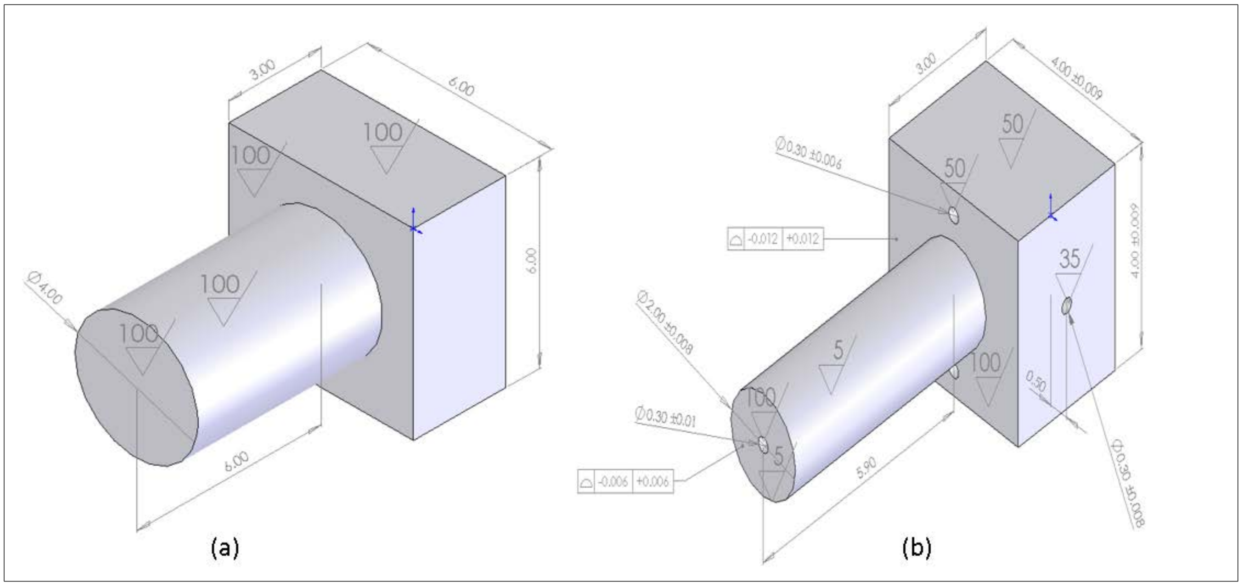

Figure 5.1. (a) Initial dimensions of the stock (b) Final dimensions of the product

Details about features to be machined

A: Cylinder. Diameter = 2 inches. Length = 5.9 inches. Surface finish required on the curved surface = 5 micro-inches. Tolerance required = 0.008 inches
B: Top flat surface of the cylinder A. Diameter = 2 inches. Surface finish required = 5 micro-inches. Tolerance required = 0.006 inch
C: Axial hole in the cylinder. Diameter = 0.3 inch. Length = 0.5 inch. Hole to be threaded at 10 TPI. Surface finish required in tapped hole = 100 micro-inches. Tolerance required = 0.01 inch

D: 4 flat surfaces (each 4 x 3 inches^2) on the bottom block which is 4 x 4 x 3 inches^3 in dimensions. Surface finish required = 50 micro-inches. Tolerance required = 0.009 inch.
E: Bottom surface of the block. Dimensions 4 x 4 inches. Surface finish required = 75 micro-inches. Tolerance required = 0.012 inch.
F: Two non-axial holes in the side of the block. Diameter = 0.3 inch. Length = 0.5 inch.
Surface finish required inside the holes = 35 micro-inches. Tolerance required = 0.008 inch.
G: Two holes on the surface G. Diameter = 0.3 inch. Length = 0.5 inch. Surface finish required = 50 micro-inches. Tolerance required = 0.006 inch.

The product is a fixture that is used to hold parts prior to machining. The first process planning (PP1) has been done by machining raw material explained below:

Gray Cast Iron. Heat treatment condition: annealed. Hardness: 150 Bhn. Melting point: 2200 F^0.
And the first process planning details and the sequence of machining processes illustrated in the table 5.1 shown below.

Table 5.1. Details of the first process planning (PP1) for machining gray cast iron.

Process Index	**Process Name**	**Total Cost of Process**	**Total Machining time**	**Total Machining cost**	**Total Tool cost**
		($)	**min**	**$**	**$**
1	Turning Cylindrical surface	6.15	2.3351	2.5297	3.6224
2	Face Grinding on the face of the cylinder	26.58	7.2593	6.6544	19.9286
3	Cylindrical grinding to the face of the cylinder	3.34	3.3539	3.0745	0.2688
4	Milling first two flat surfaces 4*3 inches^2	9.5	2.666	5.7764	3.7142
		15.58	3.0068	2.2574	4.5312
5	Milling flat surfaces 4*3 inches^2 (second two)	7.88	2.498	5.4126	2.0952
		11.98	2.7404	2.9689	3.0208
6	Milling the bottom surface of the block 4*4 inches^2	3.29	2.2669	2.4558	0.8294
7	Drilling the holes on the face of cylindrical face	1.118	0.7067	0.4712	0.7083
		1.86	1.0671	1.156	0.7083
8	Tapping hole on the face of cylindrical face	2.19	0.8656	0.9378	1.25
9	Drilling 2 holes on the side of the block	2.47	1.5767	1.0512	1.4167
		3.45	1.8608	1.2406	2.2083
10	Tapping 2 holes on the side of the block	3.57	1.6009	1.0673	2.5
11	Drilling 2 holes on the top face of the block	2.47	1.5767	1.0512	1.4167
		3.28	1.7219	1.8654	1.4167
12	Tapping 2 holes on the top face of the block	3.57	1.6009	1.0673	2.5

From table 5.1 the total cost of each process, total machining cost of each process, and total time of machining of each process have been shown for the machining gray cast iron on stock dimension in figure 5.1 (a). By using MPSEL each of the process machining parameters have been obtained and the total cost of the process including (total machining cost and tool cost) has been calculated by using the VISUAL MACH. It is clear from the result that the face grinding process is expensive, even though it was for 0.01 inch thickness only to avoid unreasonable grinding cost. Moreover, by this process, the 5 micro-inches surface finish on the flat face of the cylinder can be obtained in the case of machining gray cast iron as a raw material. The yellow highlighted numbers in the table 5.1 represent other values that have been obtained by using another machine or cutting tool for these processes through MPSEL, and these processes are more expensive with lower production rate, hence they are mentioned just to compare the difference in output between each to compatible processes.

Then, to understand and analyze these processes, table 5.2 has been constructed from table 5.1

Table 5.2. Summarized results of PP1 for machining gray cast iron

Total Machining Time (min)	28.3067
Total Machining cost ($)	31.5494
Total Tool Cost ($)	40.2503
Total processes cost of machining one part	72.128
Production rate per hour	2.11963952
Cost of Machining productivity for 1 hour ($)	152.8853593

From the result on the table 5.2, it can be ascertained that the process plan (PP1) is of high cost and there needs to be efforts aimed towards cost reduction. The cost can be reduced by enabling efforts to avoid the face grinding operation by the way of consideration of alternate raw materials. The selection of a more ductile material may help in this regard. The decision made on the alternate material was as follows. Aluminum alloy (low-elastic). Heat treatment condition: as cast. Hardness: 150 Bhn. Melting point: 1000 F^0. It was determined that the product functionality will not be affected by the use of this alternate material. The revised machining cost calculations using the alternate material have been shown on table 5.3.

Table 5.3. Details of (PP1) for machining aluminum alloy.

Process Index	**Process Name**	**Total Cost of Process**	**Total Machining Time**	**Total Machining Cost**	**Total Tool Cost**
		($)	**min**	**$**	**$**
1	Turning Cylindrical surface	2.07	1.1824	1.281	0.7906
2	Facing cylinder surface	0.83	0.7185	0.7785	0.0471
3	Milling flat surfaces 4*3 $inches^2$ (first two faces)	9.5	2.666	5.7764	3.7142
		15.58	3.0068	2.2574	4.5312
4	Milling flat surfaces 4*3 $inches^2$ (second two faces)	7.88	2.498	5.4126	2.0952
		11.98	2.7404	2.9689	3.0208
5	Milling the bottom surface of the block 4*4 $inches^2$	2.26	2.079	2.2523	0.0039
6	Drilling the holes on the face of cylinder side	1.118	0.7067	0.4712	0.7083
		1.86	1.0671	1.156	0.7083
7	Tapping hole on the face of cylindrical face	2.19	0.8656	0.9378	1.25
8	Drilling 2 holes on the side of the block	2.47	1.5767	1.0512	1.4167
		3.45	1.8608	1.2406	2.2083
9	Tapping 2 holes on the side of the block	3.57	1.6009	1.0673	2.5
10	Drilling 2 holes on the top face of the block	2.47	1.5767	1.0512	1.4167
		3.28	1.7219	1.8654	1.4167

11	Tapping 2 holes on the top face of the block	3.57	1.6009	1.0673	2.5

Table 5.4. Summarized results of PP1 for machining aluminum alloy

Total Machining Time (min)	17.0714
Total Machining Cost ($)	21.1468
Total Tool Cost ($)	16.4427
Total processes cost of machining one part	37.928
Production Rate Per Hour	3.51465
Cost of Machining Productivity for 1 Hour ($)	133.3037

Based on the information from table 5.4, the production rate has increased from 2.12 parts per hour for gray cast iron to 3.5 parts per hour in the case of machining aluminum alloy. The cost of machining for the part decreased from $72.128 for machining gray cast iron to $37.93 for machining aluminum alloy, with resulting cost savings of 47.413%.

The machining parameters for machining aluminum alloy have been selected by MPSEL program. The machining parameters for turning the cylindrical surface are:

Cutting tool selected: Diamond
Machine: NC Lathe machine
Turning process: suitable
Surface required: low
Material type: non ferrous
Material: aluminum alloy
Cooling fluid: kbs

Cutting tool materials such as carbide, ceramic and high speed steel (HSS) have not been selected.
For each combination of cutting tool and the machine that have been selected by MPSEL, cutting speed, feed rate, and depth of cut for the processes have been obtained by using the Speed_Feed_Selection spreadsheet and the resulting data input into VISUAL MACH to determine the cost of machining, the cost of the tool, and time of machining. Figures 5.2 and 5.3 explain the input and the output of VISUAL MACH for turning cylindrical surface of the part.

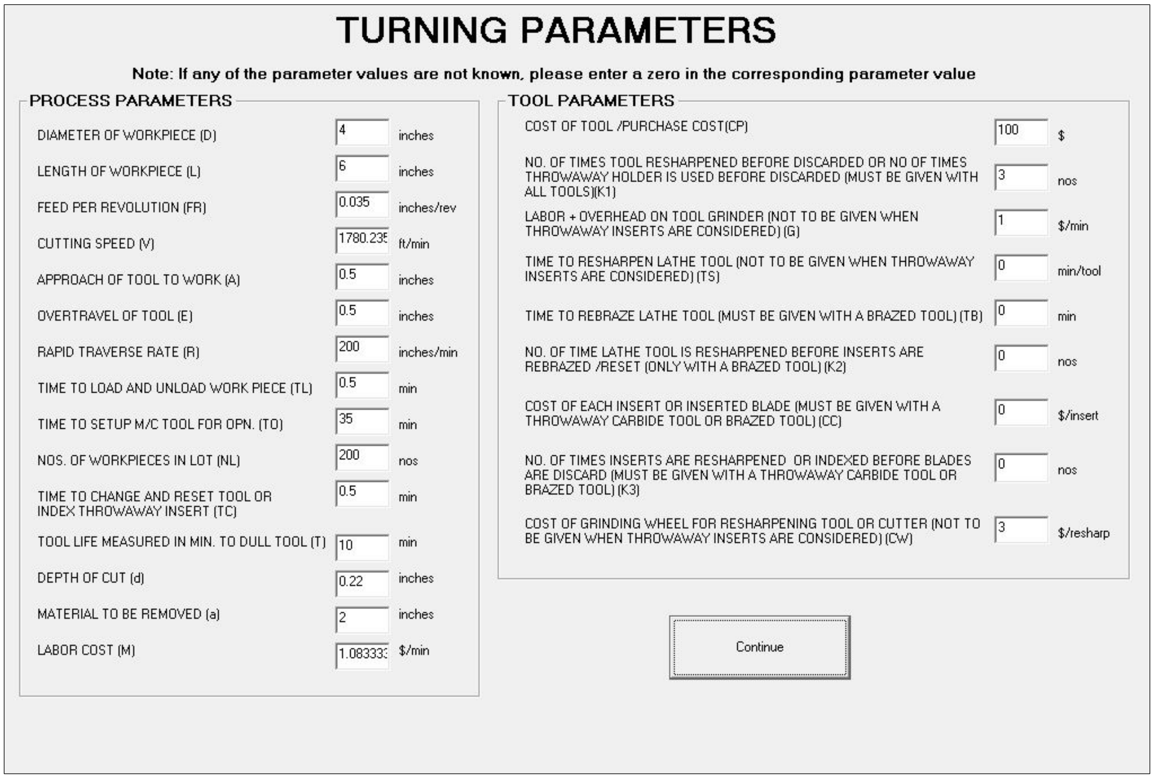

Figure 5.2. Input and output information of VISUAL MACH for turning process

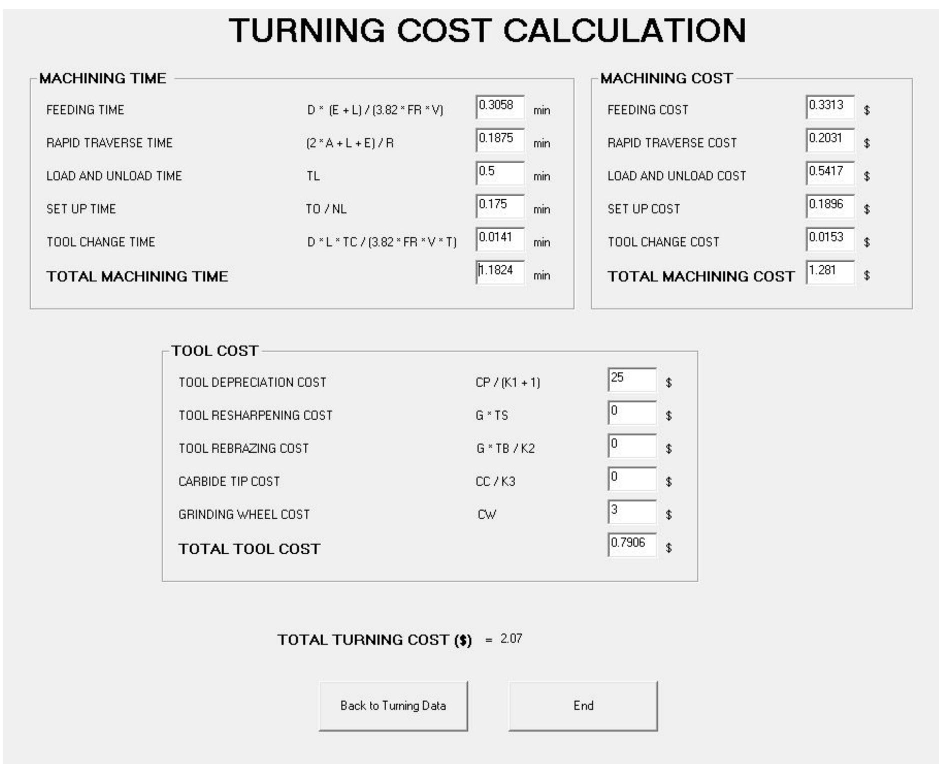

Figure 5.3. Results of VISUAL MACH for turning process

One can explore the reduction of cost and increase in production rate by altering the stock material design for the aluminum alloy product as shown in figure 5.4.

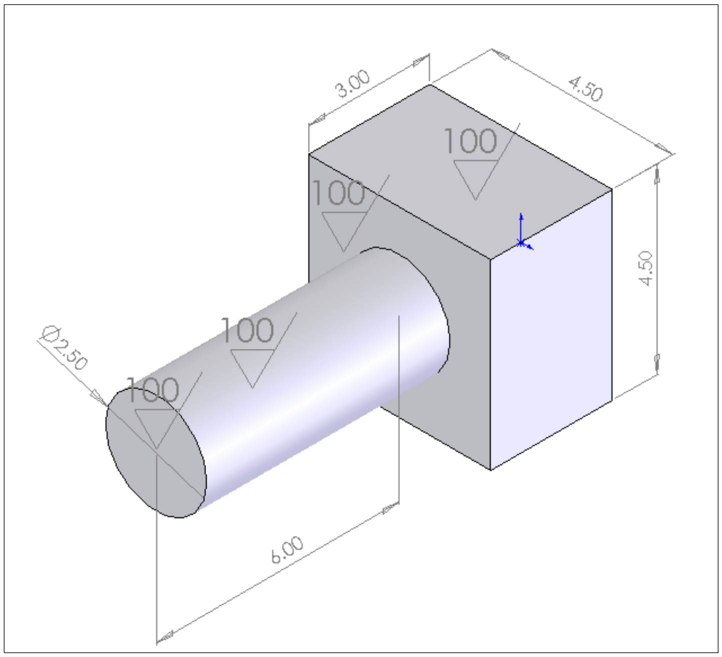

Figure 5.4. Shows the new dimensions of the stock

In the figure 5.4 for the product design stock material, the diameter of the cylinder has been changed from 4 inches to 2.5 inches and the width of the block has been changed from 6 inches to 4.5 inches. Another potential change was to machine the faces of the block by one milling processes and not by four milling processes. Thus, the length of cut of the block will be 18 inches for one process instead of 4.5 inches for each face of the block and will reduce the machine setup time. After these two efforts, the process planning 2 (PP2) has been created and the summarized results are shown on table 5.5.

Table 5.4. Summarized results of PP2 for machining aluminum alloy

Total Machining Time (min)	14.5453
Total Machining Cost ($)	12.8155
Total Tool Cost ($)	13.679
Total processes cost of machining one part	26.448
Production Rate Per Hour	4.125044
Cost of Machining Productivity for 1 Hour ($)	109.0992

From table 5.5, it can be observed that the machining cost has decreased from $37.928 to $26.448 and the cost saving was 30.26%. The production rate for one hour increased from 3.515 to 4.13. Modifications of the dimensions of the stock material and geometric changes have reduced the machining cost and increased the production rate.

The next effort is to observe the changes due to altering the surface finish of the product geometry as shown on figure 5.5.

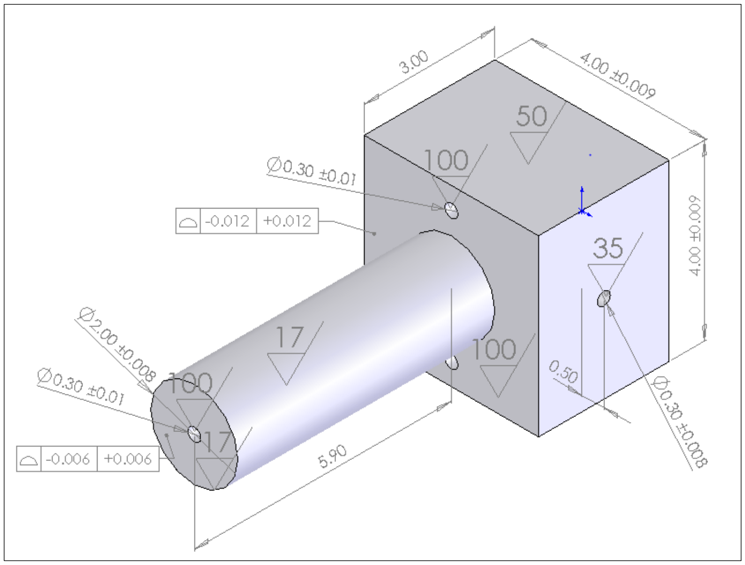

Figure 5.5. Shows the changing in the surface finish of the product

As seen on figure 5.5, the surface finish of the cylindrical surface and cylinder face has been changed from 5 micro-inches to 17 micro-inches. This has been reflected on process plan PP3. The machining parameters and machining cost have been calculated by using MPSEL and VISUAL MACH programs to evaluate the effects of this change on machining grey cast iron and the summarized results are shown in table 5.5.

Table 5.5. Summarized results of PP3 for machining gray cast iron

Total Machining Time (min)	18.3998
Total Machining Cost ($)	22.5859
Total Tool Cost ($)	22.2315
Total processes cost of machining one part	44.118
Production Rate Per Hour	3.260905
Cost of Machining Productivity for 1 Hour ($)	143.8646

From the results shown on table 5.5 and by comparison with the values on table 5.2, the cost all machining processes have decreased from $72.128 to $44.118 and the cost saving was 38.834%. Production rate increased from 2.1196 to 3.261 parts per hour. The alteration of surface finish to retain functionality has had a good effect on cost and production rate.

6. Conclusion

The results presented in this paper clearly show that computer aided iterative analysis of process plan developmental efforts can make a significant impact on cost and throughput. The CAPP approach should be tailored to specific product, process, and system attributes so as to be effective. The approach presented in this paper highlights the design modifications of the product retaining functionality in order to enable the development of the most effective process plans for manufacturing for utilization in the domain of concurrent engineering.

7. Acknowledgements

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