

## Creation of More Efficient Work Environment through the New Design of the Automatic Robotic Assembly Station

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### ABSTRACT

This paper deals with the design of an automatic robotic assembly station with the aim of creating a new and more efficient working environment in the production process on the assembly line and thus contributing to meeting customer requirements. The paper presents theoretical knowledge on innovations and on the innovation process. The introduction of an automated workplace will lead to a higher production line than it follows from evaluation of data collected over time. The result of the work is a proposal to create a new and more efficient work environment.

**Keywords:** automotive industry, innovation, automatic assembly line, efficiency, flexible production.

### INTRODUCTION

One of the most important industries is the automotive industry. It's one of the fastest growing sectors, which places demands on many other sectors, thus increasing the need to find new opportunities for cooperation. Slovakia is currently the third largest car manufacturer in Central Europe. We owe a huge impact on the development of the Slovak economy to this industry. The focus is on automotive plants, which assemble and manufacture their main components. Parts are manufactured all over the world and are delivered to the plants as assembled kits [1]. One of these kits is the car lock, which is at first glance a simple part of every car, hiding everything to a complex mechanism, including the long process of its development and manufacturing [2, 3].

Entrepreneurial activity has long been systematic, successful, managed and, above all, based on purposeful innovation. Innovative processes are special tools for business activities that give innovations a new ability to create prosperity [4, 5].

The goal of innovative activities is primarily a customer who participates in the creation

of new products and cooperates in their launch, including all activities that he has acquired from practice. Companies are forced not only to innovate products, but also to innovate the environment in which their activities take place. Innovation groups consist of people who are employees of management, service, logistics, and customers and not only from the design and development teams [6, 7, 8].

Product or production process upgrades cannot be performed indoors. It is necessary to visit the place where the process takes place. Product innovation aimed at increasing customer value is associated with innovation at the lowest possible cost. A major time advantage appears within companies that have left their development centers close to production sites and have thus ensured active communication between these elements [9, 10, 11]. Those who are able to question existing solutions should regularly occupy higher positions in the company, hence challenging old practices, which are well-established, but whose work must be constantly controlled [12, 13, 14].

Production automation is the transfer of human activity to technology. That's why technology in these fields reaches a high level [15, 16, 17,

18]. The basic element is the ability to innovate education, research, experimentation, development and information and thus apply new knowledge in society. Countries that have used these activities to strengthen innovation often show outstanding results [19, 20, 21].

### OPTIMUM RETENTION PRODUCTION LINE ANALYSIS

The production line consists of conveyor systems. 40 pallets move on them (Figure 1) and stop at individual work posts so that production operations can be performed on them. They are

available in two versions. For the final production lines X52 and BVH, as well as for the door locks on left hand - driver's side and right hand - passenger side. For this reason, the pallets are designed in a way that they are divided into two parts. After their rotation, either the left or the right side can be produced. This prevents a component from the wrong side from being used.

The line is semi-automatic and is in the shape of the letter O. In terms of product movement, it is a line with a moving product, which is moved to the next work post after the previous operation. The assembly line is built from aluminum profiles, which allow several design solutions in industrial production. Such stations can be easily

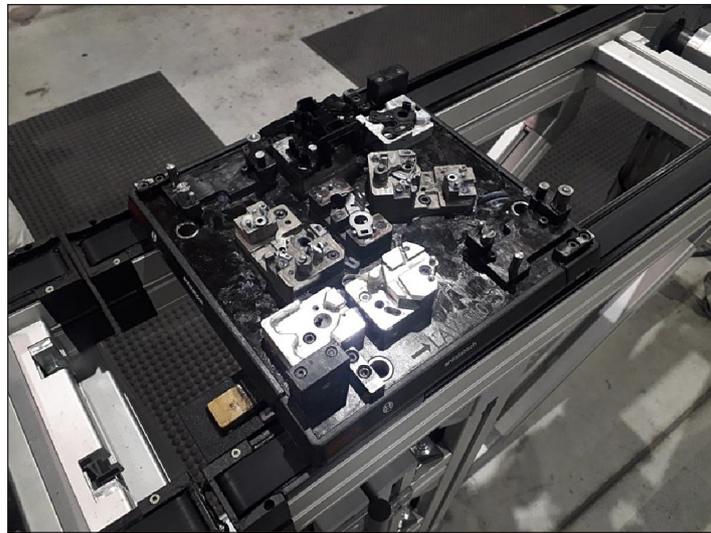


Fig. 1. Pallet placed on the conveyor belt

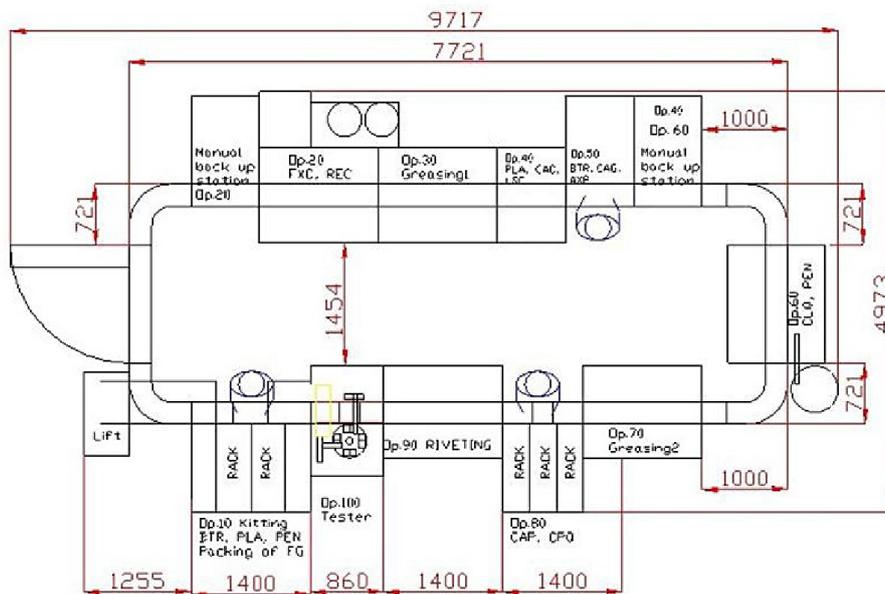


Fig. 2. Current layout of the assembly line

modified. Their advantage is low weight, the possibility of distribution of electricity and of compressed air within the production line. Last but not least, their affordability is a strong point.

The individual components are stored on a transport pallet. They are moved between individual stations on belt conveyors with an electric motor. If necessary, it is not difficult to carry out a design intervention and modifications on the assembly line. Figure 2 shows the current layout of the line.

In the current layout, there are automatic stations 20, 30, 40, 60, 70 and 90. The only stations that are not automatic are 10, 50 and 80, i.e. they are manual stations. Station 100 is specific. After testing the product on a testbed, the operator assigned to station 10 simultaneously wraps the semi-finished product and manually places it on an empty pallet so that production can continue. Each station must have a backup, i.e. a place where in the event of a malfunction of a machine, an operator is added and replaces

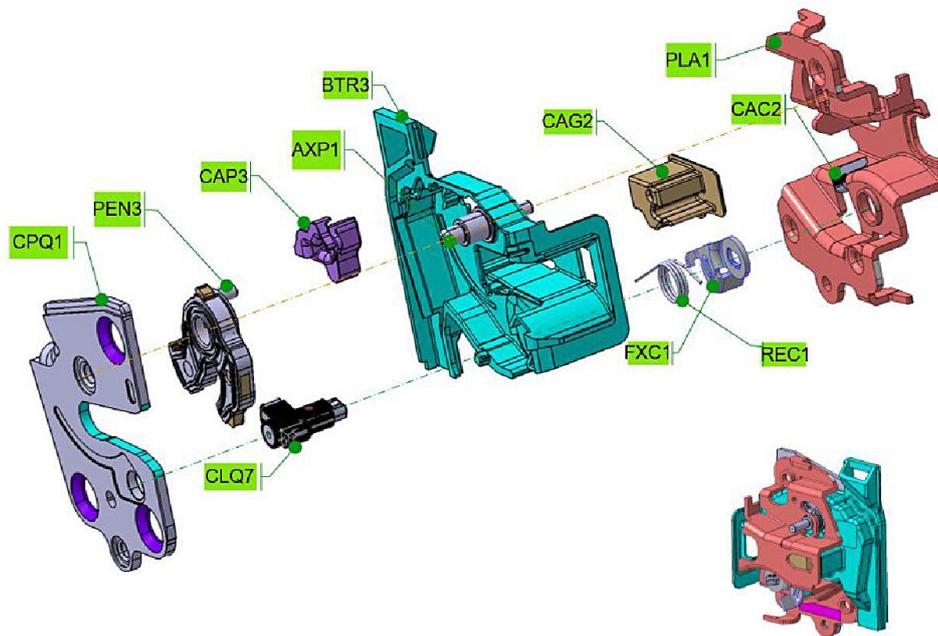


Fig. 3. Retention assembly X52

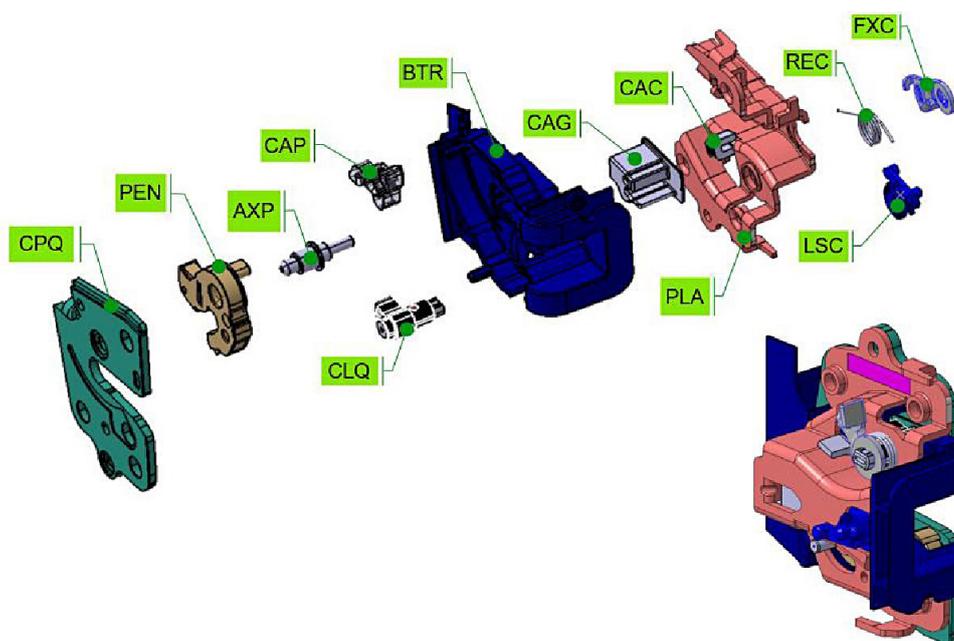
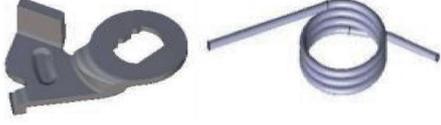


Fig. 4. Retention assembly BVH

**Table 1.** Operations and used components on the line retention

Posts	Description of activity	Used components
Post 30 Automatic	On this work post a part is manually placed in the BTR and PEN palettes	
Post 20 Automatic	Automatic placement of FXC and REC in the mounting jig	
Post 30 Automat	Automatic deletion and subsequent camera control	
Post 40 Automat	Automatic assembly of PLA and CAC into the assembly jig	
Post 50 Manual	Manual attachment of BTR and its subsequent rotation and placement of CAG and AXP	
Post 60 Automatic	Automatic rotation of the PEN and placement of the CLQ to the palette	
Post 70 Automat	Automatic CLQ pushing and deleting, camera control	
Post 80 Manual	Manual positioning of CPQ, CAP and PLA	
Post 90 Automatic	Automatic riveting CLQ and AXP	
Post 100	Testing	

the robot. Lubrication stations 30 and 70 are replaced by the operator in the nearest manual work post in the event of a fault. The testing and riveting devices don't have backups. In the event of a fault, the entire assembly line is shut down. Three operators work on the line. Each of them is in a position that is not automatic.

The output of the Optimum Retention assembly line is the pre-production for the BVH and X52 production lines. This semi-finished product is an essential part of every lock manufactured on the above lines. It consists of the parts shown in Figure 8 and Figure 9.

The difference in the production of Retention locks for X52 and BVH is in the use of a single additional component in the case of BVH locks,

which is an LSC component. Otherwise, the same components are used, which differ in shape and size, but their presence serves the same purpose in both semi-finished versions.

The sequence of operations for the assembly of the semi-finished product is important for time analysis. Individual operations and description of work activities at stations are given in Table 1.

### EVALUATION OF MEASUREMENTS AT INDIVIDUAL STATIONS OF THE RETENTION LINE

The initial measurement was a reference. It is intended as an assembly for X52 locks.

**Table 2.** Initial measurements at individual stations

Product	P10	P20	P30	P40	P50	P60	P70	P80	P90	P100
X52	6.1	5.3	5.3	7.2	12.6	6.4	6.6	7.7	7.1	6.5
	5.9	5.1	5.2	6.8	12.3	6.1	6.3	7.4	6.9	6.4
X52	6.2	5.2	5.4	7.1	12.5	6, 5	6.4	7.8	7.5	6.5
	6	5.1	5.3	6.8	12.3	6	6.6	7.3	7.2	6.4
X52	6.3	5.1	5.4	7.1	12.6	6.3	6.5	7.8	7.6	6.4
	3.1	5.3	5.2	6.8	12.3	6	6.3	7.6	7.4	6.3
X52	6	5.2	5.3	7.2	12.5	6.4	6.2	7.7	7.5	6.5
	5.8	5	5.1	6.9	12.3	6.1	6	7.6	7.2	6.4
BVH	6.2	5.4	4.9	7	12.6	6.3	6.6	7.5	7.1	6.5
	5.9	5.1	4.8	6.8	12.5	6.1	6.2	7.4	6.9	6.4
BVH	6.3	5.3	5.2	7	12.7	6.4	6.5	7.8	7.3	6.5
	3.2	5.1	4.9	6.9	12.4	6.2	6.2	7.6	7.1	6.4
BVH	6.1	5.3	5	7.1	12.5	6.2	6.5	7.9	7.2	6.5
	5.8	5.2	4.8	7	12.4	6.1	6.3	7.6	7	6.3
BVH	6.2	5.3	5.1	7.1	12.7	6.3	6.4	7, 7	7.5	6.4
	5.9	5.1	5	6.9	12.4	6.1	6.2	7.5	7.4	6.3
Average	5.7	5.2	5.1	7.0	12, 5	6.2	6.4	7.6	7.2	6.4

Measurements were performed on 4 left hand and 4 right hand locks. Later during the production of the reference for BVH locks the same number of measurements was repeated. The measurement was also performed taking into account the transport time between the two stations. The obtained measurement results are shown in Table 2.

The table shows the blue color of the automatic station and the yellow manual. The longest production time is on the P50. Its average is 12.5 seconds therefore it's the bottleneck. Three operators currently work on the assembly line and therefore the analysis was performed during this level of production line occupancy. First of all, the line cycle (TL) i.e. tact time is determined. It expresses the time interval between the two semi-finished products that the line produces. The tact of the line is affected by the number of employees. If their number is higher, the tact time decreases and vice versa, their number is lower, the tact time increases. The line cycle indicates the longest standardized cycle time of the operator i.e. the bottleneck.

*Line clock calculation in the current state*

$$TL = CTMAX \tag{1}$$

where: TL – line cycle in seconds;  
 CTMAX – longest worker cycle time in seconds.

$$TL = CTMAX = 12.7 \text{ s}$$

Another important time information is the customer tact time (CT). It's the value that indicates in which time interval the customer will take one product from us. To meet the customer's requirements for optimal delivery, it's necessary that the customer's tact time is always higher than the line's tact time. If the customer tact time is known, it is possible to flexibly manage the number of operators on the line provided that one condition is met: the customer tact time must be greater than the tact time of our production line [5].

*Calculation of customer cycle in the current state*

The cycle according to the relationship:

$$CT = \frac{PDV}{Q_z} \tag{2}$$

where: VAT – planned time usage expressed in seconds;

Q<sub>z</sub> – customer request in a certain period of time expressed in pieces.

$$CT = 78\ 600 / 6\ 950 = 11.3 \text{ s}$$

The net time we have available for production of the required number of pieces is expressed by the planned time of use of the equipment, the calculation of which is given by the time lost and

the time available. These are determined by the number of working days.

$$CD = 3600 \cdot h \cdot \sigma \tag{3}$$

where:  $h$  – number of working hours per change;  
 $\sigma$  – number of changes.

$$CD = 3600 \cdot 7.25 \cdot 3 = 81,000 \text{ s}$$

$$CS = PZ + PS \tag{4}$$

where:  $PZ$  – breaks given by law expressed in seconds;  
 $PS$  – sale of change expressed in seconds.

$$CS = 30 \cdot 60 + 10 \cdot 60 = 2,400 \text{ s}$$

*Planned use time of the device*

After calculating the time available and lost, it is possible to determine the planned time for the calculation of CT.

$$PVD = CD \tag{5}$$

$$PVD = 81,000 - 2,400 = 78,600 \text{ s}$$

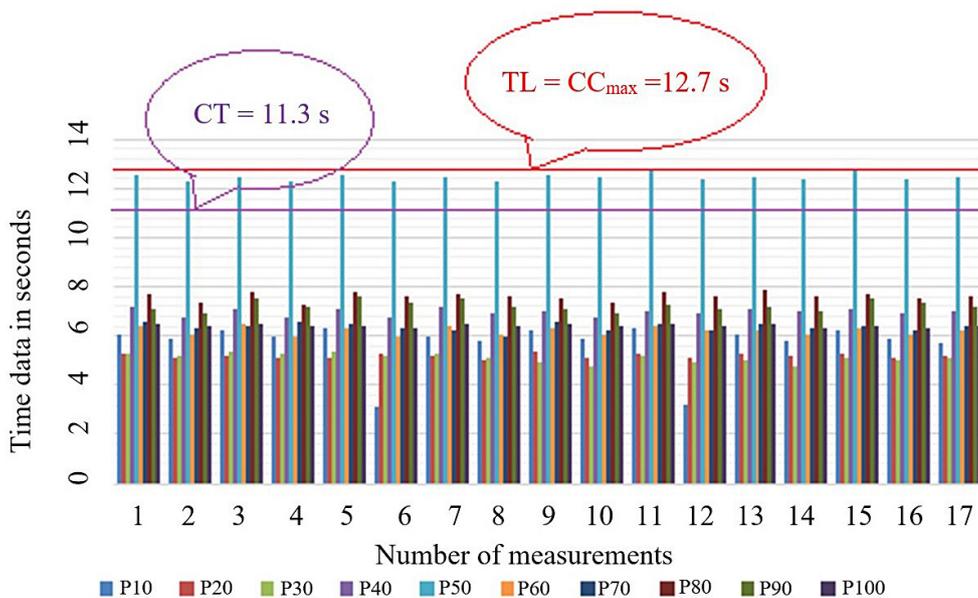
At present, the line cycle is 1.4 s shorter than the customer cycle. It's clear from the previous subchapters that the customer's request cannot be met.

**CALCULATION OF PRESENT HOURLY OUTPUT AND PRODUCTION PER SHIFT**

Based on the measurements, a longer production time on the left locks is evident, therefore the hourly capacity was determined from their measurements. This is expressed by the calculation:

$$\text{Capacity per hour} = 60 \cdot 60 \cdot \text{maximum of the given measurement}$$

The change capacity is given by the calculation:



**Fig. 5.** Customer tact time and production line tact time shown graphically

**Table 3.** Capacity of production with three operators

Hourly capacity	Capacity per shift	Bottleneck	Nb. operators	KOSU
286	2072	12.6	3	37.8
288	2088	12.5	3	37.5
286	2072	12.6	3	37.8
288	2088	12.5	3	37.5
286	2072	12.6	3	37.8
283	2055	12.7	3	38.1
288	2088	37.5	3	37.5
283	2055	12.7	3	38.1

**Table 4.** Line capacity in production with three operators with 85% efficiency

CT MAX	85% 15 shifts	85% 16 shifts	85% 20 shifts
12.7	26 202.76	27 949.61	34 937.01

Capacity per shift = Capacity per hour \*  $h$

where:  $h$  – number of working hours per shift.

The KOSU the actual time needed to produce one good product and it is expressed by the number of operators and with the bottleneck duration time. This is represented by the manual station 50.

Table 3 shows that at 7.5 hours of operation and when the line is occupied by three operators, the maximum output from the assembly line Retention is 2088 pieces of semi-finished products. The hourly output from the line is a maximum of 288 pieces, which is insufficient for the consumption on final production lines.

The change is calculated with 85% efficiency.

$$Ef = \frac{3600}{CT_{MAX}} \cdot h \cdot \sigma \cdot 0.85 \quad (6)$$

where:  $h$  – number of working hours per change;

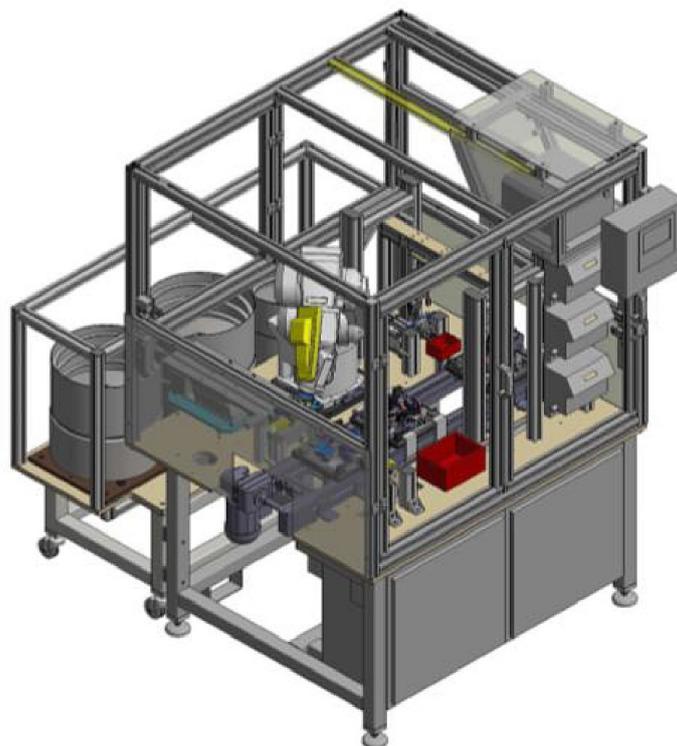
$\sigma$  – number of changes;

$CT_{MAX}$  – longest worker cycle time in seconds.

26,202 semi-finished products will be produced in fifteen shifts representing a weekly three-shift production. 27,949 pieces of Retention sets will be produced in the case of production on Saturday morning’s shift. If the specified amount of production is not met for any reason, whether it is downtime on the assembly line, scheduled maintenance, missing components, or other reasons, then a production shift is organised every Saturday. In this case, with the completion of twenty shifts, the output from the assembly line is 34 937 pcs.

Despite the overtime shifts the customer’s request for the individual months of 2019 is not achieved. Until the end of 2018, the given quantities were in line with the request of the customer. Demand increased dramatically in 2019. This results in the need to increase the output of the Retention line, or to purchase another one. The design of the station must primarily meet the design simplicity and minimize operations and control. An important aspect of the device is its reliability, given that all components will be fully adapted to this purpose.

At the manual station, the operator takes the BTR and turns it to the final position after lubrication from post 30. He positions two components manually and pushes the green confirmation button that makes the pallet move to the next station. The station has the longest



**Fig. 6.** Design of the automated post 50

production time and in the following text we propose to automate the station, which is then submitted to the company’s management for approval.

### AUTOMATIC ROBOTIC STATION P50

The automatic robotic assembly station 50 (Figure 5) will be part of the Optimum Retention line. It is used to mount CAG and AXP components and turn the BTR to the final position.

The station will be automatic. It will consist of a main and an auxiliary frame. The main frame will be equipped with a track with position units and stops, which are used to transport pallets. The robot that assembles the individual parts of the BTR, the linear vibrating feeders for the CAG and AXP transport and the manipulator for inserting the AGP will be part of the device. The additional frame will be equipped with circular vibrating feeders, which orient and feed components CAG, AXP to linear vibrating feeders. Topping up is also possible while the machine is running.

After approval and implementation of automatic station 50, stations P10 and P80 will be the only manual ones. As already mentioned, each station must have a backup, ie the place where the operator is added in the event of a

malfunction of the machine and work instead of the robot. In case an automatic station is added, it is necessary to keep the manual station 50 as a backup. Figure 14 shows an illustrative plan of a new line arrangement. The line remains semi-automatic and in the shape of the letter O. It is a line with a moving product, which is moved to the next post after the end of the previous operation.

The disadvantage of adding an automatic station is the need to extend the line by 1500 mm. From the original length of 9,717 mm, the line will be extended to 11,217 mm. The solution is to add backup P60 to the second side of the assembly line and connect manually backup stations 40 and 50.

### CALCULATION OF EFFICIENCY IN THE CASE OF A ROBOTIC STATION IMPLEMENTATION

At present, the manual station is the slowest post on the assembly line is 12.7 seconds and the duty cycle of the automated robotic station is 50 for 6 seconds. The new tact time will be comparable to manual station 80 (Table 5).

In the original state of the line there were three manual stations, after automation the number of manual stations decreased to two.

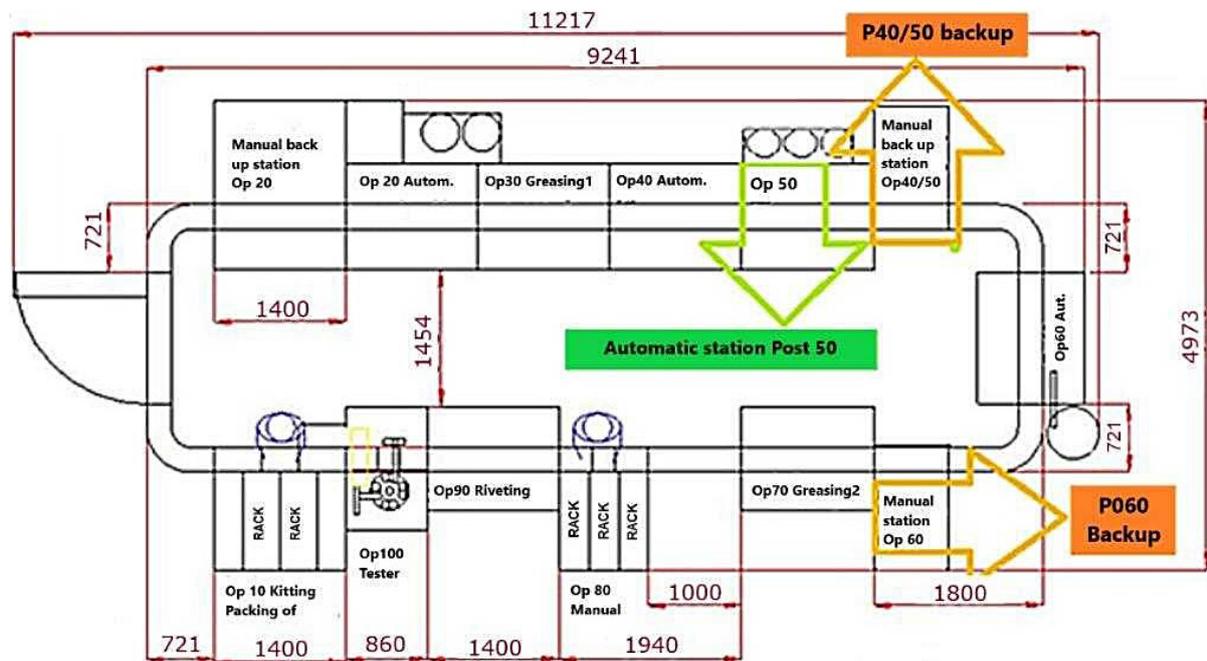


Fig. 7. Relayout after adding an automatic station 50

**Table 5.** Analysis of measurements in the case of the implementation of a robotic station

Product	P10	P20	P30	P40	P50	P60	P70	P80	P90	P100
X52	6.1	5.3	5.3	7.2	7.3	7.7	7.6	7.7	7.1	6.5
	5.9	5.1	5.2	6.8	7.3	7.4	7.3	7.4	6.9	6.4
X52	6.2	5.2	5.4	7.1	7.3	7.8	7.4	7.8	7.5	6.5
	6	5.1	5.3	6.8	7.3	7.6	6.6	7.3	7.2	6.4
X52	6.3	5.1	5.4	7.1	7.3	7.6	7.5	7.8	7.6	6.4
	3.1	5.3	5.2	6.8	7.3	7.3	7.3	7.6	7.4	6.3
X52	6	5.2	5.3	7.2	7.3	7.7	7.2	7.7	7.5	6.5
	5.8	5	5.1	6.9	7.3	7.4	7	7.6	7.2	6.4
BVH	6.2	5.4	4.9	7	7.3	7.6	7.6	7.5	7.1	6.5
	5.9	5.1	4.8	6.8	7.3	7.4	7.2	7.4	6.9	6.4
BVH	6.3	5.3	5.2	7	7.3	7.7	7.5	7.8	7.3	6.5
	3.2	5.1	4.9	6.9	7.3	7.5	7.2	7.6	7.1	6.4
BVH	6.1	5.3	5	7.1	7.3	7.5	7.5	7.7	7.2	6.5
	5.8	5.2	4.8	7	7.3	7.4	7.3	7.6	7	6.3
BVH	6.2	5.3	5.1	7.1	7.3	7.6	7.4	7.7	7.5	6.4
	5.9	5.1	5	6.9	7.3	7.4	7.2	7.5	7.4	6.3
Average	5.7	5.2	5.1	7.0	7.3	7.5	7.4	7.6	7.2	6.4

Line clock calculation after adding an automatic station

$$TL = CT_{MAX} \tag{7}$$

where:  $TL$  – tact time in seconds;  
 $CT_{MAX}$  – longest workers’ cycle time in seconds.

$$TL = CT_{MAX} = 7.8 \text{ s}$$

The customer’s tact time was calculated at 11.3s. In the current state of the line, the tact time was calculated at 12.7 seconds. This means that the customer cycle was 1.4 seconds shorter than the lines’ tact time. At that time, the customer’s production requirements could not be met. After automation, the tact time was reduced to 7.8 seconds. The customer’s requirements can only be met if the customer’s tact time is greater than the line’s. Therefore, the ideal solution is to add an automatic station and balance the line at the same time.

Calculation of hourly output and production per shift in case of implementation of robotic station 50

Capacity calculations were identical to the previous section. It was determined from measurements and is given by the formula:

$$\text{Capacity per hour} = 60 * 60 * \text{maximum from the given measurements}$$

The capacity for the shift is given by the formula:

$$\text{Capacity per shift} = \text{Capacity per hour} * h$$

where:  $h$  – Number of working hours per shift.

The capacity of the production line was given by calculations and determined at an average value of 286 pcs per hour, which represents an average of 2074 pcs of Retention sets per shift. The longest tact time of the worker in seconds was represented by station 50. After automation it

**Table 6.** The production line capacity with two operators after automation of P50

Capacity / Hour	Capacity / per change	BOTTLENECK	Number of	KOSU operators [s]
468	3390	7.7	2	15.4
462	3347	7.8	2	15.6
462	3347	7.8	2	15.6
468	3390	7.7	2	15.4
474	3435	7.6	2	15.2
462	3347	7.8	2	15.6
468	3390	7.7	2	15.4
468	3390	7.7	2	15.4

**Table 7.** Line capacity at production with two operators with 85% efficiency

CT MAX	85% 15 shifts	85% 16 shifts	85% 20 shifts
7.8	42 663.46	45 507.69	56 884.62

balanced out automatic stations 40, 60, 70, 90 and the manual station 80.

Table 6 shows that at 7.5 hours of operation and when the line is occupied by two operators, the maximum output from the assembly line Retention is given by 3435 pieces of semi-finished products. The shift is calculated with 85% efficiency.

$$Ef = \frac{3600}{CT_{MAX}} \cdot h \cdot \sigma \cdot 0.8585 \quad (8)$$

where:  $h$  – number of working hours per shift;  
 $\sigma$  – number of shifts;  
 $CT_{MAX}$  – longest worker tact time in seconds.

Table 7 shows the production line capacity with two operators with 85% efficiency. During the weekly three-shift operation, 42,663 pieces of semi-finished products will be produced within fifteen shifts. In the case of production on Saturday morning’s shift, 45,507 pieces will be produced. For any reason, whether downtime on the assembly line, scheduled maintenance, missing components, the specified amount of production is not met, so every Saturday morning shift of the month is required. The output from the assembly line in the case of twenty changes is 56,884 pieces.

**Manufacturability**

The increase in the number of pieces was mainly due to the reduction of the line cycle. This amount is only theoretical, as equipment losses have not been taken into account. Manufacturability is given by the relation:

$$Qvi = \frac{PDV}{CCT_{MAX}} \quad (9)$$

where:  $PDV$  – planned time of use expressed in seconds;  
 $CT_{MAX}$  – the longest tact time of a worker in seconds before and after the addition of automated P50.

**CONCLUSIONS**

The paper addresses the increase of output from the assembly line where semi products, essential

part of every lock, are produced. The aim of this paper is to design an automatic assembly station, which will contribute to increasing the output of the line and thus to meet customer requirements.

We characterise the innovation processes as the systematic implementation and preparation of innovation changes. The output of this process is the innovation done and the positive change associated. Its goal is to consciously influence the expansion of business with increasing customer needs in the market. The innovation process is also characterized by the creation and dissemination of innovations. In business activities we understand it as the implementation of individual innovations. Its role is to ensure the quantity and quality of variations in products, processes and organizational structure in line with other economic and social relationships. The innovation process is intentional and driven by a project or program.

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