TECHNISCHE UNIVERSITÄT
IN DER KULTURHAUPTSTADT EUROPAS
CHEMNITZ

Faculty of Economics and Business Administration
Chair of Management Accounting and Control

Prof. Dr. Uwe Götze

IT-supported Evaluation of Material Flows and Process Chains

Case study:
Nischelangelo GmbH – Modelling with Umberto®

umberto®
know the flow.

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Guided by:	Submitted by: (Group 02)	Mtr. No.
Prof. Dr. Anja Schmidt	Kaustubh Sanjay Pawar	810063
Prof. Mr. Igor Borgardt	Kaustubh Balasaheb Pawar	804112
	Tanmay Dixit	807494
	Prajjwal Garag	812210
	Sushant Shetty	812096

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1. INTRODUCTION:

The Nischelangelo GmbH is a Chemnitz-based start-up which specializes in miniature bust production. The company has a variety of products, but the annual report and a thorough market analysis indicated a significant consumer interest and popularity for the Karl-Marx aluminum head or bust. As a result of this success, the stakeholders decide to invest in a dedicated machine for the production of the "Nischel".[1]

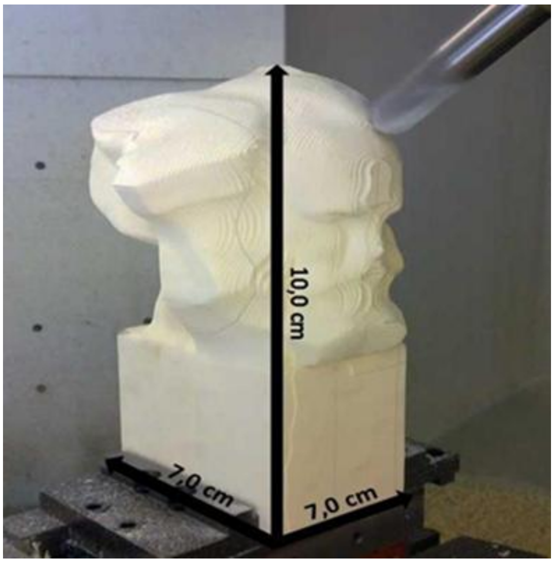


Figure 1: Nischel (Image: Danny Hösel)
Source: Nischelangelo GmbH

The company comes up with three probable production processes to fabricate the basic model: CNC Milling, Waterjet abrasive cutting and 3D Printing. The two partners, Anita Donatello and Paul Leonardo, hire a group of interns to select the optimal manufacturing process based on their manufacturing costs, efficiency and effectiveness. For this task, Umberto® software is to be used, to accurately visualize and analyze the entire production process, along with the associated materials, energy flows and costs. The software facilitates clear presentation of all the parameters involved and results.

1.1. Aim:

The aim of this report is to evaluate the three proposed processes, CNC Milling, Waterjet Abrasive Cutting and 3D Printing, using the Umberto® software, and to identify the optimal manufacturing process by analyzing the material, cost and energy flows using sensitivity analysis.[1]

1.2. Objectives:

Task 1: Outline the key input and output parameters, cost considerations, and production time along with Umberto® modelling.

(Tanmay Dixit)

Task 2: Calculation and comparison of unit costs for different production volumes for the three alternative processes, including the critical production quantities.

Task 3: Carry out Material & Energy Flow Cost Accounting (MFCA) for each process, considering volume of 20,000 units.

Task 4: Conduct research on the existing Life Cycle (impact) Assessment methods and tools, exploring their potentials and limitations. Propose strategies to improve resource efficiency, cost reduction and sustainability.

1.3. Inputs:

Based on comprehensive internet research, following input data was found for the three alternative processes:

Electricity Cost = 0.25 €/kWh

Aluminum Profile Cost = 16 €/block

Aluminum Powder Cost= 160 €/kg

Argon Gas Cost = 0.4 €/l

Abrasive Granules Cost = 0.25 €/kg

Description	CNC	Water Jet Cutting	3D Printing
Intial Cost (Euro)	350,000	460,000	67,000
Liquidation Value	45,000	30,000	-
Economic life	9	9	9
Annual Maintainace	7%	7%	7%
Interest Cost	6%	6%	6%
Max temporal utilization per year	70%	85%	90%
Power Input (KW)	25	17	10
Energy Efficiency	75%	80%	95%
Other Material	-	Abrasive (Kg/hr)	Argon (l/hr)
		45	49
Production time for 1 cycle (min)	12	9	60
Piece Produce in one cycle	1	1	3
Material Used (Kg aluminum)	0.14	0.14	0.092
Material Waste	0.05	0.05	-

Table 1: Given Data by Nischelangelo GmbH[1]

After the basic form of the bust has been fabricated, the heads are painted by hand in the next step. Each “Nischel” requires 30 minutes of working time and 0.05 l of paint.

Paint Cost = 50 €/l

Paint Efficiency = 96% (4% dries in can)

Painting Wage Cost = 38 €/hr

(Tanmay Dixit)

In the next and final step, the “Nischel” is sent for packaging. The packaging time per unit is 2 minutes.

Packaging Material Cost = 0.02 €/head

Packaging Labour Cost = 25 €/hr

2. METHODS:

To ensure consistent results, the software follows a structured, step-by-step methodology. Once the process is completed, it automatically calculates the cost and material flow for the corresponding manufacturing process. This methodology is identical across all three tasks.

2.1. Step 1:

Initially, all process chains were modelled within the Umberto® interface, as shown in the figures. The built-in functions - input, output, connectors, and arrows-- were utilized to create and finalize the flow.

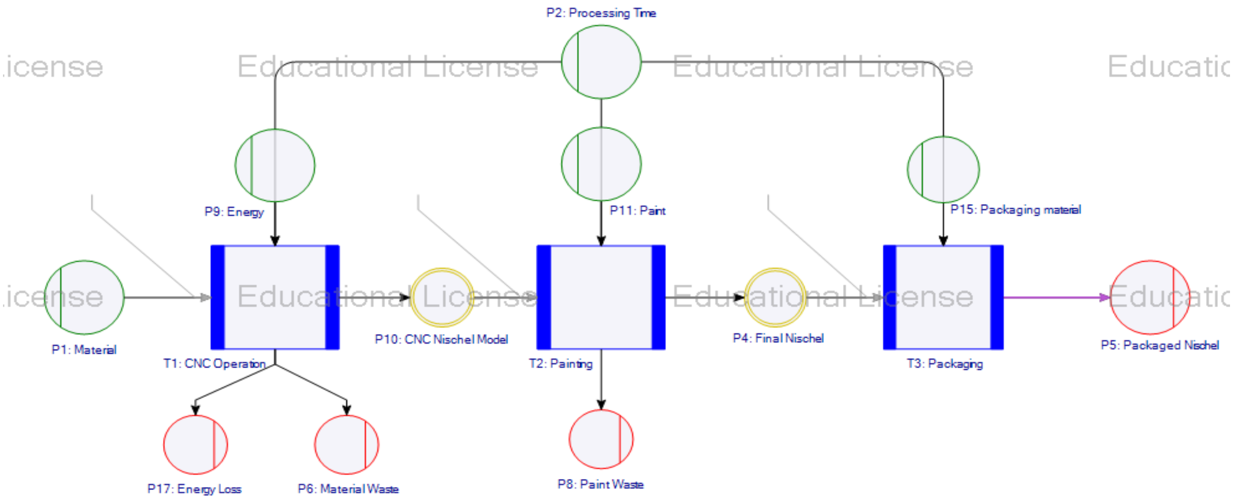


Figure 2: CNC Milling Process Flow
Source: Umberto®

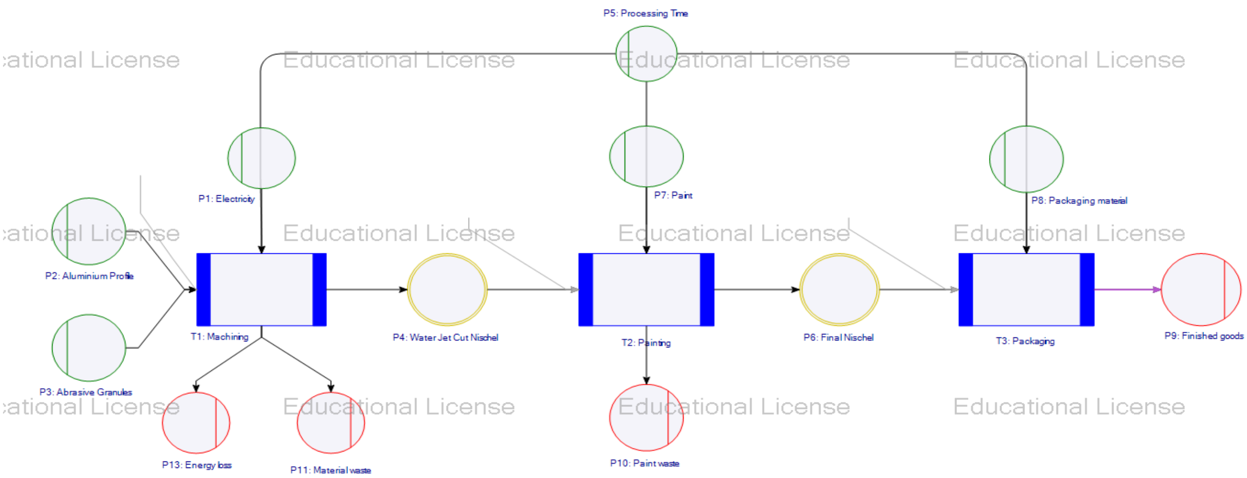


Figure 3 Waterjet Cutting Process Flow
Source: Umberto®

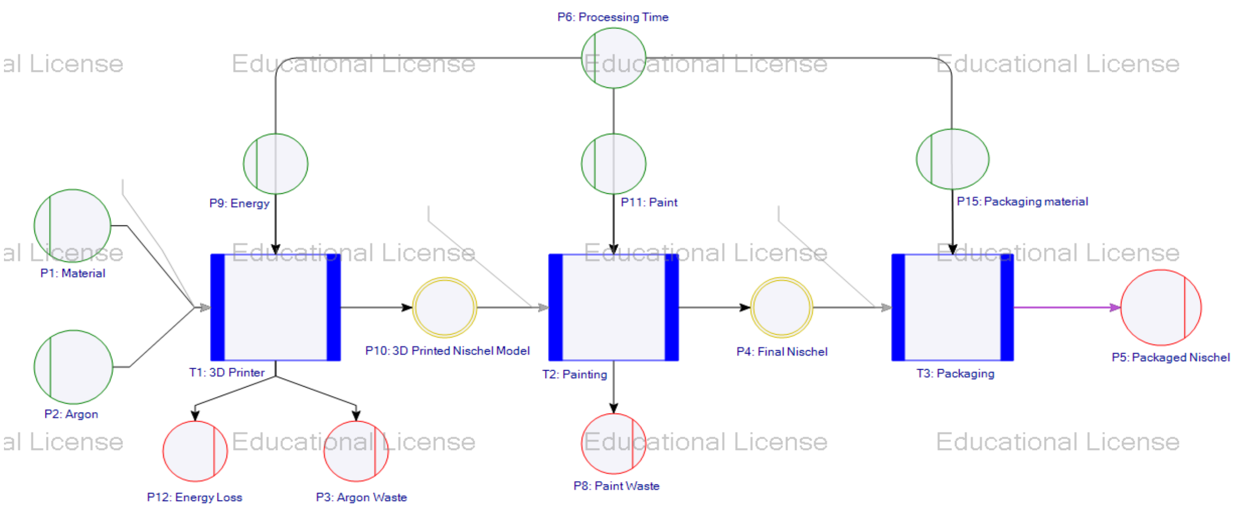


Figure 4: 3D Printing Process Flow
Source: Umberto®

2.2. Step 2:

To establish the process flow, it is essential to create the corresponding "Materials" and "Cost Factors." During this setup, units and unit prices are assigned to each material, and cost factors are categorized into fixed and variable types.

Process	Input Material	Output material	Wastage
CNC	Aluminum profile	Machined head	Chip wastage
	Electricity		Electricity waste
Water jet	Aluminum profile	Machined head	Chip wastage
	Abrasive granules		Abrasive granules waste
	Electricity		Electricity waste
3D Printing	Aluminum powder	3D Printed head	-
	Electricity		Electricity waste
	Argon		Argon Waste
Painting	Process head	Painted head	-
	Paint		Dried Paint
Packaging	Painted head	Final packaged head	-
	Packaging Material		Rejected material

Table 2 Input and Output variables for all the production processes
Source: Created by authors from the given data

2.3. Step 3:

Using the created materials relevant inputs and outputs are assigned in the specification editor for the desired process.

2.3.1 CNC Milling:

Var	Material	Place	Material Type	Unit
A00	Depreciation	CI	Fixed	EUR
A02	Maintenance Cost	CI	Fixed	EUR
A03	Imputed Interest	Cl	Fixed	EUR
X00	Electricity	Energy	Good	kWh
X01	Aluminum Profile	Material	Good	kg
X02	Processing Time	Process Time: CNC	Good	hour

Table 3: Input variables for the CNC Milling process
Source: Created by authors from the given data

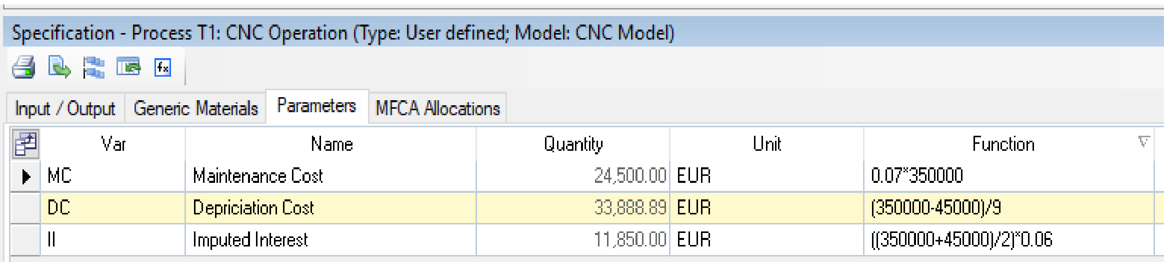


Figure 5: Parameters defined for the CNC Milling process
Source: Umberto®

Var	Material	Place	Material Type	Unit
Y00	Material Waste	Material Waste	Material Loss	kg
Y01	Electricity Loss	Energy Loss	Material Loss	kWh
Y02	Machined Head	CNC Nischel Model	Good	unit

Table 4: Output variables for the CNC milling process
Source: Created by authors from the given data

2.3.2. Waterjet Cutting:

Var	Material	Place	Material Type	Unit
A00	Depreciation	CI	Fixed	EUR
A01	Maintenance Cost	CI	Fixed	EUR

(Kaustubh Sanjay Pawar)

A02	Imputed Interest	Cl	Fixed	EUR
X00	Electricity	Energy	Good	kWh
X01	Abrasive Granules	Abrasive Granules	Good	kg
X02	Aluminum Profile	Material	Good	kg
X03	Processing Time	Process Time: Waterjet	Good	hour

Table 5: Input variables for the Waterjet Cutting process
Source: Created by authors from the given data

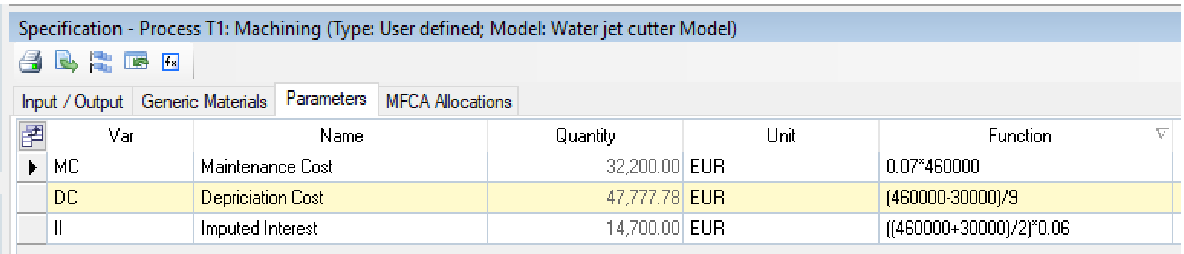


Figure 6: Parameters defined for the Waterjet Cutting process
Source: Umberto®

Var	Material	Place	Material Type	Unit
Y01	Material Waste	Material Waste	Material Loss	kg
Y02	Waste Abrasive granules	Material Waste	Material Loss	kg
Y03	Electricity Loss	Energy Loss	Material Loss	kWh
Y04	Machined Head	Waterjet Nischel Model	Good	unit

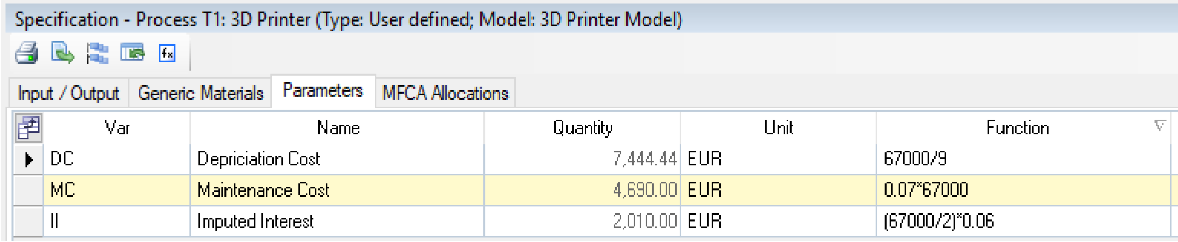
Table 6: Output variables for the Waterjet Cutting process
Source: Created by authors from the given data

2.3.3. 3D Printing:

Var	Material	Place	Material Type	Unit
A00	Depreciation	CI	Fixed	EUR
A01	Imputed Interest	CI	Fixed	EUR
A02	Maintenance Cost	Cl	Fixed	EUR
X00	Aluminum Powder	Material	Good	kg
X01	Argon Gas	Argon Gas	Good	l
X02	Electricity	Energy	Good	kWh
X03	Processing Time	Process Time: 3D Printing	Good	hour

Table 7: Input variables for the 3D Printing process
Source: Created by authors from the given data

(Kaustubh Sanjay Pawar)



Specification - Process T1: 3D Printer (Type: User defined; Model: 3D Printer Model)

Input / Output | Generic Materials | Parameters | MFCA Allocations

Var	Name	Quantity	Unit	Function
DC	Depriciation Cost	7,444.44	EUR	67000/9
MC	Maintenance Cost	4,690.00	EUR	0.07*67000
II	Imputed Interest	2,010.00	EUR	(67000/2)*0.06

Figure 7: Parameters defined for the 3D Printing process
Source: Umberto®

Var	Material	Place	Material Type	Unit
Y00	Argon Waste	Argon Waste	Material Loss	l
Y01	Electricity Loss	Energy Loss	Material Loss	kWh
Y02	Machined Head	3D Printed Nischel Model	Good	unit

Table 8: Output variables for the 3D Printing process
Source: Created by authors from the given data

2.3.4. Painting:

Var	Material	Place	Material Type	Unit
A01	Painting Labour	CI	Variable	EUR
X00	Machined Nischel Head	Machined Product	Good	unit
X01	Paint	Paint	Good	l
X02	Processing Time	Process Time: Painting	Good	hour

Table 9: Input variables for the painting process
Source: Created by authors from the given data

Var	Material	Place	Material Type	Unit
Y00	Painted Nischel Head	Painted Nischel Head	Good	unit
Y01	Dried Paint Waste	Paint Waste	Material Loss	l

Table 10: Output variables for the painting process
Source: Created by authors from the given data

2.3.5. Packaging:

Var	Material	Place	Material Type	Unit
A01	Packaging Labour	CI	Variable	EUR
X00	Painted Nischel Head	Painted Nischel	Good	unit
X01	Packaging Material	Packaging Material	Good	unit
X02	Processing Time	Process Time: Packaging	Good	hour

Table 11: Input variables for the packaging process
Source: Created by authors from the given data

(Kaustubh Sanjay Pawar)

Var	Material	Place	Material Type	Unit
Y00	Packaged Nischel	Packaged Nischel	Reference Flow (Good)	unit

Table 12: Output variables for the packaging process
Source: Created by authors from the given data

2.4. Step 4:

After assigning the materials, user-defined functions are added to produce accurate results based on the relationship specified between the input and output materials, as outlined below.

2.4.1. CNC Milling:

```
;CNC Operation Functions

;Aluminium Block Waste
Y00 = Y02*(0.14/3)

;Aluminium Block
X01=Y02*0.14

;Electricity Consumption
X00=25*((12*(Y02))/60)

;Cycle Time
X02=(Y02*12)/60

;Electricity Waste
Y01=25*((12*(Y02))/60)*0.25

;Depriciation Cost
A00=DC*1

;Imputed Interest
A03=II*1

;Maintenance Cost
A02=MC*1

;System Cost
A04=A00+A02+A03
```

Figure 8: User-defined functions for CNC Milling
Source: Umberto®

2.4.2. Waterjet Cutting:

```
;Water Jet Cutting Functions

;Aluminium Consumption
X02=Y04*0.14

;Aluminium Waste
Y01=Y04*(0.14/3)

;Electricity Consumption
X00=17*((9*(Y04))/60)

;Electricity Loss
Y03=17*((9*Y04)/60)*0.20

;Abrasive Granules Consumption
X01=(Y04*45*9)/60

;Abrasive Granules Waste
Y02=X01

;Cycle Time
X03=((Y04*9)/60)

;Depriciation Cost
A00=DC*2

;Imputed Interest
A02=II*2

;Maintenance Cost
A01=MC*2

;System cost
A03=A00+A01+A02
```

Figure 9: User-defined functions for Waterjet Cutting
Source: Umberto®

2.4.3. 3D Printing:

```
;3D Printing Functions

;Aluminium Powder
X00=Y02*0.092

;Electricity consumption
X02=(10/3)*Y02

;Electricity loss
Y01=(10/3)*0.05*Y02

;Argon consumption
X01=(X00/0.092)*(49/3)

;Cycle time
X03=Y02/3

;Depreciation cost
A00=DC*1

;Imputed interest
A01=II*1

;Maintenance cost
A02=MC*1

;Argon Waste
Y00=X01

;System cost
A03=A00+A01+A02
```

Figure 10: User-defined functions for 3D Printing
Source: Umberto®

2.4.4. Painting:

```
;Painting Functions

;Paint Waste
Y01=0.05*Y00*0.04

;Painted Nischel
X00=Y00

;Cycle Time
X02=(30*Y00)/60

;Paint Consumption
X01=0.05*1.04*Y00

;Labour Cost
A00=X02*38
```

Figure 11: User-defined functions for Painting
Source: Umberto®

2.4.5. Packaging:

```
;Packaging Functions

;Packaged Nischel
X01=Y00
X00=Y00

;Cycle Time
X02=((2*Y00)/60)

;Labour Cost
A00=X02*25
```

Figure 12: User-defined functions for Packaging
Source: Umberto®

2.5. Step 5:

Once the process chains were finalized and the materials, functions, and units were assigned, a manual flow step was added at the end. In this step, the required output quantities for different production volumes were entered to generate the relevant data.

3. RESULTS:

After entering all the inputs, the following results were obtained:

3.1. Task 1: Which is the profitable manufacturing process for 20,000 production volume

To determine a profitable manufacturing process, we calculated the total cost using the provided data. The total cost is the sum of variable costs and fixed costs. The variable costs include material costs, energy, and labor, while the fixed costs account for initial investment and maintenance expenses.

In addition to the total cost, we also calculated the processing time for each process based on the given inputs. Below are the fixed costs, variable costs, and inventory for a production volume of 20,000 units, calculated using the Umberto software.

3.1.1. Fixed Cost:

The fixed cost for producing 20,000 pieces has been calculated and broken down into depreciation, imputed interest, and maintenance costs. These values are derived based on the initial investment.

M	Cost	Value	
Fixed Cost: 70,238.89 EUR			
	Depriciation	33,888.89 EUR/year	T1: CNC Operation
	Imputed Interest	11,850.00 EUR/year	T1: CNC Operation
	Maintenance Cost	24,500.00 EUR/year	T1: CNC Operation

Figure 13: Fixed Cost CNC Milling
Source: Umberto®

Fixed Cost: 94,677.78 EUR			
	Depriciation	47,777.78 EUR/year	T1: Machining
	Imputed Interest	14,700.00 EUR/year	T1: Machining
	Maintenance Cost	32,200.00 EUR/year	T1: Machining

Figure 14: Fixed Cost Water Jet Cutting
Source: Umberto®

Fixed Cost: 14,144.44 EUR			
	Depriciation	7,444.44 EUR/year	T1: 3D Printer
	Imputed Interest	2,010.00 EUR/year	T1: 3D Printer
	Maintenance Cost	4,690.00 EUR/year	T1: 3D Printer

Figure 15: Fixed Cost 3D Printing
Source: Umberto®

(Sushant Shetty)

3.1.2. Total Variable Cost:

Material Direct Cost: 397,400.00 EUR		
Aluminium	320,000.00 EUR	T1: CNC Operation
Electricity	25,000.00 EUR	T1: CNC Operation
Electricity loss	0.00 EUR	T1: CNC Operation
Material waste	0.00 EUR	T1: CNC Operation
Packaging Material	400.00 EUR	T3: Packaging
Paint	52,000.00 EUR	T2: Painting
Processing Time	0.00 EUR	Multiple processes (T1: CNC Operation, T2: Painting, T3: Packaging)
Waste_Paint	0.00 EUR	T2: Painting
Variable Process Cost: 396,666.67 EUR		
Packaging Labour	16,666.67 EUR	T3: Packaging
Painting Labour	380,000.00 EUR	T2: Painting

Figure 16: Total Variable cost CNC Milling
Source: Umberto®

Material Direct Cost: 418,900.00 EUR		
Processing Time	0.00 EUR	Multiple processes (T1: Machining, T2: Painting, T3: Packaging)
Packaging material	400.00 EUR	T3: Packaging
Paint	52,000.00 EUR	T2: Painting
Abrasive Granules	33,750.00 EUR	T1: Machining
Electricity	12,750.00 EUR	T1: Machining
Aluminium Profile	320,000.00 EUR	T1: Machining
Electricity loss	0.00 EUR	T1: Machining
Waste_Paint	0.00 EUR	T2: Painting
Material waste	0.00 EUR	T1: Machining
Waste_abrasive_granules	0.00 EUR	T1: Machining
Variable Process Cost: 396,666.67 EUR		
Packaging Labour	16,666.67 EUR	T3: Packaging
Painting Labour	380,000.00 EUR	T2: Painting

Figure 17: Total Variable cost Water Jet Cutting
Source: Umberto®

Material Direct Cost: 494,133.33 EUR		
Aluminium Powder	294,400.00 EUR	T1: 3D Printer
Argon	130,666.67 EUR	T1: 3D Printer
Argon Waste	0.00 EUR	T1: 3D Printer
Electricity	16,666.67 EUR	T1: 3D Printer
Electricity loss	0.00 EUR	T1: 3D Printer
Packaging Material	400.00 EUR	T3: Packaging
Paint	52,000.00 EUR	T2: Painting
Processing Time	0.00 EUR	T3: Packaging
Processing Time	0.00 EUR	T2: Painting
Processing Time	0.00 EUR	T1: 3D Printer
Waste_Paint	0.00 EUR	T2: Painting
Variable Process Cost: 396,666.67 EUR		
Packaging Labour	16,666.67 EUR	T3: Packaging
Painting Labour	380,000.00 EUR	T2: Painting

Figure 18: Total Variable cost 3D Printing
Source: Umberto®

3.1.3. Inventory calculated for all manufacturing processes:

Calculated at a production volume of 20,000 units, the values in the column represent the amount of material used in the production.

M	Material	Value	Unit	Process
	Aluminium	2,800.00	kg	T1: CNC Operation
	Electricity	100,000.00	kWh	T1: CNC Operation
	Packaging Material	20,000.00	unit	T3: Packaging
	Paint	1,040.00	l	T2: Painting
	Processing Time	52,800,000.0	s	Multiple processes (T1: CNC Operation, T

M	Material	Value	Unit	Process
	Electricity loss	25,000.00	kWh	T1: CNC Operation
	Material waste	933.33	kg	T1: CNC Operation
	Packaged Nischel	20,000.00	unit	T3: Packaging
	Waste_Paint	40.00	l	T2: Painting

Figure 19: Inventories CNC Milling
Source: Umberto®

M	Material	Value	Unit	Process
	Abrasive Granules	135,000.00	kg	T1: Machining
	Aluminium Profile	2,800.00	kg	T1: Machining
	Electricity	51,000.00	kWh	T1: Machining
	Packaging material	20,000.00	unit	T3: Packaging
	Paint	1,040.00	l	T2: Painting
	Processing Time	666.67	hour	T3: Packaging
	Processing Time	10,000.00	hour	T2: Painting
	Processing Time	3,000.00	hour	T1: Machining

M	Material	Value	Unit	Process
	Electricity loss	10,200.00	kWh	T1: Machining
	Material waste	933.33	kg	T1: Machining
	Packaged Nischel	20,000.00	unit	T3: Packaging
	Waste_abrasive_granules	135,000.00	kg	T1: Machining
	Waste_Paint	40.00	l	T2: Painting

Figure 20: Inventories Water Jet Cutting
Source: Umberto®

M	Material	Value	Unit	Process
	Aluminium Powder	1,840.00	kg	T1: 3D Printer
	Argon	326,666.67	l	T1: 3D Printer
	Electricity	66,666.67	kWh	T1: 3D Printer
	Packaging Material	20,000.00	unit	T3: Packaging
	Paint	1,040.00	l	T2: Painting
	Processing Time	62,400,000.0	s	Multiple processes (T1: 3D Printer, T2: Pai

M	Material	Value	Unit	Process
	Argon Waste	326,666.67	l	T1: 3D Printer
	Electricity loss	3,333.33	kWh	T1: 3D Printer
	Packaged Nischel	20,000.00	unit	T3: Packaging
	Waste_Paint	40.00	l	T2: Painting

Figure 21: Inventories 3D Printing
Source: Umberto®

3.1.4. Summary of Total cost for all three manufacturing processes:

Process	CNC Milling	Water Jet Cutting	3D Printing
Variable Cost	€ 7,94,066.67	€ 8,15,566.67	€ 8,90,800.00
Fixed Cost	€ 70,238.89	€ 94,677.78	€ 14,144.44
Total Cost	**€ 8,64,305.56**	**€ 9,10,244.44**	**€ 9,04,944.44**
Unit Cost	**€ 43.22**	**€ 45.51**	**€ 45.25**

Table 13: Total cost and Unit cost for all the manufacturing process

The above table clearly show that CNC Milling is the most profitable manufacturing option with a production volume of 20,000 units since it provides the lowest unit cost.

The machine processing, painting, and packaging times are all included in the overall production process time. A user-defined function was used to determine each process's processing time. Notably, all three production procedures have the same painting and packaging timelines.

(Sushant Shetty)

3.2. Task 1b: Which input variables have a significant influence on the costs and the (relative) profitability of the process options?

To determine which input variables significantly influence the costs and the relative profitability of the process options, we conducted a sensitivity analysis on key parameters such as abrasive, argon, and electricity. The analysis focused on both their costs and quantities to evaluate the trend in overall prices.

Sensitivity analysis of input variables are as follows:

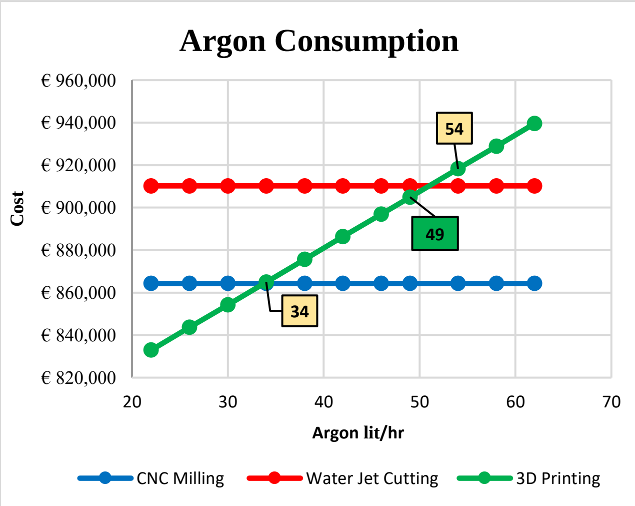


Figure 23: Argon Consumption sensitivity analysis
Source: By the author from the given data

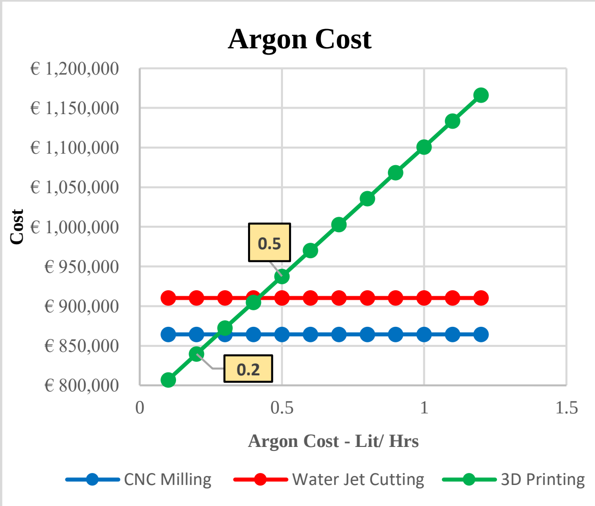


Figure 22: Argon Cost sensitivity analysis
Source: By the author from the given data

The graph shows that argon consumption affects only 3D printing costs, with no impact on CNC milling or water jet cutting. Reducing argon usage from 49 to 34 liters/hour or cost from 0.4 to 0.2 euro/lit makes 3D printing the most profitable option.

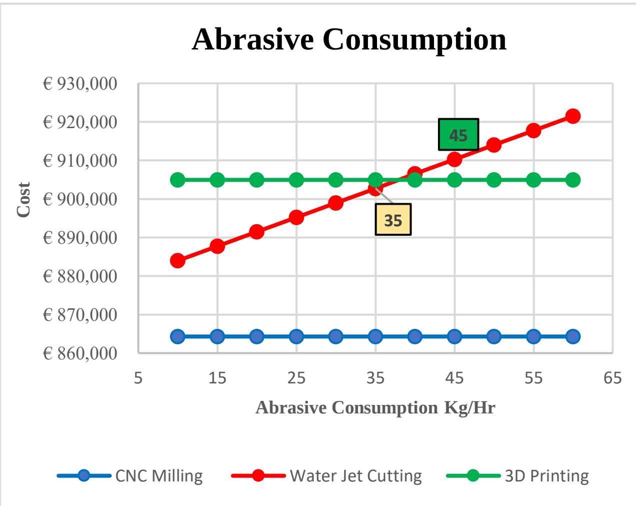


Figure 25: Abrasive Consumption sensitivity analysis
Source: By the author from the given data

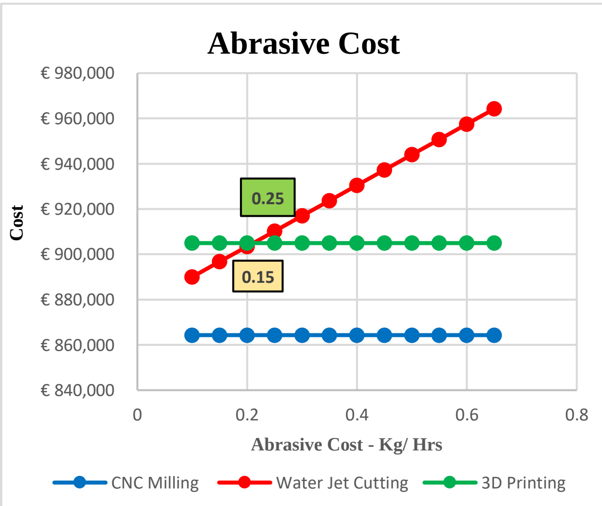


Figure 24: Abrasive Cost sensitivity analysis
Source: By the author from the given data

(Sushant Shetty)

The graph illustrates annual cost variations across all manufacturing processes, with noticeable changes only in water jet cutting. It also confirms that water jet cutting will not become profitable, regardless of changes in the cost or consumption of abrasives.

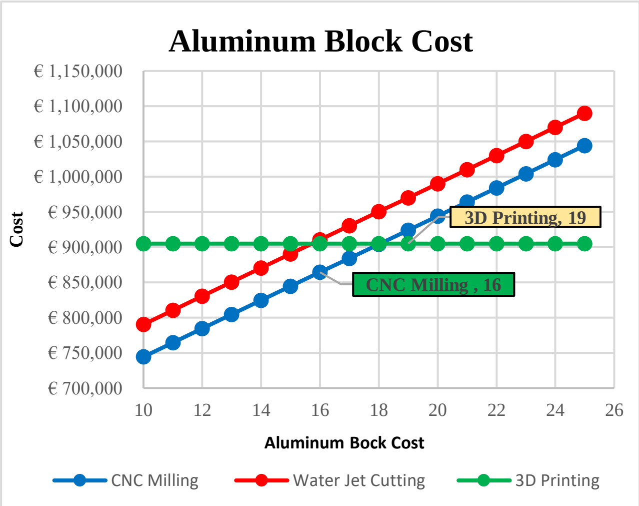


Figure 27: Aluminum Block Cost sensitivity analysis
Source: By the author from the given data

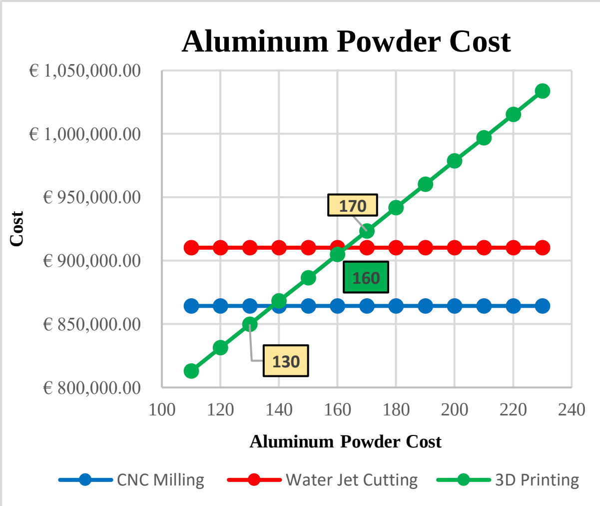


Figure 26: Aluminum Powder Cost sensitivity analysis
Source: By the author from the given data

The two graphs show changes in annual costs with variations in the prices of aluminum blocks and aluminum powder. If the price of the aluminum block increases to €19 or the aluminum powder cost decreases to €130/kg, 3D printing becomes the most profitable process.

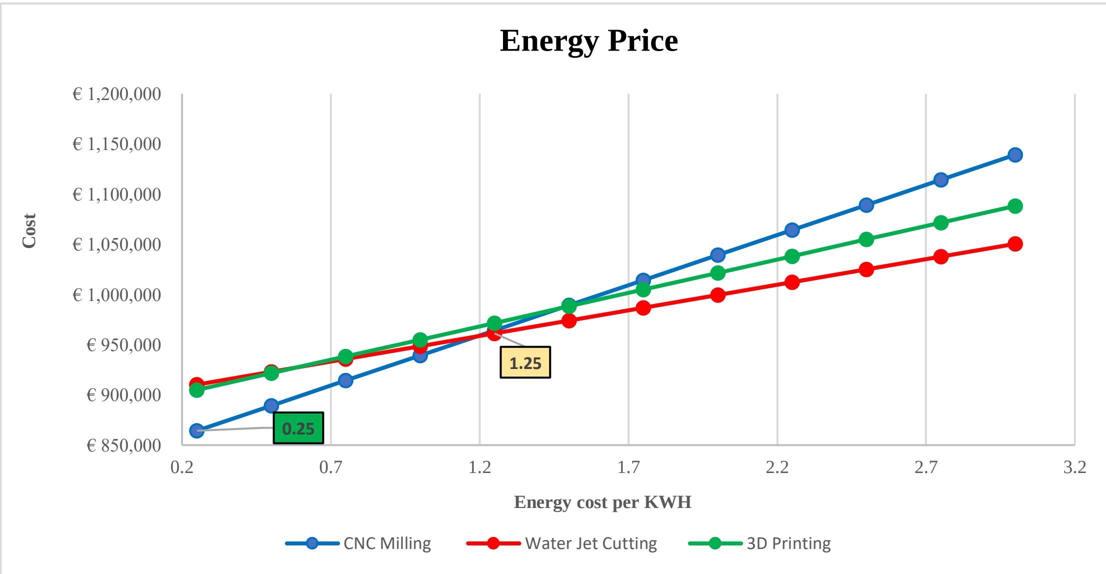


Figure 28: Electricity price sensitivity analysis
Source: By the author from the given data

This graph shows the annual cost variation with changes in electricity prices. Currently, electricity is procured at €0.25 per kWh. If future prices exceed €1.25 per kWh, water jet cutting becomes the most profitable process among all options.

(Sushant Shetty)

3.3. Task 2: Compare costs for each of the three-alternative depending on the production and sales volume.

In this task, we analyzed cost variations with changes in production volume, comparing the prices for the volumes specified by management: 15,000, 20,000, 35,000, and 50,000 units.

With changes in production volume, variable costs adjust accordingly, while fixed costs depend on machine capacity. If production exceeds the machine's capacity, the need for a new machine arises, leading to increased fixed costs reflected in depreciation, imputed interest, and maintenance expenses.

Assumptions:

a. The available number of working hours for each machine is calculated based on the maximum temporal utilization of 365 days for all production processes, as per the given data.
b. The number of working hours per day, working days per year, available shifts per day, and the number of employees per machine for painting, quality, and packaging are assumed for simplicity. These values are determined according to the total annual hours required.

3.3.1. Machine Capacity:

The capacity is calculated by given data of cycle time of each manufacturing process. With the req time for each process, calculation of machine capacity per year is made. Below table show us the maximum capacity of each manufacturing process per year.

Machine Capacity			
Process	**CNC Milling**	**Water Jet Cutting**	**3D Printing**
Piece Per Hr	5	6	3
Piece Per Year (365days, 24hrs)	30660	44676	23652
Required Machine	**1**	**1**	**1**

Table 14: Machine Capacity Source: By the author from the given data

E.g., 1.CNC | Piece Per Hour = (60/Cycle time of Production) * No of piece produced
= (60/12) * 1
= 5

2.CNC | Piece Per Year = Piece Per Hour * (24 * 365* Max temporal utilization)
= 5 * (24 * 365 * 70%)
= 30660

(Sushant Shetty)

With this capacity, we can calculate the required number of machines as production volume increases. The following graph illustrates the trend, showing how the machine count rises with higher production volumes.

No of Machine for the given volume			
Volume	**CNC Milling**	**Water Jet Cutting**	**3D Printing**
5000	1	1	1
15000	1	1	1
25000	1	1	2
30000	1	1	2
50000	2	2	3
55000	2	2	3
65000	3	2	3
75000	3	2	4
85000	3	2	4
95000	4	3	5

Table 15: Number of Machine required w.r.t Volume Source: By the author from the given data

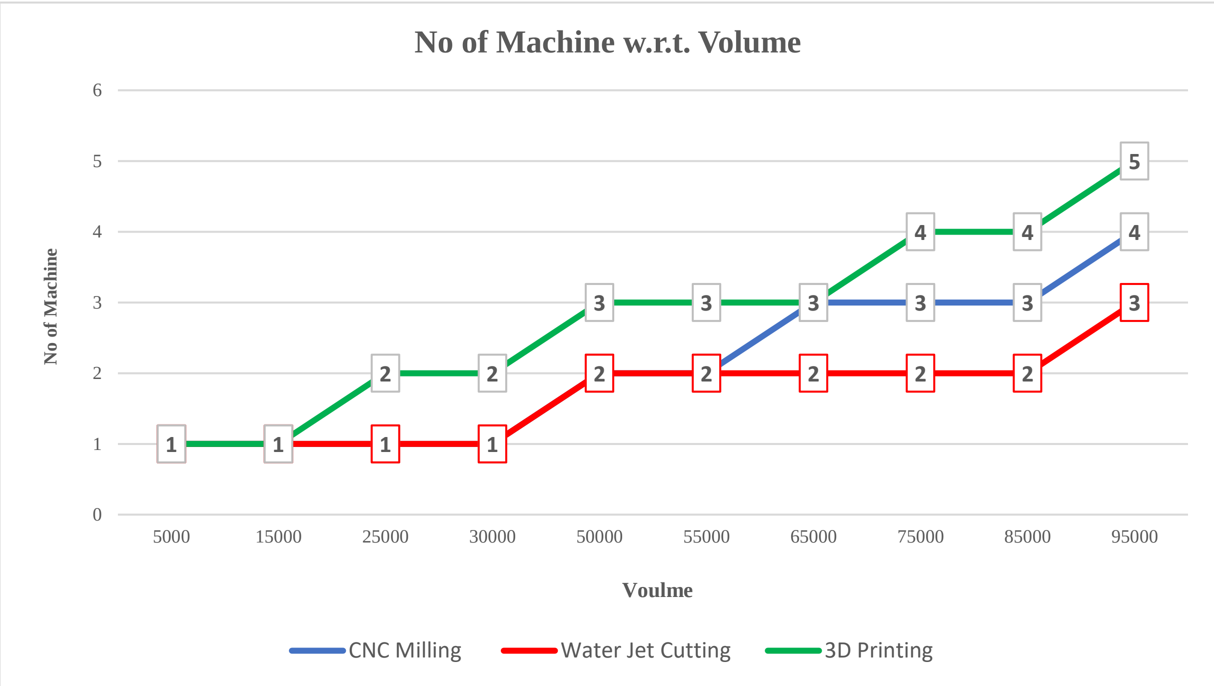


Figure 29: Graph of Production volume vs No of machine

From the above table, the required production hours for 3D printing exceed the available hours after 25,000 and 50,000 production volumes. As a result, a second machine is added after 25,000 units and a third machine after 50,000 units. Similarly, for CNC milling, a second machine is added after 32,000 units, and for water jet cutting, a second machine is added after 45,000 units.

(Sushant Shetty)

3.3.2. Critical Point of Production volume:

The critical point of production volume helps identify which process becomes more cost-effective as production volume increases. It marks the point where one process transitions to being cheaper than another. The following graph highlights two critical points for 3D printing, where it becomes the more expensive option as production volume rises. These critical volumes are 11,586 and 21,424 units.

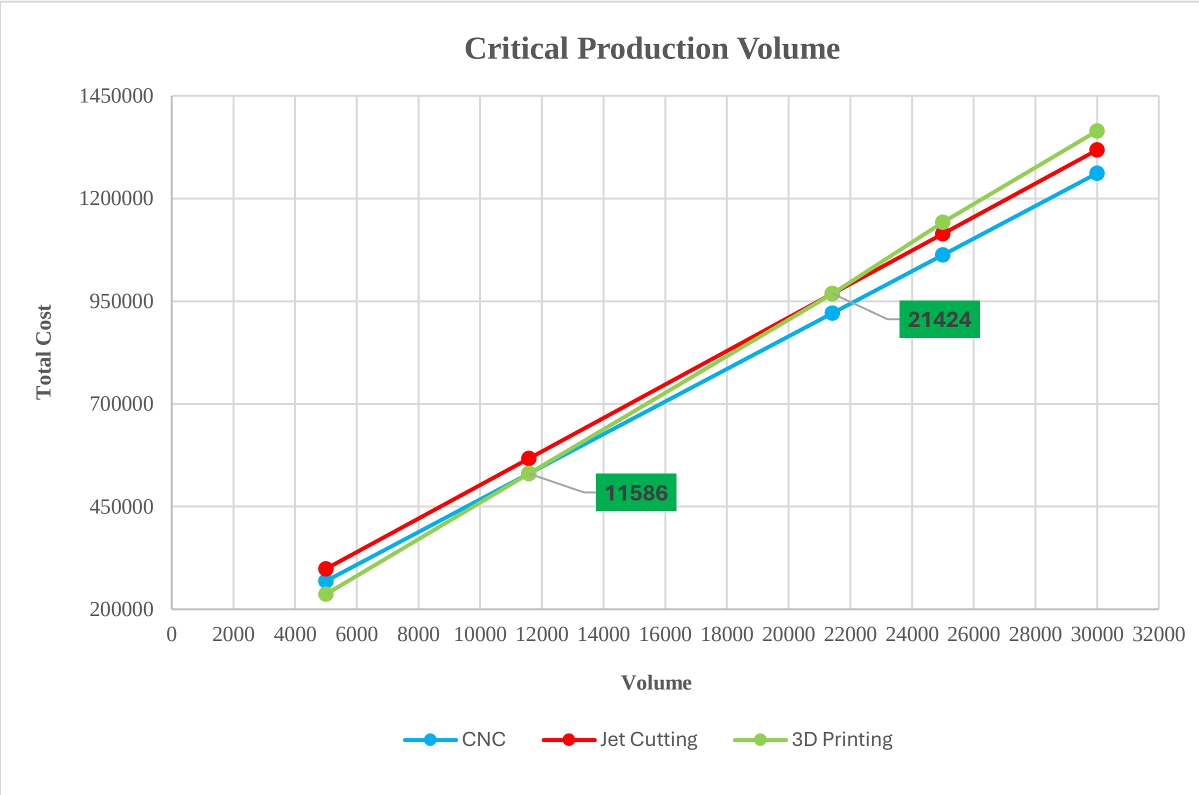


Figure 30: Critical Point of Production Volume

3.3.3. Total costs of all production processes for different production volumes:

3.3.3.1. CNC Milling (Images Source: Umberto®)

15000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (15,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	298,050.00 EU	298050.00
Variable Process Cost	367,738.89 EU	367738.89
Balance	**-665,788.89 E**	-665788.89

Figure 31: Cost Breakdown for CNC Milling at 15000 Production Volume

20000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (20,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	397,400.00 EU	397400.00
Variable Process Cost	466,905.56 EU	466905.56
Balance	**-864,305.55 E**	-864305.55

Figure 32: Cost Breakdown for CNC Milling at 20000 Production Volume

(Tanmay Dixit)

25000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (25,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	496,750.00 EU	496750.00
Variable Process Cost	566,072.22 EU	566072.22
Balance	**-1,062,822.22**	-1062822.22

Figure 33: Cost Breakdown for CNC Milling at 25000 Production Volume

30000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (30,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	596,100.00 EU	596100.00
Variable Process Cost	665,238.89 EU	665238.89
Balance	**-1,261,338.89**	-1261338.89

Figure 34: Cost Breakdown for CNC Milling at 30000 Production Volume

50000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (50,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	993,500.00 EU	993500.00
Variable Process Cost	1,132,144.44 E	1132144.44
Balance	**-2,125,644.44**	-2125644.44

Figure 35: Cost Breakdown for CNC Milling at 50000 Production Volume

3.3.3.2. Water Jet Cutting (Images Source: Umberto®)

15000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A10 (T3 -> P9)] (15,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	314,175.00 EU	314175.00
Variable Process Cost	392,177.78 EU	392177.78
Balance	**-706,352.78 E**	-706352.78

Figure 36: Cost Breakdown for Water Jet Cutting at 15000 Production Volume

20000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A10 (T3 -> P9)] (20,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	418,900.00 EU	418900.00
Variable Process Cost	491,344.44 EU	491344.44
Balance	**-910,244.44 E**	-910244.44

Figure 37: Cost Breakdown for Water Jet Cutting at 20000 Production Volume

25000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A10 (T3 -> P9)] (25,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	523,625.00 EU	523625.00
Variable Process Cost	590,511.11 EU	590511.11
Balance	**-1,114,136.11**	-1114136.11

Figure 38: Cost Breakdown for Water Jet Cutting at 25000 Production Volume

30000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A10 (T3 -> P9)] (30,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	628,350.00 EU	628350.00
Variable Process Cost	689,677.78 EU	689677.78
Balance	**-1,318,027.78**	-1318027.78

Figure 39: Cost Breakdown for Water Jet Cutting at 30000 Production Volume

50000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A10 (T3 -> P9)] (50,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	1,047,250.00 E	1047250.00
Variable Process Cost	1,181,022.22 E	1181022.22
Balance	**-2,228,272.22**	-2228272.22

Figure 40: Cost Breakdown for Water Jet Cutting at 50000 Production Volume

3.3.3.3. 3D Printing (Images Source: Umberto®)

15000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (15,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	370,600.00 EU	370600.00
Variable Process Cost	311,644.44 EU	311644.44
Balance	**-682,244.44 E**	-682244.44

Figure 41: Cost Breakdown for 3D Printing at 15000 Production Volume

20000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (20,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	494,133.33 EU	494133.33
Variable Process Cost	410,811.11 EU	410811.11
Balance	**-904,944.44 E**	-904944.44

Figure 42: Cost Breakdown for 3D Printing at 20000 Production Volume

25000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (25,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	617,666.67 EU	617666.67
Variable Process Cost	524,122.22 EU	524122.22
Balance	**-1,141,788.89**	-1141788.89

Figure 43: Cost Breakdown for 3D Printing at 25000 Production Volume

30000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (30,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	741,200.00 EU	741200.00
Variable Process Cost	623,288.89 EU	623288.89
Balance	**-1,364,488.89**	-1364488.89

Figure 44: Cost Breakdown for 3D Printing at 30000 Production Volume

50000

Accounting Item	Value	Expenses
Product: Packaged Nischel Model [A9 (T3 -> P5)] (50,000.00 unit)		
Revenue	0.00 EUR	
Material Direct Cost	1,235,333.33 E	1235333.33
Variable Process Cost	1,034,100.00 E	1034100.00
Balance	**-2,269,433.33**	-2269433.33

Figure 45: Cost Breakdown for 3D Printing at 50000 Production Volume

Process	Variable cost	Fixed cost	Total cost
5000			
CNC Milling	€ 39.70	€ 70,238.89	€ 2,68,755.56
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 2,98,569.44
3D Printing	€ 44.54	€ 14,144.44	€ 2,36,844.44
10000			
CNC Milling	€ 39.70	€ 70,238.89	€ 4,67,272.22
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 5,02,461.11
3D Printing	€ 44.54	€ 14,144.44	€ 4,59,544.44
15000			
CNC Milling	€ 39.70	€ 70,238.89	€ 6,65,788.89
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 7,06,352.78
3D Printing	€ 44.54	€ 14,144.44	€ 6,82,244.44
20000			
CNC Milling	€ 39.70	€ 70,238.89	€ 8,64,305.56
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 9,10,244.44
3D Printing	€ 44.54	€ 14,144.44	€ 9,04,944.44
25000			
CNC Milling	€ 39.70	€ 70,238.89	€ 10,62,822.22
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 11,14,136.11
3D Printing	€ 44.54	€ 28,288.89	€ 11,41,788.89

Process	Variable cost	Fixed cost	Total cost
30000			
CNC Milling	€ 39.70	€ 70,238.89	€ 12,61,338.89
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 13,18,027.78
3D Printing	€ 44.54	€ 28,288.89	€ 13,64,488.89
35000			
CNC Milling	€ 39.70	€ 1,40,477.78	€ 15,30,094.44
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 15,21,919.44
3D Printing	€ 44.54	€ 28,288.89	€ 15,87,188.89
40000			
CNC Milling	€ 39.70	€ 1,40,477.78	€ 17,28,611.11
Water Jet Cutting	€ 40.78	€ 94,677.78	€ 17,25,811.11
3D Printing	€ 44.54	€ 28,288.89	€ 18,09,888.89
45000			
CNC Milling	€ 39.70	€ 1,40,477.78	€ 19,27,127.78
Water Jet Cutting	€ 40.78	€ 1,89,355.56	€ 20,24,380.56
3D Printing	€ 44.54	€ 28,288.89	€ 20,32,588.89
50000			
CNC Milling	€ 39.70	€ 1,40,477.78	€ 21,25,644.44
Water Jet Cutting	€ 40.78	€ 1,89,355.56	€ 22,28,272.22
3D Printing	€ 44.54	€ 28,288.89	€ 22,55,288.89

Table 16: Total Cost for each process w.r.t volume change with Variable and Fixed Cost

As the production volume increases, the total process cost changes, leading to variations in the most efficient process for different volumes. The table above highlights the green-marked processes as the most efficient options among the three, based on the given production volumes

3.4. Task 3: Evaluating material and energy flow cost accounting for each process with respect to 20,000 units.

3.4.1. MFCA for CNC Milling:

	Carry over [EUR]	New costs [EUR]	Total in this QC [EUR]	Share of intermediates [EUR]	Share of intermediate material losses [EUR]	Share of products [EUR]	Share of material losses [EUR]
Quantity Centre: T1: CNC Operation							
Material costs	0.00	320,000.00	**320,000.00**	213,333.33	0.00	0.00	106,666.67
Energy costs	0.00	25,000.00	**25,000.00**	18,750.00	0.00	0.00	6,250.00
System costs	0.00	70,238.89	**70,238.89**	70,238.89	0.00	0.00	0.00
Waste management costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Total	**0.00**	**415,238.89**	**415,238.89**	**302,322.22**	**0.00**	**0.00**	**112,916.67**
Quantity Centre: T2: Painting							
Material costs	213,333.33	52,000.00	**265,333.33**	263,333.33	0.00	0.00	2,000.00
Energy costs	18,750.00	0.00	**18,750.00**	18,750.00	0.00	0.00	0.00
System costs	70,238.89	380,000.00	**450,238.89**	450,238.89	0.00	0.00	0.00
Waste management costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Total	**302,322.22**	**432,000.00**	**734,322.22**	**732,322.22**	**0.00**	**0.00**	**2,000.00**
Quantity Centre: T3: Packaging							
Material costs	263,333.33	400.00	**263,733.33**	0.00	0.00	263,733.33	0.00
Energy costs	18,750.00	0.00	**18,750.00**	0.00	0.00	18,750.00	0.00
System costs	450,238.89	16,666.67	**466,905.56**	0.00	0.00	466,905.56	0.00
Waste management costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Total	**732,322.22**	**17,066.67**	**749,388.89**	**0.00**	**0.00**	**749,388.89**	**0.00**

Table 17: MFCA for CNC Milling Source: Umberto®

(Tanmay Dixit)

	Share of products [EUR]	Share of material losses [EUR]	Total costs [EUR]
Material costs	263,733.33	108,666.67	372,400.00
Energy costs	18,750.00	6,250.00	25,000.00
System costs	466,905.56	0.00	466,905.56
Waste management costs	0.00	0.00	0.00
Other costs	0.00	0.00	0.00
Total	**749,388.89**	**114,916.67**	**864,305.55**

Table 18: CNC Milling printing Material loss representation Source: Umberto®

<u>Total Cost for 20000 units = 864305 €</u>

<u>Total Cost/unit = € 43.22</u>

QC1: CNC Milling Machine

Material Costs:

Material Input Cost = Prod. Volume x Cost of 1 Aluminum block in kg

= 20000 x 16 = 320000 €

Since 1/3rd of the material is removed as chip waste,

Product Flow = 320000 x (2/3) = 213333.33 €

Material Loss Flow = 320000 x (1/3) = 106666.33€

Energy Costs:

Total Input Energy Cost = Input Power x Production Time (hr) x Electricity Cost (€/kWh) x Prod. Volume

= 25 x (12/60) x 0.25 x 20000 = 25000 €/kWh

Considering energy efficiency of 75 %,

Product Flow = 25000 x 75 % = 18750 €

Energy Loss Flow = 23000 x 25 % = 6250 €

System Costs:

Since we assume no labour involved in the milling machining process, employee wage costs = 0 €

Fixed Costs = Depreciation + Maintenance + Imputed Interest

= 33888.89 + 24500 + 11850= 70238.89 €

Product Flow = 18750 €

Loss Flow = 0 €

QC2: Painting

Material Costs:

Cost of previous QC (material) = 213333.33 €

Paint Cost = Volume of paint required (liters) x Cost of paint/liter

= 1040 x 50 = 5200 €

(Tanmay Dixit)

Total Material Input Cost	= Cost of previous QC + Paint Cost
	= 213333.33 + 52000= 265333.33€
Product Flow	= Cost of previous QC + (Volume of paint x Cost of paint/liter x Prod. Volume)
	= 213333.33 + (0.05 x 50 x 20000) = 263333.33 €
Material Loss Flow	= Total Input Cost – Product Flow
	= 265333.33– 263333.33 = 2000 €

Energy Costs:

Since no electricity is used in the painting process,

Product Flow	= Product Flow (energy) of previous QC = 18750 €
Energy Loss Flow	= 0 €

System Costs:

Cost of previous QC (system)	= 70238.89 €
Employee Wage Costs	= Prod. Volume x Time taken for painting 1 unit (hr) x Wage Cost (€/hr)
	= 20000 x (30/60) x 38 = 380000 €
Total Input Cost	= Cost of previous QC + Employee Wage Cost
	= 70238.89 + 380000 = 450238.89 €
Product Flow	= 450238.89 €
Loss Flow	= 0 €

QC3: Packaging

Material Costs:

Cost of previous QC (material)	= 26333.33 €
Packaging Box Cost	= Cost of 1 box x Prod. Volume = 0.02 x 20000 = 400 €
Total Input Cost	= Cost of previous QC + Packaging Box Cost
	= 263333.33 + 400 = 263733.33 €
Product Flow	= 263733.33 €
Material Loss Flow	= 0 €
Cum cost of product flow	= 263733.33 €
Cum cost of loss of material flow	= 165333.33 €

(Prajjwal Garag)

Energy Costs:

Since no electricity is used in the packaging process,

Product Flow = Product Flow (energy) of previous QC

= 17250 €

Energy Loss Flow = 0 €

Cum cost of product flow = 18750 €

Cum cost of loss of material flow = 6250 €

System Costs:

Cost of previous QC (system) = 450238.89 €

Employee Wage Costs = Prod. Volume x Time taken for packing 1 unit (hr) x Wage Cost (€/hr)

= 20000 x (2/60) x 25 = 16666.67 €

Total Input Cost = Cost of previous QC + Employee Wage Cost

= 450238.39 + 16666.67 = 466905.55 €

Product Flow = 466905.55 €

Loss Flow = 0 €

Cum cost of loss of material flow = 0 €

Total Cum. Cost of product flow = 749388.893 €

Total Cum. Cost of Material loss flow = 114916.67€

Total Cost = 864305.563 €

Cost per unit = 43.22 €

3.4.2. MFCA for Water Jet Cutting:

	Carry over [EUR]	New costs [EUR]	Total in this QC [EUR]	Share of intermediates [EUR]	Share of intermediate material losses [EUR]	Share of products [EUR]	Share of material losses [EUR]
Quantity Centre: T1: Machining							
Material costs	0.00	353,750.00	353,750.00	320,000.00	0.00	0.00	33,750.00
Energy costs	0.00	12,750.00	12,750.00	10,200.00	0.00	0.00	2,550.00
System costs	0.00	94,677.78	94,677.78	94,677.78	0.00	0.00	0.00
Waste management costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.00**	**461,177.78**	**461,177.78**	**424,877.78**	**0.00**	**0.00**	**36,300.00**
Quantity Centre: T2: Painting							
Material costs	320,000.00	52,000.00	372,000.00	370,000.00	0.00	0.00	2,000.00
Energy costs	10,200.00	0.00	10,200.00	10,200.00	0.00	0.00	0.00
System costs	94,677.78	380,000.00	474,677.78	474,677.78	0.00	0.00	0.00
Waste management costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**424,877.78**	**432,000.00**	**856,877.78**	**854,877.78**	**0.00**	**0.00**	**2,000.00**
Quantity Centre: T3: Packaging							
Material costs	370,000.00	400.00	370,400.00	0.00	0.00	370,400.00	0.00
Energy costs	10,200.00	0.00	10,200.00	0.00	0.00	10,200.00	0.00
System costs	474,677.78	16,666.67	491,344.44	0.00	0.00	491,344.44	0.00
Waste management costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**854,877.78**	**17,066.67**	**871,944.44**	**0.00**	**0.00**	**871,944.44**	**0.00**

Table 19: MFCA for Water Jet Cutting Source: Umberto®

	Share of products [EUR]	Share of material losses [EUR]	Total costs [EUR]
Material costs	370,400.00	35,750.00	406,150.00
Energy costs	10,200.00	2,550.00	12,750.00
System costs	491,344.44	0.00	491,344.44
Waste management costs	0.00	0.00	0.00
Other costs	0.00	0.00	0.00
Total	**871,944.44**	**38,300.00**	**910,244.44**

Table 20: Water Jet Cutting Material loss representation Source: Umberto®

(Prajjwal Garag)

<u>Total Cost for 20000 units = 910244 €</u>

<u>Total Cost/unit = 45.51 €</u>

QC1: Water Jet Cutting Machine

Material Costs:

Material Input Cost = (Prod. Volume x Cost of 1 Aluminum block in kg) + (Prod. Volume x Granule Usage (kg/hr) x Granule feed rate x Cost of granule (€/kg))
= (20000 x 16) + (20000 x 45 x (9/60) x 0.25)
= 353750 €

Since 1/3rd of the material is removed as chip waste,

Product Flow = (Aluminum Cost x (2/3)) + Granule Cost
= (2/3) x (20000*16) + (20000 x 45 x (9/60) x 0.25)
= 247083 €

Since all of the granules used are re-used,

Material Loss Flow = Aluminum Cost x (1/3) = 106666.67 €

Energy Costs:

Total Input Energy Cost = Input Power x Production Time (hr) x Electricity Cost (€/kWh) xProd. Volume
= 17 x (9/60) x 0.25 x 20000 = 12750 €/kWh

Considering energy efficiency of 80 %,

Product Flow = 12750 x 80 % = 10200 €

Energy Loss Flow = 12750 x 20 % = 2

System Costs:

Since we assume no labour involved in the machining process,

Employee wage costs = 0 €

Fixed Costs = Depreciation + Maintenance + Imputed Interest
= 47777.78 + 32200 + 14700 = 94677.78 €

Product Flow = 94677.78 €

Loss Flow = 0 €

QC2: Painting

Material Costs:

Cost of previous QC (material) = 247083 €

(Prajjwal Garag)

Paint Cost = Volume of paint required (liters) x Cost of paint/liter

= 1040 x 50 = 52000 €

Total Material Input Cost = Cost of previous QC + Paint Cost

= 247083 + 52000 = 299083 €

Product Flow = Cost of previous QC + (Volume of paint x Cost of paint/liter x Prod. Volume)

= 299083 + (0.05 x 50 x 20000) = 297083 €

Material Loss Flow = Total Input Cost – Product Flow

= 299083 – 297083 = 2000 €

Energy Costs:

Since no electricity is used in the painting process,

Product Flow = Product Flow(energy) of previous QC = 10200€

Energy Loss Flow = 0 €

System Costs:

Cost of previous QC (system) = 94677.78 €

Employee Wage Costs = Prod. Volume x Time taken for painting 1 unit (hr) x Wage Cost (€/hr)

= 20000 x (30/60) x 38 = 380000 €

Total Input Cost = Cost of previous QC + Employee Wage Cos

= 94677.78 + 380000 = 474677.78 €

Product Flow = 474677.78 €

Loss Flow = 0 €

QC3: Packaging

Material Costs:

Cost of previous QC (material) = 297083 €

Packaging Box Cost = Cost of 1 box x Prod. Volume

= 0.02 x 20000 = 400 €

Total Input Cost = Cost of previous QC + Packaging Box Cost

= 297083 + 400 = 297483 €

Product Flow = 297483 €

Material Loss Flow = 0 €

Cum cost of product flow = 297483 €

(Prajjwal Garag)

Cum cost of loss of material flow = 108667 €

Energy Costs:

Since no electricity is used in the packaging process,

Product Flow = Product Flow(energy) of previous QC

= 10200€

Energy Loss Flow = 0 €

Cum cost of product flow = 10200 €

Cum cost of loss of material flow = 2550 €

System Costs:

Cost of previous QC (system) = 474677.78 €

Employee Wage Costs = Prod. Volume x Time taken for packing 1 unit (hr) x Wage Cost (€/hr)

= 20000 x (2/60) x 25 = 16666.67 €

Total Input Cost = Cost of previous QC + Employee Wage Cost

= 474677.78 + 16666.67 = 491344.45 €

Product Flow = 491344.45 €

Loss Flow = 0 €

Cum cost of loss of material flow = 0 €

Total Cum. Cost of product flow = 799028 €

Total Cum. Cost of Material loss flow = 111217 €

Total Cost = 910244 €

Cost per unit = 45.51 €

3.4.3. MFCA for 3D printing:

	Carry over [EUR]	New costs [EUR]	Total in this QC [EUR]	Share of intermediates [EUR]	Share of intermediate material losses [EUR]	Share of products [EUR]	Share of material losses [EUR]
Quantity Centre: T1: 3D Printer							
Material costs	0.00	425,066.67	**425,066.67**	294,400.00	0.00	0.00	130,666.67
Energy costs	0.00	16,666.67	**16,666.67**	15,833.33	0.00	0.00	833.33
System costs	0.00	14,144.44	**14,144.44**	14,144.44	0.00	0.00	0.00
Waste management costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Total	**0.00**	**455,877.78**	**455,877.78**	**324,377.78**	**0.00**	**0.00**	**131,500.00**
Quantity Centre: T2: Painting							
Material costs	294,400.00	52,000.00	**346,400.00**	344,400.00	0.00	0.00	2,000.00
Energy costs	15,833.33	0.00	**15,833.33**	15,833.33	0.00	0.00	0.00
System costs	14,144.44	380,000.00	**394,144.44**	394,144.44	0.00	0.00	0.00
Waste management costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Total	**324,377.78**	**432,000.00**	**756,377.78**	**754,377.78**	**0.00**	**0.00**	**2,000.00**
Quantity Centre: T3: Packaging							
Material costs	344,400.00	400.00	**344,800.00**	0.00	0.00	344,800.00	0.00
Energy costs	15,833.33	0.00	**15,833.33**	0.00	0.00	15,833.33	0.00
System costs	394,144.44	16,666.67	**410,811.11**	0.00	0.00	410,811.11	0.00
Waste management costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Other costs	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Total	**754,377.78**	**17,066.67**	**771,444.44**	**0.00**	**0.00**	**771,444.44**	**0.00**

Table 21: MFCA for 3D printing Source: Umberto®

(Prajjwal Garag)

	Share of products [EUR]	Share of material losses [EUR]	Total costs [EUR]
Material costs	344,800.00	132,666.67	477,466.67
Energy costs	15,833.33	833.33	16,666.67
System costs	410,811.11	0.00	410,811.11
Waste management costs	0.00	0.00	0.00
Other costs	0.00	0.00	0.00
Total	**771,444.44**	**133,500.00**	**904,944.44**

Table 22: 3D printing Material loss representation Source: Umberto®

Total cost for 20000 units = 904944 €

Total cost per unit = 45.25 €

QC1: 3D Printing

Material Costs:

Material Input Cost = Prod. Volume x (Cost of Aluminum powder in kg + Cost of Argon gas in liter

= 20000 x ((0.092 x 160) + (49 x 0.4 x (20/60)))

= 425066.6667 €

Since we assumed that the required material is 100% utilized in this process.

Product Flow = 425066.6667 €

Material Loss Flow = 0 €

Energy Costs:

Total Input Energy Cost = Input Power x Production Time (hr) x Electricity Cost (€/kWh) x Prod. Volume

=10 x (20/60) x 0.25 x 20000 = 16666.66667 €/kWh

Considering energy efficiency of 95 %,

Product Flow = 16666.66667 x 95 % = 15833.33 €

Energy Loss Flow = 16666.66667 x 5 % = 833.33 €

System Costs:

Since we assume no labor involved in the printing process,

Employee wage costs = 0 €

Fixed Costs = Depreciation + Maintenance + Imputed Interest

= 7,444.44 + 4690 + 2010 = 14144.44 €

Product Flow = 14144.44 €

Loss Flow = 0 €

QC2: Painting

Material Costs:

Cost of previous QC (material) = 294406.53 €

(Prajjwal Garag)

Paint Cost	= Volume of paint required (liters) x Cost of paint/liter
	= 1040 x 50 = 52000 €
Total Material Input Cost	= Cost of previous QC + Paint Cost
	= 294406.53 + 52000 = 477066.6667 €
Product Flow	= Cost of previous QC + (Volume of paint x Cost of paint/liter x Prod.Volume)
	= 14144.44 + (0.05*50*20000) = 475066.6667 €
Material Loss Flow	= Total Input Cost – Product Flow
	= 477066.6667 – 475066.6667 = 2000 €

Energy Costs:

Since no electricity is used in the painting process,

Product Flow	= Product Flow (energy) of previous QC = 15833.33 €
Energy Loss Flow	= 0 €

System Costs:

Cost of previous QC (system) = 14144.44 €

Employee Wage Costs	= Prod. Volume x Time taken for painting 1 unit (hr) x Wage Cost(€/hr)
	= 20000 x (30/60) x 38 = 380000 €
Total Input Cost	= Cost of previous QC + Employee Wage Cost
	= 14144.44 + 380000 = 393300 €
Product Flow	= 394144.44 €
Loss Flow	= 0 €

QC3: Packaging

Material Costs:

Cost of previous QC (material)	= 475066.6667 €
Packaging Box Cost	= Cost of 1 box x Prod. Volume = 0.02 x 20000
Total Input Cost	= Cost of previous QC + Packaging Box Cost
	= 475066.6667 + 400 = 475466.6667 €
Product Flow	= 475466.6667 €
Material Loss Flow	= 2000€
Cum cost of product flow	= 400940 €
Cum cost of loss of material flow	= 2000 €

(Prajjwal Garag)

Energy Costs:

Since no electricity is used in the packaging process,

Product Flow	= Product Flow (energy) of previous QC
	= 15833.33 €
Energy Loss Flow	= 0 €
Cum cost of product flow	= 15833.33 €
Cum cost of loss of material flow	= 833.33 €

System Costs:

Cost of previous QC (system)	= 394144.44 €
Employee Wage Costs	= Prod. Volume x Time taken for packing 1 unit (hr) x Wage Cost (€/hr)
	= 20000 x (2/60) x 25 = 16666.67 €
Total Input Cost	= Cost of previous QC + Employee Wage Cost
	= 394144.44 + 16666.67 = 410811.11 €
Product Flow	= 410811.11 €
Loss Flow	= 0 €

Cum cost of product flow	= 410811.11 €
Cum cost of loss of material flow	= 0 €
Total Cum. Cost of product flow	= 902111.11€
Total Cum. Cost of Material loss flow	= 2833.33 €
Total Cost	= 904944.4433 €
Cost per unit	= 45.2472 €

(Kaustubh Balasaheb Pawar)

4. Task 4: PROPOSAL OF LIFE CYCLE IMPACT (LCIA) APPROACH

4.1. Goal and Scope Definition of the LCA:

The purpose and scope of the Life Cycle Assessment (LCA) are specified in detail in the first stage to direct the study. Identifying environmental hotspots, weighing options, and assisting in decision-making to increase sustainability and resource efficiency are the objectives. The functional unit, which is a measurable unit of product performance (e.g., one unit produced), the system boundaries, which specify which stages of the product life cycle (e.g., extraction, production, use, and disposal of raw materials) are included, and the time frame, which specifies the duration over which impacts will be evaluated, establish the scope. [3] In order to assure that the LCA is in line with the business's sustainability goals, this aim and scope definition offers an organized framework for data gathering, effect assessment, and result interpretation.

4.2. Inventory Analysis:

The next step in the Life Cycle Assessment (LCA) process is to create a comprehensive inventory of all inputs and outputs related to the processes under evaluation, including Nischel, CNC, 3D printing, and water jet processes, after the goal and scope have been established. Throughout the life cycle of the product or process, this inventory contains information on materials, energy consumption, emissions, and waste.

The process of collecting data is centered on learning about the extraction of raw materials, energy use, emissions to the air, water, and soil, and waste generated during the course of a product's whole life cycle. For the LCA results to be reliable, it is crucial that the data be as complete and correct as possible. After the data is gathered, it is arranged into a Life Cycle Inventory (LCI), which forms the foundation for the impact analysis and assessment processes that follow. A crucial step in the life cycle assessment (LCA) process, inventory analysis provides the information needed to assess environmental consequences.

4.3. Life Cycle Impact Assessment:

In conducting the Life Cycle Impact Assessment (LCIA), several methods were considered, including CO2 Equivalent, Eco-indicator 99, and the CML method. For this study, the Eco-indicator 99 method was selected to assess the environmental impact of the processes involved. We have selected Eco-Indicator considering 3 factors of Human Health (HH), Ecosystem Quality (EQ) and Resources(R). [3]

(Kaustubh Balasaheb Pawar)

The software tools available for LCA analysis include Umberto, Signavio, SimaPro, GaBi, and OpenLCA. During the study, Umberto® was used to simulate material flows and process chains, along with a cost analysis. However, due to the limitations of an educational license for Umberto®, it was not possible to perform a full LCIA within the software. As a result, a Life Cycle Engineering (LCE) approach was proposed using MS Excel to assess the performance of different machining processes across environmental, functional, and economic dimensions over the product's life cycle.

The LCIA focused on evaluating the environmental impact of the processes in relation to the materials and energy required for annual production. Additionally, the End-of-Life (EOL) phase was included in the assessment, ensuring that the full life cycle of the product, from production to disposal, was accounted for. Based on the results of this LCIA, performance values for each manufacturing process were calculated, including the Life Cycle Cost (LCC in €/unit) and the Life Cycle Assessment (LCA in points/unit).[5][6][7]

The Life Cycle Cost, LCC (€/unit), which is obtained from the calculations using the Umberto® results, and Life Cycle Assessment, LCA (points/unit) were assigned in addition to a Functional Assessment as shown below in Table below.

We have assumed the argon density 0.0017837 kg/l[2]

Material	Aluminum	Aluminum (EOL)	Argon gas	Energy	Abrasive Granules (Sic)
EI 99 (Points)	0.7	-0.3	0.78	0.5	0.2

Table 23: Eco-Indicator Points for Process Consumables [4]

Process	Production			Points		
	CNC	Jet Cutting	3D Printing	CNC	Jet Cutting	3D Printing
Production Material (Kg/Year)	2,800	2,800	1,840	1,960	1,960	1,288
Other Material in Process (Kg/Year)	-	135,000	326,667	-	27,000	454
Energy Consumption (KWH/Year)	100,000	51,000	66,667	50,000	25,500	33,333
End of Life (EOL) (Kg/Year)	2,800	2,800	1,840	-840	-840	-552
Total EI' 99 Points				**51,120**	**53,620**	**34,524**
LCA Per Unit (Points)				**2.56**	**2.68**	**1.73**

Table 24: Life Cycle Impact Analysis for all Processes Source: Calculated values from given data and EI’99 data

4.3.1. Sample Calculation for Water Jet Cutting:

Assuming an annual production volume of 20000 units,

Points = Material production x Aluminum

= 2800 x 0.7 = 1960

Points = Other Material x Abrasive Granules (Sic)

= 135000 x 0.2 = 27000

Points = Energy Consumption x Energy

=51000 x 0.5 = 25500

Points = End of Life (EOL) x Aluminum (EOL

=2800 x -0.3 = -840

Functional Analysis					
Features	Importance	Scale	CNC	Jet Cutting	3D Printing
Surface Finish	20%	1-5	5	4	2
Aesthetic	50%	1-5	4	5	2
Weight	10%	1-5	3	3	5
Durability	20%	1-5	5	4	3

Table 25: Functional Assessment Analysis for all the processes

The five parameters in the Table (above) were used to assess the functional analysis of the different machining processes and points out of 5 were assigned (1 being the worst, 5 being the best). The average points were then used for weighing the functional assessment of the processes. These values were then normalized in order to form a Ternary Diagram which is a type of graphical analysis method that best summarizes all three dimensions (economic, environmental, and functional) and shows how the “best option” can be decided based on how much weightage of each dimension (in %) the manufacturer wants to opt for, for an annual production volume of 20000 units.

Process	LCC (Euro/Unit)	LCA (Points/Unit)	Functional Assessment
CNC	43.22	2.56	96.0%
Jet Cutting	45.51	2.68	68.0%
3D Printing	45.25	1.73	50.0%
	Minimum is Best	**Minimum is Best**	**Maximum is Best**

Table 26: Assessment Scores for all the processes

Normalization	LCC (Euro/Unit)	LCA (Points/Unit)	Functional Assessment
CNC	1.00	0.68	1.00
Jet Cutting	0.95	0.64	0.71
3D Printing	0.96	1.00	0.52
	Maximum is Best	**Maximum is Best**	**Maximum is Best**

Table 27: Normalization According to the Assessment Scores for all the Processes

4.3.2. Ternary Diagram:

Depending on how much importance the manufacturer can afford to give to each of the three dimensions, considering 100% weightage to every separate dimension, we can summarize the results as shown below for 20000 units.

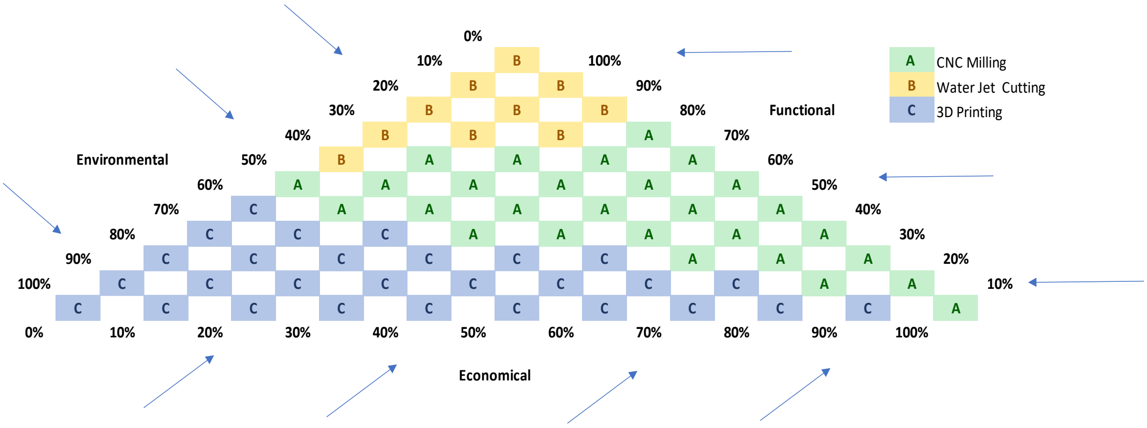


Figure 46: Ternary Diagram considering Economical, Functional and Environmental Impact Parameters
Source: By Author from the given data

4.3.3. Key Observations:

Dominance of CNC Milling (A):

CNC Milling (A) performs best (green cells) in most scenarios, particularly when functionality and cost-effectiveness are emphasized (high values on the economic and functional axes).

It dominates in mixed weightage regions (e.g., 40%-60% emphasis across all criteria), showcasing balanced performance across environmental, economic, and functional aspects.

Preference for Water Jet (B):

Water Jet (B) (yellow cells) performs best in scenarios with a moderate balance between environmental concerns and economic priorities (e.g., 50% environmental and 50% economic focus).

It tends to dominate when environmental factors take precedence but not overwhelmingly (30%-50%).

Strength of 3D Printing (C):

3D Printing (C) (blue cells) performs best in scenarios where environmental sustainability is the highest priority (e.g., 80%-100% environmental emphasis) or when economic constraints are low (e.g., lower economic weightage).

This suggests that 3D Printing excels in green manufacturing applications but may lag in cost or functionality compared to the other methods.

4.4. Potentials of Umberto®

- Umberto® allows for the modeling of even highly intricate production processes with ease. It provides flexibility in assigning parameters to accurately reflect the system.
- The software supports the extraction of results in multiple formats, such as MS Excel and image files (e.g., .jpg), making data analysis and reporting convenient.
- It enhances process transparency by offering clear visualizations of material flows, energy consumption, and associated costs, helping users understand their production systems better.
- The integrated Material Flow Cost Accounting (MFCA) feature in Umberto® simplifies the identification and evaluation of critical cost drivers, including material, energy, and system expenses. [8]

4.5. Limitations of Umberto®

- A significant challenge in Umberto® is its treatment of "Energy" and "Time" as "Materials," which complicates flow simulations. Moreover, incorporating variables like employee numbers and machine requirements requires defining them as "Materials," which may not align with typical modeling needs.
- While the software allows classification of materials as "good" or "bad," it does not permit "bad" outputs to act as cost carriers. To calculate costs associated with material losses, all inputs and outputs, including waste, must be classified as "good."
- Fixed costs are not included in the cost matrix generated by Umberto®, which limits its capability to provide a comprehensive cost analysis. [8]

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TECHNISCHE UNIVERSITÄT CHEMNITZ

Fakultät für Wirtschaftswissenschaften
Technische Universität Chemnitz, 09107 Chemnitz

Selbstständigkeits- und Einverständniserklärung*

(für alle Studiengänge der Fakultät für Wirtschaftswissenschaften)

Name:	Pawar
Vorname:	Kaustubh Sanjay
Geburtsdatum:	03.09.1999
Matrikelnummer:	810063

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