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# E-learning in logistics of production – business process management perspective

E-learning w zakresie logistyki produkcji – perspektywa zarządzania procesowego

**Słowa kluczowe:** e-learning, logistyka produkcji, zarządzanie procesowe, BPM, STEM, systemy informatyczne.

**Streszczenie:** Postępująca digitalizacja i dynamiczny rozwój technologii teleinformatycznych generuje nowe możliwości dla przemysłu, logistyki, społeczeństwa, a w szczególności edukacji STEM (ang. *Science, Technology, Engineering, Mathematics*) nazywanej edukacją przyszłości. Efektywność e-learningu jako metody nauczania z wykorzystaniem technik komputerowych i Internetu w zakresie STEM należy doskonalić zarówno od strony technologicznej, jak i w aspekcie zarządzania tym procesem. Głównym celem artykułu jest przedstawienie e-learningu w zakresie transportu technologicznego w ujęciu procesowym, ponieważ właśnie takie podejście pozwala jednoznacznie identyfikować i optymalizować procesy, a zatem przyczynia się do efektywniejszego zarządzania nie tylko samym nauczaniem na odległość, ale także projektowaniem i doskonaleniem oprogramowania. Do analizy stanu wiedzy w zakresie edukacji STEM oraz zarządzania procesowego na potrzeby edukacji procesów logistycznych przeprowadzono analizy desk research. W części empirycznej badań obejmujących modelowanie, bazowano na głównych założeniach zarządzania procesowego i notacji BPMN (ang. *Business Process Modelling Notation*) oraz zastosowano dedykowane oprogramowanie do mapowania procesów. Przeprowadzone testy empiryczne potwierdziły, że podejście procesowe może przyczyniać się do zwiększania efektywności nauczania zdalnego w zakresie STEM. W wyniku modelowania wskazano możliwości optymalizacji procesu e-learningu od strony programowej oraz potencjał rozbudowy modelu w kierunku nabywania większej liczby umiejętności w zakresie programowania sterowników PLC. Opracowany model stanowi punkt wyjścia do doskonalenia procesu nauczania na potrzeby m.in. logistyki produkcji zarówno od strony informatycznej, jak i organizacyjnej.

**Key words:** e-learning, production logistics, process management, BPM, STEM, computer systems.

**Abstract:** Progressive digitization and dynamic development of ICT technologies generate new opportunities for industry, logistics, society and education. Education in Science, Technology, Engineering, Mathematics (STEM), also called ‘the education of the future’, has become of great importance, because we are experiencing a shortage of STEM workers in various sectors. The effectiveness of STEM e-learning as a teaching method should be a key principle in management of this process. The main goal of the paper is to present a process approach to e-learning of automated transportation used in production logistics. The framework allows one to identify and optimise processes, and it may contribute to efficient management of distance learning. Moreover, it could improve the process of software development and software design skills. Desk research analyses were carried out to describe the state of art in the field of STEM education and potential of process management for remote teaching. In the empirical part of the paper, the modelling was based on the main assumptions of process management and BPMN (Business Process Modelling Notation), and dedicated process mapping software was used. The article examines the potential of the process approach and confirms that it can contribute to increasing the effectiveness of distance learning in the field of STEM. As a result of modelling, the optimization concepts regarding designing the e-learning course and the possibility of expanding the existing model towards acquiring more skills, for instance in programming PLC controllers were indicated. The developed model is a starting point for improving teaching of STEM for production, logistics, engineering and other domains.

## Introduction

The rapid rise of emerging information technologies such as artificial intelligence, automatization, digital twins, virtual reality, big data etc. also implies its growing importance in the global economy [OECD, 2020]. However, the emergence of advanced ICT tools, new business models, technological, social and environmental challenges create a competence gap for business. Businesses today strive for digital competency, so e-learning of STEM is one of the ways to provide students with remote, flexible and hybrid courses (e-learning together with remote or stationary operation on the real device) and access to specialist teaching. Also, COVID-19 pandemic has impacted digitalization, and many programs including STEM-based courses that require hands-on approach have gone online [Sukumaran et al., 2023, pp. 259].

The digital economy promotes responsible production and consumption through technological solutions [Rosário & Dias, 2023, pp. 11]. For this reason, it is important to implement and continuously improve teaching of technologies that are present in real industrial conditions including logistics of production (also known as production logistics). Production logistics comprises several processes, such as planning, management, stock control, transport and handling to ensure the flow of materials within the company [Burganova et al., 2021, pp. 554]. The material flow is a crucial part of every production and logistics as it covers the physical movement of materials, products and goods through the entire manufacturing process. Efficient material flow design can help avoid bottlenecks and delays, increase productivity and reduce costs [Weiß, 2023]. In that context e-learning of digital competences enables students to learn how to manage i.e., identify, understand, control, monitor and improve various industrial processes, including production and logistics.

On the other hand, Business Process Management (BPM) and process modelling help to implement changes effectively, and not only help to improve the process, but also creates a flexible system that quickly reacts to change [Labedzka, 2022, pp. 84]. Hence, it is crucial for all stakeholders – managers, educators and students to collaborate in a concerted manner so that STEM education impactfully contributes to the development of technologically adept workforce [Sukumaran et al., 2023, pp. 269].

Therefore, the main aim of presented research is to highlight the importance of process approach in STEM e-learning and provide the BPMN model of automated transportation commonly used in manufacturing industries.

## E-learning of STEM

In the era of Industry 4.0 and its rapid growth, the labour market has seen a demand for highly qualified engineers. Unfortunately, according to the Statistics Poland report, the number of graduates in technical fields is decreasing every year. Only 46 619 students (15.7%) out of 297 368, completed their BTech degree (including technology, industry and construction) in the 2020/2021 academic year [Statistics Poland, 2023].

In an international setting, education is of great importance in creating a competitive advantage. The possibility of acquiring knowledge and training at renowned Polish universities in technical fields contributes to generating a highly qualified engineering workforce. Therefore, continuous updating of curricula is required, which must be implemented starting from early childhood education, school through vocational schools to technical universities. This is especially important in the context of gaining a competitive advantage in knowledge-based economies. A key factor in the long-term perspective is to anticipate market demand for human resources, which influences the development of companies and industry [Matusiak at al., 2009, pp. 7–8].

To meet all these requirements for acquiring and improving STEM competencies, it is important to support theoretical knowledge of skill-based subjects by practice. World leaders in industrial automation are creating teams of professionals promoting e-learning with the use of physical systems such as didactic stands. The teaching apparatus that is currently available on the market give the student the opportunity to gain practical skills and access to simple measurement and control systems using elements commonly used in industrial practice, for instance PLCs, HMIs, sensors, actuators [Błaszczuk et al., 2015, pp. 291–292].

However, one has to beware that the use of the e-learning method brings benefits as well as difficulties. Among advantages the following were identified by [Sito et al., 2018]:
- students can access on-line materials at any place and time;
- no need to commute or relocate that save time and money;
- availability of wide range of learning formats i.e., video, courses, interactive modules; and,
- can be tailored to various needs.

On the contrary, possible limitations of online learning include [Al Rawashdeh at al., pp. 109–110]:
- lack of personal contact with educator during the whole process;
- virtual environment reduces or excludes an interaction between learners;

- the problem of maintaining self-discipline and motivation to learn;
- cultural barrier;
- lack of competence of teachers preparing e-learning activities; and,
- problem of verification of the acquired knowledge by the teacher.

There is a need to research and test various methods, techniques and concepts to optimise the e-learning process in terms of course content, physical system supporting e-learning and other ICT technologies involved.

## Process approach in education

Business Process Management (BPM) has been widely recognised as an essential management idea that enables organisations to perform better by paying explicit attention to their business processes by optimization and alignment that improves the development of a product or service [Reijers, 2021, pp. 1]. A process approach is acknowledged as a basic principle of ISO 9000 that defines performance as a 'measurable result' which is related to the activities, processes, product management (including services) systems or organisations [Saida & Taibi, 2021]. Therefore, in a process-oriented mindset, a special attention is paid to customer needs and final results in that context. The desired result is achieved more efficiently if the various activities and related resources are managed as a process [Levina et al., 2015, pp. 235] which is comprehended, measured, improved and controlled. Focusing on processes, their rational course and improvement with the aim of flexibly responding to changing customer requirements is the basic idea on which the process approach is built as a new concept of BPM [Papulova, 2020, pp. 2].

The origins of the process orientation are related to production, organisational management, quality management and later it was applied to education, for instance process approach in teaching. The process approach in education is oriented to regulate the educational process on the basis of assessing its condition according to specially defined quality criteria for all the components of the process itself, as well as the factors that influence the final results [Levina et al., 2015, pp. 236]. The successful cultivation of students' complex skills requires a systematic approach which could reflect a contemporary understanding of the educational relationships between learning inputs, learning processes, and learning outputs [Xu et al., 2023, pp. 2].

To make any impact on education processes, such as STEM e-learning, it is fundamental to capture and characterise it in some way [Reijers, 2021, pp. 2], so significant improvements could be done in order to increase overall efficiency. On the other hand, a process-oriented approach to learning together with evaluation procedures inspires communicating, comprehension and contributes to boosting the effectiveness.

Traditional teaching tends to focus on the content (knowledge and/or skills), while process-oriented instruction also deals explicitly with the process of acquiring this content [Bolhuis, 2003, pp. 339]. The teacher models learning, showing how a learner gets on with the learning process by thinking aloud, e.g., mobilising and scrutinising prior knowledge, considering what to do next, checking results, going back to the question, restating goals, searching for information, reading text, asking others, etc. [Bolhuis, 2003, pp. 340]. Process-orientation in education is applied for instance in a pedagogical approach such as POGIL (Process Oriented Guided Inquiry Learning) that al the lows students to socially construct knowledge through iterative cycles that include three steps: exploring a model, inventing a concept, and applying resulting ideas [Rodriguez et al., 2020; Simonson, 2019]. On this account, process-oriented learning paradigm is to foster and facilitate self-directed learning through an interactive process of constructing one's understanding by facilitating the development of important process skills, including higher-level thinking and the ability to learn and to apply knowledge in new contexts [Process Oriented Guided Inquiry Learning, https://pogil.org/, access 13.11.2023].

Moreover, self-directed learning can be defined as the outcome of creating an experience that empowers learners to make decisions about the information they want to become proficient in [Robinson & Persky, 2020, pp. 292]. It is quite clear, then, that e-learning, especially in STEM, requires refining one's understanding in order to succeed in workplace environments. Thus, the process approach would be beneficial not only in teaching, but also in developing computer tools for supporting it.

## Research methodology

Only a few studies have focused on the process approach to the virtual learning environment. However, there is a lack of models of the STEM e-learning framework that is not only based on a virtual system, but also on a real device that is operated remotely by the student. Consequently, by this twofold approach, results of the learning process can be observed straight away by the student and supervisor.

Therefore, to identify, monitor and improve e-learning processes based on virtual and real environment, the research objective of the study concerned developing a BPMN model of an exemplar STEM e-learning process i.e. automated transportation that is one of common tasks found in food production, pharmaceutical and cosmetic industries. Three research questions have been raised to address the current lack of information in this field: 1. How to apply process management to STEM e-learning? 2. What are specific tasks delivered by a didactic stand? 3. How could the model be established to monitor and continuously improve STEM e-learning?

The methodology used in order to investigate the research consisted of the following steps: a) literature review and observations of transportation within logistics production performed on the didactic stand, b) development of the BPMN model of automated transportation that is carried out in real system, c) analysis of the results and optimisation of the process of e-learning.

First, a literature review was conducted to describe the business processes management and its importance in reengineering and efficient improvement. Then, the identification of issues and challenges of STEM e-learning was performed. In the experimental part of the study, the BPMN model of the automated transportation for production logistics was developed, validated and optimised.

## Transportation process – descriptive framework

There are several processes observed in the didactic stand intended for learning (online or stationary) of automated transportation for logistics of production. The main student's task is to learn the principle of the process, understand how to control and adjust the process by programming PLC (Programmable Logic Controller) and HMI (Human-Machine Interface). The learner is also learnt how to use the software and set up a development environment. The following processes are covered by the stand: storing, identifying and transporting products placed in carriages, moving on plate conveyor belts arranged oppositely in a 2U shape. In addition, the stand allows students to learn how to control valve islands, pneumatic actuators and programming of sensors. Aforementioned processes and elements are commonly observer in real industrial condition, so in that context, students gain practical knowledge and skills needed in the present labour market.

The first process involves the storage of products. The selection criteria are based on the element colour, its height or type of material (steel, Teflon). When selecting by height, carriages are redirected between two lines (1, 2) depending on whether the item is categorised as high or low. Height detection is carried out using two laser fork sensors located at different heights. If a product moving on the production line crosses two sensors' beams, the measurement and control system recognises it as a high element. When only one (the lower one) sensor detects the presence of an element – it is marked as a low element. Information with the number of detected products is displayed on the HMI screen.

Another process is to identify products by the type of material they are made of (metal or Teflon). Inductive and reflective sensors are used for this algorithm. Reflective sensors react to metal parts, while reflective ones confirm the presence of a product on the transport line at the detection point. Both types of sensors are located at two points on the didactic stand, which enables detection of the type of material in motion as well as during queuing. If there are simultaneous signals from both sensors, first we are dealing with a product made of metal. In the case of a signal from the reflection sensor only, the measurement and control program interprets it as a product made of Teflon. Information about a product identification by material type is displayed accordingly on the HMI screen. Additionally, a student has an access on the didactic stand to digitalised technical specification of sensors and other elements that is helpful in learning the principles of operation and greatly facilitates the correct programming of the control algorithm for the PLC.

The flow of the process due to the control system requires the assignment of the appropriate function to be performed by the controller outputs in response to the state of the inputs. The student is required to be familiar with the IEC 61131-3 standard for programming languages, in particular the Ladder Diagram language

(LD), which is used on the didactic stand. It is one of the most popular programming languages because of its similarity to electrical engineering drawing. The software is provided by the PLC manufacturer. One environment allows programming of PLCs as well as HMIs. It is important to design algorithms for the operation of the various components placed on the stand. When proceeding to PLC programming, the first step is to select the CPU and assign it an appropriate IP number for Ethernet communication (as in the didactic-stand). Information from sensors, such as fork sensors, should be assigned to the appropriate inputs of the controller, and actuators to outputs, such as pneumatic actuators. The principle of PLC operation is to respond to changes of inputs by controlling outputs according to implemented control rules [Kasprzyk, 2006, pp. 30].

In order to design the process of selecting products by height, the student must switch on the motors driving the conveyors in the right sequence, and after receiving input information from a fork sensor, start/not start the actuator that redirects products between conveyors. In addition, in order to count low and high items, it is necessary to use incremental counters and configure them properly.

## BPMN model of automated transport

Business Process Modelling Notation (BPMN) has worldwide acceptance, which is increasing continuously in recent research, as one the most universal and efficient standards when it comes to process management [Lopes & Guerreiro, 2022, pp. 137; Choudhary & Riaz, 2023, pp. 2]. Its growing application in distinct domains can be also observed. BPMN and UML-AD (Activity Diagram) as potentially feasible solutions are often taken into account, ultimately selecting BPMN due to its high expressiveness [Farshidi, Beer Kwantes & Jansen, 2023, pp. 11]. Due to this fact BPMN standard has been selected for modelling the process of automated transportation that is crucial in completing tasks within logistics of production. The BPM lifecycle consists of five phases: design, model, execution, monitor, and optimization [Szelągowski, 2018, pp. 205]. It is possible to apply the notation at any BPM stage in order to give support to the continuous improvement cycle. The following steps were taken in order to deliver the model:

- stakeholders and owners description;
- determining of process boundaries;
- identification of tasks and their types;
- listing the skills to teach;
- process modelling with BPMN;
- creating a process flow diagram;
- defining roles and responsibilities;
- validation; and,
- analysis and optimization.

The BPMN model of automated transportation dedicated to production logistics in various industries was presented at Fig. 1. The model captures present activities

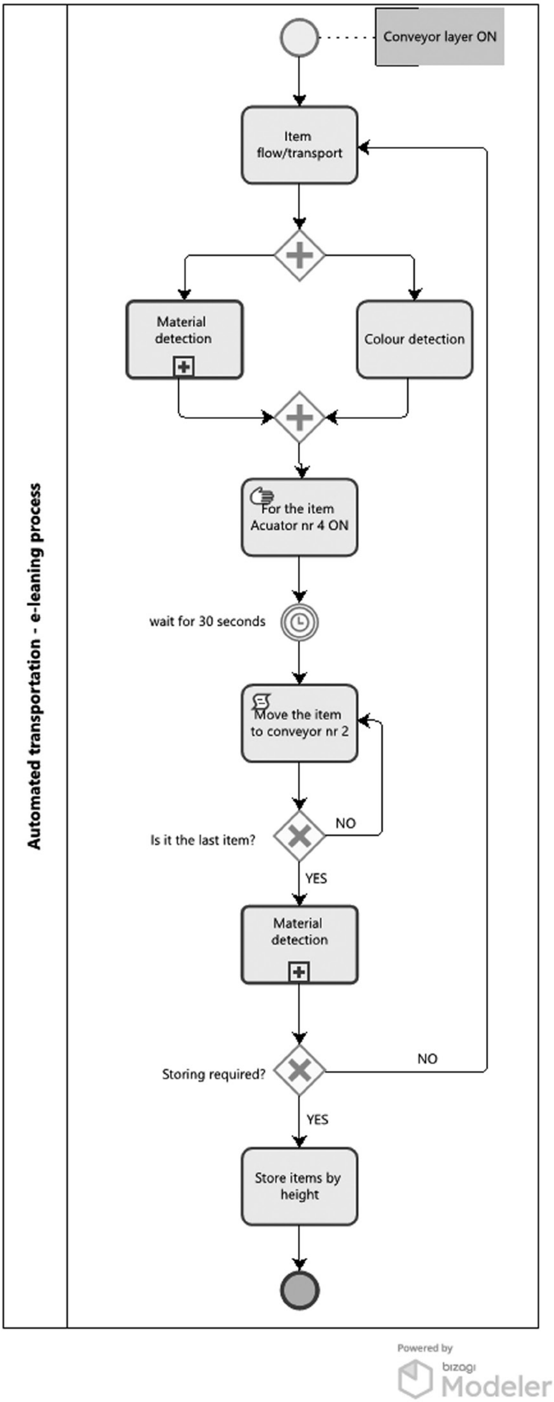


**Fig. 1. The BPMN model of automated transportation process – AS IS model**

Source: Authors' elaboration with Bizagi software.

in the e-learning process performed with the use of a didactic stand that visualises process areas of risk and improvement. The model should be also monitored, documented, maintained and updated if implemented to real processes.

On the basis of the model developed it can be concluded that one procedure realising a product identification by material type is redundant, as the same skill training is covered twice on the same activity (Fig. 2).

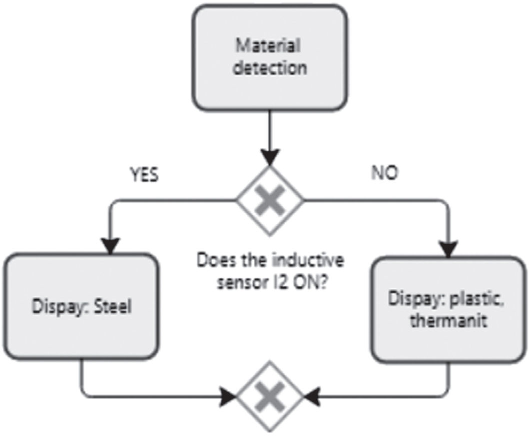


**Fig. 2. Redundant activities within the model of transportation process**

Source: Authors' elaboration with Bizagi software.

From the hardware point of view, this is extremely valuable, cost-cutting information for the design and development of next applications of didactic stands. The stand itself is reconfigurable, which makes possible to disconnect individual stand actuators. In that case, the presented process is reduced to a few function blocks.

Products move on the automated production line at a certain speed and distance between each other. If the distance between the moving products is reduced, a situation can occur when the height sensor detects a high product and the program wants to redirect it to a parallel track, and a low product appears in between. The consequence is that there is not enough time to redirect a high product to the correct conveyor belt. This is an undesirable state that results in improper execution of the measurement and control program. Another abnormal situation is that the carriage with the product gets stuck in the redirection areas between the lines. This can cause a jam on the conveyor belt, resulting in the need for the intervention of the engineer to restore its full functionality. After in-depth analysis of the current model and its limitations, the optimised BPMN model was developed (Fig. 3) that provides the student with the theoretical and practical knowledge and programming skills in more efficient manner.

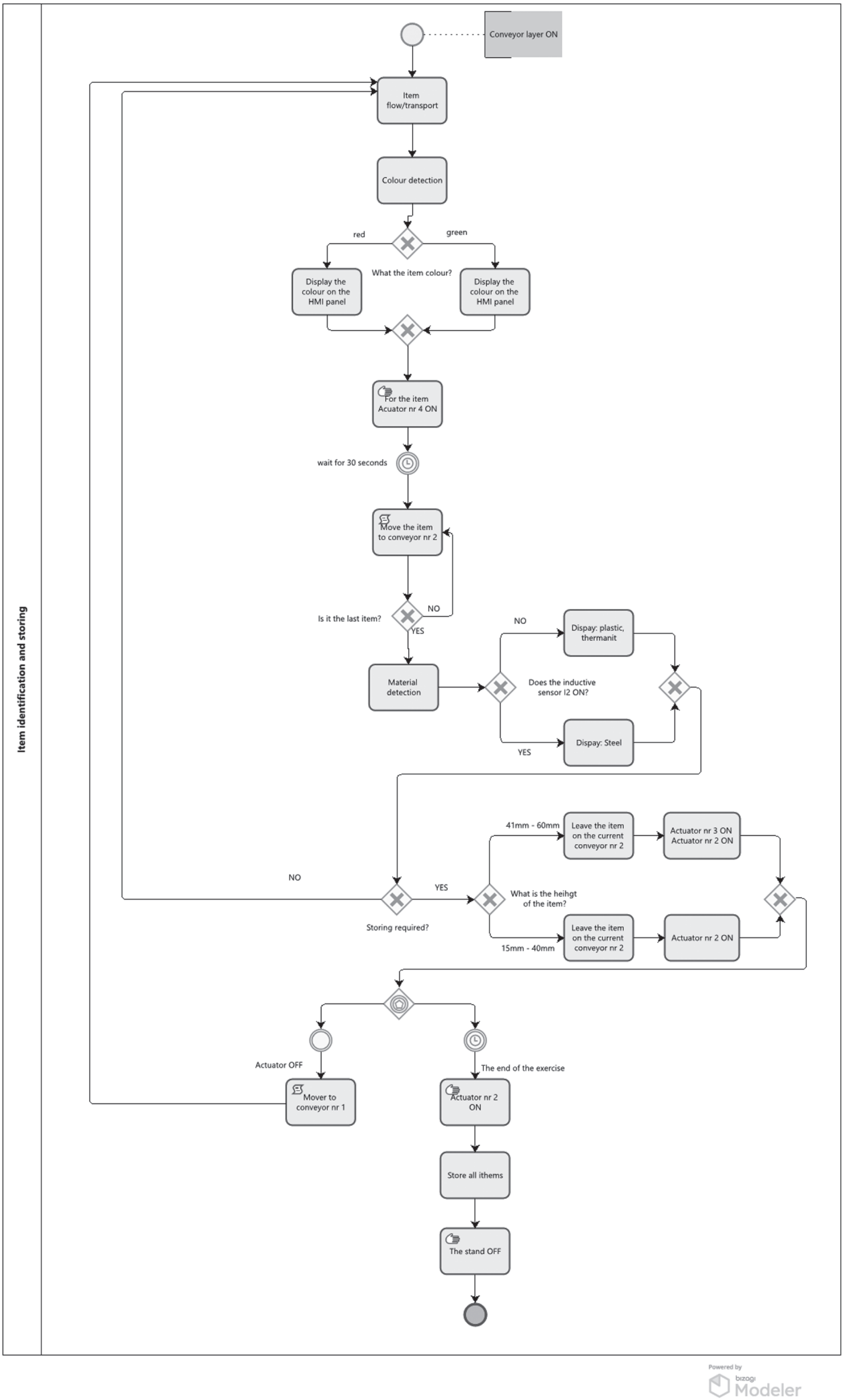


**Fig. 3. Optimised model for e-learning of transportation process**

Source: Authors' elaboration with Bizagi software.

The model optimisation provides a way to identify and eliminate inefficient activities within e-learning that is leading to cost savings. Process approach to online teaching allows one to improve process performance and because it is customer/ student oriented, controls to maintain a high degree of learning results delivery.

## Summary

The emergence of digital education is accelerating the transformation of traditional methods and techniques. Development of process models and management mechanisms for educational activities, such as e-learning, allows one to continuously improve the process of training students by ensuring the quality of the educational procedure itself. What is more, the process approach to online education that is supported by hardware such as didactic stands, also helps to efficient using the available computer software, information and personnel. What is more due to the description of the educational activity processes, the definition of efficiency and effectiveness indicators of its processes, the process owners and the management structures of educational organizations get an integrated technology for implementing and monitoring all the activities of the educational process.

This study was specifically devoted to proving the relevance of BPMN notation for modelling of STEM e-learning supported by real didactic stands. An analysis of the state of knowledge in the field of STEM education and the main assumptions of process management were presented. Then, a business analysis of the elements constituting the remote learning process was carried out on the example of an e-learning stand for automated transportation. In the empirical part of the article, analyses of current e-learning process were carried out. As a result, BPMN process model was developed and then optimized. Paper examines the potential of the process approach, which considers management as a continuous performance of certain interrelated activities, also in reference to STEM e-learning including the entire scope of complex skill learning processes. Then, in the case of expanding educational opportunities of various didactic stands for STEM e-learning, it is necessary to carry out modelling for all processes and create a holistic map that would enable further process optimization. The presented process approach is also beneficial for easier designing the assessment plan for learning activities

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