Production System

### 2.3. Proposed Architecture: **Advanced Plant Model (APM)**

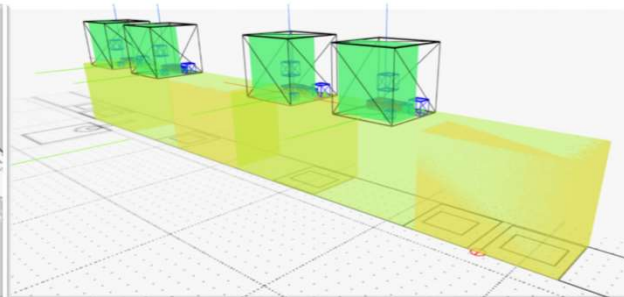
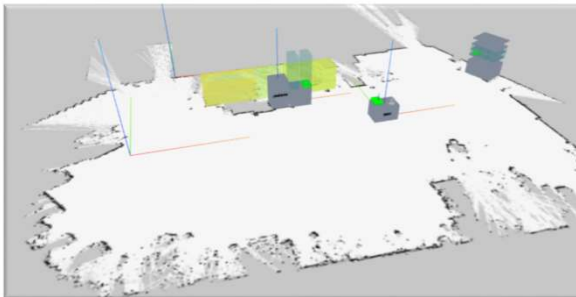
- **Central Entity** that stores a near real-time **Digital Representation** of the ongoing state of the shop floor, in the form of **Semantic** and **Geometrical** information:
  - Logistic Warehouse: Racks, Boxes, Pallettes, Kits, Parts
  - Assembly Line: WorkStation, Manufacturing Line.
  - Fixed + mobile robotic manipulators
  - Production Schedule
- **Synchronizes** a **Digital Twin** representation between multiple software modules in the system



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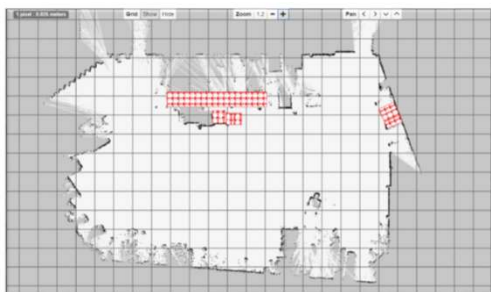
### Task 5.2 – APM – 3D Visualization

- Manufacturing Area Model (navigation tasks)
- Task Context Model (manufacturing tasks)

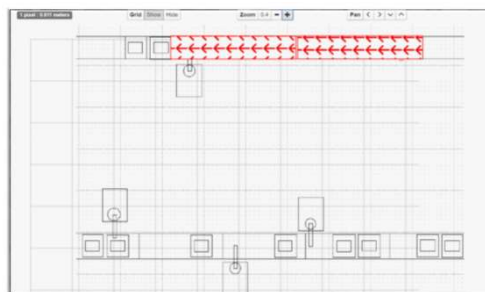


## Task 5.2 – APM – Implantation - 2D editor

- 2D editor within the APM allows to specify which physical objects are implanted thus building the World Model of the physical area
- Simoldes use case



- PSA use case



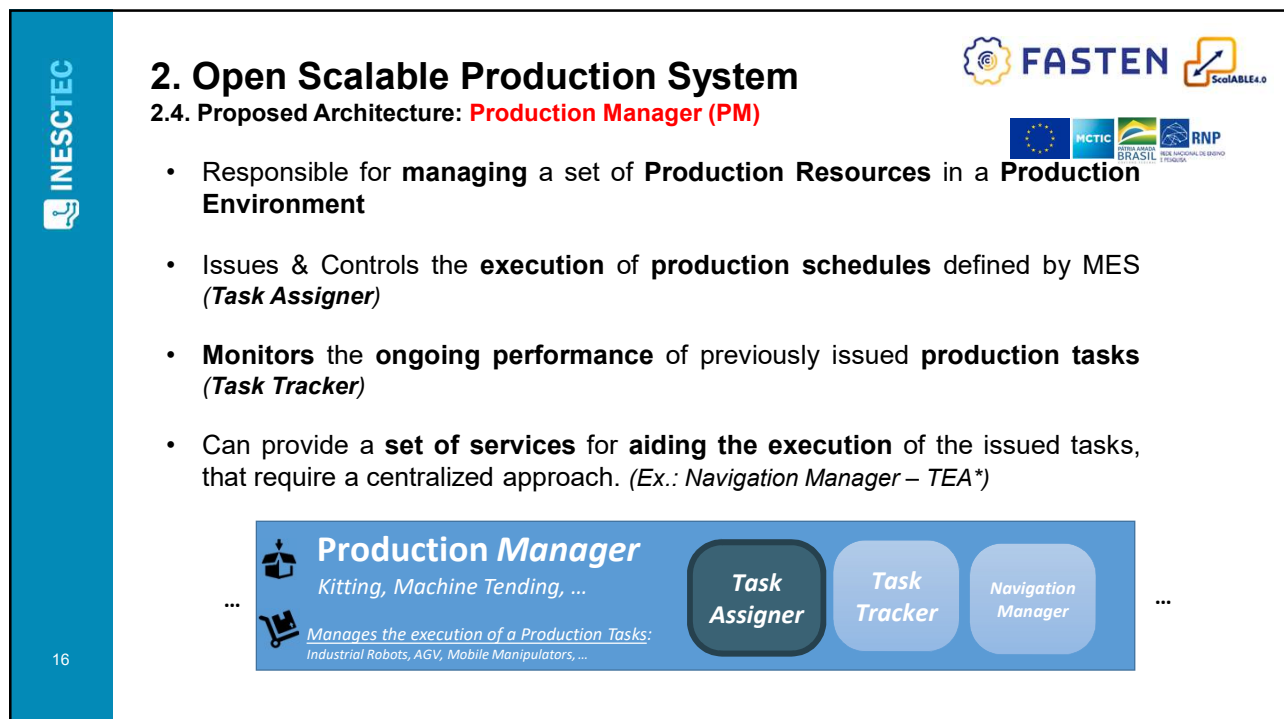
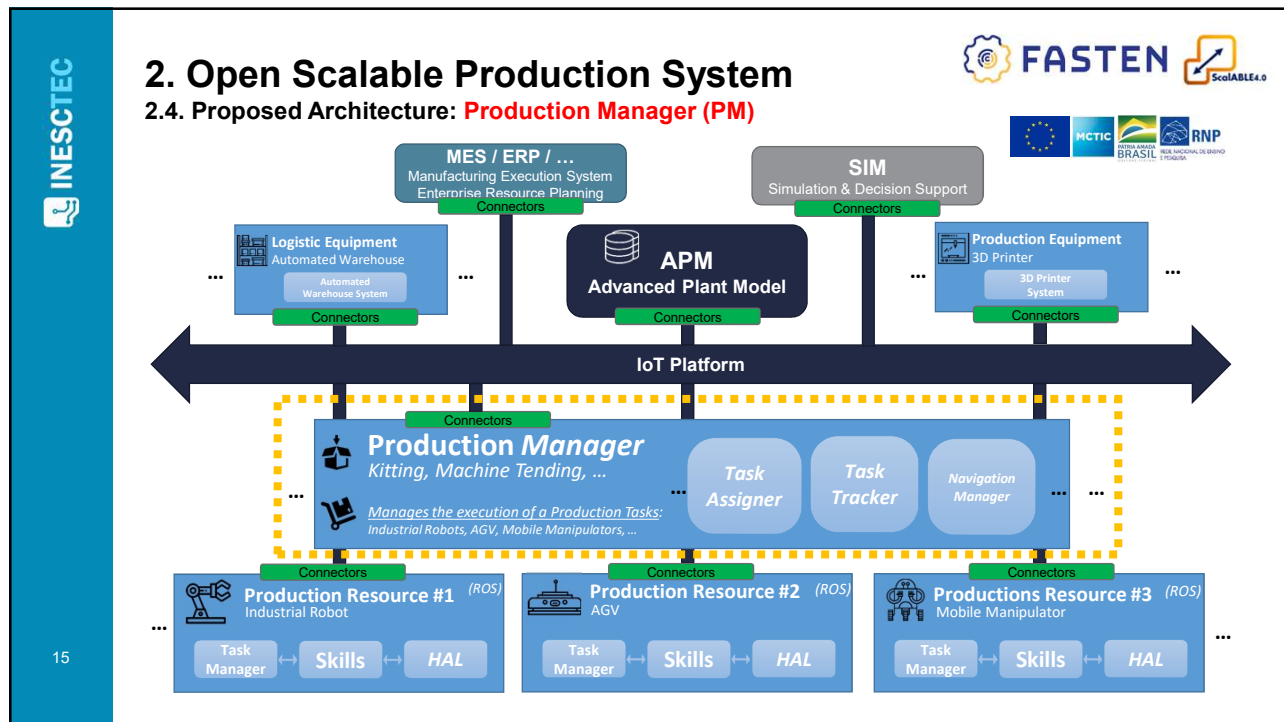
## 2. Open Scalable Production System

### 2.3. Proposed Architecture: **Advanced Plant Model (APM)**



# Advanced Plant Model (APM)

Configuration of an Assembly Line





## Task 5.4 – Production Manager (PM)

- Responsible for **managing** a set of **Production Resources** in a **Production Environment**
- Issues & Controls the **execution** of **production schedules** defined by MES (**Task Assigner**)
- Monitors** the **ongoing performance** of previously issued **production tasks** (**Task Tracker**)
- Can provide a **set of services** for **aiding the execution** of the issued tasks, that require a centralized approach.
- Allows the import of custom production orders (logistic warehouse environment)

Physical Area		Start Date	End Date	Released on	Actions
17:08:42:1020000					
Production Order	#	Start Date	End Date	Final Product	Actions
Assembly_01	1	17:07:58	17:28:58	Nanite_B208	
Simulation_01		Execution Finished	17:08:42	17:16:50	
Assembly_01		Execution Finished	17:08:47	17:16:50	taskname
Simulation_01		Executing	17:16:50		
Drive_Rack1		Execution Finished	17:16:54	17:16:57	2424
Positioning_Rack1		Execution Finished	17:17:02	17:17:05	2424
Drive_Rack2		Executing	17:17:08		2424
Positioning_Rack2		Planned			2424
Simulation_01		Planned			
Drive_Rack2		Planned			2424
Positioning_Rack2		Planned			2424
Drive_Rack3		Planned			2424
Positioning_Rack3		Planned			2424

Task  
Assigner

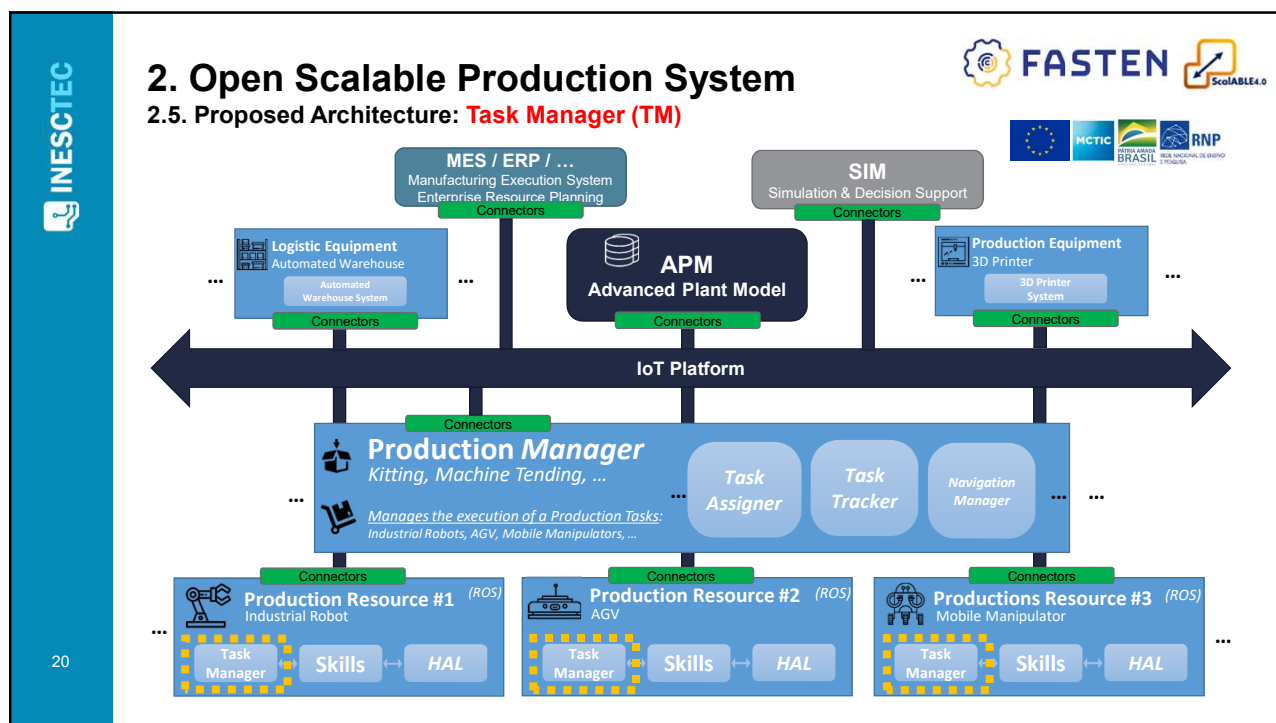
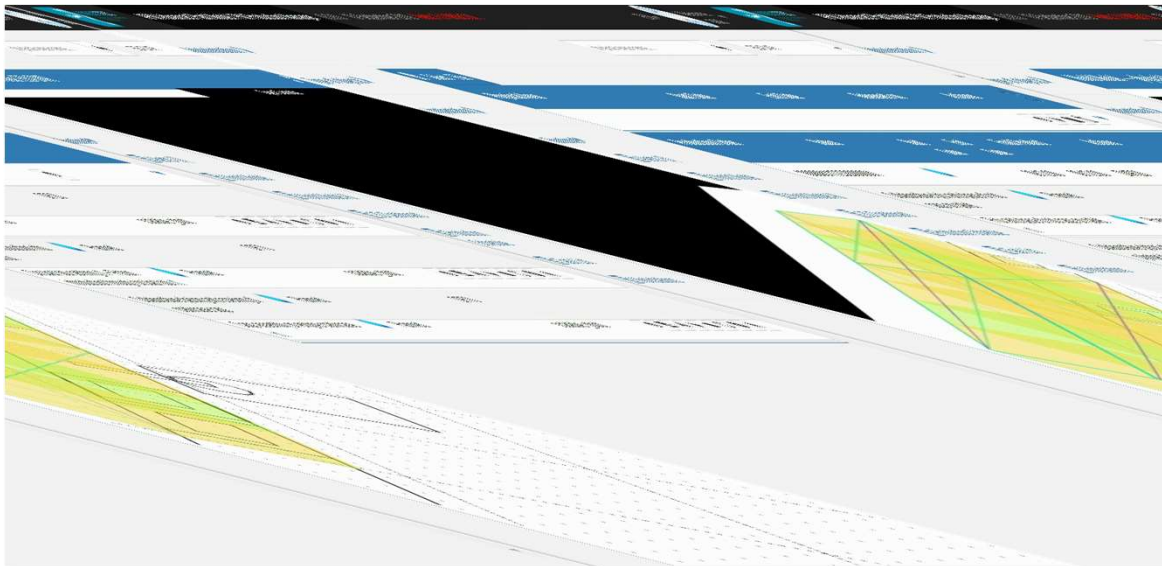
Task  
Tracker

## Task 5.4 – Production Manager (PM)

- Manufacturing Tasks Management between PM and TM

Physical Area		Start Date	End Date	Released on	Actions
17:09:13-19:09:02					
Production Order	#	Start Date	End Date	Final Product	Actions
190201103514000008	1	09:48:00	09:48:00	EB20	
Collaborative pick and place of rod caps on pallet		Execution Finished	17:09:14	17:09:45	
Unscrewing & Separation of the rod head with the body x2		Execution Finished	17:09:14	17:09:14	qp00_resource_robot
Unscrewing & Separation of the rod head with the body x1		Execution Finished	17:09:14	17:09:14	qp00_resource_robot
Pick and place of rod caps on pallet x2		Execution Finished	17:09:14	17:09:14	qp00_resource_robot
Pick and place of rod caps on pallet x1		Execution Finished	17:09:43	17:09:45	scalable_robot
Collaborative piston introduction into cylinder block		Execution Finished	17:09:45	17:09:53	
Circular tool centring x2 • Piston introduction through circular tool x2		Execution Finished	17:09:45	17:09:45	qp00_resource_robot
Circular tool centring x1 • Piston introduction through circular tool x1		Execution Finished	17:09:51	17:09:53	scalable_robot
190201103514000007	1	06:47:00	06:47:00	EB70	
Collaborative placing and screwing of crankcase caps		Execution Finished	17:10:36	17:10:44	
Centring and placing the bearing on cylinder block x2		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Centring and placing the bearing on cylinder block x1		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Oiling 3 cylinder blocks bearings and 2 conrod bearings		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Oiling 1 cylinder block's bearing and 1 conrod bearing		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Conrods orientation x2		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Loading crankshaft in cylinder block		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Crankshaft detentative reading		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Lateral bearing assembly		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Oiling 3 cylinder block's bearings and 2 conrod bearings		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Oiling 1 cylinder block's bearing and 1 conrod bearing		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Caps assembly on engine crankcase x3		Execution Finished	17:10:36	17:10:36	qp00_resource_robot
Caps assembly on engine crankcase x1		Execution Finished	17:10:42	17:10:44	scalable_robot
190201103514000008	1	06:47:00	06:47:00	DVR20	
Pick and place of rod caps on pallet		Execution Finished	17:11:27	17:11:27	
Unscrewing & Separation of the rod head with the body x2		Execution Finished	17:11:27	17:11:27	qp00_resource_robot
Pick and place of rod caps on pallet x2		Execution Finished	17:11:27	17:11:27	qp00_resource_robot

## Task 5.2 – Synchronization of the Data Model between the APM/PM and TM



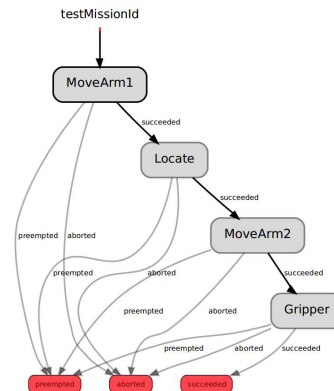
## 2. Open Scalable Production System

### 2.5. Proposed Architecture: **Task Manager (TM)**

- **Central Module** running **onboard** the Robot
- Provides **Integration Mechanisms** between the **Robot**, **APM** & **PM**
- **Orchestrates production tasks** in the form of sets of **robotic Skills**
- **Task Scripting** approach based on **Hierarchical & Concurrent State Machines**. (*ROS SMACH*)
- Supports Task Scripting based on SCXML files



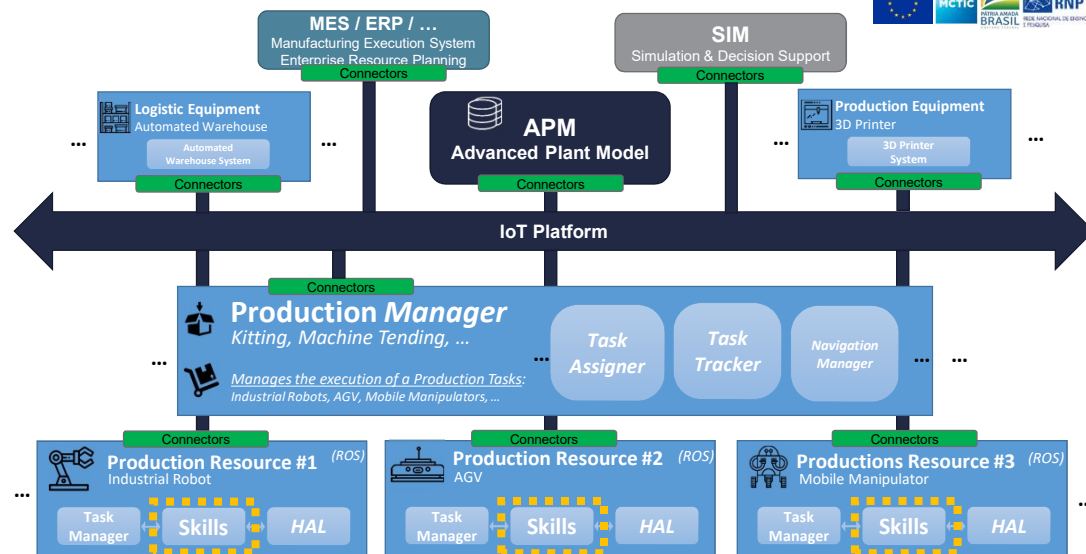
smach



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## 2. Open Scalable Production System

### 2.6. Proposed Architecture: **Skill-based Robot Programming**



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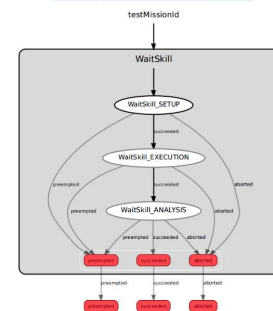
## 2. Open Scalable Production System

### 2.6. Proposed Architecture: **Skill-based Robot Programming**

- Meant to be **Hardware Agnostic**.
- Should be **Reusable** by **different platforms**, for **different tasks**, and in **different environments**.
- Built on top of **ROS Actions**.
- Each **Skill** is constructed as a **ROS Action Server**.
- **TM** implements the **ROS Action Client**.

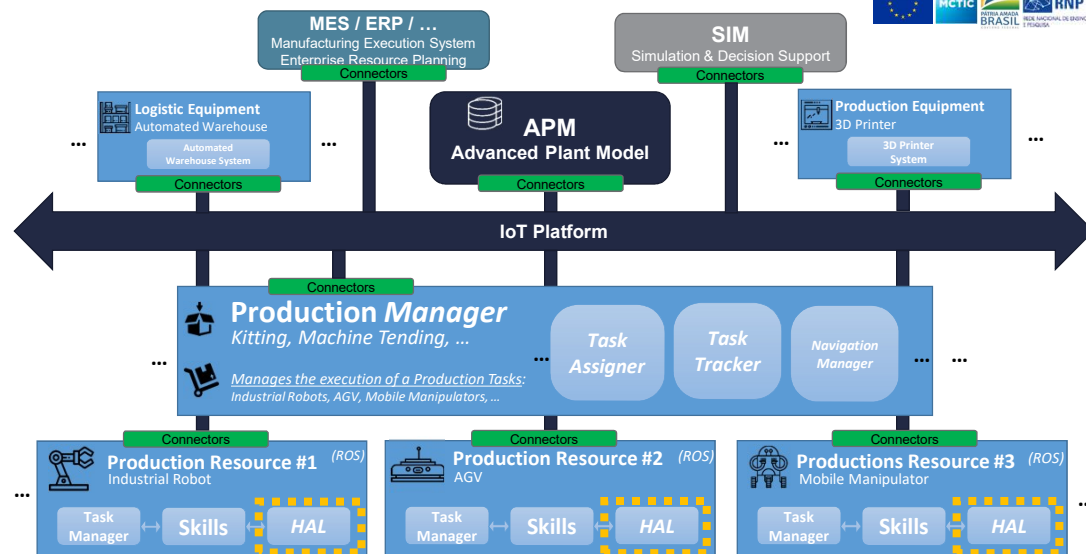


```
#goal definition
Int32 waitTime
---
#result definition
int32 percentage
string skillStatus
---
#feedback
int32 percentage
string skillStatus
```



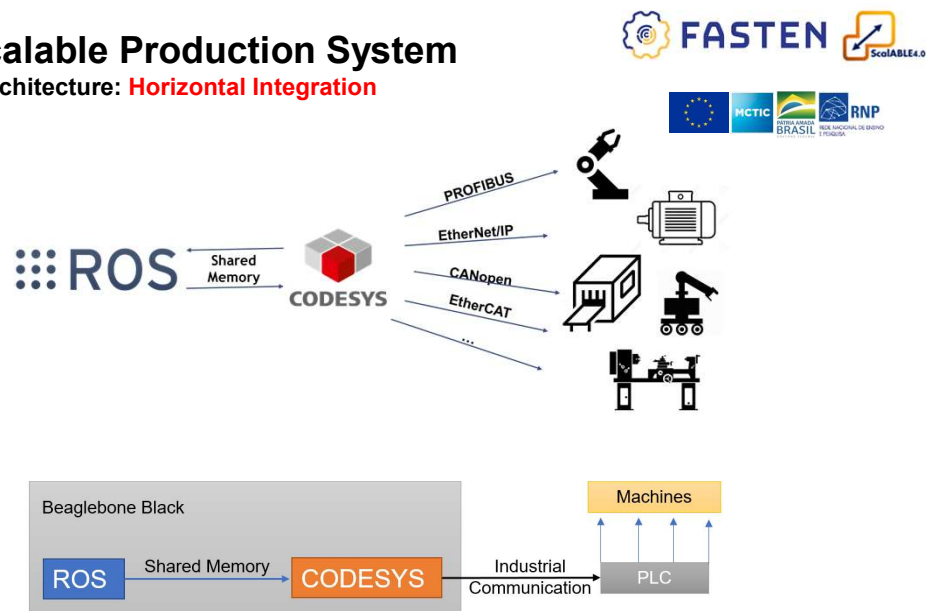
## 2. Open Scalable Production System

### 2.7. Proposed Architecture: **Horizontal Integration**



## 2. Open Scalable Production System

### 2.7. Proposed Architecture: **Horizontal Integration**



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## 3. Industrial Application Examples

### 3.1. H2020 ColRobot Demonstration



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### 3. Industrial Application Examples

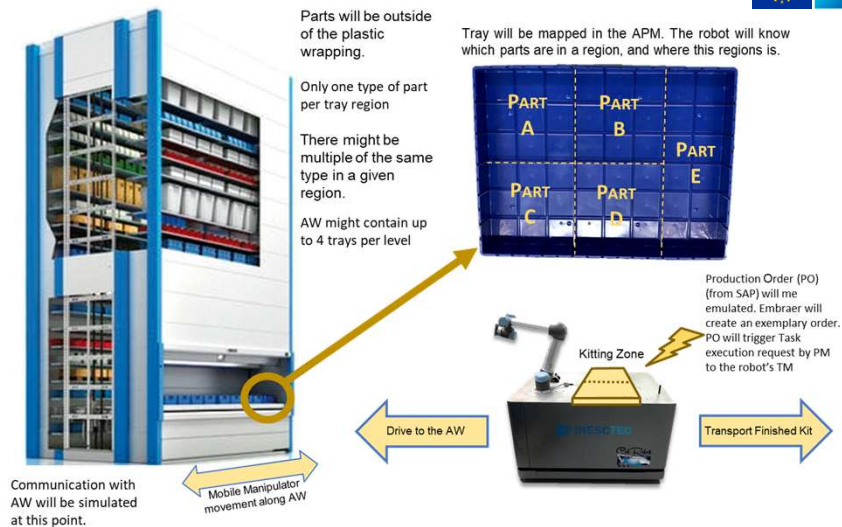
#### 3.2. H2020 ScalABLE4.0 Preliminary Demonstration



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### 3. Industrial Application Examples

#### 3.3. H2020 FASTEN Preliminary Demonstration



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## 3. Industrial Application Examples

### 3.3. H2020 FASTEN Preliminary Demonstration








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from knowledge  
production to  
science-based  
innovation



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