Designing a CNC Machine Tending Cell

Lean Robotics in Action

CNC Machine Tending Application Example

For this example, let's take a machining manufacturer with a new contract requiring more capacity.

The manufacturer then needs to increase its production. Let's have a look on how the Lean Robotics methodology can help them reach their goal.

LEAN ROBOTICS

Manual Map - Overview

Steps	Information to capture
1. Identify cell customer	Where do the parts go when the station is done with them?
2. Define output	What are the qualities of a "good input" for the next station? In other words, how does the customer define value? • Parts and their specifications • Part presentation method • Pace/cycle time
3. Define input	What is coming to this station? • Parts and their specifications • Part presentation method • Pace/cycle time
4. Define process	How are the parts processed? • Which steps are done manually? • Which steps are value-added? Which are not?

Manual Map - Overview

Steps	Information to capture
5. Document flow of information	• What information is used at the station? • Where does it come from? In which form? • What information is produced and transferred from the station? Where to, and in what form?
6. Measure KPIs	• What are the KPIs and their target values? • How will the KPIs be measured? KPI examples include: • Cost of producing parts • Cycle time • Inventory at cell
7. Summarize map	• Combine all the previous information in a visual representation of the map
Manual Cell Layout	
Sketch current layout	• What is the current spatial arrangement of the station?

LEAN ROBOTICS

Manual Map

1. Identify cell customer

The cell customer is the operator who brings the machined parts to an inspection station.

2. Define valuable output

As the internal customer (the operator), what I need you to give me is…
A tray of 60 parts every 2 hours

… so I can…
Transport it to the inspection station.

LEAN ROBOTICS

Manual Map - Output

Are the parts singulated? What is the space around them?

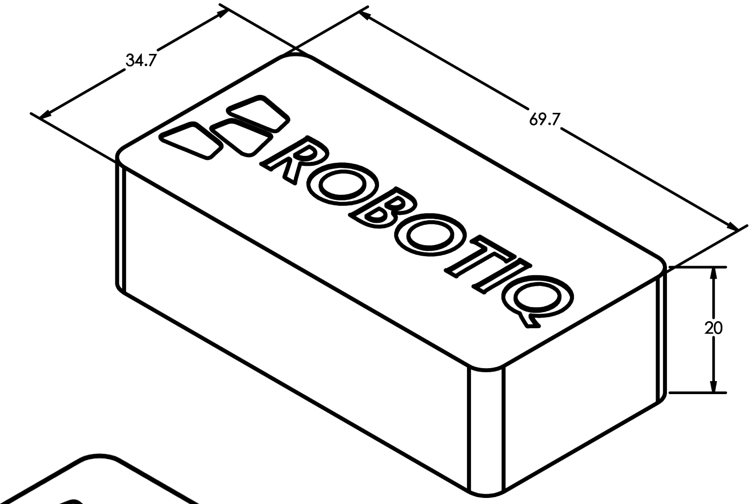
Stacked on top of each other

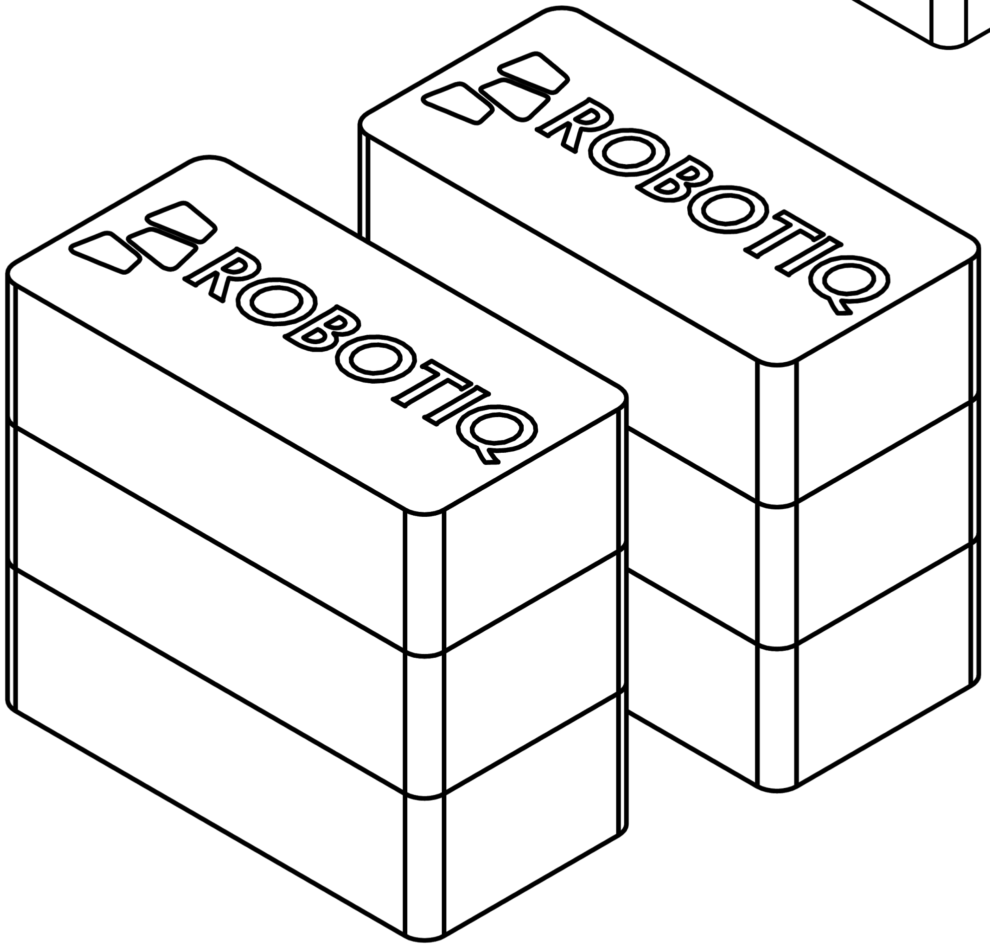
What is the actual presentation?

On a table

Is the output target moving? How so?

On a stable surface

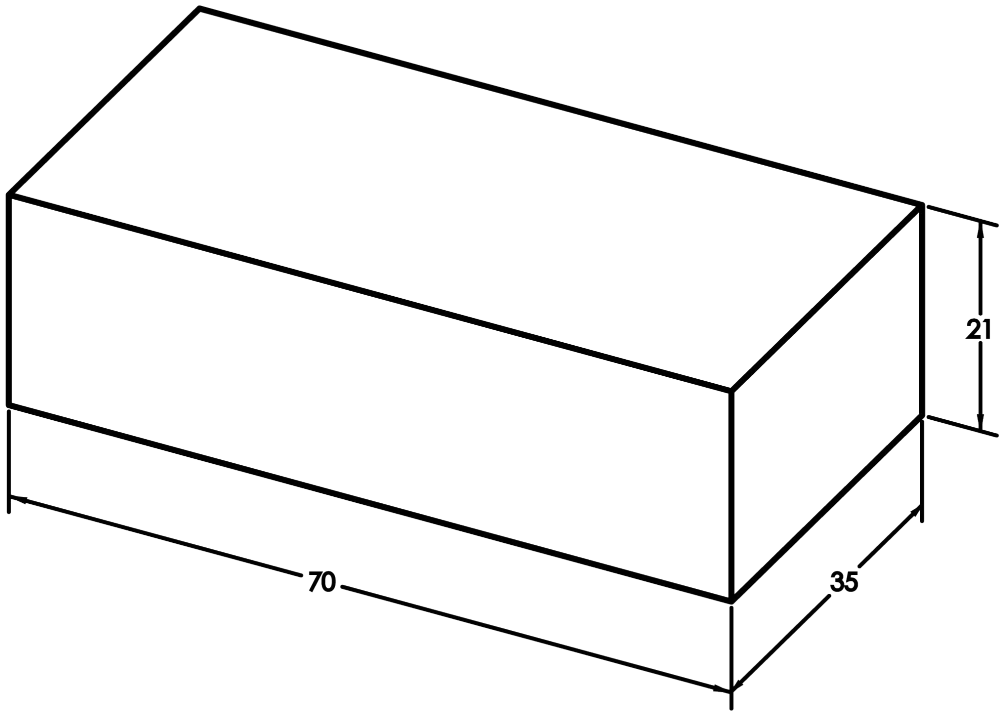




Manual Map - Input

Number of parts

4 different blanks



Characteristics of the parts

Size:

max: 70 mm x 35 mm x 21 mm rectangular blocks

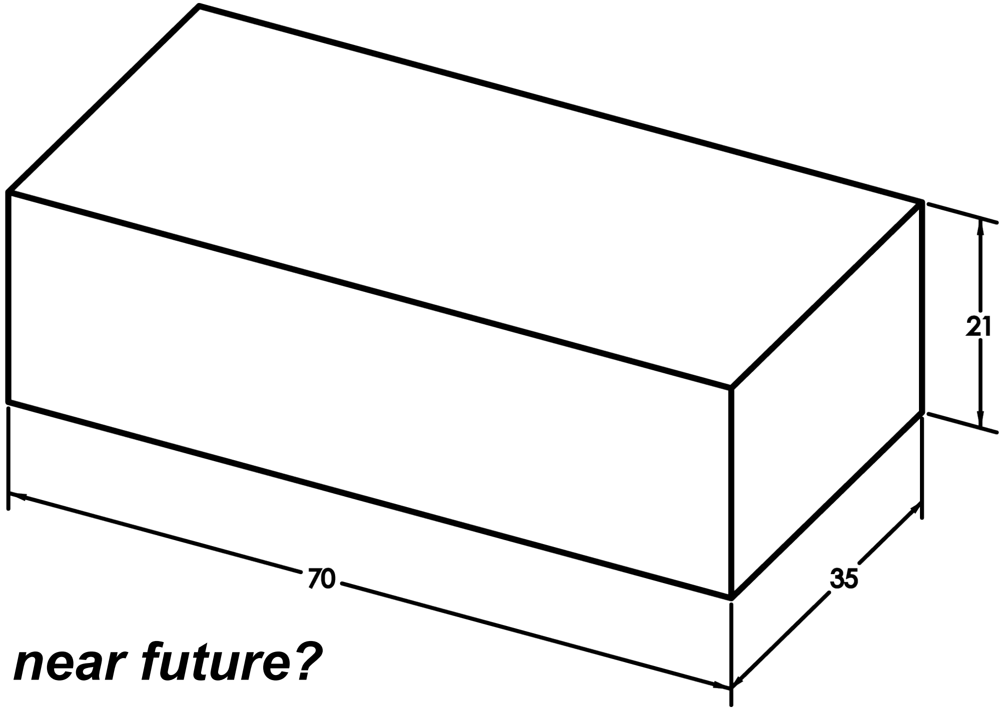
min: 69.8 mm x 34.8 mm x 20.1 mm rectangular blocks

Weight: max: 0.139 kg

Material: Solid aluminum

LEAN ROBOTICS

Manual Map - Input



Variation in time

Are there changeovers at this station?

2-3 times a week

Are you planning to introduce new parts in the near future?

Maybe in 9-12 months, similar kind of blank at input, will be within min-max defined above.

Manual Map - Input

Part presentation

Are the parts singulated? What is the space around them?

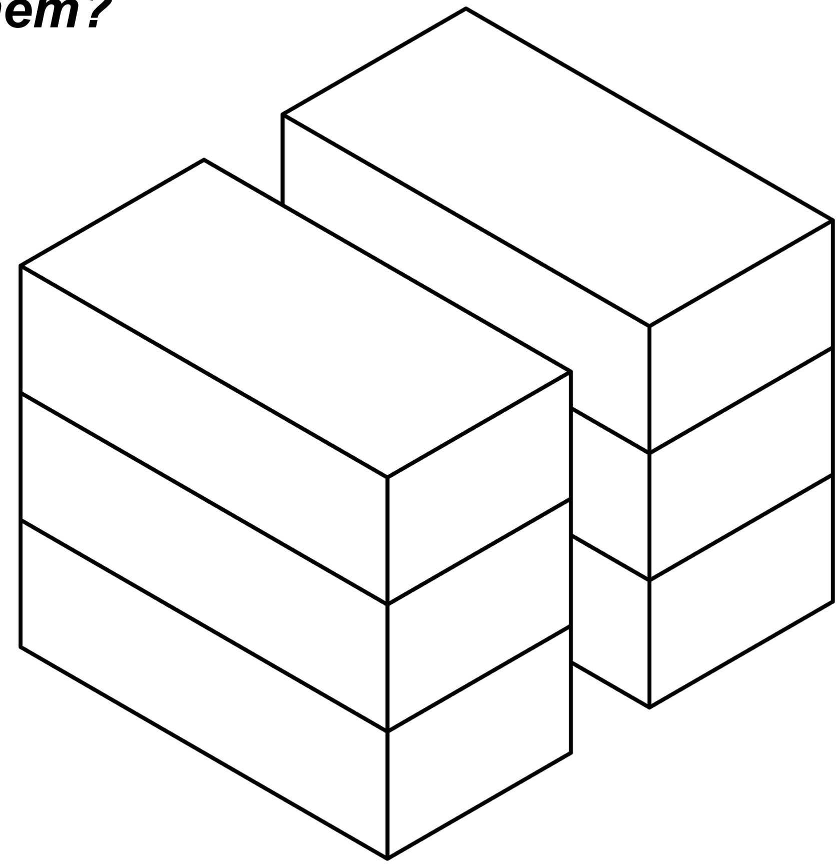
Stacked on top of each other

What is the actual presentation?

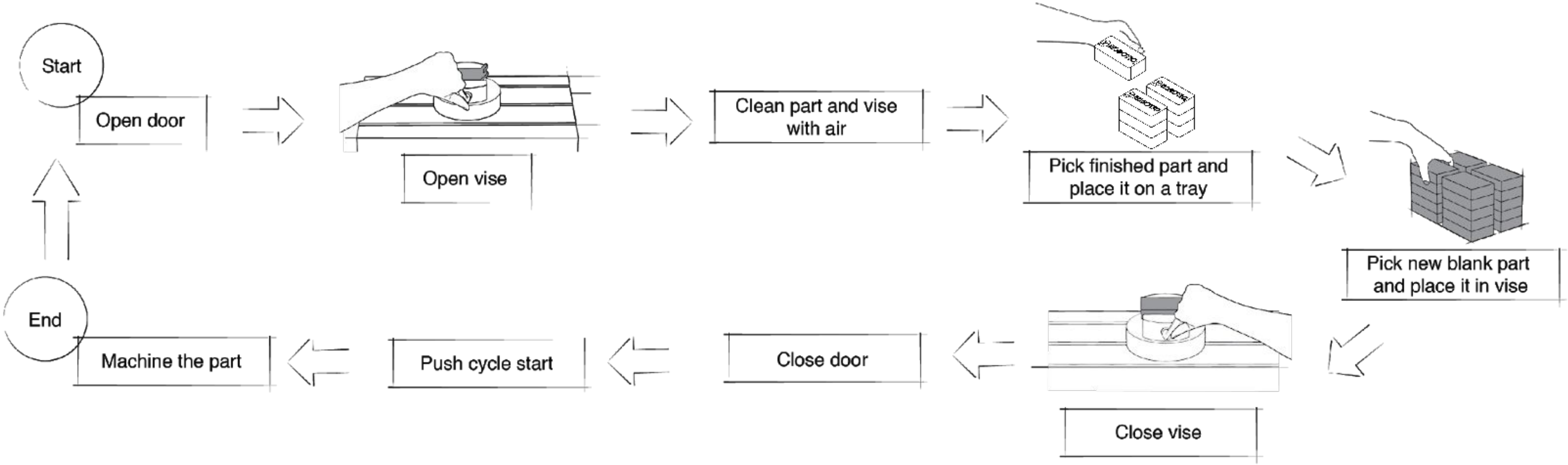
On a table

Are parts moving when presented? How so?

Stopped when picked



Manual Process



Manual Map - Process

	Non-Value-Added Time (seconds)	Value-Added Time (seconds)	Total Time (seconds)
Open door	2	-	2
Open vise	3	-	3
Clean part with air	2	-	2
Pick finished part and place it on tray	2	-	2
Pick new blank part and place it in vise	2	-	2
Close vise	3	-	3
Close door	2	-	2
Push cycle start	2	-	2
Machine the part	-	75	75
Total (s)	18	75	93

Manual Map - Information Flow

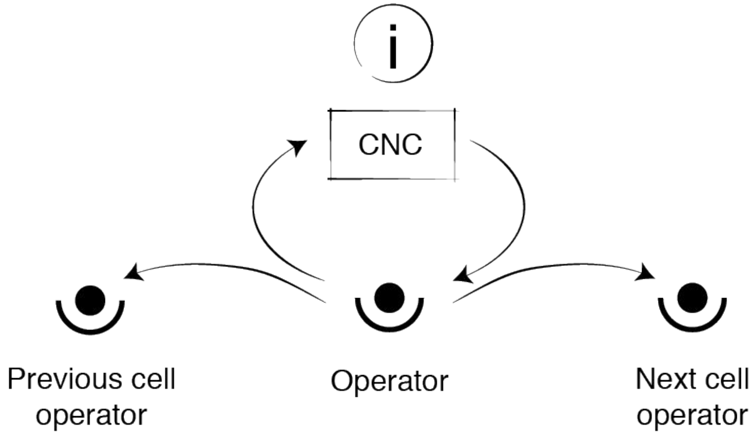
Information	Coming from	Going to	Format	How it's used
Cycle finished	CNC	Cell operator	Light signal	• Operator comes to remove part • Machine allows door opening
No infeed parts	Cell operator	Previous cell operator	Verbal	• Previous cell operator gets more blank parts
Outfeed full	Cell operator	Next cell operator	Verbal	• Next cell operator delivers part to inspection station

Manual Map - KPIs

The most important performance indicators for the cell are:

- Actual cell output — 210 parts per day.
- First pass yield — 97% (3% of the parts are rejected at the next station, which is quality inspection).

Manual Map - Task



KPIs

Cell output: 210 parts / day
First pass yield: 97%

Input

- 4 types of parts
- Aluminium blocks
- Stacked on table

Process

- Open door
- Clean part and vise with air
- Pick finished part, place on tray
- Pick blank part, place in vise
- Close vise
- Close door
- Push cycle start button
- Machine part

Output

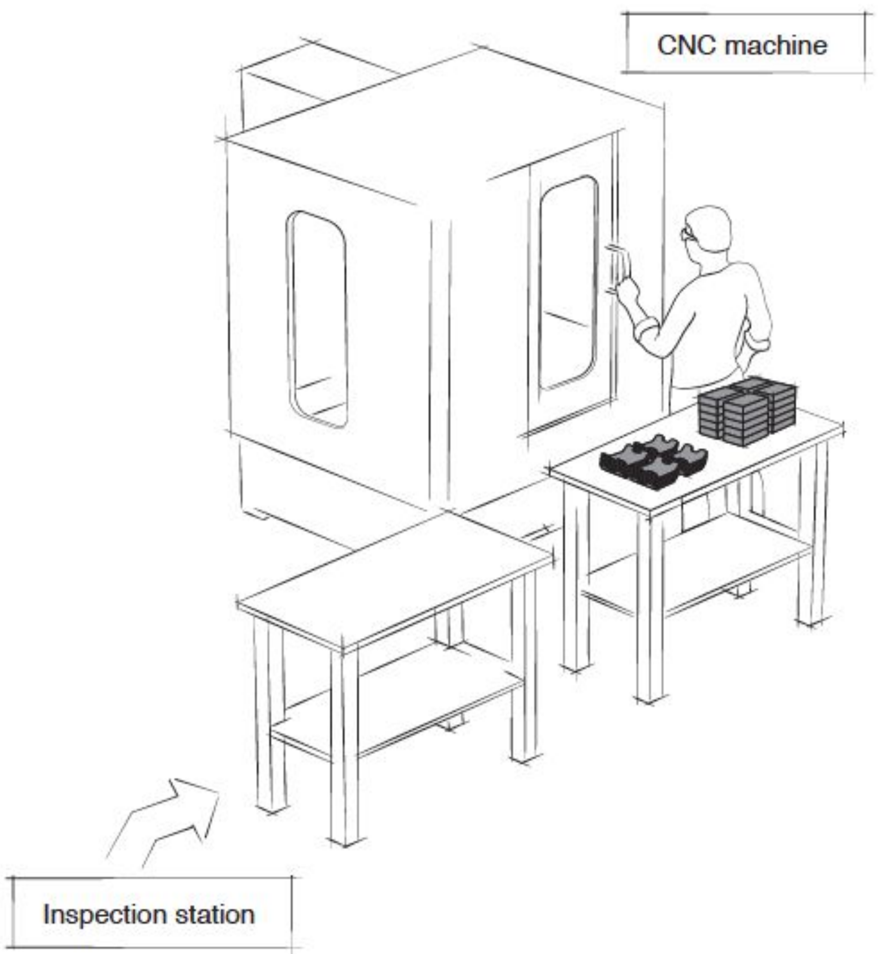
Part family #AGSxxx on a tray

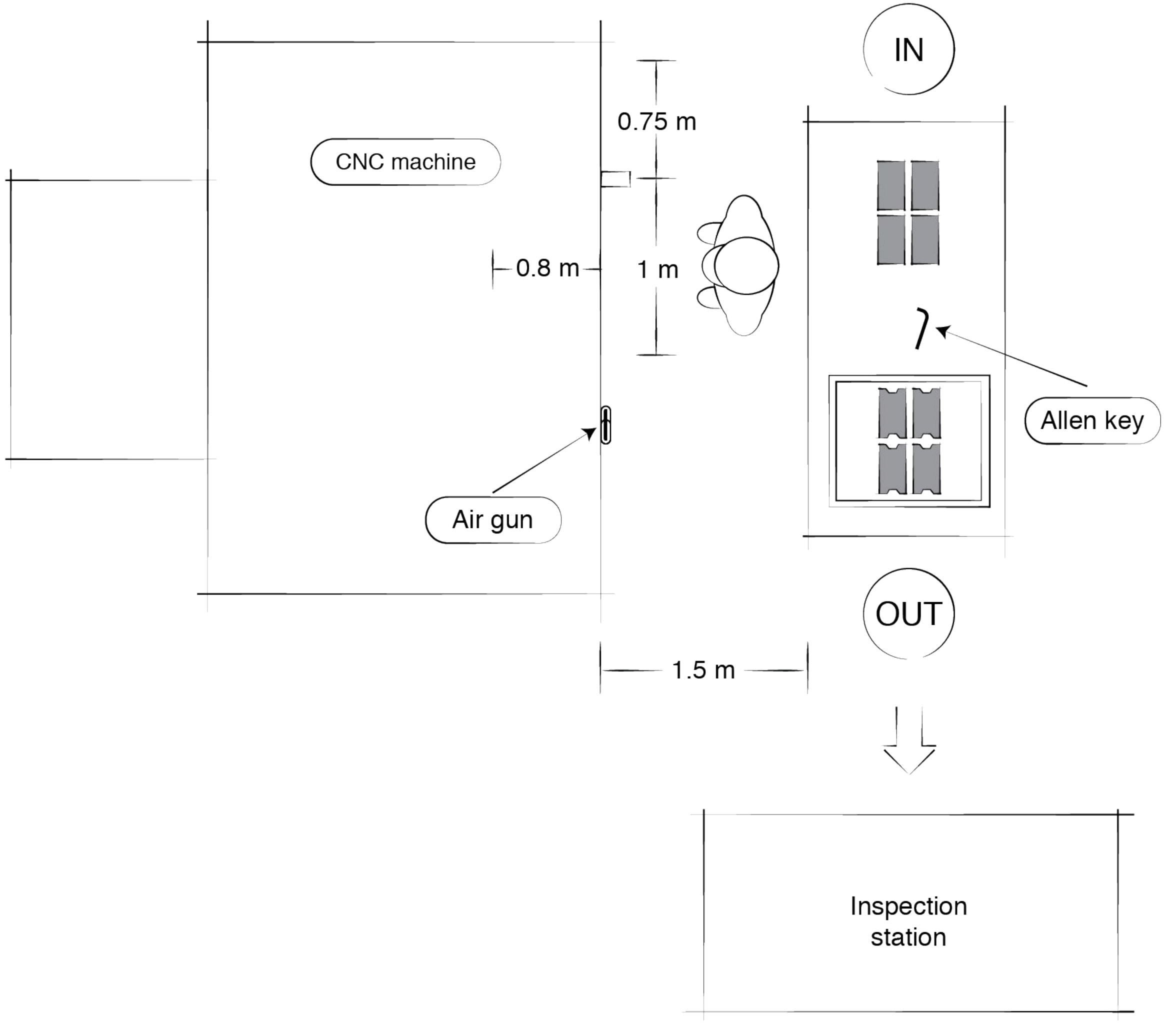
Customer

Operator who can bring tray of 60 parts to inspection station every 2 hours

Value-added time (s)	75
Nonvalue-added time (s)	18
TOTAL (s)	93

Manual Map - Layout





Robotic Map - Overview

Steps	Information to define in the robotic task map
High level robotic cell concept	
Concept	Cell components and concept
Robotic cell layout	
Sketch of robotic cell concept	What would be the spatial arrangement of the station?
Robotic task map	
1. Identify customer	What's the next step after the robotic cell finishes its task?
2. Define output	How does the customer define value? • Parts specifications • Part presentation • Pace/cycle time

Robotic Map - Overview

Steps	Information to define in the robotic task map
3. Define input	What's coming in at the robotic cell? • Parts (list of parts and specifications) • Part presentation • Pace/cycle time
4. Define process	• How are the parts processed? • What is the sequence of events happening at the station? • Which steps are value-added, and which are not?
5. Document information flow	• What information comes into the robotic cell, in what format, and where from? • What information goes out of the robotic cell, in what format, and where to? • Same thing within the robotic cell.
6. Measure KPIs	• What are the target KPIs? • How will we measure them?
7. Summarize task map	Combine all the previous information into a visual representation of the map.

Robotic Map - Output

1. Identify cell customer

The cell customer is the operator who brings the machined parts to an inspection station.

2. Define valuable output

As the internal customer (the operator), what I need you to give me is…
A tray of 60 parts every 2 hours

so I can ...
Transport it to the inspection station.

Robotic Map - Output

Are the parts singulated? What is the space around them?

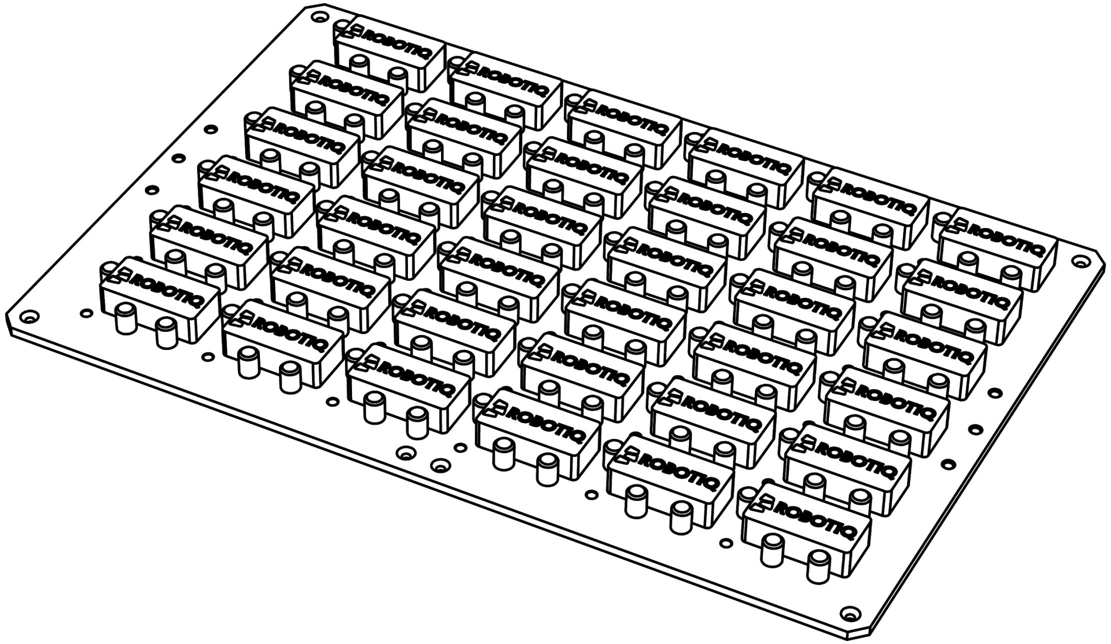
The parts will be laid side-by-side on a table according to a matrix (rows and columns) with enough space between them for the gripper's fingers to fit.

What is the actual presentation?

On a table

Is the output target moving? How so?

On a stable surface



Robotic Map - Input

Number of parts

4 different blanks

Characteristics of the parts

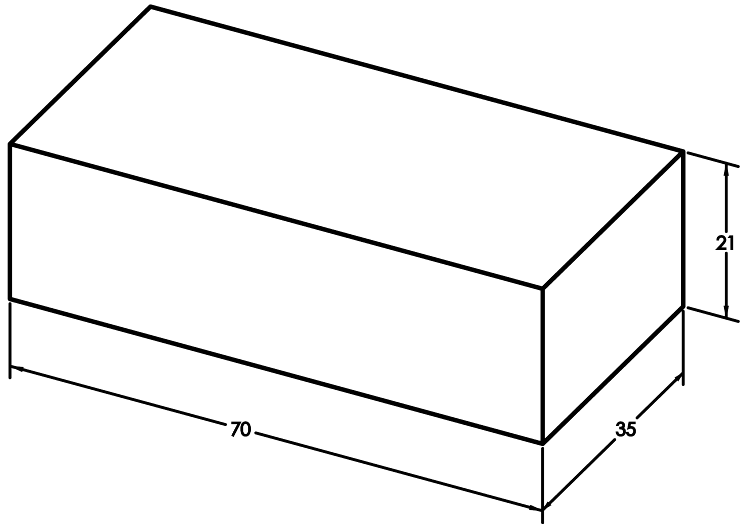
***Size*:**

max: 70 mm x 35 mm x 21 mm rectangular blocks

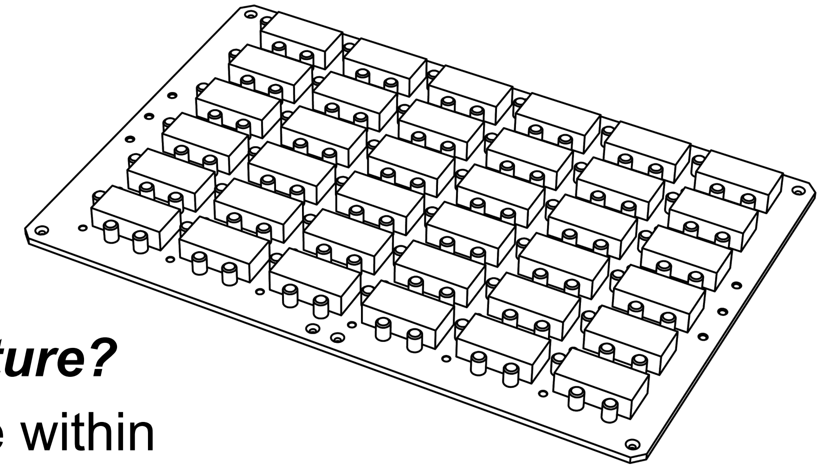
min: 69.8 mm x 34.8 mm x 20.1 mm rectangular blocks

Weight: max: 0.139kg

Material: Solid aluminum



Robotic Map - Input



Variation in time

Are there changeovers at this station?

2-3 times a week.

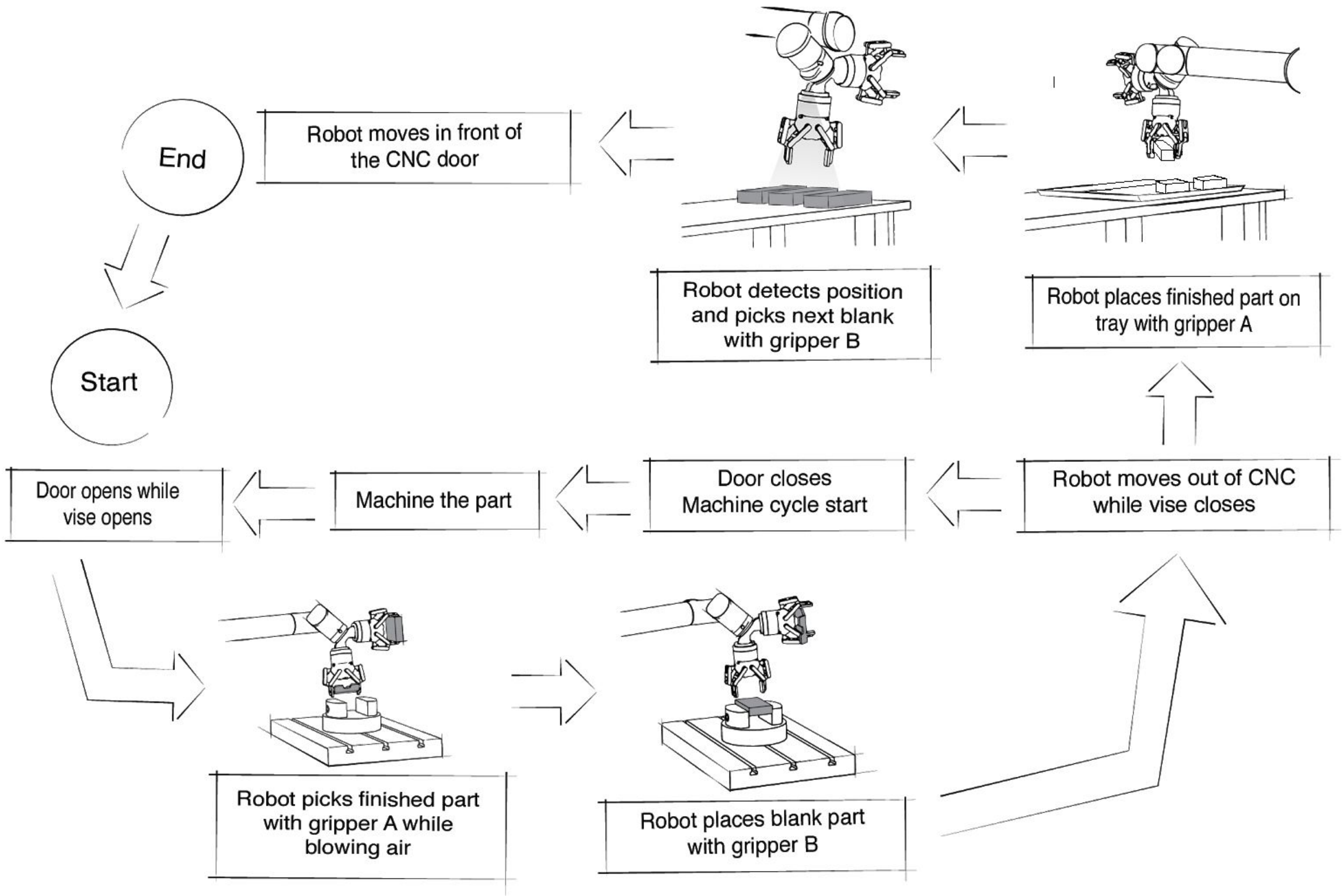
Are you planning to introduce new parts in the near future?

Maybe in 9-12 months, similar kind of blank at input, will be within min-max defined above.

Part presentation

The chosen concept is to position the parts in a tray.

Robotic Map - Process



Robotic Map - Process

	Non-Value-Added time (seconds)	Value-Added Time (seconds)	Total Time (seconds)
Door opens while vise opens	2	-	2
Robot picks finished part with gripper A while blowing air	5	-	5
Robot places blank part with gripper B	2	-	2
Robot moves out of CNC while vise closes	2	-	2
Door closes	2	-	2
CNC machining cycle starts	0	-	0
CNC machining of part while robot detects next blank position	-	75	75
Robot places finished part on tray*	0	-	0
Robot detects next blank position*	0	-	0
Robot picks new blank*	0	-	0
Robot moves in front of door*	0	-	0
TOTAL	13	75	88

The steps identified with a * are done at the same time as the part machining step, so their time does not add to the total process time; hence their time being 0.

Robotic Map - Information Flow

A summary of the input/output signals exchange for the robot communication can be found at the end of this document.

Information	Going from	Going to	Format	How it's used
Close CNC door	Robot controller	CNC controller	Digital I/O	When the robot is out of the CNC machine, the door can be closed
Start CNC cycle	Robot controller	CNC controller	Digital I/O	CNC can start the machining cycle
Dimensions of blank	Operator	Robot controller	Manual input in program via teach pendant	Modify gripper opening
Door is open	CNC controller	Robot controller	Digital I/O	Robot can enter the machine
Vise is open	CNC controller	Robot controller	Digital I/O	Robot can pick the part if it is inside the machine
Vise is closed	CNC controller	Robot controller	Digital I/O	Robot can open the gripper to release the part
Blank required at the infeed.	Robot controller	Operator	Message on teach pendant	A message appears on the teach pendant, informing the operator that all blank parts have been machined.
Outfeed full	Robot controller	Cell customer	Message on teach pendant	When parts are ready to be delivered to inspection station, a message is given to the operator

Robotic Map - KPIs

What is the target KPI?

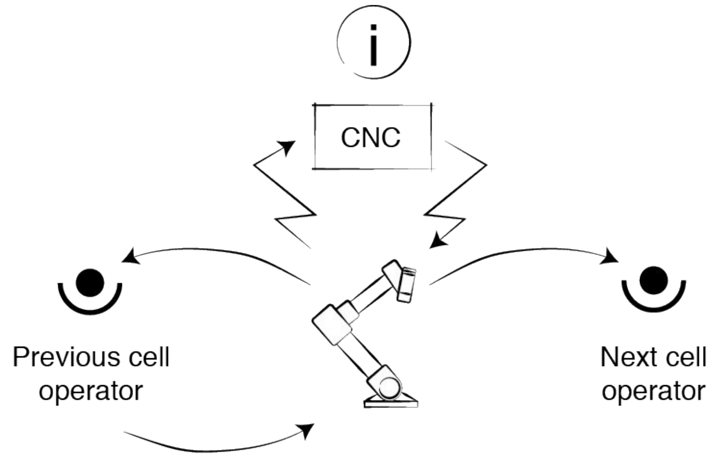
The KPI is the number of parts machined per day. The target number is up to 300 parts per day (running during breaks plus 1 tray unattended at night, plus shorter cycle time)

We are also targeting a first pass yield (FPY) of 97%.

How will the KPI be measured?

Using a counter in the robot's program.

Robotic Map



KPIs

Cell output: 300 parts / day
First pass yield: 97%

Input

- 4 part types
- Aluminium blocks
- Stacked on table

Process

-Door opens while vise opens
- Robot picks finished part with gripper A while blowing air
- Robot places blank part with gripper B
- Robot moves out of CNC while vise closes
- Door closes
- Machining cycle start
- Machine part
- Place finished part on tray
- Detect next blank position
- Pick new raw part
- Robot moves in front of door

Output

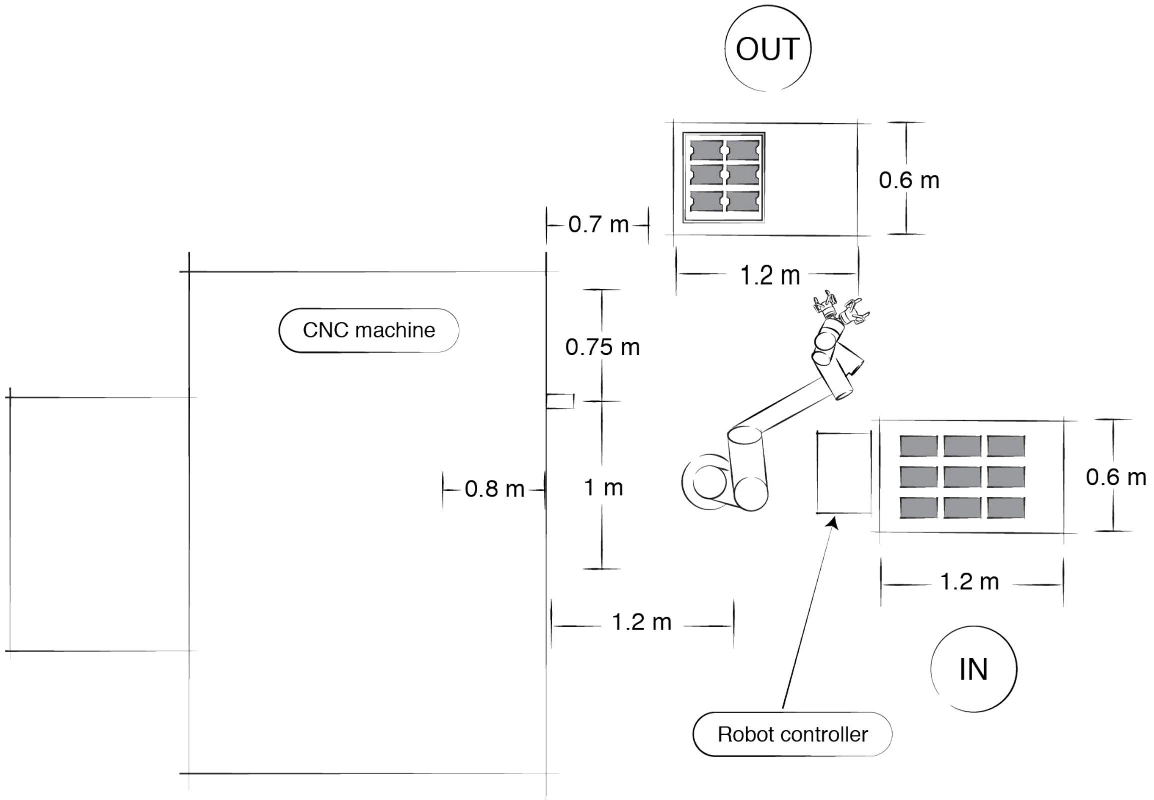
- Part family #AGSxxx on a tray

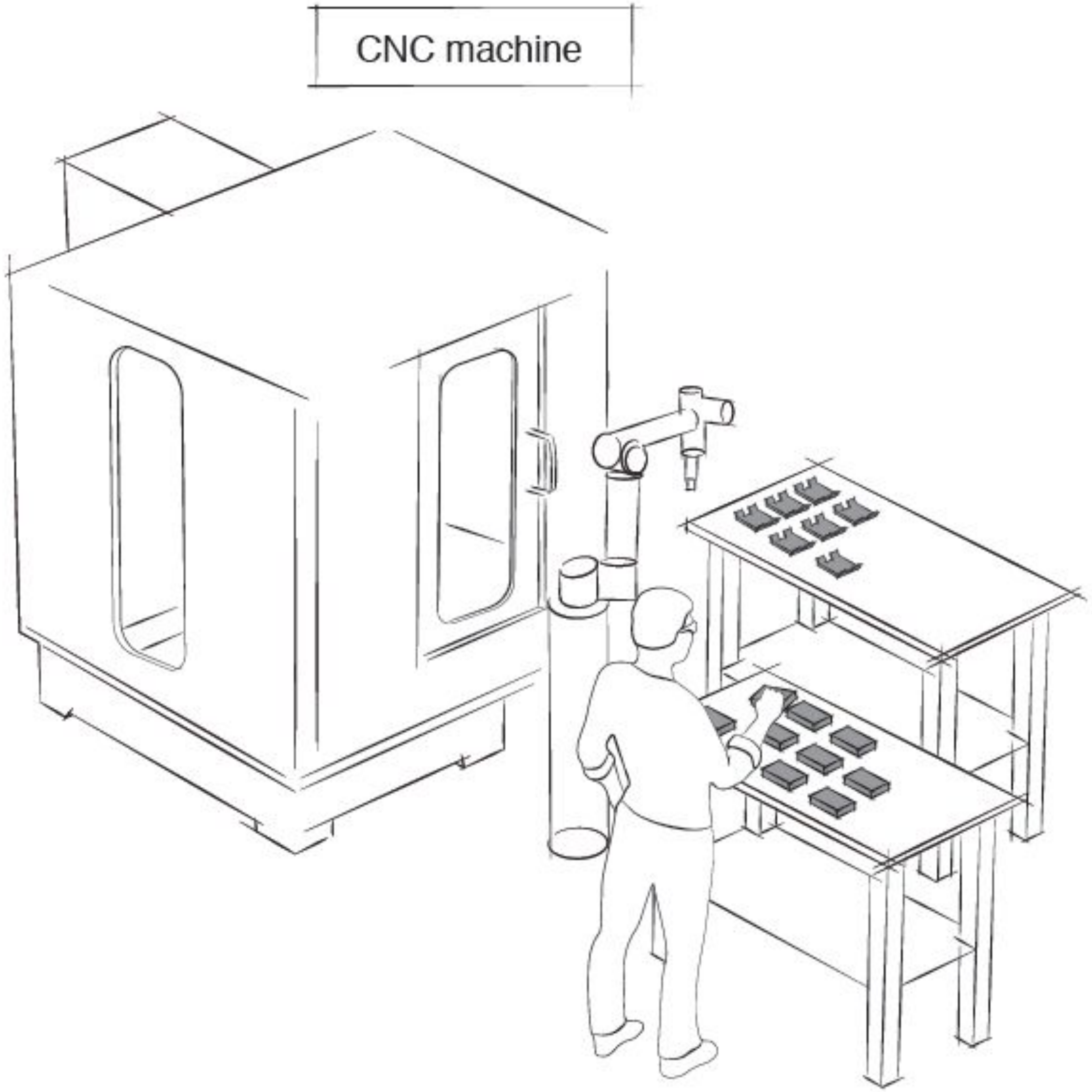
Customer

Operator who can bring tray of 60 parts to inspection station every 2 hours

Value-added time (s)	75
Nonvalue-added time (s)	13
TOTAL (s)	88

Robotic Layout





Manual/Robotic Comparison - Overview

Tasks map comparison	
1. Identify customer	Can we provide what our customer originally needed, or should we add an intermediary step?
2. Define output	Are we raising or lowering the amount of value provided to the customer's cell?
3. Define input	Do we need to change how the parts are presented?
4. Define process	Are we improving the process? Reducing the number of non value-added operations?
5. Document information flow	Do we need to change the input or output information? Do we generate new information that can be useful elsewhere?
6. Measure KPI	How does the robot cell affect the KPIs themselves? Do the KPIs need to be tracked differently?
Layout comparison	
	Will you need to add, modify or move equipment in this cell, or in neighboring cells?

Manual/Robotic Comparison

	Same	Different
1. Identify customer	The customer of the robotic cell is the same as the customer of the manual cell.	N/A
2. Define output	The parts provided to the robot cell and to the manual cell are the same. All the parts will still be produced.	The robot will not be able to stack the parts on top of each other. The tray will need to be slightly larger in order to receive the 60 parts.
3. Define input	The parts provided at the cell input will be the same. The robotic cell will be able to pick the complete range of input parts.	The part presentation will need to be different. Parts will need to be separated and spaced out on a single plane since the robot cannot work with stacked parts. The operator will need to come 3x more often to feed parts to the cell.

Manual/Robotic Comparison

	Same	Different
4. Define process	N/A	The steps taken by the robot will be different than the ones taken by the manual operator. A manual operator will not be needed anymore at the cell. Total cycle time should be shorter and more repeatable with the robotic cell (88 s vs. 93 s).
5. Document flow of information	N/A	Digital communication will need to be set up between the robot and CNC controllers. Operator will need to input the dimensions of the blank in robot controller when there is a changeover. Operator from input station will need to check on the infeed more frequently. Robot has no way to tell him if parts are missing.

Manual/Robotic Comparison

	Same	Different
6. Measure KPI	FPY should stay constant	Production capacity should go from 210 to 300 parts per day. Counter in robot program will be used to measure.
7. Layout	N/A	The CNC machine will stay at the same place. The table currently used by the operator will need to be moved, giving room to the robot. Marks on the ground will be added to identify robot workspace.

Finalizing Robotic Cell Design: Overview

Items	Description
Calculate ROI	Payback period: ((Cost of project)/(Monthly gains from project)) + Time from start of project to production ROI: Monthly gains X (12 months - project time) / project cost Calculate 12 months in, and 24 months in
De-risk the project	Identify and analyze unknowns, plan for validation or plan B
Part listing	What will you need for this project?
Freeze the MVRC	You’ve got a minimum viable cell design ready to move to the Integrate phase!

Finalizing Robotic Cell Design: ROI

Gross margin per item produced:	$10
Working days per month:	20
Robotic cell cost:	$115,000

	Manual	Robotic	Change
Daily production, after FPY	204	291	+87
Daily gross margin produced	$2,040	$2,910	+$870
Monthly gross margin produced	$40,800	$59,200	+$17,400

Finalizing Cell Design: Payback Period

$$\frac{\text{Cost of robot cell}}{\text{Monthly gains}} + \text{Months spent on Design, Integrate phases}$$

$$\frac{\$115{,}000}{\$17{,}400} + \textbf{3}\text{ months spent on Design, Integrate phases}$$

6.6 + 3 = **9.6 months payback period**

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Finalizing Cell Design: ROI over 12 months

$$\frac{\left(\text{Target period} - \text{Months spent on Design, Integrate phases}\right) \times \text{Gains per month}}{\text{Cost of robot cell}}$$

$$\frac{\left(12 - 3 = 9\right) \times \$17{,}400}{\$115{,}000}$$

$$\frac{\$156{,}600}{\$115{,}000} =$$

136% ROI
after 1 year

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Finalizing Cell Design: ROI over 24 months

$$\frac{\left(\text{Target period} - \text{Months spent on Design, Integrate phases}\right) \times \text{Gains per month}}{\text{Cost of robot cell}}$$

$$\frac{\left(24 - 3 = 21\right) \times \$17{,}400}{\$115{,}000}$$

$$\frac{\$365{,}400}{\$115{,}000} =$$

318% ROI
after 2 years

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Finalizing Robotic Cell Design - De-Risking

Question	Hypothesis	Confidence level	Impact on cell	Validation plan	Time and $ to validate it?
Will the robot be able to communicate with CNC controllers?	Yes	Medium	Critical	Connect controllers, make simple I/O exchange	Robot vendor can take 2 days, collaborating with CNC vendor to test communication. Will need to stop production by moments.
Will it be simple enough for the operator to enter the part dimensions when a changeover occurs?	Yes	High	Critical	Demo from partner	2-hour demo
Will the pneumatic vise work well?	Yes	Medium	Critical	Test from vise vendor	1/2 day trial on CNC, need to stop production
Will the cell reach the target cycle time?	Yes	High	Critical	Proof of concept from partner	2 working days from robot vendor. Will be able to reuse for production cell.

Finalizing Robotic Cell Design - Bill of Materials

- UR10 collaborative robot
- Stand for UR10
- CNC Machine Tending Kit
- Pneumatic/Hydraulic vise for CNC machine
- Robot ready interface for CNC machine

Signals Exchange Summary - Robot Communication

#	Information	From	To	Description
Di0	Request_Unload	CNC	Robot controller	The machining process is finished
Di1	Vise_Closed	Vise	Robot controller	The vise is closed
Di2	Door_Closed	Door sensor	Robot controller	The door is closed
Di3	Door_Open	Door sensor	Robot controller	The door is open

#	Information	From	To	Description
Do0	Loading_Complet	Robot controller	CNC	Start CNC cycle
Do1	Vise_Open_Close	Robot controller	Vise	Action on vise (0 = open, 1= close)
Do2	Open_Door	Robot controller	Door actuator valve	Activate the door actuator to open the door
Do3	Close_Door	Robot controller	Door actuator valve	Activate the door actuator to close the door

Freeze the Robotic Cell Design!

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