Design of the New Production Line in the Automotive Company

Naqib Daneshjo [1], Dušan Sabadka [2], Peter Malega [2], Lukaš Piatra [1]

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

***Abstract* – Innovation is one of the key competitiveness strategies for small, medium, and large companies. Production line innovations using Lean methods are currently one of the most important ways to change the shape of the production line in a positive direction. Emphasis must be placed on the resulting innovation and the form of the production line, which should be as efficient and functional as possible and meet the required parameters of productivity and quality assurance. The primary goal of production line innovations using Lean methods is the elimination of bottlenecks in the production process that do not add value and the balancing of individual assembly stations. The aim of the contribution was to design a semi-automatic line for the completion and testing of seat locks under the name D3P2. The result of the solution is the creation of a robotic workplace that will ensure a higher production capacity and the related packaging of finished products. On the assembly line, an analysis of line balancing was carried out using the Yamazumi graph to eliminate unnecessary assembly process activities, Cycle time and Tact time. An analysis of the measurements of individual production activities and places was carried out on the line, and the proposal for a new production line was subsequently shared. Its main goal was to meet all customer requirements through high flexibility. The result of the analysis and applied measures was a reduction in the cycle time of the new line, balancing of individual posts and economic benefits.**

***Keywords* –Innovation, flexibility, design, robotic workplace.**

DOI: 10.18421/TEM131-11
https://doi.org/10.18421/TEM131-11

Corresponding author: Naqib Daneshjo,
University of Economics in Bratislava, Faculty of Commerce, Dolonozemská cesta 1, 852 35 Bratislava, Slovak Republic
Email: daneshjo47@gmail.com

Received: 07 September 2023.
Revised: 13 December 2023.
Accepted: 19 December 2023.
Published: 27 February 2024.

1. Introduction

Ensuring competitiveness, i.e. delivering the roduct on the agreed date, in the required quality and without receiving unnecessary complaints, are important pillars of the services provided to customers [2], [6]. The key is to focus on satisfying the customer's needs by means of added value, not only for the customer, but also for all interested participants in the production process . Added value for the customer can be the ability to customize the product within certain limits according to their needs.

Due to the high competition on the market, it is necessary for every company to invest in technological innovations [8]. Innovation will ensure growth in the market and strengthen the market position [7], [9]. This innovative proposal ensures the use of new technologies, faster dispatch of products, and lower prices. The proposal was created regarding production process efficiency. [3], [10].

The production posts manage an increasing output from the assembly line. This assembly line produces outputs essential for every automobile. The goal of this paper is to design a semi-automatic production line that will increase the output of the production line and fulfill customer requirements [1], [4]. The work begins with an analysis of the current state of the assembly line and based on it a proposal is made [5]. The goal is to eliminate the inefficiencies and implement improvements leading to increased production efficiency of the assembly line and customer satisfaction.

2. Analysis of the Current Status of the T9 Seat Latch Manual Lines

The paper is focused on manual assembly lines, which consist of two individual stations: station 10 and station 20. The seat locks are in the back part of car seats, specifically in their upper part. Their function is folding the seats. Covers are distributed with the locks. Their task is to divide the visible part from the part that is mounted in the bowels of the seat. They are produced in two versions, for left and right seat locks (Figure 1).

Figure 1. Final product of the T9 line – left and right seat lock

The production lines are located next to each other and connected to each other. For that reason production at only one post is not possible. Testing of the product on P20 will take place only after the components are assembled on P10. The number of employees varies: one, two, and at most often four.

Both lines are made of aluminum profiles, which are affordable and their construction is easy to adjust in case of various modifications and movements.

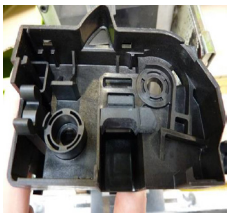
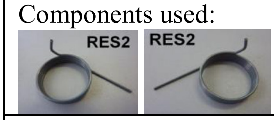
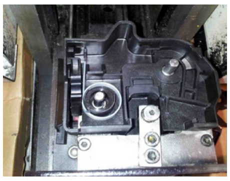
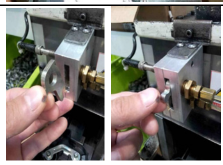
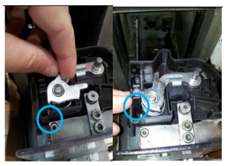
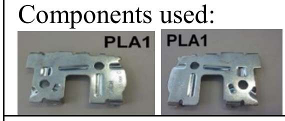
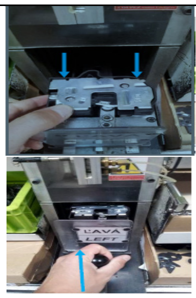
The products are intended for customers who haves leading position in the development and production of equipment for the automotive industry and are the preferred supplier of the largest car producers. The T9 seat latch is intended for production plants of car producers, whose priority is product quality. The seat lock is an essential part of every car, and its main function is to fold the seats and thereby increase the boot storage space.

Operations on P10: Post 10 (Figure 2) is characterized by a simple layout of aluminum profiles with roller conveyors on which boxes are placed. These boxes contain components described in more detail in Table 1.

Figure 2. Post 10 left seat lock

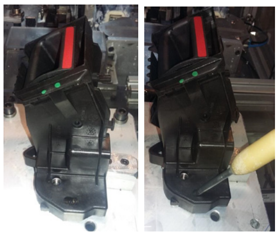
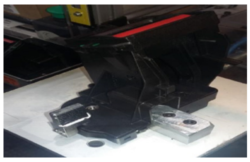
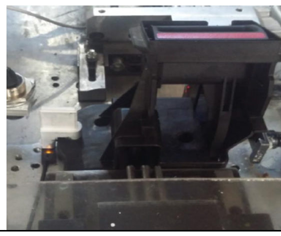
At station 10, one operator performs activities and his objective is to assemble components into a semi-finished product, which is then moved to the next assembly station. It is a manual assembly line, the operations are not difficult and the operator learns it in an average of three days.

Table 1. Individual activities and used components on P10

1. A CAG rubber band is inserted into the BTR+BTN. Components used: 	
2. RES2 is inserted into the BTR as shown in the picture and then inserted into the socket for fixation. Components used: 	
3. BRE1 is inserted into the BTR. Components used: 	
4. CLQ1 in lubricated. Components used: 	
5. The lubricated CLQ is inserted into the BTR as shown. The CLQ pin must be grounded after RES2 - in a pre-tensioned state.	
6. PEN1 is inserted into the BTR so that the lock is in the closed state. Components used: 	
7. PLA1 is placed in the BTR as shown in the picture, first with the rear side, and then the carriage is inserted into the machine, where automatic pressing takes place. Components used: 	
8. The carriage will automatically slide out after clipping the platinum.	

P20 operations: P20 operations are semi-automatic. This post follows after the completion of the final lock at post 10. Lock testing does not begin until the carriage has been extended from P10. In this way, quality is ensured as the principle of finishing one piece at a time is respected. This prevents mixing up of products or the occurrence of defects (Table 2).

Table 2. Activities performed at P20

1. A piece of P10 with an open PEN is inserted into the preparation for setting up RES1, which ensures the stability of the open lock. 	
2. Manually insertion of the RES 1 spring at an angle. The spring partially protrudes from the piece because the tool is inserted into the end of the spring. The spring-loaded tool is pushed into the hole by downward pressure on the spring so that the spring is not visible.	
3. The process key is inserted into the BTR opening as far as it will go.	
4. The piece with the process key is taken out of the jig and inserted into the P20 slot - the test is started. 5. Testing is followed by checking the marking of the piece and subsequent packing in a C13 box.	

3. Evaluation of Measurements at Individual Posts

Both stations produce the same product for the same customer. Components are mirror images of each other. The first step was to determine the working hours of individual positions.

The times were measured on both P10 and P20, in three shifts (morning, afternoon and night) by different operators who are trained at the given posts and who control them for a longer period of time. The time data of four operators was recorded on each shift (Figure 3).

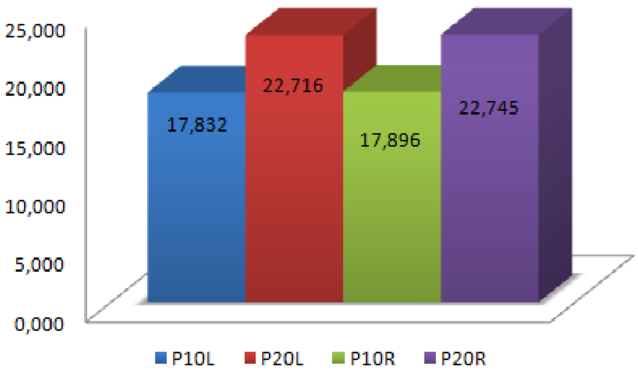


Figure 3. Measured average times at individual posts of the T9 line

The average time from individual posts on all changes is recorded in Table 3.

Table 3. Measured post times

Measurements	P10L	P20L	P10R	P20R
1. Morning shift	18.002	22.953	17.939	22.844
2. Morning shift	17.958	22.789	17.896	22.753
3. Morning shift	18.011	22.953	17.956	22.769
4. Morning shift	18.042	22.956	17.968	22.864
5. Afternoon shift	17.661	22.547	18.010	22.858
6. Afternoon shift	17.699	22.535	17.836	22.657
7. Afternoon shift	17,769	22.679	17.891	22.658
8. Afternoon shift	17.948	22.869	17.788	22.856
9. Night shift	17.496	22.417	17.624	22.493
10. Night shift	17.779	22.636	18.002	22.797
11. Night shift	17.672	22.498	17.946	22.669
12. Night shift	17.946	22.756	17.889	22.718
Average	**17.832**	**22.728**	**17.896**	**22.745**

P20 is a slower post, as manual installation of the RES by the operator is performed on it and the next step is the testing of the lock and the inspection and packaging by the operator. If the machine is testing the lock, the employee inserts the component into the lock and its operation is within the working time of the machine. After the lock is tested, the date is checked and the product is packaged, where placing the inserts and sticking the labels on the box is time consuming.

The measurement concluded that the P10 left side is on average 4.884 seconds slower than the P20L and the P10 right side is 4.849 seconds longer than the P20R. The speed of assembly on the P10 also depends on the skill of the operator (Figure 4).

CYCLE TIME DIAGRAM					
Line:	**T9 L, R**	**Site: Kosice**			
Product:	**Seat Latch**				
				Customer request/day:	7 200
				Work shifts:	3
				Daily request per work shift:	2 400
Average of 12 measurements					
Post	**Average(s)**	**Minimum (s)**	**Variability (s)** (average-mini)/mini	Working time (min):	480
P20L	22.7	22.4	1%	Break:	30
P20R	22.7	22.5	1%	Meeting (5 minutes):	5
				Final cleaning:	5
				Production time (min):	440
				Tact time (s):	**11**
				Capacity per hour:	**316**
				Capacity per work shift:	**2 326**
Total	45.4387	44.91		**COSU**	**46**
Cycle time			22.7		
Best time achieved			22.5	Current number of operators:	**4**

Figure 4. Cycle time diagram for T9

The individual posts are interconnected. The average P20 time when it's occupied by two operators is important. An initial measurement was carried out. Its result is the final packaged lock intended for the customer. One working shift is eight hours, during which a half-hour break is given by law, and each shift is shortened by an initial 5-minute meeting and final cleaning. Production takes place in three shifts. The presence of four operators, two on the left and two on the right side of the T9 assembly lines, is ideal. The customer's request is 1 200 pcs per shift from each side, which is 7 200 pcs in 24 hours. In the state of the production line, this volume can only be produced with overtimes. In the event of downtime or absences of employees, there is a possibility of not meeting the customer's requirements.

A) Hourly capacity calculation: The hourly capacity of one side of the T9 line is 158 pieces of products, while in production on both sides the hourly capacity is 316 pieces per hour of trouble-free production.

$$\textit{Hourly capacity} = \frac{\textit{Number of seconds per hour}}{\textit{Cycle time}} * \text{Number of lines}$$

$$Hourly\ capacity = \frac{60 * 60}{22.7} * 316\ pcs\ per\ hour$$

B) Calculation of capacity per shift: The shift capacity is given by the production time and the cycle time indicating the number of products per 7.5 hour work shift. 1.162 pieces/side are produced on the lines, and the total output is 2.324 pieces/shift.

$$Capacity\ per\ change = \frac{production\ time * 60}{Cycle\ time} * number\ of\ lines = 2\ 324\ pcs\ per\ shift$$

C) HOW: It is calculated by the following formula and represents the time required to produce 1 good piece:

$$WHAT = \frac{Working\ time(s) * pocet\ operatorov}{hourly\ capacity}$$

$$WHAT = \frac{60 * 60}{316} = 45.6\ s$$

The measurement was carried out on both T9 assembly lines of the left and right side in the number of 12 on both sides with different variability and operators. Based on them, all calculations were collected in Tab. 4. With the current customer demand in the number of 1,200 pieces per side in three-shift operation after deducting time losses, it is also necessary to use two operators based on calculations. Cycle time was measured at approximately 23 seconds. It is clear from this that the line is inefficient and is adapted to higher production at the expense of efficiency. The efficiency of all lines in the company is set at 85%.

Weekly production on one T9 line represents 17,430 pcs of final seat locks, which is a multiple of two due to production on two sides of the lines. This represents a total production capacity of 34,860 pcs for 15 shifts. Monthly production depends on the number of working days in a year. 240 working days were calculated, it follows that 139,440 locks are produced on assembly lines during 20 days/month.

The total annual production amounts to 1,673,280 left and right seat locks. This depends on various factors, such as sufficient components from suppliers, sufficient workforce, in case of incapacity for work or various absences, planned downtimes and modifications (Table 4).

Table 4. Analysis of production on T9 lines

Output on both T9 lines	Number of pieces
Hourly output	316
For a 7.5 hour shift	2 324
Daily output	6 972
Weekly output (5 working days)	34 860
Monthly output (20 working days)	139 440
Annual output (240 working days)	1 673 280

After finishing the box of 20 pieces, the operator on P20 sticks the label, checks the data on it, visually checks the presence of markings on each piece, puts a spacer in the middle of the box due to the separation of layers with products, and moves the box to the finished place using a roller conveyor production. The posts were first measured separately and finally together, for the purpose of tracking from the beginning to the storage of the finished product to be sent to the customer. The company tries to eliminate operations that are performed outside of the production of the final product.

D) Delivery: The delivery represents the proportion of the number of produced pieces per day and the quantity requested by the customer. It is calculated as follows:

$$Delivery = \frac{Reana\ production\ per\ day}{Planned\ quantity\ by\ logistics}$$

$$Delivery = \frac{2\,324 * 3}{2\,400 * 3} = \frac{6\,972}{7\,200} = 0.960 * 100 = 97\%$$

The planned volume is higher than the given production lines are capable of producing, as the customer's demand is 7,200 pcs on a daily basis. This cannot be fulfilled under the given conditions with the current weekly production. Current production is 6,972 units per shift. It is necessary to produce even during weekend shifts and during holidays, and this represents increased costs for the company.

4. Design of the D3P2 Line for Handling Semi-Finished Products

Part of the proposal was the creation of a robotic workplace that will ensure the handling of semi-finished products between P10 and P20 and the subsequent placement of products into boxes that are ready for shipping. In the case of implementation of the designed solution, it is possible to keep the T9 assembly lines as backup lines in case of a possible malfunction on the newly designed device or eventually sell them or dismantle them. On the initially manual lines, the operator takes the assembly of components from P10, then inserts the RES component on P20 with a tool and places it in the testing device in the closed position. After testing the functionality of the lock, the operator removes the product, puts the process key in the place designated for it, checks the presence of markings, and stores it in the prepared box.

The subject of the proposed improvement is the modification of 2 existing T9 lines (P10L/P20L and P10R/P20R) for T9 components - right (R) and left (L) versions. The D3P2 seat latch lines will be located in the production hall next to the existing lines. One workplace consists of 6 conveyors, a robotic manipulator, a 2-axis manipulator for folding, post 20, two rotary tables and post 10 (Figure 5).

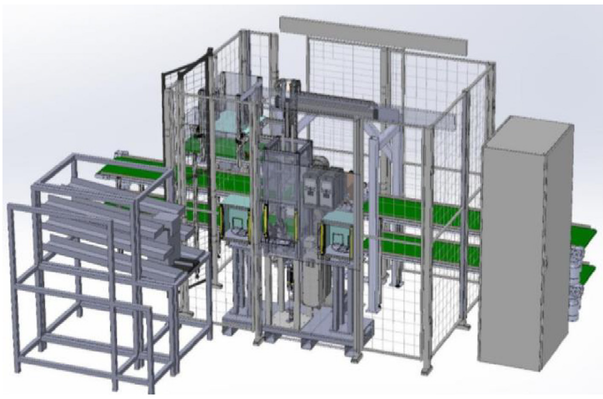


Figure 5. Line D3P2L

The D3P2 line includes left and right identical parts for left and right lock assemblies. Most of the components are identical with the difference of mirroring. Post 10 of the D3P line is the original device, which was modified by adding a camera, a control panel and integrating the overall control of the line from this line. Post 10 is a station with manual operation, which will be supplemented with a control camera system. After completing the operations on P10, the operator places the T9 component in position on the rotary table in automatic mode (Figure 6).

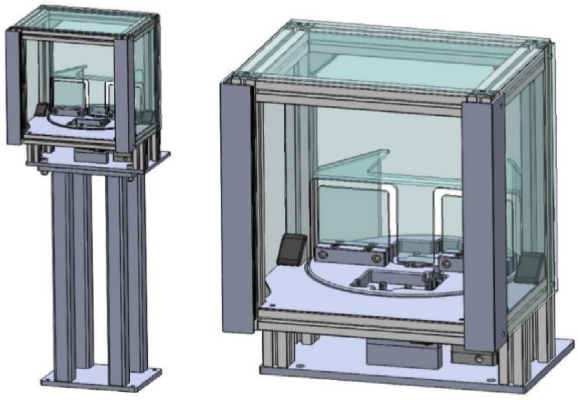


Figure 6. Turntable

The rotary table is used to move the seat latch between the operator and the robot. It is equipped with optical gates that do not allow the rotary table to move, as long as the operator inserts the seat latch and has his hand in the area of the optical gates. The nest of the rotary table is shaped exactly according to the seat latch, provided with pins for centering and an additional pin on the Poka-Yoke for inserting the piece in the closed state. The rotary table is controlled pneumatically with damping at the end positions. The end positions are additionally secured by an additional pneumatic cylinder. There are two rotary tables, located on the sides of post 20, to compensate for the operator-robot cycle time.

Post 20 is an automatic line in the design, that is, the automatic spring feeder (common to both lines) separates and prepares the spring, which is placed in the required place in the T9 component by the automatic spring inserter.

Station P20 is separated from station P10 by a security fence. If necessary, the P20 can also be operated manually. The post contains several checks and additions.

The robot translates the seat latch from the rotary table into the nest of post 20. The seat latch is fixed by screwing and at the same time the threads in the component are checked with the prescribed tightening torque and tightening time (Figure 7). After fixing, the RES spring can be inserted into the latch.

The springs are fed to the P20 through a calibrated hose with top feed and the formation of a stack of RES springs in the hose above the spring divider. The divider lets one spring into each cycle. The RES spring is pushed into the seat latch by a pneumatic cylinder, and then the inserted RES is checked for presence and correct position. After the RES is established, the seat latch is locked and unlocked to check the functionality of the lock. Other checks are for the presence and recognition of the correctness of the CAG rubber reference.

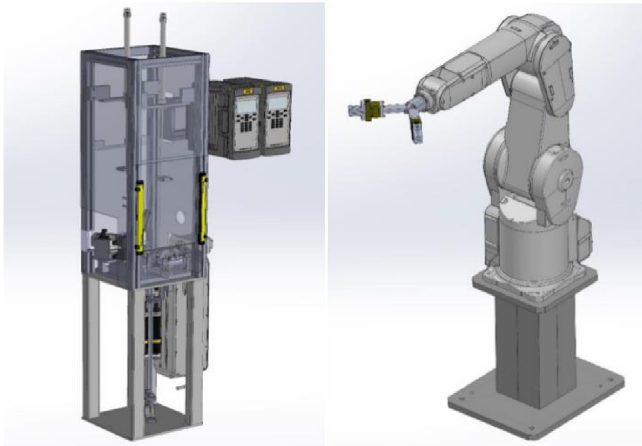


Figure 7. Automatic spring feeder RES2 and robot

Part of the Mitsubishi RV-FR-D robot with accessories is a two-grip effector. The first gripper takes the component from the rotary table and the second gripper picks up the complete component and the first gripper slides the component into position for finishing. The second gripper then places the T9 component in the box. Based on the robot's movements, the system continuously counts the number of components in the box, checks their location and instructs the P&P manipulator to separate the layers of components in the box. Rotary table no. 1 is two-position and serves to move the component from P10 to P20. Rotary table no. 2 is two-position, while it will be used to move the component from the upcoming P10 to P20, and the Mitsubishi manipulator is used to move the paper interlayers between the individual layers of the final products.

The entire line consists of modules (Figure 8) that can be moved by forklift and pallet truck separately (if necessary). The Robot + P20 + rotary tables' module is on one basic base. Conveyors are in modules of two levels. The vertical conveyor and the manipulator are separate. Individual modules are anchored to the floor, which must be taken into account when moving.

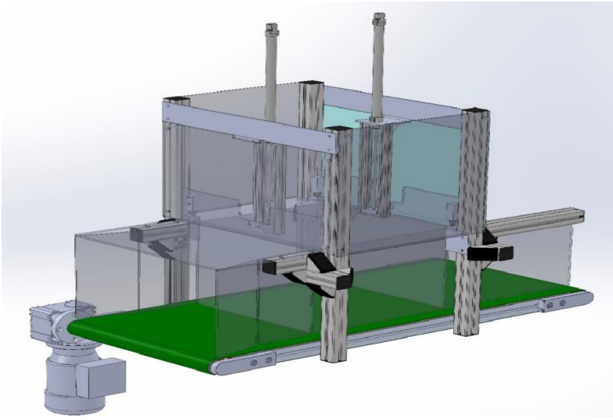


Figure 8. Folder feeder

5. Time Data Analysis of D3P2 Lines

As with the initial analysis, this was followed by measurement of the posts and estimated P20 cycle time including testing and packing for 18 seconds (Figure 9).

The measurement was carried out by the same persons working on the T9 line, who had to undergo training for the new line.

The process on the P10 remained unchanged, except for possible adaptations of the post to the operator, due to the ergonomics of the workplace and the addition of camera control. The post focuses on post 20, whose average activity time was 27.7 seconds.

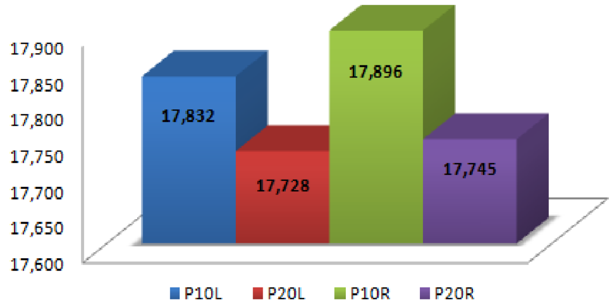


Figure 9. Average times at individual posts of the new D3P2 lines

The cycle time of the original T9 lines was 22.7 seconds. D3P2 lines contributed to reducing this time to 17.7 seconds (Table 5), which represents a difference of 5 s.

Table 5. Measured post times on the D3P2 line

Measurements	P10L	P20L	P10R	P20R
13. Morning shift	18.002	17.953	17.939	17.844
14. Morning shift	17.958	17.789	17.896	17.753
15. Morning shift	18.011	17.953	17.956	17.769
16. Morning shift	18.042	17.956	17.968	17.864
17. Afternoon shift	17.661	17.547	18.010	17.858
18. Afternoon shift	17.699	17.535	17.836	17.657
19. Afternoon shift	17.769	17.679	17.891	17.658
20. Afternoon shift	17.948	17.869	17.788	17.856
21. Night shift	17.496	17.417	17.624	17.493
22. Night shift	17.779	17.636	18.002	17.797
23. Night shift	17.672	17.498	17.946	17.669
24. Night shift	17.946	17.756	17.889	17.718
Average	**17.832**	**17.728**	**17.896**	**17.745**

From the Table 5, it is clear that posts 20, i.e. posts that have been replaced, have almost the same average times as posts 10, where manual assembly of components continues. The introduction of D3P2 lines reduced the cycle time so much that it is shorter than posts 10. The difference is negligible in production with an experienced operator. During the training for the new process, the robot "waited" for the operator, but as the operators gradually got to know each other, the time of the operators on P10 returned to the original time as on T9 lines. The introduction of new lines was preceded by various fine-tuning and monitoring of micro-downtimes, and subsequently the elimination of identified deficiencies, such as screwing error, faulty camera control, robot collision, RES insertion error, non-shifting and jamming of folders and boxes, for which an action plan was created and competent employees were appointed to solve them. The introduction of semi-automatic D3P2 lines has brought a balance of posts and thus production flow.

A reduction in cycle time will result in an increase in production and the ability to meet increased customer needs. Cycle time diagram for D3P2 is in Figure 10.

CYCLE TIME DIAGRAM					
Line: **Product:**	**T9 L, R** **Seat Latch**			**Site: Kosice**	
				Customer request/day: Work shifts:	3 770 3
				Daily request per work shift:	2 923
Average of 12 measurements					
Post	**Average(s)**	**Minimum(s)**	**Variability (s)** (average-mini)/mini	Working time (min):	480
P20L	17.7	17.4	2 %	Break:	30
P20R	17.7	17.5	1 %	Meeting (5 minutes):	5
				Final cleaning:	5
				Production time (min):	440
				Tact time (s):	**9**
				Capacity per hour:	**406**
				Capacity per work shift:	**2 976**
Total	35.4603	34.91		**COSU**	**18**
Cycle time			17.7		
Best time achieved			17.5	Current number of operators:	**2**

Figure 10. Cycle time diagram for D3P2

A) Hourly capacity calculation: The hourly capacity of one side of the D3P2 line is 203 pieces of products, while in production on both sides the hourly capacity is 406 pieces per hour with trouble-free production.

$$Hourly\ capacity = \frac{Number\ of\ seconds\ per\ hour}{Cycle\ time} * number\ of\ lines$$

$$Hourly\ capacity = \frac{60 * 60}{17{,}7} * 2 = 406\ pieces\ of\ waste$$

B) Calculation of capacity per shift: The shift capacity is given by the production time and the cycle time and indicates the number of products per 7.5 hour work shift. 1,488 pieces/side are produced on the lines, and the total output is 2,976 pieces/shift.

$$Capacity\ per\ change = \frac{Production\ time * 60}{Cycle\ time} * number\ of\ lines = 2\ 976\ pcs\ per\ shift$$

C) HOW: The measurement was performed on both left and right side D3P2 assembly lines in the number of 12 on both sides with different variability and operators. Based on them, all calculations were collected in one transparent Table 6.

Table 6. Analysis of production on D3P2 lines

Output on both D3P2 lines	Number of pieces
Hourly output	406
For a 7.5 hour shift	976
Daily output	8 928
Weekly output (5 working days)	44 640
Monthly output (20 working days)	178 560
Annual output (240 working days)	2 142 720

$$WHAT = \frac{Working\ time(s) * pocet\ operatorov}{Hourly\ capacity}$$

$$WHAT = \frac{60 * 60 * 2}{406} = 17.7\ s$$

The cycle time was measured at 17.7 seconds. It can be concluded that the newly designed line is efficient and adaptable for higher production. The efficiency of all lines in the company is set at 85%.

Weekly production on one D3P2 line represents 22 320 pcs of final seat locks, which is a multiple of two due to production on two sides of the lines, which represents a total production capacity of 44 640 pcs for 15 shifts. Monthly production depends on the number of working days in a year. During the year, a fund of 240 working days is considered, it follows that 178 560 locks on the lines will be produced during 20 days/month.

The total annual production thus amounts to 2 142 720 left and right seat locks, which depends on various factors, such as sufficient components from suppliers, sufficient workforce, in case of incapacity for work or various absences, planned downtimes and modifications.

D) Delivery calculation: The calculation shows that the fulfilment of the delivery is possible at almost 102%, which is satisfactory, but the supplier has changed the requirements for the quantity of delivered products in the first half of 2023.

$$Delivery = \frac{Real\ production\ per\ day}{Planned\ quantity\ by\ logistics}$$

$$Delivery = \frac{2\,976 * 3}{2\,923 * 3} = \frac{8\,928}{8\,770} = 1.018 * 100 = 101.8\ \%$$

The specific increase in production is shown in Table 7.

Table 7. Overview of production and customer requirements for the period of the first half of 2023 after the addition of automatic P20

The month of 2023	January	February	March	April	May	June
Number of days	21	20	22	20	19	22
Production in one day	8 928	8 928	8 928	8 928	8 928	8 928
Production per month	187 488	178 560	196 416	178 560	169 632	196 416
Quantity requested by customers	184 000	175 600	192 500	175 600	167 200	192 500

In the case of the customer's request for the following period in the number of pieces 2923 pcs/shift in three-shift operation after deducting time losses, one operator is required for each side, even based on calculations. The cycle time is given by P10, while on the original T9 line P10 was slower than P20, and an average of 17.7 seconds was measured, which represents an hourly production of 316 pcs. The current number of operators on the lines has been reduced from four to two. It is clear from this that the line is more efficient. The capacity per shift is calculated at 1 488 units with trouble-free operation. It is not necessary to produce even during weekend shifts or during holidays, which represents significant costs for the company.

6. Conclusion

The paper addressed the proposal of innovation in the selected company using the Yamazumi methodology and production line balancing. As part of the optimization, an automated line was created for testing seat locks in the selected company. The result of the applied measures was a reduction of the cycle time to 17.7 seconds, compared to the original cycle time of 27.7 seconds, which is an improvement of about 37%. Other benefits include balancing individual processes, saving costs during production and during overtime shifts, reducing the number of operators needed by post automation.

The priority was to meet the required demand of customers and thereby ensure the continuity of contracts for the next period.

Acknowledgements

This work has been supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic (Project KEGA 030EU- 4/2022, VEGA 1/0064/23 and KEGA 019TUKE-4/2022).

References:

[1]. Connelly, M. C., Dismukes, J. P., & Sekhar, J. A. (2009). New relationships between patents and technological innovation: Modeling patent activity as a driver of innovation. In *PICMET'09-2009 Portland International Conference on Management of Engineering & Technology*, 2722-2739. IEEE.

[2]. Connelly, M. C., Dismukes, J. P., & Sekhar, J. A. (2011). New relationships between production and patent activity during the high-growth life cycle stage for materials. *Technological Forecasting and Social Change*, *78*(2), 303-318.

[3]. Colledani, M., Gyulai, D., Monostori, L., Urgo, M., Unglert, J., & Van Houten, F. (2016). Design and management of reconfigurable assembly lines in the automotive industry. *CIRP Annals*, *65*(1), 441-446.

[4]. Figenbaum, E., Assum, T., & Kolbenstvedt, M. (2015). Electromobility in Norway: experiences and opportunities. *Research in Transportation Economics*, *50*, 29-38.

[5]. Goffin, K., & Mitchell, R. (2016). *Innovation management: effective strategy and implementation*. Bloomsbury Publishing.

[6]. Inman, R. R., Blumenfeld, D. E., Huang, N., & Li, J. (2003). Designing production systems for quality: research opportunities from an automotive industry perspective. *International journal of production research*, *41*(9), 1953-1971.

[7]. Moon, D. H., Cho, H. I., Kim, H. S., Sunwoo, H., & Jung, J. Y. (2006). A case study of the body shop design in an automotive factory using 3D simulation. *International Journal of Production Research*, *44*, 4121-4135.

[8]. Nelson, R. R., & Winter, S. G. (2007). *Preface to the Japanese translation of'An evolutionary theory of economic change'* (Working Paper, No. 2007/04). LEM Working Paper Series.

[9]. Tidd, J., Bessant, J., & Pavitt, K. (2007). Rízení inovací. *ComputerPress: Brno, Czech Republic*, 250-312.

[10]. Womack, J. P., Jones, D. T., & Roos, D. (2007). *The machine that changed the world: The story of lean production--Toyota's secret weapon in the global car wars that is now revolutionizing world industry*. Simon and Schuster.