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APPLICATION OF SIMULATION RESEARCH TO ANALYSE THE PRODUCTION PROCESS IN TERMS OF SUSTAINABLE DEVELOPMENT

Abstract

Sustainable development is an very important idea nowadays and it influences on many factors. It is very important to focus on the goals of sustainable development and implement them both in industry and in everyday life. The aim of the article is to analyse the impact of implementing an automatic conveyor belt transport system between the stands of an exemplary assembly line on sustainable development in economic and environmental terms. The analyzed production process consists of one production line with six assembly stations. The efficiency of individual design solutions and electricity consumption were adopted as the evaluation criteria. To compare the two processes, a simulation analysis was performed in the Plant Simulation program. First chapter is the introduction to the article. The second chapter describes the current applications of simulation tests. The third chapter describes the production system that is improved by adding conveyors. The next chapter compares the processes with and without the use of conveyors and presents how much energy must be used additionally by implementing conveyor belts, but also what energy savings can be obtained by installing additional stop sensors. The fifth chapter presents the conclusions: the conducted research allowed concluding that the implementation of conveyor belts affects a higher number of finished products at the same time as the transport of components is manual. However, the best solution is to use conveyors with stop sensors, and the power consumption is then low and more profitable for the enterprise.

1. INTRODUCTION

Sustainable development has many definitions, but the main goals of sustainable development are to focus on economic, social and environmental factors (Adamczyk, 2009). According to the World Commission on Environment and Development, sustainable development is a process of progress in which asset utilization, investment management, organization of technological development, and corporate revolution are perpetuated against

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new and existing requirements (Gazzola, Del Campo & Onyango, 2019). It should be emphasized that nations show different levels of development. Sustainable development is emerging as a global key perception we must recognise to meet socio-economic, technological and environmental challenges (Jovane et al., 2008; Tucki et al., 2022). In manufacturing companies, we have an influence on all the factors mentioned above. Starting with economic factors, you can influence the process optimisation by using energy-saving and efficient machines, and you can also optimise production processes so that energy efficiency is as high as possible. Energy consumption is also very important in a social context. Energy consumption has doubled over the last 40 years and is expected to double again in the next 10 years (May et al., 2015). Industry is one from major energy consumers. It is necessary to reduce energy consumption and demand in the manufacturing industry. Industry plays a key role in meeting the continual increase in demand as the standard of living increases. Direct reduction of energy supply for manufacturing industry is unrealistic because energy is an irreplaceable production factor. Enterprises limit to some extent the reduction of energy consumption while maintaining the same power. Hence, questions arise as to how to improve energy efficiency or reduce energy demand for the same production, and this becomes a critical approach to achieving the goal of reducing energy consumption and sustainable development (Gao et al., 2020). Economic factors affect the minimisation of expenses and increase the company's profits, with a simultaneous positive impact on the environment. The growing interest in more ecological solutions influences the search for solutions with a positive impact on the environment (Seroka-Stolka, 2014). By having an impact on the environment, the production company contributes to lower energy consumption, the use of renewable materials, as well as minimising material scrap, and this affects social factors. Society is not exposed to an unhealthy natural environment, lack of natural resources, and an excessive amount of post-production waste. Therefore, sustainable development is important and touches on many levels. Influencing all of the above factors, more and more companies are trying to meet the requirements of sustainable development (Misztal, 2018). Achieving sustainable development is important to any society, especially developing ones, but industrial growth may not be enough. On the one hand, development means an increase in GDP; on the other hand, it is a means to raise the financial and social status of impoverished economies, raise employment levels, make better use of resources and stimulate social equality (Salih, 2003). A very important element of implementing sustainable development in any field is the support of social, management, and regional and national policy, which is described in detail in the dissertation (Conroy & Berke, 2004).

The aim of the article is to analyse the impact of implementing an automatic conveyor belt transport system between the stands of an exemplary assembly line on sustainable development in economic and environmental terms.

First chapter is the introduction to the article. The second chapter describes the current applications of simulation tests. The third chapter describes the production system that is improved by adding conveyors. The next chapter compares the processes with and without the use of conveyors and presents how much energy must be used additionally by implementing conveyor belts, but also what energy savings can be obtained by installing additional stop sensors. The fifth chapter presents the conclusions.

2. APPLICATION OF SIMULATION RESEARCH

One of the methods of analysing production processes is the use of simulation tests. Having access to many computer programs, it can be recreated or create the desired process and optimise it. With such tools, at a low cost, it can be checked what changes or how to create a production line to meet the goals and requirements of sustainable development. For example, in real processes, machine tools remain idle most of the time and then consume about 80% of the energy (Mouzon, Yildirim & Twomey, 2007). In this case, the appropriate planning of the machining process as well as the appropriate use of production scheduling can significantly affect the efficiency of the process. When analysing the research to date, one can refer to the research (Misztal, 2018), where the assessment of the progress of the sustainable development of Polish business entities was carried out, taking into account economic, environmental and social conditions. However, these studies do not focus on a specific example of an improvement used in a given enterprise, but on a total of 105 enterprises in a given period. Sustainable development is described a bit more in the book (Kronenberg & Bergier, 2010), but the authors focused on general knowledge without researching the sustainable development of enterprises. Also, in the article (Terelak Jardzioch & Biniek, 2018), the impact of the use of production scheduling on energy efficiency was analysed, and the results showed that in the scheduling of production orders, from 5 to 45% electricity savings can be achieved, while in my research, I am going to use the scheduling of production orders and check whether it will affect the sustainable development of the company. In the article (Lee, Zhang & Ng, 2019), the authors presented a comparison of simulation results with a real process, how decisions are made to optimise the workforce, improve performance in a specific dishwasher factory, and the impact of these studies on sustainable development. Optimisation of work on the production line is presented. Another example of simulation tests was described in the article (Liu et al., 2018; Jasiulewicz-Kaczmarek & Gola, 2019)), first, the drivers and challenges were analysed, and the boundaries and connotations of production systems were defined. Next, an energy-based computational model for energy, materials, services, and waste was presented, taking into account the diversity and input and output dimensions of production systems. In addition, certain indicator systems have been established, including functional energy indicators, structural energy indicators, eco-efficiency indicators and sustainability indicators of production systems. Thanks to these indicators, the internal relationship between the economic, environmental and social benefits of production systems is revealed. On this basis, an improvement card was developed to achieve excellent quality, high efficiency, reduction of energy consumption, resource-saving and environmental protection of production systems. Finally, the case study illustrates the feasibility of the proposed method, and the results show that the proposed method provides theoretical support for assessing and improving the sustainability of production systems to coordinate resources and develop the manufacturing industry. Additionally a very important issue in production is to use modern transmitters, sensors and telematics tools. In the article (Topolski, 2018), the authors proved that replacing the push method with the pull method shortened the production time, additionally, the implementation of RFID technology increased the company's turnover by 19.9–21.2%.

3. DESCRIPTION OF THE PRODUCTION SYSTEM

The production process consists of one production line with six assembly stations. The layout is shown in Figure 1. All assembly stations are used for the manual assembly process. One production order consists of fifteen identical products. No retuning of the production line is required. Operation times at each workstation are similar; however, in the production process, where employees transport the product between workstations, the time is extended. To show the impact of the ranking on sustainable development, the value of the energy consumed was assigned, which is consumed at each station and in the second model, in which transporters are used. To compare the two processes, a simulation analysis was performed in the Plant Simulation program.

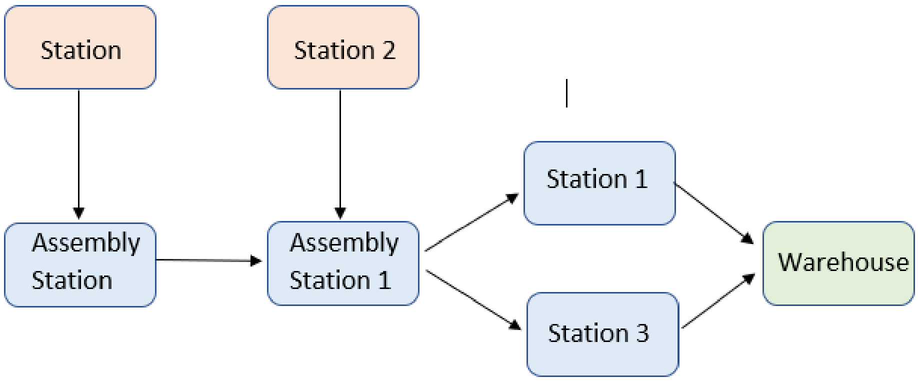

Fig. 1. Diagram of the production line

Table 1 shows the original working times at the given positions. After simulating with conveyor belts, times will be optimized. The times for station1 and station3 are extended by 1 minute – this is an additional time to transfer the final product to the storage place. In the model with the use of tapes, this time is not needed.

Tab. 1. Working time at given positions

Position	Working time [min]
Station	10:00
AssemblyStation	08:00
Station2	10:00
AssemblyStation1	10:00
Station1	21:00
Station3	21:00

As part of the drive to build a system that meets the requirements of sustainable production development, the company decided to investigate whether the implementation of conveyors will allow optimizing the production process, increase the efficiency of the production line and the work of employees (Kopas & Paulikova, 2009). Additionally, to reduce energy consumption (Zhang, 2019), the company decided to check how installing stop sensors in conveyor belts would affect energy consumption. Given that one of the goals of sustainable development is also to facilitate employees' work, this is an additional factor that impacts labour productivity.

4. COMPARISON OF THE PRODUCTION PROCESS WITH AND WITHOUT THE USE OF CONVEYORS

The original production process assumes that employees move components between stations by themselves. The assembled product in the first operations weighs about 3 kg, while the final product weighs 20 kg. Due to the loads transferred, workers move 1 m/s. Employees work 7.5 hours (450 minutes) in one shift.

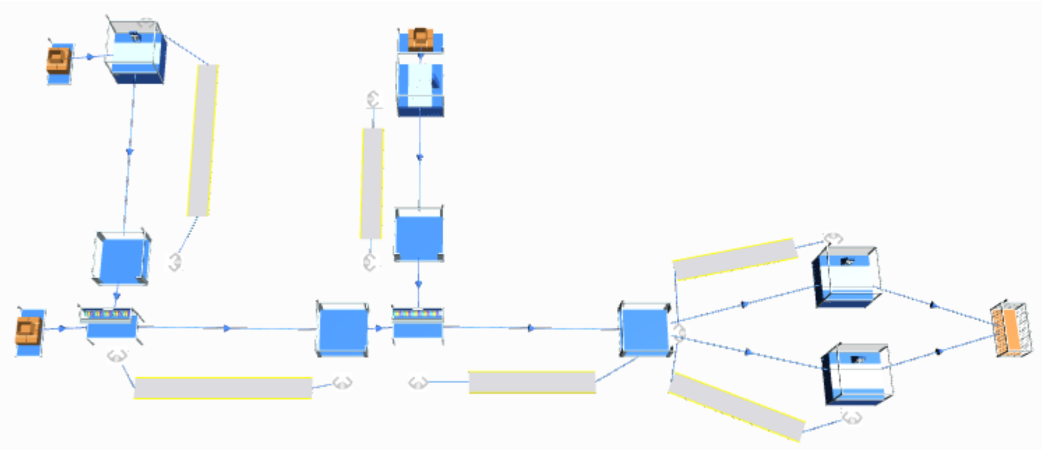

Fig. 2. Scheme of distribution of production stations on the production line without conveyors

Figure 3 shows a diagram of the production line with the use of conveyors between stations.

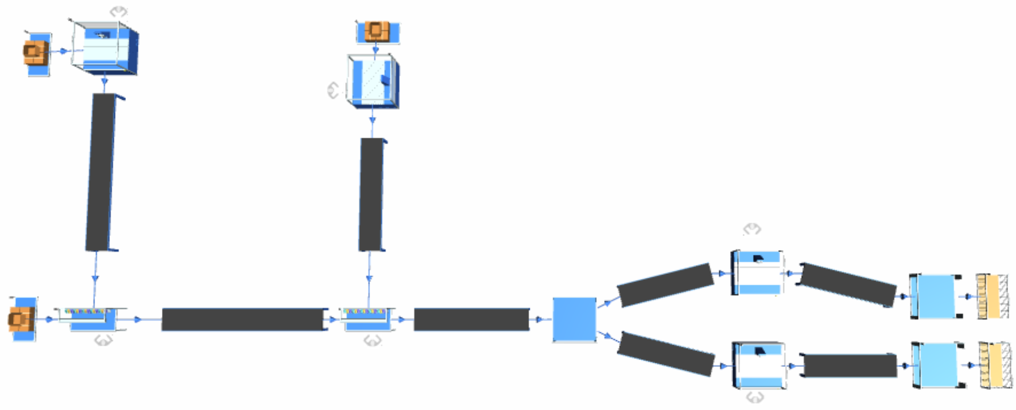

Fig. 3. Scheme of distribution of production stations on the production line with conveyors

4.1. Comparison of the performance of the two production lines

The first data was collected for a line without belt conveyors and with belt conveyors during one shift and during one month of operation, assuming three shifts. The results are showed in Table 2.

Tab. 2. The number of products produced on the production line with and without conveyors at a specified time.

	1 shift (7,5 h)	1 month (3 shifts)
The number of products produced on the production line without conveyors	38	3949
The number of products produced on the production line using conveyor belts	41	4181

During production without the use of conveyors, 38 units of the finished product were produced during one shift and 3,949 units of the finished product were produced during one month. During production with the use of conveyor belts, 41 units of the finished product were produced during one shift and, 4181 units of the finished product were produced during one month.

4.2. Comparison of energy consumption

The results of energy consumption by individual conveyors are presented below. Two options for installing conveyors were analysed: without and with a stop sensor. The belt conveyor stop sensor allows the belt conveyor to be stopped when nothing is being transported. Simulation tests were carried out to check whether the installation of such a sensor allows a significant reduction in the electricity consumption needed to transport items in the production system under consideration.

4.2.1. One shift – 7.5 hours

The first data of energy consumption was collected for a line without and with stop sensors during one shift of operation. The results are showed in Table 3.

Tab. 3. Energy consumption of the production process with the use of conveyors without and with stop sensor

Energy Consumers	Without stop sensors [kWh]	With stop sensors [kWh]
Conveyor	52.5	6.30
Conveyor2	52.5	1.59
Conveyor5	52.5	3.47
Conveyor6	52.5	4.63
Conveyor1	52.5	6.97
Conveyor7	52.5	8.07

4.2.2. One month of production line operation for three shifts

The first data of energy consumption was collected for a line without and with stop sensors during one month of operation, assuming three shifts. The results are showed in Table 4.

Tab. 4. Energy consumption of the production process with the use of conveyors without and with stop sensors during one month of operation

Energy Consumers	Without stop sensors [kWh]	With stop sensors [kWh]
Conveyor	4882.5	489.30
Conveyor2	4882.5	41.84
Conveyor5	4882.5	15.25
Conveyor6	4882.5	16.43
Conveyor1	4882.5	139.16
Conveyor7	4882.5	140.34

4.3. Comparison of the results

When analysing the production process where conveyor belts have been implemented, it can be noticed that the increase in the number of manufactured products is about 6–8%, which means that about a month of work on the production line can be saved per year.

Tab. 5. Comparison of the number of units produced at a given time on two different production lines

	Production line without conveyors	Production line with conveyors	Difference
7,5 h 1 shift	38 pcs	41 pcs	7.3%
1 month 3 shifts	3949 pcs	4181 pcs	5.5%

However, it is equally important to compare the energy consumption of transporters. The parameters of belt conveyors with and without the use of a stop sensor were compared. Below is an overview of the energy consumption of the conveyors.

Tab. 11. Comparisons of energy consumption by conveyors with and without the use of stop sensors

	Conveyors without stop sensor, average power consumption for one belt [kWh]	Conveyors with stop sensor, average power consumption for one belt [kWh]	Difference
7,5 h 1 shift	52.0	5.17	1005.8%
1 month 3 shifts	4882.5	140.39	3477.8%

The cost of 1 kWh for an enterprise is approximately 0.66 PLN on average. Thus, the cost for one shift is approximately PLN 3.41. The rates for 1 kWh are calculated individually for each company. The purchase of conveyor belts is also an individual cost, and each entrepreneur must analyse for himself whether the cost of purchasing belts, maintenance, maintenance, and electricity costs are higher or lower than the profit from shorter maintenance of the production line.

5. CONCLUSIONS

The article presents a simulation that allows comparing two solutions of the designed assembly system. One solution involved transporting products by employees, and the other transporting products using belt conveyors. In the case of the use of belt conveyors, the influence of the use of additional sensors allowing for stopping the conveyor when there are no items to be transported was also checked. The efficiency of individual design solutions and electricity consumption were adopted as the evaluation criteria. The conducted research allowed concluding that the implementation of conveyor belts affects a higher number of finished products at the same time as the transport of components is manual. The difference changes exponentially with longer production times. The lack of conveyor belts is a cheaper solution at the time of implementation, but with annual production, we gain an additional month of production using transporters. The downside of this solution is the high consumption of electricity, which significantly increases production costs. However, the best solution is to use conveyors with stop sensors, and the power consumption is then low and more profitable for the enterprise. Of course, a high initial cost is the purchase, implementation, and then servicing of the conveyors, but these are certainly costs; however, the purchased transporters can be used in other production lines or sold in the future. An additional profit, which is very important and uncountable, is the satisfaction, safety and less burden on employees. Employees do not have to move products between workstations every 10 or 20 minutes. It will have a positive impact on their health, but also increase work safety.

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