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Evaluation and Analysis of Production Processes Affected by Unmeasured Situations: Case Study of a Metal Processing Company

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1. Introduction

Society faced extreme changes in behavior and daily lifetime routines during 2020. As the pandemic appeared to spread all over the world, there is not a single country which had no struggle dealing with the consequences of COVID-19. More than a year has passed since the beginning of the virus and it is already can be stated that one of the most affected areas is production - the pandemic forces working with a reduced workforce or limited workforce, which reduces the productivity [1] and regarding [2] the whole supply chain system is affected and it will take months for companies to recover from supply chain disruptions.

Business suffered from this pandemic and according to a survey made by The National Association of Manufacturers in the USA, almost 80% of respondents expect that the pandemic will have a financial impact on their business [3]. As stated in [4], economic activity as measured by real GDP contracted at an annualized rate of 5 % in the first quarter and by an astounding 32 % in the second quarter in the USA. Economy of Lithuania also had a challenging year of 2020 - GDP decreased by 1,3 % in first-third quarters of 2020. Even under the fact that this decrease can be considered as one of the best in Europe, almost all companies face challenges [5].

Restrictions in countries during quarantine resulted business to freeze their activities. Work from home has become as a standard and more appropriate working model which may even stay after the pandemic [6]. Companies must avoid downtime in production and at the same time they need to take actions to provide a safe environment for employees. To guarantee that the virus would not spread unstoppable, companies receive government regulations and recommendations. Following all given rules help to stop the spread of virus, but companies face additional time and financial costs. Adding additional tasks to everyday routines will slower the pace of company, so planning production processes from now on must include unexpected situations and evaluate them. This rapidly growing situation of pandemic issues and the knowledge that pandemics are reoccurring events prove the need of change in production process planning [7].

The latest research also shows significant need of modernization and use of technologies to help adapt and make decisions in factories as fast as possible. To do so, Digital Twin idea pops out in several articles to prove its potential [8 -11]. The article provides information about Industry 4.0 implementation and importance as one of the main aspects to catch up with the existing situation - this pandemic identified big data analytics and modernization opportunities [12, 13].

This article is focused on three parts - description of the problem, creation of production processes algorithm, and proposals from an engineering perspective how to cope with this situation. Only a few articles were found related to production planning failures due to COVID since this is a new field of investigation.

2. Investigated company

Case study is made in one metal processing company. It is a Lithuanian metal works company which was found in 2005 and now has 75 employees (10 administration employees and 65 employees directly in production). The company is located in northern Lithuania. Specialization of this company is metal tube processing and manufacturing of furniture components. At the moment, company mostly produces goods to Baltic and Scandinavian countries. This company belongs to a group of more than 20 other companies and produces items for them, so any production delays in this company lead to delays in other connected companies. The company is a supply chain member to produce the final product, so accuracy must be ensured. Main areas of production are aluminum furniture legs, carbon steel furniture legs, mounting brackets and frames for shelfs, tables, and others. The company also offers tube bending and rolling services: bending of tubes up to ⌀38mm, 3D CNC and 3 stack 4 axis bending are available as well as tube rolling, hole punching options. The company is capable to weld either with MIG or TIG. The company also offers CNC turning, metal sheets stamping and punching, powder coating. Company has no fully automated production processes, therefore employee's availability and productivity related problems have a significant impact on the company's processes and results. Another important factor is the limited probability to substitute employees with ones coming from different workplaces (many employees have quite narrow specialization).

3. Situation in country

In Lithuania, as in most of EU countries, the first quarantine started in the middle of March. With the first wave, Lithuania had around 50 new cases a day, so factories mostly worked as normal. After the first restraints were announced, everyone understood that preparation for the second wave is inevitable. By the beginning of December of 2020, Lithuania was the first country in European Union according to the spread of the virus and had almost 50 thousand active cases. Daily cases reached 3000 a day so this accelerated situation carried to stricter regulations inside factories. The investigated company had approx. 10 % of employees isolated by the end of November. However, the company has not stopped its activity but implemented new internal rules.

4. Internal rules implemented in the company

According to health organizations and government, several rules are implemented in the company. Every employee must abide by them.

1. Before entering production area each worker has to check temperature with automatic temperature scanner. Scanner is connected with door lock and higher than 37 degrees' Celsius temperature blocks the door. In this case, production manager must check temperature with certified contactless thermometer and provide access to the production manually if temperature is lower than 37. This is one of the most time consuming rules because people often stand not in the right position, wear masks, hats and this led to longer measuring time and bigger number of faulty alarms.

2. Employees must use protective masks or shields during all shift. Production air is dusty and according to health organization recommendations, masks must be changed every two hours. To keep masks as hygiene as possible, they are held in the administrational office quarters. That means, a person leaves its workplace every two hours just to change a mask. It is necessary to mention that automatic temperature scanning machine must be passed in this way. So first mentioned process repeats every two hours.

3. Personal protective equipment is also held in administrational office quarters to assure control of their use. So, if employee is missing of some, he or she goes through the same steps as mentioned before. This decision could look like time spending process but this forces workers to measure their temperature even more often which is one of main virus prevention tool.

4. As World health organization recommends, employees have to clean their hands before and after the change of mask. This means that employee has to wash hands minimum every two hours twice. This is a standard requirement which helps to prevent and control virus spread since outside of mask collects all dirt and microbes. According to recommendations, every hand cleaning process should take at least 40-60 seconds [18].

5. Another recommendation is to keep 1-2 m distance between working positions. To do that shifts are divided so less people are working in one group. The distance and gathering problem is solved by making workday 15 minutes shorter. Now first shift ends 14:15 and only after 15 minutes new shift starts their work. This forms a time gap between shifts let ventilate the premises, disinfect them.

6. If an employee feels any kind of illness or weakness a production manager must be informed. Then check of symptoms is made.

7. Production manager is the contact link between production and office employees. To prevent additional contact, simple form with employee name, date, production order number and numbers of produced/damaged products is filled by workers with each production order finalization. If forms are filled incorrect, employee must correct it answering provided questions.

8. Workplace must disinfect before and after every shift.

5. Evaluation of production processes

Each of the mentioned rules caused more than additional time consumption. ETD (estimated time of delivery) is postponed with each production order and the situation does not give lots of hope. In the algorithm of production processes planning, there were never included any extra objects for some unpredicted situations. This new but not ending situation showed that the workflow must be improved to avoid wrong production planning.

Whole process of metal furniture leg production is presented and then the specific operation is analyzed in this article. Algorithm of metal leg production is depicted in Fig. 1. As seen, after each operation, a quality inspection is made to prevent quality problems in the last step.

As mentioned, only one operation from this sequence is selected for full investigation - operation of welding (welding of a plate in a tube). To observe this process and provide meaningful recommendations, a workflow is created and presented in Fig. 2. In this algorithm, all filled with color parts are from the preCovid time. Only the circled parts in the algorithm present steps which only appeared due to COVID-19 prevention. It is visually seen how many extra steps are included in this COVID-19 routine which was never predicted or evaluated. All of these steps consume important production time.

To evaluate the impact of these additional tasks in the whole daytime, one employee activities were monitored for a week. Employee works in the described operation of plate and tube welding. The observation was based on LEAN standard work steps. In Lean Manufacturing, standardized work is a means of establishing precise procedures to make products in the safest, easiest, and most effective way based on current technologies [19]. This investigation was only made with one employee and in one described operation. After observation, the most time-consuming subtasks were recognized and presented in Table 1.

Total time of 115 minutes is what one employee wastes in a week due to new implemented rules for COVID-19 prevention. What is visible from Fig. 1, there are 7 separate production operations to produce the metal leg: cut tubes, punch plates, weld plate with screw, weld plate with the tube, paint, add bottom cap and pack. Therefore, it is assumed that the time which is spent by one employee, could be multiplied by the number of employees working in all these 7 operations. This gets us to the point where 805 minutes are wasted per week. This time is not involved in the production plan and is not evaluated when the production order is released and the estimated time of delivery is given. Production orders are still based on time limits when the situation was not affected by the pandemic. With every production plan, the company manipulates with numbers which do not correspond to the real situation because the productivity ratio in reality is lower. From this, a conclusion could be reached that production management systems need to have additional data input for these unexpected situations. To correctly input the data, attention should be paid to the main points envisaged: number of operations, number of employees, time of additional tasks.

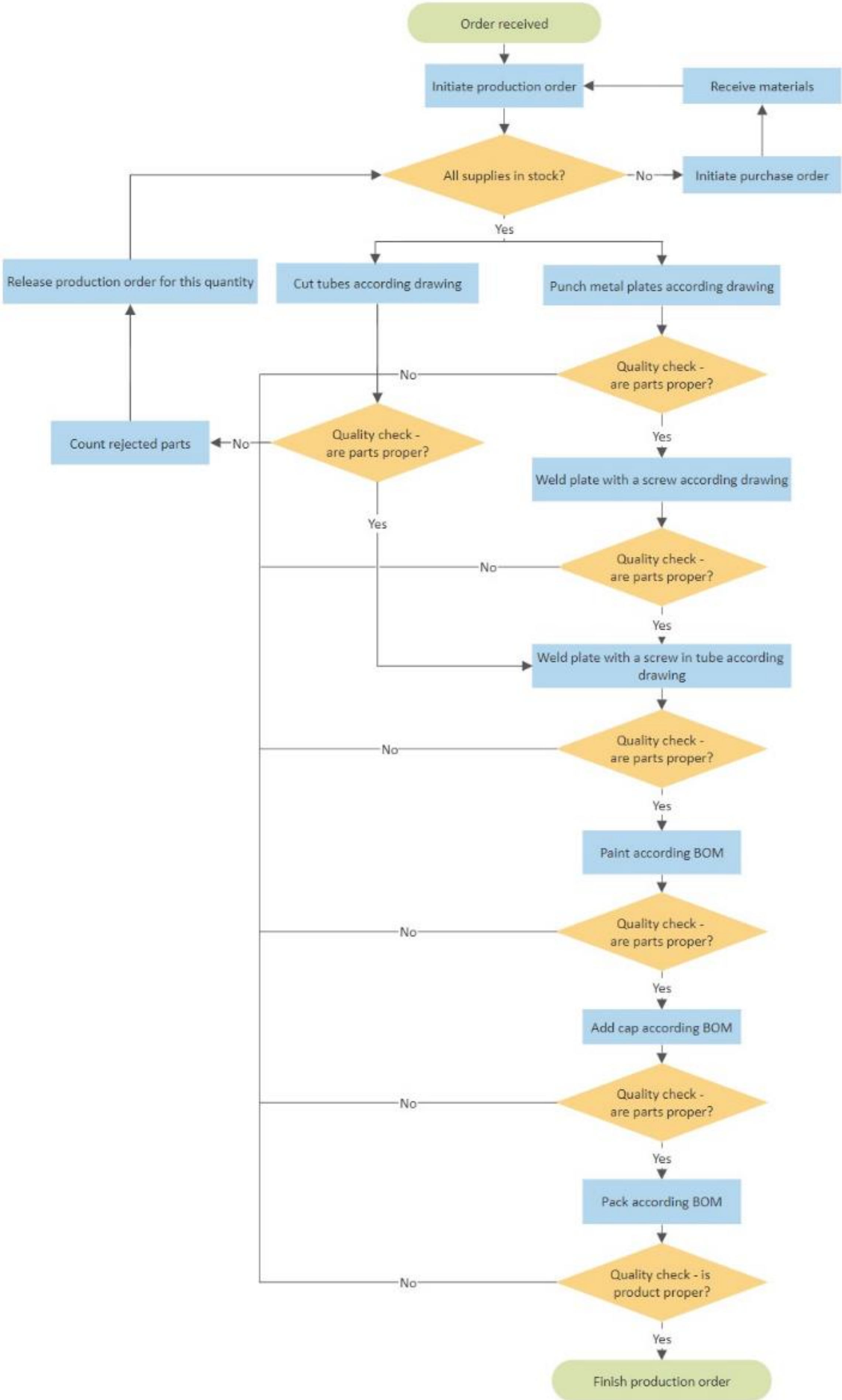

Fig. 1 Workflow of metal leg production

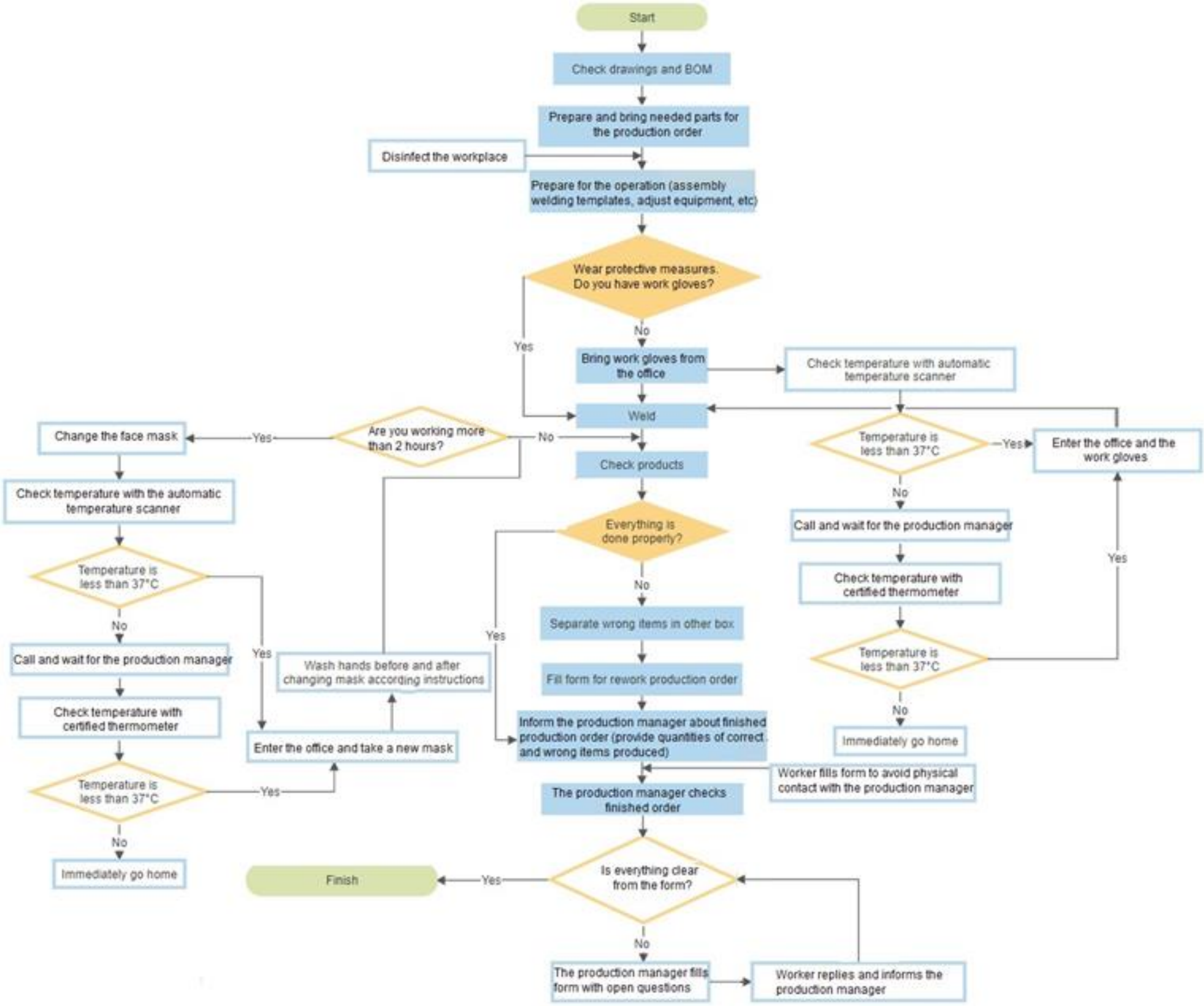

Fig. 2 Algorithm of welding operation

Table 1

Time values of daily additional tasks of one employee (welding operation)

Weekday	Unproductive time additionally spent due/for, minutes					
	Checking temperature with automatic scanner	Changing mask	Disinfecting workplace	Washing hands	Shorter shift duration	Miscommunication with production manager
Monday	1,5	1	1,5	2	15	3
Tuesday	2	1	1	2,5	15	0
Wednesday	2	1	1	2	15	0
Thursday	1,5	1	1,5	2	15	5
Friday	2	1	1,5	2,5	15	1,5

6. Welding operation

Described welding operation is MIG (metal inert gas) welding. It is commonly used process of welding in most frequently industries. MIG welding processes are performed with little electrode which is continuously fed during welding by the competent operator [16]. Company use Ferroline C20 gasses for welding (EN ISO 14175). These gasses are commonly used in the welding of low-carbon or low-alloy steel. The composition of them are 20% CO2 and 80% Argon. Using this type of gas provides even welding seam which is required in furniture manufacturing. For the operation, a welding machine ESAB REBEL EMP 205ic AC/DC is used. It is universal portable, all-process machine, complete with MIG, Flux-Cored, Stick, DC TIG, DC Pulse TIG, and AC TIG capabilities (Fig. 3).

Fig. 3 Interface of ESAB REBEL EMP 205ic with selection of welding processes

Welding wire in this specific operation is ESAB OK AristoRod 12.50 - 0,8mm thickness wire which ensures an extremely clean surface, high-quality winding on the spool, and a stable diameter along its entire length.

Two parameters have a main influence during the welding process - voltage and electric current value, either speed of welding wire fed. This can be done manually or automatically. Fig. 4 shows how the parameters are changed by the welding machine itself, just selecting the thickness of metal and welding seam appearance.

Fig. 4 Automatic selection of welding parameters

7. Insights and suggestions for the company

As the production time expands due to the mentioned additional daily tasks, the company must compensate it in other areas if it wants to stay competitive. With the beginning of the pandemic, companies realized that having fully robotic lines would show the best results at the moment - significantly lower human factor let production to work almost unstoppable, the waste of time would be much lower. Augmented reality (AR) could be perfectly used to avoid face to face contact - many operations could be explained with AR. In the investigated company, the temperature of employees is measured with an automatic scanner which connects a person with the received results - this is an example how contactless check and information gathering is combined. This pandemic brought many important innovations in the planning field, one example is given in [17] where Decision support system is used to generate balanced shift schedules in hospitals. Based on this example, the company could implement DSS for shifts because now there is no system or plan how to finish tasks when an employee needs to go home due to temperature or other symptoms. At the moment, only production manager or other expert can propose possible solution in this case. The tendency is that the amount of data in the production increase and change rapidly so it is hard to memorize all important information. Also, such expert desicions can be made wrong based on emotion, lack of time or knowledge. Example of vendor selection with DSS is given in [14]. The same way employees can be differentiated when looking for available and suitable candidate.

Suggestions for a welding process are made based on this specific investigation.

1. At the moment, the metal plate is welded in the tube with a full circle welding ring. Welded place is not visible for the final consumer, so welding only spots instead of the full line would reduce the operation time (Fig. 5). Welded metal plate does not need to make sealant connection with the tube, it also gets no load during usage, so the welding is only for metal plate connection to the tube and could be reduced from line to spot.

Fig. 5 Left side - fully welded circle, right side - partly welded circle (proposal)

Welding time reduced from 24 s to 20 s for one leg. During a shift, one worker welds around 1200 of metal tubes to a plate.

2. Welding operation now has a simple device on which the metal tube is positioned and the welder rotates it manually to weld a full circle line (Fig. 6). To speed this operation, an automated device could be applied for rotational move. Workers would only position a metal tubes on the device and it would go in circle with the help of device. This would give an even welding line due to the constant rotational move and speed. Compared to the existing situation, which is 24 s for one welding operation, the usage of this device would reduce the time to 21 s.

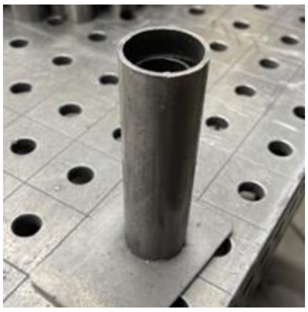

Fig. 6 Device for metal leg welding

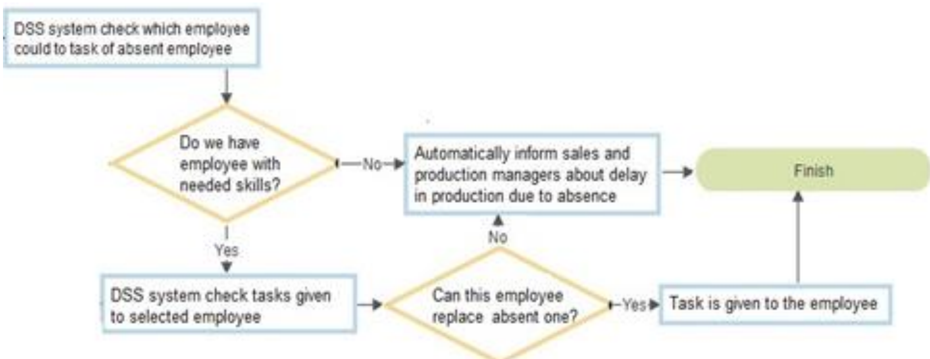

Fig. 8 Changes in the algorithm with DSS

3. Now the parts for welding operation are transported in boxes. After the cutting operation, the tubes fall in the box randomly without any order. Welder has to pick up the tubes for the operation, so the proposal would be to make a simple transporter so the parts would be positioned in the box.

The investigation was made when one box was sorted and the other box of tubes was the same as always. The time of 1 leg welding was increased average 1 s. Therefore, in one shift it is 1200 s or extra 52 legs

4. Since most of the welded legs are standard, a welding robot would be a solution for this operation. An investigation was made with a robot manufacturing company to identify the possibility to use the welding robots for this operation. Welding robot Fanuc ArcMate 100iD with a 7 axis rotational desk was offered. Welding operation would be divided in three cycles with 4 legs in each (Fig. 7). A person would load the robot and then the welding operation would start.

Fig. 7 Fanuc ArcMate 100iD with 7 axis rotational desk

The cost of modernizing a workplace consists of 4 main parts: robot price; peripherals (safety barriers, safety systems, safety sensors); price of design works (programming, installation, maintenance); project management costs [15].

All of these costs would be around 89 000 eur as the company made an offer. At the moment, 3 shifts are welding these legs, so one robot would change three welders. At the same time, the robot will need 3 employees to upload and unload the metal parts. New employees would have lower qualifications than welders, so they will get lower salaries. Moreover, the robot would weld faster and in the shift will make 1400 legs instead of 1200, so more than 4000 more in a month which is average 3 days of work. Formula for time period in which modernization would be profitable is given:

$$T = \frac{I}{w(s.d. + d.s. * n)},$$

where: *I* is one time cost of modernization; *s.d.* is salary difference between workers; *w* is number of employees; *d.s.* is daily salary of welder; *n* is days saved due to faster production.

Time in this case would be 55 months.

5. As mentioned before, DSS adaptation for organizing shifts is the way to maintain a continuous flow of production. The presented algorithm with additional tasks during COVID prevention should be filled with information how to react if a person should go home. Fig. 8 presents the algorithm with the steps that should follow in this situation.

Implementing 1-3 proposals would reduce the time of welding operation for this leg by 8 s or 160 min/day, which is more than wasted time per day. Optimization of this welding process will let the company to maintain the same and even better productivity. If there would be even more additional tasks due to COVID or other preventions, there is a reserve to compensate these interferences.

7. Conclusions

This study set out to investigate the impact of unpredicted situations in manufacturing processes. At the moment, while the situation of COVID-19 pandemic in the world still raises challenges, companies experience increasingly production productivity and efficiency problems performing the same operations which were done many years before. Companies have taken many different prevention measures and this reduces the production pace. This research was based on the example of a case studies. The investigated company, due to COVID prevention, implemented internal rules in total waste 115 min/week of one employee working time. One specific operation was examined - welding of a metal plates in tubes. After full inspection of this operation, 5 possible recommendations were given: weld the parts with open loop, automate the device for welding, improve the delivery of details for the operation, use robot, and review algorithm of the process. Three of these proposals were checked and total 160 min/week could be saved. This is more than the existing waste, so the adaptation of these recommendations would give the company a possibility to get back on track without any drastic decisions.

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S u m m a r y

As the unpredicted situations can occur anytime, the production should be prepared to maintain the same pace as always. The pandemic of 2019 proved that proper production processes are vital. A case study was made in a metal processing company to examine how the workflow has changed after the implementation of virus prevention rules. Welding operation of metal furniture leg was observed and calculations presented – 115 minutes are wasted due to additional daily tasks caused by prevention of the pandemic. The recommendations were described and 160 minutes could be saved in accordance with them. The robotization of processes and DSS implementation were presented.

Keywords: production processes, workflow, optimization.

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