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INTRODUCTION OF A NEW FLEXIBLE HUMAN RESOURCES PLANNING SYSTEM BASED ON DIGITAL TWIN APPROACH: A CASE STUDY

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Abstract

Digital twin technology has become one of the key directions of intelligent manufacturing with a strong relationship to product lifecycle management. It contributes to increasing efficiency and flexibility in solving highly complex problems in constantly changing conditions. However, many circumstances make the real implementation of effective scenarios generated by simulation software tools difficult. One of them are rigid working schedules that complicate flexible human resources planning in accordance with optimal production and logistics plans. This article aims to examine the role of the digital factory twin in advanced human resources planning. Using the case study method, a solution for better coordination of internal logistics processes and utilization of logistics staff based on discrete-event simulation is presented. Several scenarios were tested and results showed the inevitability of using flexible working schedules for maximum utilization of logistics staff. The purpose of this study is not only to show one special case of one company, but to emphasize the potential of these software tools to achieve long-term synergies in coordinating logistics, production and human resources management activities. As a result of this study, an extended physical-digital-physical loop model is presented. This extension consists in adding the second loop including communication with HR portal.

Keywords: digital factory twin, discrete event simulation, flexible work systems, human resources planning, internal logistics

1. INTRODUCTION

The Fourth Industrial Revolution represents a completely new philosophy, bringing global change and spanning a wide range of spectra, from industry, through technical standardization, security, education, science and research or the labor market (Ministry of Industry and Trade, 2016). Under the term digital factory, we can

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imagine an extensive network of digital methods, models and various tools that are integrated in the ongoing data management to create a clear, comprehensive and system plan (Axiom Tech, n.d.). Each organization has its individual needs and it is up to the management of the company what will be the next strategic procedure in the implementation of an intelligent factory (Balga, 2018). The modern phenomenon is the interconnection of the Internet of Things, services and people and the related immense amount of generated data, whether machine-machine, human-machine or human-human communications (Ministry of Industry and Trade, 2016). However, as Parmar et al. (2020) correctly point out, value of any advanced technology is derived from performance improvements and conceptual approach. Belás et al. (2021) also point out the necessity to increase the level of strategic risk management when improving business processes in order to increase the competitiveness of companies. Mohsin Raza et al. (2020) emphasizes that the implementation of the digital twin in industries will ensure seamless data transmission, proper system diagnostics, stabilization of operations leading to increased productivity and prediction of possible errors. Resman et al. (2021) states that there are different software solutions for developing digital models, from a basic mathematical modelling (Moser et al., 2020), through agent-based modelling (Makarov et al., 2019) and various discrete-event simulation software tools (Straka et al., 2022; Ferro et al., 2018).

Many authors speak about positive influence of digital twins to production planning, but too little attention is paid to human resources management. While the capacity of machinery, logistics vehicles or material stocks can be managed relatively flexibly, human resources planning is highly influenced by fixed working schedules. Therefore, our research focuses on this research gap and aims to examine the role of the digital factory twin in advanced human resources planning approaches using flexible working schedules. Many people, especially younger generations, are carefully considering the amount of time they spend working. An appropriate balance between income and leisure time is often a key parameter when deciding about future employment (Tang, 2007). Thus, the use of flexible work schedules can bring many benefits not only to employers (better utilization of labor), but also to the employees themselves.

2. THEORETICAL BACKGROUND

2.1. Physical-digital-physical loop

Resman et al. (2021) mention a loopback between the actual model and the digital twin, where the actual production system sends input data to the digital model, which generates a suboptimal production plan, and the actual production plan should be modified. Modoni et al. (2019) mention the closed loop between real and virtual factory worlds. Peruzzini et al. (2020) states that incorporating the human factor into the digital loop can lead to the creation of a more powerful digital factory in business due to the human factor intelligence. Kuehn (2018) mentions a closed loop, which will ensure the application of the findings from the digital twin to the real process and ensure continuous process improvement. Chen et al. (2020) describe a cyber-physical system as a new trend in smart manufacturing, where a physical system collects data from sensors and communicates with computing modules using multiple feedback loops.

2.2 Digital factory in relation to the worker and logistics

Bécue et al. (2020) focus on the research of digital twins and the influence of human behaviour influencing the resilience of the digital factory, especially in its dependence and vulnerability on the permanent physical presence of people on factory shop floors. Peruzzini et al. (2020) use various Industry 4.0 elements to measure various monitored parameters leading to the evaluation of physical and mental stress. Through these measured data, knowledge is collected to create a digital twin, which is used to simulate and improve ergonomic principles at the workplace. Lu et al. (2021) describe digital twin integrated into the production process through the value stream mapping method, which serves to optimize inventory, production flow and shorten production lead time. Lee and Lee (2021) state that the digital twin can also be used for Supply Chain coordination in modular construction to detect and prevent potential logistics risks. Kuehn (2018) emphasizes the need for modern data and driven multi criteria decision approaches through simulations for comprehensive management of production and logistics processes.

2.3. Digital platform in form of crowdwork

Crowdwork platforms and digital platforms for freelancing are used mainly for digital work performed from the home environment. Moritz (2020) analyzed crowdwork platforms that offer digital work to digital workers across the globe. Crowdwork platforms provide manpower according to current requirements and workers use their space. In his study, Haltofova (2018) mentions how crowdsourcing overcame the limitations in the traditional urban planning process and contributed to the occasional involvement and increased competitiveness of the city of Ostrava to prevent the depopulation of citizens. Hartmann et al. (2019) report the contribution to the development of employees' competencies in the use of digital learning platforms. Mantymaki et al. (2019) emphasize that from the point of view of employees, flexibility for the performance of work in industrial relations is a positive element of working on platforms. Runi and Furrer (2020) state that these platforms are beneficial for people with disabilities and carers.

3. RESEARCH OBJECTIVE, METHODOLOGY AND DATA

The main goal of this study is to propose a new flexible model to integrate human resources planning into standard physical-digital-physical loops typical for digital twins approach. A discrete-event simulation model was developed to analyze and evaluate this idea on example of an internal logistics process, more specifically supplying production lines with input material in selected industrial company. It is a medium-sized company producing various plastic products and components for final customers as well as for other industries. For our purposes, the process of supplying one production hall with material was selected. In this hall, there are 47 independent machines which are supplied by Milkrun. Milkrun train drivers represents targeted staff for purposes of this study.

Company has faced problem with decision about the number of Milkruns operating in the system. Low number of Milkrun trains can cause delayed supplies, higher number of trains can cause their low utilization rate as well as the utilization of Milkrun drivers. Ten experiments with ten different numbers of Milkrun trains in the system were done.

Methodology is divided into several steps:

1. Current state analysis and simulation model

Firstly, the real data from manufacturing process of selected industrial company were collected and the main problem to be solved was identified. Data was collected by combination of several methods including interviews, personal observations and studying of relevant documentation. Input variables monitored include: shop-floor layout analysis, material flow analysis, cycle times of all machines, maintenance and breakdowns of machines, production plans for individual machines, frequencies of delivering material, routes length and rules of supplying process and capacities of logistics equipment.

After that, data was used to create a digital model of the real manufacturing environment using Plant Simulation Software.

2. Experiments focused on improving of the current state

The next step included experiments and validation of new scenario. Firstly, the conventional approaches were used, such as: layout changes (rearrangement of machines based on the frequency of their logistics needs), changes in used logistics equipment (capacities, type of vehicles etc.), changes in rules for supplying of production lines (frequencies, routes etc.).

After that, current scenario was reproduced by new premises including integration of flexible work schedule for Milkrun drivers. The results of all experiments were compared to each other.

3. Proposal of a new model of physical-digital-physical loop

Finally, results presented through case study and simulation-based model were generalized into a theoretical model for integration of modern approaches in human resource planning into physical-digital-physical loops. This step consisted of:

- Summary of previous analysis and results of experiments
- General assumptions that emphasizes the advantageousness of flexible work schedule integration into production and logistics planning
- Simulation based model of new scenario including flexible work schedule approach in the process of supplying production lines
- Final model definition

3. RESULTS AND DISCUSSION

The study aims at introducing a new model of physical-digital-physical loop for industrial companies extended by new flexible approaches in human resources planning. In the following chapters, our idea is presented in form of case study. The problem formulation and simulation-based model is followed by a set of experiments that prove our assumptions.

3.1. Case study

The company, where our assumptions were tested, is a manufacturing plant including 47 independent machines. The original problem that was solved focused on improving logistics processes, more specifically supplying individual workstations with required material. Company implemented Milkrun system, but there was a problem to decide about the optimal number of trains, regarding also engaged logistics staff. Because many capacity problems occurred, discrete-event simulation model was created to identify the main problem.

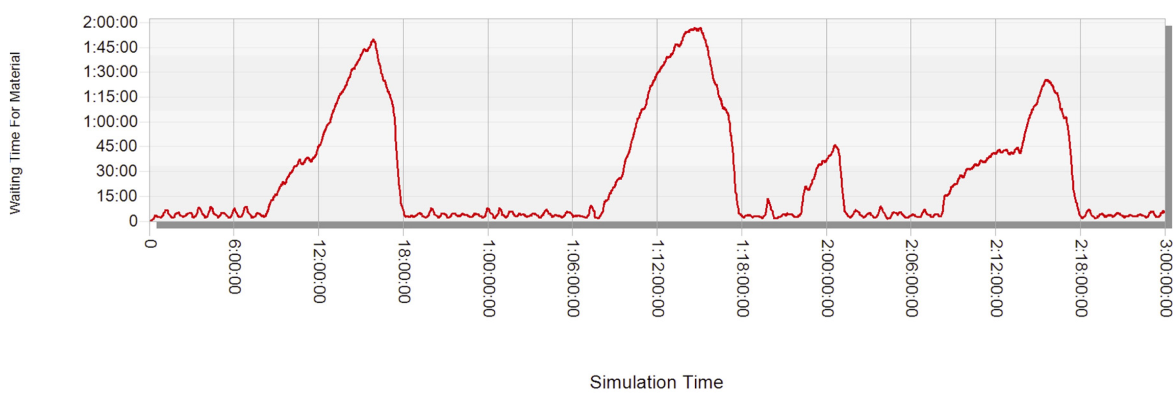
Milkrun serves all machines on the shop floor, its route is the shortest possible way how to deliver material from warehouse to production lines and it is fixed, Milkrun must always drive throughout the whole route. The average speed of Milkrun train is 1 m/s and it spends around 10 seconds by loading and unloading material at each workstation or warehouse. The cycle times of machines are fixed and production orders are managed by automatically generated production plans from ERP system. There is some variability in requirements, sometimes all machines are fully utilized, and sometimes many of them wait for production order for several hours.

Model validation and experiments with different scenarios

The main problem of Milkrun implementation in the targeted company is decision about the number of Milkruns needed for supplying production lines. Figure 1 shows average times of waiting for material when 3 Milkruns operate in the system. The number of needed Milkruns was carefully calculated based on historical data about average production and average material requirements, capacity limitations and all other relevant input data.

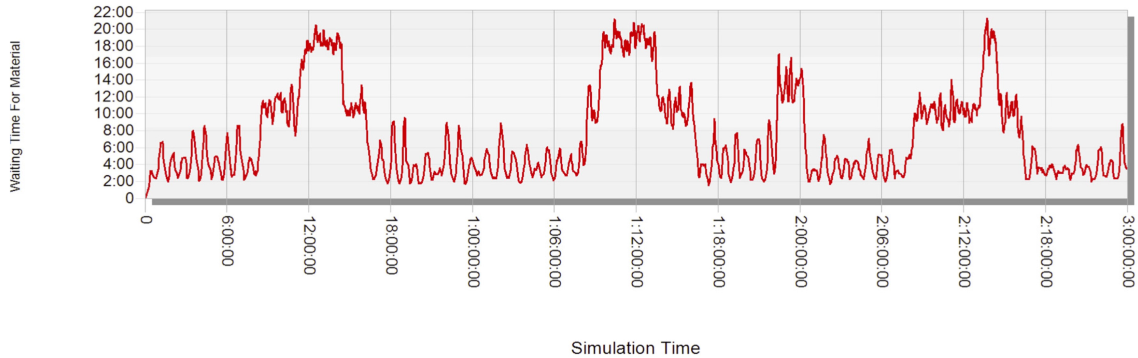
Despite the fact that calculations were correct from the viewpoint of its methodology, the large variation in production orders during shifts causes very long idle times due to the lack of input material. Figure 2 shows that the peaks sometimes attack 2 hours long delays.

More scenarios with different numbers of Milkruns in the system were tested. Figure 2 shows how average waiting times change when 10 Milkrun trains operate in the system.



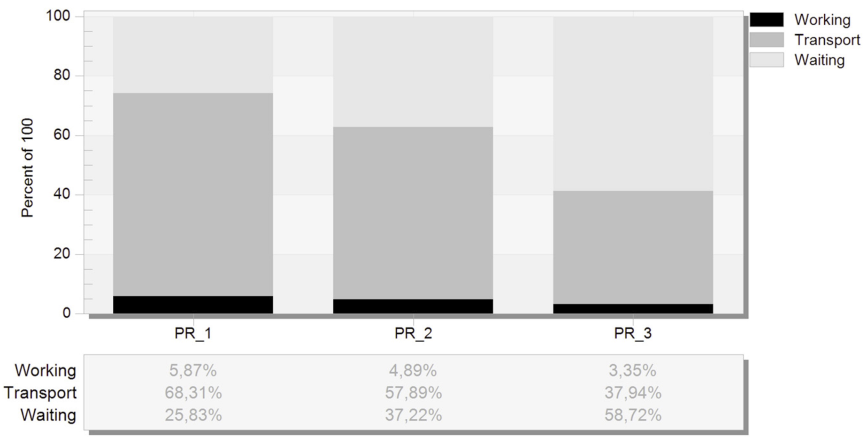
Source: own research

Figure 1. An average waiting time for material when 3 Milkruns operate.



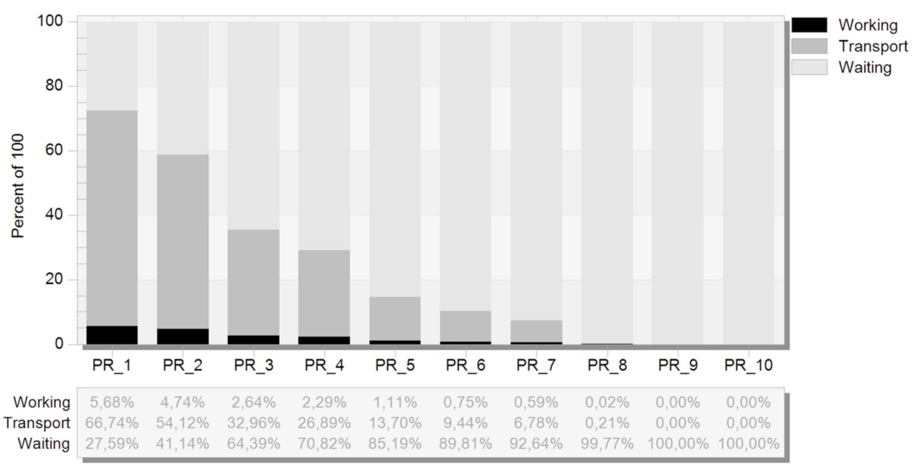
Source: own research

Figure 2. An average waiting time for material when 10 Milkruns operate



Source: own research

Figure 3. An average utilization of 3 Milkruns operating in the system



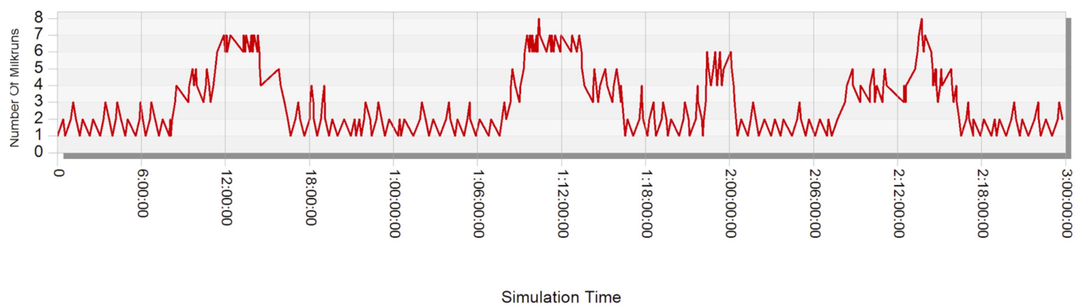
Source: own research

Figure 4. An average utilization of 10 Milkruns operating in the system

Table 1. Summary of all experiments

Experiment	Number Of Milkruns	Average Waiting Time For Material	Idle Time	Working Time
Exp 01	1	3:11:30	0.015	0.985
Exp 02	2	1:04:48	0.052	0.948
Exp 03	3	37:29	0.122	0.878
Exp 04	4	21:50	0.198	0.802
Exp 05	5	15:27	0.284	0.716
Exp 06	6	12:30	0.376	0.624
Exp 07	7	11:03	0.471	0.529
Exp 08	8	11:01	0.571	0.429
Exp 09	9	11:01	0.671	0.329
Exp 10	10	11:01	0.771	0.229

Source: own research



Source: own research

Figure 5. Number of required milkruns per shift

It is evident that average waiting times decreased rapidly. However, another problem occurred, the problem with low utilization of Milkrun trains. Figure 4 and 5 show utilization of all Milkrun trains in two scenarios: system with 3 Milkruns (Figure 3) and 10 Milkruns (Figure 4).

Table 1 provides the summary of all ten experiments. Regarding average waiting time for material, it decreases with higher number of Milkruns in the systems. However, it is important to point out that system with 7 and more Milkruns show almost the same results. Therefore, we can conclude that using more than 7 Milkrun trains does not bring any additional benefits. Regarding utilization (Working Time), it logically decreases with increasing number of Milkruns. Average utilization of 1 – 4 Milkruns is still above 80% what is quite good result.

The best way to solve both problems (waiting time and utilization) is to manage number of Milkrun trains flexibly according to the current needs of production lines. Using simulation-based model, we can automatically update input model data based on current situation and current production plans (for example for the next shift). Updated model shows us during which hours demand peaks are expected and it enables logistics managers to react on this situation in advance. Figure 5 shows an experiment, in which we let the simulation to plan number of needed Milkrun trains automatically according to expected production plans of all production lines. Based on this simulation output, required number of Milkrun drivers could be planned more accurately. However, this accurate human resource planning requires the possibility of using alternative flexible working schedule models.

3.2. Assumptions for new physical-digital-physical loop model

To sum up outputs of our case study and theoretical research, we can determine basic assumptions that emphasizes the importance of studied problem. Based on these assumptions, the main conflict in the field of human resources planning on both sides, employers as well as employees was identified. High variability in production requirements affects human resources planning in production and logistics processes. Employers aim to ensure maximum utilization of employees what is challenging, especially when using standard work schedules. Utilization of human resources and quality and reliability of processes are very important drivers of organization performance. Our study focused on logistics processes, but the main goal and conflict remains the same in all business areas (Figure 6).

The employee perspective is very similar. As was described before, there are two main drivers of life satisfaction: time and money. Many employees highly value having more free time for their families and hobbies what influences their job decisions. On the other hand, the life standard of young people is increasing what requires higher incomes. This conflict of priorities of employees is demonstrated through the conflict resolution diagram (Figure 7).

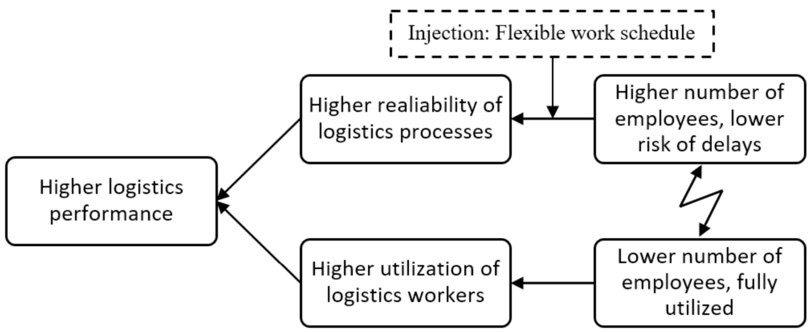


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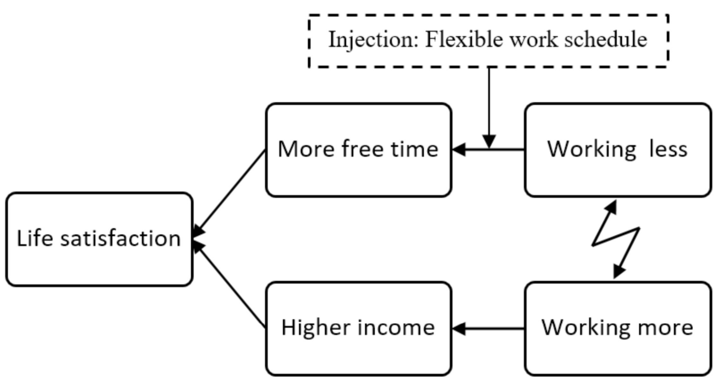
Figure 6. Conflict resolution diagram: Employer´s conflict



Source: own research

Figure 7. Conflict resolution diagram: Employee´s conflict

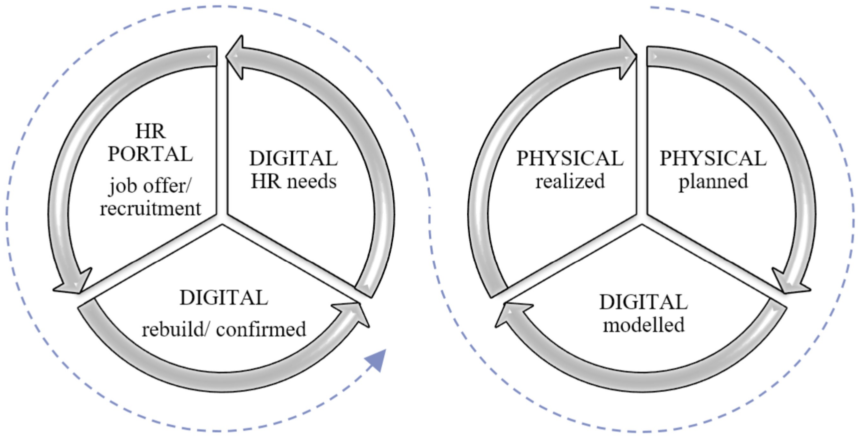
In both cases, flexible work schedule could be a possible solution of described problems. As our case study proved, demand variation causes problems with capacity planning in all areas of business processes, especially in production and logistics. Companies face decisions about appropriate number of human resources necessary to fulfill customer requirements. However, these human resources needs are not stable, sometimes even during one work shift. Nevertheless, standard work shift is stable, usually lasting eight or twelve hours, overtime work is expensive and insufficiently utilized human resources mean waste. Therefore, combining flexible work schedules with stable ones is a way to cope these challenges.

3.3. Discussion and model construction

To generalize results of presented case study a theoretical model for integration of modern approaches in human resources planning into physical-digital-physical loops was proposed. Standardly, based on planned reality, virtual manufacturing system is modeled using discrete-event simulation software. After that, individual scenarios are tested and the best solution is applied into practice, physical world.

It is important to point out that people are crucial part of these closed loop digital twins as they do final decisions. It confirms also Resman et al. (2021) when describing a loopback principle between the real production environment and digital twin. They highlight that suboptimal production plan generated from digital model must be modified by experts in order to reach the best possible results. However, people also plays an important role as resources, the subject of planning. To reach optimal results offered by digital model, all resources must be utilized as much as possible. In case of human resources, standard rigid working schedules often creates the main barrier in adoption of offered best solutions. A solution is presented in form of flexible human resources portal linking demand for labor with available supply of experienced labor including exact specification of preferred time span of each employee. Due to the fact that there is no time for some trainings, this portal should include only internal staff or agency workers who already worked for the company. The whole idea is based on very similar principle as crowdwork platforms. Using of various crowdwork platforms has become very popular in recent years, but they usually offer digital work to digital workers (Moritz, 2020). It brings benefits to both, employers as well as employees. As was mentioned before and also Mantymaki et al. (2019) confirm, employees appreciate the flexibility of working in such environment. Moreover, this kind of employment could be beneficial for some groups of people, for example the disabled, mothers, students etc. (Runi & Furrer, 2020).

Due to the reasons explained above, the standard model was extended by integration of flexible human resources planning portal that receives data from digital model in order to plan required human resources needs. It represents some kind of a new closed loop that exists besides the standard one and fill the gap between simulation-based generated production plans and future reality (Figure 10). Digital model is able to find optimal solution in every situation, but the problem is its realization. Especially when planning human resources, currently used rigid work schedules bind companies in their possibilities to apply optimal solutions into practice.



Source: own research

Figure 8. Extended closed loop model

Of course, this system has many limitations. The most serious one is a question of training, as was mentioned before. This problem limits using the HR portal just internally including current employees of the company or agency workers who worked for the company in the past. Another question is a willingness of applicants to work in some specific daily time. Pfeifer and Kawalec (2020) also point out that crowdwork platform causes high uncertainty in job planning or problems with the transparency in performance evaluation. Due to these or other questions, this model of extended closed loop digital twin must be studied more deeply in the future.

4. CONCLUSIONS

This article presented the possibility of using discrete-event simulation software in conjunction with human resources portal to improve the logistics efficiency. This idea was demonstrated through the case study from the real industrial company. Several experiments have shown that without the use of flexible work schedules, it is not possible to achieve at the same time higher utilization of human resources and lower downtime due to lack of inventory. Many companies use simulations to improve and better plan their production processes. However, they usually construct models using standard fixed shift schedules what limits possible improvements. Integration of flexible shift schedules into simulation models helps to optimize production and logistics processes much better. Therefore, as a result of our study, some kind of extended closed-loop digital twin model including human resourcing planning portal was proposed. This approach should help companies flexibly react to current staff needs reflecting production plans.

The limitations of the study lie in the fact that only one special case of one company was used to test various scenarios proving our assumptions. Therefore, in the future research activities, we plan to focus on developing this idea and testing in various production environments. We are also working on extension of proposed model by critical success factors for its implementation.

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УВОЂЕЊЕ НОВОГ ФЛЕКСИБИЛНОГ СИСТЕМА ПЛАНИРАЊА ЉУДСКИХ РЕСУРСА ЗАСНОВАНО НА ДИГИТАЛНОМ БЛИЗАНИЧКОМ ПРИСТУПУ: СТУДИЈА СЛУЧАЈА

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Извод

Технологија дигиталних близанаца постала је један од кључних праваца интелигентне производње са снажном везом са управљањем животним циклусом производа. Доприноси повећању ефикасности и флексибилности у решавању веома сложених проблема у условима који се стално мењају. Међутим, многе околности отежавају стварну имплементацију ефикасних сценарија генерисаних софтверским алатима за симулацију. Један од њих су ригидни распореди рада који отежавају флексибилно планирање људских ресурса у складу са оптималним плановима производње и логистике. Овај чланак има за циљ да испита улогу дигиталног фабричког близанца у напредном планирању људских ресурса. Методом студије случаја представљено је решење за бољу координацију интерних логистичких процеса и коришћење логистичког особља на основу симулације дискретних догађаја. Тестирано је неколико сценарија и резултати су показали неминовност коришћења флексибилних радних распореда за максимално коришћење логистичког особља. Сврха ове студије није само да прикаже један посебан случај једне компаније, већ да истакне потенцијал ових софтверских алата за постизање дугорочне синергије у координацији активности логистике, производње и управљања људским ресурсима. Као резултат ове студије представљен је модел проширене физичко-дигитално-физичке петље. Ово проширење се састоји у додавању друге петље укључујући комуникацију са ХР порталом.

Кључне речи: дигитални фабрички близанац, симулација дискретних догађаја, флексибилни системи рада, планирање људских ресурса, интерна логистика

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