Int j simul model 22 (2023) 1, 64-75

Original scientific paper

# PROPOSAL OF A SOFTWARE TOOL FOR MANUAL ASSEMBLY OUTPUTS SIMULATION

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**Abstract**

Manual assembly operations are often the bottlenecks of production processes. Usually, in order to find out, what the throughput of these manual assembly operations will be, it is first necessary analysing them in the context of the workstation and the whole processes as well. For these analyses, one of the most useful tools is the use of simulation. Despite existing several complete software for these purposes, they often demand significant time and effort to create good simulations. Sometimes, however, it is just enough to simulate a few key aspects of the assembly process to get key results, which are often the base for immediate and/or further process improvement. In these cases, creating a special analytical tool that allows efficiently obtaining a sufficiently good solution to the given problem becomes a viable and convenient option. This paper presents an assembly simulation and analysis tool designed and created in Microsoft Excel by the authors. The tool is useful for quick analyses of assembly tasks without the need of having to engage in creating complex 3D models and extra analyses. The proposal is implemented into a practical case study, which allows verifying its validity.

(Received in August 2022, accepted in December 2022. This paper was with the authors 1 month for 2 revisions.)

**Key Words:** Assembly, Simulation, Time Analysis, Microsoft Excel, Software Tool

## 1. INTRODUCTION

As generally defined by VDI [1], simulation is a display mode where a real or imaginary system with its internal dynamic processes is created in such a way that it is possible to experiment with it in order to gain knowledge that can then be translated into reality. Simulation is also the process of realizing an experiment with a model that is generally an abstract representation of the system under study. According to Zsifkovits and Altendorfer-Kaiser [2], such system is created with a lower degree of detail in terms of its structure or behaviour if compared to the original system. On the other hand, such simulations systems are usually analysed under a system approach in accordance with systems theory, which is based on a way of thinking and solving problems where the phenomenon is comprehensively understood in its external and internal contexts. Each system is bordered, has inputs, and outputs, and behaves in a certain way.

The fact that a system is defined for a certain purpose means that it is possible to define several systems relating to the same part of reality. Defining the system by its elements, relationships and internal structure usually means that the system is a simplification of reality, i.e., is a more or less an accurate model, not an exact replica. Simulations based on such a model requires a correct interpretation of the results achieved in the final phase. Models cannot be confused with reality.

The model is also characterized by abstraction, i.e., by conscious neglect of certain attributes, to highlight those model properties that are essential for the model maker or modelling goal.

A more general definition was offered by the philosopher Wüstneck [3], who stated: "A model is a system that, as a representative of a complicated original, utilizes, chooses or creates, based on the common, essential features of a third system for a particular function, not least to enable or facilitate the understanding or control of the original respectively its replacement …".

In terms of assembly processes and systems, simulation is seen as a support tool and is mainly oriented to several basic directions or areas, some of which are briefly explained next. Because very often assembly workstations are arranged in assembly lines, there is, in consequence, the need to balance these assembly lines. Nowadays, there are modern approaches to solve this task. For example, Salam and Liu [4] use heuristics, while Didden et al. [5] use a genetic algorithm. Moreover, the layout of the assembly line can be different. Lee et al. [6] use modelling and simulation to compare different layouts and a Classification and Regression Trees algorithm (CART) is used to extract decision rules from the simulations.

As is described by Butlewski et al. [7], another area which is especially important in the case of manual assembly workstations is Ergonomics. Ergonomic analyses and simulations using calculations and methodologies such as the RULA analysis presented in Snook & Ciriello, NIOSH, and the like can be applied using a 3D model of the workplace and the worker. The created 3D models can be used for virtual reality and its application to optimize ergonomics as it is also described by Guo et al. [8]. On the other hand, in this area several authors have also proposed and/or used more mathematically oriented tools, e.g.: multi-objective genetic algorithms, and this to address the ergonomics in the context of balancing whole assembly lines as is described by Dalle Mura and Dini [9].

Another area where simulation is highly useful refers to the simulation of the operation of individual devices, or industrial robots as is described by Wojciechowski and Suszyński [10], conveyors, or AGV described by Grznar et al. [11], etc. or even the whole assembly processes and/or stations, respectively system as a whole.

The next areas where modelling and simulation is usually applied to are the creation of assembly sequences as is described by Suszynski and Zurek [12] and also in time and capacity analysis. For time analysis evaluation and setting, standard methods are usually used, e.g. modelling as it is described by Yilmaz [13], simulation as it is described by Turk et al. [14]. However, there are also newly suggested approaches like the knowledge and mixed integer linear programming described by Qian et al. [15], the fuzzy analytic suggested by Suszynski and Cieslak [16] or the virtual reality approach described by Gorobets et al. [17]. These virtual reality, augmented reality, mixed reality, and similar assistance systems find application in more and more assembly activities nowadays. Not in vain, there are thus huge expectations and an increased use of these technologies in industry as is described by Wolfartsberger et al. [18] and Daling and Schlittmeier [19]. Software like Delmia from Dassault Systems or Plant Simulation by Tecnomatix offer numerous tools to cope with the tasks of all of the mentioned areas as it is also mentioned in Schmidt [20].

In some cases, other software such as ARENA from Rockwell Automation, WITNESS from the Lanner Group, and other applications primarily intended for assembly processes such as Proplanner or specific proposals like the Human Factor Analyser tool (HFA) presented by Faccio et al. [21] may be also beneficial in the analysis of manual assembly operations or workstations.

## 2. MATERIALS AND METHODS

The purpose of this section is to present the design of a tool suitable for quick analyses of given manual assembly activities. This form of quick and simple analysis is required because making a precise model is time-consuming and sometimes unnecessary when needing to make a quick decision. In these cases, it is sometimes enough and more viable option using instead a simple comprehensive tool like the one proposed within this paper. An example of an approach like this can be found, for example, in Grznar et al. [22].

In the process of designing the simulation model, the first step was to define a system, in this case a manual assembly workplace. However, it was necessary to consider that there was a huge diversity in manual assembly itself, and thus, in order for the simulation model to have a broad validity and be robust, i.e., that it could be used for manual assembly workplaces of different types (setups, general functioning, etc.), it was decided to define the sub-system of a single worker. By defining this sub-system, it was possible to contribute eliminating the diversity factor of assembly workplaces, *t*. Similarly, it was also important to consider that the human intervention in a manual assembly place is also very variable like screwing, positioning, riveting, etc. These operations can then be then further classified in even more detail, for example, using the MTM classification mentioned by Suszynski and Cieslak [16]. The division of worker's activities proposed by this method is appropriate in certain analytical procedures like time setting analysis, however, it suffers from certain inflexibility mainly given to its strict time constraints as is described by Tang et al. [23], and thus, for the design of the simulation model discussed within this paper, it was not applicable. The reason for this is that this approach is individually dependent on a specific installation task as well as on the technical solution of the workplace. Thus, it was necessary to find another functional model of the worker's work at the manual workplace, which would have a more general character but would also be in line with the existing classification methods.

Based on these previous elements, five basic and two complementary activities of the worker were defined for the simulation model. Each activity was assigned a basic parameter, i.e.: time. In Fig. 1 it is possible to see a schematic diagram of a simulation model, i.e.: its basic structure. According to this model, one employee's activity is divided into five consecutive activities characterized by time, as follows:

- *T* input B (number 1) – the time needed for activities that must be performed before the start of the assembly and are bound to a predetermined number of products (lot size). These are activities such as pallet exchange, product setup, tool change, workplace supply, and so on.
- *T* input A (number 2) – the time required for activities that must be performed before the product is assembled. These are activities such as component clamping, tool replacement, manipulation, and the like.
- *T* assembly (number 3) – assembly time, the time required to perform all assembly operations by one person.
- *T* output A (number 4) – time needed for activities to be performed after the product has been assembled. These are activities such as removing the component from the fixture, placing it part in a pallet, and the like.
- *T* output B (number 5) – the time needed for the operations performed after the completion of the assembly and are bound to a certain predefined number of assembled products, respectively, (lot size). These are activities such as pallet exchange, tool layout and removal of assembled products, and the like.

Based on Fig. 1, it is important to state that 1 and 5, the ones in blue, may well refer to operations which are not essential, e.g., before assembly it may refer to taking parts that were packed together in a box and after assembly it may well refer to operations like packing the parts together. On the other hand, operations 2 and 4 appearing in yellow, refer to operations that cannot be obviated and are always to be executed before and after the processing of each part or component. The number 3 in green colour refers to assembly operation duration time.

This model is valid for existing assembly processes as well as for designed/proposed new assembly process. In addition to these basic employee activities, the model is expanded with activities that are related to the occurrence of errors and failures in the workplace. In this regard, two more times were defined:

- *T* mistake – the time, the worker needs to fix the product error.

- *T* failure – the time, that a worker needs to eliminate a device malfunction or failure. Another signal that informs of the problem at the workplace.

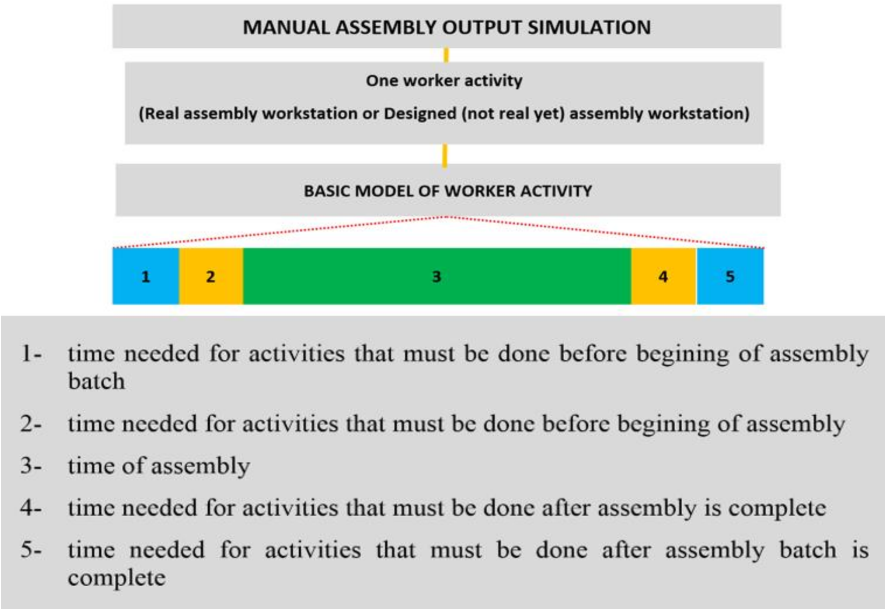



Figure 1: Basic schematics of the simulation model-Manual Assembly Output Simulation (MAOS).

The errors and failures themselves were divided into two basic categories, namely errors and failures whose removal is carried out by the worker, and errors and failures where the work is stopped and their removal requires the intervention of another person or people, see Fig. 2. For this STOP activity, time is defined separately.

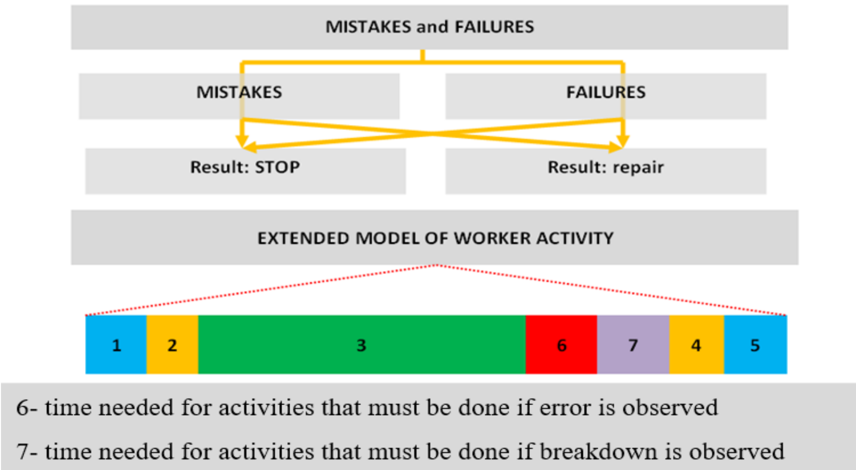



Figure 2: Simulation model with additional activities.

For the basic simulation model, there are several variants in dependence of the input time data. The assembly time itself can be entered as a fixed value or as the minimum and maximum values. Other time data may also be entered as zero, where, for example, zero-time value *T* input B means that assembly is not performed in a batch. In theory, a simulation model can create 162 time data combinations based on the type of input value.

The simulation model containing the errors and failures also takes into account input data from both the real and planned assembly process. In addition to the identification data of each error and failure, it is also necessary to enter the data on the number of occurrences of each error and failure, the repair time as well as the time for the STOP status.

In this case two basic methods are used for processing. The first is the Normal distribution that is used to determine the occurrence, i.e., the number of the same time data for those input time values that are entered in the form of the minimum and maximum values. The second principle is to create a random combination of all time data in each assembly cycle. Based on the required number of assembly cycles, a matrix of time data is produced. According to this, it happens that for identical input data, assembly times in assembly cycles are not identical as this is a random process. Identical is the result of simulation and number of assembled products, composition of time data, occurrence of errors and faults overall.

## 3. PROPOSAL OF AN ASSEMBLY SIMULATION AND ANALYSIS TOOL

For the implementation of the above-presented concept, an Excel application has been developed which fulfils the following identified requirements:

- Easy application and use of all its functions,
- the possibility of easy expansion and replenishment by users,
- compatibility with other applications to support Lean Assembly,
- ability to integrate applications into a larger unit.

The Excel application concept is based on the use of a wide range of existing Excel features, including macros and VBA (Visual Basic for Applications). The entire application contains 9 sheets, with only the first sheet being essential for the user, while the others are just for processing the entered data only. Based on the input data, time data for the selected number of assembly cycles are automatically generated. From these simulated data, the results are then further processed as shown in Table I. These are data such as the number of products per hour, the number of irreparable products, the number of assembly cycles, the total number of flawless products.

The Excel application is designed to be user-friendly, for example, it provides various views, the ability to scroll through results, among others. When all the required input data are available, the total simulation time, including entering the data, is a maximum of 1-2 minutes.

Table I: Excel application – input time data.

| | input B | input A | assembly | assembly time | type of mistake | time of mistake correction | output A | output B | continue? | Failure 1 | time of failure 1 remove |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1,98 | 0,99 | ok | 6,80 | | | 1,00 | | a | | |
| 2 | | 0,93 | ok | 6,90 | | | 1,07 | | a | | |
| 3 | | 1,01 | ok | 6,77 | | | 0,99 | | a | | |
| 4 | | 1,00 | ok | 6,97 | | | 1,03 | | a | Failure 1 | 4,00 |
| 5 | | 1,02 | ok | 6,74 | | | 1,04 | | a | | |
| 6 | | 0,98 | ok | 6,74 | | | 0,99 | 1,94 | a | | |
| 7 | 2,04 | 0,90 | not ok | 6,87 | Mistake 2 | 5,00 | 1,07 | | a | | |
| 8 | | 1,06 | not ok | 6,77 | Mistake 3 | 5,00 | 1,03 | | a | | |
| 9 | | 0,95 | ok | 6,91 | | | 1,05 | | a | | |
| 10 | | 1,08 | ok | 6,74 | | | 1,05 | | a | | |
| 11 | | 0,94 | ok | 6,74 | | | 0,95 | | a | | |

Since the mass production of parts is assumed for the purposes of the application, the whole proposal relies on the use of the Normal distribution. In this sense, the authors have used the Excel NORMDIST function for the generation of the random duration times of specific assembly operations. As detailed in [24], this Excel NORMDIST function resolves the above-mentioned Normal Probability Density function or the Cumulative Normal Distribution function for a supplied set of parameters. The syntax of the function is defined as follows:

NORMDIST (*x*, mean, standard_dev, cumulative),

where the function arguments are:

$x$ – the value at which one wants to evaluate the distribution function,
mean – the arithmetic mean of the distribution,
standard_dev – the standard deviation of the distribution,
cumulative – a logical argument specifying the type of distribution to be used:
TRUE – Cumulative Normal Distribution Function,
FALSE – Normal Probability Density Function.

In the particular case of this research the FALSE argument was the one used.

## 4. IMPLEMENTATION OF THE PROPOSED SIMULATION MODEL INTO A PRACTICAL CASE STUDY

To verify the simulation model, the process of assembling the interior trim of a car door was selected. The assembly process is carried out in three workplaces. The object of the simulation is the second workplace shown in Fig. 3. This workplace was selected because of being the bottleneck of the assembly process and thus needing a more immediate analysis and improvement. At the first workstation, the average assembly time is about 37 seconds, in the third workstation is about 27 seconds, and in the second workstation where the simulation is to be applied to is about 1 minute. The assembly procedure at this workplace is divided into eight assembly operations:

- O1 – gripping the plastic part and moving it to the mounting workplace,
- O2 – insertion of the plastic part into the fixture,
- O3 – taking the anti-noise insulation from the box,
- O4 – removing half of the cover foil from the noise insulation,
- O5 – gluing against noise insulation for plastic parts, complete releasing of the foil and bonding against noise insulation,
- O6 – closure of the fixture and automatic checking of all components,
- O7 – removing the plastic part from the fixture,
- O8 – relocating the assembled part to the next mounting location.

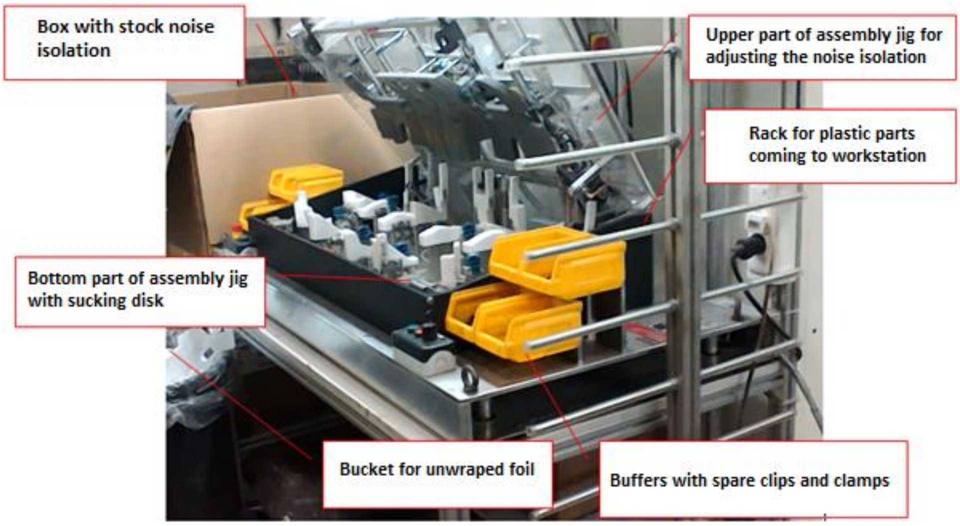



Figure 3: Assembly workplace object of the simulation.

It is important to mention that none of the above assembly operations can be moved to another workstation as an attempt to balance the assembly time.

The simulation model application process was implemented in two steps. In the first step, data on the existing assembly process were entered into the simulation model, and in the second, the simulation was performed. Tables II to IV show the assembly process input data used in the simulation process. The input data presented in Table II were obtained from the real workplace by recording a video of the operations performed and its subsequent processing. The operations were recorded for 2 hours and the data in the tables are the values from this measurement. Each operation, although repeated, does not have the same duration. The differences are due to the fact that the worker cannot carry out the operation completely identical and also by the fact that the workers are in the process of being rotated or changed over. For example, operation 4 – removing half of the cover foil from the noise insulation, is very specific operation because that noise insulation is made from a dense fleecy material, and it never has the same structure. In this regard, sometimes it is easy for worker to remove the cover foil, however sometimes it is very complicated. This variability is one of the reasons behind the selection and use of the Normal distribution to forecast operation times. The base parameters for the use of the distribution were the minimum and maximum time achieved or recorded during the observation of the assembly operation. The data in Tables III and IV were obtained directly from the company.

Table II: Input time data.

| **Time category** | **Value** [min] |
|---|---|
| Minimal assembly time | 0:00:50 |
| Maximal assembly time | 0:01:06 |
| Minimal input time 1 | 0:00:04 |
| Maximal input time 1 | 0:00:06 |
| Minimal output time 1 | 0:00:03 |
| Maximal output time 1 | 0:00:05 |

In the case of Table II, the number of mistakes in 100 products was 2.

Table III: Input mistake data.

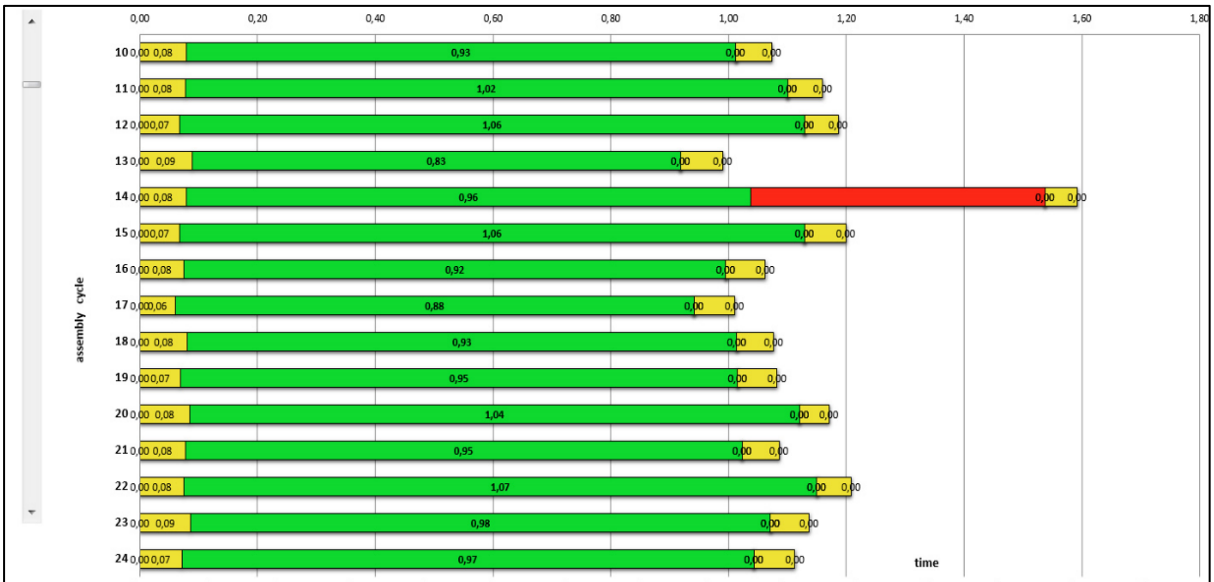
| **Mistake type** | **Time for mistake removing** [min] | **Percentage share** [%] |
|---|---|---|
| Error – bad noise isolation placement | 0,5 | 10 |
| Error – injection moulding | 0,1 | 20 |
| Error – missing clips | 0,3 | 10 |
| Damage through manipulation | 0,1 | 5 |

Table IV: Input failure data.

| **Failure** | **Number of cases per 100 cycles** | **Action** | **Time for failure removing** [min] |
|---|---|---|---|
| Sensor failure | 0,01 | STOP | 10 |

### 4.1 Simulation of the assembly process

To simulate the workplace, the data specified above was entered into the excel application. Given that only 1000 work cycles can be simulated using the application at the current stage, a number that is enough if considering the relatively long cycle times of this particular case study, the simulation of twelve hour of a work shift was performed. During this time, 720 pieces of products were produced on average, i.e., 720 work cycles theoretically without mistakes and failures. Given that the company runs 12 hours work shifts, this value would be enough for one work shift. Next, Fig. 4 shows the simulation results, also part of the graph showing the generated times and one error cycle. Taking into account the occurrence of failures and errors, an average of 49 products were produced per hour. This value can vary (from 47 to 52) depending on failures and mistakes randomly generated. For one work shift, this is an average of 588 products. The simulation results correspond to reality in this case.




| | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| input B | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| input A | 0,07 | 0,09 | 0,08 | 0,08 | 0,08 | 0,07 | 0,08 | 0,06 | 0,08 | 0,07 | 0,08 | 0,09 | 0,07 | 0,08 | 0,08 |
| assembly time | 0,97 | 0,98 | 1,07 | 0,95 | 1,04 | 0,95 | 0,93 | 0,88 | 0,92 | 1,06 | 0,96 | 0,83 | 1,06 | 1,02 | 0,93 |
| time of mistake correction | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,50 | 0,00 | 0,00 | 0,00 | 0,00 |
| time of failure 1 remove | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| time of failure 2 remove | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| time of failure 3 remove | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| time of failure 4 remove | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| time of failure 5 remove | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| output A | 0,07 | 0,07 | 0,06 | 0,06 | 0,05 | 0,07 | 0,06 | 0,07 | 0,07 | 0,07 | 0,05 | 0,07 | 0,06 | 0,06 | 0,06 |
| output B | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

Figure 4: Simulation results using the proposed Excel application.

## 5. RESULTS AND DISCUSSION

As already mentioned, the analysed workplace is a bottleneck in the selected production instance. Based on the analysis of the duration of the operations performed at the workplace, see Fig. 5, it was found that, at the same time, the inner bottleneck of this workplace is the bonding of noise insulation to a plastic part, i.e., operation No. 5. In this operation, the plastic part is placed in the lower part of the fixture where it is secured by the suction cups. The operation itself consists on removing the noise insulation from the box and removing the cover sheet and applying the sound insulation to the plastic. The problem with this operation is to remove the cover foil (heavy separation of the film from the fabric) and to apply the sound insulation to the work piece accurately. Noise insulation is a relatively large piece of material, and in the event of a lack of attention, the part is caught in the wrong place. Separating the sound insulation and sticking it to the right place is problematic due to tearing of the fabric when unpacking. For this reason, the authors aimed at making this operation more efficient.

The proposed solution for this issue consists of creating a fixture for which a noise insulation with a sealed cover sheet is placed and the plastic part is placed on top of it. This change requires a change in the design of the original preparation jig. On the underside of the original fixture jig, a new product is placed into which the noise insulation will be applied, and the entire original lower part of the suction device will turn 180 degrees and place it up. It is important that the sound insulation is properly glued and therefore it was necessary to design the shape of the fixture jig so that it could accurately copy the shape of the plastic part. Given that this is a rough surface, the application of 3D scanning of the plastic part was used. The plastic part was scanned, and a CAD model of the work piece was created based on the obtained cloud of points, which served as a basis for creating the CAD model of the fixture. Based on the CAD model, a prototype of the fixture was made on a CNC milling machine. The prototype was used in the experimental workplace to verify the proposed assembly procedure, see Fig. 6.

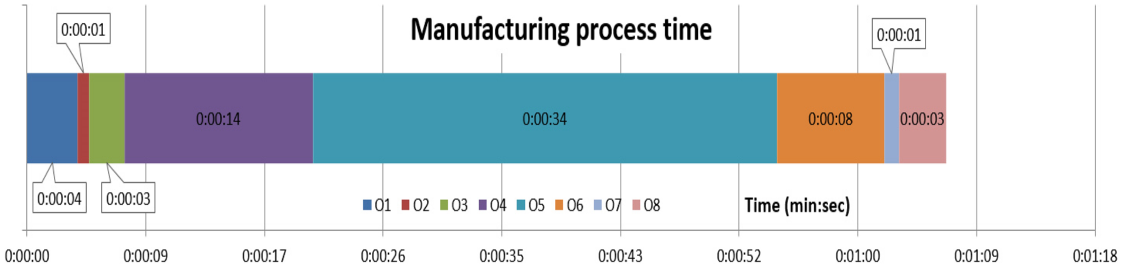



Figure 5: Duration of each operation of the workplace.

Figure 6: Assembly fixture for better application of noise isolation.

On the basis of the experiments, it was found that the fixture would have an effect on reducing the number of faulty glued parts, while it also shortens the time required to correctly apply noise insulation to the work piece, see Fig. 7. The sequence of the operation No. 4 and its method will be also changed. While in the original process, only a half of the foil was removed during the operation No. 4, now the foil is completely removed all the time, and since the insulation is already in the fixture, it is not necessary to handle it so difficult, and that means the overall assembly time is shortened. The input and output time are the same as in the original process.

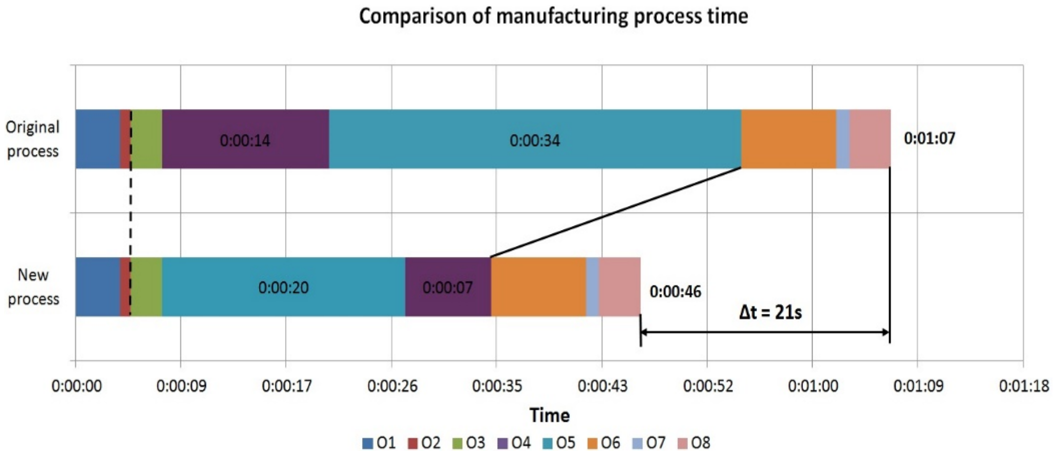



Figure 7: Time differences and displacements between the original and proposed assembly methods.

After taking these changes into account new data was entered into the simulation model, see Table V. Since the changes concerned only the assembly operation itself, the other data remained the same.

As the execution time was shortened in 21 seconds, more work cycles can be done in one hour. From the simulation results it is possible to see that the number of pieces made goes up to 65 pieces per hour as opposed to the 49 pieces being done before. For one work shift, this achieved number represents an average of 780 products. Without failures and mistakes this value can be higher, but it would be a theoretical value only.

Table V: Input time data – new process.

| **Time category** | **Value** [sec] |
|---|---|
| Minimal assembly time | 0:00:44 |
| Maximal assembly time | 0:00:47 |
| Minimal input time 1 | 0:00:04 |
| Maximal input time 1 | 0:00:06 |
| Minimal output time 1 | 0:00:03 |
| Maximal output time 1 | 0:00:05 |

## 6. CONCLUSIONS AND FURTHER RESEARCH

To keep company competitive, it is necessary to carry out all processes effective, quickly and with less costs. That means never ending effort for uncovering problems, bottlenecks and look for ways how to carry out processes more effectively including assembly processes. Because very high importance of time, sometimes is more suitable to use some simple and quick method to evaluate designed change. Simulation is the answer.

Based on the simulation results as well as on the experience with the proposed Excel application, it can be stated that the simulation results match the entered data, and that the application offers good results in a convenient and fast way without having to use special software or 3D models, which may complicate and delay the process of simulation to a big extent. The results obtained, in particular the probable number of assembled products, can be considered as the basic data needed for deciding on the most appropriate variant of the manual assembly work, if there are several variants of manual assembly procedures for the same product, which has an impact on the number and type of errors and faults. The tool is possible to use for any assembly operation which fulfils and meets the basic structure of assembly operations described in chapter 2 i.e., *T* input B, *T* input A, *T* assembly, *T* output A and *T* output B. As is it being possible to see the model also requires the input of time data. In the case of a new design of assembly workstation, one of the predetermined time methods that that can be used to determine the time is the MTM – Method Time Measurement. However, also other time analysis methods like the time sampling or other recording or tracking methods are a viable option as well. The proposed model is part of a more complex solution for the design of lean assembly workplaces and systems. Within this framework, methods and tools have been modelled in a modular way so that they cannot only be used individually, but in conjunction with others, for example, the Ishikawa Diagram and Pareto Analysis are available for error analysis.

The presented simulation model is designed to be in line with the concept of further lever development tools. Performance data as well as all other data obtained as a simulation output will then be used to simulate the assembly process of several interconnected manual assembly workplaces. This planned model will allow getting closer to the reality of the concept of performance, site linking parameters and bottlenecks of the assembly line or system.

It can be assumed that the proposed application will find use in smaller companies and businesses, especially in terms of time measurement and economy that would ultimately lead to an increased work productivity. The modular concept of the simulation model as well as the overall concept of levering tools does not exclude the use of other methods and tools such as Tecnomatix or Delmia software. On the other hand, if financial and time resources are available, the combination of these methods and tools can lead to the obtain of more accurate and comprehensive data and results.

Since each research has its own limitations, the authors would like to mention that the one presented here has been mainly limited to assembly operations of the manual type whose cycle times are “long”, i.e., in the order of seconds or more. In this regard, we acknowledge that further research should and may indeed encompass the use the proposed methods and software tools for operations of shorter duration. On the other hand, there is also a limitation in terms of assembly operation types that this research is to address and focus on, i.e., at present it is mainly focused on only those operations whose time variations can be explained by the Normal distribution.

## ACKNOWLEDGEMENT

This work has been supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic (KEGA 002TUKE-4/2020).

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