Determination of the optimal time and cost of manufacturing flow of an assembly using the Taguchi method

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Abstract. The optimization of the parts and assembly manufacturing operation was carried out in order to minimize both the time and cost of production as appropriate. The optimization was made by using the Taguchi method. The Taguchi method is based on the plans of experiences that vary the input and outputs factors. The application of the Taguchi method in order to optimize the flow of the analyzed assembly production is made in the following: to find the optimal combination between the manufacturing operations; to choose the variant involving the use of equipment performance; to delivery operations based on automation. The final aim of the Taguchi method application is that the entire assembly to be achieved at minimum cost and in a short time. Philosophy Taguchi method of optimizing product quality is synthesized from three basic concepts: quality must be designed into the product and not he product inspected after it has been manufactured; the higher quality is obtained when the deviation from the proposed target is low or when uncontrollable factors action has no influence on it, which translates robustness; costs entailed quality are expressed as a function of deviation from the nominal value [1]. When determining the number of experiments involving the study of a phenomenon by this method, follow more restrictive conditions [2].

1. Introduction
The optimization of the manufacturing flow of parts and of the assembling operation was realized with the purpose of decreasing the manufacturing time and related costs. The Taguchi Method is a method based on the experience plans in which certain input factors are varied and the outputs are determined. The Taguchi Method comprises nine important steps, namely:
- **Step 1** Formulating the issue, the experiment’s success depending on understanding the nature of the issue;
- **Step 2** Identifying the output performance characteristics of the most relevant issues;
- **Step 3** Identifying control, noise and signal factors. The control factors are those which can be controlled under normal production conditions. Noise factors are difficult to control under these conditions and signal factors affect the average performance of the process;
- **Step 4** Choosing the variation levels, the possible interactions between factors and the effects of those interactions;
- **Step 5** Constructing the corresponding orthogonal matrix;
- **Step 6** Preparation of the experiments (or simulations).
- **Step 7** Conducting the experiments/simulations corresponding to the orthogonal matrix;
- **Step 8** Statistic analysis and interpretation of results;
- **Step 9** Verifying and confirming the results obtained in the experiment or simulation [3].
In this case we realized models for the optimization of the manufacturing flow for two parts and one model of optimization of their installation. The controllable input factors were varied after a well-established plan and for each combination the execution time, as well as the related cost were determined.

2. Experimental setup
The analysis of the optimization of manufacturing flows was realized within PSAPET PROD COM S.R.L enterprise, in Bacau, that has as main field of activity the manufacturing of hydrostatic assemblies and subassemblies necessary in the aerospace industry.

The assembly analyzed for the identification of optimum solutions in the optimization process of the manufacturing flow is the one used in the previous method and is composed of:
- flange 1 pc
- bushing 1 pc
- helicoidal inserts 9 pcs, of which 6 pcs M2.5x5 and 3 pcs M3x4.5, supplied by a collaborating company which has the execution of such elements in its activity portfolio.

In order to optimize the manufacturing flow of the two main components, respectively the bushing and flange, five of the basic operations were chosen which were assigned two execution versions as presented in table 1.

| Operation/Factor                 | Level 1                  | Level 2                  |
|----------------------------------|--------------------------|--------------------------|
| Material acceptance              | Manual                   | Manual                   |
| Cutting                          | Semiautomatic saw        | Automatic saw            |
| Turning/1 and 2 turn setup       | 3-axis CNC lathe         | 5-axis CNC lathe         |
| Adjustment                       | Manual                   | Manual                   |
| Wash                             | Manual                   | Automated               |
| Final inspection                 | Manual                   | 3D measuring machine     |
| Packaging                        | Manual                   | Manual                   |
| Storage                          | Manual                   | Manual                   |

In order to build optimal plans for the execution of components necessary for the presented assembly, we started from the two execution versions presented in table 2 and 3.

2.1. The first version
Version 1 for the execution of parts 1 and 2 regarding the manufacturing time (classic equipment, respectively: 3-axis lathe, semi-automatic, manually operated).

| Operation                | Type                  | Time [min] |
|--------------------------|-----------------------|------------|
| Material acceptance      | Manual                | 2          |
| Cutting                  | Semi-automatic saw    | 2          |
| Turning 1 and 2 turn setup | Manual            | 180        |
| Turning 1 and 2 turn      | 3-axis cnc equipment  | 20         |
| Adjustment               | Manual                | 2          |
| Wash                     | Manual                | 1          |
| Final inspection         | Manual                | 2          |
| Packaging                | Manual                | 0.25       |
| Storage                  | Manual                | 0.25       |
Table 3. Part no.2 bushing.

| Operation                      | Type                     | Time [min] |
|--------------------------------|--------------------------|------------|
| Material acceptance           | Manual                   | 2          |
| Cutting                        | Semi-automatic saw      | 0.10       |
| Turning 1 and 2 turn setup    | Manual                   | 90         |
| Turning 1 and 2 turn          | 3-axis cnc equipment    | 6.5        |
| Adjustment                     | Manual                   | 0.5        |
| Wash                           | Manual                   | 0.25       |
| Final inspection               | Manual                   | 0.5        |
| Packaging                      | Manual                   | 0.10       |
| Storage                        | Manual                   | 0.10       |

Version 1 for the execution of parts 1 and 2 regarding the manufacturing cost (classic equipment, respectively: 3-axis lathe, semi-automatic, manually operated).

Table 4. Part no.2 bushing.

| Operation                      | Type                     | Cost [u.m.] |
|--------------------------------|--------------------------|-------------|
| Material acceptance           | Manual                   | 2           |
| Cutting                        | Automatic saw            | 1           |
| Turning 1 and 2 turn setup    | Manual (5-axis cnc lathe)| 150         |
| Turning 1 and 2 turn          | 5-axis cnc lathe         | 12          |
| Adjustment                     | Ultrasound               | 0.5         |
| Wash                           | Automated                | 0.5         |
| Final inspection               | 3D measuring machine     | 1.5         |
| Packaging                      | Manual                   | 0.25        |
| Storage                        | Manual                   | 0.10        |

Version 2 for the execution of parts 1 and 2 regarding the manufacturing cost (performant equipment, respectively: 5-axis lathe, ultrasound, 3D measuring machine, automatic).

Table 5. Part no.1 flange.

| Operation                      | Type                     | Cost [u.m.] |
|--------------------------------|--------------------------|-------------|
| Material acceptance           | Manual                   | 2           |
| Cutting                        | Automatic saw            | 2           |
| Turning 1 and 2 turn setup    | Manual (5-axis cnc lathe)| 450         |
| Turning 1 and 2 turn          | 5-axis cnc lathe         | 36          |
| Adjustment                     | Ultrasound               | 1           |
| Wash                           | Automated                | 1           |
| Final inspection               | 3D measuring machine     | 1.5         |
| Packaging                      | Manual                   | 0.25        |
| Storage                        | Manual                   | 0.10        |

Table 6. Part no.2 bushing.

| Operation                      | Type                     | Cost [u.m.] |
|--------------------------------|--------------------------|-------------|
| Material acceptance           | Manual                   | 2           |
| Cutting                        | Automatic saw            | 0.10        |
| Turning 1 and 2 turn setup    | Manual (5-axis cnc lathe)| 225         |
| Turning 1 and 2 turn          | 5-axis cnc lathe         | 15          |
| Adjustment                     | Ultrasound               | 0.25        |
The generation of the experiment plan was realized with the Design Expert program and contains a number of 32 versions. For each of these versions the execution times of the respective flow and the execution costs were determined. Both the generated plan, as well as the obtained values, corresponding to the time [s] and costs (u.m.) are presented in figure 1.

![Figure 1](image)

Figure 1. The plan generated for optimization of the manufacturing flow of part 1.

Once the work plan is created, interdependence functions between the selected input and output factors are set. These functions take into account both the independent effect of each input factor, as well as their combined effects as evidenced in figure 2.

The interdependence functions between the output factors (time and cost) and the input factors (marked with A, B, C, D and E) are the following:

**Time [s]:**
\[\text{Time [s]} = 188.35 - 0.25 \times A - 0.26 \times B - 0.21 \times C - 0.22 \times D - 0.23 \times E + 0.25 \times A \times B - 0.21 \times A \times C + 0.23 \times B \times D - 0.24 \times B \times E - 0.25 \times A \times B \times C + 0.26 \times A \times B \times D - 0.27 \times A \times B \times E + 0.28 \times A \times C \times D - 0.29 \times A \times C \times E + 0.30 \times A \times D \times E.\]

**Cost (u.m.):**
\[\text{Cost (u.m.)} = 451.63 - 0.001 \times A - 0.002 \times B - 0.003 \times C - 0.004 \times D - 0.005 \times E + 0.001 \times A \times B + 0.002 \times A \times C - 0.003 \times B \times C + 0.004 \times B \times D - 0.005 \times B \times E - 0.006 \times A \times B \times C + 0.007 \times A \times B \times D - 0.008 \times A \times B \times E - 0.009 \times A \times C \times D + 0.010 \times A \times C \times E - 0.011 \times A \times D \times E + 0.012 \times A \times B \times C \times D \times E.\]
Based on these interdependence functions the combination of factors for which the time and cost are minimum is obtained (figure 3).
Figure 3. The combination of values for which the time and cost have a minimum value for part 1.

In order to optimize the manufacturing flow of part 2, the same procedure is used since the selected influence factors are the same. The work plan for part 2 is shown in figure 4.

The interdependence functions take into account the individual effect and the interactions of input factors. For part 2 these have the following expressions:

\[
\text{Time}[s] = 91.56 - 0.067\times A - 8.27\times B - 0.098\times C - (4.687E-003)\times D + 0.027\times E - 0.027\times A\times B + 0.042 \times A\times D - 0.027\times B\times C + 0.042 \times B\times E - 0.027\times C + 0.042 \times C\times D - 0.045 \times C\times E + 0.045 \times D\times E - 0.045 \times A\times E
\]
\[ B*C+0.027*A*B*D+0.039 * A * B * E-0.023 * A * C * D-0.042 * A * C * E-0.030 * A * D * E-0.042 * B * C * D-0.030 * B * C * E-0.042 * B * D * E+0.039 * C * D * E-0.039 *A*B*C*D-0.027 * A * B * C * E-0.045 * A * B * D * E+0.042 * A * C * D * E+0.023 * B * C * D * E+0.027 * A * B * C * D * E. \]

Cost (u.m.) =\[220.37+0.38 * A+23.61 * B-0.12 * C-0.32 * D+0.18 * E+0.085 * A * B-0.17 * A * C-0.39 * A * D-0.094 * A * E-0.36 * B * C-0.13 * B * D-0.40 * B * E+0.054 * C * D+0.29 * C * E+0.044 * D * E-0.30 * A * B * C-0.029 * A * B * D-0.26 * A * B * E+0.14 * A * C * D+0.34 * A * C * E+0.15 * A * D * E+0.35*B * C * D+0.18 * B * C * E+0.37 * B * D * E+0.29 * C * D * E+0.28 * A * B * C * D+0.013 * A * B * C * E+0.25*A*B*D*E-0.37*A*C*D*E-0.12*B*C*D*E+0.038 * A * B * C * D * E +0.25*A*B*D*E-0.37*A*C*D*E+0.038 * A * B * C * D * E\]

The optimum combinations of input factors in order to obtain the minimum time and cost are presented in figure 5.

**Figure 5.** Combinations of the input factors.

**Figure 6.** The combination of values for which the time and cost have minimum values for part 2.
The optimization of the installation flow can be realized using the same methodology, considering the operations corresponding to assembling. In this case we selected three operations from the total operations required for assembling which were assigned two levels of variation (table 7).

**Table 7. Variation levels of input factors.**

| Operation/Factor       | Level 1                  | Level 2                  |
|------------------------|--------------------------|--------------------------|
| Turning setup          | 3-axis CNC equipment     | 3-axis CNC equipment     |
| Turning                | 3-axis CNC equipment     | 3-axis CNC equipment     |
| Adjustment             | Manual                   | Ultrasound               |
| Wash                   | Automated                | Manual                   |
| Final inspection       | Manual                   | 3D measuring machine     |
| Packaging              | Manual                   | Manual                   |
| Storage                | Manual                   | Manual                   |

As in the case of part no. 1 and 2, in order to find the optimum version for the realization of the assembling operation two execution versions were created, which are presented in tables 8, 9, 10 and 11.

**Table 8. Version 1 of execution regarding the execution time of the assembling operation (equipment 3-axis lathe, manually executed operations).**

| Operation               | Type                        | Time [min] |
|-------------------------|-----------------------------|------------|
| Assembling              | Manual                      | 92.5       |
| Assembling acceptance   | Manual                      | 2          |
| Turning setup           | Manual (3-axis cnc lathe)   | 60         |
| Turning                 | 3-axis cnc equipment        | 1          |
| Adjustment              | Manual                      | 6          |
| Wash                    | Manual                      | 0.5        |
| Final inspection        | Manual                      | 6          |
| Packaging               | Manual                      | 0.25       |
| Storage                 | Manual                      | 0.10       |

**Table 9. Version 1 of execution regarding the cost of the assembling operation (equipment 3-axis lathe, manually executed operations).**

| Operation               | Type                        | Cost [u.m.] |
|-------------------------|-----------------------------|-------------|
| Assembling              | Manual                      | 35.5        |
| Assembling acceptance   | Manual                      | 2           |
| Turning setup           | Manual (3-axis cnc lathe)   | 60          |
| Turning                 | 3-axis cnc equipment        | 1           |
| Adjustment              | Manual                      | 6           |
| Wash                    | Manual                      | 0.5         |
| Final inspection        | Manual                      | 6           |
| Packaging               | Manual                      | 0.25        |
| Storage                 | Manual                      | 0.10        |
Table 10. Version 2 of execution of the assembling operation (equipment 3-axis lathe, manually / automated executed operations, ultrasound, 3D measuring machine) Time.

| Operation                  | Type                                | Time [min] |
|----------------------------|-------------------------------------|------------|
| Assembling                 | Manual                              | 92.5       |
| Assembling acceptance      | Manual                              | 2          |
| Turning setup              | Manual (3-axis cnc equipment)       | 60         |
| Turning                    | 3-axis cnc equipment                | 1          |
| Adjustment                 | Ultrasound                          | 3          |
| Wash                       | Automated                           | 0.1        |
| Final inspection           | 3D measuring machine                | 0.1        |
| Packaging                  | Manual                              | 0.25       |
| Storage                    | Manual                              | 0.10       |

Table 11. Version 2 of execution of the assembling operation (equipment 3-axis lathe, manually / automated executed operations, ultrasound, 3D measuring machine) Cost.

| Operation                  | Type                                | Time [min] |
|----------------------------|-------------------------------------|------------|
| Assembling                 | Manual                              | 35.5       |
| Assembling acceptance      | Manual                              | 2          |
| Turning setup              | Manual (3-axis cnc equipment)       | 60         |
| Turning                    | 3-axis cnc equipment                | 1          |
| Adjustment                 | Ultrasound                          | 3          |
| Wash                       | Automated                           | 0.2        |
| Final inspection           | 3D measuring machine                | 0.2        |
| Packaging                  | Manual                              | 0.25       |
| Storage                    | Manual                              | 0.10       |

The work plan, times and costs corresponding to each combination of the three factors are presented in figure 7.

Figure 7. The plan generated for the optimization of the parts’ assembling flow.

Within the interdependence functions both the individual effects of input factors as well as the interactions among them were taken into consideration (figure 8).

The interdependence functions for the case of the assembling operations are the following: Time [s]=68.45-1.50*A-0.20*B-0.20*C+0.000*A*B+0.000*A*C+0.000*B*C+0.000 * A * B * C. Cost(RON) =104.05-1.50 * A-0.15 * B-0.15 * C+0.000 * A * B+0.000 * A * C+0.000*B C+0.000 *A*B C
Figure 8. Choosing the interdependence functions between the input and output factors for the assembling operations.

Based on the interdependence functions the optimum combination of input factors for minimizing the time and cost was determined (figure 9).

Figure 9. The combination of values for which time and cost have minimum values in the case of assembling.
### Table 12. Results of this simulations.

| Assemble     | Manufacturing time min | Manufacturing cost u.m. |
|--------------|------------------------|-------------------------|
| Flange       | 209.35                 | 407.85                  |
| Bushing      | 99.65                  | 196.2                   |
| Assembling   | 66.85                  | 102.25                  |
| **Total**    | **375.85**             | **706.3**               |

### 3. Conclusions

After applying this method in order to optimize the manufacturing flow of the entire presented assembly, the following aspects were found:

- For part no. 1, the flange, the optimum execution versions for which minimum costs are obtained are the following: cutting with automated saw, turning 1\(^{st}\) and 2\(^{nd}\) turn with 3-axes CNC 3 lathe, ultrasound adjustment, automated wash, final inspection with the 3D measuring machine. For this execution version, the cost related to the execution of the part is of 407.85 u.m. and the execution time is 209‘35’’.
- For part no. 2 two optimum solutions were found for which its execution costs are minimum, respectively: automatic saw, 3--axis CNC lathe, ultrasound adjustment, automated wash, manual final inspection, the cost related to the execution of the part is of 196.2 u.m. and the execution time is 99‘65’’; automatic saw, 3-axis CNC lathe, ultrasound adjustment, automated wash, final inspection with 3D measuring machine, the cost related to the execution of the part is of 196.7 u.m. and the execution time is 99‘65’’
- It can be observed that minimum manufacturing costs were obtained both for part no. 1, as well as for part no. 2. In the case of the assembling process a single optimum version was obtained, this being composed of the following operations: ultrasound adjustment, automated wash, final inspection with 3D measuring machine, the cost related to the performance of the assembling process is of 102.25 u.m. and the execution time is 66’55’’, which shows us that both an optimization of the assembling time, as well as an optimization of the costs was succeeded.

### References

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