



Risk analysis and safety concept development for delta picker robot  
cell in an Industry 4.0 plant

# Thesis

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BY:

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## **Declaration of authorship**

I hereby declare that the master thesis here presented is my own work and did not use any other sources than those identified as references. The drawings or illustrations in this work have been created by myself or have been provided with a corresponding source.

I also declare that this thesis has not been presented at any other institution nor been published.

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## **Abstract**

Industry 4.0 has a service oriented architecture where the services are modular and autonomous. The communication between the services needs to be developed due to different protocols and programming languages. To release a machine in Europe must be certified by CE and comply with the standard ISO 12100 that is helped by other standards like ISO 13489. This thesis presents the development of a Delta picker application in an Industry 4.0 environment. The safety system for the robot cell is developed to protect the people inside the room achieving the performance level necessary. A gateway is created to allow the robot controller to communicate with the ERP service in the cloud allowing the machine to assemble products.

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## **Chapter 1. Introduction**

Industry 4.0 is the next step in the production processes. An Industry 4.0 system is cloud based and it is oriented to services. It allows the exchange of information between systems. In service orientation the services are modular and take care of one function; this allows the combination of services as needed and the interoperability even when they use different platforms and languages[7]. Therefore, in the integration of a robot cell to a cloud based ERP service, both are seen as services. This thesis presents the development of a Delta picker application in an Industry 4.0 environment.

In order to achieve the production of the cell, a control system is needed. In the chapter 3 is presented the integration of the robot, PLC, sensors and actuators to accomplish the goals of the machine and ensure its proper functioning.

When a production cell is built, besides the control system, the safety must be considered. When there are moving parts, a risk of an accident is always present. From a minor injury to death, the hazards must be prevented. Every machine must have a CE conformity mark. Through EN ISO 12100 norm, the conformity of the machine can be reached. This norm provides the guidance to achieve a safe operation environment. A high-speed Delta picker application requires of a safety system to prevent the hazards related to its safe operation. The first step is to make a risk analysis in order to find all the risks presented. After the finding of this risks, actions can be taken. This will be developed in chapter 4.

Chapter 5 presents the implementation of an interface to communicate the robot with a cloud based service reaching the concept of Industry 4.0. Last, Chapter 6 presents results and conclusions of this thesis.

## 1.1 Background

One of the main ideas of Industry 4.0 is the Smart Factory. Smart factory is a “production environment in which production plants and logistics systems self-organize without human intervention” [1]. Also, considers an exchange of information between the product and the production plant. Industry 4.0 is considered as a specialization of the Internet of Things in connection with engineering.

The structure of an Industry 4.0 system consists in services that share information between them. The CMC (Car Manufacturing Cube) present at the FH Aachen includes a ERP as a service in the cloud that provides all the information to fabricate Lego cars according to what was selected in OpenCart webshop and a Cell that is able to assemble the cars.

A robot cell is present at the FH Aachen. This robot cell is able to work without the intervention of an operator. If the robot cell receives the information of the pieces and their location, it can build the products.

This robot cell is placed in a laboratory where there are students present. The high velocity and the force that the robot can achieve demand the needs for safety. The physical integrity of the students is of main importance.

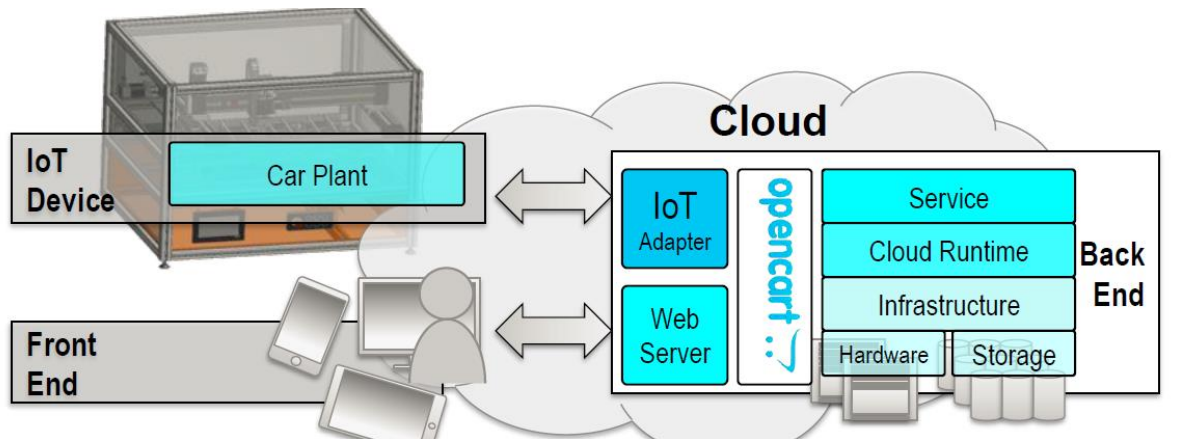


Image 1.1 Structure of Car Manufacturing Cube

## **1.2 Problem statement**

In the present day, the FH Aachen counts with an autonomous Robot cell. There is the need of a service infrastructure for a plant-ERP service and the interfacing the IRC5 ABB controller in Industry 4.0 world. There is also the need of a safety system for the robot cell in order to protect the people around.

### **1.3 Justification**

Developing a concept and system solution for autonomous Robot cell as a sample for FH-AC with a Delta picker for Lego car manufacturing. Making a risk-analysis and realizing the safety system and ERP connection for this robot cell to have a safe machine integrated with Industry 4.0.

## 1.4 Aim and Objectives

### **Aim:**

The aim in this project is to design a control and safety system for an automated assembling cell using a high-speed delta robot and the concepts of Industry 4.0 for the assembling of parts in a one-piece-workflow with high flexibility, and implementation of a gateway to achieve a communication between the ERP and the IRC5 controller.

### **Specific objectives:**

- To put in operation the ABB Flexpicker™ IRB 340.
- To make the proper interconnection between the ABB Flexpicker™ IRB 340 and the ABB IRC5 controller.
- To define PLC controller, sensors and actuators for the control system to check for goods in the stock bay and working area.
- To define communication protocols.
- To specify modules and cables needed for the communication protocols.
- To make a risk assessment.
- To design and implement a safety system for the assembling cell.
- To implement an existing web application for ordering process to assign to the robot cell the production of cars. (Industry 4.0)
- Proof of concept for a one-piece-workflow based on the constrains individually produced Lego-Duplo cars.

## **1.5 Hypothesis**

A Delta Robot assembly cell is designated as an autonomous Industry 4.0 cell with all constraints towards a EN 12100 conforming implementation. Additionally, it is integrated in a Cloud-based ERP system with a standardized internet connection as a service structure.

## 1.6 Methodology

As a first step a literature review must be done. The literature review is considered gathering information about Control systems, safety systems, risk assessment, communication protocols and industry 4.0.

To put the robot in operation the Flexpicker IRB340 and the IRC5 controller is inspected for missing parts comparing the physical units with the user manual. After that, a list of needed spare parts is made and later, the parts are ordered. When the parts come, they are installed and the robot is tested using the graphical terminal performing basic moves explained in the manual.

The sequence routine is established in order to define needed sensors and actuators. The selection of sensors is done trying to re-use sensors available at the FH-Aachen. The protocol used to communicate the PLC with the robot is selected according to the manuals of both devices. Once the protocol is selected, cables and connectors are specified. Later, control enclosure and cable routing are designed according to the PLC, modules and sensors selected.

After that, necessary parts are ordered to test the PLC and communication with the robot.

Before the design of the safety system, a risk assessment must be done. The risk assessment is done supported on ISO 12100 and ISO 13849-1 standards. Then, the necessary safety devices and cables will be selected in order to design the system. The system will be tested after the arrival of the parts, using the risk assessment to evaluate again the machine.

There will be defined also communication protocols between the robot and the safety system as well as the server.

A gateway is developed in two stages, first, the communication with the IRC5 controller through OPC DA; then, to the ERP using HTML.

## Chapter 2. State of the art

### 2.1 Industry 4.0

Since 2012 Germany is having industry 4.0 as a project to be implemented. Thus, every year in Hannover Fair are celebrated industry 4.0 milestones in order to establish Germany as the lead provider of Cyber Physical Systems. Industry 4.0 has the connectivity in a very important place. This ability to exchange information communicate through physical connections and protocols, allowing an intelligent networking of industries under a cloud-based approach[8]. Industry 4.0 has six design principles: Interoperability, virtualization, decentralization, Real-Time Capability, Service orientation and Modularity[9]. Industry 4.0 can be a support for lean production, going from mass production to one-piece workflow[10]. Industry 4.0 is able to build a full digital workflow from ordering to fulfillment reducing times and costs.

In the year 2015 was developed an assembling machine for one-piece-workflow. This machine applies the concepts of industry 4.0. An order can be placed in the server, the assignment of an order depends on the stock.



Image 2.1 Cloud based built-to-order[1]

In the connection of Industry 4.0 components, exist two domains: “Shop floor” and “Office Floor” Every domain has its own requirements. Office floor includes Apps, business processes, cloud, etc. It’s an enterprise network. Shop floor is a realtime network and includes the production processes, control, sensors, machines and events.



## 2.2 Robot cells

Robot cells are very common in manufacturing industry. The robots are used for mass production, where the tasks are repetitive but must be done quickly and with precision. There are two types of robots, serial and parallel. Compared to the serial robots, the parallel robots have as advantages, more flexibility, high stiffness and high accuracy but they work in a small area and the models are complex.

In 1991, Professor Reymond Clavel presented a thesis called “Conception d’un robot parallele rapide a 4 degres de liberte” at the Ecole Polytechnique Federale de Lausanne[11] This parallel robot has three translational and one rotational degree of freedom. This kind of robots are based on parallelograms. Parallel robots have a fixed base and a moving end effector connected by linkages.

In 1999 the IRB 340 FlexPicker™ was launched by ABB. This robot has as main applications assembly, material handling, picking and packing. It can handle more than 150 picks per minute, a capacity of 1 kg and a max speed of 10 m/s. The working range is 1130 mm of diameter. The main target sectors are foo, pharmaceutical and electronics. [12]



Image 2.2 IRB 340 FlexPicker™ [4]

When a robot is present, its work area is isolated by fences, guards, doors with safety devices or light curtains, to separate from the human working area. Norms like ISO 14120 provide the guidance for the selection and design of safety guards. Projects have been developed to create architectures to allow robots operate in open spaces keeping a safe environment for humans[13], [14].

## 2.3 DIN EN ISO 12100

This standard provides to the designers a guide for the construction of safe machine. This standard forms a basis for standards with the following structure:

- Type A (basis safety standards): basic concepts and principles for design applied to machines.
- Type B (generic safety standards): focus in one safety aspect (B1) or one type of protective devices (B2).
- Type C (machinery safety standards): focus on the requirements in a particular type of machines.

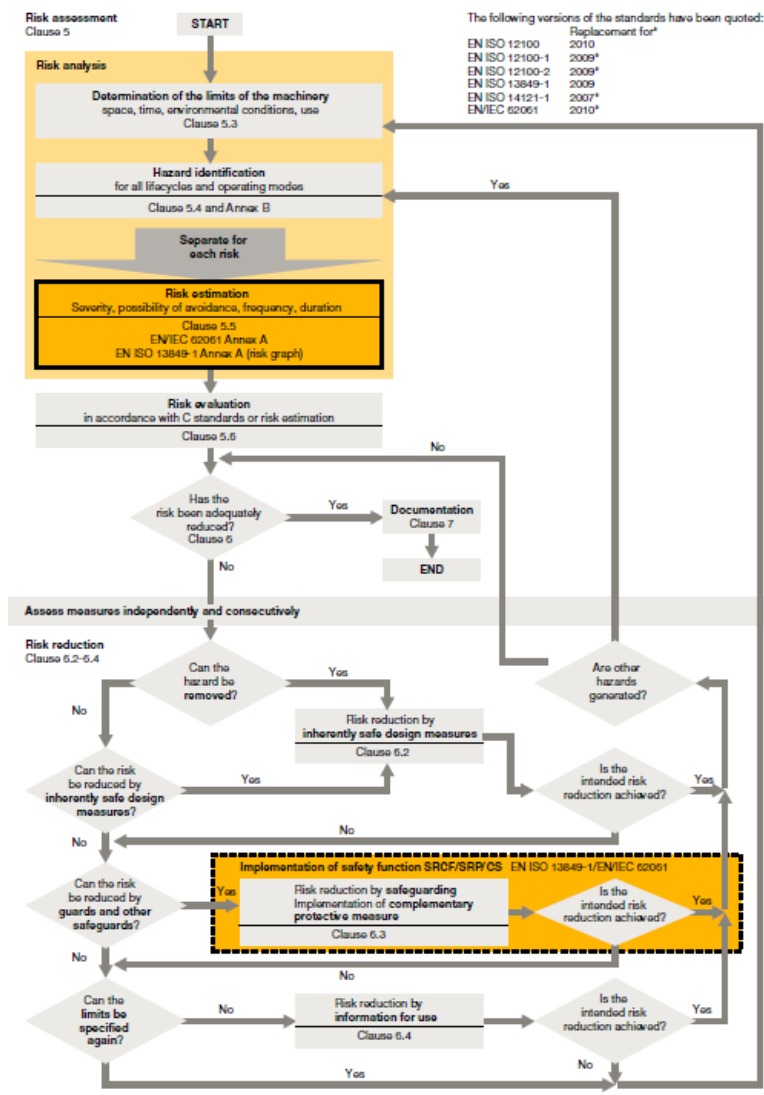


Image 2.3 Risk estimation and risk reduction according with EN ISO 12100[2]

The algorithm to perform a risk assessment is shown in the image 3.1 according to the norm DIN EN ISO 12100. The steps for the risk assessment are:

- 1.- Determination of the limits of the machine (operating modes, possibilities of intervention of Users, application of machine, spatial boundaries and time limits).
- 2.- Identification of the hazards.
- 3.- Separate every risk found to evaluate them independently and estimate severity, possibility of avoidance, frequency and duration.
- 4.- Finally a risk evaluation in accordance to the risk estimation.

### 2.3.1 Risk assessment

A risk assessment is done to detect the risks existent in the machine and to find a solution to reduce them. It consists in a risk analysis and a risk reduction. The risk analysis is used to find the hazards; each risk will be estimated by separated. The risk reduction is the modification in the design in order to remove or reduce the risk found in the analysis.

According to Pilz[15] the risk assessment takes four things into account: Likelihood of occurrence, frequency of exposure, degree of possible harm and the number of persons at risk. The risk level is calculated according to the next formula:

$$\text{Risk level} = LO * FE * DPH * NP$$

Risk level	
Negligible	0-5
Low but significant	5-50
High	50-500
Unacceptable	500+

Table 2.1 Risk level [6]

Interpreting the table 2.1, the result of the calculated value can give an equivalent risk level. The lowest level is Negligible and is the recommended to reach.

The tables 2.2 – 2.5 show the values that may take the variables with the observations made by the evaluator and the people working with the machine:

Likelihood of occurrence (LO)		
Almost impossible	Possible only under extreme circumstances	0.033
Highly unlikely	Though conceivable	1
Unlikely	But could occur	1.5
Possible	But unusual	2
Even chance	Could happen	5
Probable	Not surprising	8
Likely	Only to be expected	10
Certain	No doubt	15

Table 2.2 Likelihood of occurrence [6]

Likelihood of occurrence is how probable is the contact with the hazard to happen.

Frequency of exposure to the hazard (FE)	
Annually	0.5
Monthly	1
Weekly	1.5
Daily	2.5
Hourly	4
Constantly	5

Table 2.3 Frequency of exposure to the hazard [6]

Frequency of the exposure depends on the amount of time that a person spends near the hazard.

Degree of possible harm (DPH), taking into account the worst possible case	
Scratch/bruise	0.1
Laceration/mild ill-effect	0.5
Break minor bone or minor illness (temporary)	2
Break major bone or major illness (temporary)	4
Loss of one limb, eye, hearing loss (permanent)	6
Loss of two limbs, eyes, (permanent)	10

Fatality	15
----------	----

Table 2.4 Degree of possible harm [6]

Degree of possible harm is the consequence in the integrity of the person exposed to the hazard. The worst possible harm must be taken into account.

Number of persons exposed to the hazard (NP)	
1-2 persons	1
3-7 persons	2
8-15 persons	4
16-50 persons	8
50+ persons	12

Table 2.5 Number of persons exposed to the hazard [6]

Table 2.5 provides an equivalent to the number of persons at risk.

After the value of the risk evaluation is obtained, can be decided if a risk reduction is needed or can be neglected.

### 2.3.2 Risk mitigation

DIN EN ISO 12100 presents a “three-step process” to achieve a risk reduction eliminating hazards or separate or reduce the extent of damage and its probability.

Step 1: An inherently safe design can eliminate or reduce the risks through the consideration of all the geometric factors, physical aspects as velocities or mass, specification for constructions, selection of appropriated technologies, among others.

Step 2: Technical protective measurements like guards or two-hand control can reduce the risk

Step 3: User information like texts or signs must show the residual risks left by the steps 1 and 2.

ISO 14120 is the norm that presents the requirements for the design of the guards. In the image 2.4 is shown the process for the selection of a guard.

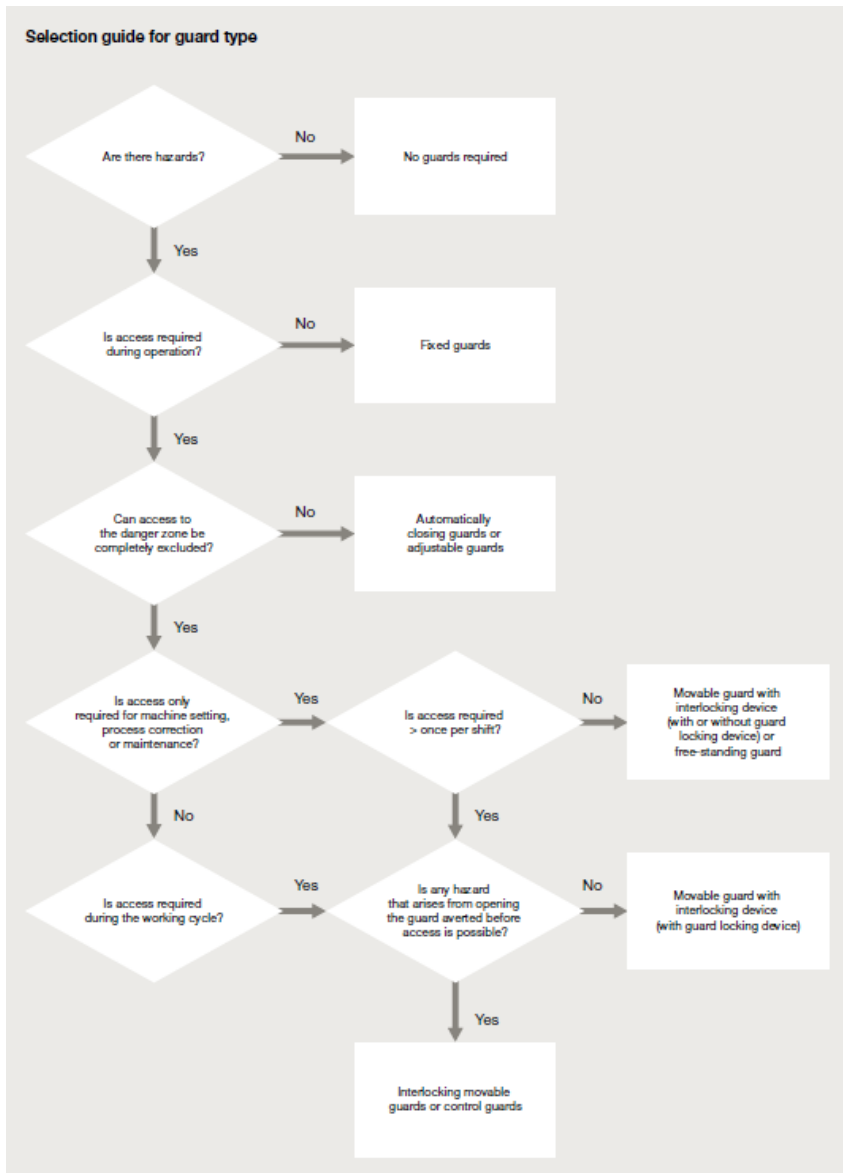


Image 2.4 In accordance with EN 953 Annex A[2]

For the selection of the guide, the access during operation, frequency of access and the existence of hazard if opening the guard are evaluated to decide the kind of guard to be used.

When there is not a risk of objects that can be turned into projectiles, Optoelectronic devices can be selected. These devices facilitate the access to the machine.

To select the appropriated distance to collocate an optoelectronic device according to EN 13855, the next formula is used:

$$S = 2000 \times T + 8 (d - 14)$$

Where:

$S$  is the distance in mm

$T$  is the total response time

$d$  is the resolution of the curtains

## 2.4 DIN EN ISO 13849

### 2.4.1 Performance level

According to DIN EN ISO 13849-1, when a safety system is developed, a level is reached considering all the components involved. There are five performance levels (PL). These levels represent the capability of devices to perform a safety function under some conditions. ISO 13849 establishes that “the performance levels are defined in terms of probability of dangerous failure per hour”-

Performance Level (PL)	Probability of dangerous failure per hour
a	$\geq 10^{-5}$ to $< 10^{-4}$
b	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$
c	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$
d	$\geq 10^{-7}$ to $< 10^{-6}$
e	$\geq 10^{-8}$ to $< 10^{-7}$

Table 2.6 Performance level [3]

When a risk analysis is done, and a risk reduction is implemented, a required performance level can be calculated.

The PL of safety devices in a control system is determined using the following elements:

- Mean time to dangerous Failure (MTTF<sub>d</sub>)
- Diagnostic coverage (DC)

MTTF <sub>d</sub>	
Designation	Range for each channel
Low	3 years $\leq$ MTTF <sub>d</sub> $\leq$ 10 years
Medium	10 years $\leq$ MTTF <sub>d</sub> $\leq$ 30 years
high	30 years $\leq$ MTTF <sub>d</sub> $\leq$ 100 years

Table 2.7 Mean time to dangerous failure [3]

The MTTF<sub>d</sub> is the mean time for a device to fail and create a dangerous condition.

DC	
Designation	Range
None	$DC < 60\%$
Low	$60\% \leq DC < 90\%$
medium	$90\% \leq DC < 99\%$
high	$99\% \leq DC$

Table 2.8 Diagnostic coverage [3]

The Diagnostic Coverage is estimated using methods like FMEA (Failure Modes and Effects Analysis). It is the ratio of the failure rate of detected dangerous failures and the failure rate of total dangerous failures.

Categories are also parameters used to find a PL. ISO 13849 describes[3]:

- Category B: A fault leads to a loss of safety function.
- Category 1: There is an increment in the resistance to failure by a selection of components.
- Category 2: Tests the achieve of the safety function when it is executed.
- Category 3: The safety function does not lead to loss of safety function with a single fault.
- Category 4:is resistant to error accumulations.

As a simplified method to estimate the PL using the table 2.9. First, the column for category and DC is selected. Then the  $MTTF_d$  is chosen. The PL can be found in the intersection point.

Category	B	1	2	2	3	3	4
$DC_{avg}$	none	none	low	medium	low	medium	high
$MTTF_d$							
Low	a	Not covered	a	b	b	c	Not covered
Medium	b	Not covered	b	c	c	d	Not covered
high	Not covered	c	c	d	d	d	e

Table 2.9 Simplified method to estimate an achieved PL [3]



## 2.4.2 Required performance level

To determine the required performance level, a qualitative method is present in DIN EN ISO 13849.

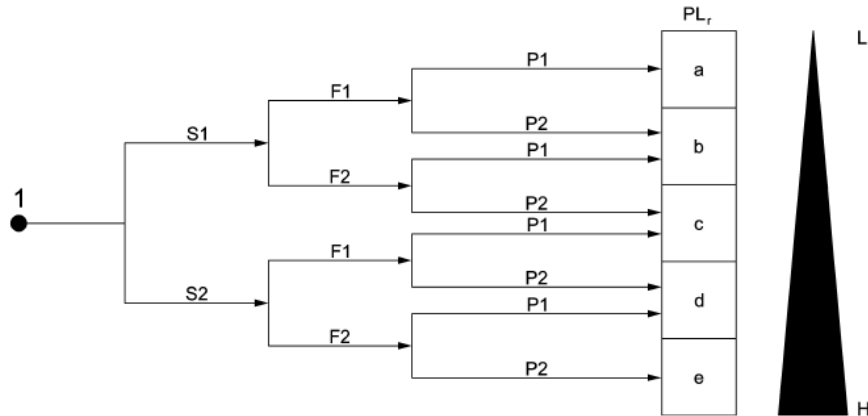


Image 2.5 Graph to determine the required PL for safety function[3]

In the image 2.5 the method to determine the PL<sub>r</sub> is shown. Through three parameters (S, F and P) the performance level required is selected.

Where:

- Severity of injury: Slight (S<sub>1</sub>) or Serious (S<sub>2</sub>)
- Frequency and duration of exposure to hazard: low to less often and short exposure time (F<sub>1</sub>) or frequent to continuous and long exposure time (F<sub>2</sub>).
- Possibility of avoiding: Possible under specific conditions (P<sub>1</sub>) or scarcely possible (P<sub>2</sub>)

## **Chapter 3. Actual Plant**

### **3.1 Description**

The plant has a conveyor with several belts to feed the material to the picking range of the Delta picker. When the picker takes a block, it places it on the assembly area. The delta picker lifts the blocks with vacuum through a suction cup. The picker does this piece by piece until it gets the final product. Last, the delta picker takes the final product and send it to the discharge ramp.

### **3.2 Requirements for sensors and actuators.**

#### **3.2.1 PLC for conveyor and analog inputs**

The IRC5 controller have 8 Digital inputs, 8 Digital Outputs and 2 Analog Outputs in each I/O module. The communication with the modules is with DeviceNet and can be connected up to 63 devices on the network. Therefore, the modules in the IRC5 can take care of the digital inputs and the digital outputs. The communication protocol available in the IRC5 is the Profibus DP.

Must be selected a PLC able to read the analog signals and control the motor for conveyor. This PLC must have a Profibus DP module to communicate with the IRC5.

### 3.2.2 Motor for conveyor

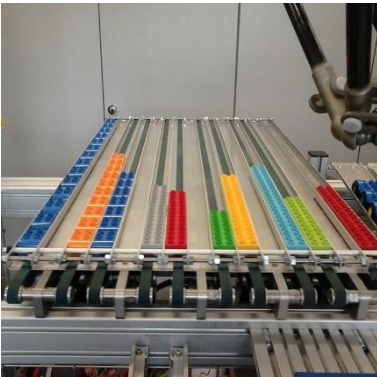


Image 3.1 Conveyor present in Delta robot machine

Must be selected a motor able to move the conveyor and that can be controlled with the current control system.

### 3.2.3 Force sensor and presence of end effector



Image 3.2 End effector in delta robot

When the end effector place a block, the force must be measured to assure a good assembly, but avoiding a pressing greater than needed.

In order to guarantee the presence of the end effector (black part in image 3.2) a sensor must be selected.

### 3.2.4 Presence of chassis in assembly area



Image 3.3 Assembly area

To assure the presence of the chassis in the assembly area a sensor must be chosen.

### 3.3 Requirements for the plant

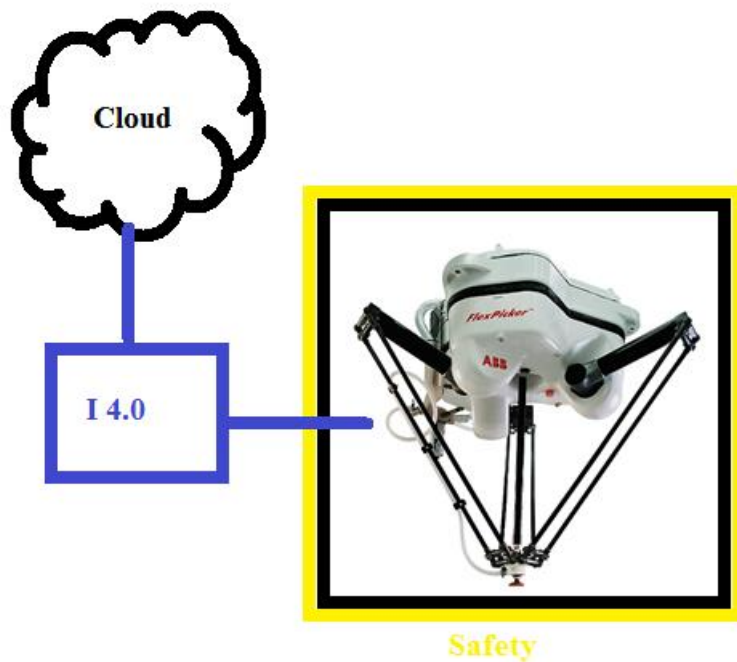


Image 3.4 Needs of the current plant[4]

The plant needs to fulfill a safe environment to protect the people in the room where the robot is installed. Also, there must be a communication between the plant and the cloud to achieve the Industry 4.0.

### **3.3.1 Requirements for safety**

First, a risk analysis must be performed in order to know the safety needs of the plant. Then actions must be taken to fulfill the risk reduction to an acceptable state creating a safe system to protect the physical integrity of the people in the room.

### **3.3.2 Requirements for Industry 4.0**

The connection between the station and the cloud needs to be established, achieving a communication and understanding between the delta picker and the cloud.

## **Chapter 4. Sensors, actuators and Safety system**

### **4.1 Selection of sensors, actuator and PLC**

#### **4.1.1 PLC**

The selected PLC is 4PP065.0571-P74 from B&R. This PLC has a touchscreen and can be added modules to read analog inputs, a module to control a stepper motor to move the conveyor and a module with a PROFIBUS DP V0/V1 interface to communicate with the IRC5, covering all the needs.

#### **4.1.2 Motor for conveyer**

The motor is a 2-Phase hybrid stepper motor that works with 24 VDC, 2.5A serial, 1.1 Nm of holding torque and 0.8 Nm stall torque. The motor includes a gear box to get a lower velocity and a larger torque.

#### **4.1.3 Force sensor**

The requirements considered for this sensor were:

- Small
- Robust
- Range between 0 – 1 kg.

The sensor selected is a Low Force Compression Load Cell with a range of 0 to 1.5 kg. This sensor gives an output of 1 – 4 Vdc and has a Safe Load Limit of 2.5X. The size is small enough to fit in the end effector.



Image 4.1 FS2050-0000-1500-G[16]

#### **4.1.4 Sensor for presence of end effector**

According to the size of the end effector, the selected sensor was a magnetic sensor due to its size. To achieve the operation, was necessary to add a magnet in the end effector.

#### **4.1.5 Sensor for presence of chassis in assembly area**

For this application, were considered reflective and thru-beam sensors. The sensor selected was a fiber sensor because it can help to detect the presence of the chassis as well as the good positioning of the chassis. It consists of an amplifier that contains a Red LED that produces the light beam and detects the light received. One fiber acts as a transmitter and the other as a receiver. The amount of light needed to activate can be adjusted with the sensitivity adjustment trimmer.



Image 4.2 FSM1 Fiber sensor[5]

## **4.2 Safety system**

## 4.2.1 Risk assessment

During inspection, three risks were found. The first is the absence of a protective device around the robot. This allows people to put an extremity inside the machine when the robot is moving. The risk analysis is the following:

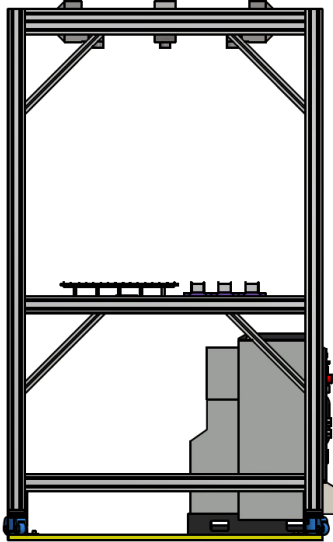


Image 4.3 Delta picker structure

<b>Hazard id</b>		<b>Hazard No: 1</b>
<b>Title</b>	No safeguard around the robot	
<b>Location</b>	ABB IRB340 robot	
<b>Target</b>	Upper extremities and head	
<b>Activity</b>	Normal mode	
<b>Task</b>	Operation	
<b>Function</b>		
<b>Type of hazard</b>	Mechanical	
<b>Description</b>	The students are not protected from the area of movement of the robot.	
<b>Risk estimation and assessment</b>		
Probability of occurrence 5	Frequency of event 4	
Degree of possible harm 6	Number of persons affected 1	
<b>Hazard Rating Number (HRN): 120</b>	<b>Overall result: High</b>	



<b>Risk Reduction</b>	<b>Reference</b>
Install safe guard with interlock. Access will be prevented. Install light curtains. The robot will stop if somebody introduce an extremity.	
<b>Anticipated residual risk</b>	
Probability of occurrence 0.033	Frequency of event 4
Degree of possible harm 0.5	Number of persons affected 1
<b>Hazard Rating Number (HRN): 0.066</b>	<b>Overall result: Negligible</b>

The second risk found was the pinch point present at the end of the conveyor:

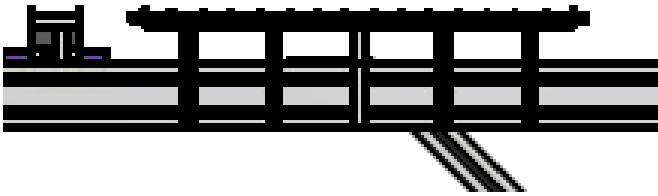


Image 4.4 Conveyor

<b>Hazard id</b>		<b>Hazard No: 2</b>
<b>Title</b>	Pinch point	
<b>Location</b>	ABB IRB340 robot	
<b>Target</b>	Hands	
<b>Activity</b>	Normal mode	
<b>Task</b>	Operation	
<b>Function</b>		
<b>Type of hazard</b>	Mechanical	
<b>Description</b>	The students are not protected from the pinch points at the end of the conveyor	
<b>Risk estimation and assessment</b>		
Probability of occurrence 5	Frequency of event 5	
Degree of possible harm 6	Number of persons affected 1	
<b>Hazard Rating Number (HRN): 150</b>	<b>Overall result: High</b>	
<b>Risk Reduction</b>		<b>Reference</b>
Install mechanical safe guard to cover the pinch point.		
<b>Anticipated residual risk</b>		
Probability of occurrence 0.033	Frequency of event 4	
Degree of possible harm 2	Number of persons affected 1	
<b>Hazard Rating Number (HRN): 0.264</b>	<b>Overall result: Negligible</b>	

## 4.2.2 Risk reduction

For the first risk:

Was decided to have one side of the robot with a safe guard covered.

The selection of the safe guard to reduce the risk was made in accordance with the image 2.4.

There is access required during operation, there is required to access more than once time per shift and there isn't hazard that arises from opening the guard averted before access is possible. Thus, a movable guard with interlocking devices (with guard locking device) should be installed.

Three sides of the structure will have curtains. OY228S Light curtains were selected. This light curtains have a resolution of 20 mm and a time response of 16.5 ms. G1501S Safety relay was chosen and it has a time response of 16 ms. Thus,  $T = 0.0165 \text{ s} + 0.016 \text{ s} = 0.0325 \text{ s}$

$d = 20 \text{ mm}$

$$S = 2000 \times T + 8 (d - 14)$$

$$S = 113 \text{ mm}$$

The structure has 185 mm of distance to the closest point where the robot can be. So, it's safe to have these curtains.

For the second risk:

A fixed safeguard was selected to reduce the risk since the access is not required during operation.

## 4.2.3 PLr

According to the image 2.5, the PLr was obtained.

The parameters are:

- Severity of injury:  $S_2$  (Serious)
- Frequency or exposure to hazard:  $F_1$  (low to less often and short exposure time)
- Possibility of avoiding the hazard:  $P_1$  (possible under specific conditions)

Therefore, the required PL is C.

#### 4.2.4 Bus Safety system

The bus safety system selected is AS-interface. It is a separated bus safety system that is not connected to the main control system.

To be considered as ASIsafe it needs to have a safety monitor and safety slaves. The devices selected are:

- 3RK1105-1BE04-0CA0 Siemens safety monitor
- 3RK1205-0BQ00-0AA3 Safe module
- 3RK2200-0CQ20-0AA3 AS-i module to connect a controlled start
- AZM 161 Z ST1-AS RA AS-i solenoid interlock

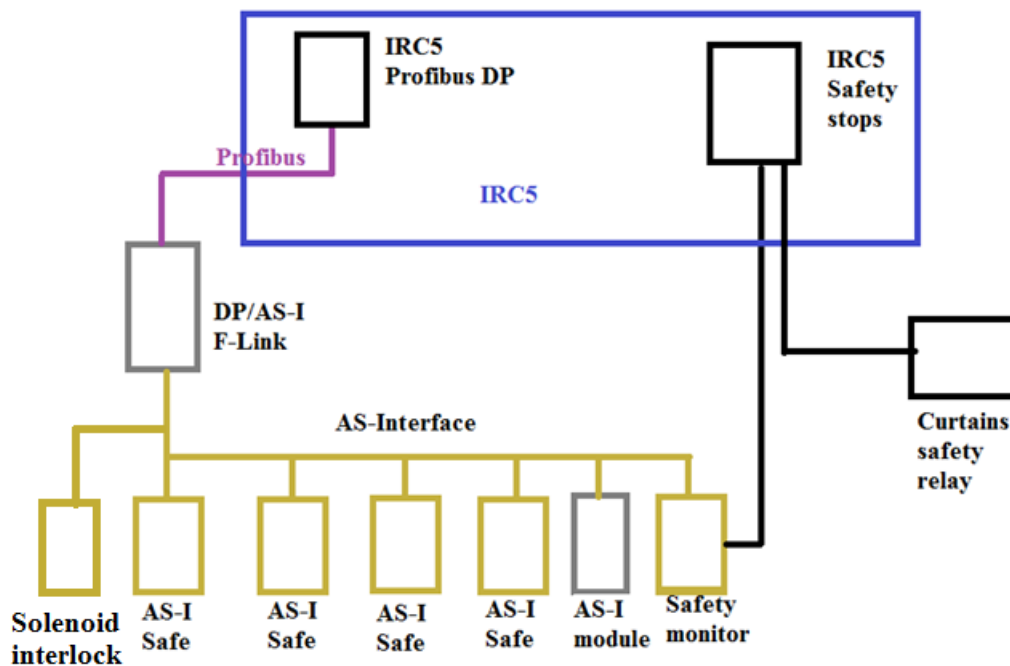


Image 4.5 Bus communication

The DP/AS-I Link works as an interface between the safety system and the IRC5, to share the status of the signals. But, the safety monitor takes care of the IRC5 safety stop in order to stop the robot when a signal connected to an AS-I safe is activated. One E-Stop is connected to the AS-I safe module in the following configuration:

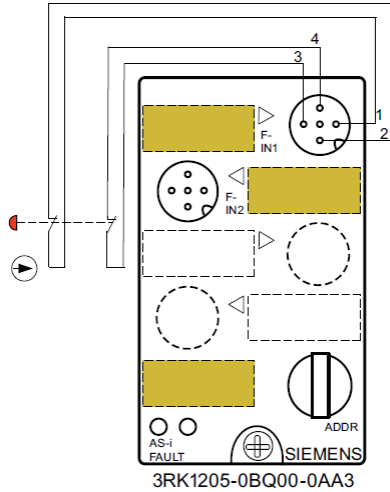


Image 4.6 3RK1305-0BQ20-0AA3 module with E-stop cat 4

According to SIAM, this configuration provides a E-Stop monitoring with category PL e.

The complete configuration provided for the safety monitor is shown in the following image

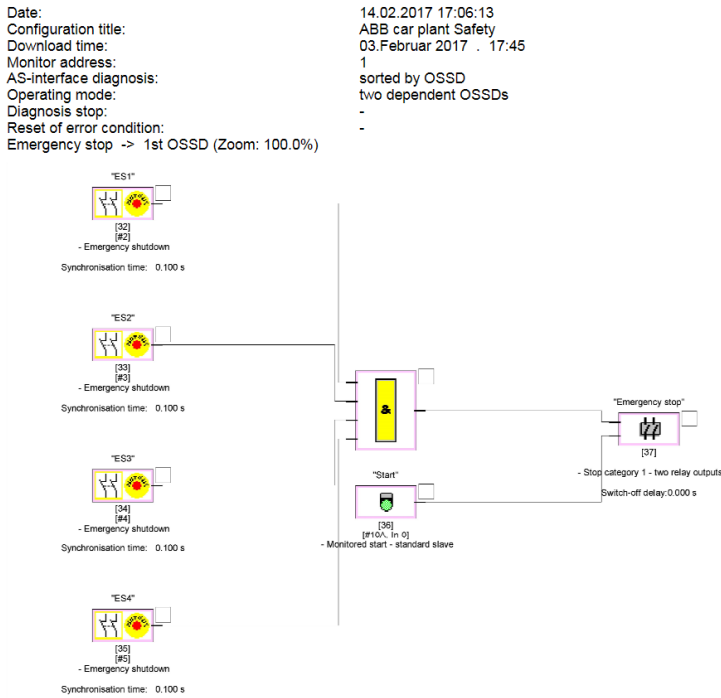


Image 4.7 Configuration of safety monitor

# Chapter 5. Industry 4.0

To have a communication between the IRC5 and the cloud, a Gateway is developed. This gateway will communicate the “office floor” with the “shop floor”.

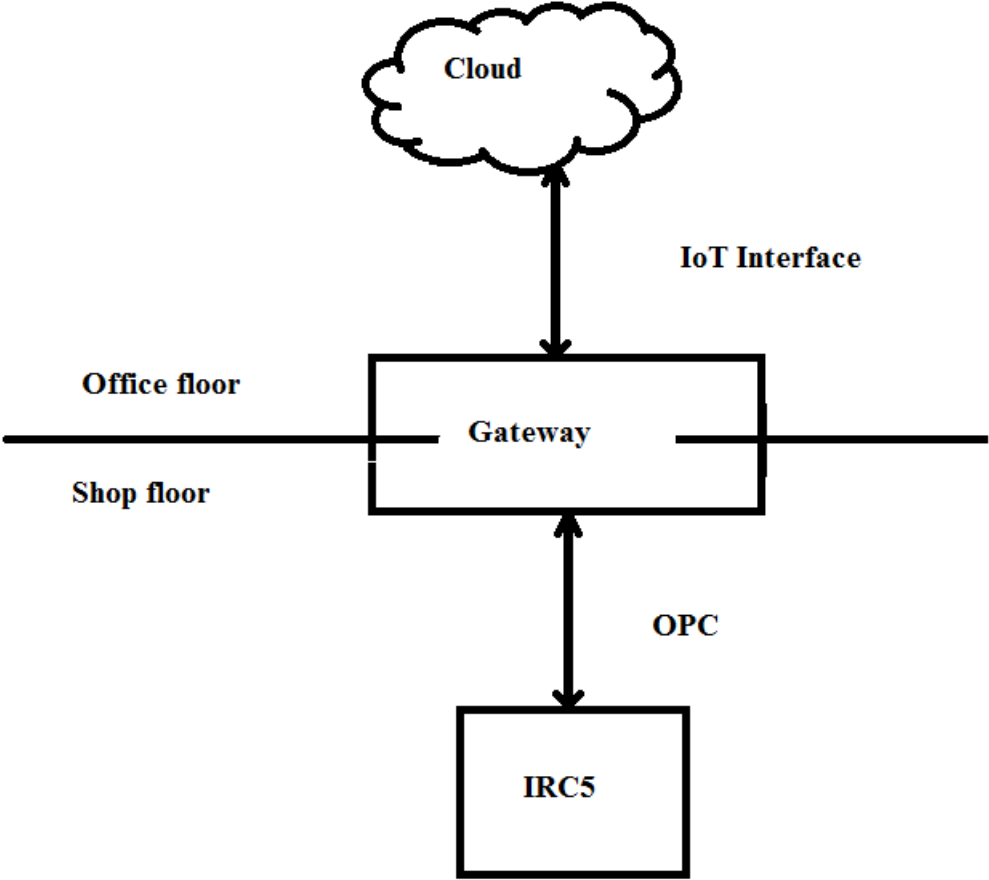


Image 5.1 Gateway as an interface between the cloud and IRC5

## **5.1 Office floor**

The first part of the gateway is the interpretation of the information sent by ERP in the cloud. Through a request of an action of OpenCart, the model, blocks and position selected by the customer are sent through HTML in json format.

The process is the following:

1. The order is requested.
2. If the status code of the response is 200, it means there is an order waiting to be built. If it is 503, there isn't an order.
3. The order is read and the state of the delta picker station is put in reading.
4. The state of the delta picker station is put in done to tell the ERP that the product was built.

## **5.2 Shop floor**

The way to write and read in the IRC5 controller is using OPC DA. In order to read or write, a connection must be established with the server. The IRC5 provides the tags of variables in the robot and in the rapid program. These variables can be read and modified. Through the assignment of values to the variables, the model, the stone and the chassis can be selected to use them in the assembling process.

The process is the following:

1. The client is created.
2. The connection with the server is started.
3. The variables are modified according to the products wanted.
4. The status of the car assemble is read to know when it is finished.

## **5.3 Gateway**

The language used to create the gateway was Python. There are libraries for the HTTP request and for the OPC client. In the annex A the code can be found.

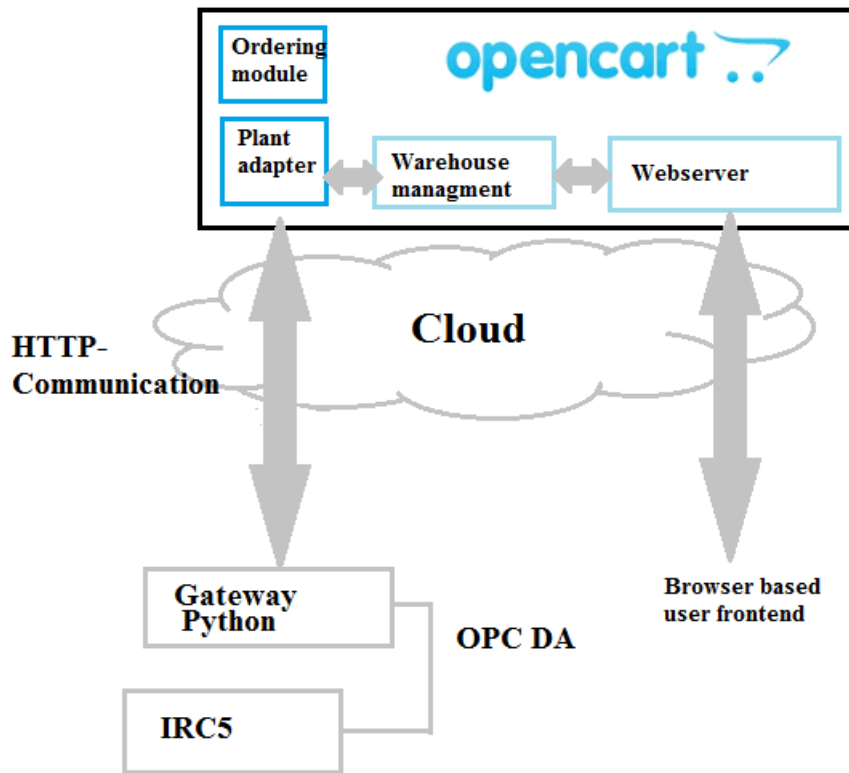


Image 5.2 Implementation of gateway



## **Chapter 6. Results and conclusions**

The delta robot assembly cell is able to work as an autonomous Industry 4.0 cell with all the constraints towards a EN 12100 conforming. The integration in a Cloud-based ERP system was also possible.

The aim proposed at the beginning of the project was reached. Evaluating the machine after the risk assessment reduced considerably the hazards making the risks levels negligible. The corresponding part of the E-Stops in the safety system was installed and tested. The use of AS-interface as a bus to connect all the safety modules for Emergency Stop was successful and a PLe was reached even when the required performance level was PLc.

The installation of the light curtains was not possible due a delay in the delivery time.

The gateway to communicate the robot cell with the cloud was developed and tested. The orders assigned to this cell were built. The robot cell works as an autonomous Industry 4.0 station.

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## Annex A

```
#Libraries are imported

import OpenOPC
import requests
import time

#Client is created and connects to the server in the IRC5 controller
opc = OpenOPC.client()
opc.connect('ABB.IRC5.OPC.Server.DA')

while 1:
    #order is requested and its status evaluated
    order = requests.get('http://149.201.218.203:8000/p/action/flexpicker/')
    while order.status_code == 200:

        #Order is read and values are written in the variables
        car = order.json()
        opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.model', car[0][1]))
        model=opc.properties('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.model')
        while model[2][2] != int(car[0][1]):
            opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.model', car[0][1]))
            model=opc.properties('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.model')

        opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.chassis', car[1][1]))
        chassis=opc.properties('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.chassis')
        while chassis[2][2] != int(car[1][1]):
            opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.chassis', car[1][1]))
            chassis=opc.properties('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.chassis')

        if car[0][1] == '1':
            opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.Block232T', car[4][1]))
            opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.Block222', car[5][1]))
            if car[0][1] == '2':
                opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.Block232T', car[4][1]))
            if car[0][1] == '3':
                opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.Block232T', car[2][1]))

        #variable start is set to 1 to begin the building process
        start=opc.properties('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.start')
        opc.write(('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.start', 1))
        while start[2][2] == 0:
            start=opc.properties('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.start')
```

```
#state is set to "read"
state = requests.post("http://149.201.218.203:8000/p/state/flexpicker/",json=1)

#the rapid program sets variable start to 0 to notify that it has finished
while start[2][2] == 1:
    start=opc.properties('ABB_CAR_PLANT.RAPID.T_ROB1.Module1.start')

#State is set to finished to tell that the car is built
state = requests.post("http://149.201.218.203:8000/p/state/flexpicker/",json=4)
time.sleep(2)

    order = requests.get("http://149.201.218.203:8000/p/action/flexpicker/")
time.sleep(5)
opc.close()
```