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RUHR-UNIVERSITÄT BOCHUM

MechEng
Mechanical Engineering
INTEGRATION



Vietnamese-German University

Collaborative Robot application for Needle Roller Bearing assembly process

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BINH DUONG 2023

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COLLABORATIVE ROBOT APPLICATION FOR NEEDLE ROLLER BEARING ASSEMBLY PROCESS

A Thesis Presented

By

DINH QUANG HUY

Submitted to the department of Mechanical Engineering of the
RUHR-UNIVERSITÄT BOCHUM and VIETNAMESE-GERMAN UNIVERSITY

in partial fulfillment

of the requirement for the degree of
BACHELOR IN MECHANICAL ENGINEERING



Sep 2023

Major: Mechanical Engineering

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COLLABORATIVE ROBOT APPLICATION FOR NEEDLE ROLLER BEARING
ASSEMBLY PROCESS



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AFFIRMATION

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I hereby declare in lieu of an oath that I have produced the aforementioned thesis independently and without any other means except the aids listed. Any thoughts directly or indirectly taken from somebody else's sources are made discernible as such. To date, the thesis has not been submitted to any other board of examiners in the same or a similar format and has not been published yet.

Ho Chi Minh City, September 27th, 2023



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ABSTRACT

In recent years, the high global market has driven the manufacturing world to have more and more innovations in productivity, especially after the impact of the COVID-19 pandemic. In order to adapt to the needs, companies are required to develop mass production systems with high productivity, and high agility, and ensure consistency in quality while keeping all the costs under their control. The new but efficient solutions are automation by using Collaborative Robots, called Cobots. In the form of a human arm, Cobots are expected to have high agility to fit the needs of customers following a high variation of environments and tasks given. Different from traditional Robots, by integrating physical sensor systems and virtual fence software, the new Cobots are designed to collaborate with humans under safety conditions while ensuring suitable speed and high accuracy.

This thesis will go through an actual process of developing the Cobot system integrated into an existing mass production assembly process. The contents will cover from survey, analysis, and benefit calculation to finalize the concept, testing, and then final implementation for mass production. The project finished successfully by achieving all initial targets. However, the hindrances of applying Cobots will also be discussed as this innovation was only developed in recent years and might still need to be the global solution in real-world problems.

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ABBREVIATION

Abbreviation	Meaning	Units
Cobot	Collaboration Robot	
SG	Schaeffler Group	
SVC	Schaeffler Vietnam Company	
TRB	Tapper Roller Bearing	
NRB	Needle Roller Bearing	
RIBB	Radial Insert Ball Bearing	
DGBB	Deep Groove Ball Bearing	
SCB	Steering Column Bearing	
OR	Outer Ring	
IR	Inner Ring	
RW	Raceway	
G1	Grinding 1	
G2	Grinding 2	
OD	Outer Diameter	
BO	Black Oxidize	
IFR	International Federation of Robotics	
GM	General Motors	
PLC	Programmable Logic Controller	
MAP	Manufacturing Automation Protocol	
AI	Artificial Intelligence	
IoT	Internet of Things	
AGV	Automated Guided Vehicle	
HCR	Human Collaboration Robot	
CNC	Computer Numerical Control	
IP	Ingress Protection	
AM	Ante Meridiem	
PM	Post Meridiem	
REFA	Reichsausschuss für Arbeitszeitermittlung	
HCO	Headcount	
COVID-19	Corona Virus Disease of 2019	
pcs	Pieces	[pcs]
min	Minute	[min]
s	Second	[s]
mm	Millimeters	[mm]
kg	Kilograms	[kg]
CT	Cycle Time	[s/pcs]
R.CT	Routing Cycle Time	[s/pcs]

A.CT	Actual Cycle Time	[s/pcs]
OT	Operating Time	[min]
DT	Downtime	[min]
TEEP	Total Effective Equipment Performance	[%]
OEE	Overall Equipment Effectiveness	[%]
OF	Operating Factor	[%]
AF, A-factor	Availability Factor	[%]
PF, P-factor	Performance Factor	[%]
QF, Q-factor	Quality Factor	[%]

1. Manufacturing field

1.1 Introduction of Schaeffler Vietnam

Schaeffler Group was founded in 1946 by brothers Wilhelm and Georg Schaeffler in Germany. The company initially produced ball bearings, but soon expanded into other areas of automotive and industrial technology, including engine components and linear technology. Over the years, Schaeffler Group has grown through a combination of organic growth and acquisitions. In 2001, the company acquired Kugelfischer, a leading producer of rolling bearings, which helped to solidify Schaeffler's position as a major player in the automotive and industrial sectors. Today, Schaeffler Group is a global company with operations in over 50 countries and more than 80,000 employees. The company is committed to innovation and sustainability and has invested heavily in research and development to create new products and technologies that meet the evolving needs of its customers. Schaeffler Group's rolling bearings are used in a variety of applications, including automotive engines, transmissions, and chassis systems, as well as in industrial machinery and equipment. The company's linear technology products include linear guidance systems, linear actuators, and linear tables, which are used in automation and handling systems, as well as in machine tools and medical equipment. Schaeffler Group also produces engine components such as valve train systems, chain drive systems, and thermal management modules for passenger cars, commercial vehicles, and industrial engines. In addition to its core product offerings, Schaeffler Group provides a range of services to its customers, including engineering support, training, and maintenance and repair services.

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Schaeffler Vietnam (SVC) was officially inaugurated in Amata Industrial Zone, Bien Hoa City, Dong Nai province in December 2007. Now, Schaeffler has developed with Ho Chi Minh as the headquarter of Schaeffler Vietnam. In SVC, the plant focuses on mass production of a wide range of varieties of bearings with Taper Roller Bearing (TRB), Needle Roller Bearing (NRB), Radial Insert Ball Bearing (RIBB), Deep Groove Ball Bearing (DGBB), Steering Column Bearing (SCB) are the main product types. Hence, following the Industry 4.0 transformation, the Schaeffler Vietnam plant was chosen to be the pilot plant for Digitalization projects and to roll out the successful stories for the whole Schaeffler Group.

1.2 Industrial Revolutions

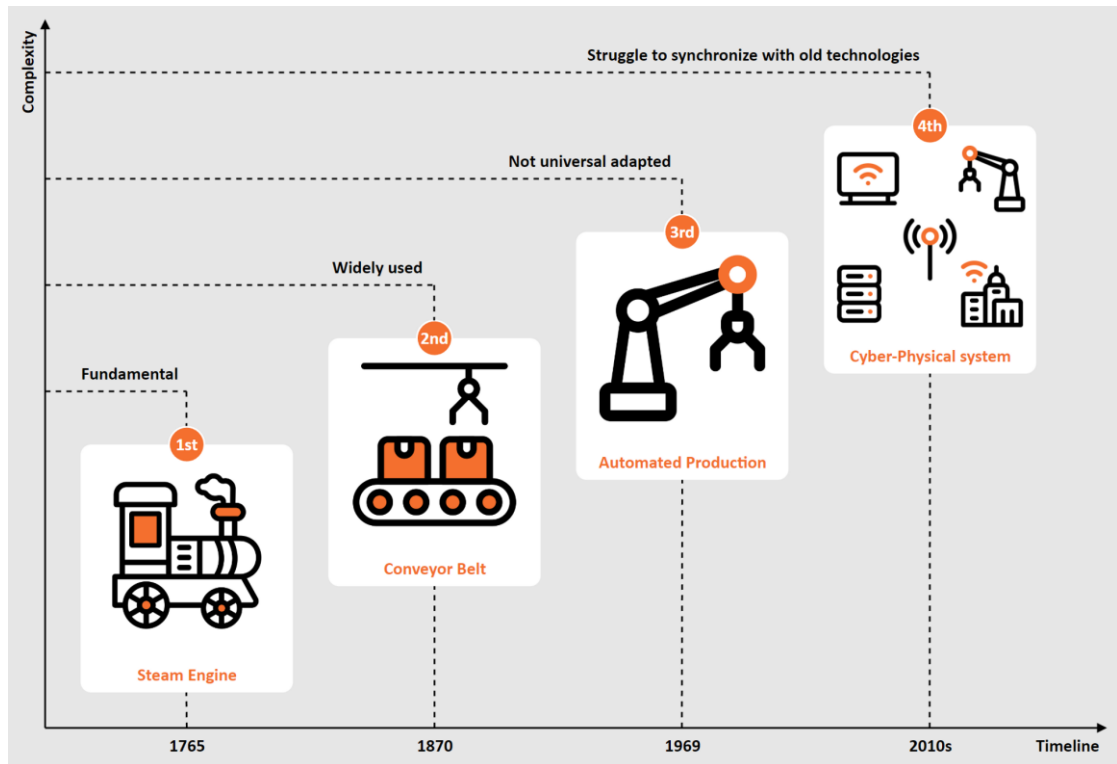


Figure 1: Four Industrial Revolutions



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The world has experienced 4 Industrial Revolutions since the need for production was increased to adapt to the growth of population, each marked by multiple significant technological advancements that transformed the way we live and work.

The First Industrial Revolution began in 1765. It was characterized by the mechanization of textile production, which led to the development of factories and the use of steam power. This revolution also saw the invention of the steam engine, which was used to power machines and transportation via hot water steam. This laid the foundation for the modern industrial world by introducing mass production and changing the way goods were manufactured and transported.

In 1870, after a hundred years, the Second Industrial Revolution began as the urge to adapt to high demand from the population that was growing every day. This period was marked by significant advancements in technology, including the development of electricity, the telephone, and the internal combustion engine. But the most remarkable invention was the conveyor belt, which led to various manufacturing techniques, and

allowed for achieving faster and higher efficiency production. This revolution led to an increase in productivity and economic growth, as well as significant improvements in transportation and communication.

The Third Industrial Revolution, also known as the Automation Revolution, began in 1969 and continues to this day. This period is characterized by the widespread adoption of automation technologies, including computers, robotics, and the Internet. From this point, it is not remarked by hardware inventions as the last two revolutions, but with lean to a software world. The Programmable Logic Controller (PLC) was invented and initiated the waves of automation and led to the rise of robotics. The use of robotics has transformed many industries, enabling automation and efficiency in ways that were previously impossible. Robots are being used to perform tasks that are repetitive or dangerous for humans. They can work full-time simultaneously without the need for breaks or rest, leading to increased productivity and cost savings. In addition to the manufacturing field, robotics has also had a significant impact on healthcare. They could be designed for specific medical settings to perform surgeries with greater precision and accuracy than human capabilities. The rise of robotics has also brought new job opportunities in fields such as robotics engineering and programming. As robots become more advanced and sophisticated, there is a growing demand for skilled professionals who can design, build, and program them.

The Fourth Industrial Revolution, also known as Industry 4.0, is currently underway and is characterized by the integration of digital technologies with physical systems. This revolution is marked by advancements in Artificial Intelligence (AI) and the Internet of Things (IoT). Industry 4.0 has the potential to transform various fields such as manufacturing, healthcare, and transportation by enabling greater automation and efficiency. It also presents new challenges related to cybersecurity and privacy. Human is still living in this revolution and on the journey to perfect it.

1.3 Growth of Cobots

Following the International Federation of Robotics (IFR), the first Industrial Robot was in development way back in 1959, 10 years before the official record of the Third Industrial Revolution. However, until 1969, they were only able to apply it to mass production by General Motors (GM) for welding and assembly processes. In order to establish communication between PLCs, Robots, and other equipment, their engineering team has developed a standardized computer language called Manufacturing Automation Protocol (MAP). This allowed them to successfully operate a fully automated production line, no human was required to operate but still needed to be supervised to avoid any issues happening.

During the COVID-19 pandemic, we witnessed isolation throughout the entire world which led to a frozen population, led to low activities in the manufacturing field along with others. In 2021, after recovering, according to IFR research, the number of annual installations for Robotics has drastically increased to half a million in a wide range of fields and applications, increasing 31% compared to the previous year.



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In more detail, as well as research from IFR in 2022, the number of Robots serving in the “Electronics industry” is at the top compared to others. But, by calculating the growth rate compare, the “Automotive industry” with the “Metal and Machinery industry” has increased by 42% and 45% compared to the previous year. With this trend, the number of Robotics is ensured to keep increasing in the upcoming years but will be dominated by the “Automotive industry”.

Contrary to the initial expectations, Robotics is not focused on complex applications, but rather utilized for simple, repetitive tasks. As shown in research from IFR in 2022, the “Handling application” stayed at the top place throughout the years with more than double the amount of the next one the “Welding applications” and nearly quadruple the amount of the third place the “Assembling applications”. These figures led to multiple questions regarding the demand for robots as simple as “Handling”, or, whether the current technology of robots is being challenged to perform higher complexity tasks in mass production. Through the content of this thesis, we can understand more of the situation.

With these figures, Robotics showed a significant benefit and the need from various fields is still increasing year by year.

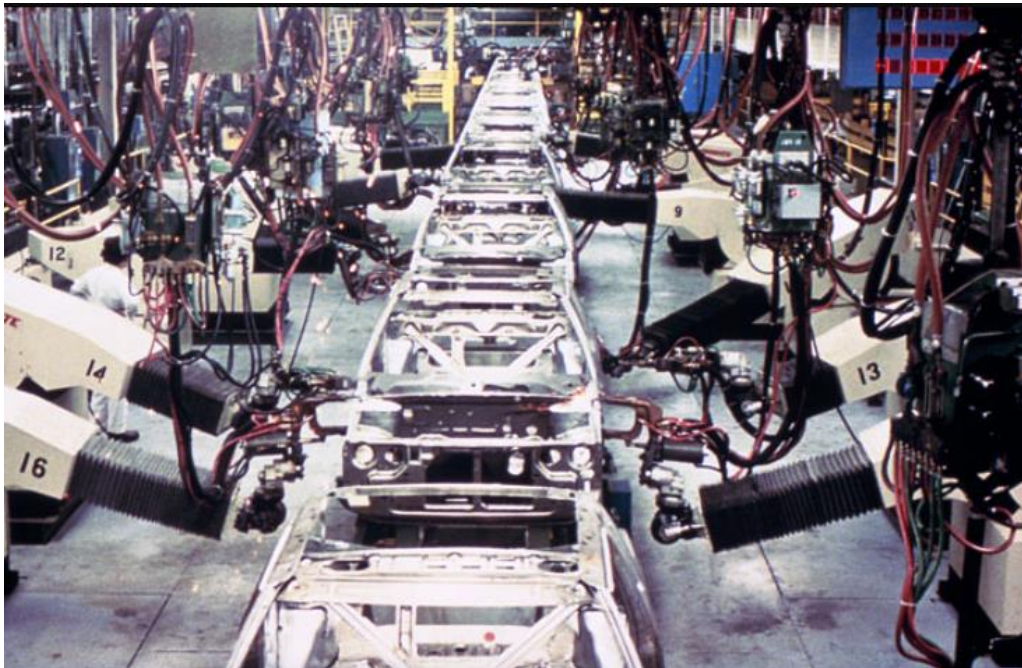


Figure 2: First application of Cobots system in mass production



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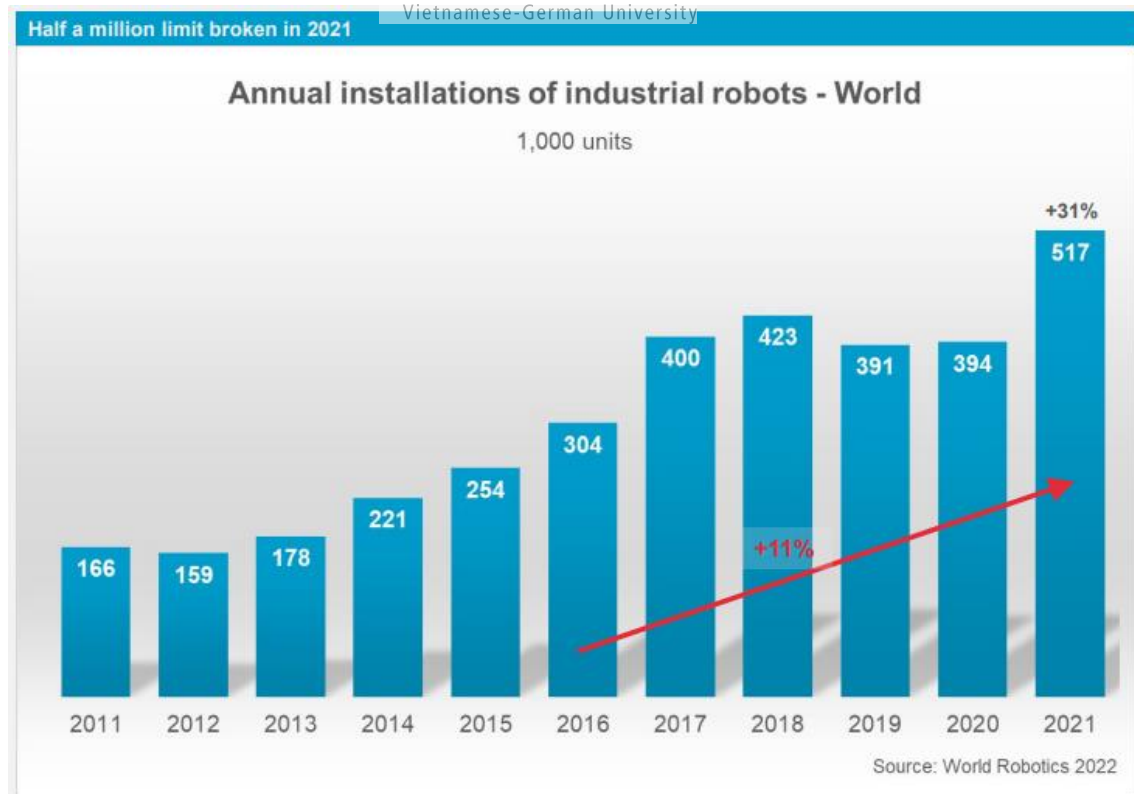


Figure 3: Diagram of Annual Installation of Industrial Robots

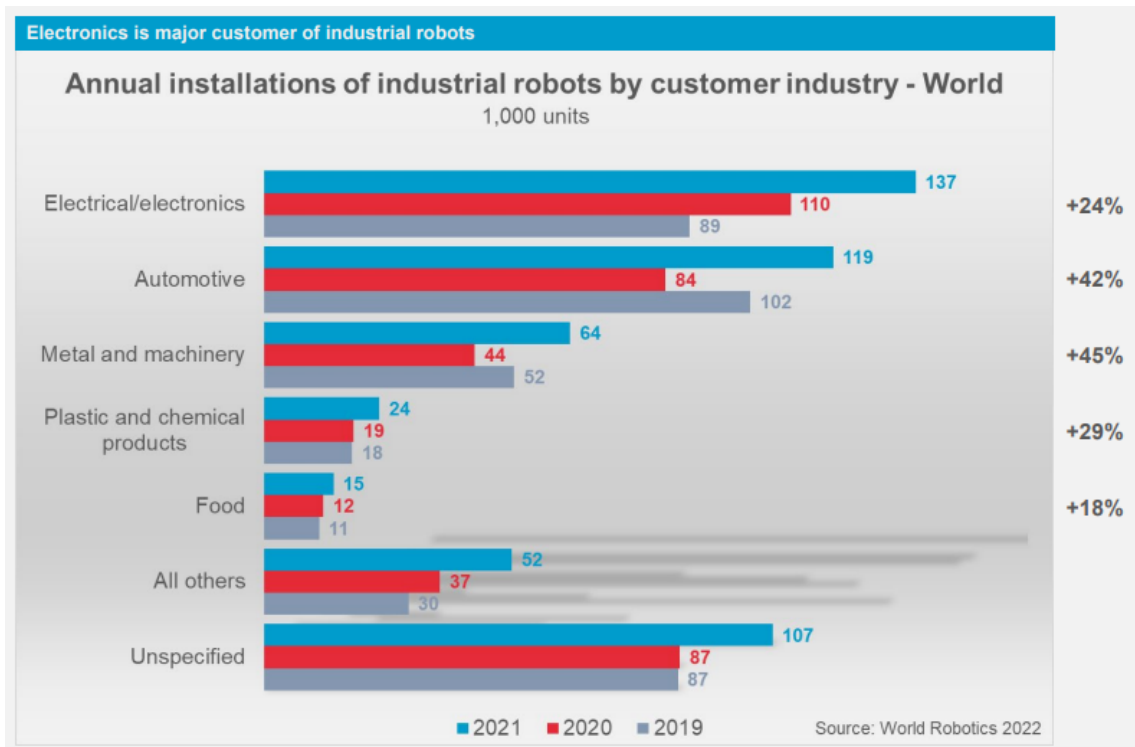


Figure 4: Diagram of Industrial Robots breakdown by customer industry

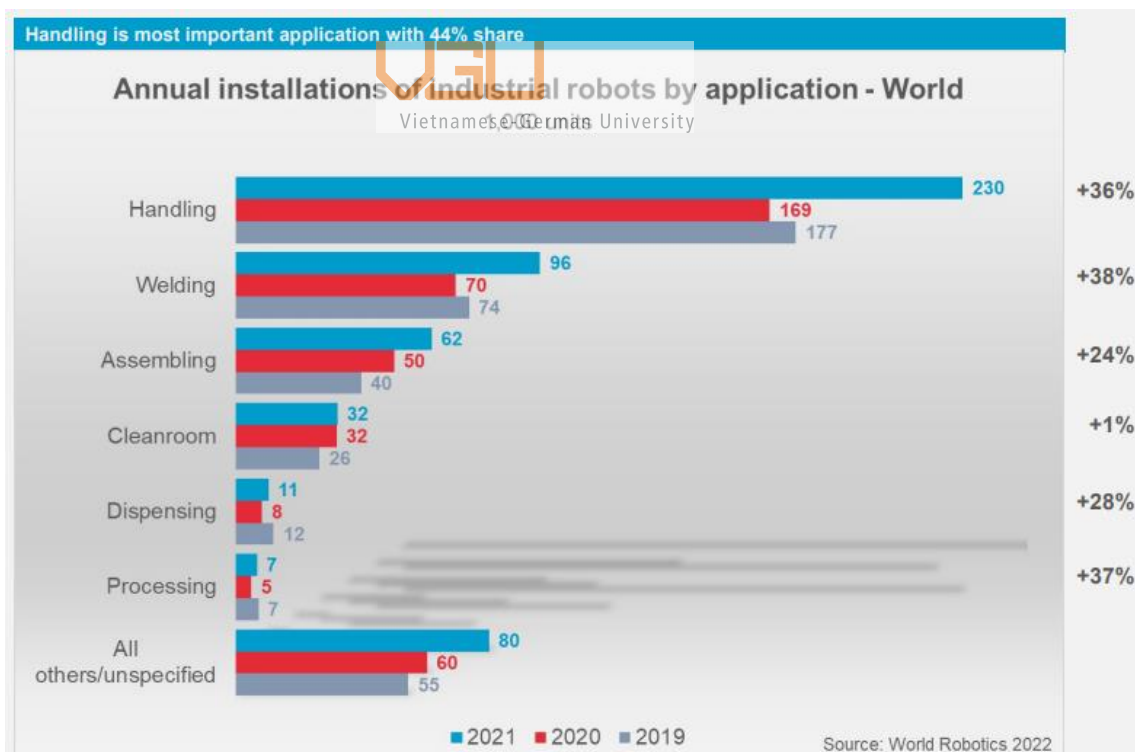


Figure 5: Diagram of Industrial Robots breakdown by application

2. Cobot overview

2.1 Cobot Introduction

Following the need to work together with close interaction, a new type of Industry Robot was invented called the Collaboration Robot (Cobot). As the name emphasizes, Cobots are built to enhance the collaborating operation between Robots and Humans, opening a vast approach to both sides of suppliers and customers. In 1999, after years of study and through the development process and law restrictions at that time, Colgate and Peshkin were finally able to file their first patent. Due to the constraints on both software and hardware in their time, the first group of Cobots was able to support a load against gravity with great precision, but the versatility was not able to be on par with their expectations.

2.2 Automation Task

Nowadays, after years of analyzing and understanding more about the requirements, tasks of Cobots along with other Automation tasks have been recorded and structured, allowing the customer and manufacturer to have a common ground of knowledge and, a high influence on the future of Cobots.

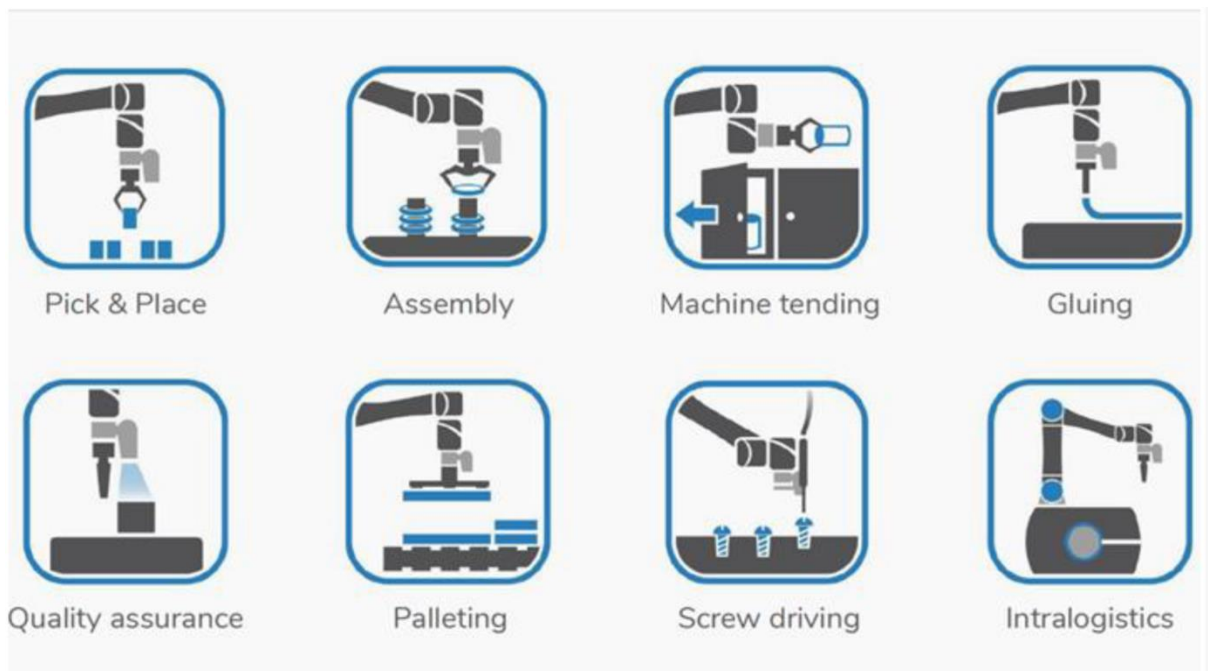


Figure 6: Automation task categories

- Pick & Place: This is the most simple and repetitive task, only requiring the cobot to pick, hold, move, and place the object between defined areas. This required less flexibility compared to other tasks and can be done with other automation solutions.
- Assembly: This task will require high precision of Cobot to be able to follow the sequence and assemble multiple objects in a defined area.
- Machine tending: For the manufacturing field, it is required to close the machine door while operating, ensure safety, and avoid excess spilled out. The worker is required to continuously manually load and then unload the work object into the machine working area. In order to release the worker from this repetitive task, Cobot will support loading the object into the machine and unloading it after the process is finished. This is where the small footprint, high precision, and flexibility of Cobots take the lead in advantages compared to traditional Robots or other automation solutions. But, there will be challenges when applying new technologies to an existing working system.
- Gluing: (and Welding, Spreading, Flattening) are tasks that require steadiness, and even distribution along the length or area, which are advantages of machines compared to Humans. With Cobots, the flexibility to perform the task anywhere brings further enhancement.
- Quality assurance: with this task, Cobots will need to be equipped with designed quality equipment to continuously perform checking activities, which Humans will show fatigue from long working time.
- Palleting: This task is similar to “Pick and Place” but increases in object number and requires higher precision.
- Screw driving: different from other tasks, Cobots will be equipped with working equipment (screwdriver). To be able to perform this task, the Cobot will require software and hardware to simultaneously keep the Cobot stable and synchronize with the equipped device.
- Intralogistics: with the development of Automated Guided Vehicle (AGV), Cobots can be equipped on top of it, combining the mobility of AGV with the flexibility of Cobot to move and work between multiple areas.

Along with task categorization, collaboration levels between Humans and Cobot are also being specified based on tasks, interactions, and safety requirements. This clarification can help the customer to narrow down the options of Cobot and strongly improve the analysis and development processes with a clear direction.

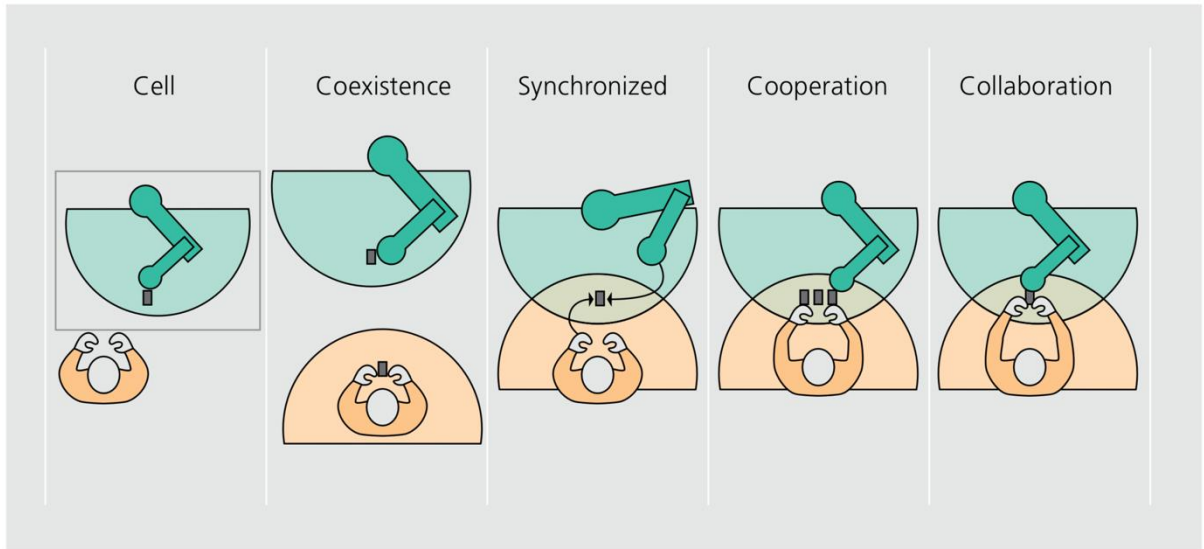


Figure 7: Interaction and Workspace scenarios

- Cell: For traditional Robots, which focus on performing with high speed while carrying heavy payloads, the physical fence is mandatory to ensure a safe environment for humans. But for modern Cobots, which are aimed and built to work in collaboration with a highly complex safety system integrated already, there is no need to be surrounded by a safety physical fence.
- Coexistence: Cobots will operate in an open workspace, without the need for a safe physical fence. But, there will be no overlap workspace between Cobot and Human. They will work independently of each other and have no direct physical contact.
- Synchronize: Following coexistence, the collaboration is further improved. Human and Cobot will be working with an overlapped workspace. In this case, they will operate in a sequence, dependent on each other, but not operate at the same time.
- Cooperation: Human and Cobot will have a shared workspace, but work on different objects or tasks at the same time. This required a high level of reaction from Cobot, it will need to perform its task while constantly checking to not interrupt, make direct contact, and cause injuries to Humans.
- Collaboration: this highest level of collaboration will require the Cobot will work simultaneously with humans on the same object or task. At this level, Cobot will

mostly perform simple tasks to support but is required to have suitable reactions to avoid causing injuries to Humans. Humans are also required to be trained and certified with the skill set to work with Cobot.

Except for the “Cell” scenario, the remaining 4 collaboration levels required the Cobots to have more safety restrictions to avoid any risk of causing injuries to humans. The Safety protocols, which are now mandatory, are the results of input from sensors and program systems, then generate the required actions performed by Cobot itself. They are also divided into different levels of Cobot reaction, also based on the interaction between Humans and Cobot.

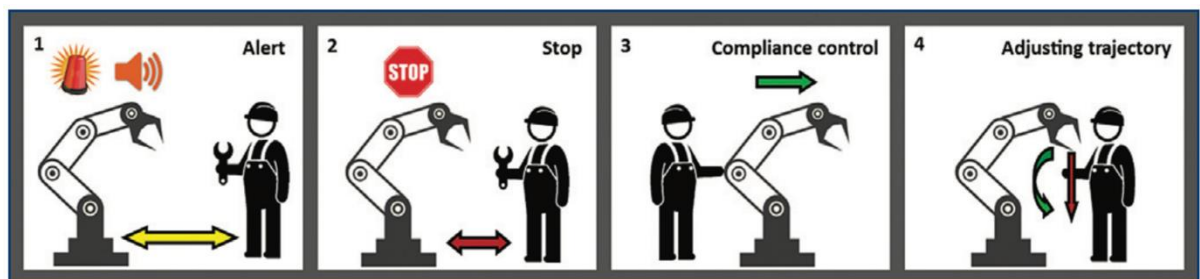


Figure 8: Reaction level
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- Alert: The production area will use specific alert signals, such as light and sound, to alarm when a Human is entering the defined workspace of Cobots. But, it will continue to perform the task, either with the same speed or reduced to a certain safety level.
- Stop: when a Human enters a risky distance, the Cobot will stop working immediately with slow acceleration to avoid any inertia collision
- Compliance control: Cobots will lower their torque and follow the guidance of Humans via direct physical teaching. Humans will expect to apply a minimum of force to guide the Cobot.
- Adjusting trajectory: this is the most sophisticated system because it will require the Cobot to not stop working, not follow guidance from Humans, but calculate a new trajectory itself to continue performing the task while avoiding physical contact with the Human.

2.3 Robots vs Cobots

With various constraints being applied to Cobots, the gap between traditional Robots and modern Cobots got wider from time to time to serve different applications. They are not completely inferior to each other, but they are built and developed with 2 different purposes:

- Traditional Robot: focusing on replacing human operators with highly specialized automatic tasks.
- Modern Cobot: will serve as a partner and collaborate with human operators by utilizing its agile capability.

Specification	Traditional Robot	Modern Cobot
Interaction	Only work as program	- Flexible to the situation - Respond to human operators
Speed	High (>4 m/s)	Low (~1 m/s)
Payload	Heavy (>1000 kg)	Light (35 kg as maximum)
Size	Bulky	Agile
Workspace	Separate with safety fence	Shared with human operators
Safety	No interact with human operators	- Controlled by sensor and program system - Slow down or Stop when a risk is detected
Program	- Required sufficient Technical skill - Low update frequency	- Friendly for basic tasks - Update continuously to adapt latest situation
Installation	- Fixed location - Big footprint	- Flexible location - Small footprint
Flexibility	Operate as manufacturing purpose	Can cover a wide range of task
Cost	Expensive	Economical
Role	Completely replace human operators	Collaboration with human operators

Figure 9: Highlight specification between Robots and Cobots

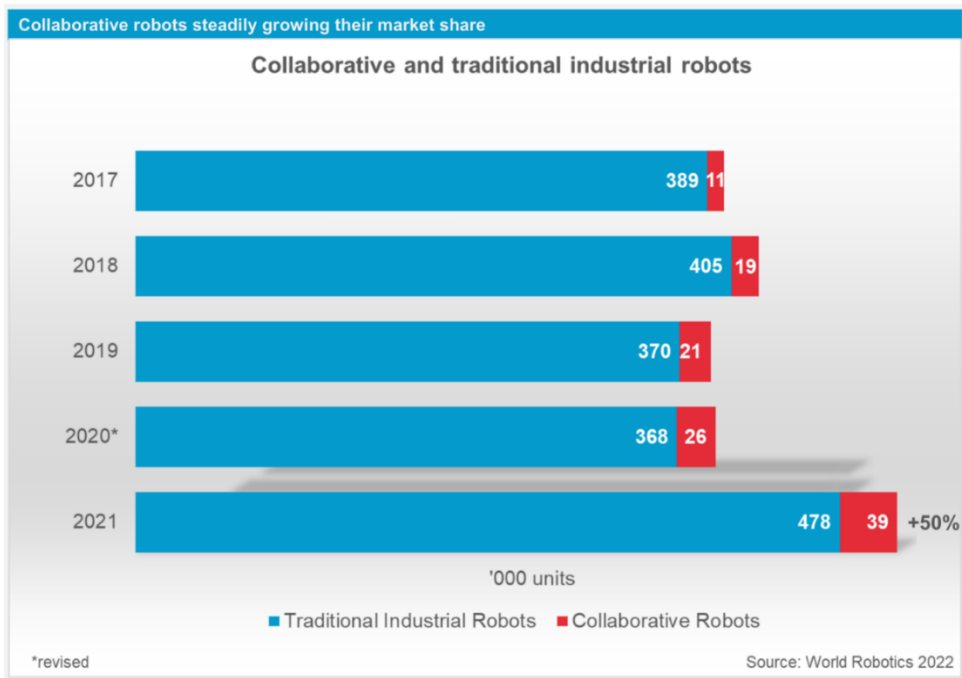


Figure 10: Comparison of Annual Installation between Robots and Cobots

3. Hanwha HCR-5 Cobot

3.1 Hanwha Robotics

Hanwha, founded in 1952, has become the seventh-largest business in South Korea and a Fortune Global 500 company by diversifying its business portfolio to include energy and materials, aerospace, finance, and retail services. The company is committed to pursuing global leadership in all of its businesses and is focused on building a foundation for sustainable development and a brighter future for everyone.

Hanwha Corporation/Machinery, established in 1953, has emerged as a prominent manufacturer of industrial machinery and systems integrators in Korea. With a focus on enhancing productivity and improving quality, the company has diversified its product portfolio to include industrial furnaces, factory automation systems, and CNC lathes. Additionally, Hanwha Corporation/Machinery is actively engaged in seeking new growth engines from its own Research and Development institute. The company commits to providing total engineering solutions for a brighter future. Hanwha Corporation/Machinery is a leader in developing technologies that contribute to the productivity and increased quality of domestic and international companies. With a strong emphasis on continuous research, the company is well-positioned to meet the evolving needs of its customers.

Hanwha Group has made a strategic move towards robotics in response to the Fourth Industrial Revolution. With a focus on collaborative robots, the company launched the HCR series in 2017, marking the first-ever Cobots produced in Korea. Hanwha Group's diverse portfolio includes interests in energy, industrial equipment, and camera sectors. As a market leader in these fields, the company has extensive expertise in precision machinery, motion control technology, image recognition software, and autonomous navigation, all of which are integral to robotics. By combining this knowledge with people skilled in robotics and software development, Hanwha Group has successfully developed its robotics division and brought innovative products to market. The company's commitment to robotics is a testament to its forward-thinking approach and dedication to staying ahead of industry trends.

3.2 Hanwha HCR-5 Cobot

The HCR-5 Cobot is a cost-effective and versatile industrial robot that boasts an impressive reach radius of 915 mm and a repeatability of only 0.1mm, making it ideal for precision work. With a weight of only 20kg, it can be easily moved without the need for special equipment. The user interface is also friendly with a touchscreen teach pendant and a direct teaching function that allows operators to teach the cobot tasks by simply moving its body with their hands while the program records it for future use. The collision detection function ensures the safety of operators by stopping the robot when an imminent impact is detected. Moreover, the HCR-5 Cobot has won numerous design awards for its mix of simple straight lines and smooth curves with color harmony of black and orange colors that represent the harmony between a robot and its human operator working side-by-side. Overall, the HCR-5 Cobot is an excellent investment for any business looking to reduce operating costs and increase productivity.



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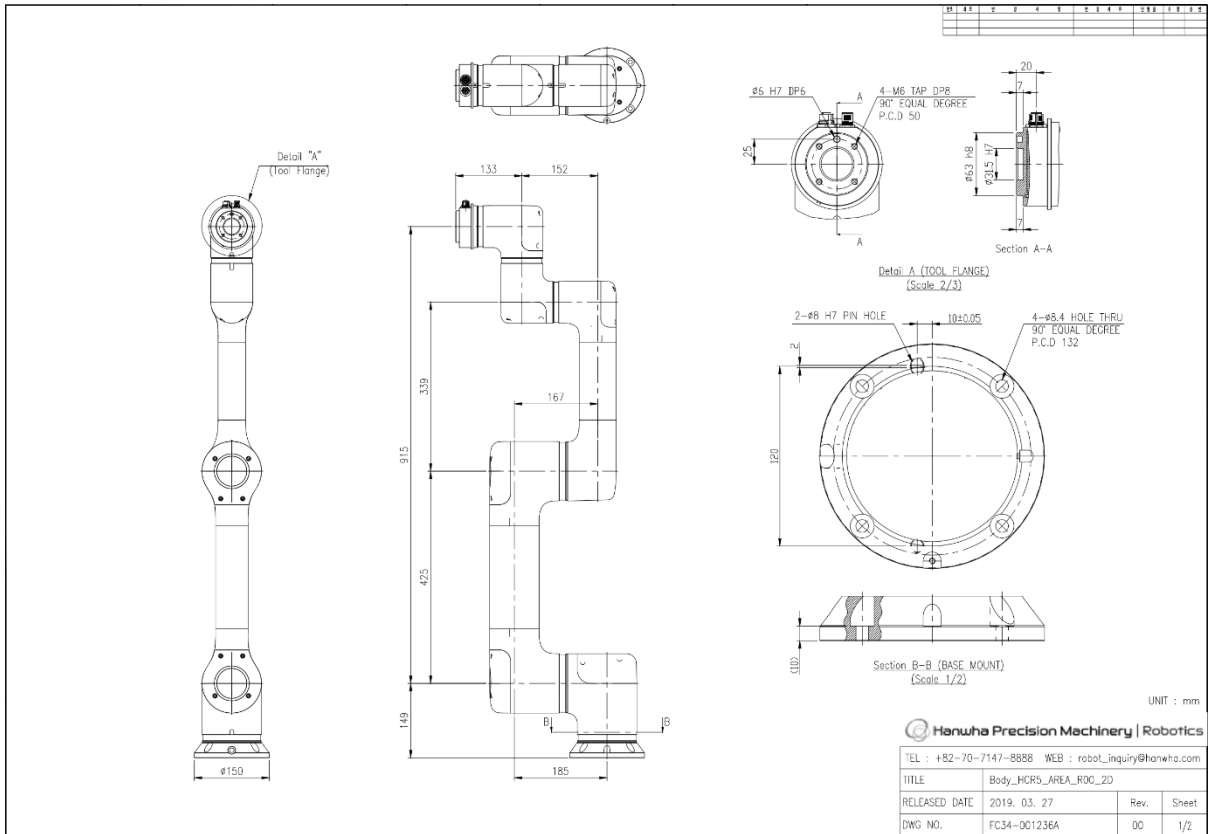


Figure 11: Drawing of HCR-5 Cobot



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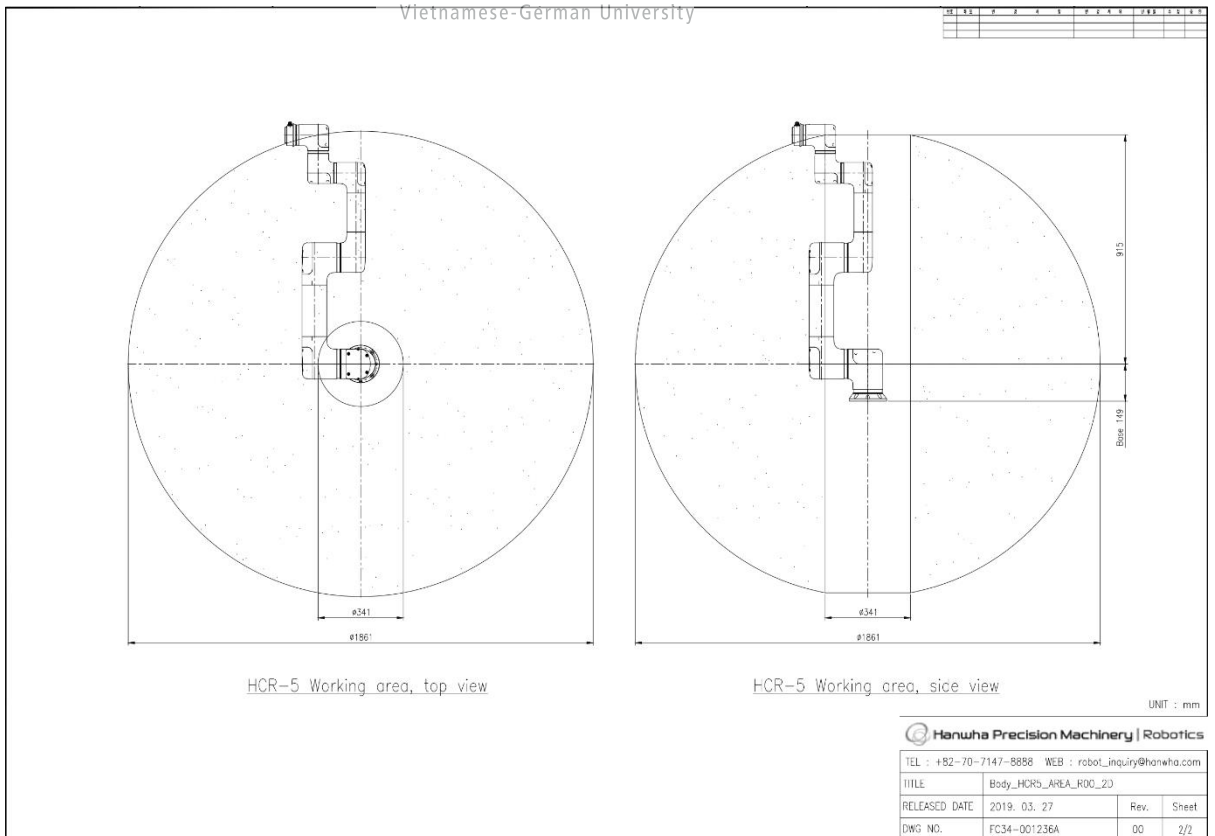


Figure 12: Working range of HCR-5 Cobot

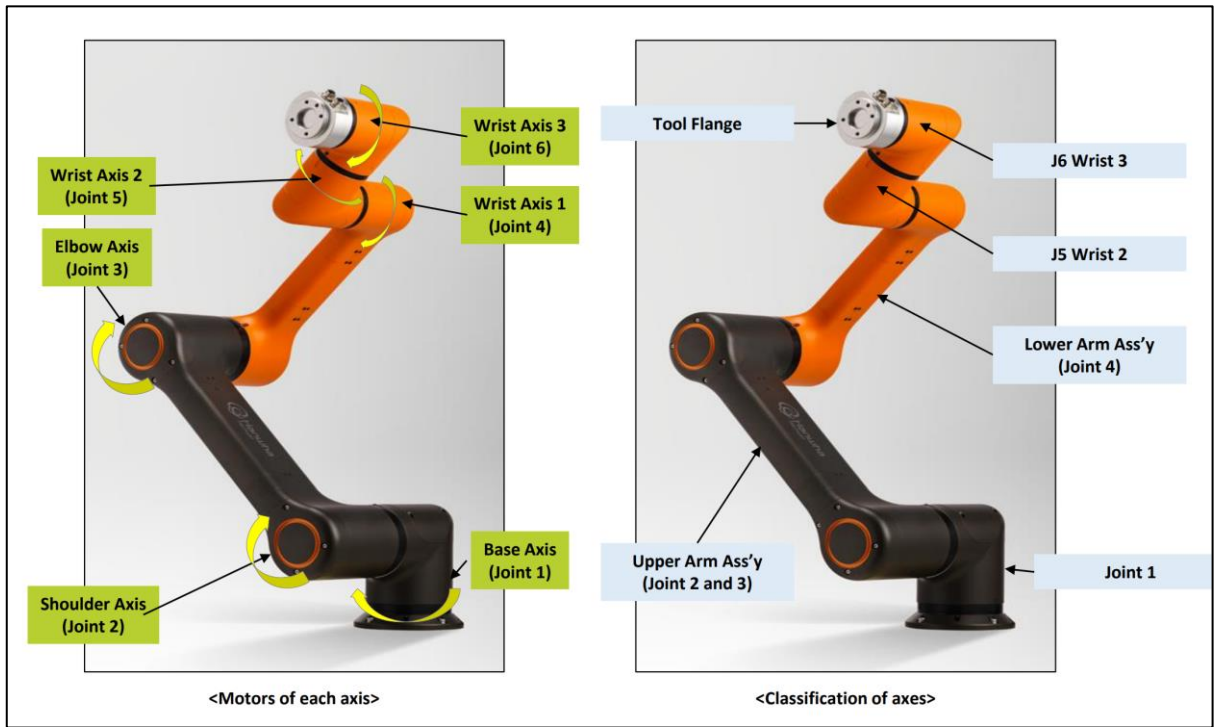


Figure 13: Joint - Axis - Wrist allocation of HCR-5 Cobot



Figure 14: Factory specification of HCR-5 Cobot

3.3 Safety Mechanism

The main difference between traditional Robots comparing with modern Cobots is their ability to work with Humans. Therefore, the safety is the top priority. For Cobot Hanwha HCR-5 series, are built with 2 detection methods to ensure the safety of users, physical sensors, and a virtual fence

- Physical sensors will be based on the Force and Torque limitation. During operation, if the Cobot is being applied force to reach a certain amount, they will stop all the activities until the system is restarted after ensuring nobody or nothing got damaged. But this method still opposed a threat due to high excessive inertia during operation at high speed can still cause damage after being contacted.
- A virtual fence will be set up in the control software by defining a limited operation space for Cobot, which does not allow them to move outside. This setting can be applied to both the body of the Cobot and the installed tool at the flange. By combining the virtual fence and the physical marked layout, the accident rate will be strictly controlled without the need for an additional physical fence



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① Preset (Values are set in advance)

② Torque setting for collision (Range: 25Nm~150Nm)

③ Force setting for collision at tool end point (Range: 100N~250N)

④ Set maximum linear speed based on TCP(Range: 0.1~1000mm/s)

⑤ Collision mitigation
- If set 'Enable', the robot is converted to 'Free Drive' mode after collision for 3 seconds to avoid the damage

⑥ Joint operation range setting

⑦ Setting for maximum speed at each joints

⑧ Setting for speed of reduced mode
- Linear Move:
Setting for linear speed at reduced mode
- Joint Move:
Setting for speed at reduced mode

Figure 15: Safety limitation setting

① Click to 'Add' button('+')

② Setting boundary plane at Manual control of robot menu

③ Setting for use or not

[Caution]
- Note that safety boundary detects only the TCP or tool boundary, and can't detect the parts of other equipment.

Figure 16: Virtual fence setting

3.4 Program

To operate the Cobot, we will use its designed software named Rodi, also developed by Hanwha. This software is written based on C# with C++ programming language and uses the ladder thread method to execute the command. The software is intuitive and does not take much time to get used to. However, due to its simplicity, it will show a lack when the situation requires more complex tasks and calculations with conditions to be done. During the shipment period, I studied and researched the capabilities of the program offline before the Cobot arrived. This experience has smoothed the practical learning process by knowing what should be done and what to avoid doing. By combining with Modbus devices, the Cobot Hanwha HCR-5 can upload its information to cloud service and store it for tracking and future analysis. However, the capabilities to update in real-time and online control are still under development.



Figure 17: Signal status with Input- Output control of HCR-5 Cobot

	A	B	C	D	E	F	G
1	2021-03-19_11-07-41						
2		joint_1	joint_2	joint_3	joint_4	joint_5	joint_6
3							
4	2021-03-19_11-07-41						
5		joint_1	joint_2	joint_3	joint_4	joint_5	joint_6
6	Joint_Speed	18.2436136680074	2.5631321066677	0.81353215887995	3.23492975518255	0.021918268487005	18.1950997834158
7	Temperature	44	43	44	46	44	45
8	Current	0.966553079947575	2.33661861074705	2.58060288335518	0.140344827586207	0.104310344827586	0.180172413793103
9	Voltage	0.966553079947575	2.33661861074705	2.58060288335518	0.140344827586207	0.104310344827586	0.180172413793103
10	Joint_Angles	16.3251397161201	-86.0621084081064	-96.2861376469678	-87.6280408802599	90.0102248994431	16.3251397161201
11							
12	2021-03-19_11-07-42						
13		joint_1	joint_2	joint_3	joint_4	joint_5	joint_6
14	Joint_Speed	19.8481614518874	4.26835163985149	6.99888928101795	2.82582500193379	0.018056737314357	19.7392227626083
15	Temperature	44	43	44	46	44	45
16	Current	0.844560943643512	0.713184796854522	2.68382699868938	0.153620689655172	0.121379310344828	0.21051724137931
17	Voltage	0.844560943643512	0.713184796854522	2.68382699868938	0.153620689655172	0.121379310344828	0.21051724137931
18	Joint_Angles	0.871455126469678	-89.659315052599	-90.4751314975248	-89.8625077351485	90.0008158164449	0.866016350170173
19							
20	2021-03-19_11-07-43						
21		joint_1	joint_2	joint_3	joint_4	joint_5	joint_6
22	Joint_Speed	0.007124796952351	0.024474493347772	0.00560193958849	0.005221225247525	0.000598265392946	0.013868879563738
23	Temperature	44	43	44	46	44	45
24	Current	0.872712975098296	2.59937090432503	0.94778505897772	0.436206896551724	0.096724137931035	0.166896551724138
25	Voltage	0.872712975098296	2.59937090432503	0.94778505897772	0.436206896551724	0.096724137931035	0.166896551724138
26	Joint_Angles	3.67862512569616	-88.659994295328	-91.8979697652383	-89.439370939047	89.999619285659	3.67672155399134
27							

Figure 18: Operation Data of HCR-5 Cobot

3.5 Setup Training Station

3.5.1 Install Cobot to Training Table

Due to the COVID-19 pandemic, the Korean service team could not travel to Vietnam for the acceptance test and setup of the Cobot. Therefore, to overcome these difficulties, we have worked together to hold an online conference call with each other. Despite the lack of direct communication. The Factory team has successfully set the Cobot to the Training Table and also recorded the steps for future installation.



Figure 19: Shipment package of HCR-5 Cobot

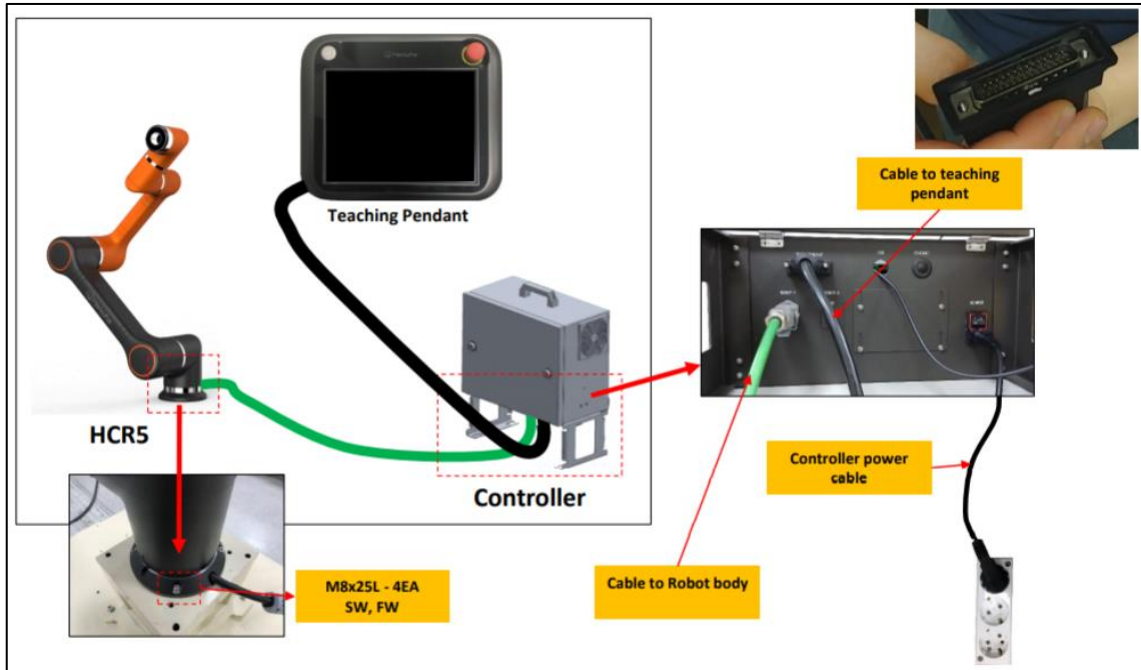


Figure 20: Setup instruction from Supplier

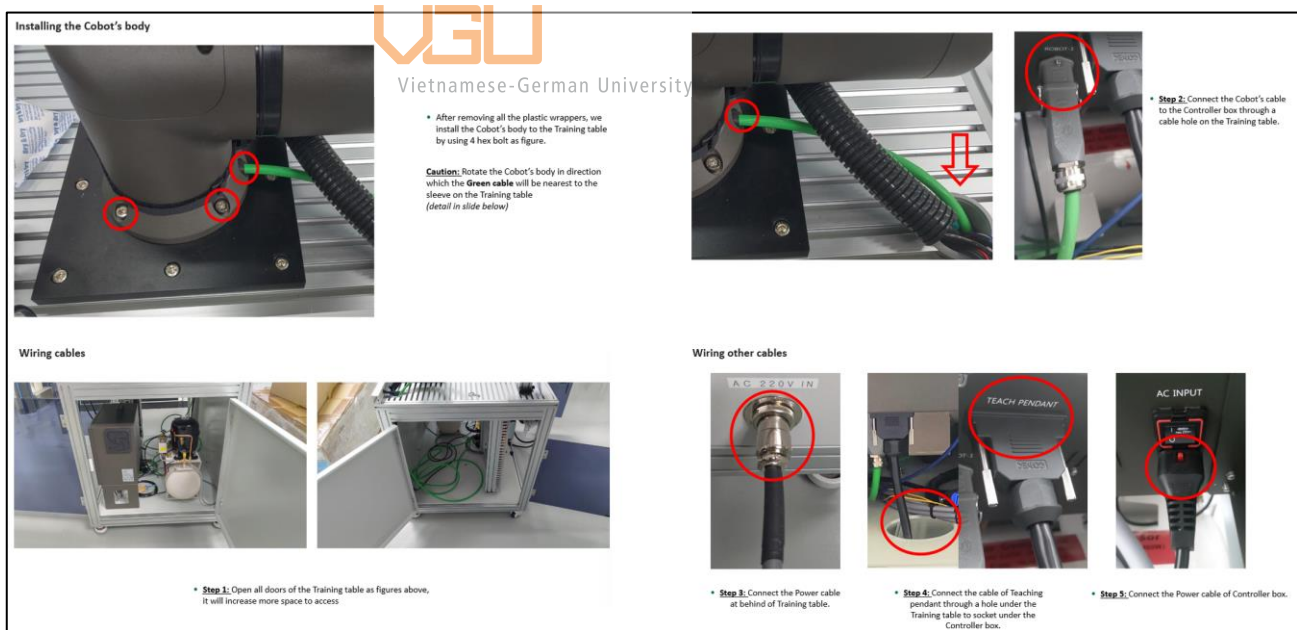
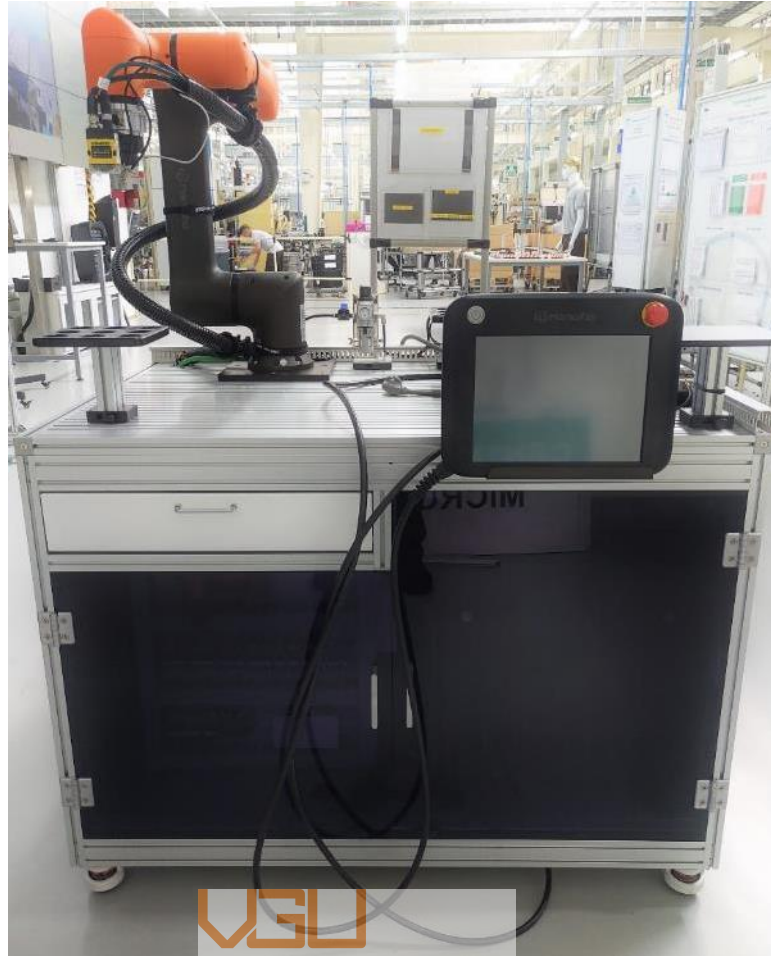


Figure 21: Setup instruction after recorded

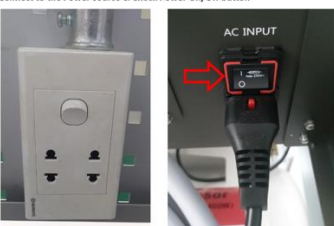


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Figure 22: Completed Training Table with HCR-5 Cobot

3.5.2 Testing Functionality

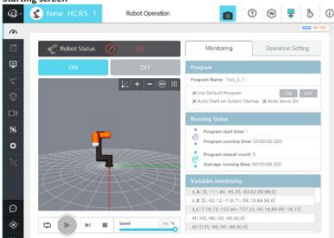
After installing the physical body of Cobot to the Training Table, we continued to set up the power source, signal response, and then the functionality test.

Connect to the Power source & Check Power On/Off button




- **Step 1:** Check the Power source (220VAC 50/60Hz) then plugged the Power cable to the Power source.
- **Step 2:** Turn on the Black switch under the Controller box, otherwise, there will be no power although we have plugged to the power source.

Starting screen



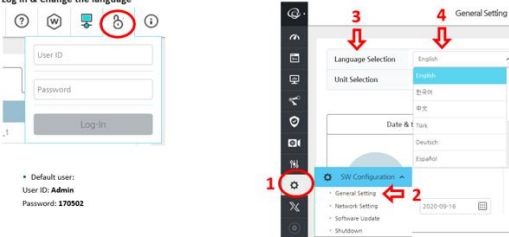
- After waiting a few seconds, the Teaching pendant will automatically open the **Robot Simulation software**.
- The User Interface will be similar to the software on computer (only minor differences due to versions of the software)

Turn on the Cobot



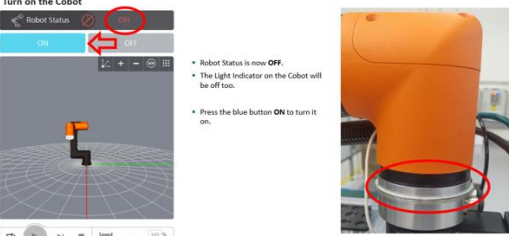
- Press the upper-right button on the Teaching pendant to turn on the Cobot
- If it turns Green, then the program will start after seconds. Otherwise, check Power source and the **Black switch** as mentioned above

Log in & Change the language



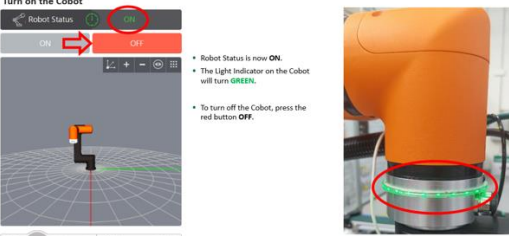
- Default user:
User ID: **Admin**
Password: **179502**
- Follow the steps above in order to change the language.

Turn on the Cobot




- Robot Status is now **OFF**.
- The Light Indicator on the Cobot will be **off** too.
- Press the blue button **ON** to turn it on.

Turn on the Cobot



- Robot Status is now **ON**.
- The Light Indicator on the Cobot will turn **GREEN**.
- To turn off the Cobot, press the red button **OFF**.


Attach the Cables of Gripper / Vision system



All the cables of gripper/vision system is wrapped inside a **Black sleeve**.

The sleeve should be attached **ABOVE** the Cobot's body to reduce the possibility that the sleeve will stuck or prevent the Cobot's actions.

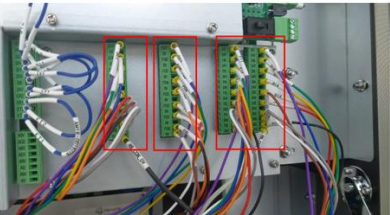
Install Gripper / Vision system



- Step 1:** Install the Vision system directly to the Cobot's body by using 4 hex bolts
- Step 2:** Install the Gripper to the Cobot's body through the base of Vision system by using 2 hex bolts

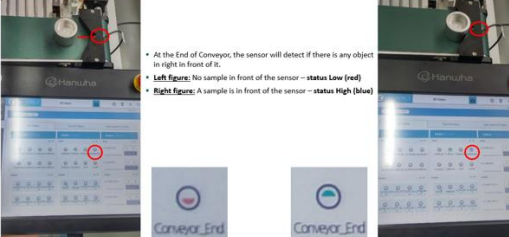
• **Caution:** Must be installed as the same direction with the Cobot coordinate as yellow arrows

Check I/O wiring



- Inside the Controller box, there will be a wiring circuit for I/O signal. Each wire has specific **colour** and **name** on it.
- **Step 2:** Check if the wires are plugged in the right sockets by checking the wire's name and the socket's name is matched or not.
- **Step 3:** Re-wiring if needed.

Check I/O signal



- At the End of Conveyor, the sensor will detect if there is any object in right in front of it.
- **Left figure:** No sample in front of the sensor -- status **Low (red)**
- **Right figure:** A sample is in front of the sensor -- status **High (blue)**

Figure 23: Power and Input-Output test

Check Robot movements

- Here is the UI of **Manual Control** tab.
- This is the **default Home position** of the Robot. If we want the Robot move to the Home position, **press and HOLD** the **Home button** until the Robot reach the desired position (this apply to all other movement commands)
- In this tab, we can see the information about:
 1. **Tool position** (if a Tool/Gripper/Camera is setup)
 2. **Joint position** of each joints
 3. **Reference frame**: The Robot will moving according to it
 4. **Buttons** to control the Robot movements
 5. **Speed bar** to control the Robot's speed (lower speed for testing is recommended)

Check Robot movements

- We can change the Rotation angle of each joint manually by pressing the **+/-** button
- White number**: Current angle of each joint
- Blue number**: Limit angle of each joint

This figure will show the position of each joint in the Robot's body

Check Robot movements

1. 3D Visual frame
2. Choosing Reference frame between Base or any coordinate
3. Move the Robot linearly to a specific direction
4. Rotate the Robot respect to a specific axis

Check Robot movements

- By pressing **Direct Teaching** button, we can use hand to directly hold the Robot and move to a desire position.

The Light Indicator will turn **BLUE** when in Direct Teaching mode

Check Emergency buttons

- There are **2 Emergency buttons**:
 - 1 on Teaching pendant
 - 1 on V/D board attached on the side of Training table
- **Step 1**: Turn on the Robot then push the button. If it works, the Robot will stop immediately.
- **Step 2**: We rotate the button to release it. Do the same for 2 buttons.

Figure 24: Functionality test

4. Analyze phase

4.1 Product portfolio and Material flow

In the Schaeffler Vietnam manufacturing plant, the majority of processes are grinding process.

For standard bearing, it will contain four components:

- Outer Ring (OR): this is the Ring located outside of the bearing and serves as the contact point to the machine. It can be connected to a static part or rotary part, depending on the required application. The Outer Ring (OR) has three areas that require strict specification: Raceway (where the roller element makes contact), Outer surface (where the Bearing connects to the machine), Height (significant impact to flatness, parallelism)
- Inner Ring (IR): this is the Ring located inside of the bearing and serves as the contact point to the machine. It can be connected to a static part or rotary part, depending on the required application. The Inner Ring (IR) has three areas that require strict specification: Raceway (where the roller element makes contact), Bore surface (where the Bearing connects to the machine), Height (significant impact to flatness, and parallelism)
- Rolling element: this element mostly takes the form of a ball, needle, or cone. This element is located between the Outer Ring (OR) and Inner Ring (IR), with contact points are their raceway, to support their rotation. This element has one parameter that strictly controls tolerance. The Raceway of the Inner Ring (IR) and Outer Ring are ground with a strict tolerance of 3 micrometers. Therefore, the Rolling element must ensure the tolerance to fit perfectly between the Outer Ring and Inner Ring.
- Retainer (also called Cage): to help the Rolling elements stay at a desired location and not fall apart, the Bearing will use a Retainer located between the rolling elements. They are mainly made from steel, and plastic and can be made from other materials based on the requirement of application. Aside from this Retainer, some bearings require to installation of a Seal (or Shield) to cover the Rolling elements and and the Retainer, this will prevent the substance outside from entering the Bearing and keep the Grease (or Lubricant) from leaking while operating.

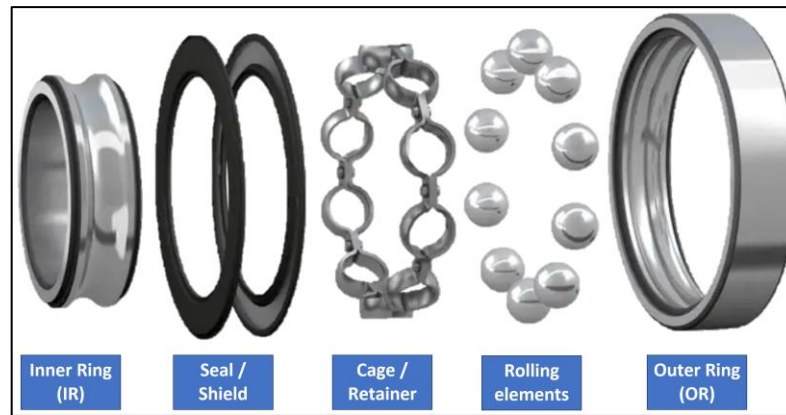


Figure 25: Standard structure of Bearings

In general, Schaeffler Vietnam focuses on manufacturing the Outer Rings and Inner Rings. For the 2 components, they will be purchased from suppliers and to be delivered to the plant as soft rings. Then, they will go through a heat treatment process to harden the rings to are called hard rings after this process. To execute the next steps, the newly heated hard rings will need to be placed in an open space with free convection cool down to reach the environment temperature.

After cooling down, both the Outer Rings and Inner Rings will then go through the Grinding 1 (G1) area. In this area, they will grind the outside surfaces of the Rings ensuring the accuracy of following steps. This area will be divided into 2 groups of grinding processes, the Face grinding process and the Outer Diameter (OD) grinding process. As the name implies, these surfaces from both Outer Rings and Inner Rings will be ground to achieve a required parameter with a tolerance of up to 4 micrometers while ensuring other critical characteristics such as waviness, parallelism, roundness, and roughness.

Next, the Rings will be transferred to the next area and distributed to their corresponding Production lines with specific manufacturing processes, based on the type and size of the Bearings. As a start, both Outer Rings (OR) and Inner Rings (IR) will need to go through Grinding 2 (G2) processes. Different from the Grinding 1 area, they will be grind at different surfaces with different parameters and sizes. But the most critical surfaces are the Raceway of Inner Rings and Outer Rings with the Bore of Inner Rings. Then, they will be moved to the Assembly area. In this process, all the main components (Outer Rings, Inner Rings, Rolling element, Retainer) with other optional

support components (Seal, Shield, Grease, Rivet, etc.) will be assembled to create one fully functional Bearing. As a final step in Production lines, the Bearings will go to the Packaging area, where they will be packed and labeled following the required methods from the customer, and wait to be transported to the warehouse.

Depending on the product types and requirements of the customers, there will be an additional step to insert the Bearings into the Housing (or Flange) to make a complete set of products. Also, there will be other surface treatment processes (Galvanic, Black Oxidize) to improve the surface quality of the Bearings.

4.2 Potential areas for automation

As initial plan, the Cobot will be delivered to the plant in around September, which is 3 months since we received information regarding this project. During the waiting time, we conducted some overview survey by ourselves to define which areas are suitable to apply automation, specifically Cobot solutions based on 3 main criteria:

- Spaceous area
- Mono- & Repetive activities
- Hazardous environment



Then, the task and area have been summary into 4 main figures as below

- Current situation: manual, safety, ergonomics, workload.
- Benefit for automation: productivity, safety, workload, Headcount.
- Process information: Cycle Time (CT), Object weight, Headcount.
- Constraint: Space, Product variation, Programming, Stability of synchronization.

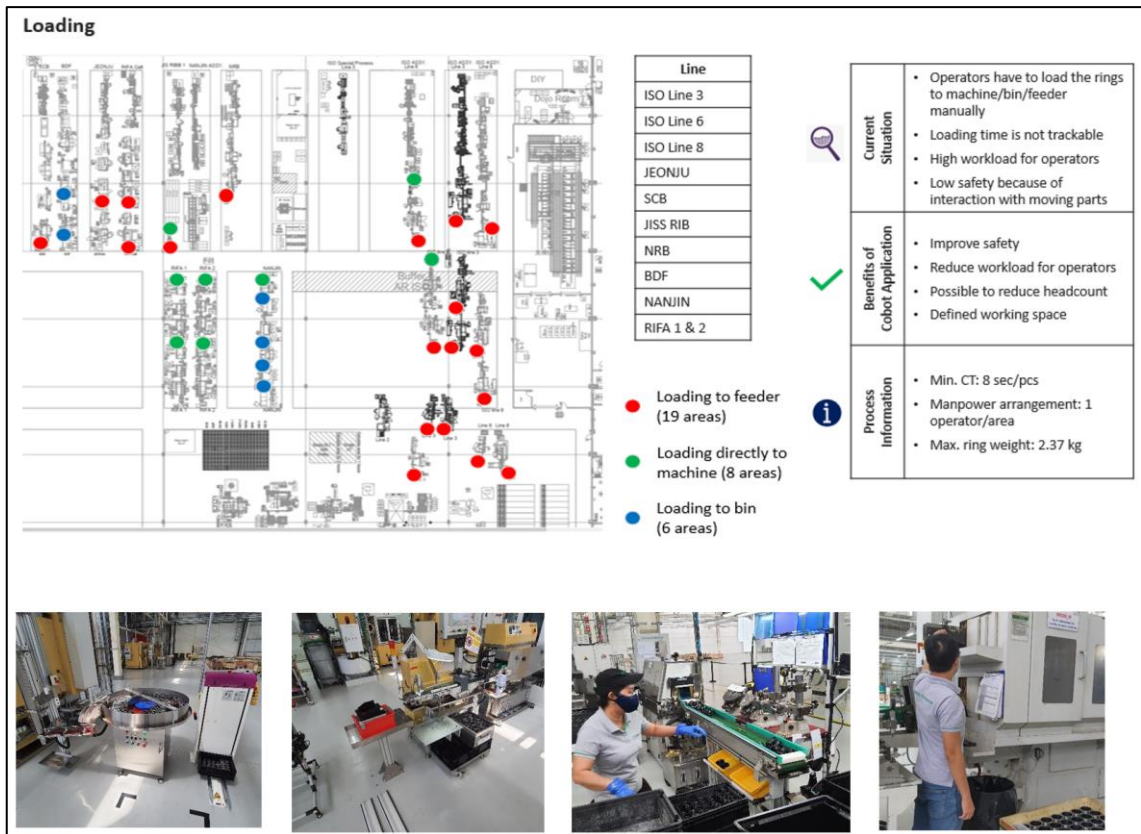


Figure 26: Summary of potential area for Loading activities



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Figure 27: Summary of potential improvement for Housing Assembly activities

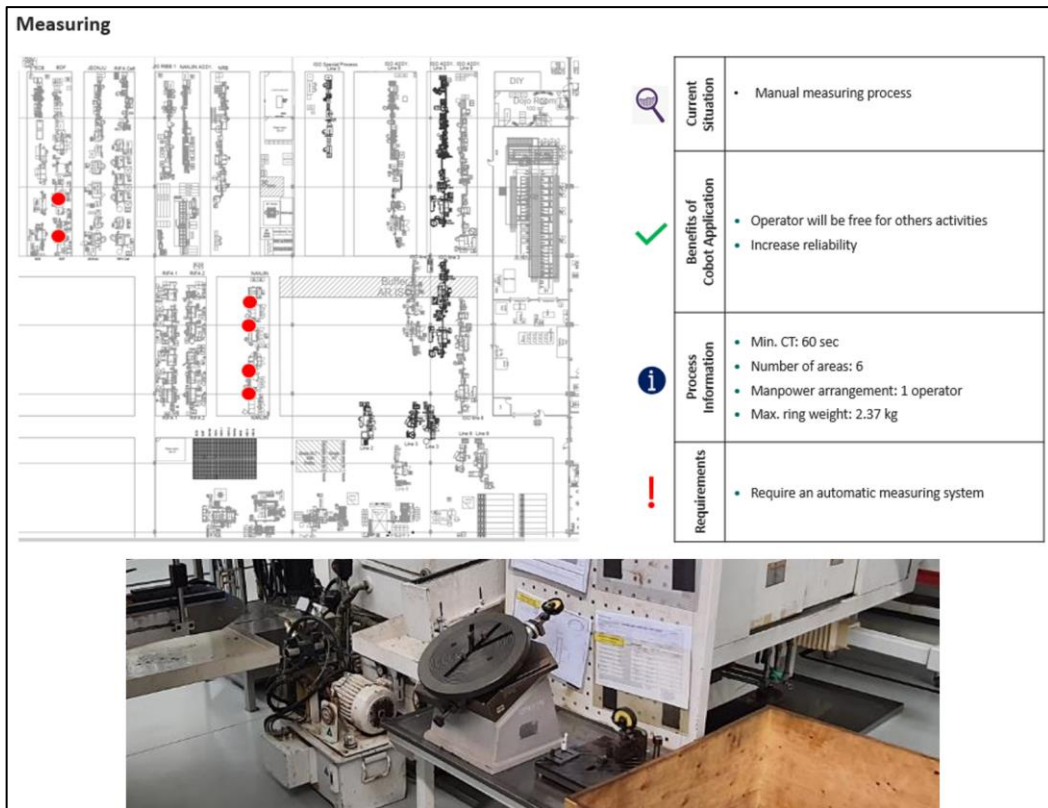


Figure 28: Summary of potential improvement for Measurement activities



Figure 29: Summary of potential improvement for Packaging activities

4.3 Benefit analysis

4.3.1 Performance Indicator Explanation

Nominal Operating Time (Nominal OT): is the time taken in account of full-day duration, which means 1440 minutes as default and fixed value for performance calculation.

Planned Operating Time (Planned OT): the time was planned to have production, based on several shifts. In a day, the time will be divided into 3 operating shifts with 8 hours for each one: Shift 1 (6 AM to 2 PM), Shift 2 (2 PM to 10 PM), Shift 3 (10 PM to 6 AM).

Downtime (DT): is the total idle time of the production, which is unable to perform production activities (either planned or unplanned).

Production time: is the time that the line uses for producing. This will be calculated by subtracting the Planned Operating Time (or Nominal Operating Time) from the total Downtime in the measured duration.

Cycle Time (CT): is defined as the time of process to produce 1 part. This is measured by 2 methods: measure the duration between the start of the process and finish the process, and measure the duration between the 2 times the process is finished. For Schaeffler, the designed performance to achieve a target cycle time is called Routing Cycle Time (R.CT). In reality, the performance will have variation and it will be called Actual Cycle Time (A.CT).

Planned Time Produced Quantity: is the time that is needed to produce actual output quantity following the production plan. This will be calculated by multiplying the actual output quantity with the Routing Cycle Time.

Planned Time Yield Quantity: is the time that is needed to produce actual good output quantity, after subtracting the scrap quantity from the total output. This will be calculated by multiplying the actual good output with the Routing Cycle Time.

Operating Factor (OF): is an indicator for the operation of the production line and is to be used for determining the maximum utilization has been reached. This will be calculated by dividing the Planned Operating Time by the Nominal Operating Time with 100% as the maximum value.

Availability factor (A-factor or AF): is an indicator of the availability of the production line according to the production plan. This will be calculated by dividing the Production Time by the Planned Operating Time with 100% as the maximum value.

Performance factor (P-factor or PF): is an indicator of the performance of the line during the production time. This will be calculated by dividing the Planned Time Produced Quantity with the Production Time and the value can exceed 100%. In case the Actual Cycle Time is higher than the Routing Cycle Time, the P-factor will be lower than 100% and the production team will have to carry out improvement activities. In case the Actual Cycle Time is lower than the Routing Cycle Time, the P-factor will be higher than 100% and the production team will have to validate and update the new Routing Cycle Time.



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Quality factor (Q-factor or QF): is an indicator of good output quantity produced and scrap quantity lost during the production, to trigger improvement or overhauling the machine to control higher accuracy follow the required specification. This will be calculated by dividing the Planned Time Yield Quantity by the Planned Time Produced Quantity.

Overall Equipment Effectiveness (OEE): is an indicator of the actual performance of the production line in a defined operating duration. This will be calculated by multiplying the Availability factor, Performance factor, and Quality factor. Another method to calculate is dividing the Planned Time Yield Quantity by the Planned Operating Time.

Total Effective Equipment Performance (TEEP): is an indicator for the actual performance and utilization of the production line in a fixed duration (1 full day). This will be calculated by dividing the Planned Time Yield Quantity by the Nominal Operating Time.

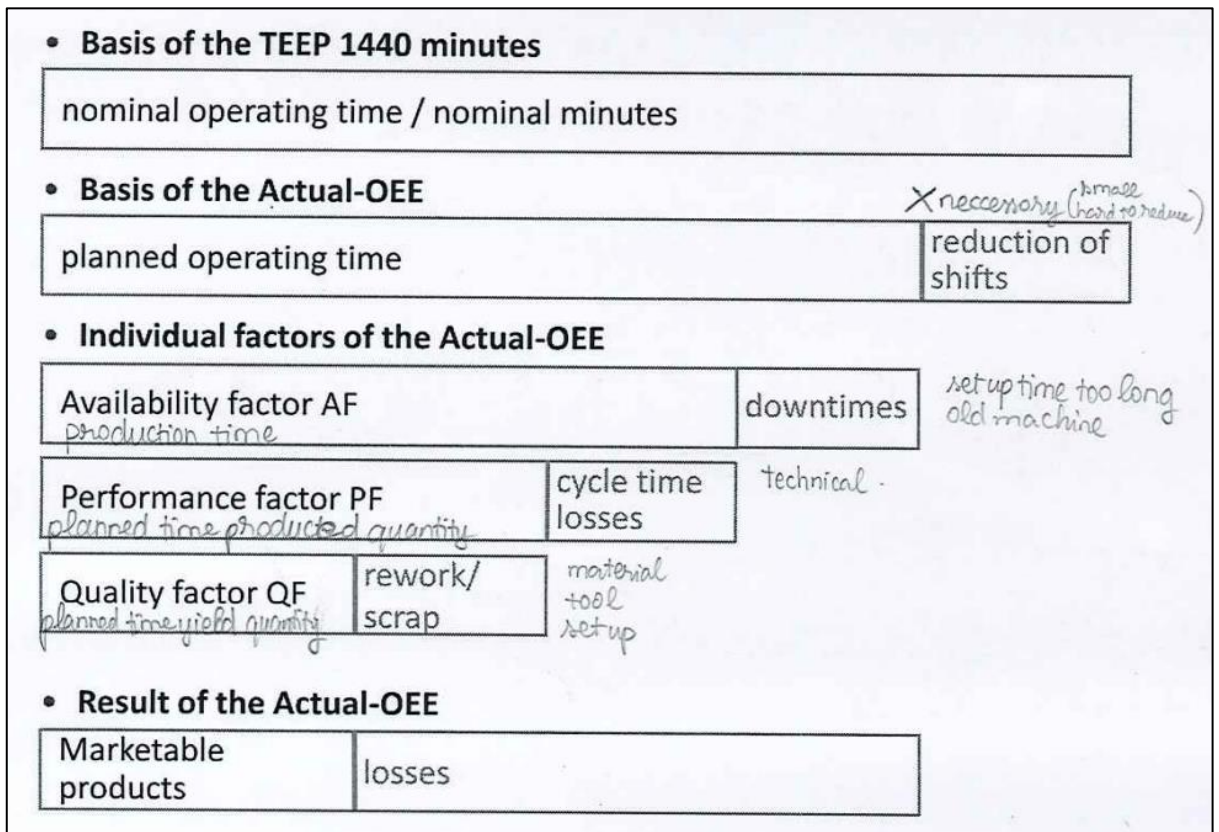


Figure 30: Theory of Performance Indicators
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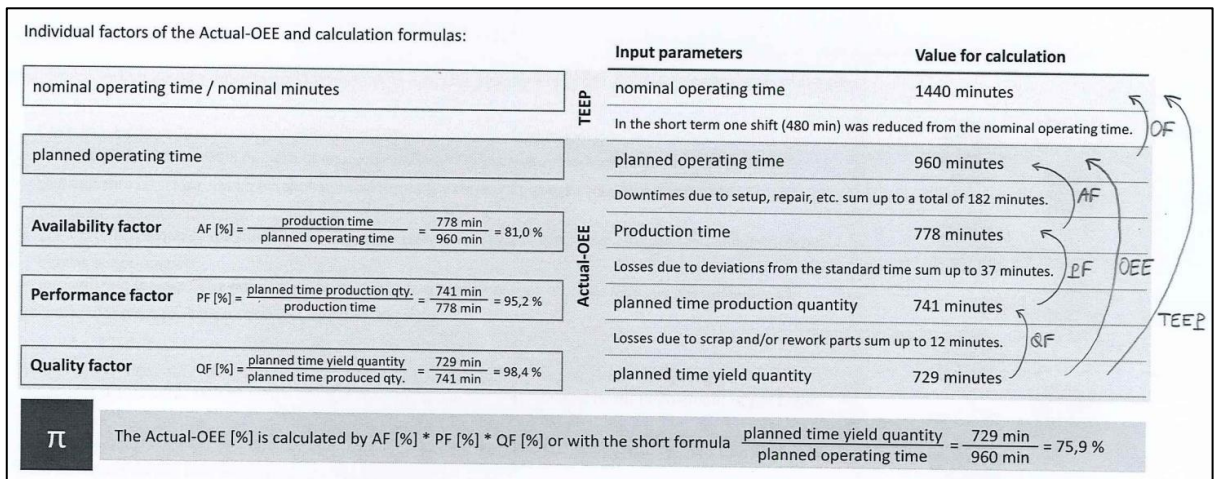


Figure 31: Calculation of Performance Indicators

4.3.2 Benefit based on Productivity

In the manufacturing world, Output is the critical indicator of the performance of the production line. As explained above, we categorize the indicators into 3 groups: Availability, Performance, and Quality. In these research cases, the main tasks are performed by the designed specific machine and the Cobot will not interfere with these processing steps. The thesis will focus on the automation potential and feasibility concept for integrating the Cobot into mass production to improve the Availability factor and the Performance factor while ensuring the Quality factor is a must.

For the Availability factor, we will focus on how to keep the production line operating continuously with minimum downtime. As explained above, the Downtime will consist of Planned Downtime and Un-planned Downtime:

- **Planned Downtime:** the type of Downtime that is being planned to support the production. This will be further broken down into more detail such as break time for the operator, setup time, transport material, etc...
- **Un-planned Downtime:** the type of Downtime that occurs unexpectedly during production such as machine breakdown, waiting for material, missing personnel, etc

As the direction for planning improvement, the Planned Downtime will be the focus of analysis and is expected to have a reduction. Regarding the unplanned downtime, it is required to at least remain the same and must not be increased. Therefore, the target for integrating the Cobot as a new technology into the existing production line is to at least keep the line stable the same as before, in other words, the Availability factor after the integration must not be lower than before.

For the Performance factor, we will analyze and develop following the direction of eliminating waste from manual processes, then optimize the overall working system of Machine-Human-Cobot collaboration and stabilize the entire process flow. With the Time study REFA methodology, all the steps have been recorded, categorized, and analyzed to define the potential improvement, with a priority to reduce the time for ancillary activities, and waiting activities caused by the human operators.

4.3.3 Benefit based on the Saving amount

Saving will be calculated based on process cost, which consists of fixed cost and variable cost.

- Fixed cost: the constant cost that the company must pay through a period to be independent of customer demand. The cost of machines, equipment, and land plots would significantly contribute to the fixed cost.
- Variable cost: the cost that will be changed corresponding to the customer demand, such as electricity, emulsion, headcount, etc

These costs will be transferred to the unit of value over a period of time [€/minute].

4.3.4 Benefit based on Capacity requirements

The above benefit criteria were based on the in-house situation. But the performance of a company will also be based on adaptation to the requirements of customers. To ensure the delivery plan, the company must ensure the stability of the entire supply chain, which includes external material logistics and internal work systems. For the scope of this project, we will only focus on internal performance. To be aware of the internal situation, companies will have a function for Demand-Capacity-Check, as its name implies, this will support a clear picture of the situation and whether the in-house production is overloaded or not.

- Demand: is the demand from the customer. For the short term, the demand will be mostly fixed with minimum fluctuation, and to be converted to a production plan. But for the long-term view, the company will communicate with the customer to get the information of forecast demand, this will support both sides for their plan and allow the production to carry out an improvement plan on time to align with the demand from the customer. The time zone for “short-term demand” and “long-term demand” depends on the company policies with their customers, and suppliers.
- Capacity: the amount of output that can be produced in a period of time. There will be 3 main criteria that influence the capacity, which are Cycle Time (CT), Overall Equipment Effectiveness (OEE), and Shift model. For the real situation, the plan

will be a collection of multiple products with different Cycle Time. In order to acquire the Capacity for a product mix, the term weighted average Cycle Time will support the calculation.

- Shift model: is the term to represent the number of shifts and working days planned for production. There will be standard common shift models as below, and also other shift models that the production will be flexible to adapt to the up-to-date situation
 - 5-shift: working from Monday to Friday with 1 standard shift each day
 - 6-shift: working from Monday to Saturday with 1 standard shift each day
 - 9-shift: working from Monday to Saturday with 1 standard shift and 0.5 overtime shift each day
 - 12-shift: working from Monday to Saturday with 2 standard shifts each day
 - 15-shift: working from Monday to Friday with 3 standard shifts each day
 - 18-shift: working from Monday to Saturday with 3 standard shifts each day (as standard for calculated Capacity)
 - 21-shift: working from Monday to Sunday with 3 standard shifts each day (extreme situation)
- Check: this is an activity to review the loading situation of Demand over Capacity. This is calculated by dividing the Demand by Capacity and having a unit of [%]. In case loading reaches 95% with an 18-shift model, it is an alarm to trigger improvement activities as soon as possible to avoid overload risk. In case loading goes beyond 100% with an 18-shift model, it is confirmed that the production has been overloaded. At this stage, the temporal solutions are to increase to a 21-shift model with working non-break to optimize production time, but those are not preferred in a long-term perspective. Therefore, long-term sustainable improvement activities must be planned.

Based on Capacity requirements, the project would be categorized for a suitable prioritization amongst other projects in the company. This will allow the team to focus their resources and drive their innovative ideas.

4.4 Finalize Target

4.4.1 OD Jupiter

4.4.1.1 Product

At this station, the machine will carry the grinding process for the Outer Diameter (OD) surface of the Outer Ring (OR) and Inner Ring (IR). For this process, the target is to grind the Ring to reach a specific dimension while ensuring the quality of key characteristics.

4.4.1.2 Current Process Flow

Following on-site observations, there will be 3 people who are requested to operate the entire workflow of this process, consisting of 2 operators and 1 technologist. The technologist will focus on monitoring the whole process with the main activities checking quality and adjusting parameters. For the operators, they will be responsible for loading and unloading the products throughout the process, with other additional tasks such as material transport.

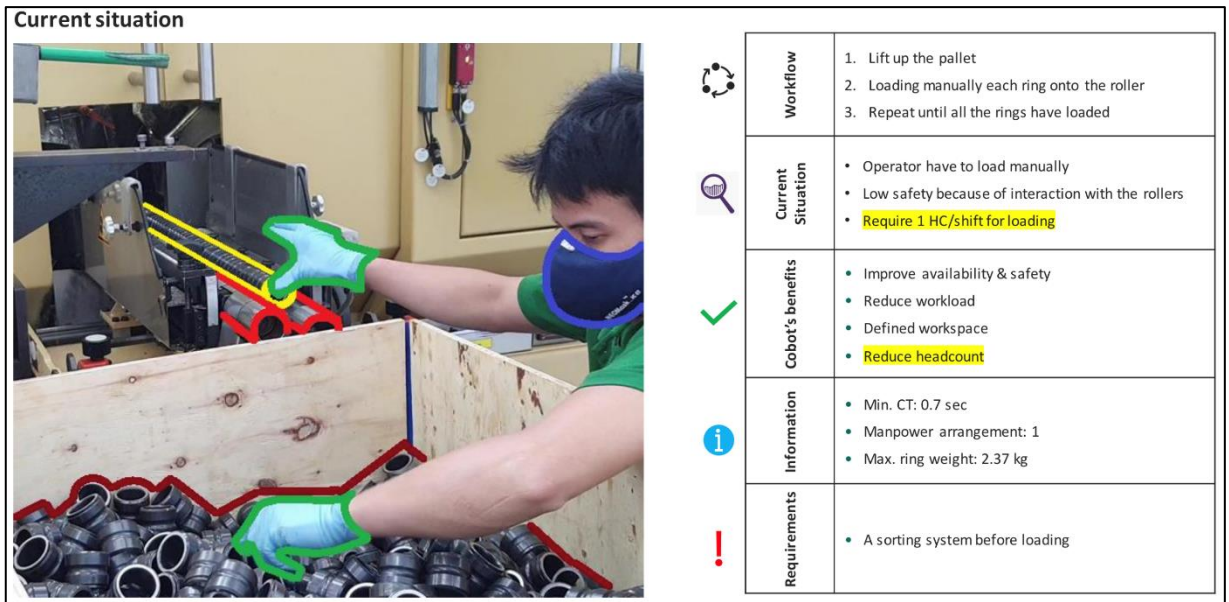


Figure 32: Highlight points of OD Jupiter station

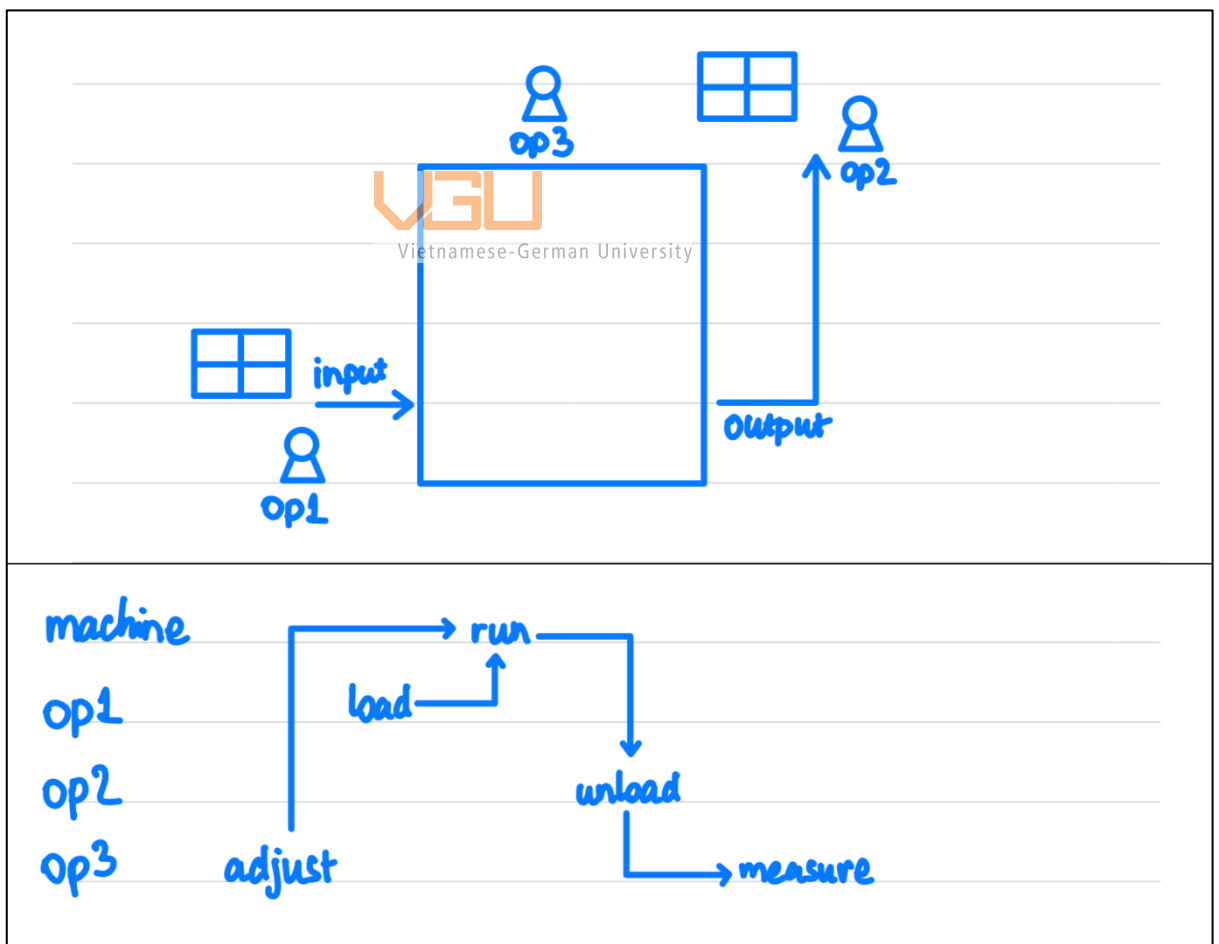


Figure 33: Material flow and Task assignment of OD Jupiter station

4.4.1.3 Potential improvement and benefit

For initial ideas from the management team, we have made a rough analysis of the benefit if the cobot successfully replaces 1 operator for the loading process. Based on the Overall Effectiveness Equipment (OEE) structure, the improvement will be reflected in the Availability factor (AF) by increasing the Production Time. For Human operators, according to a policy of working, they will have breaks for eating and recovery. That duration will be counted as Downtime for the machine. For the cobot, we are expecting it to be able to operate full-time continuously in standard conditions. Then, the machine will be automatically loaded by the cobot and work continuously with a break. Below are the results of the observation of a full-day period. Next, with the cobot to support, we will reduce the total number of headcounts from 3 to 2, with the updated task assignment.

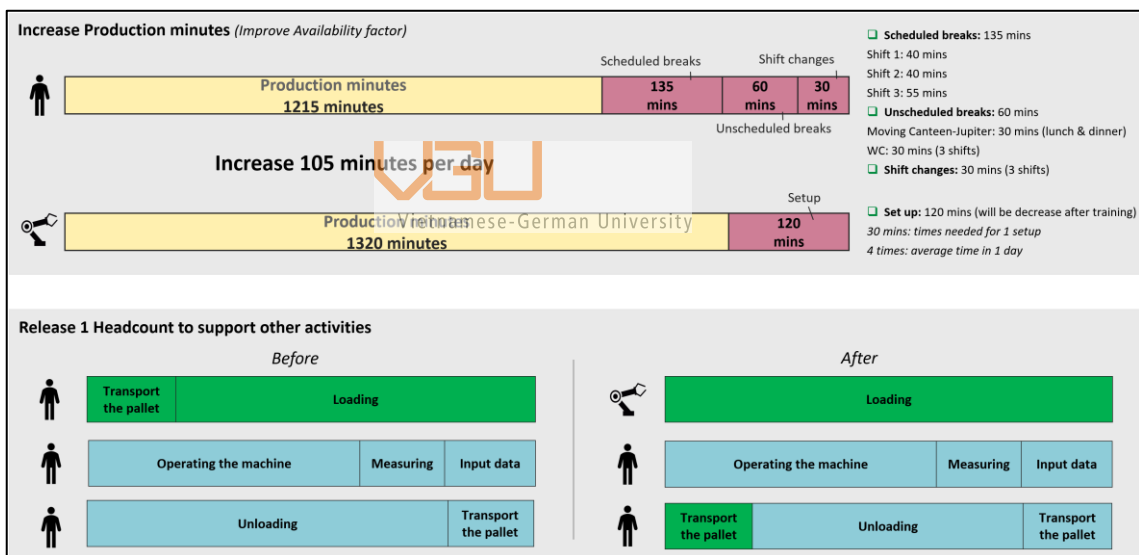


Figure 34: Potential improvement of OD Jupiter station with Cobot

4.4.1.4 Feasibility review

This Jupiter machine is specialized in mass Outer Diameter grinding. Therefore, the Cycle Time is significantly low, which is the challenge for the Cobot to keep up the pace with the machine, with no expectations to improve for Performance factor (PF) in this case. There are several solutions were discussed to make the concept work.

The Rings will be loaded into the machine on 2 rollers while being applied by a consistent force. This problem can be solved by adding a pressing device with a mechanism to apply horizontal pressure to the Rings after finishing loading on the rollers by Cobot.

To adapt to the high speed of the machine, the pick-up tool for Cobot must be able to pick and release a certain amount of Rings precisely. The first option is to use an electromagnetic gripper with the specified adapter mold. This will allow the Cobot to pick multiple Rings in a specific position on the adapter and place them precisely on the rollers. But the electromagnetic will magnify the Rings, causing the machine components to magnify as well. The second option is to use 1 headcount to organize the Rings in a structured way that suits the Cobot. But this option will then need an extra headcount, leading to no headcount can be saved. Another idea for the Second option is to invest 1 more Cobot in palletizing instead of using a human operator, hence this will increase the cost of this project.

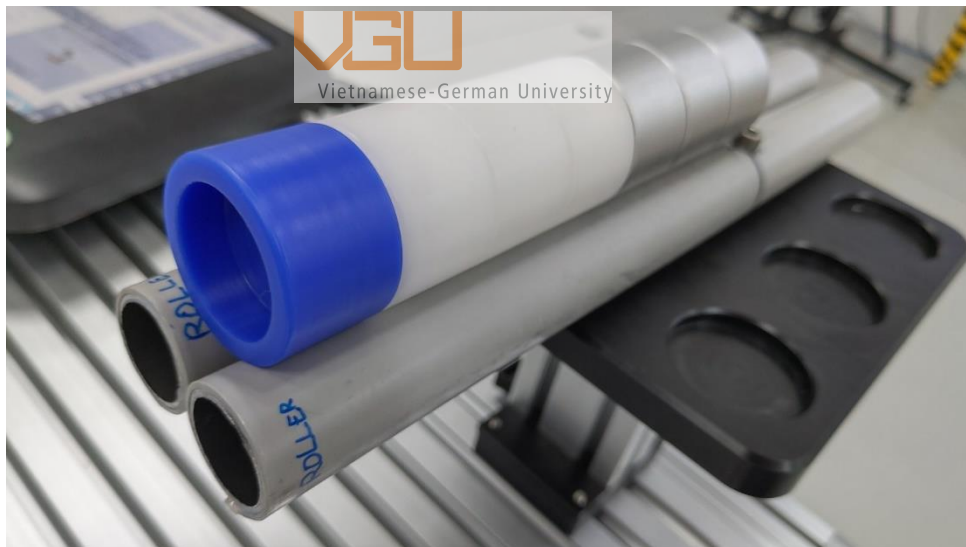


Figure 35: Simulate Inchure Roller of OD Jupiter machine



Figure 36: Structure loading (left) and Bulk loading (right)

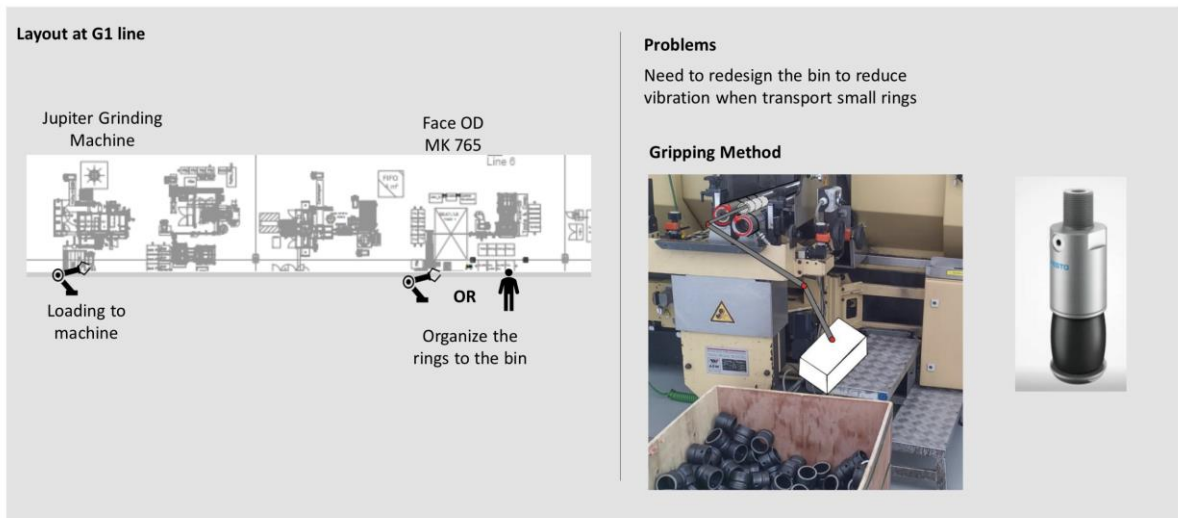


Figure 37: Propose solution by add an extra Cobot for sorting materials in advance



Figure 38: Sketch after Installation of Cobot

4.4.2 NRB Assembly

4.4.2.1 Product

Aside from using the ball as a rolling element, Bearings can use another shape to handle the rotating ability to adapt for the specified application. For steering control, the bearing will use a cylindrical shape to have better parallelism so-called Needle Roller Bearing (NRB). This type of bearing normally does not have an Inner Ring along with it, instead, the customer will use the shaft of their product to act as one.

4.4.2.2 Current Process Flow

At the Assembly line, the Outer Ring (OR) will be transported to a feeding bowl from the previous grinding line. Then, it will be put together with the Cage, and placed into the Filling machine to install the Needles, combining 3 components. Next, the product will have the weight test carried by a scale inside the machine to check and alert if there are any missing Needles. Afterward, they will be transported automatically to the Laser marking machine, Washing and Preserve oil machine. Then, they will go through a final test on Noise and Visuals by the operator with support from the measuring devices. After passing all the qualifications, the set will be packed and transported to the Warehouse and ready for shipment.

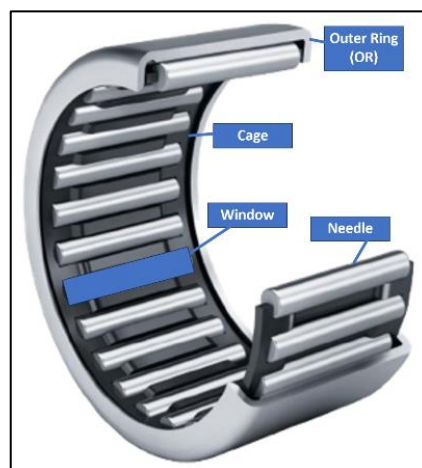


Figure 39: Structure of Needle Roller Bearing

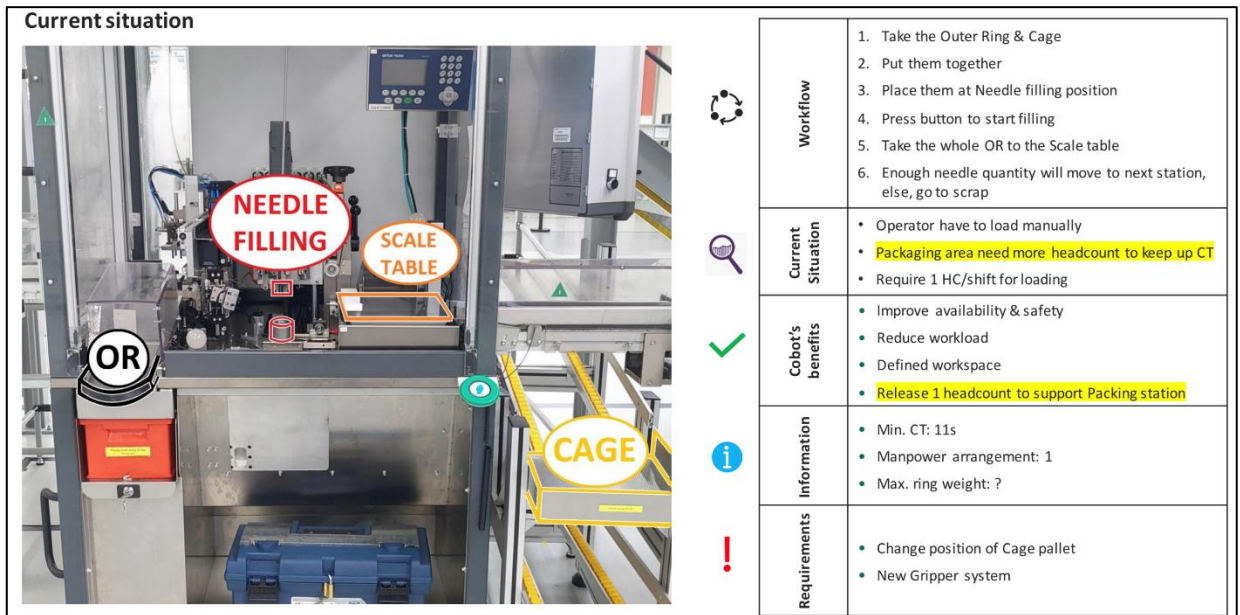


Figure 40: Highlight points of NRB Filling station

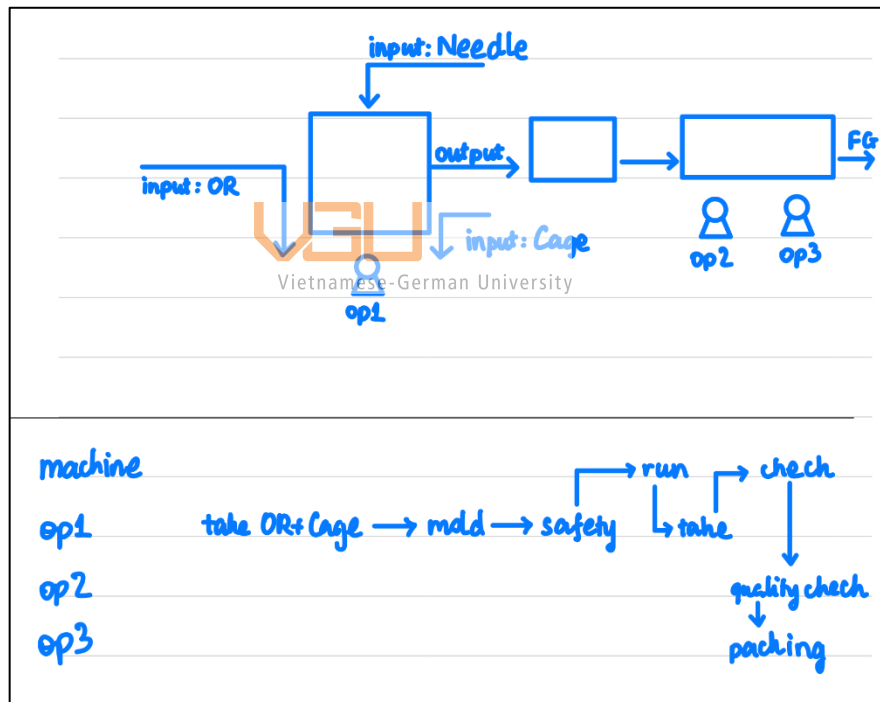


Figure 41: Material flow and Task assignment of NRB Assembly line

The bottleneck of the entire Needle Roller Bearing (NRB) production line, including Grinding and Assembly, is the Filling station. The Assembly line operates with 3 headcounts and is to be assigned 1 dedicated headcount at the Filling station, 2 flexible headcounts for Quality check and Packing along with other auxiliary activities.

4.4.2.3 Potential improvement and benefit

For initial ideas, we can apply 1 Cobot to replace the operator at the Filling station. Same as in the OD Jupiter case above, we will follow the improvement structure of Overall Equipment Effectiveness (OEE) improvement. For the Availability factor (AF), same as the case above, we expect the Cobot will be able to work continuously, instead of having downtime caused by humans. Not only that, for the Filling station, we can also see the potential to reduce the Cycle Time (CT) to increase the Performance factor (PF) by modifying the station to specialize for Cobot and optimize the task assignment for the headcount.

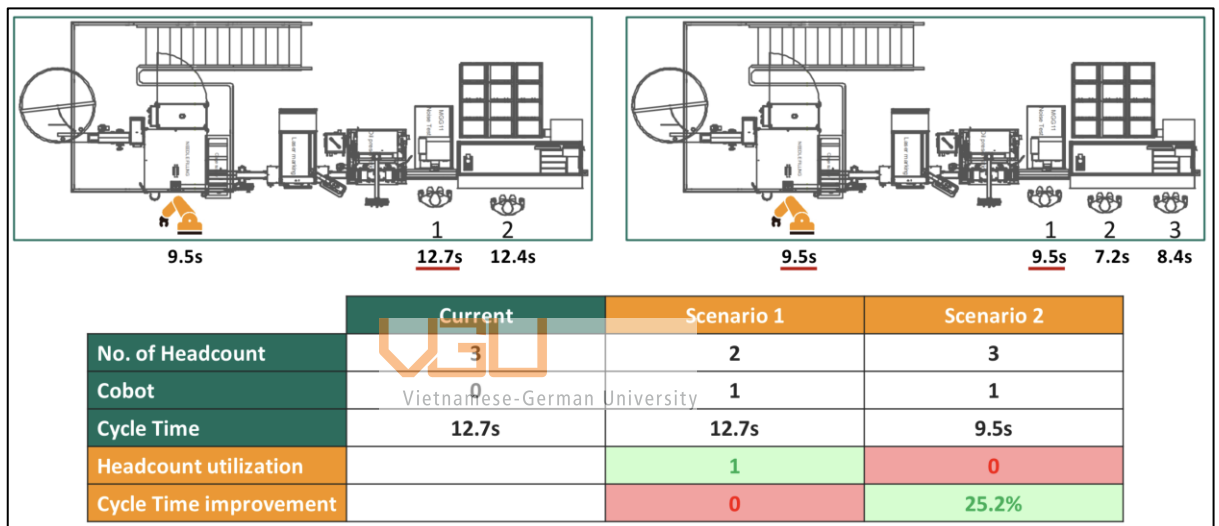


Figure 42: Propose solution to increase total Output of NRB Assembly line

4.4.2.4 Feasibility review

In this case, the biggest concern is the specialty of this Filling station, which is the only machine in the whole factory and the programs were locked by the machine builder. Therefore, the management team found major risks if something happened to the Filling machine. The problem was partly solved after the team discussed with the Headquarter and Regional teams regarding the detailed concept with promising benefits. The machine builder side still refuses to unlock the program, but they will support us by sending us the technical drawings for wiring and a backup program. With this, the Cobot and other external devices will be able to communicate with the Filling machine via signal from additional sensors.

The next concern would be the accuracy of the Cobot regarding the placement of 2 free components, which are the Outer Ring (OR) and Cage, into the mold of the Filling machine. Based on the technical requirement of the Filling machine and the technical specifications of the Cobot, we found that the Cobot will have higher accuracy and reliability than the requirements of the mold. However, since this is the first Cobot project in the factory, teams still have to be wary of this risk during the testing and mass production.



Figure 43: Simulate loading into mold position of Filling machine

4.4.3 Comparison and Finalize

After review with the management team, both of the stations have shown potential for automation improvements. Considering the current and future situation, the Needle Roller Bearing (NRB) line was prioritized for investment. Hence, the expected improvements are also higher with fewer technology constraints compared to Jupiter station. Therefore, the Filling station of the Assembly line was chosen to have the investment to apply the Cobot system

After the finalization, I attended a training section on how to run the project in the company, which steps are mandatory, and who will be the person in charge. For this specific case, the project will continue to go through 3 main phases after analysis:

- Supplier selection with Coupa (standard procedure and not covered in this thesis).
- Development phase: focus on finalizing and realizing the Cobot system.
- Integration phase: apply the Cobot system for mass production.

Figure	Weight	OD Jupiter	NRB Assembly	
Capacity requirement	35%	2	2	Higher means higher capacity loading
Productivity	30%	2	3	Higher means higher output increased
Headcount	15%	1	1	Number of headcount saving
Technical constraint	20%	1	2	Higher means less constraint
Total	100%	1.65	2.15	

Figure 44: Prioritize comparison between OD Jupiter and NRB Assembly

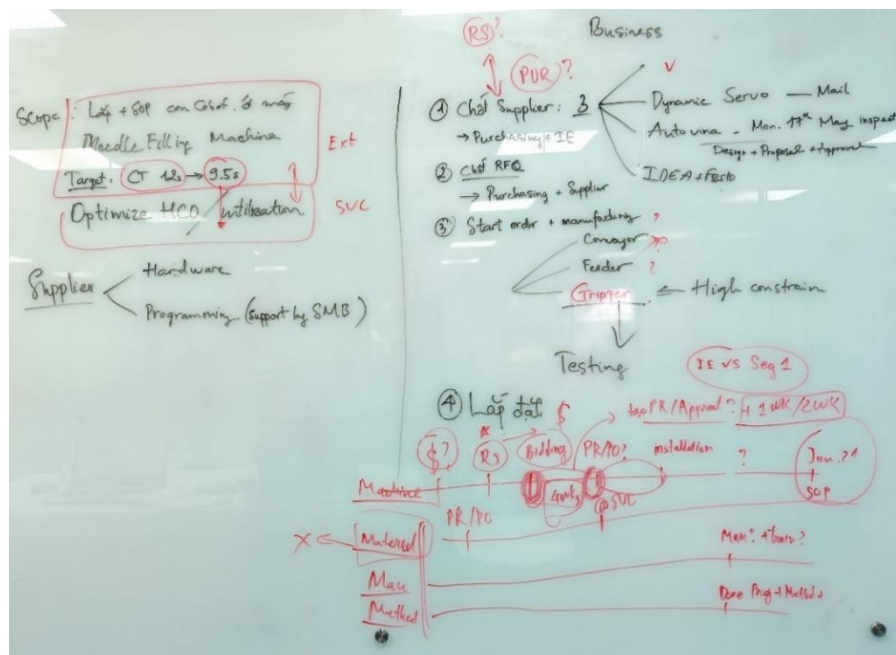


Figure 45: Proposed Roadmap for Cobot Project

5. Development phase

5.1 Working concept

5.1.1 Human working process

Depending on the product requirement of the customer, the detailed process at the Filling station may differ from one product to another but still based on the standard procedure. The Outer Rings (OR) will be transported from Grinding by a conveyor into a rotating table that acts as a buffer and a feeder to the upcoming process. The Needles will be supplied from upstairs with a frequency of 1 or 2 times per shift, depending on the required quantity of each product. The Cages will be refilled and stored at the station with a frequency of 1 to 8 times per shift, depending on the required output per shift. For the layout of incoming materials at the Filling station from the perspective of the operator, the Outer Rings (OR) will be coming from the left-hand side, and the Cages will be located on the right-hand side. During mass production, the operator will take the Outer Rings (OR) with the left hand, and then take the Cages with the right hand. After that, they will be put together with a Cage inside the Outer Rings while ensuring both of them are fit and aligned on the face surface. Next, the operator will carefully place the combined set into the mold located in the center of the Filling machine, checking the surfaces are aligned and in contact with each other. This process is required with an accuracy of 0.01mm from the center of the mold radius. After successfully placing the combined set, the hand will be removed from the inside to the outside of the machine, the laser light curtain installed at the Filling machine door will ensure the safety of the operations by continuously checking whether there is any object in between the door. Then, the operator will place a hand on the button on the right side of the door. The machine will then grab the Outer Rings (OR) and the Cage by separate grippers. By using a laser point to find a window location of the Cage, the mold will rotate the Cage to the proper position for filling the Needles. The shooter will move to inside of the Cage and the damper will move the outside of the Outer Rings (OR) in the opposite direction. The damper will support the combined set to not be tilted while the Needles are being shot from inside. After all machine parts are moved to their working position, the Needles will be supplied from upstairs and shot into the Cage windows one by one with the mold rotating the Outer Ring (OR) and the Cage until all windows are

filled with Needles. During this time, an operator will prepare for the next cycle in parallel by taking and putting the Outer Ring (OR) and the Cage together. After the filling process is done, the finished product will be taken out of the mold and placed in the scaling device to check whether the quantity of the Needles is enough or missing, then move to the next process if the product is filled as required. The moment the Product is placed on the scaling device will be marked as the trigger point for the Cycle Time (CT) measurement. The prepared set will be placed into the mold and the operator will start the next cycle.

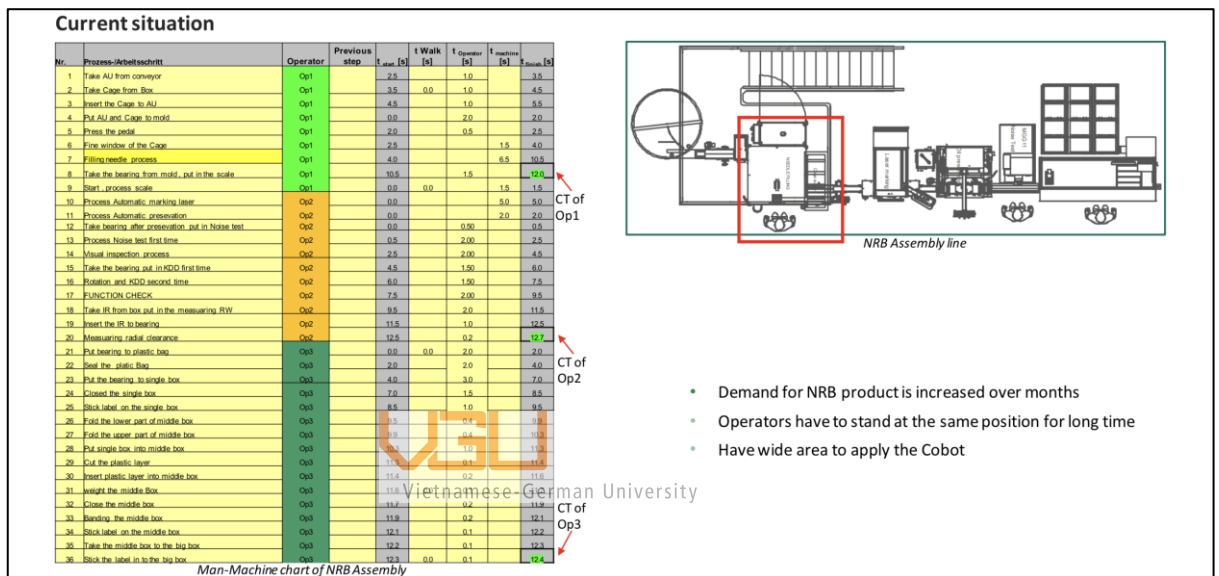


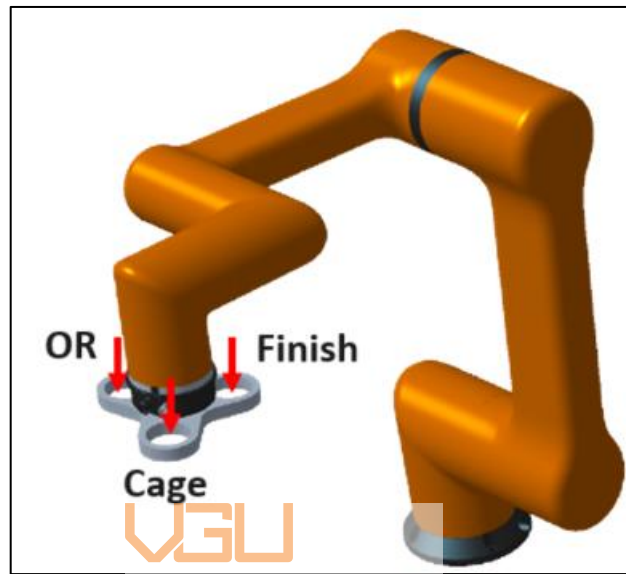
Figure 46: Summary of Task breakdown

5.1.2 Automation process with Cobot

After analyzing the manual process, 2 potential improvements can be made by applying the Cobot:

- The laser light mechanism will require the operator to move their hands outside after finishing placing the combined set into a mold and placing their hand on a button to start the operation of the machine. This process is required to ensure safety but increases the Cycle Time (CT) of the entire process. This duration can be eliminated by interfering with the program and by deactivating the laser light curtain while operating with Cobot. With this, the machine can start the filling process immediately right after the combined set is placed into the mold.

- The current layout was designed for humans to operate. Therefore the incoming materials are located on 2 sides for 2 hands taking them, the Outer Rings (OR) on the left side with the Cages on the right side. With Cobot operations, the layout will be designed to have the incoming materials come from one side, and the Cobot can pick up both of them with the minimum movement distance, then place the Cage and the Outer Ring (OR) sequentially into the mold.



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Figure 47: Concept Cobot with 3-Gripper system

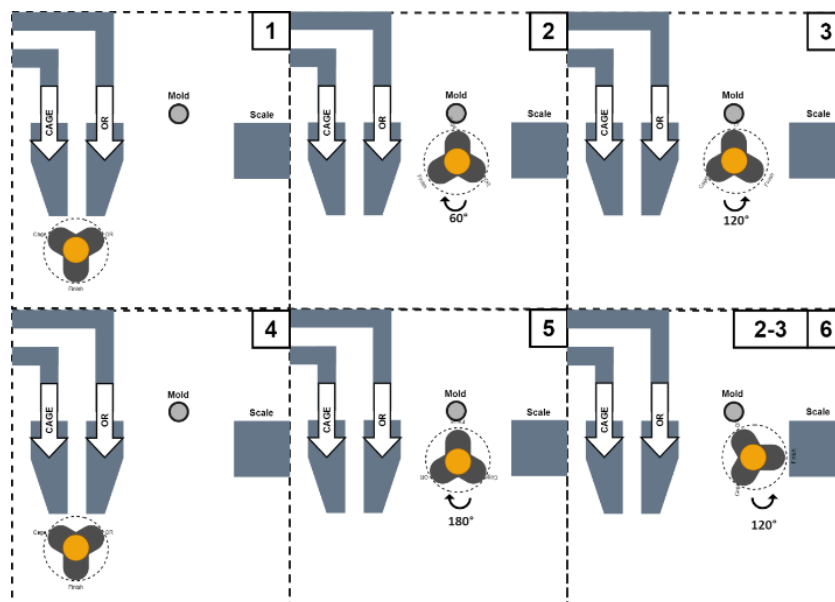


Figure 48: Sketch process for Cobot system

Therefore, we utilize the flexibility of the Cobot and design a concept using a fan-wheel shape with 3 positions for 3 grippers to be installed. Each of the grippers will handle different tasks with different functions and gripping methods:

- Gripper 1: this gripper will be in charge of taking out the finished Output from the mold to place it on the scaling device. This gripper will be a 3-joint type and grab the product from outside. The finger will be designed to follow the curve of the Outer Rings (OR) to avoid any scratches.
- Gripper 2: this gripper will pick up the Outer Ring (OR) from the incoming material area. This one also shared the same design and mechanism as Gripper 1.
- Gripper 3: this gripper will handle the task of taking the Cage from the incoming material area. Different from the 2 grippers above, this is a 3-joint type gripper but to grab the product from the inside.

With 3 Grippers installed on a fan-wheel base, the Cobot will utilize its rotating joints to perform a series of required tasks. The incoming materials area will supply the Outer Rings (OR) and Cages one by one to a specific position with the same height, allowing the Cobot will able to pick up both of them at the same time with minimum movement distance. After finishing the acquisition of the Outer Ring (OR) and the Cage, Cobot will move to the mold position located in the center inside of the machine, while rotating the fan wheel to have the free Gripper 1 facing the mold. With Gripper 2 and Gripper 3 being occupied for the materials, Gripper 1 will pick up the finished product at the mold. For the placing steps, instead of combining the Outer Rings (OR) and the Cage before placing them into the mold as human operations, Cobot will place them into the mold in a sequence of steps. The most critical accuracy was the position of the Cage, and it will be placed first with a slower speed to ensure the placement follows the required tolerance. Then, the Outer Rings (OR) will be placed from above the Cage and combined as a set after being placed in the mold. After successfully placing the Outer Rings (OR) and the Cage into the mold, the finished product that was picked up earlier will be placed on the scaling device to proceed quality check for the next steps. As mentioned above, as per the safety regulation for humans, the operator is required to move all their body parts outside of the machine and place their hand on a button to start the filing process. With Cobot, we expect that the filling process will start immediately after the finished product is placed on the scaling device. All the pick and place steps inside the machine are the combination of the flexibility of the rotating joints in a small

footprint of the modern Cobot with the utilization of the 3 Gripper system on a fan-wheel base to optimize the capability.

To implement the above process, the system will need a further adjustment. The Cage supply will move from the right side to the left side of the machine and be stored and loaded by a bowl feeder. For the production order to have a changeover between the products, the Setter will need space to access inside the machine to change the mold and the needle shooter. Also the risk of the Cobot or Filling machine facing malfunction issue, the human will require a working space. Therefore, the Cobot will be installed on the railway to travel between 2 fixed positions, the working position in front of the Filling machine and the backup position when the human is required to interact with the filling machine.

But from the production point of view, the main goal is to increase the total output of the Assembly line. Therefore the downstream process behind the Filling station will need to have improvements in parallel with the Cobot application. Those improvements will be the combination of the Line Balancing and Time Study activities, but they will not be covered since they are not the focus topic of this thesis.



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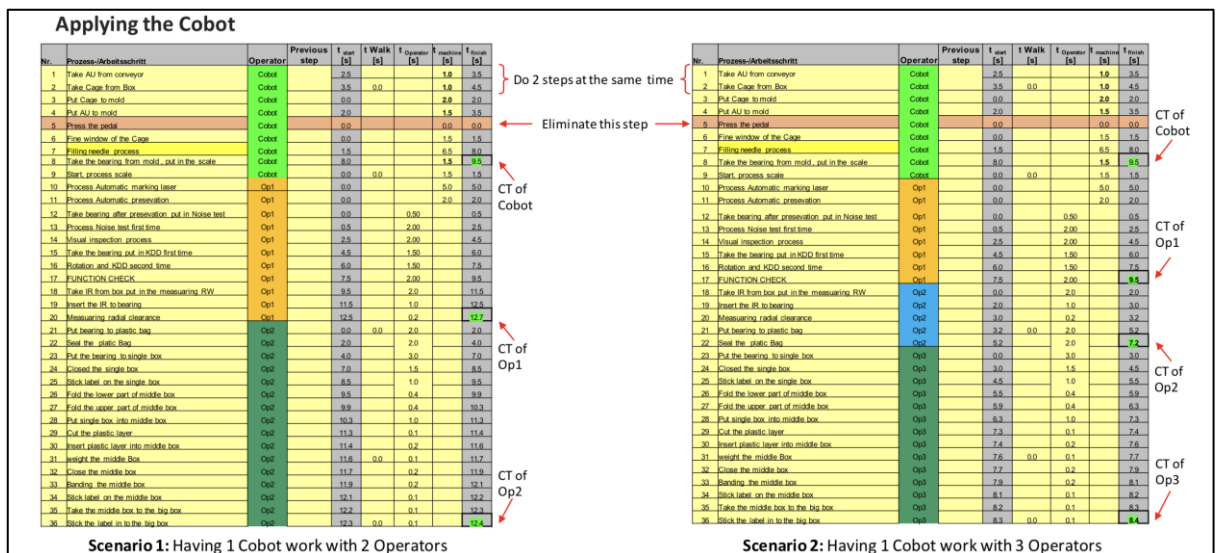


Figure 49: Process comparison on different number of headcounts

Scenario	Headcount	Manual steps	Cobot steps	Other Machine steps	Finish time process	Benefits	Risks	Requirements
Current	Op1	6	7s	0	3	9.5s		
Current	Op2	9	12.7s	0	2	7s		
Current	Op3	16	12.4s	0	0			
Option 1	Cobot	0	5	7s	8	9.5s	Automatic process	3-Grippers system
Option 1	Op1	9	12.7s	0	2	7s	Reduce 1 headcount	Redesign area to optimize for Cobot
Option 1	Op2	16	12.4s	0	0			Training for others
Option 2	Cobot	0	5	7s	8	9.5s	Automatic process	3-Grippers system
Option 2	Op1	6	9.5s	0	2	7s	Op1 can check when machines get errors	Redesign area to optimize for Cobot
Option 2	Op2	5	7.2s	0	0		Balancing workloads & CT	Training for others
Option 2	Op3	14	8.4s	0	0			

Figure 50: Cycle Time and Risk comparison on different number of headcounts

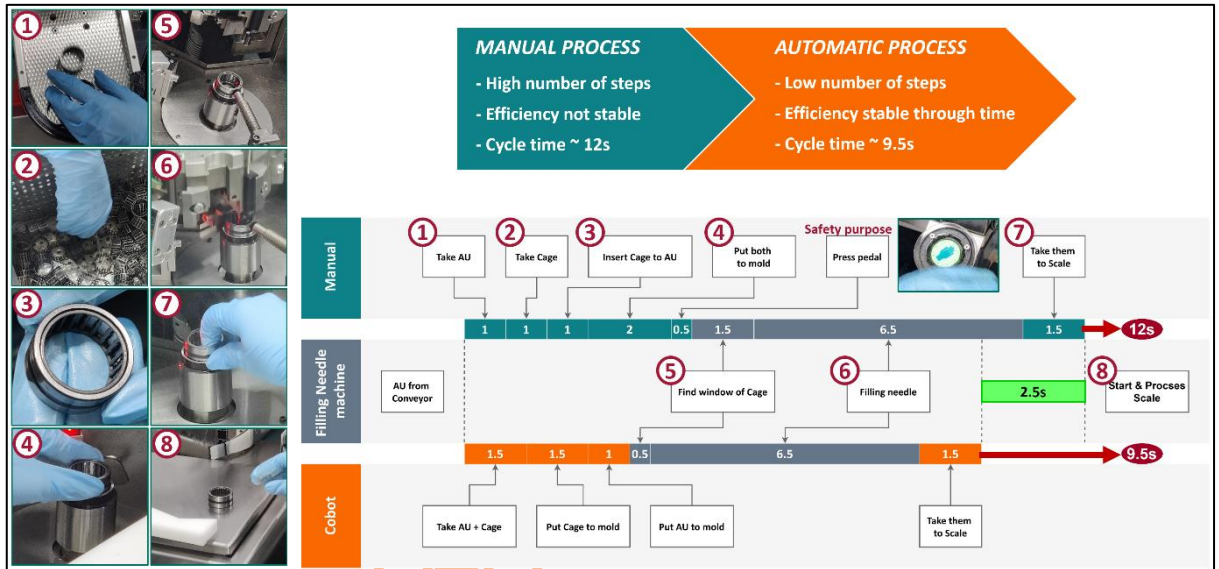


Figure 51: Process improvement at Filling station

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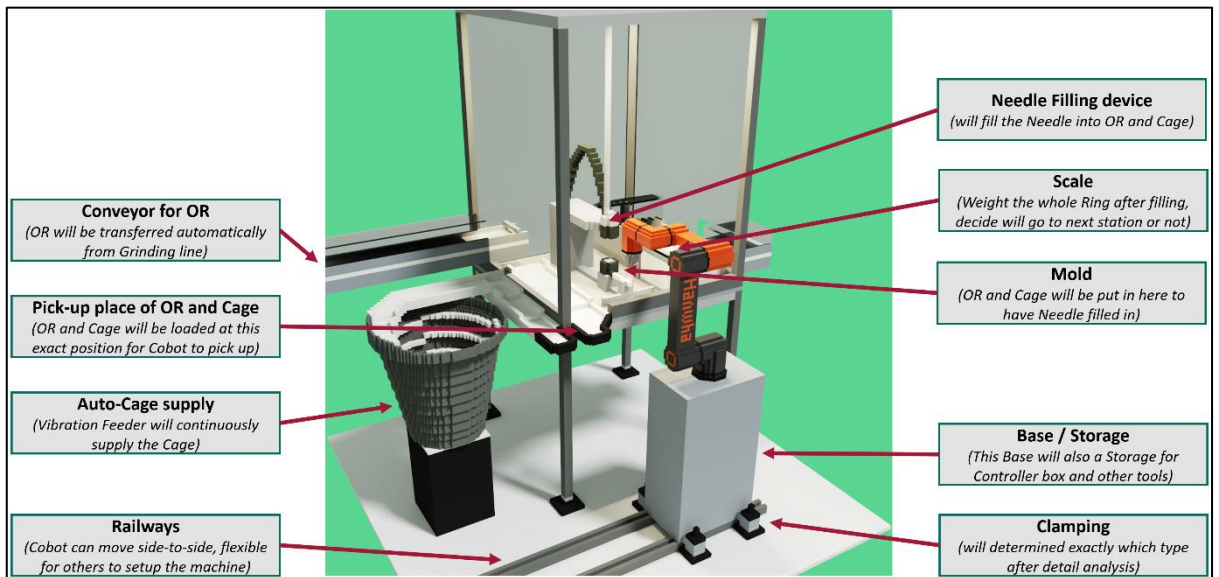


Figure 52: Future integration of Cobot into Filling station

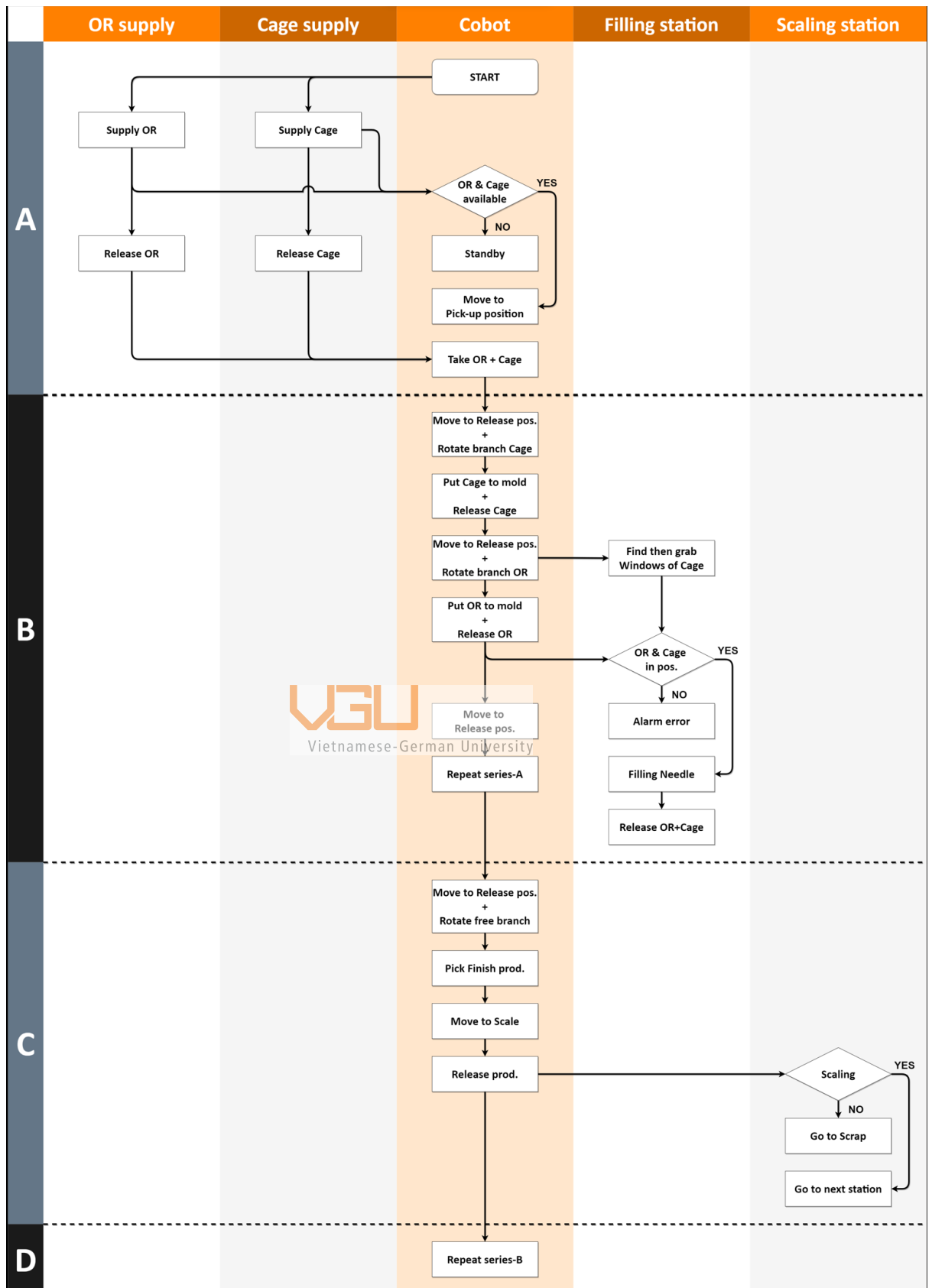


Figure 53: Future swimlane of Filling station (overview)

5.2 Process comparison

After the team has finalized the concept for working with the Cobot, we have presented it to the management team to have a final review and start the Budget phase and Timeline. Following the observation and the tracking Cycle Time record, the downstream process will be the bottleneck after the Cobot is applied successfully, leading to the total output of the Assembly line not increasing. Therefore, we have proposed to keep the same 3 headcount, instead of reducing to 2 headcount, to have the downstream process keep up with the Cobot speed and increase the total output. After discussions, the Production team will support working with the operators to increase the speed of 2 headcounts at the Quality station and Packing station. Another highlight is that the Downtime for changeover will increase due to the Setter needing to set up both the Filling machine and the Cobot at that station. So we have cross-checked with the Planning team regarding the estimation of the maximum Setup per day the Assembly line could have. After increasing the setup time with Cobot, the total Output per day is reduced but still higher than the current situation, due to a significant increase in the Production time and the improvement in the Cycle Time (CT).

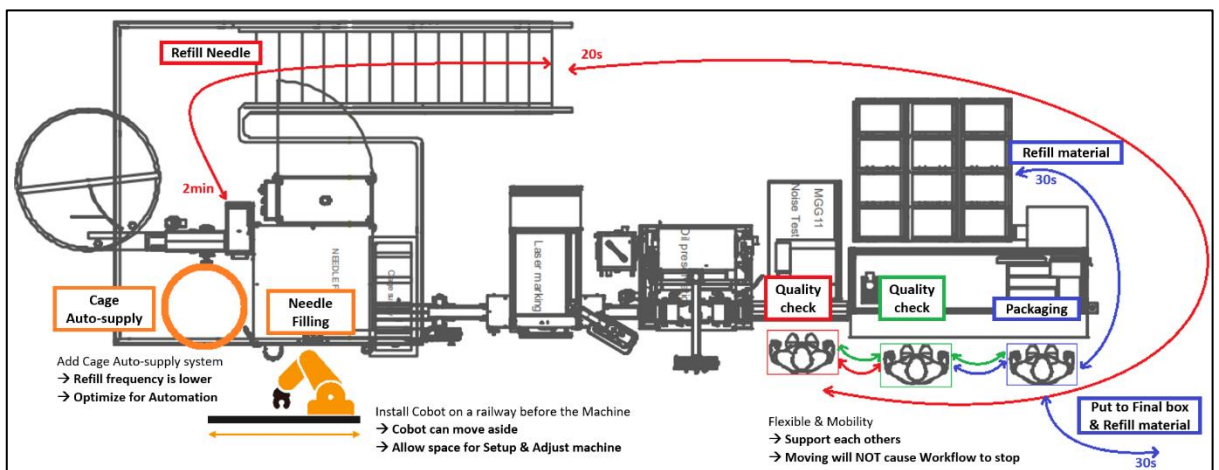


Figure 54: Initial proposal to maximize total Output of NRB Assembly line

Criteria	3 Operators	2 Operators + 1 Cobot	Deviation [%]
Planned Operating time [min]	1,440	1,440	0.0%
Total Headcount required	3	2	-33.3%
Cycle Time [s/pcs]	12.7	9.5	-25.2%
Break time [min]	135	-	-100.0%
Maximum Output [pcs]	6,165	9,095	47.5%
Estimate Setup per day	6	6	0.0%
Downtime per Setup [min]	20	35	75.0%
Output with Setup [pcs]	5,598	7,768	38.8%

Figure 55: Output comparison between before and after integrate with Cobot system

5.3 Setup Testing environment

Following the policies of the company, we have worked with multiple suppliers to build the concept and finalize the chosen following the process from the Purchasing team. The supplier will be in charge of making drawings, manufacturing the support components, and keeping the timeline. For the company side, we will provide the key information to them and work with the machine builder of the Filling station regarding the programming and signal.

After working with the Supplier to finalize the technical concept, some modifications have been made:

- Due to the wide variation in the range of products, we will use 2 bowl feeders for cages, instead of using 1 as the initial concept, based on their outer diameter size to divide.
- The location of the bowl feeders will also move to behind the machines. The Cages will be transported via conveyor and a sensor will be installed to control the operations, ensuring there will be 1 Cage at the pick-up location.
- The original slider of the Outer Rings (OR) will be replaced by a conveyor, installed inside of the Filling machine. This will ensure the speed and fix the position of Outer Rings (OR) at the pick-up location.

- As the initial design, to not block the control panel of the Filling machine on the right side, the railway for Cobot was designed to move from the center to the left side of the Filling machine. But as the layout constraint and to optimize the area for maintenance of the Filling machine, the railway will move the Cobot from the center to far off to the right side, staying behind the control panel of the Filling machine.

Because this is the first Cobot project in the plant and a tight production plan, there are high risks of installing the Cobot to the Filling station immediately. Therefore, the Supplier team is required to set up a simulation area for testing the performance and stability of the system, before installing the new Cobot system to the mass production environment. We have provided the Testing environment directly at the center area in our plant, allowing all the members including the management team to monitor the process and give feedback as well.

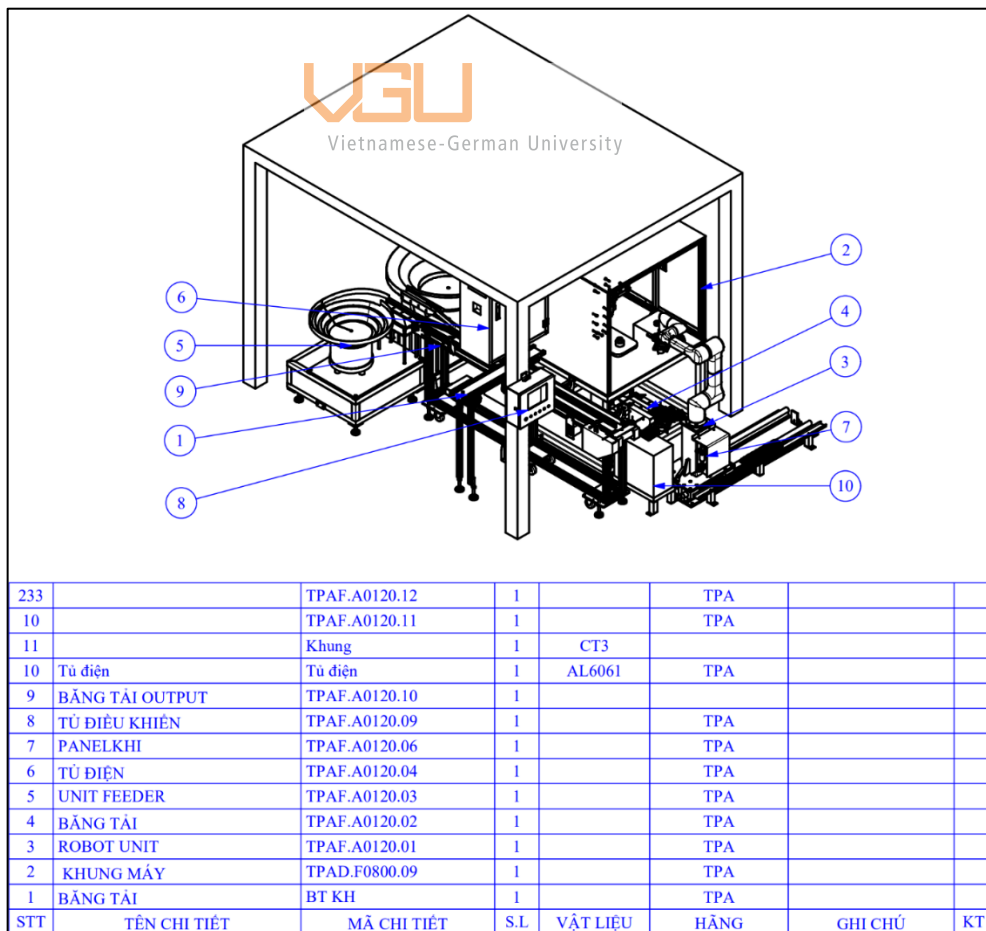


Figure 56: Drawing of overall Filling station after integrate with Cobot system

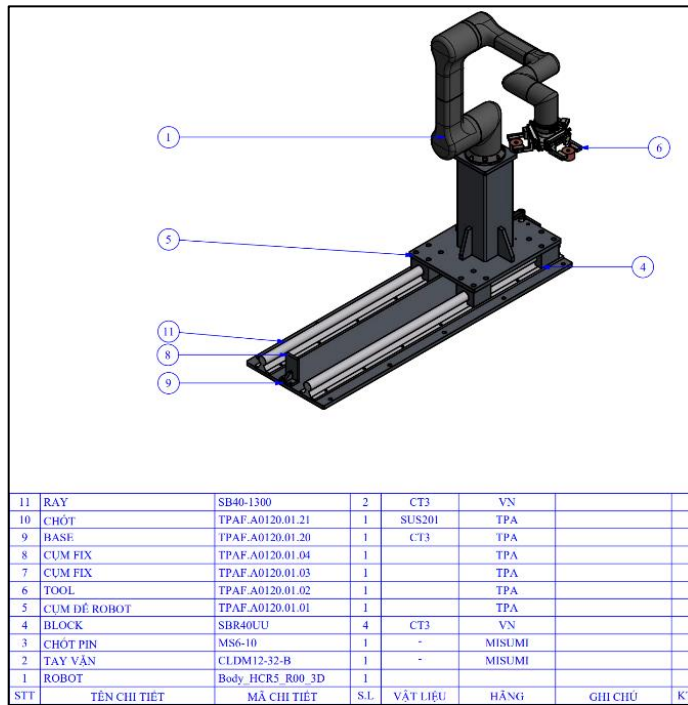


Figure 57: Drawing of Cobot with 3-Gripper system on railway

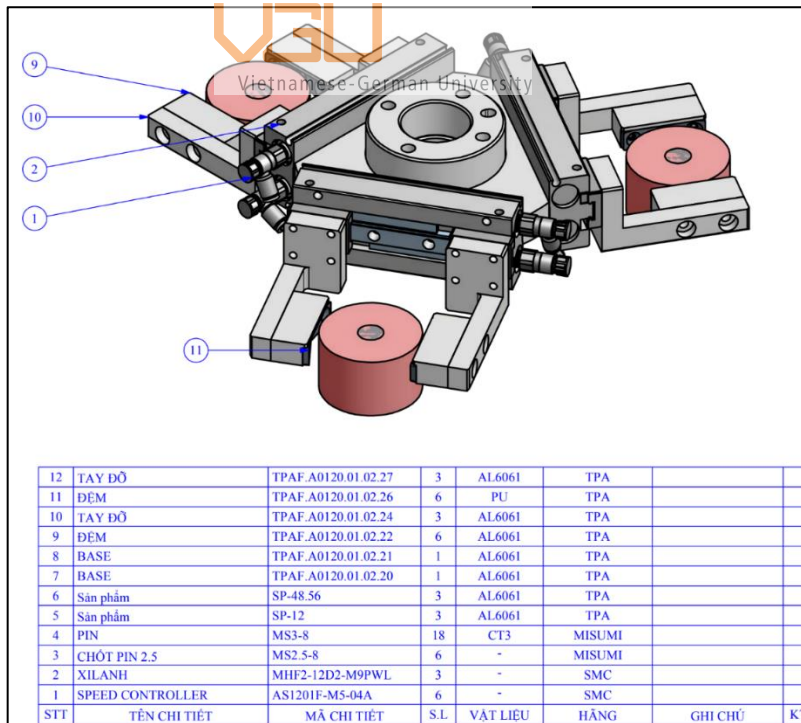


Figure 58: Drawing of 3-Gripper system (after modified)

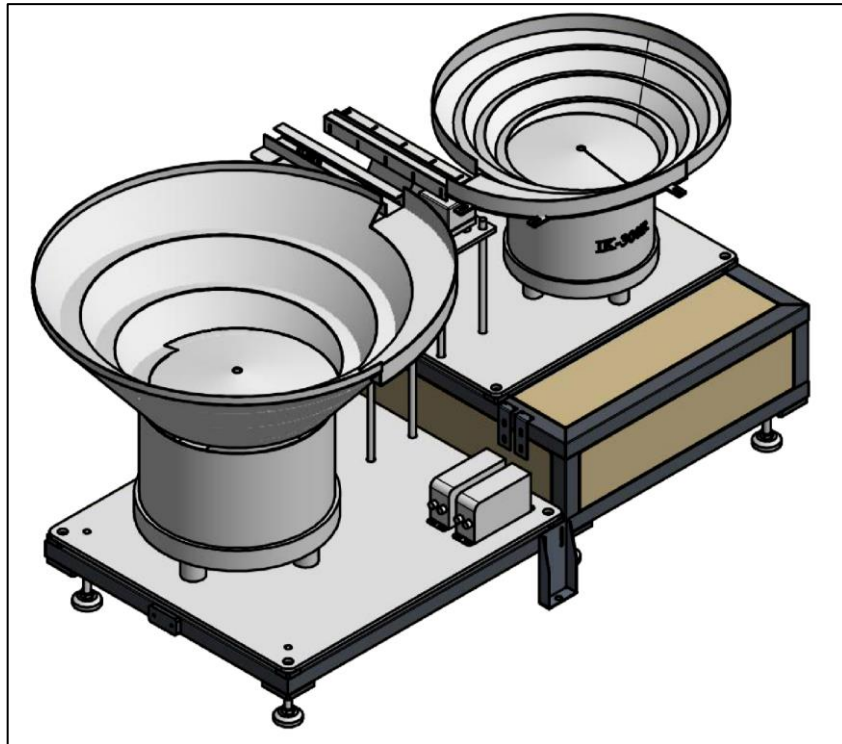


Figure 59: Drawing of Bowl Feeders set

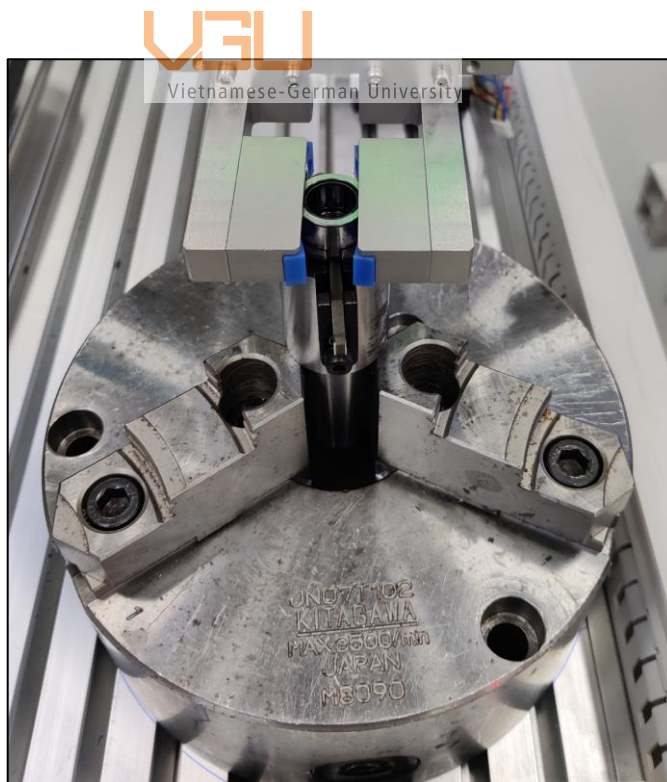


Figure 60: Mold holder for testing



Figure 61: Actual 3-Gripper system (after modified)
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Figure 62: Actual Bowl Feeders set

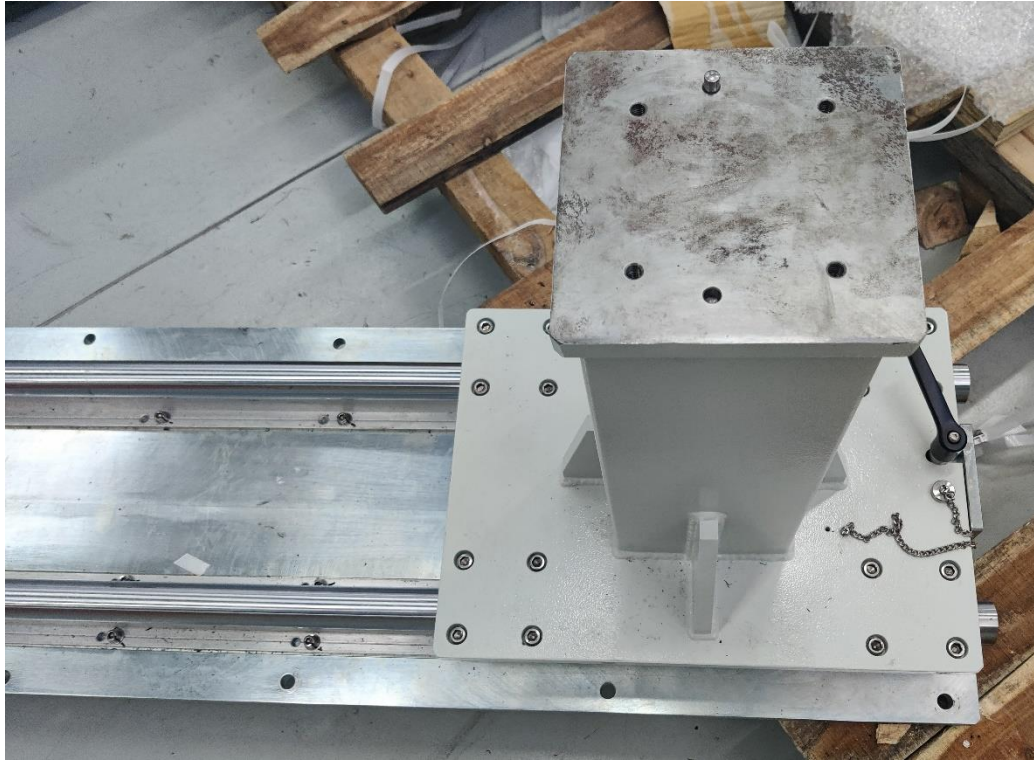


Figure 63: Actual railway for Cobot



Figure 64: Testing area after completely setup

5.4 Finalize model

After finishing setting up the Testing environment, the team has to update the program and carry out some trial runs.

- Step 1: Set up coordinate for the Cobot with tool flange. Then test run the systems, without the product. Focusing stabilize the movement and ensure safety when working near human.
- Step 2: Materials will be put into this phase for testing the process flow. At this phase, the team will focus on the material transportation, the pick and place accuracy of the Cobot and the gripper system, and the signal communication between the sensors from multiple systems.
- Step 3: After all conditions are under control, the Cobot will start to operate in a mass production environment. During step 3, the Cobot system was able to reach stability continuously in the testing period of 4 hours straight. With feedback from the management team, the system has shown promising results and the potential to apply the Cobot in other areas in the plant. But still, the initial defined Target Cycle Time (CT) has not been reached yet.
- Step 4: The entire flow is recorded and analyzed again to find where is the bottleneck to make further optimization.

After recording the videos for analysis, it was found that the time to load the Outer Ring (OR) and the Cage was taking too long. The reason was the process plan to rotate the joints with a wide angle and the total time for the grippers to grab and release was also accumulated a noticeable portion. The design for the Gripper system was reviewed and re-constructed with directions to combine the operation time:

- New system will use the same number of grippers, but replace 1 3-joint gripper with 1 cylindrical gripper.
- The base also changes from a fan-wheel shape into a platform shape.
- The position and functionality of 3 grippers will also be changed. The 2 3-joint gripper will be placed in a straight line with the center coordinate at the head of Cobot, and will perform an inside grab from a vertical axis. The cylindrical gripper will be placed at the head of the Cobot to perform the outside grab from a horizontal axis.

With the modified design, the working process also has changed. The outside 3-joint gripper will pick up the finished product. The Cobot will move forward to the center of the Filling machine until the inside gripper is aligned with the mold. Instead of processing the Outer Ring (OR) and the Cage one by one in a sequence, they will now be placed and released at the same time to the mold. Then, the Cobot will move backward, placing the finished product on the scaling device. With this modified process, the speed of Cobot is increased by reducing the wide angle movements, combined with performing multiple tasks at the same time.

After modifying the systems, we carried out all the tests the same as before to ensure the stability of the new process flow. Then, we have another test run for 4 hours straight with a closed review with the management team. During the testing period, the new system operated better than expected with Cycle Time (CT) reaching 9.3 s/pcs as the fastest and 9.6 s/pcs as the slowest.

With these results, the teams have decided to execute the next phase to integrate the Cobot system into the Filling station for mass production.

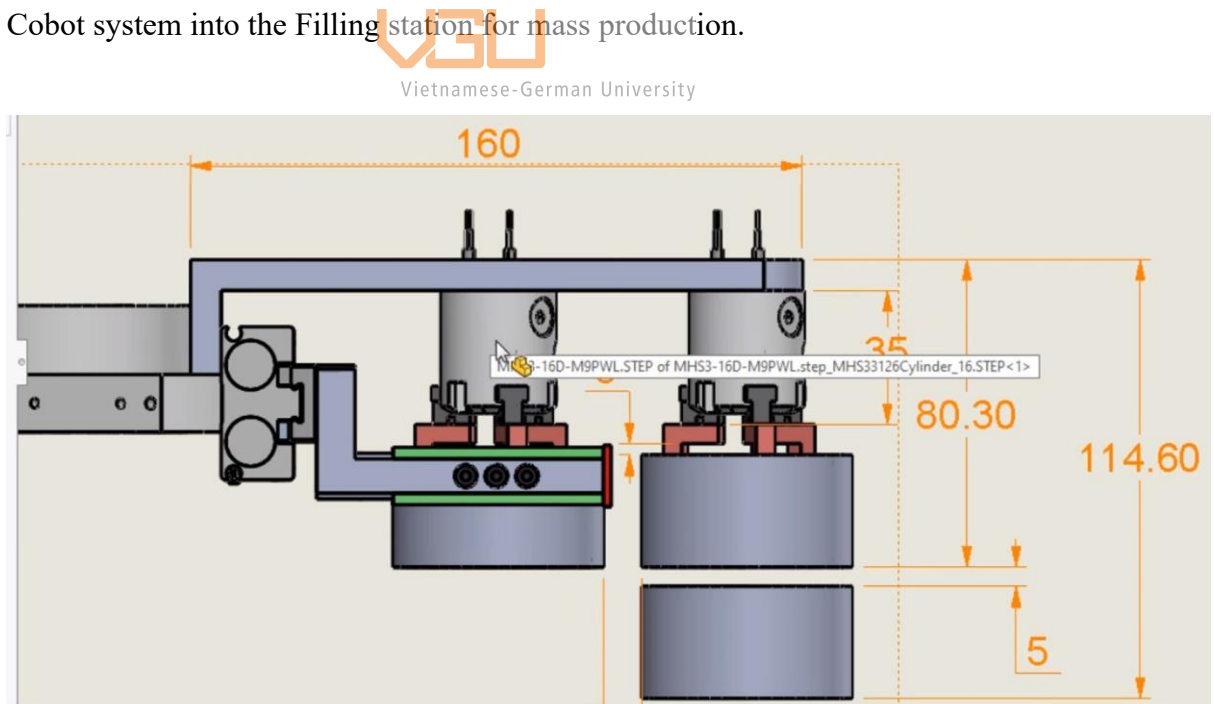


Figure 65: Drawing of New Gripper system

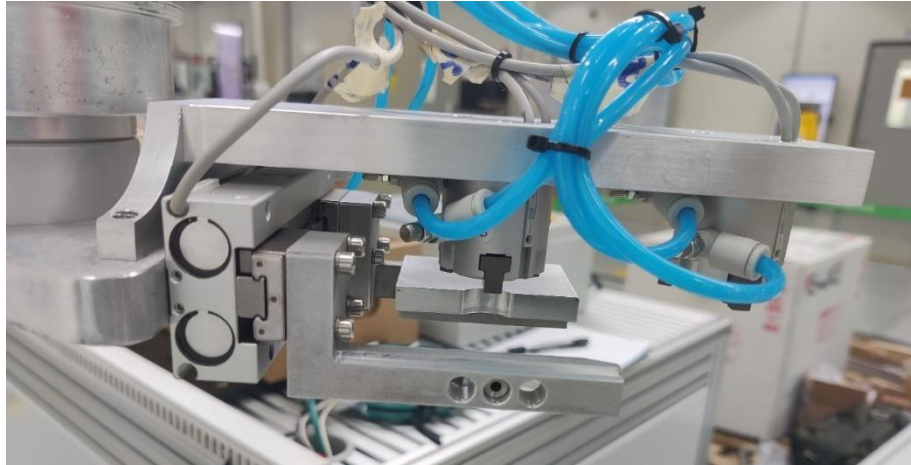


Figure 66: Actual New Gripper system



Figure 67: Quick replacement by using spring and ball



Figure 68: Flat finger to ensure the fitness of the Cage

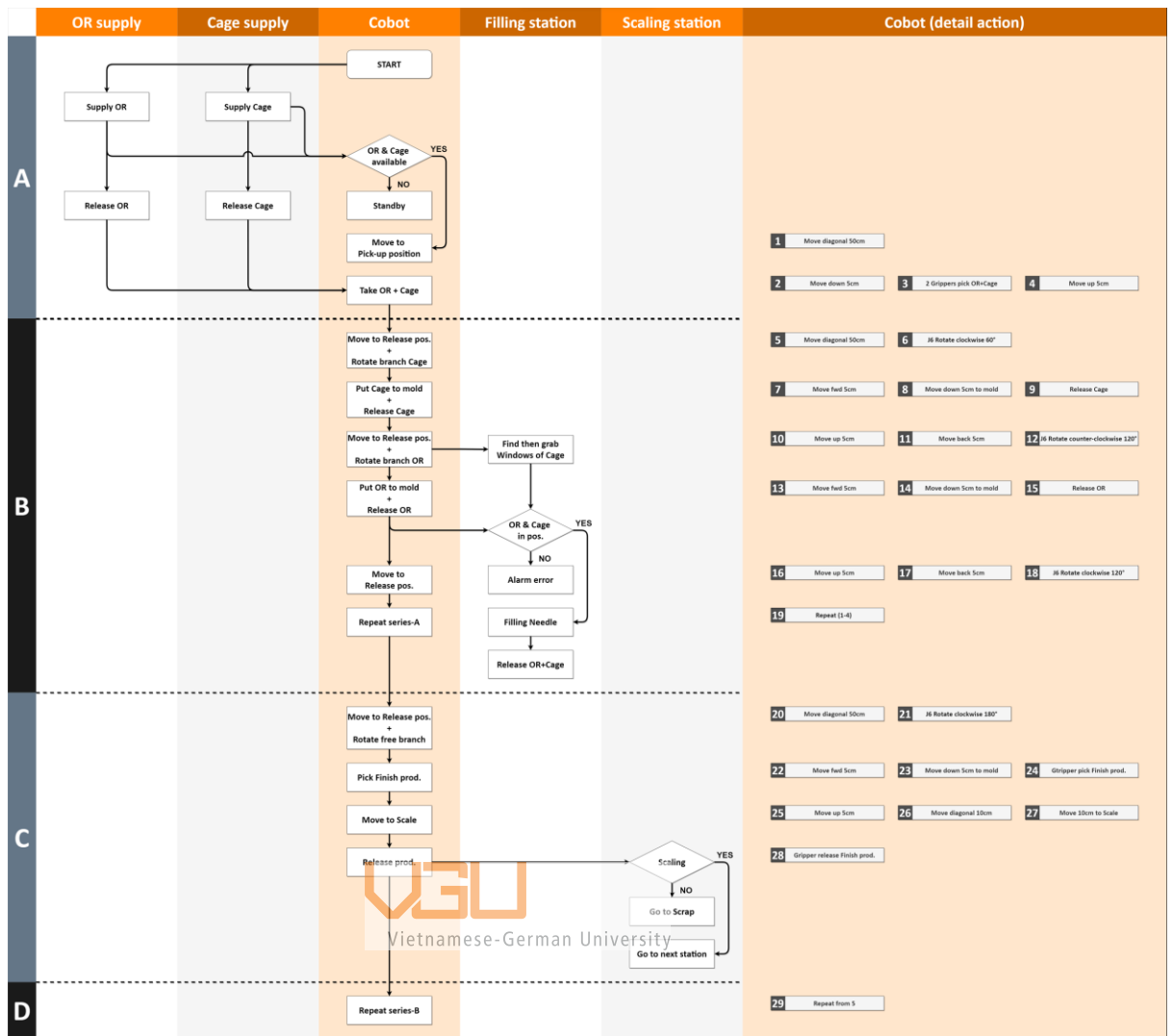


Figure 69: Final swimlane at Filling station (Detail action for Cobot)

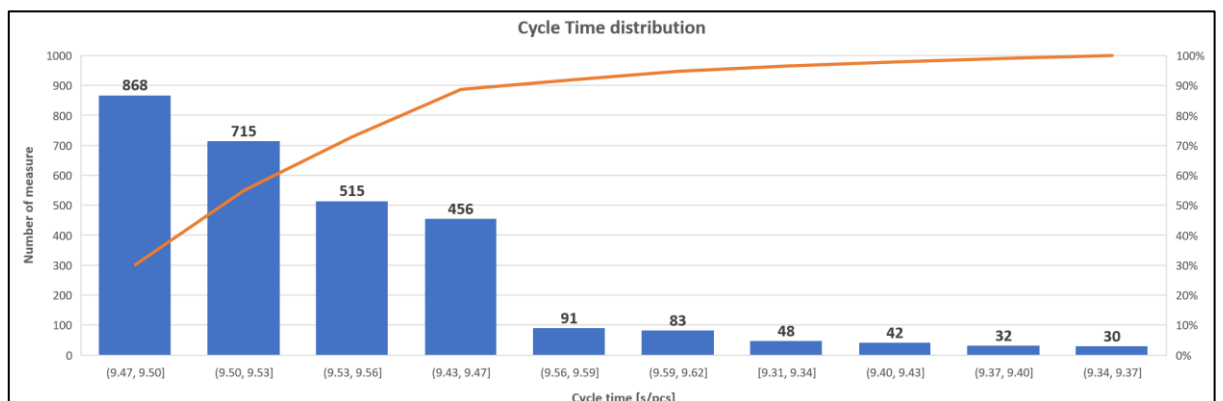


Figure 70: Cycle Time distribution in 4-hour period

6. Integration phase

6.1 Installation

As the time was filled with the production order, we will plan to focus on integrating the Cobot system in Shift 1 (6 AM to 2 PM) and the normal operation will resume at Shift 2 (2 PM to 10 PM) and Shift 3 (10 PM to 6 AM) until the whole system is operate stable. To save more time for production, hardware systems that do not interfere with human operators will be installed in advance.

- Step 1: The Cobot system will be disassembled at the Testing area and transported to free space located in front of the Filling station in the Assembly line.
- Step 2: The bowl feeders, the conveyors for the Cages, and the electrical cabinet will be installed during normal production. The above hardware is located in positions that do not interrupt the operator when they are working.
- Step 3: From this point, the Production will need to stop at Shift 1 (6 AM to 2 PM) to have space for installation and setup of the program. Now the remaining hardware (including the Cobot, the railways, the control pad, and the conveyor for Outer Rings) will be installed. After they are finished, the remaining support systems (electrical wiring, sensors, air compressors) will continue to connect with other components and complete the whole system.
- Step 4: After all the hardware has been set up. The Maintenance team will support writing a new operation mode to work with the Cobot for the Filling machine. This newly created program will not overwrite the existing mode that works with human operators. This is crucial to protect the original program and have the ability to have human operators work in case the Cobot has issues. The signal tests were carried out to simulate multiple scenarios that have a high potential to occur. The main objective was to have both systems, the Cobot and Filling machine, stop functioning immediately if either of them faced an issue during mass operation. This is a top priority to ensure the safety of the Filling machine, as there are no backups and the appropriate skill with experience to fix the damaged parts.

Only after ensuring that the whole system can operate properly together, the Cobot will start to run the program for trial test. At beginning cycles, the general speed control will be limited to only 40% to review the signal and the trajectory. Due to differences between the Testing area and the Filling station, the coordinate of Cobot will need to be reviewed and updated to match the current station.



Figure 71: Transport Cobot system to NRB Assembly line



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Figure 72: Hardwares was installed in advance

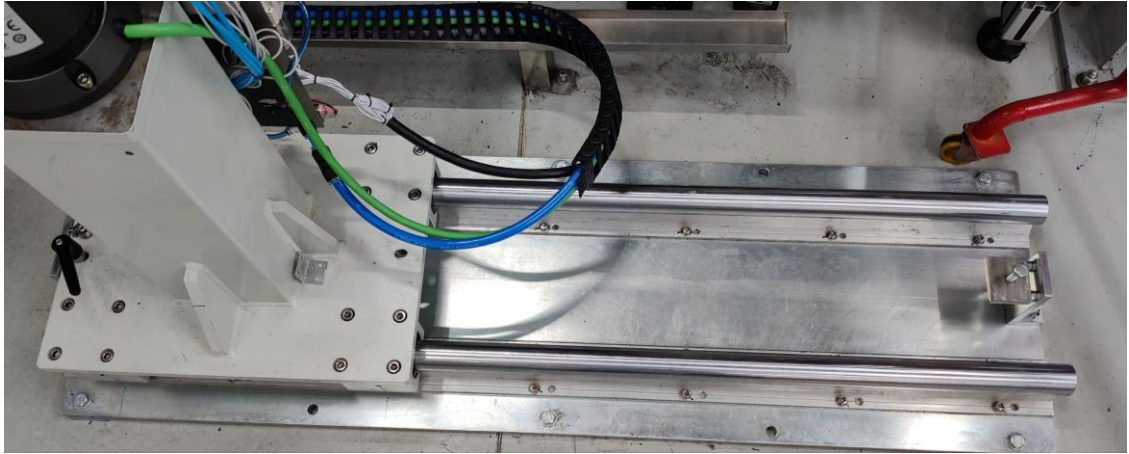


Figure 73: Install railway with Cobot in front of Filling machine



Figure 74: Install Conveyor for Outer Ring

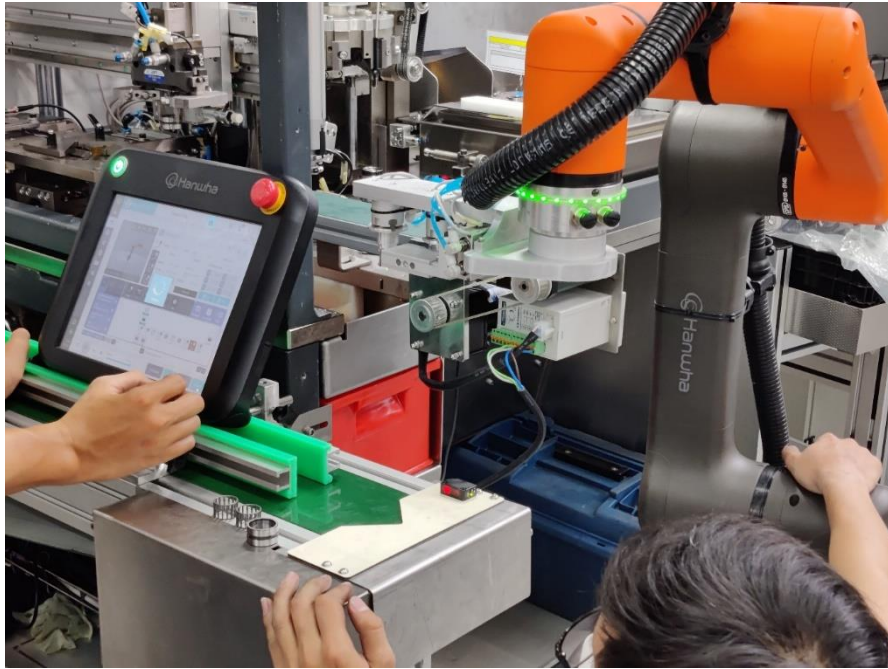


Figure 75: Setup and Test program

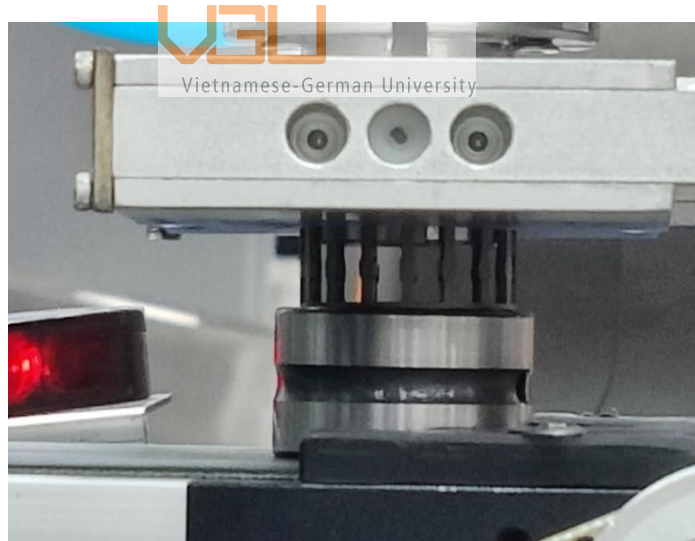


Figure 76: Accuracy test and update coordinate

6.2 Synchronization, Stabilization

After all the functionality and the trajectory have been tested step by step ensuring the accuracy of each placement, the Cobot will move to the automation sequence to operate with the Filling station as one system.

The initial cycles had no issues and have performed as planned. However, since the stability of the Filling machine is not consistent, more and more cycles need to have human operators interfere and solve the issues manually. This is a major problem for the project as it will impact the initial target of Production Time and need an additional human operator to check and fix the issues. As the fact that the root cause was the stability of the Filling machine, not caused by Cobot, the Technologist team with the Maintenance team have put their effort into working together to improve the stability of the Filling machine. Parallel to this activity, the process was under review to find any potential improvements that could be made to avoid any interruption that can occur during mass production.

One of the risks was the Outer Ring (OR) could be flipped when dropped onto the conveyor. This is a new risk compared to the human operator because they will use their hands to take it and combine it with the Cage outside of the machine. But with Cobot, all the materials are required to be positioned correctly. Due to the constraints of components of the machine, the location of them cannot be changed. Therefore, a slider has been installed, connecting the drop location to the conveyor. This slider will support the Outer Rings (OR) to be positioned correctly by reducing the speed with a better contact angle to the conveyor. With this additional slider, no Outer Rings were flipped during the remaining trial run afterward.

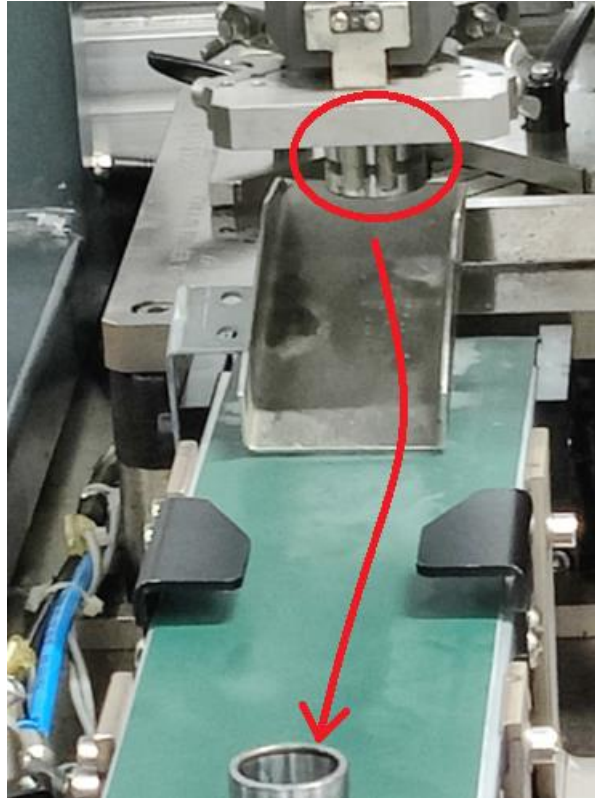


Figure 77: Slider to reduce flipping risk of Outer Ring

6.3 Final Results



After the stability of the Filling machine has improved, the system has gone through several days of trial runs with Cobot. During the automatic operation, with the teams taking turns to observe the process, the Cobot performed as expected. The Actual Cycle Time (CT) was able to reach the defined target of 9.5 s/pcs for standard types. The Production time also reached the maximum time as the production plan. The reason it was not able to operate full-time was the change in production order and the need to set up between different items.

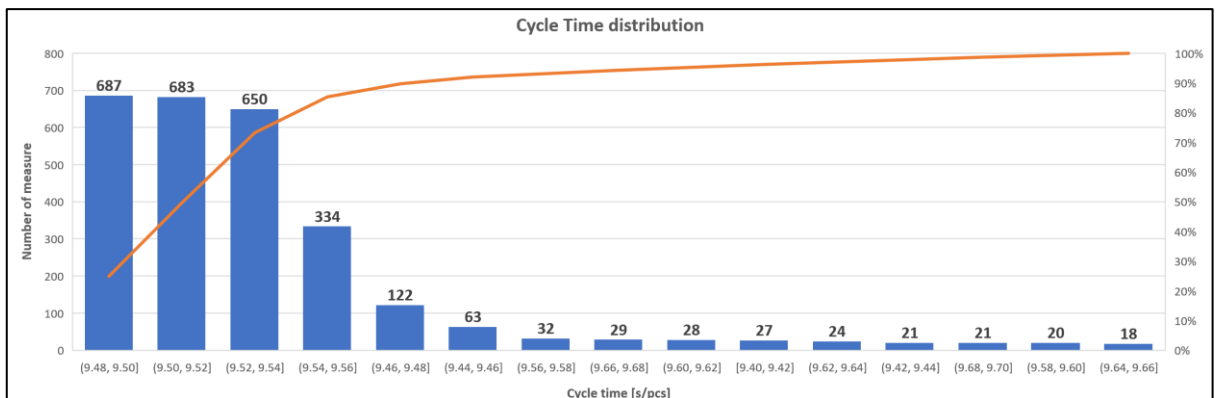


Figure 78: Cycle Time distribution in 8-hour period

6.4 Handover for mass production

Following the acceptance process stated in the contract, the Supplier team is required to be on-site observing the operation until the Cobot system can run through all the current product types. Hence, they will work with relevant teams, including the Maintenance team and Technologist team, to prepare work instructions for the Cobot based on the standards of the plant.

The Production team has dedicated their members to the training of how to operate the Cobot. This was the chance for them to get more knowledge on the new technology, also they will be in charge of this system after the project is handed over. During this period, the project not only gained attention but also received valuable feedback from the team on what could be the issues during the mass production and how to further optimize the entire workflow.

After the new system has run through all the product types and the Production team has gained sufficient experience, the Cobot system has been released for automatic operation into mass production. But as the concerned teams, a physical safety fence still needs to be applied until the operator gets used to the working space of the Cobot.

7. Conclusion

Based on the accomplishment of this project, the Cobots will be developed to be a fitting part of the production industry. Depending on the end user of these products, the development of cobot will go in different directions.

The development of Cobot will focus more on simple tasks instead of making it work on complicated tasks. It can be used to support employees and acts as a replacement for humans in some cases such as a peak production time that does not extend so long, for example, if the peak time is around 1 month, it is better to use cobot to support humans instead of hiring new employees for that time.

Cobot is also a user-friendly and flexible machine, which can be installed and start to work in a short time. The program to either control or set new actions on the cobot is also quite simple. It is also able to work in different departments due to being easy to install and change the program.



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