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LOGISTICS MANAGEMENT AS A SYSTEM CONSTRAINT

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Abstract: This paper presents a comparative simulation model of several logistic systems and their impact on operational performance. It stresses the importance of logistic processes and their management in the context of lean production and the theory of constraints. The main goal of our experimental study is to prove how significantly supporting logistic processes can influence production process performance in situations where logistic management represents a system constraint. More specifically, our study considers the capacity of handling units, and their impact on material flow continuity and efficiency. The experimental model is based on real data that was acquired by the authors over the last several years during their research and practical experience. Our results are presented in the form of software statistics that were provided after the experiment and compared with the set hypotheses. The experimental study has shown that a managerial decision to increase the capacity of handling units does not always result in the expected behaviour pattern.

Key words: logistics, production process, material flow analysis, simulation modelling, performance analysis

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Introduction

Logistics activities concentrate on the planning and coordination of materials and information flows. Internal logistics addresses the set of logistics activities occurring within a given company, which includes, among others, warehousing, distribution, order processing control, and supply. If incorrectly managed, internal logistics may have a major impact on the competitiveness of today's companies, including a direct effect on the performance of production processes.

When trying to improve production processes many practitioners focus on production planning and scheduling issues, overlooking the impact of internal logistics. During our practice and other research activities, we witnessed many situations where internal logistics caused serious problems in the production process area, having a negative influence on operational performance. Sometimes, it is not very easy to identify the real causes of system inefficiency and finding an answer requires deeper analyses. The underlying problem may be process organisation, communication, human resource management and so on (see Bencsik et al., 2016; Colledani and Tolio, 2011; Huo et al., 2016; Koval et al., 2016).

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Our hypotheses are set on the basis of real expectations of companies who decide to increase the capacity of their internal logistic processes. Our main goal is to disprove their hypotheses through an experimental simulation model that is created in discrete-event simulation software. Simulation models are an effective way to analyse the performance of production processes, enabling us to compare and evaluate different scenarios. Dynamic evaluation supports decision-making and helps us to choose the best course of action out of several options.

Literature Review

Many researchers have confirmed the important role of logistics processes in the management of the production process (Brzozowska, 2014; Colledani et al., 2014; Huo et al., 2016; Mehrsai et al., 2014; Muntean et al., 2016), which has recently been influenced by the following tendencies: real time technologies, intelligent inventory control and supply technologies, the use of robots in warehouses and transportation, better shipment tracking, using autonomous vehicles to supply production lines, globalisation, bridging lean to agile logistics, and better logistics performance management. Most companies demand appropriate responsiveness in unpredictable situations, which causes problems when optimising production and logistics processes because some goals are contradictory (Althaler and Schmidt, 2007; Mehrsai et al., 2014).

In our paper, we deal specifically with production logistics as an important factor that influences the performance of the production process. Reducing production costs very often also includes logistics costs while, on the other hand, well controlled logistic activities can also help companies to improve their production process flexibility. Liberko et al. (2015) presented the possibility of reducing logistic costs through their case study from a selected manufacturing company.

As Gimenez and Venture (2005) have proven, the integration achieved in the logistics-production interface has a positive impact on the performance measures. Colledani and Tolio (2011) highlight the same condition when saying that production and logistics performance should be considered and measured together.

Performance management is a very complex area and it is influenced by many factors that are more or less close to the main problems. Due to this fact, some important causes can be unintentionally ignored and, consequently, the methods that are implemented do not bring the anticipated effects. For example, Koval et al. (2016) found that age and gender can significantly influence the interest and commitment of employees to collaborate with the other team members and it can influence their willingness to cooperate in increasing the performance of the process. Okoń-Horodyńska et al. (2016) confirmed this finding when examining the contribution of women and men in the process of innovation. They found that women tend to be more likely to believe that the ability to make decisions is important for process improvements. Bencsik et al. (2016) studied Y and Z generations in the workplace and found that the influence of age and gender influence is not always negative, while the cooperation of different age-groups could also provide positive results. Therefore, we can state that human resource management has a very important role for driving process performance in all areas. Huo et al. (2016) strengthened this view in their study of the inter-relationships between the management of five flows (human, information, decision, logistics and production) and their impact on operational performance. They discovered that human flow management is positively associated with the other four flows. Zámečník and Rajnoha (2015) confirmed that companies in the Czech and Slovak Republic have gradually accepted a number of concepts and tools to manage their performance. However, in comparison to the rest of the world, its usage is still limited. Especially in the field of logistics, we can often notice that there is a problem with performance management. Although logistics is generally understood to be a support process, in many cases it seriously influences the performance of the production process and it can even be a system constraint. For example, warehouse management and material handling management may have a significant effect on the quality and costs of the final products. The selection of an adequate material handling strategy has a significant influence on the company´s competitiveness and it must be considered very carefully (Dobos et al., 2016). The other problem is the ability and willingness to share knowledge across the whole company in order to increase global performance. Patalas-Maliszewska (2014) discussed workers evaluations, salary for new ideas and individual praise as potential knowledge sharing barriers in her study.

Despite the fact that we stand on the brink of a fourth Industrial Revolution, which includes a range of new technologies affecting not only industrial companies, some areas continue to remain dependent on human factors. Advanced logistics problems are usually solved using various heuristic or metaheuristic algorithms that are implemented through advanced technologies. However, as Wauters et al. (2016) states in their benchmarking study, not every single advanced model is suitable for each logistics environment. Strandhagen et al. (2016) confirm this statement because they were unable to identify any general roadmap or set of guidelines for moving towards Industry 4.0 in the field of logistics. Their findings suggested that the roadmap is dependent on the characteristics of each production or logistics system. In their study of synchronisation emergence and its effect on performance in queuing systems, Schipper et al. (2016) have proven that different types of manufacturing systems display different behaviour.

In summary, each type of production system faces its own specific problems and requires a specific approach. Chen et al. (2016) dealt with logistics problems in cellular production area in their study and they point out the problems of local constraints, equipment sharing or process route intercrossing, which makes logistic management very difficult. According to their study, too dense a logistic rate usually indicates that too many parts are transferred on the channel. However, from the global viewpoint, this general statement can be wrong and the problem can be caused by many other reasons as described above. In our paper, we have analysed a situation where internal logistics causes problems with the performance of the production process and with the continuity of material flows. In many cases, the unavailability of handling units or handling equipment is solved by raising their capacity. However, is this always the right solution? We aim to find the answers to these questions in our experimental study.

Main Goal and Methodology

The authors of this paper have previously performed several follow-up surveys, which have focused on production planning, scheduling, control, and production process performance. Through a number of interviews, questionnaire-based studies or through our own practical experiences, we have found that in many cases logistics alone quite significantly influences the performance of production processes. Certainly, we can identify a combination of several factors that influence process performance but each system has one or a limited number of critical points, which are the so called system constraints. Very often, these logistics constraints are what causes waiting, accumulating work-in-process (WIP) stocks in buffers and discontinuity of materials flows. On the other hand, in many cases increasing the capacity of logistics processes (number of handling units, capacity of handling equipment etc.) does not help to remove system constraint. The problem of production logistics is more complex and closely connected with production process organisation. This is the reason why it cannot be considered separately and why many final decisions do not bring anticipated positive results.
The main goal of our contribution is to study if significantly supporting logistics processes can influence production process performance in those situations where logistics is considered to be a system constraint. More specifically, we have focused on the number of available handling units (crates, containers, pallets, hang on movable racks etc.) that are used for transporting materials and WIPs through the shop floor from one working station to another.
Considering the main goal of our study, we have formulated the following two hypotheses:

H1: A higher number of available handling units in circulation always positively influences the performance of the production process.

H2: A higher number of available handling units in circulation always positively influences the continuity of material flows.

These hypotheses are based on the authors' experiences during their practical projects and observations in practice. To evaluate set hypotheses, we used a software tool called Plant Simulation (which is described more in detail in the next section) that helped us to demonstrate and compare several different model situations. Plant Simulation is an application that is provided by Siemens Product Lifecycle Management (PLM) Software and it was chosen for its complexity and detailed functionality, which is able to cover and consider all possible situations in the field of production process organisation, material flows and logistics processes.

Discrete Event Simulation and Model Description

Simulation itself can be defined as an imitation of real-life processes, systems or facilities. Discrete event simulation (DES) uses mathematical and logical models to describe real-life systems and their state changes at defined points in simulated time. There are many software applications that can support discrete event simulation and they are particularly used in the production area. These software tools are event based, where the events represent changes of the state of variables in modelled systems (Allen et al., 2015; Katsaliaki and Mustafee, 2011).
In our study, we used Plant Simulation, which is simulation software, and its programming language SimTalk to modify the basic behaviour of individual objects and to describe material and information flows within the model. Our input data, constants and variables were approximated to the real conditions of several companies, solving similar problems in the field of logistic management. The fixed input data include several production workstations with precisely set processing times, recovery times, availability of the machines, shifting conditions and so on (Table 1) that are connected through the various types of rules and methods influencing the type of material flows, uploading and unloading processes and warehouse management system (as described in the next section).

Table 1. System constants (per one batch including 30 pieces)

Production step	Number of machines	Processing time (min)	Recovery time (min)	Availability	Shift
Step #1	8x laser	20	0	95 %	24 h
Step #2	1x painting	40	0	100 %	24 h
Step #3	3x preassembly	10	1	95 %	24 h
Step #4	5x assembly	5	1	90 %	24 h

Lasers, assembly and preassembly machines are represented by standard single process objects, while the painting machine is programmed as a "place buffer" object, which means that inputs came every minute, but just 15% of the inputs are our monitored products. The rules and method of logistics activities are described through the SimTalk algorithm, which controls small supplying trucks transporting handling units within the shop floor. The number of available handling units (including one batch) in circulation is understood as a variable that acquires the following values in our tested models: 80, 160, 240 or 320 pieces. The following input data, rules and assumptions were used to build our simulation model:
- Loading and unloading times are fixed to 20 seconds in all buffer areas,
- Speed of the supply truck is fixed to 0,7 m/s, acceleration was not defined,
- Maximum capacity of the truck is six pallets and the whole road is 500 meters,
- Shifting is 24 hours with four pauses with a duration of 30 minutes,
- Supply truck is programmed in a way to upload the maximum possible number of pallets and transfer them to the next destination (buffer).

If the number of pallets waiting for transportation is lower than the maximum capacity of the supplying truck, then the truck should not wait for the next pallets and it transports only the available quantity (all these rules are programmed in detail through the SimTalk programming environment).

Results and Discussion

This section introduces our model and its outputs. It is important to point out that the authors have had extensive real-world practical experience with models portraying logistics and production problems similar to those addressed in this work. The results observed in practice were found to be very close to the illustrative model that is described in the following sections.

Initial Position and System Variables

To test our hypotheses, we created a model of a production system whose parameters are very similar to real production systems (Figure 1).

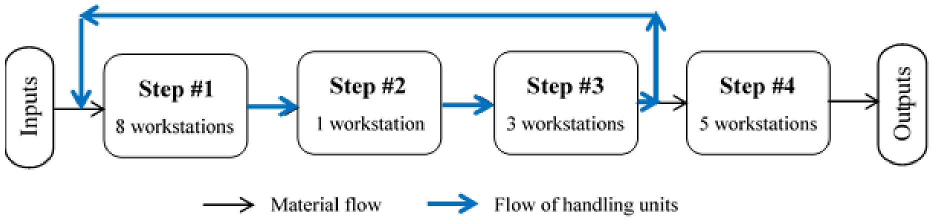

Figure 1. The schema of the modelled production system

Our model includes four production processes with several workstations. A product can be processed at any workstation but it must go through all four production steps. Before the final production stage, the empty pallets are put back at the beginning of the whole system. Basic process parameters were set at the beginning and they remained unchanged during all of the testing phases. With respect to our hypotheses, only the number of available pallets in the system was changed. We tested models with 80, 160, 240 and 320 pallets in circulation. At the beginning the pallets were uniformly distributed in all eight buffers within the shop floor area.

System Outputs and evaluation of set hypotheses

Output data and statistics were tested for a period of one week (five working days) production. More specifically, we monitored the following variables: pallets and trucks utilisation, number of pallets in all buffers, waiting times at the first production stage caused by the unavailability of empty pallets and process lead times (i.e. the time from the point when the pallet was filled at the first production stage until the point when the pallet was again empty). When internal logistics is a system constraint, companies look for ways to increase the capacity of the handling units or handling equipment. In our model, we did the same in order to prove that sometimes this decision does not solve the problem. Table 2 shows the relative utilisation of pallets and trucks in four tested situations: with 80, 160, 240 and 320 pieces of available pallets in the circulation.

Table 2. Pallets and truck utilisation, in percentage

Pallets and trucks utilisation	**80 pallets**	**160 pallets**	**240 pallets**	**320 pallets**
Pallet is processed at some workstation	10	4	3	3
Pallet is transported to the next buffer	5	3	2	1
Pallet is waiting in a buffer (stored)	85	93	95	96
Relative utilisation of pallets	**88**	**93**	**94**	**95**
Relative utilisation of supply trucks	**64**	**66**	**67**	**68**

The main problem of the system is not enough empty pallets for continuous production. However, as can be seen from Table 2, having a higher number of pallets in circulation does not solve the problem. We can even notice a lower level of utilisation when just 80 pallets are in circulation. Moreover, the higher number of pallets in circulation negatively influences the capacity of all of the buffers, as we can notice from Figure 2, which illustrates the development of the stock level in all of the buffers. We pay particular attention to the first two buffers (input 1 and input 2 for process 1), which represents our bottleneck in the form of missing empty pallets for new production.

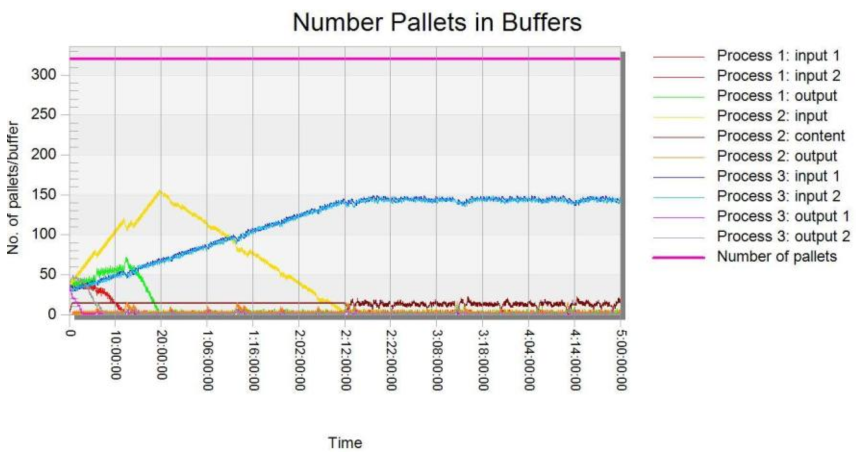

Figure 2. Pallet distribution in the model with 320 pallets

The trucks have to unload empty or full pallets to their maximum capacity when passing the defined loading area. However, there are no strict rules about the priority of transported units and some production operations block available pallets

if they are waiting too long to be transported to the beginning of the production process, which causes delays at the first production operation (Table 3).
As can be seen from Table 3, the average percentage of working time was not improved after increasing the number of pallets in circulation. Based on the above-mentioned output data and statistics, we can conclude that our first hypothesis was disproven.

Table 3. Working times of the first production step in percentage

All machines	80 pallets		160 pallets		240 pallets		320 pallets	
	works	waits	works	waits	works	waits	works	waits
Laser 1	29	71	28	72	28	72	28	72
Laser 2	29	71	29	71	28	72	28	72
Laser 3	29	71	28	72	27	73	27	73
Laser 4	29	71	28	72	28	72	28	72
Laser 5	89	11	89	11	89	11	89	11
Laser 6	86	14	86	14	86	14	86	14
Laser 7	83	17	84	16	84	16	84	16
Laser 8	76	24	76	24	76	24	76	24
Average	**56**	**44**	**56**	**44**	**56**	**44**	**56**	**44**

Actually, having a higher number of available handling units in circulation does not influence the production process performance when not considering other related conditions, such as line balancing, standardisation and organisational and management issues.
In the second phase of our research, we monitored the lead-times. During the time of our simulation (5 days), our system produced 45.878 pieces. Because of the fact that at the initial phase some pallets were located too close to the final production step, we had to clean the statistical data and finally, we managed to get 45.591 records together. Table 4 includes our summary statistical report.

Table 4. Lead time (unit: "hh:mm:ss") summary statistical report

Type of model	Mean value	Median value	Standard deviation	Coefficient of variation
80 pallets	3:44:15	3:24:15	0:41:05	0,18
160 pallets	7:46:38	6:53:56	1:48:02	0,23
240 pallets	11:38:37	10:25:19	3:00:00	0,26
320 pallets	15:19:20	14:02:23	4:14:54	0,28

The results show that increasing the number of handling units in circulation does not positively influence the production process duration and material flow continuity. On the contrary, it can even have a negative impact because the variation increased from 18% to 28% and the average lead-time is more than quadrupled.

Therefore, we can also disprove our second hypothesis about the material flow continuity and state that a higher number of available handling units in circulation negatively influence the continuity of material flows.

In summary, we can state that a higher number of available handling units in circulation do not solve any logistic problem in itself. The examined problems are always influenced by some other reasons, in the most cases on the side of production or logistic management.

Managerial Implications and Discussion

Our study showed how the number of handling units in circulation could influence some of the production performance indicators. As we discussed, increasing the production process performance usually also requires some necessary changes on the side of logistics or production management and organisation. During our expertise and practical projects, we witnessed many precipitate decisions. Especially in cases where there was a lack of logistic capacity, many managers decided to invest in new handling units or other equipment without taking a more detailed analysis.

However, in most cases the main problem comes from the communication between the logistics and production area. Many of the people involved in this process do not share information and they are oriented on meeting their own local goals. This state causes unbalanced processes, chaotic operational management and the need to solve stressful situations every day. The results of this experimental study have proven that local managerial decisions do not always bring the awaited results. Therefore, production and internal logistics should not be managed separately and people from all of the involved areas should collaboratively discuss all of the managerial decisions.

Conclusions

Logistics management has recently grown in importance. Customers require shorter delivery times and production processes must be increasingly flexible. Therefore, production logistics should be managed very seriously as an integral part of a production system.

However, logistic decisions are sometimes made separately from other production-related decisions and this is the reason why they often fail to meet expected results. Our experimental study was focused on production systems where logistics represents a system constraint because of low transportation capacity. Through our simulation-based model, we showed that increasing logistic capacity does not always solve the capacity problem; moreover, it may even make the existing problems worse. For example, increasing the number of pallets proportionally

increases the lead-time and this can also cause further problems such as more WIP, waiting, searching, chaotic operation management, and so on.
Very often, the problem is on the side of management and organisation, communication standards, human responsibility, set rules and standards or others.
For future research, we plan to discuss other issues related to the production process performance from the viewpoint of production logistics. We also aim to develop a more complex model that encompasses other influential factors and their implications. Moreover, further testing can be made in real-world case studies to better measure the impact of incorrect internal logistics management.

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ZARZĄDZANIE LOGISTYCZNE JAKO OGRANICZENIE SYSTEMOWE

Streszczenie: Niniejszy artykuł prezentuje porównawczy model symulacji kilku systemów logistycznych i ich wpływ na wydajność operacyjną. Podkreśla znaczenie procesów logistycznych i zarządzania nimi w kontekście szczupłej produkcji i teorii ograniczeń. Głównym celem naszych badań eksperymentalnych jest udowodnienie, jak znaczne wspieranie procesów logistycznych może wpłynąć na wydajność procesu produkcyjnego w sytuacjach, w których zarządzanie logistyczne stanowi ograniczenie systemu. Ujmując problem bardziej szczegółowo, nasze badanie uwzględnia pojemność jednostek manipulacyjnych oraz ich wpływ na ciągłość przepływu materiału i wydajność. Eksperymentalny model oparty jest na rzeczywistych danych, które zostały zebrane przez autorów w ciągu ostatnich kilku lat w trakcie ich badań i praktycznych doświadczeń. Wyniki przedstawione zostały w formie statystyk oprogramowania dostarczonych po eksperymencie i porównanych z założonymi hipotezami. Badanie eksperymentalne wykazało, że decyzja menedżerska, dotycząca zwiększenia pojemności jednostek manipulacyjnych, nie zawsze prowadzi do oczekiwanego wzorca zachowań.

Słowa kluczowe: logistyka, proces produkcyjny, analiza przepływu materiałów, modelowanie symulacyjne, analiza wydajności

物流管理作為一個系統約束

摘要：本文提出了幾種物流系統的比較模擬模型及其對運行性能的影響。它強調後勤流程及其管理在精益生產和約束理論的背景下的重要性。我們的實驗研究的主要目標是證明在後勤管理代表系統約束的情況下，物流過程可以顯著支持多大程度上影響生產過程績效。更具體地說，我們的研究考慮了處理單元的能力，以及它們對材料流動連續性和效率的影響。實驗模型基於在過去幾年中作者在研究和實踐經驗中獲得的實際數據。我們的結果以實驗後提供的軟件統計形式呈現，並與設定的假設進行比較。實驗研究表明，增加處理單位能力的管理決策並不總是導致預期的行為模式。
關鍵詞：物流，生產過程，物料流分析，仿真建模，性能分析