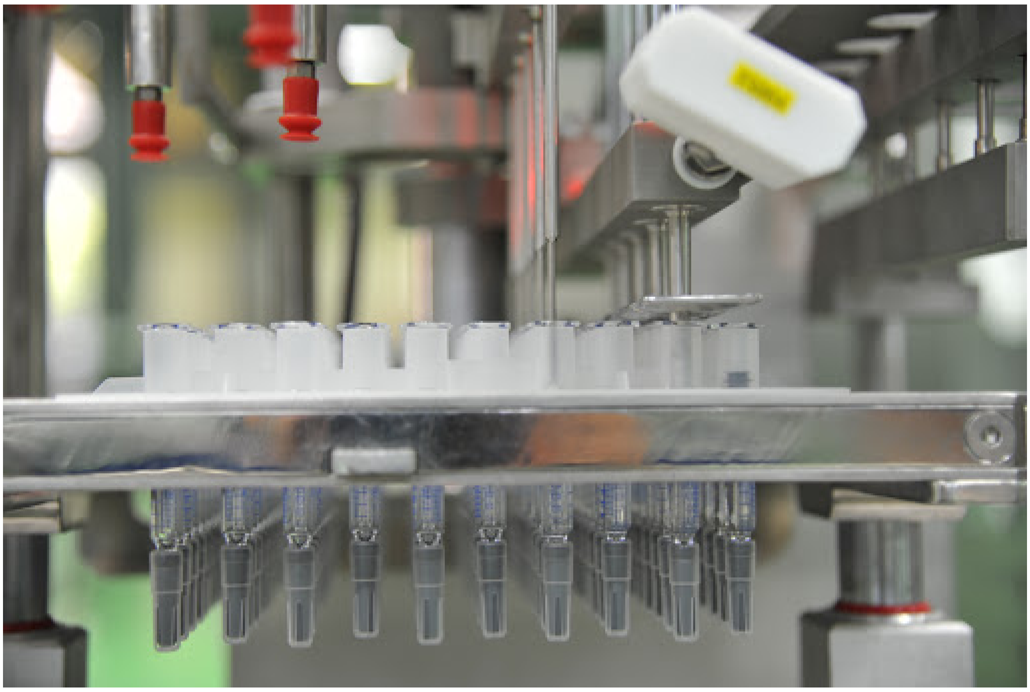
Automation of COVID 19 Vaccination

ME3302 - Automation in Manufacturing - Course Project

Guide: Prof. Sathyan S



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1. Introduction

COVID cases are rapidly rising in a country called MahaNadu. MahaNadu's prime minister Mr. Edapadhav has decided to mass vaccinate the entire population, within a short span of time, by setting up factories that automate the process of vaccination. He has code named this operation - Covictory (COVID factory). The objective of this project is to help set up these Covictories with required automation of the process using a robot (human-friendly one!). There are several tasks to be automated. The target is to vaccinate the entire 18 Crore population within a span of 8 weeks(both the doses).

The plan is to come up with completely automated factories that can function on their own except for maintenance purposes and during loading of new stock from outside.

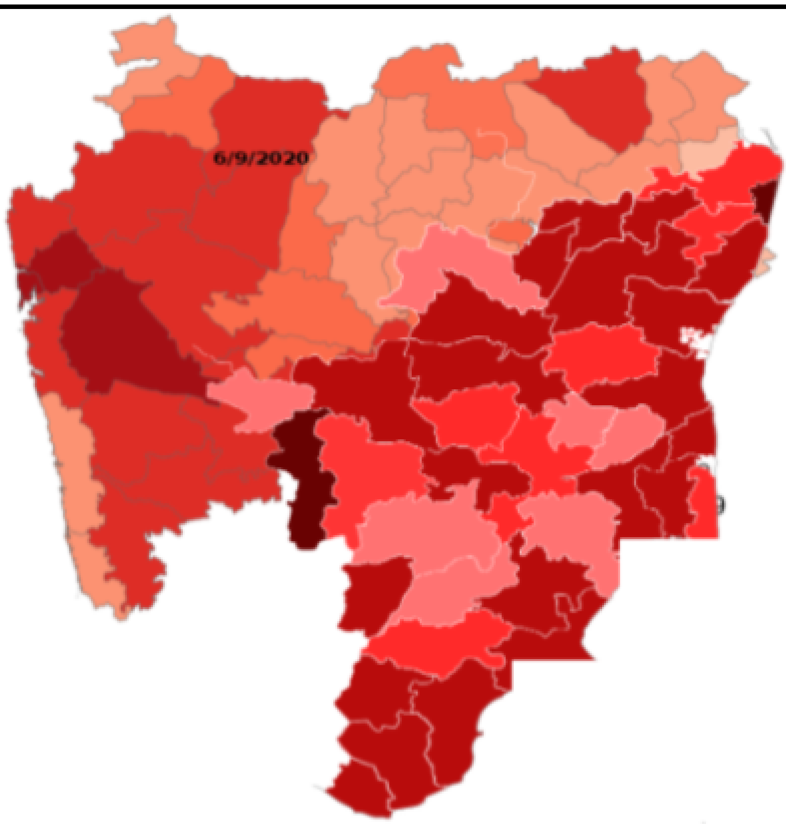


Fig 1 : Illustrative Map of MahaNadu highlighting the rapid rise in Covid 19 cases

2. One v/s Many

2.1. Calculations for injecting a person manually one by one

Let us say there are 6000 vaccination clinics. Each clinic can only vaccinate one person at a time and it takes 7 minutes for the same. Let the clinics work from 8am to 6pm everyday(10 hours). For the entire population of 18 crores, the total time to vaccinate everyone with a single dose will be

Time taken for 1st dose:

$$\frac{18\ cr}{6000} * \frac{7}{60} * \frac{1}{10} = \textbf{350 days}$$

Therefore, from the above calculations, we require almost 1 year for one single dose for the entire population. This poses various disadvantages some of which are the following

- The vaccines have an expiry date of 6 months from manufacture. Hence procurement cannot be done efficiently and have to be done in batches. This increases transportation and customs costs.
- Since only one person is vaccinated at a time, this leads to long waiting queues which by itself is very unsafe given the trend of increasing cases.
- The medical staff are already overworked with treating Covid positive patients and there are shortages of them. Hence, this poses a problem if we vaccinate the population in the above mentioned way.

2.2. Calculations for injecting a person simultaneously

Let us assume we set up 1000 factories in which each of them can vaccinate 50 people at a time in 5 mins. Let the factories also work from 8am to 6pm everyday. Then, the time taken to vaccinate the entire population with the 1st dose is:

$$\text{Time taken for 1st dose} = \frac{18\ cr}{1000*50} * \frac{5}{60} * \frac{1}{10} = \textbf{30 days}$$

Therefore from the above calculations, it is clear that using automated vaccination factories will be efficient in completing the vaccination process with the number of facilities being ⅙th of thar required in the manual case. Also, it meets the target set by the Prime Minister of vaccinating the entire population(both doses) by 8 weeks.

We can assume in this case that the 1st 4 weeks will be used to vaccinate the 1st dose only, and the latter 4 weeks will be used for the 2nd dose.

3. Quantity v/s Variety

3.1. Classification based on Quantity (Q)

Based on quantity, the 3 types of classification are Low volume, Med volume, High volume. The standard for classification is given in terms of production quantity per year. However, in our case, it is not practical to compare it in that fashion as it is an 8 week process. Since the entire nation has to be vaccinated, obviously 18 Crore vaccines have to be administered. Hence, we can classify it under the **High Volume** category.

3.2. Classification based on Variety(P)

Based on variety, there are 2 types of products which are hard and soft. Since all the vaccines of a single dose are identical, we can consider it to be a **Soft Variety** product.

4. Factory Layout

4.1. Based on Q and P

Since our factory type is high Q low P, the following are the ideal choices for the factory layout: (Fig 2)

- Process Layout
- Product Layout

Every station should be clearly defined and care must be taken about the storage conditions of the vaccine vials. Multiple people should be vaccinated simultaneously. As this is a temporary factory which will be removed/reused in some other application after this pandemic ends, cost of setup should also be a major factor for selecting the layout. Considering all the above factors, **process layout was decided as the best option for this factory.**

4.2. Based on n_o and n_p

The purpose of this factory is for vaccination. It receives the vaccine vials and the syringes. Using these, it loads the liquid into the syringe and administers the vaccine into the human. From this, we can see that there is no manufacturing of parts. It uses the existing components for the purpose. Hence, this factory is classified with **Assembly Plants.**

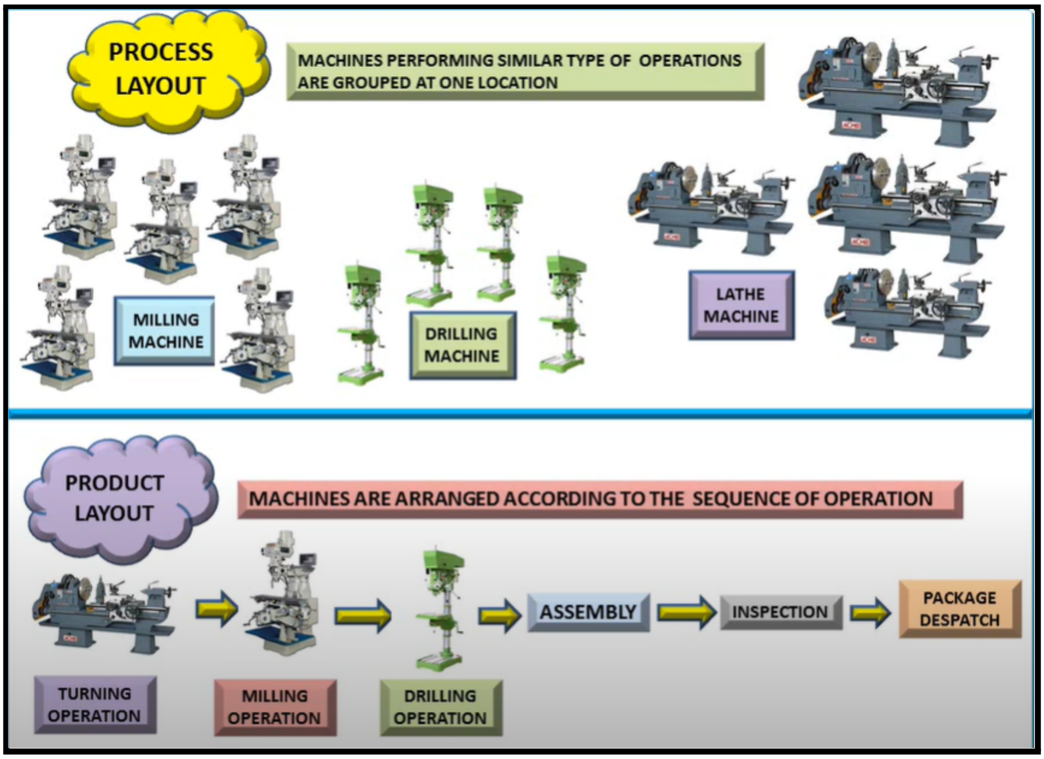


Fig 2: Examples of process and product layout
Source: https://www.youtube.com/watch?v=WYqMh5cf8fY

4.3. Factory outline (blueprint)

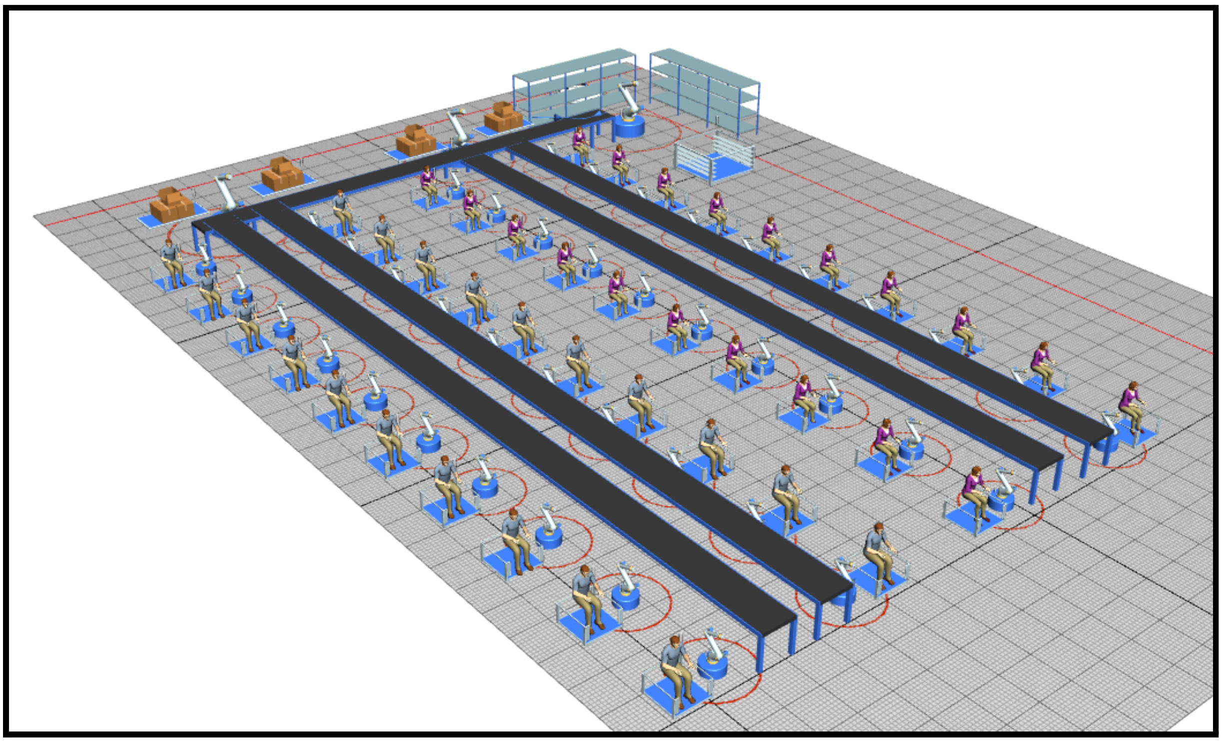


Fig 3: Inside view of the factory

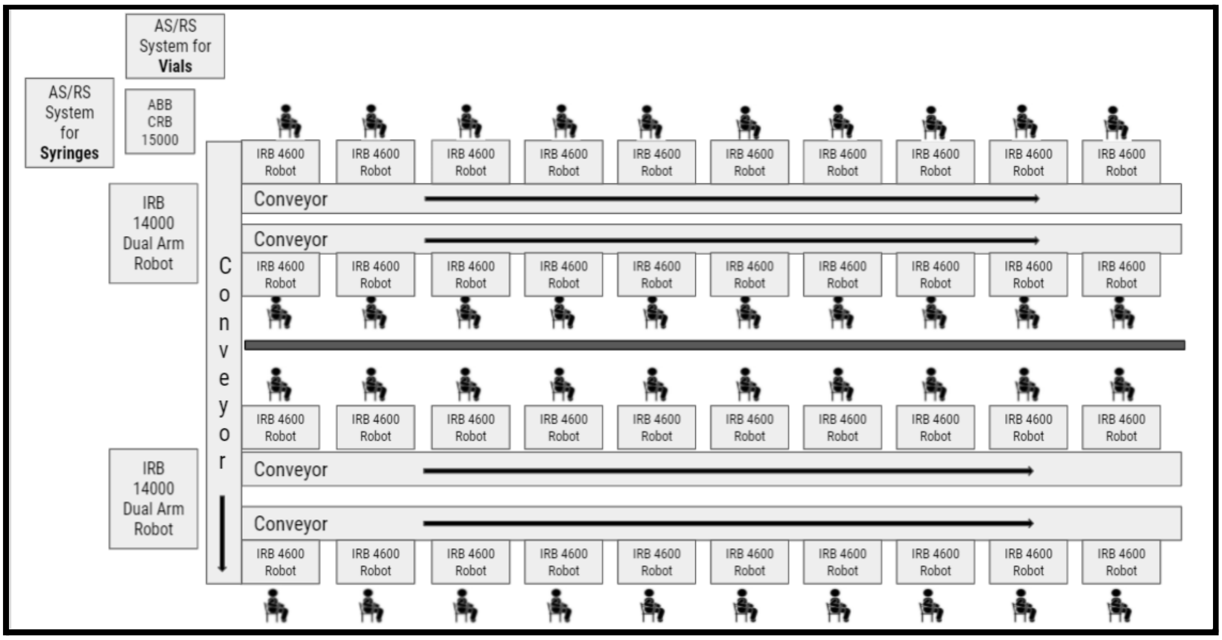


Fig 4:Factory blueprint

5. Manual v/s Automated

5.1. Manual Tasks

a) Sending vaccine and syringe boxes - By supplier from an opening outside which takes it in using a conveyor.
b) Alcohol wiping on the skin surface - By the patient.
c) Fastening of arm to arm rest using belts - By the patient

5.2. Automated Tasks

Every task apart from the manual tasks are automated. The tasks and the implementation will be discussed in detail in the next section

6. Automation details

6.1. Storage of vials and syringes - AS/RS system

a) 2 separate Aisles for vaccine vials and syringes
b) The vaccine boxes will be in a specialized refrigerated Aisle with temperature 2 degree Celsius whereas the syringe boxes are stored in a room temperature Aisle.
c) If a box(vaccine/syringe) is needed, then the aisle takes the box with the closest expiry date.

Fig 5:AS/RS with refrigeration - for vials

6.2. **Robot 1** - Unpacking and transporting boxes

6.2.1. Sequence of steps

- Transfers the box from aisle output to the conveyor.
- Cut open the seal.
- Send it to the assembly station through the conveyor.

6.2.2. Robot Specifications (Fig 6)

Considering the above sequence of steps, the robot selected was **ABB GoFa CRB 15000.** Some of the specifications are:

- Reach: 950 mm
- Payload: 5 kg
- Number of axes: 5

6.2.3. End effector Specifications (Fig 7)

- Dual Gripper - custom made
- One end will be vacuum gripper to transfer the boxes
- Other end will have cutter to cut open the seal

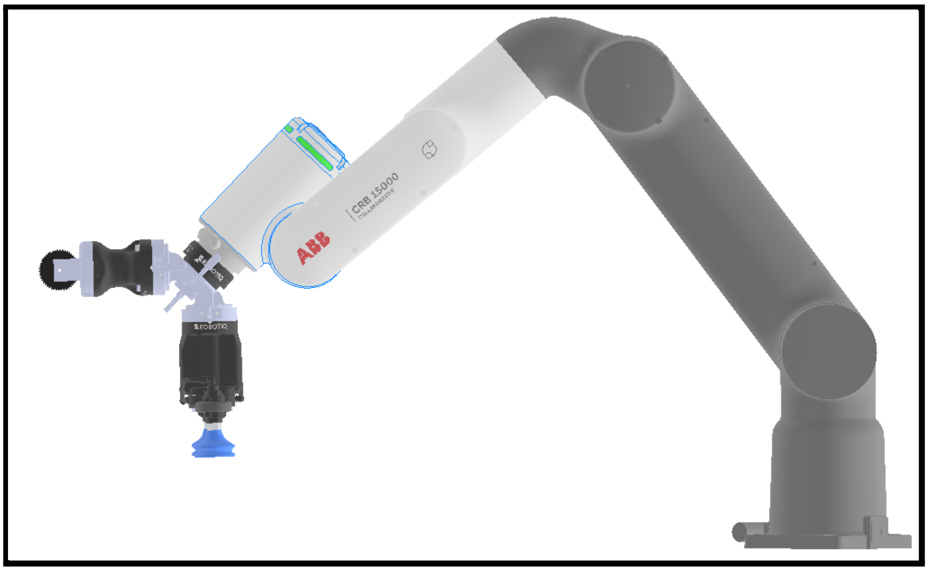


Fig 6: ABB GoFa CRB 15000

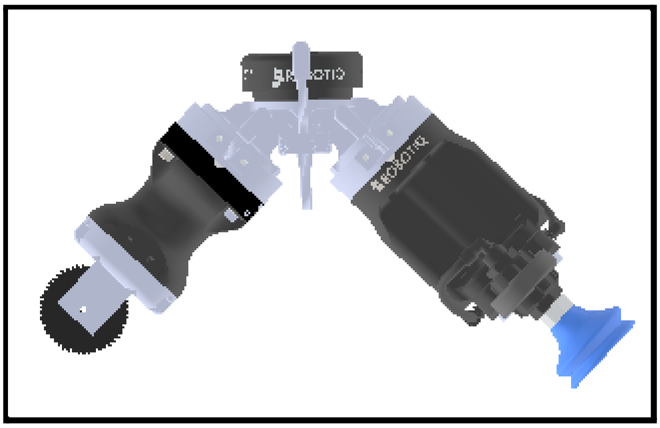


Fig 7:End effector for the Robot which is shown in fig 3. One end is vacuum gripper and the other end is the cutter

6.3. **Robot 2** - Filling the syringe

6.3.1. Sequence of steps

- Picking up a syringe and the vial from the box.
- Piercing the syringe into the vial and sucking the liquid
- Placing the filled syringe into a conveyor
- Disposing off the empty vial

6.3.2. Robot specifications (Fig 8)

Considering the above sequence of steps, the robot selected was **ABB YuMi IRB 14000**. Some of the specifications are:

- Arms: 2 - one to hold the vial and the other to hold the syringe
- Reach: 559 mm
- Payload: 500 g
- Number of axes: 14

6.3.3. End effector specifications - custom designed(Fig 9)

- **First End effector**: Parallel motion two jaw gripper to hold the vial.
- **Second End effector**: Parallel Motion Two Jaw gripper to hold the syringe and Vacuum gripper to draw the syringe needle.

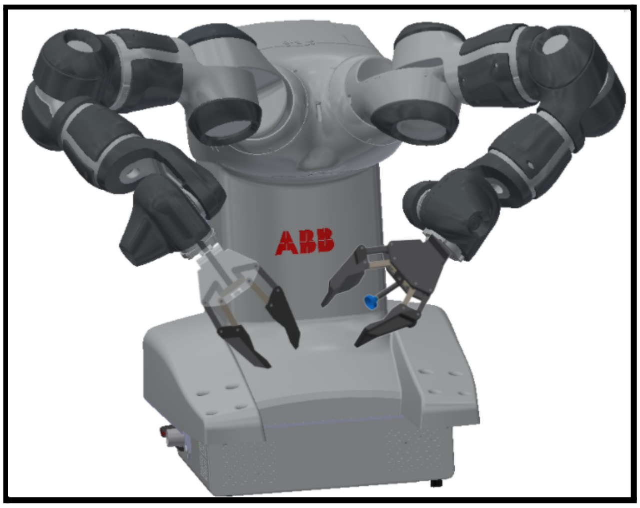


Fig 8:ABB YuMi IRB 14000

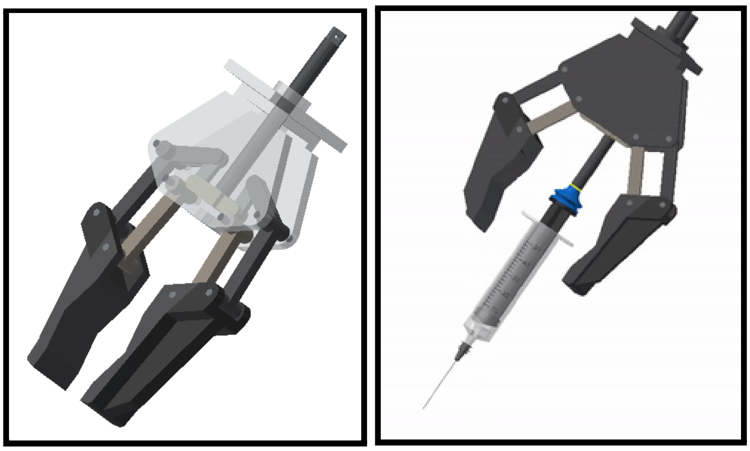


Fig 9:1st end effector(left), 2nd end effector(right)

6.4. **Robot 3** - To inject syringe into human

6.4.1. Sequence of steps

- The human places the hand on the L-shaped hand rest and fixes the belts.
- The robot takes the ready-to-inject syringe from the conveyer and approaches the location to be injected.
- The robot injects the syringe into the skin at optimum speed and compresses the plunger so that the liquid goes into the patient.
- After injecting the liquid, the robot pulls the syringe out and disposes it off in the bin.

6.4.2. Robot specifications(Fig 10)

Considering the above sequence of steps, the robot selected was **ABB IRB 4600**. Some of the specifications are:

- Reach: 2.5m
- Payload: 200 g
- Number of axes: 6

6.4.3. End effector specifications - custom designed(same as Fig 9 - right)

- Custom made End Effector to inject syringe into Human arm and drop the used syringe to the bin

Fig 10: ABB IRB 4600

7. Sensors

7.1. AS/RS system

a) Rotary encoder and Linear sensors are used in these systems to give the position of the loading equipment with respect to the vertical racks where goods are stored.
b) Temperature sensor - to make sure that the vials are stored at 2 degrees Celsius
c) The manufacturing date of all the boxes are scanned and stored before they enter the aisle. The details of the box along with its location is stored. When there is a necessity to unload a box, the one with the earliest manufacturing date is pulled first.

7.2. Robot 1 - Unpacking and transporting boxes

a) Contact sensor for sensing the box to lift/cut it
b) Contact sensor in the conveyor belt to indicate if the box has been placed.

7.3. Robot 2 - Filling the syringe

a) Weight sensor on the end effectors to check increase/decrease in weight - to ensure that liquid is being filled into the syringe.
b) Optical sensors - to count the number of vials/syringes and to send for a new box if the count is 0.
c) Contact sensor for sensing the syringe/vial to lift it/pull the plunger.
d) Contact sensor in the conveyor belt to indicate if the syringe has been placed

7.4. Robot 3 - To inject syringe into human

a) Speed sensor - to control the speed of injecting the vaccine
b) Emergency buttons/sensors
   i) Sound sensors - to stop operations if a person shouts
   ii) Emergency contact sensors in visible proximity for safety.
c) Optical Sensor - to notify if the disposal bin is full.
d) Contact sensors - to ensure that the human has kept his hand tightened on the hand rest with the belts fastened.

7.5. Other miscellaneous sensors

a) Fire alarm - Temperature sensors and smoke detectors
b) Emergency stop buttons

c) Aadhar Card scanner - while coming in and out to record the entry and exit time and to update vaccination status. If the count inside is full, then it will not allow the person inside.

LIST OF SENSORS AND THEIR SPECIFICATIONS			
Sensor Type	Application		Sensor Choice which meet the required specifications
	Usage	Description	
Temperature Sensor	AS/RS System	To make sure the Vials in the AS/RS system are stored at 2 deg C	TMP04FT9
Rotary Encoder & Linear Sensor	AS/RS System	To give the position of the loading equipment with respect to the vertical racks where goodsare stored.	LINARIX Linear Sensor & IXARC Rotary Encoder
Contact Sensor	Robot 1	For sensing the box to lift/cut it	Littelfuse 59070-010
	Robot 2	Contact sensor for sensing the syringe /vial to lift it/pull the plunger.	Littelfuse 59140-040
	Robot 3	To ensure that the human has kept his hand tightened on the hand rest with the belts fastened.	Littelfuse 59070-010
	Conveyor Belt	To detect whether the box/syringe has been placed on the conveyor	Littelfuse 59070-010
Weight Sensor	Robot 1	To ensure that liquid is being filled into the syringe.	HX711 Weight Pressure Sensor
Optical Sensor	Robot 2	To count the number of vials/syringes and to send for a new box if the count is 0	IR-LOCK Sensor
	Robot 3	To notify if the disposal bin is full.	
Speed Sensor	Conveyor Belt	To control the speed of the conveyor	IFM DI6001
	Robot 3	To control the speed of injecting the vaccine	
Sound Sensor	Robot 3	For Emergency : to stop operation if a person shouts	DFR0034
QR Code Reader	At Entry/Exit	To Detect AADHAR card of people while moving in and out to record the entry and exit time and update vaccination status	JT308 125KHz USB Proximity Sensor Smart RFID ID Card Reader

Table 1: Sensors used in the factory

8. Ladder Logic Program for a factory

8.1. Rung 1:

a) S1,S3: Sensors at temporary storages of syringes.

b) A1: AS/RS with syringes

8.2. Rung 2

a) S2,S4: Sensors at temporary storages of vaccine vials.

b) A2 : AS/RS with vials

8.3. Rung 3

a) R1: Robot 1

8.4. Rung 4

a) S5: Sensor to detect presence of patient at a station

b) R2: Signal to Robot 2 to fill a syringe

8.5. Rung 5

a) S6: Sensor at the station to sense if a filled syringe has arrived
b) R31: Signal to Robot 3 to pick up the received filled syringe
c) M1 : Relay that is turned on to denote that the syringe is picked up

8.6. Rung 6

a) S7 : Sensor to detect if arm is fastened properly to arm rest
b) S8: Sensor to detect vein
c) B1: Button input from patient if ready
d) R32: Signal to Robot 3 to inject

8.7. Rung 7

a) S9: Card scanner to detect patient entry
b) S10: Sensor to detect if all seats are full
c) Entry : Door opens

8.8. Rung 8

a) Error display : "House full" message displayed when person tries to open door when seats are full

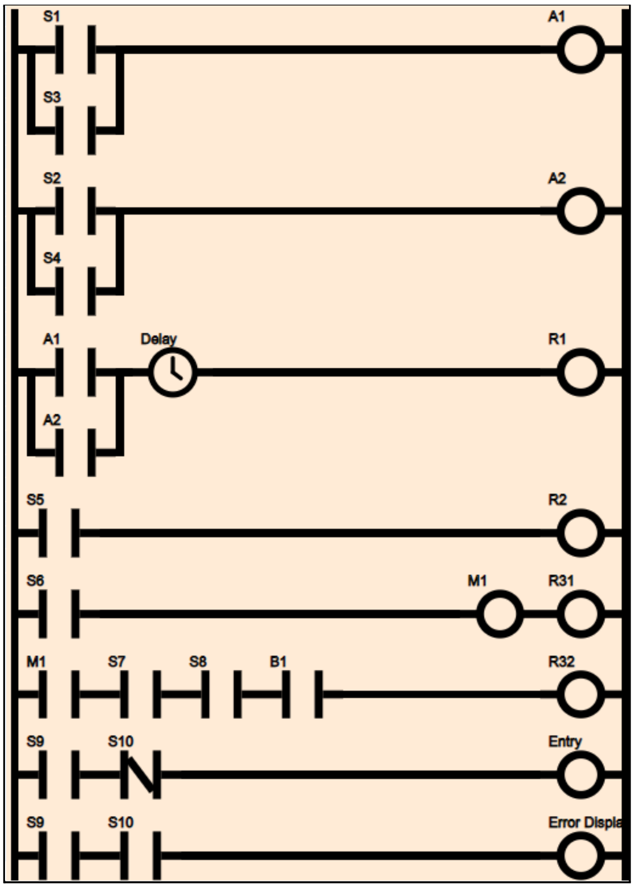


Fig 11: Ladder Logic PLC program

9. Factory metrics and economics

9.1. Fixed cost

A fixed cost is one that remains constant for any level of production output. Examples include the cost of the factory building and production equipment, insurance, and property taxes. The fixed costs for this factory are:

- Cost of building the factory: Rs. 5,00,000 per factory
- Cost of purchasing equipments(per factory):
    - AS/RS: 5,00,000
    - Robot 1 + Gripper : Rs. 20,00,000
    - Robot 2 + Gripper : Rs. 25,00,000
    - Robot 3 + Gripper : Rs. 5,00,000
    - Conveyor: Rs. 1,00,000
    - Miscellaneous(chair, fire alarm, etc) : Rs. 20,000

9.2. Variable cost

A variable cost is one that varies in proportion to production output. Examples include direct labor, raw materials, and electric power to operate the production equipment. The ideal concept of variable cost is that it is directly proportional to output level.

The variable costs for a factory are as follows:

- Syringes: Rs. 10 per piece
- Vaccine Vials: Rs. 400 per vial (according to Serum Institute)
- Alcohol wipes: Rs. 1 per piece
- Transportation costs: Rs. 1000 for a truck of 200 boxes(1 box will have 60 vials/syringes)

9.3. Total cost and cost of vaccination/person

Adding fixed and variable costs results in the following total cost equation:

$$TC = C_f + C_v Q$$

where TC is the Total Cost, C_f is the fixed cost and C_v is the variable cost, Q is the total quantity. The following are some of the details obtained from Section 2.2

- Number of factories: 1000
- Number of stations/factory: 50
- Number of vials/syringes in a box: 60
- Number of boxes of syringes & vials used in a day: 100 each = 200 total
- Time taken for complete vaccination of both doses: 60 days(8 weeks)

Calculations per factory

C_f = Rs. 61,20,000

C_v = 10 + 400 + 1 + (1000/(100*60)) = Rs. 411.166

Q_1(1st dose) = 18 Cr/1000 = 1,80,000 (ref. Sec 2.2 for number of factories calc)

Q_2(2nd dose) = 1,80,000

Q = 3,60,000

=> Total Cost for a factory = 61,20,000 + 3,60,000*411.166

= **Rs. 15,41,39,760 per factory**

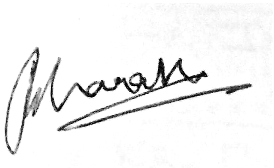
=> **Total Cost =** TC per factory * n(factories) = **Rs. 154,13,97,60,000**

Population: 18 Crores:

Cost of vaccinating a person: (15413,97,60,000/18,00,00,000) = Rs. 857 (for both doses)

10. Individual Contributions

Factory layout	Bharath Chandar + P Aravindh + Karthik S
AS/RS + Robot 1	Karthik S
Robot 2	P Aravindh
Robot 3	Bharath Chandar
Sensors	Karthik S + Bharath Chandar
Logic ladder	P Aravindh
Factory metrics	Karthik



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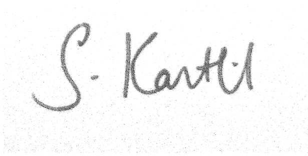

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