Analysis of the Assembly Process of a Selected Component in an Automobile

Naqib Daneshjo [1], Albert Mareš [2], Peter Malega [2], Róbert Rehák [1], Matúš Dzuro [1]

[1] *University of Economics in Bratislava, Faculty of Commerce, Dolonozemská cesta 1, 852 35 Bratislava 5, Slovak Republic*
[2] *Technical university of Kosice, Faculty of Mechanical Engineering, Letná 9, 042 00 Košice, Slovak Republic*

***Abstract* – The paper deals with the analysis of the assembly process of the selected component. The purpose of the analysis is to identify bottlenecks in the assembly process and to suggest possible improvements to the assembly process. The carburettor of a passenger car was chosen as the object of assembly. By analysing the assembly process, we measure the duration of individual assembly operations. Subsequently, we propose measures to improve and shorten the assembly time for problematic operations. We design and describe the assembly tool that has been tested and evaluated.**

***Keywords* – assembly process, assembly process analysis, production phase, time reduction**

1. Introduction

Assembly is an important factor in the production phase of components. The automotive industry is an area where analysis and time reductions are a necessity [10]. Based on the analyses, it is possible to find bottlenecks that prolong the installation time.

DOI: 10.18421/TEM112-31
https://doi.org/10.18421/TEM112-31

Corresponding author: Daneshjo Naqib,
Faculty of Commerce of the University of Economics in Bratislava, 852 35 Bratislava 5, Slovak Republic.
Email: daneshjo47@gmail.com

Received: 09 February 2022.
Revised: 20 April 2022.
Accepted: 26 April 2022.
Published: 27 May 2022.

The analysis can be done if a complete decomposition of the whole component assembly process is created. Improving the assembly process is an important factor, especially in manual assembly, which is still a necessity for final assembly in car production, but also in car service activities, where it is necessary to look for ways to reduce times [8]. Improvements in the production process represent a reduction in costs, which is also reflected in the prices of manufactured components [12].

The entire carburettor assembly process is analysed to achieve the papers objectives. Before the analysis, the whole assembly procedure is described, where the selected component is divided into individual components. Based on this information, individual assembly operations are analysed [11]. Their duration is recorded and evaluated in graphs. In the next step, the paper deals with the proposal of possible improvements to the most time-consuming operations [2], [6]. The result of the paper is the design and application of the mounting tool, which helped to reduce the assembly time of the carburettor.

2. Carburettor Assembly Process Analysis

For the analysis of the carburettor assembly process, we used the Excel application, in which we use tabs on the bottom bar of the program (Figure 1.). This application is used for visualisation of the progress of operations. It is also possible to perform time measurements (DTM1 and DTM2). Both measurements are performed at one workplace [3], [7]. The only difference is at the time the measurements were made. To evaluate the assembly times, we also used a Yamazumi diagram and graphs, based on which we were able to compare the length of time required for the assembly of individual operations, select the best times and calculate the average time required for the overall carburettor assembly [4], [9]. These analyses have selected for us the longest operations, which prolong the assembly time.

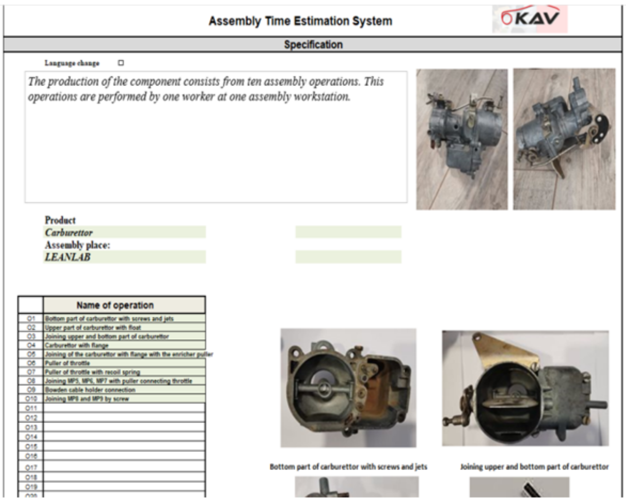
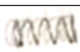
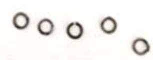
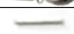


Figure 1. Analysis of the carburettor assembly process using the Excel application

If we wanted to optimize the assembly itself, we could use DFA (Design for Assembly) analysis, which is based on the evaluation of individual components according to criteria such as joint quality, number of assembly groups, ease of handling of components (Table 1.), etc. We did not apply DFA, as our work is focused on component assembly and the resulting evaluation, resp. improving of the assembly, shortening the assembly times of the component in its current form, without the possibility to change the shapes of components [1], [5]. A common result of DFA analysis is a change in component design to make them easier to assemble. Our goal is not to change the shape of the components, but to improve the assembly process of the existing components.

Table 1. List of components

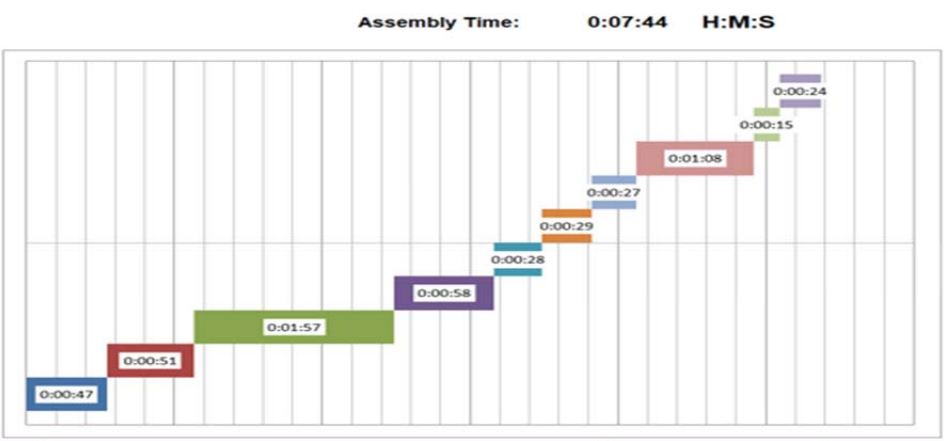
No.	Component image	Description	Weight in grams/ piece
S1		Screw M4x13	2.00
S2		Spring washer M4	0.03
S3		Cable Bowden holder	20.00
S4		Bowden cable screw M4x19	2.00
S5		Spring washer M4	0.03
S6		Nut M8	4.00
S7		Fan washer M6	0.05
S8		Flap rod	26.00
S9		Screw M4x18	2.00
S10		Return spring	0.08
S11		Flap rod	7.00
S12		Nut M4	2.00
S13		Screw M4x25	1.00
S14		Return spring	2.00
S15		Rod connecting the throttle valve with the air intake shaft	12.00
S16		Flap stop holder nut M8	4.00
S17		Enrichment control rod	3.00
S18		Screw M4x23	2.00
S19		Spring washer M4	0.02
S20		Flange with flap	296.00
S21		Paper gasket	0.02
S22		Screw M6x22	5.00
S23		Spring washer M6	0.40
S24		Cable holder	33.00
S25		Upper part of the carburettor	419.00
S26		Float pin 0,2x20	0.06
S27		Carburettor float	1.00
S28		Fuel valve	3.00
S29		Paper gasket	0.04
S30		Nozzle	1.00
S31		Mud screw M8x12	9.00
S32		Gasket washer	0.04
S33		Idle nozzle screw M8x12	5.0
S34		Sealing washer M8	0.04
S35		Lower part of the carburettor	786.0

During the assembly process, after creating the assembly sub-assemblies, we defined the assembly operations (Table 2.), which we named based on the components used in them. The input for any operation consists of at least two parts. The output for the first to ninth operations are assembly subassemblies. The output for the tenth operation is the final product (PV). The total number of operations for the final carburettor assembly is 10.

Table 2. Operations in the assembly procedure

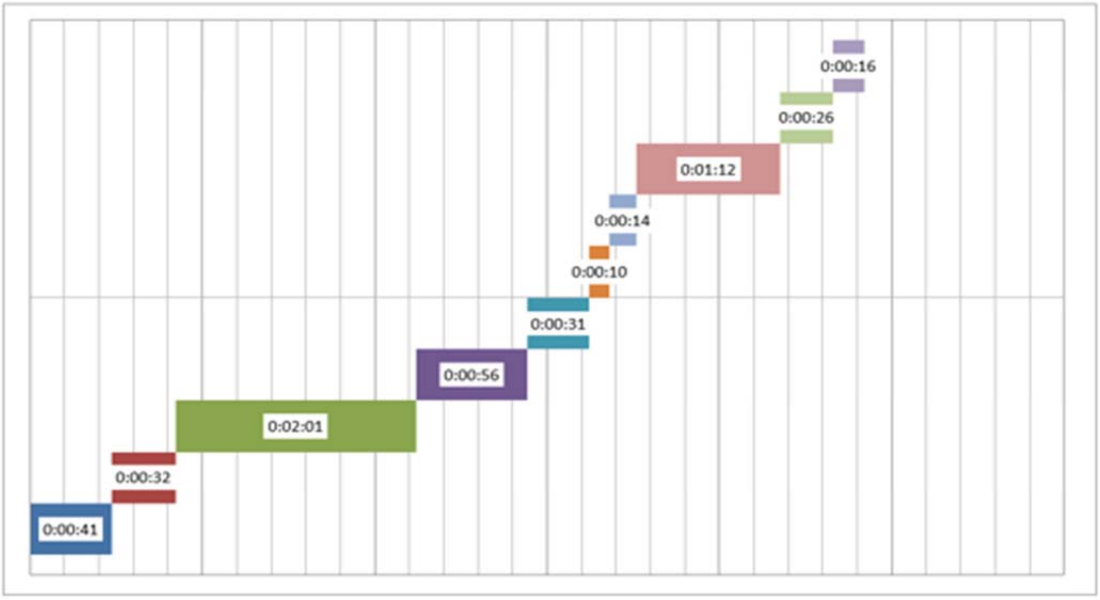
Sign	Name	Specification	Input	Output
O1	Carburettor lower part with screws and nozzles	Assembly	S35/1x , S34/1x , S33/1x , S32/1x , S31/1x , S30/3x	MP1
O2	Upper part of the carburettor with a float	Assembly	S25/1x , S28/1x , S27/1x , S26/1x	MP2
O3	Connection of the upper and lower part of the carburettor	Assembly	MP1/1x , MP2/1x , S29/1x , S24/1x , S23/5x , S22/5x	MP3
O4	Carburettor with flange	Assembly	MP3/1x , S20/1x , S21/1x , S19/2x , S18/2x	MP4
O5	Connection of carburettor with flange with enrichment rod	Assembly	MP4/1x , S17/1x , S16/2x	MP5
O6	Flap rod	Assembly	S11/1x , S12/1x , S13/1x	MP6
O7	Flap rod with return spring	Assembly	S8/1x , S9/1x , S10/1x	MP7
O8	Connection of MP5, MP6, MP7 with rod connecting flap	Assembly	MP5/1x , S15/1x, S14/1x , MP6/1x , MP7/1x , S7/1x , S6/1x	MP8
O9	Connection of cable Bowden holder	Assembly	S3/1x , S4/1x , S5/1x	MP9
O10	Connection of MP8 and MP9 with screw	Assembly	MP8/1x , MP9/1x , S2/1x , S1/1x	FV

Graphs were created based on the determined times of assembly operations. The times of assembly operations were determined based on direct observation, where we monitored the duration of operations. The individual time intervals are shown graphically. When measuring operations, we used a stopwatch to record the assembly time. The measurement was repeated several times, the measured times are average values. When measuring DTM1 (Figure 2.), the total assembly time was longer than it was in DTM2 (Figure 3.), since we performed the DTM2 measurement next in line, we already had the skills that allowed us to speed up the assembly.



	Name of operation	Measuring		Total time
		From	To	
O1	Carburettor lower part with screws and nozzles	10:11:24	10:12:11	0:00:47
O2	Upper part of the carburettor with a float	10:13:37	10:14:28	0:00:51
O3	Connection of the upper and lower part of the carburettor	10:14:44	10:16:41	0:01:57
O4	Carburettor with flange	10:17:22	10:18:21	0:00:58
O5	Connection of carburettor with flange with enrichment rod	10:18:43	10:19:11	0:00:28
O6	Flap rod	10:19:53	10:20:22	0:00:29
O7	Flap rod with return spring	10:20:29	10:20:56	0:00:27
O8	Connection of MP5, MP6, MP7 with rod connecting flap	10:22:01	10:23:10	0:01:08
O9	Connection of cable Bowden holder	10:23:25	10:23:40	0:00:15
O10	Connection of MP8 and MP9 with screw	10:24:10	10:24:34	0:00:24

Figure 2. Graph of DTM1



	Name of operation	Measuring		Total time
		From	To	
O1	Carburettor lower part with screws and nozzles	10:35:29	10:36:10	0:00:41
O2	Upper part of the carburettor with a float	10:36:18	10:36:51	0:00:32
O3	Connection of the upper and lower part of the carburettor	10:37:00	10:39:01	0:02:01
O4	Carburettor with flange	10:39:10	10:40:06	0:00:56
O5	Connection of carburettor with flange with enrichment rod	10:40:14	10:40:46	0:00:31
O6	Flap rod	10:40:52	10:41:02	0:00:10
O7	Flap rod with return spring	10:41:06	10:41:20	0:00:14
O8	Connection of MP5, MP6, MP7 with rod connecting flap	10:41:52	10:43:04	0:01:12
O9	Connection of cable Bowden holder	10:43:19	10:43:45	0:00:26
O10	Connection of MP8 and MP9 with screw	10:43:50	10:44:06	0:00:16

Figure 3. Graph of DTM2

After measuring the times, we used the Yamazumi diagram, where we selected the shortest operation times when comparing the best and worst assembly times. Although the DTM2 measurement was performed as the next in order and the total assembly time was shorter. When comparing the individual operations, the DTM2 had a better time by only one operation, also due to the more difficult handling of components. Even the acquired skill did not ensure that the washer, screw, or nut will not slip. Even with experience in manual assembly, such unwanted time losses cannot be avoided. Each of the operations in the Yamazumi diagram represents the added value (AV) for the assembly of the final component. The average time obtained by adding the shortest times per operation is shown in Figure 4. and Figure 5.

	Name of assembly operation	Time	Workplace selection		Workplace 1
O1	Carburettor lower part with screws and nozzles	0:00:41	Workplace 1	AV	0:00:41
O2	Upper part of the carburettor with a float	0:00:32	Workplace 1	AV	0:00:32
O3	Connection of the upper and lower part of the carburettor	0:01:57	Workplace 1	AV	0:01:57
O4	Carburettor with flange	0:00:56	Workplace 1	AV	0:00:56
O5	Connection of carburettor with flange with enrichment rod	0:00:28	Workplace 1	AV	0:00:28
O6	Flap rod	0:00:10	Workplace 1	AV	0:00:10
O7	Flap rod with return spring	0:00:14	Workplace 1	AV	0:00:14
O8	Connection of MP5, MP6, MP7 with rod connecting flap	0:01:08	Workplace 1	AV	0:01:08
O9	Connection of cable Bowden holder	0:00:15	Workplace 1	AV	0:00:15
O10	Connection of MP8 and MP9 with screw	0:00:16	Workplace 1	AV	0:00:16

Figure 4. Data for Yamazumi graph – DTM 1

	Workplace 1	
AV	0:06:37	value added activity
SA	0:00:00	not value added activity
VA - 1	0:00:00	optional activities according to variant - not always executed
VA - 2	0:00:00	optional activities according to variant - always executes, time depend on variant
NA	0:00:00	necessary activities - always executed, not added value
SUM	0:06:37	

Figure 5. Total assembly times at the workstation

The Yamazumi graph is a stacked bar chart, and the times are also shown graphically (Figure 6.), which shows the source of the cycle time in each process. The graph is used to graphically represent processes for optimisation purposes. This chart can be used for the process of eliminating waste of time, as well as for improving assembly lines.

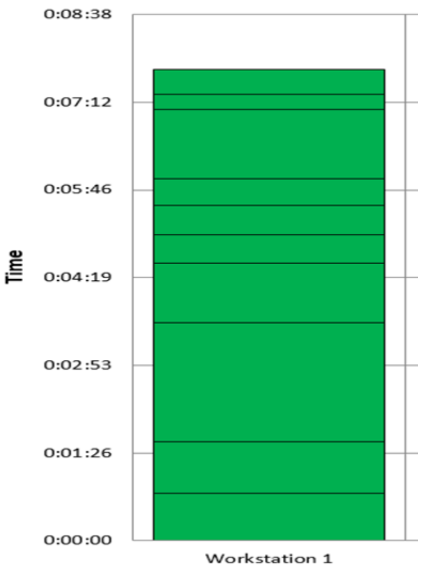


Figure 6. Yamazumi graph - Workstation 1 – DTM 1

Based on the measured times, we created a comparison chart (Figure 7.), which contains a summary of operations and their associated times. The times of the ten operations are compared from two measurements, where the green bars - DTM1 represent the first measured times, the red bars - DTM2 the average of the shortest times. Comparing the individual operations, we found that operation 3 (O3) takes the longest time, operation 2 (O8) takes the second longest time, and operation 4 (O4) takes a similarly long time.

We also found that the time required for operations was shortened during reassembly, but the exception are longer operations, where the opposite effect would be expected. These time differences were due to the use of a larger number of parts, and therefore also occurred with O3, due to the handling of washers and screws, which occasionally slipped out of the hands. The O8 requires the correct orientation of the rod connecting the throttle to the air intake shaft, the correct mounting of the return spring and the direct fitting of the nut. With O4, it is necessary to position the paper seal precisely so that it does not prevent the screws from fitting.

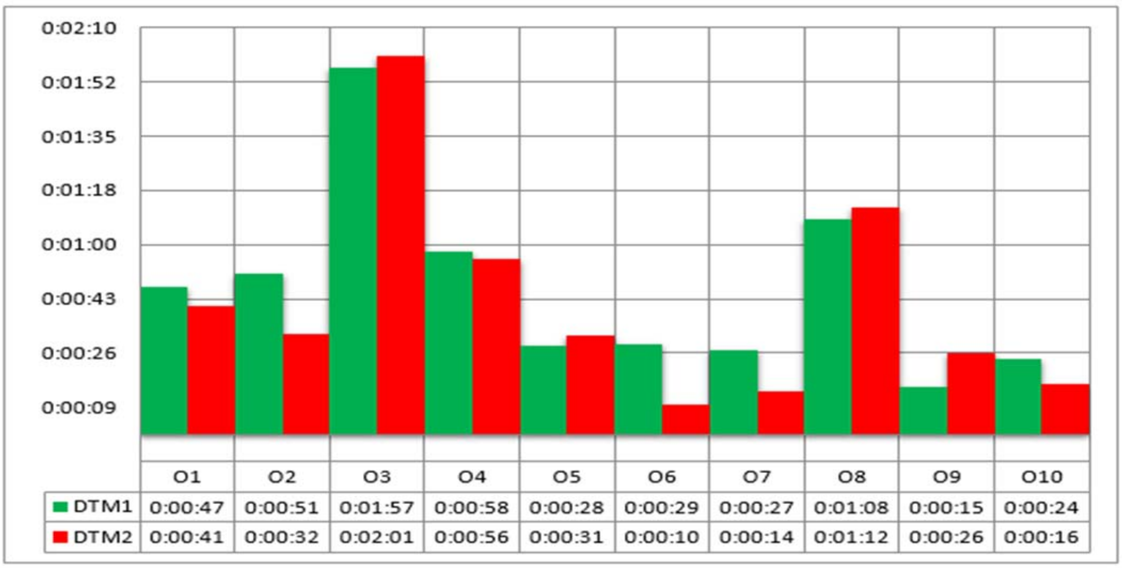


Figure 7. Time comparison for DTM 1 and DTM 2

To streamline the application of the component assembly time results, we calculated the number of workplaces needed to create a larger number of products (Figure 8.). We based our calculation on the total time required for assembly and on the time of activities required before and after assembly. The resulting time was 8 minutes and 23 seconds. For production of 10000 pieces per year, we would need one workplace, for 16000 pieces we would need one and a half workplaces, which is not possible, and therefore we would have to create 2 workplaces. This would lead to large losses, as the capacity of the workplace would not be used. A similar case occurs with 30000 pieces of products, where we theoretically need 2.5 workplaces, which in practice would mean a total of 3. The most advantageous and with the least losses for us is to produce 50000 pieces of carburettors per year, for what we need 4 workplaces, with a work shift of 7.5 hours with 3% planned downtime and one shift per day. Our normalised production would be respected at a level of 95%.

		Product A	Product B	Product C	Product D	Product E	Complex product	Total time in min.
Assembly	Others activities before assembly	0.66	0.00	0.00	0.00	0.00	0.66	8.23
	Assembly	6.58					6.58	
	Others activities after assembly	0.99	0.00	0.00	0.00	0.00	0.99	

	Total time of assembly (t_{op})	Planned number of products per year (n_{si}): 10 000	16 000	30 000	50 000
Number of Assembly workstations	8.23	0.79	1.26	2.37	3.95

		Explanation for calculation:
Effective available working time (in hours):	1826.025	$T_{ef} = p*h*(1-t_{pr}/100)$ [h]
Number of working days in year 2020	251	**p** = Number of working days in year 2020
Number of working hours per working shift:	7,5	**h** = Number of working hours per working shift:
Planned downtime in percentage:	3	t_{pr} = Planned downtime in percentage:
Theoretical number of workstations:	P	P workstations = $n_{si}*t_{op}/60*T_{ef}*k_{sm}*k_{p}$ [ks]
Working shift per day:	1	k_{sm} = Working shift per day:
Standard of fulfilment:	0.95	k_{p} = Coefficient of fulfilment of standards (e.g. 95% = 0.95)

Figure 8. Calculation of the number of workstations

Operations O3 and O8 were standing out in the analysis of the duration of individual operation times in the graph (Figure 9.). One of the primary reasons for their longer time duration is the larger number of components in the assembly operation, another is the complexity of the correct orientation of the components and the complex handling of the component. These operations take half as long as the others.

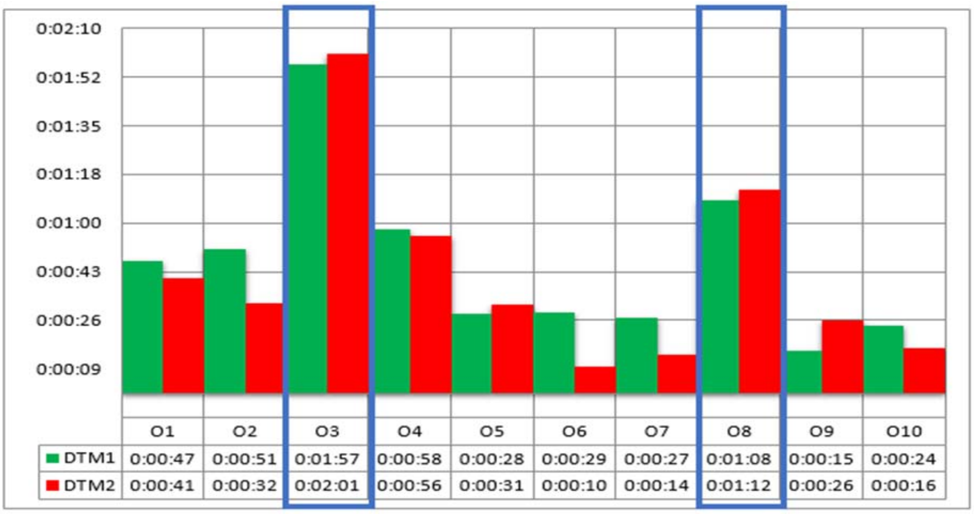


Figure 9. Selection of operations for time reduction

3. Carburettor Improvement Application

As the most efficient option / variant, we have chosen the production of the tool that will shorten the assembly time most efficiently. The disadvantage of such a tool (Figure 10. and Figure 11.) is its specialization. In our case, such tools would have to be two and would have to be the exact negative of our component. While this would facilitate the assembly of our component and shorten its assembly times, it would be necessary to create two tools that would ultimately take up space on the assembly table and require time to choose the right one for the operation. There would be also the extra costs as two pieces would have to be produced.

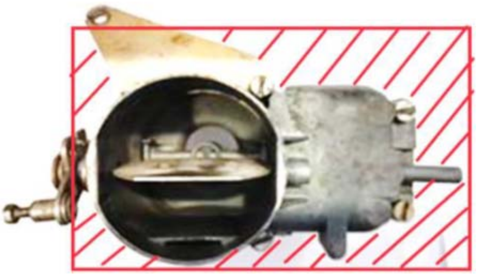


Figure 10. Location of fixation tool - top view

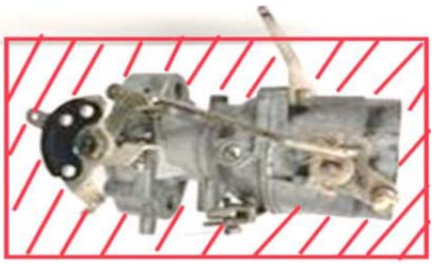


Figure 11. Location of fixative - top view

A suitable alternative to improving the assembly with a tool is an instrument created by ourselves (Figure 12.). This tool eliminates all the disadvantages of the fixing tools originally introduced by us. It has better stability and low production costs.

The time required for production is shorter, as we create only one tool and not two, as was proposed in the initial improvements. The advantages of the tool in the first place are the shortening of assembly times and possibility of having one free hand (during assembly we can assemble with both hands), which was our main goal. Its biggest advantage is versatility. It is suitable for use with several types of components with a single limitation, namely the need to attach it to components that have a thread with a diameter of 8 mm. It is space-saving, it can be moved anywhere without lengthy assembly operations, it has no mounting base, so it can be used on any type of workbench (no need to fasten it to the tabletop), as it is enough to position it directly on the table. It is not difficult to handle. When using this tool to our component, we used the technological opening on the carburettor, which is shown in Figure 13. This opening was not used during assembly, so we used the thread with a diameter of 8 mm. Using a screw placed in this thread, we fasten the assembled part to the tool.

Figure 12. Tool

Figure 13. Technological hole - M8 thread

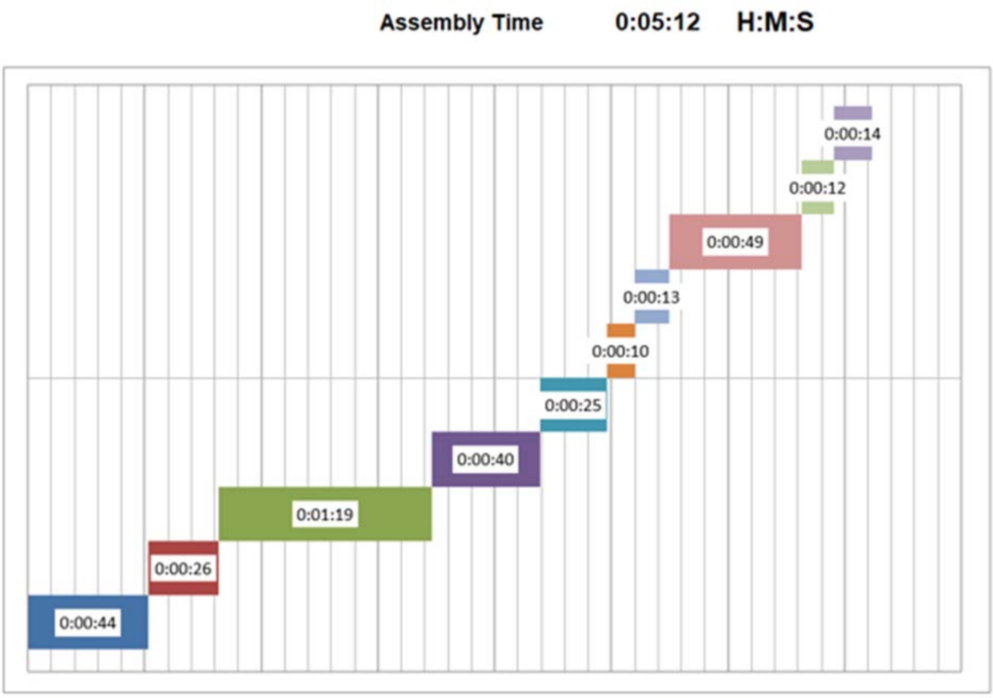
4. Evaluation Tools Efficiency

To evaluate the effectiveness of the tool, it was necessary to verify its effect on the duration of the assembly process. The verification consisted of its introduction into the assembly process (Figure 14.).

We have included the tool among the tools needed to mount a carburettor. We were using it since the first operation, which, unlike other operations performed on it, took longer than without it. However, this requested an additional action, namely the attachment of a carburettor to it. However, this action accelerated the remaining operations.

Figure 14. Use of the tool during assembly

We managed to shorten the assembly time by up to 1 minute and 38 seconds. Figure 15. shows the individual operation times using the tool. The total assembly time with the tool was 5 minutes and 12 seconds. This difference is graphically illustrated by comparing the Yamazumi graphs in Figure 17.



	Name of operation	Measuring		Total time
		From	To	
O1	Carburettor lower part with screws and nozzles	12:28:39	12:29:23	0:00:44
O2	Upper part of the carburettor with a float	12:29:59	12:30:25	0:00:26
O3	Connection of the upper and lower part of the carburettor	12:33:19	12:34:38	0:01:19
O4	Carburettor with flange	12:35:00	12:35:40	0:00:40
O5	Connection of carburettor with flange with enrichment rod	12:35:54	12:36:19	0:00:25
O6	Flap rod	12:36:37	12:36:47	0:00:10
O7	Flap rod with return spring	12:37:02	12:37:15	0:00:13
O8	Connection of MP5, MP6, MP7 with rod connecting flap	12:37:47	12:38:36	0:00:49
O9	Connection of cable Bowden holder	12:38:51	12:39:03	0:00:12
O10	Connection of MP8 and MP9 with screw	12:39:14	12:39:28	0:00:14

Figure 15. DTM3 - measurement operation times with using the tool

When comparing the initial best assembly times and assembly times with the tool, only one operation took longer. Figure 16. shows the times of the workplace 1, which represent the times without the use of the tool, and the times of the workplace 2, which represent the assembly using the tool.

	Name of operation	Time	The selection of workstation		Workstation 2
01	Carburettor lower part with screws and nozzles	0:00:44	Workstation 2	AV	0:00:44
02	Upper part of the carburettor with a float	0:00:26	Workstation 2	AV	0:00:26
03	Connection of the upper and lower part of the carburettor	0:01:19	Workstation 2	AV	0:01:19
04	Carburettor with flange	0:00:40	Workstation 2	AV	0:00:40
05	Connection of carburettor with flange with enrichment rod	0:00:25	Workstation 2	AV	0:00:25
06	Flap rod	0:00:10	Workstation 2	AV	0:00:10
07	Flap rod with return spring	0:00:13	Workstation 2	AV	0:00:13
08	Connection of MP5, MP6, MP7 with rod connecting flap	0:00:49	Workstation 2	AV	0:00:49
09	Connection of cable Bowden holder	0:00:12	Workstation 2	AV	0:00:12
010	Connection of MP8 and MP9 with screw	0:00:14	Workstation 2	AV	0:00:14

Figure 16. Data for Yamazumi graph – DTM 3

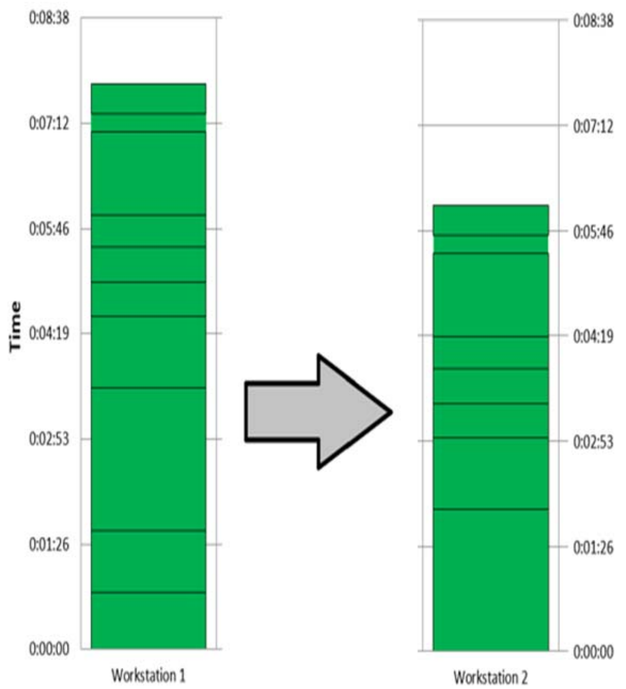


Figure 17. Yamazumi graph-comparison for DTM 1 and DTM 3

By comparing in the Yamazumi chart (Figure 18.), where the green bars represent the selection of the best assembly times without the use and the red bars the times with the use of the tool, we have shown that the proposed tool shortens the times of individual operations. We managed to significantly shorten the operations that this product was aimed at. Operation 3 initially lasted 1 minute and 57 seconds, and with the use of the preparation, this time was reduced to 1 minute and 18 seconds. The time saved for this operation is 40 seconds. Operation 8 lasted 1 minute and 18 seconds and now 49 seconds, reducing the operation time by 29 seconds. In total, only 2 minutes and 9 seconds were saved on these 2 operations alone.

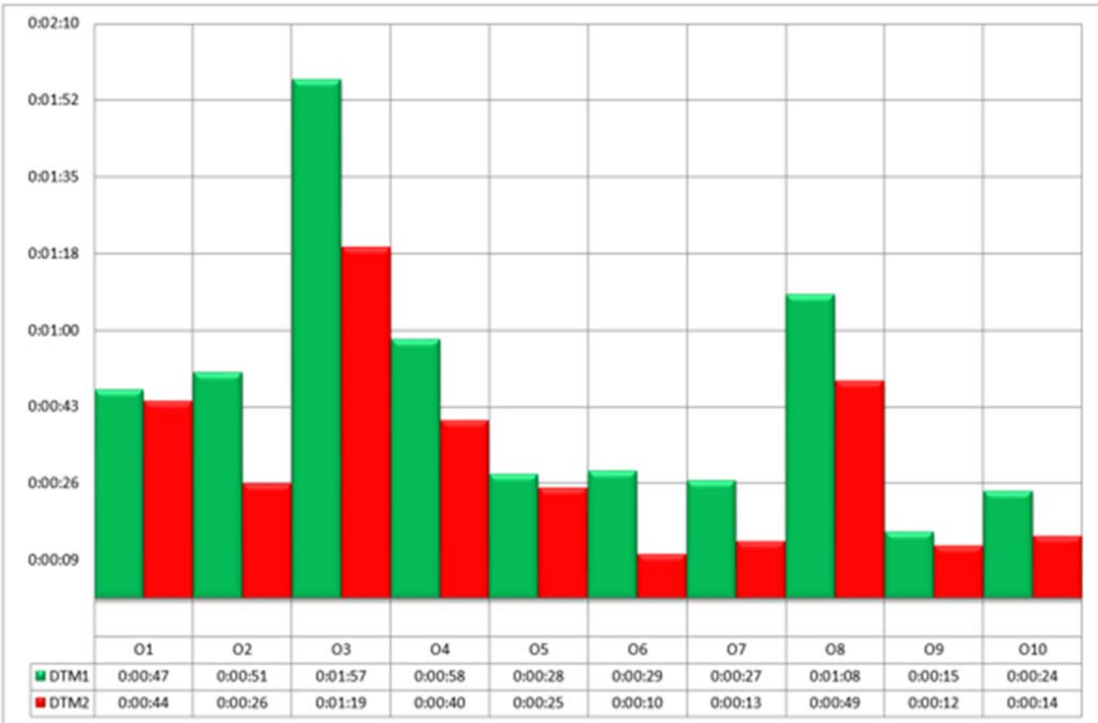


Figure 18. Graphical comparison of times before and after using tool

To better compare the effect of using the tool on shortening assembly times, we use Figure 19. This figure shows the original assembly time without tool use in this process, which lasted 8 minutes and 23 seconds with all preparatory operations. At such a time, we found out by analysis that the most advantageous and least loss-making option is the production of 50,000 pieces of products, with the need for four workplaces.

By using the tool, the assembly time was reduced to 6 minutes and 39 seconds with other activities before and after assembly. Thus, while maintaining all conditions, it was possible to increase the number of assembled carburettors at the same number of workplaces. So, 4 workplaces can produce 65000 pieces of carburettors. We would be able to assemble the original 50000 pieces at 3.07 workplaces, which is almost one workplace less.

WITHOUT FIXTURE		Product A	Product B	Product C	Product D	Product E	Complex product	Total time in min.
Assembly	Others activities before assembly	0.66	0.00	0.00	0.00	0.00	0.66	8.23
	Assembly	**6.58**					**6.58**	
	Others activities after assembly	0,99	0.00	0.00	0.00	0.00	0.99	

	Total time of assembly (top)	Planned number of products per year (n_{si})			
		10 000	16 000	30 000	50 000
Number of Assembly workstations	8.23	0.79	1.26	2.37	3.95

WITH FIXTURE		Product A	Product B	Product C	Product D	Product E	Complex product	Total time in min.
Assembly	Others activities before assembly	0.51	0.00	0.00	0.00	0.00	0.51	6.39
	Assembly	**5.11**					**5.11**	
	Others activities after assembly	0.77	0.00	0.00	0.00	0.00	0.77	

	Total time of assembly (top)	Planned number of products per year (n_{si})			
		10 000	16 000	50 000	65 000
Number of Assembly workstations	6.39	0.61	0.98	3.07	3.99

Figure 19. Comparison of the number of produced pieces in 1 year

5. Conclusion

The aim of the work was to evaluate the assembly process of the selected component and to suggest improvements. The carburettor of a passenger car was chosen as the subject of the analysis. A carburettor decomposition created a list of used components. This forms the basis for creating list of subassemblies and defining the assembly procedure. The duration of operations was measured by direct observation of the assembly process. The most time-consuming operations of the assembly process were selected by analysis of the carburettor assembly procedure. These operations have been examined in detail and measures have been proposed to reduce their duration. The starting point for improving manual assembly is the creation of a tool that will ensure more efficient work. To verify the effectiveness of the preparation, the preparation was manufactured and tested in the assembly process. Analyses and comparative results were performed to demonstrate the efficacy of the tool. It managed to shorten the time of the assembly process and increase production productivity.

Acknowledgement

This work has been supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic (Project KEGA 032EU-4/2020 a KEGA 019TUKE-4/2022).

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