Indian Institute of Technology, Madras

ME3302

Automation in Manufacturing

Covid Vaccination Automation

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1 INTRODUCTION

The goal of this project is to automate the Covid vaccination process that is being done currently in a manual way. This is a very interesting idea that can be of potential use to both manufacturing and medical industries.

In the present manual process, there are many challenges. The speed of vaccination is a prime concern. Although this is also related to the production of vaccines, the delay in administering them through humans also adds to the trouble and this can be sped up by automation. Also, automation immensely reduces the human-to-human interaction and this may provide reduced risk of exposure to health care employees, thus enabling them to focus on more important things.

Industrial Robots are the advanced tools in automation. They are known to perform repetitive jobs better than humans, if properly programmed. So, we use robots in this. Our solution for automation of this process involves establishment of a factory like setting, with proper facilities of transporting humans, vaccine bottles, syringes and wastage.

The basic layout is drawn and explained properly. Sketches are drawn wherever needed. The types of robots needed, their architecture, basic functions, design and sensor issues are also analyzed. Parts like conveyor belts, robot arms and end-grippers are described with their **sketches/CAD/Fusion 360 designs** attached wherever required. **We also attached them separately in appendix, to make the accessibility easier.** These are also attached for steps of some processes like injection of vaccine, syringe filling etc. The ladder logic and the factory metrics are also evaluated.

We have followed simple approaches in design, sensor issues, end-effector choices, etc. The idea is to reduce complexity in the ideas for effective implementation and also for cost reduction.

2 One vs Many

Vaccination of 1000's of people poses many challenges when compared to single person vaccination.

Single Person Vaccination:

1. Since it involves only one person, there is no issue of time taken for vaccination, because others are not waiting for their turn.

2. The cushion (s)he placed his hand on, and the chair (s)he seated on need not be sanitised afterwards, because there are no others.

3. We need not worry about social distancing to be maintained since there is only one person.

4. There is no issue of transportation because the dose needed for him can be bought manually and no automation and factory setup is needed virtually.

Mass Vaccination:

1. It involves many at a time. So, the time taken for eac hperson should be sped up as there will be others waiting in line behind.

2. The cushion and chair need to be sanitised after every person's turn because there is a risk of virus spread through contact.

3. Social distancing protocols need to be maintained strictly.

4. Transportation in efficient manner is a big issue because stalls are needed to be set up.

3 Product Quantity vs Variety

Here, there are a large quantity of vaccine bottles and syringes to be transported. So, the quantity is large. Also, the variety is small, because pretty much every vaccine type is manufactured in a bottle of similar shape and sizes. So, the only significant variety is that, there are two kinds of things to be transported i.e. Vaccine bottles and syringes. So we have high quantity (Q) and low variety (P), which again supports the choice of process layout.

4 Factory Layout

There are many tasks to be automated, but we will start with designing a basic framework for the factory layout as shown below.

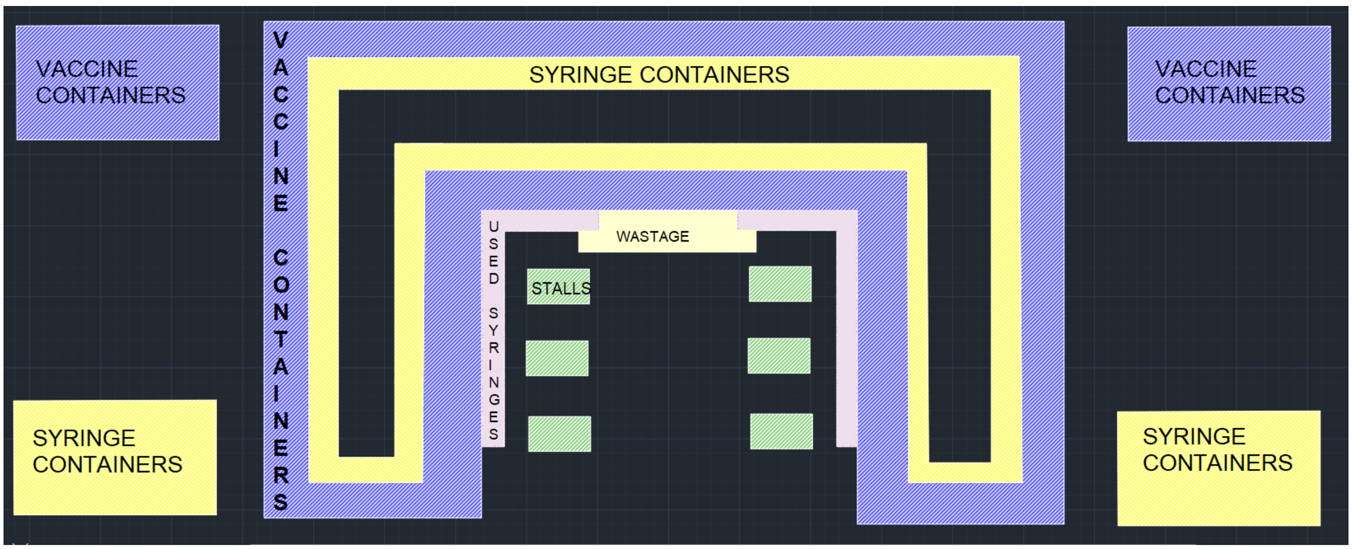


Figure 1: The Factory Layout.

We use **Process Layout**. The basic layout is as shown in above figure 1. We used this layout because it is beneficial here to group the machines according to the type of their operation than the sequence. Also, we have standardised products (vaccines and syringes) and we should transport them. Eventhough the process layout takes more time and cost for transportation, it is chosen here to reduce the moment of robots, as mass vaccination is being done here and we want the robots and other machines to move minimally. Also, we want to achieve **100 percent** automation, and if we use fixed position layout then we need more manual agents to supervise, and navigate the robots properly.

We have 3 conveyor belts- One for carrying vaccine bottle containers (in blue colour), one for carrying syringe containers (yellow conveyor) and one to dispose off the used syringes (the pink conveyor).

The basic structure of factory is explained as follows. At first, we maintain stocks of vaccine bottles and syringe bottles in containers or crates, in the units that are shown in the figure, adjacent to the conveyors. These are like the storage units and these are filled with the respective vaccine or syringe crates. The number of crates is ensured such that they are sufficient for that particular day. It is to be noted that, since the size of these storage units is irrelevant to the conveyors, they can be increased, but the shopfloor area will be increased. These are filled at the beginning of the day's shift at once with the available stock and they will be refilled only on the next day's morning.

There are robots that load these crates from storage units onto the respective conveyors and unload empty crates from conveyors to the units.

Stalls can be seen inside the conveyors. These are the ones in which vaccination occurs. Every stall has 2 openings, from front and back, perpendicular to the conveyors. Each stall has 2 robots, one for picking up syringes and There is also a conveyor connecting the back of the stalls to dispose off the used syringes into the wastage disposal area.

In every stall, we have 3 robots and 5 fixed structures. The **fixed structures** are **Arm placement frames** for left and right arms (as per the person's wish), **Vaccine bottle platform**, **Syringe platform** and **Garbage bin**.

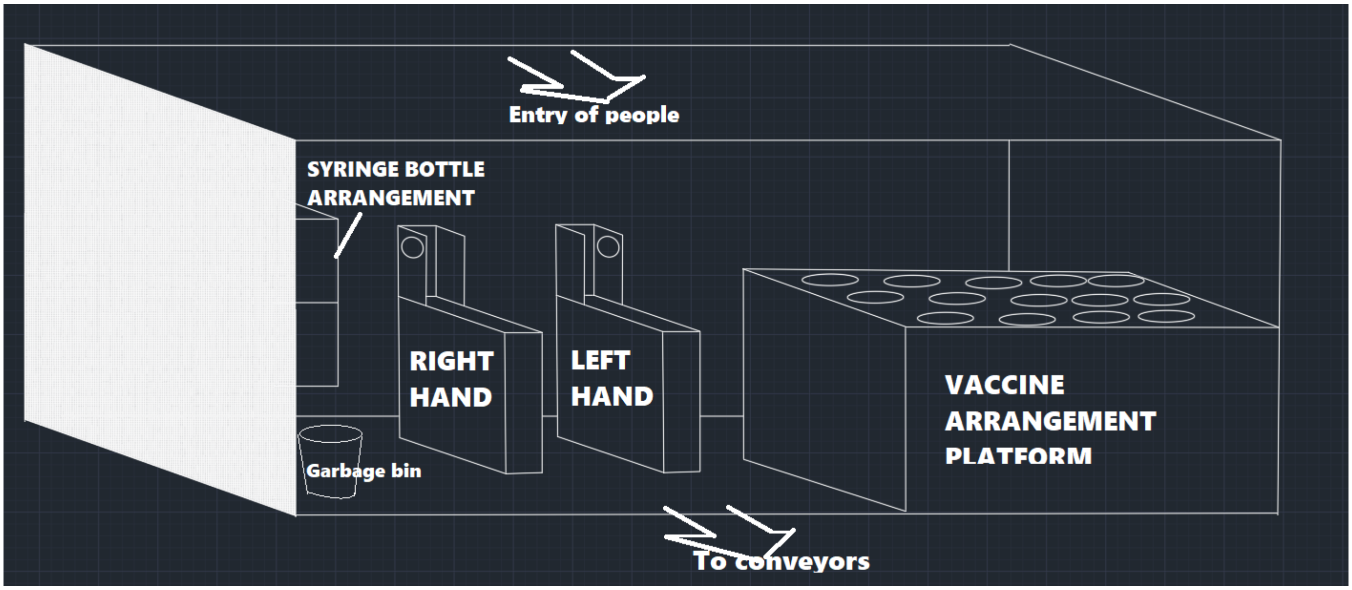


Figure 2: The components of a stall, without the robots.

As shown in in fig:1, persons enter the stall through their front. The back of the stall is also open, through which the contents of conveyor belts are accessed by the robots in the stall. In each stall, the following operations are done: One robot **R1** takes the vaccine bottles from each crate on the conveyor and arranges them into the slots in the vaccine bottle platform. The robot **R1a** unloads the syringe crate from the conveyor and places them in syringe platform. Now, Another robot **R2** will take the syringe, align it needle down, inject the vaccine into it from a vaccine bottle in the platform and gives it to the person. The person, according to his/her preference, chooses either left arm or right arm to be vaccinated on and places the arm into the fixed arm placing structure. The hole in the structure helps R2 to locate the area of injection. Then it injects the vaccine into the person's upper arm and then dumps the syringe used into the garbage bin. Every person is given a small cotton piece prior to their entry into the stall and they may use these immediately after the injection.

5 Manual vs Automated

This project aims for 100% automation.The different tasks in their proper sequence and their nature are discussed below:

1. **Transport of people - Manual**:

The people will be seated/waited in a waiting area after their entry into the factory. Outside each stall, we have some markings on it's entry lane, say 10 at a time, separated by a distance. A fixed no. of people (say 10 at a time) will wait outside each stall, maintaining social distancing. The people will walk to the stalls from the waiting area when one of the places get vacated. This choice is due to the fact that most people are able to walk the short distance till their stall from the waiting place and also to reduce the cost of automation.

2. **Filling of stock of vaccines and syringes - Manual/Automated**:

At the beginning of each day's shift, the vaccine and syringe storage units need to be filled with sufficient stock for the day. The vaccine bottles and syringes are assumed to be arrived in crates (shown in the Appendix). This is done either by robos or by manual filling of stocks at the beginning of each day.

3. **Transport of vaccines to stalls - Automated**:

At each vaccine storage unit, there is a robot **R3**, that will hold and lift a crate from the vaccine storage unit, place it on the vaccine conveyor belt and supply it to the stalls.

4. **Transport of syringes to stalls - Automated**:

At each syringe storage unit, there is a robot **R4**, that will hold and lift a crate from the syringe storage unit, place it on the syringe conveyor belt and supply it to the stalls. The syringes are assumed to be along with their needles fitted.

5. **Arranging of vaccine bottles in the vaccine platform - Automated**:

The vaccine crates will come to each stall and stop for a while. In each stall, the robot R1 will take individual vaccine bottles from the crate, and arrange it in the slots of the platform. This is done at once for all stalls before the start of the day and also, during the vaccination process to save time.

6. **Arranging of syringe crates into the syringe platform - Automated**:

This involves lifting the syringe crate as a whole from the syringe conveyor and placing it in a cupboard kind of a platform inside the stall. It is done by R1a. This task is also performed once for all stalls till the platform in every stall is filled and later, it is performed in intermediate steps to speed up the process.

7. **Removing of empty syringe crates from the stalls - Automated**:

After all the syringes in a crate are used up and there is a need for more, the empty crate is placed on the syringe conveyor belt again. This will be collected by the robot R4 and will be placed in the vaccine storage unit.

8. **Syringe holding and aligning - Automated**:

The syringes in the syringe crate are dumped as a bunch, as opposed to the vaccine crate in which bottles are neatly arranged. So, first a syringe will be picked up by one arm of R2 and it is aligned and placed with needle down into another arm of R2 by this arm.

9. **Loading of vaccine into the syringe - Automated**:

After the previous step, the arm of R2 with syringe in needle down position will be aligned to the vaccine bottle and another arm will pull the piston to load the vaccine into the barrel. After this, the syringe will be smoothly raised.

10. **Administering the vaccine - Automated**:

The robot R2 will administer the vaccine by locating the arm holder in which the person placed his/her arms. It will locate the area to be vaccinated (as explained later in **Automation section**) and do it.

11. **Wastage Handling - Automated**:

The used syringe with needle after the previous step will be disposed into the garbage bin by R2. When this bin gets filled after vaccinating more persons, R1a will hold it and dump its contents on the conveyor belt that is labelled as **Used Syringes**. It will take these and dump in the wastage area.

12. **Signalling - Automated**: After the vaccination is done for a person, a signal will be sounded and this provides an indication for another person from waiting area to join the queue before the stall.

Note that almost all the tasks are automated. This is done because as said in the introduction, the goal is to harness the power of robots as much as possible. But, whenever the cost is unnecessary, we shift to manual mode. Here, the only tasks that are done manually are transport of persons to and from the stalls and possibly a supervisor for the entire process. (This is common in every automation, so this may not be considered as manual process.)

6 Automation Details

In this section, we provide the full details of processes, along with CAD sketches and schematic drawings. Also, the questions asked in the project description are all answered in various subsections.

6.1 Levels of Automation

1. **Level - 1**:

This is about the sub system level. Here, the robots we use are R1, R1a, R2, R3 and R4.

R3 and R4 are identical in structure and motion. They are fixed without floor moment at the vaccine and syringe storage blocks respectively. They have 4 axis motion, 2 arms each but both connected rigidly with separation equal to the crate length.

R1a has similar structure but with floor moment. It takes syringe crates and arranges them in compartment. R1 has floor moment and it has 5 axis motion. It grips the vaccine bottles and places in vaccine compartment.

R2 has 6 axes motion, 2 arms. It has floor moment. This is the most complicated robot because it has to perform injection loading, administering and syringe disposal.

2. **Level - 2**:

This is machine level automation. It involves motion and positioning of machines.

Here, the robots R3 and R4 should move up, down and sideways and their arms should move into and outside the storage units to hold crates and place them onto containers. The position of placement on containers is to be perfectly controlled.

R1a has also similar setup needed. R1 should properly hold the vaccine bottles and place them in the slots correctly. R1a should hold and dump the garbage bin properly.

R2 should have floor moment. It will move to the syringe crates stored **in the stall**, and hold a syringe with an arm. Another arm properly aligns it. Later, it moves to the vaccine compartment, loads the vaccine. Then it moves to the person and injects it, later it reaches the garbage bin and dumps it. This sequence of motions needs to be controlled properly.

3. **Level - 3**:

This is Cellular level. Here, every stall can be defined as a cell. This involves motion of parts between cells. Here is where we use Conveyors.

There are 4 Conveyors used, belonging to 2 types. The 2 conveyors for Vaccine containers and syringe containers respectively are **Recirculating roller belt conveyors** that complete the loop, rotating anti-clockwise. These supply the filled crates to the stalls and bring back empty crates from them. The Conveyors for wastage disposal are **Belt conveyors** that move single direction, towards the wastage disposal zone.

4. **Level - 4**:

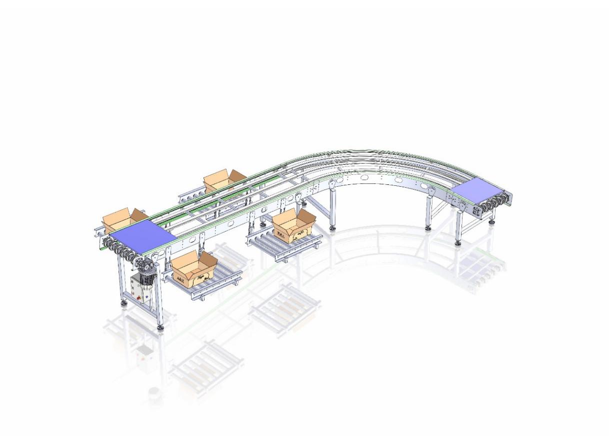
This is the Factory level. The entire layout that is shown in figure 1 can be considered as a factory floor. This level involves filling of stock in the storage units and moment between them. Conveyors are used as explained. Also, people move from waiting area to the stalls and comeback.

5. **Level - 5**:

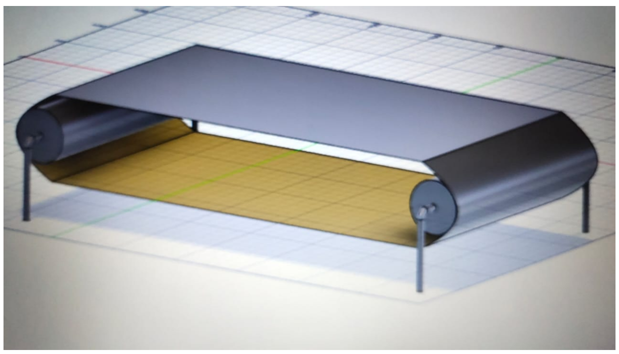
This is the Enterprise level. We can make multiple floors of the layout shown and make it as a full-scale enterprise.

6.2 Transport of injections and vaccines

The Conveyors are as shown below:



(a) To deliver vaccine and syringe crates

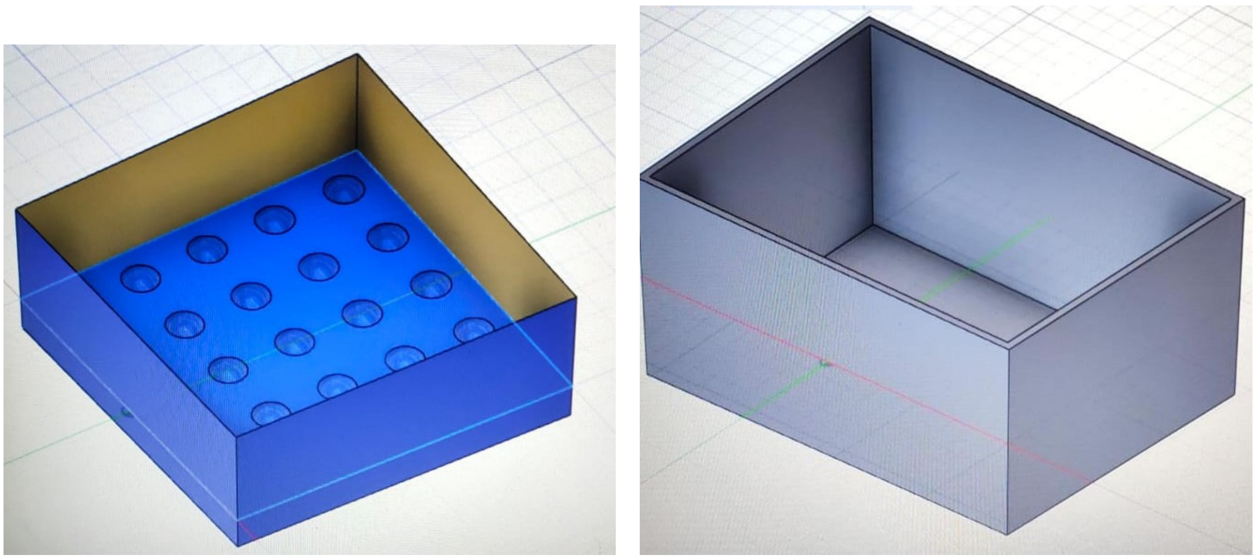


(b) To dispose used syringes

Figure 3: Conveyor designs and schematics

The conveyor shown in (a) is for both vaccine and syringe crate supply.It has the material only on top side. It just moves in loop fashion, supplying and taking crates from and to the stalls. The other conveyors are separately atttached to the disposal area, and these are belt conveyors.

The crate designs for transport of vaccines and syringes are as follows:



(a) Crate for Vaccine bottles.

(b) Crate of Syringes

Figure 4: Crate designs

The vaccine bottles crate has slots at the bottom, which hold the bottles safely since they are made of glass or delicate materials. Each crate above contains 20 bottles. **Each bottle has 5ml**, which is sufficent for one dose for one person (Either Dose 1 or Dose 2). Now, we plan to vaccinate 2000 people, 1 dose per person, per stall, per day. So, we need 200 bottles for 1 stall or 10 crates per 1 stall.

The vaccine platform inside the stall has 40 slots. So, It needs refilling for 5 times a day.

The time for injecting of 1ml is 10 seconds as per standard injection protocols. So, we take 5 seconds per person and if we add 10 more seconds to the person's entry, exit from the tall, we have 15 seconds per person. This requires 30000 seconds for vaccinating 2000 people per stall. So,we can say that the work time should be 9 hours nearly, including allowance for idle time of the robots, the conveyor belts and the wastage handling.

So, we need 10 crates per 8 hours or 1 crate per 48 minutes per stall. Since there are six stalls, the conveyor belt should have 6 crates per 48 minutes or one crate per 8 minutes on it. This is the rate of arrival of vaccines.

The rates of movement of syringes are simpler. Each syringe crate can easily have 100 syringes, since the syringes are randomly placed, along with their needle. Now, we need 20 crates of syringes at once, in its worktime of 8 hours. So, we get 1 syringe crate per 24 minutes.

The disposal has no relevance with rate. The wastage disposal conveyor has a grip that holds the dumped syringes and this conveyor can be running at normal speed, say 65 feet per minute.

6.3 Transport of People

One of the main aims in this is to reduce the cost also. Since the end grippers needed further and the conveyor belts take considerable budget, we want to reduce the unnecessary machines. For this, we ask the people to wait initially in a waiting area with social distancing. We place **Ultrasonic sensors** inside the stall and outside, that detects the presence of people, and when there is a vacancy in the queue before the stall,the sensor signals to be ready to get up. We draw separate inlet-exit routes to and from the stall to reduce the chaos i.e machine-person and person-person collisions.

6.4 Robots, sensors, end-grippers and process steps

1. **R1**: R1 is present in the stalls. Its main duty is to collect vaccine bottles one by one from a vaccine crate stopped on the conveyor belt, and places them into the vaccine bottle platform.

It is a 5 axis motion robot. It has floor moment. It is of the configuration RRR:T. The end gripper is impactive. It can translate along the arm for holding of vaccine bottles and dropping them in the slots. The figure below shows the sketch of robot.

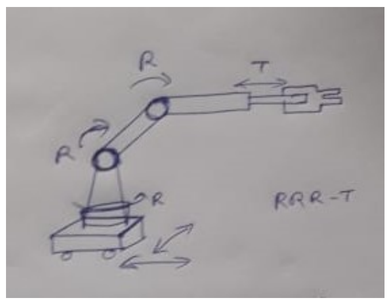
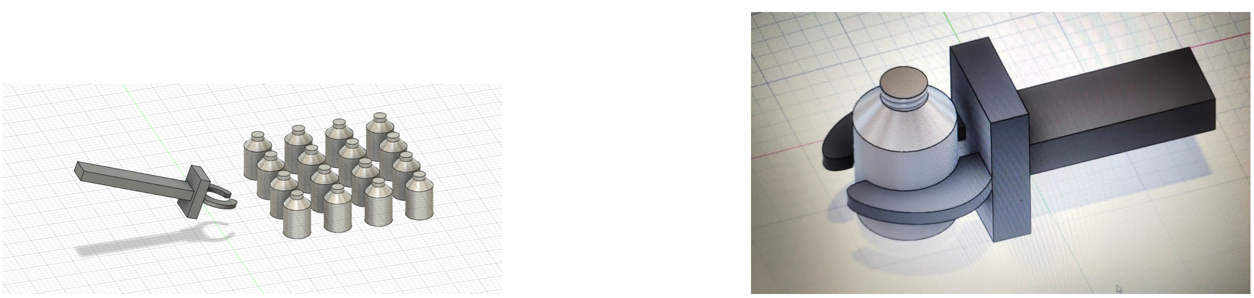


Figure 5: The robot R1

The end gripper is of the form of a clutch. It approaches the crate, holds the vaccine bottle. This process is shown in below CAD diagrams.



(a) R1 gripper approaching vaccine crate

(b) R1 gripper holding a vaccine bottle

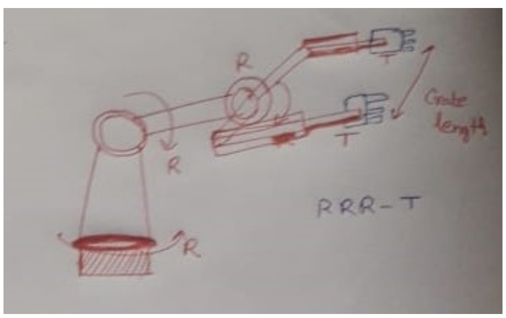
Figure 6: CAD diagrams of end gripper and movements of R1

To approach the vaccine crates correctly, we can attach a bar code scanner to R1 and a bar code sticker to the crates of vaccines, so that it correctly identifies them. The motion is controlled using PLC.

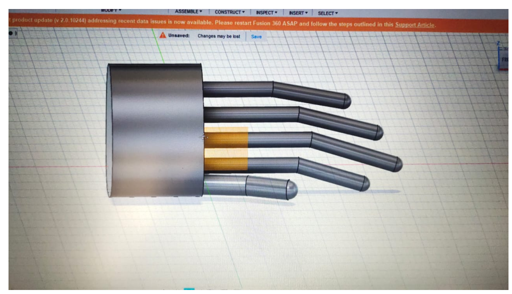
After collecting the vaccine bottles, it later arranges them neatly in the platform, waiting for R2 to take action on them.

2. **R1a**:

This is a RRR:T robot. It has 4 axis of motion, with floor moment. The end gripper is of the form of human arm. It is present in the stalls, unloading the syringe crates into the stall, loading empty syringe crates on the conveyor and disposal of waste. Its gripper is also impactive. The gripper CAD diagram and the robot sketch is as shown below:



(a) R1a sketch crate



(b) R1a gripper

Figure 7: CAD diagrams of end gripper and movements of R1

3. **R3 and R4**: The structure, design of these both are similar to R1a above. The main difference is that they don't have floor movement. R3 is fixed at the vaccine storage units and R4 is fixed at the syringe storage units.

4. **R2**:

This is the most complicated robot in the stall. It has 6 axis motion. It is of type RRRR: RRt. It has 2 arms, which are independent of each other. It also has floor movement. It has 2 end grippers, which are specially designed by us. See the figures:

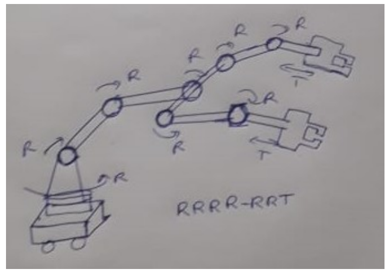
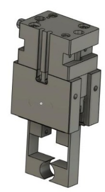
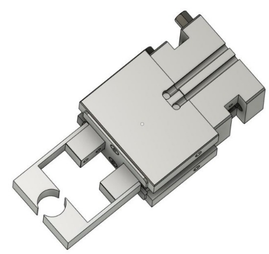


Figure 8: The robot R1

The complexity is essential because it has to perform the complicated tasks of syringe holding, aligning, filling, administering and disposal. The end gripper is as below:



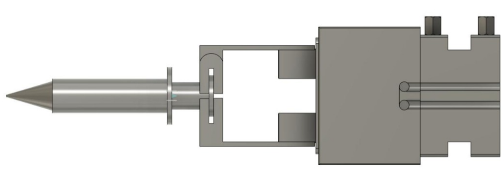
(a) Top view



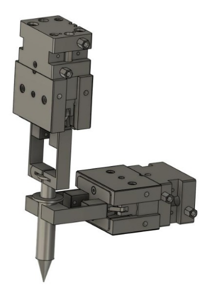
(b) Lateral view

Figure 9: CAD diagrams of end gripper and movements of R2

The syringe holding is done by one arm and another arm aligns it, as shown below:



(a) Gripper holds syringe



(b) Another arm aligns syringe

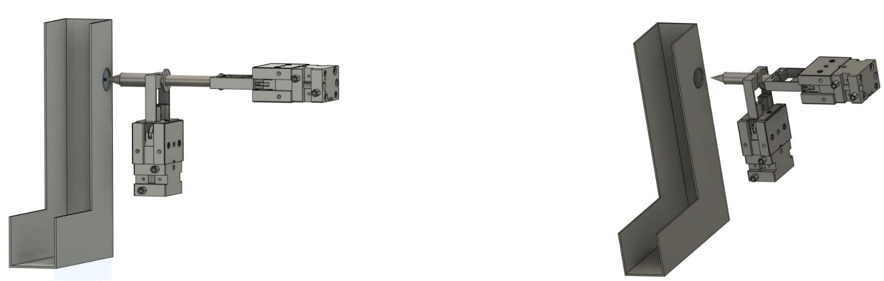
Figure 10: CAD diagrams of alignment of syringe

After this, It will fill the syringe. There is no movement of vaccine bottle, they lie on platform. The syringe starts filling from leftmost vaccine bottle towards right and top to bottom. It is fed into it that one bottle gives 10 doses. The process is given below for filling.

(a) Injection aligning with vaccine (b) Filling of syringe

Figure 11: CAD diagrams of filling of syringe

The precise moments for this are controlled using PLC. After this, the robot moves to the person's arm area and gives vaccine to him. To easily detect the upper arm area, there is a hole in the arm holder. The person places his/her left/right hand as per preference in it and using ultrasonic sensors in the stall, information is sent to the robot whether the arm holder is occupied or not. Now, the robot uses optical sensors to locate the area of hole and gives vaccine as shown below:



(a) Detection of upper arm of person (b) Injecting the vaccine

Figure 12: CAD diagrams of injection process

The disposal of injection is done next. It detects the dust bin using a barcode sensor (Attaching a unique bar code to dustbin makes this easy). The CAD sketches are as below:

(a) Detection of dustbin

(b) Disposing the syringe

Figure 13: CAD diagrams of disposal process

7 Instruction sequence

Firstly, there will be 20 places on the both conveyors (Each 20) on which bar codes are marked. Also, there are barcodes on every crate of vaccines and syringes. So, at a time, there are only 20 crates can be kept on each conveyor for vaccines and syringes.

Now, the instructions for R3 and R4 are as follows: The notations are for inputs to PLC.

1. First, at the start of process, fill all the slots on conveyors with respective crates.

2. Both R3 and R4 will be attached with barcode scanners. Now, when process starts, the robots will read the bar codes. It will either read the code on conveyor or on the crate.

3. If it reads the code on conveyor(XV1), it the conveyor will stop for a while(CV1) and it places new crate on it.(NCV)

4. If it reads the code on a crate, then it will see if it is empty(NEV) or not. If it is empty, the conveyor stops for a while and the empty crate is unloaded(NCVU) and placed in respective

storage.

5. If it is full, then no action is done. The conveyor continues to be in motion.

For R1a, the instructions are as follows:

1. Read the bar code. If it is on the conveyor of syringes then do no action. If it is on the crate of syringes, scan the crate.(SC)

2. If it is full then scan the stall's platform for syringes.(SC2) Unload it into the stall's vaccine platform if it is not full.(SC3) Else, take no action.

3. If the stall is full then scan the crates(SS).If empty crates are found then wait till the conveyor slot gets empty(SES). Unload the empty crates. Else, take no action.

4. Scan the garbage bin in the stall(GB). If it is full then dump the waste on the conveyor(D). Else, take no action.

Instructions for R1:

1. Scan the vaccine conveyors. If crate is found, scan it, If it is full then conveyor stops for a while and all the vaccine bottles are unloaded onto the platform. The crate is not lifted. Else, take no action.

2. Check for the platform periodically (once in every 10 minutes). If the slots are empty, start loading. Else, take no action.

Instructions for R2:

1. Take the syringe from the syringe platform in the stall (S1)and align it(S2).

2. If the vaccine platform is not empty,(S3) go to the vaccine bottle and fill the syringe(S4). Else, take no action.

3. If the arm slot is non-empty (S5)then give the vaccine to the person and dump the syringe in the garbage bin(S6). Else, take no action.

The Ladder Logic is as follows:

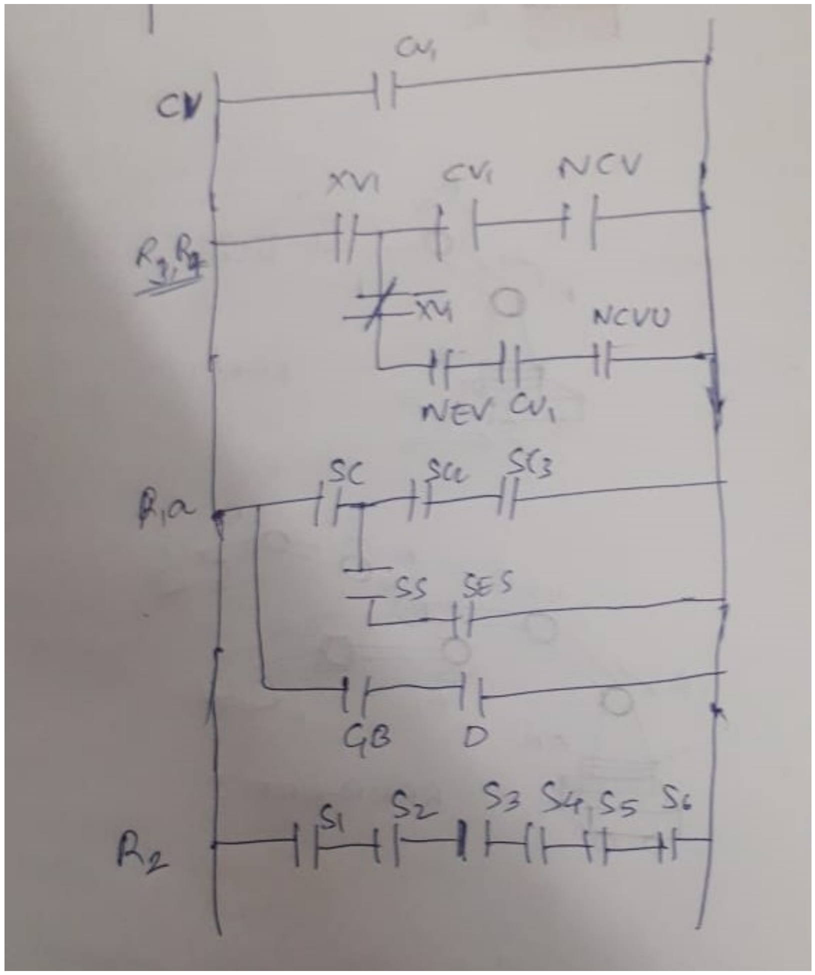


Figure 14: PLC Ladder Logic for all the robots and conveyors

8 Factory Metrics

Let us say that the cost of 1 dose of vaccine to bring it to the shop floor is INR 1000. This includes manufacturing, transportstion etc. Also, Let the cost of 1 disposable syringe is 10 rupees.

As said earlier, we need 200 vaccine bottles per stall and 2000 syringes per stall. So this makes a total of 220,000 INR for 1 stall. For the layout of 6 stalls, we need 1,320,000 INR.

Also, the cost of end grippers is to be considered. The cost of human hand grippers for R3 and R4 is 100 USD each. Since there are 2 such robots of each 2 grippers, we need 58000 INR for these grippers.

The same gripper is there for another robot R1a in each stall, so, 14000 INR for it. The gripper for R1 is of low cost, say 60 USD. This makes 9000 INR. We assume same cost as R1a for R2, which amounts to 14000 INR.So, for every stall, we need 40000 INR.

The cost of other robotic parts is hard to estimate, so we take based on data to be 750 USD for 5 axis motion robot. This gives 166500 INR for a stall and 222000 for the 4 robos R3 and R4.

Considering the 6 stall model and adding all costs, this amounts to 2721000 INR per day (9 hours). The electricity costs etc are not included. Now, since we estimate 2000 people per stall, dividing the total cost by 12000 gives 236.5 INR. So, we can set the price of Vaccine giving to be 250 INR. These metrics may be inaccurate due to unavailability of data, but the logic is demonstrated.

9 Conclusion

The entire analysis is done. The theory is used accurately in design, sensor issues description and end gripper design and selection. The motion control is explained and the level of automation is also explained. It should be observed that there should be a superviser for this whole process in case there is any error. This is also the scheme of Factory 5.0, using IoT and other Networking technologies. The problem is interesting and it is analysed completely as per the questions asked.

10 Contributions

Here, in 3 separate statements, we declare what we have done for the project, with the respective signatures under each line.

1. **K.Srivatsava, ME18B055:**

I have conceptualised the basic approach, written the full report, designed the CAD diagram of conveyor belts of vaccine and syringe, and drawn the factory layout, the robot hand-sketches and the PLC ladder logic program.

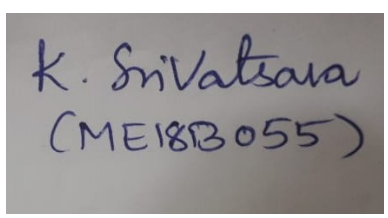


Figure 15: Sign of K.Srivatsava

2. **T.Mahesh, ME18B034:**

I have designed the vaccine bottle arrangement in the platform approach, drawn the CAD sketches for R2's syringe position, alignment, injection, disposal operations and designed end grippers for R2 and the garbage bin.

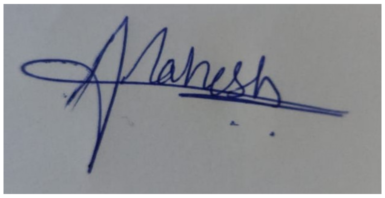


Figure 16: Sign of T.Mahesh

3. **P.Akash, ME18B021:**

I have done some of the Factory metrics part in the report (The gripper names and their approximate rates), designed the CAD diagrams for wastage disposal belt, crates, R3,R4 and R1a grippers and the figures for the process of vaccine bottle arrangement into the platform.

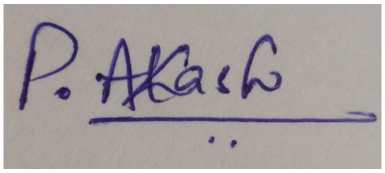


Figure 17: Sign of P.Akash

11 Appendix A: CAD diagrams

This is an ensemble of all the CAD diagrams used in this report.