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Customized Lean 3D Simulation Environment for Intralogistics

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Abstract:

Purpose: *The aim of the article is to summarize the author's work, experiences, and publications in the form of a presentation of a coherent concept (requirements) for a simulation environment dedicated to intralogistics and based on Lean principles.*
Design/Methodology/Approach: *Methodology is based on taking into account the achievements of Lean and building it into the methodology of simulation modeling of intralogistics.*
Findings: *The findings include defined criteria for the evaluation of general-purpose simulation programs and dedicated program and their evaluation.*
Practical Implications: *The presented approach and methodology is practically used in the LogABS simulation application introduced to didactics and offered on the market.*
Originality/Value: *As an original author contribution, this concept is, simulation modeling referred to as "one-to-one" in the description of processes carried out in the enterprise, changing the method of creating simulation models by defining mechanisms that automate the construction of models, adopting as the basis the analysis of the operations performed and not the states of the objects performing the operations, implementation of a cycle-based approach and cycle management, separation of the executive level from the decision level.*

Keywords: *Intralogistic, Simulation, Lean Management.*

JEL Classification: *C63, M2.*

Paper Type: *Research article.*

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1. Introduction

The article presents the concept of a simulation environment dedicated to intalogistics and based on Lean principles. This concept is the result of the experience gained during the implementation of over 150 simulation projects implemented by the author for industry. Most of these projects were carried out in the area of intralogistics. It was quite common to implement several projects at the same time. The projects were implemented with the use of commercial simulation software offered on the market. These works resulted in ideas that were published by the author in the form of scientific articles.

The aim of the author's scientific and practical activities is to build such an approach – that, starting from what is happening in the factory, it is possible to build simulation models of factories in the same way as processes are built (designed and implemented) in real factories. This would destroy the existing barriers to the implementation of simulation technologies in the practice of factory operations – providing production engineers and logistics engineers with tools that are clear and understandable to them and, above all, necessary.

The aim of this article is to summarize these works, experiences, and publications in the form of a presentation of a coherent concept (requirements) for a simulation environment dedicated to intralogistics and based on Lean principles.

The highlights of the article are:

- taking into account the achievements of Lean and building it into the methodology of simulation modeling of intralogistics,
- defining criteria for the evaluation of general-purpose simulation programs and a dedicated program.

As an original contribution of the author is the concept:

- simulation modeling referred to as "one-to-one" in the description of processes carried out in the enterprise,
- changing the method of creating simulation models by defining mechanisms that automate the construction of models,
- adopting as the basis the analysis of the operations performed and not the states of the objects performing the operations,
- implementation of a cycle-based approach and cycle management,
- separation of the executive level from the decision level.

The structure of the article is as follows. The second section provides an overview of the literature on intralogistics, simulation, and lean methods. The third section focuses on the analysis of simulation software available on the market and the requirements that this software imposes on users. The fourth section presents the requirements to be met by simulators dedicated to intralogistics.

On the other hand, the fifth section defines the criteria and compares the features of such a simulator to general purpose simulators.

2. Literature Review

The article concerns the area of intralogistics, the design, redesign, and analysis of which is carried out with the use of simulation technology, in accordance with the principles of Lean. The term "Intralogistics" was defined by The Intralogistics Forum Verband Deutscher Maschinen- und Anlagenbau (VDMA) (Hompel and Heidenblut, 2008) as, "Organization, control, execution and optimization of the flow of materials and information inside the plant as well as goods transshipment in industrial and distribution facilities. and the public sector ". You can find other definitions as well, for example (Wynright.com/intralogistics, 2020), "every dimension of logistics within the four walls related to the implementation, management, monitoring and optimization of material handling and information flow."

The term is popular especially in the German industry - there are many scientific articles on this area from recognized German universities (Kartnig *et al.*, 2012; Schuhmacher *et al.*, 2019; Trott *et al.*, 2019). The appearance of this term, according to the author, is the result of the development of internal, intelligent internal transport systems, which along with the development of monitoring, communication, and planning systems (including digital technologies in enterprises) resulted in the combination of production and logistics systems into one comprehensive system.

Designing, analyzing, and redesigning such systems is a complicated task due to the fact that they are complex and dynamic systems. On the one hand, complexity results from the complexity (degree of complication) of the manufactured products and manufacturing technology, on the other hand, the complexity is influenced by the structure of the processes carried out in the factory. On the other hand, the dynamics is the result of both changes in the market (requiring changes in the products offered) and internal changes resulting from changes in processes carried out inside factories caused, for example, by a change in the organization of material flows, the introduction of new products, the phasing out of processes related to products withdrawn from the offer, etc.

Simulation it is the only tool for capturing and understanding cause-effect relationships that are distant in time and space and are linked by multiple feedback loops (Cempel, 2005), it is also one of the key technologies for Industry 4.0 (Schwab, 2017).

Simulation methods rely on direct description of the modeled object. The most important feature is the similarity of the structure of the object and the model – this means that each element of the object important from the point of view of the task being solved corresponds to an element of the model. When creating the simulation model, the principles of operation of each element of the object and the relations between them are described. Working with a simulation model consists in conducting a simulation experiment.

The method of designing the internal logistics system of the factory and the method of managing it (Harris *et al.*, 2003; Conrad and Rooks, 2010) is proposed by Lean.

It is a business concept based on the work of James P. Womack and Daniel T. Jones (Womack and Jones, 1996; Womack *et al.,* 1990) of the Massachusetts Institute of Technology. This concept aims to provide a new way of thinking about how to organize human activity to bring more benefits to society and value for individuals while reducing waste. Lean is defined as a concept that effectively eliminates or at least mitigates wastage in systems (Womack and Jones, 1996).

In this thinking, the process is organized by focusing on five concepts: Value, Value Streams, Flow, Suction, Perfection. Lean provides a set of principles and tools that are used to achieve operational efficiency, reduce process losses, and increase productivity. While most research focuses on one aspect of Lean, successful application often needs to focus on multiple aspects such as Value Stream Mapping (VSM), Line Balancing, One Minute Die Replacement (SMED), Visual Management, Production Leveling, 5S, LLD etc., (Wilson, 2010).

There are many articles in the literature describing how certain Lean tools have been supplemented or tested with simulation, including, for example, Value Stream Mapping (VSM) and Just in Time (JiT). Over the past decade, more and more authors have started to identify the benefits that can be obtained by combining Lean concepts and simulation (Robinson *et al.,* 2012; Uriarte *et al.,* 2015).

A very good review of the literature on the use of Lean methods in simulation can be found in (Tokola *et al.,* 2015). The main conclusions of these analyzes can be summarized as follows:

- VSM, Kanban, WIP, Layout and Tact Time are easy to simulate and therefore have been popular lean methods among articles. Methods that are not widely used are those that affect processing time variability;
- WIP, lead time, labor and floor area reductions were common simulation results. As with the lean methods, the results related to variability were rare.

The literature shows that the traditional, classical approach to simulating discrete events is an object-oriented approach (Van Mierlo and Vangheluwe, 2018), i.e., one in which simulation models are built from a set of objects. Many authors indicate that the analyzed, designed and built systems are becoming more and more complex. This complexity is due to various sources, such as the complex interaction of physical components (sensors and actuators) with software, large amounts of data that these systems must process, etc.

Almost always these complex operating systems exhibit event processing behavior. This means that the system responds to stimuli from the environment (in the form of input events) by changing its internal state, which can then influence the environment through the output events. Such event processing systems are fundamentally different from more traditional software systems that are transformative (i.e., receive a series of input parameters, perform calculations, and return the result as an output). Reactive systems operate continuously, often have multiple simultaneous components and are reactive with the environment (White and Ingalls, 2018).

Such complex event processing must be specified in the appropriate language to verify the behavior against its specification (using verification and validation techniques such as formal verification, model validation and testing techniques) and ultimately deploy the software on the system hardware components. Traditional programming languages were designed for transformational systems and are not well suited to describing synchronous, autonomous, reactive, and concurrent behavior.

In fact, describing complex systems with threads and semaphores quickly results in unreadable, incomprehensible, and unverifiable program code (Lee, 2006). This is due in part to the cognitive gap between the abstractions offered by languages and the complexity of the specification, and sometimes to poorly defined semantics of programming languages, making it difficult to understand. The state-chart formalism was introduced by (Harel, 1987) and proposed as an alternative solution.

Many simulation programs use state plots as the main simulation modeling tool (Anylogic, Simio). Another modeling tool is Process Flow, offered by FlexSim (FlexSim Software Products Inc.), which combines a programming language with graphics - it replaces almost all computer code with a block diagram. These tools focus on the details of the modeled system and require the user (production engineer, logistics) programming skills and knowledge of a large number (hundreds) of functions. Based on the author's experience, these users do not want to deal with the details of simulation programs (especially programming); want to solve problems in terms of operational concepts.

3. Definition of Research Problem

Currently, there are many simulation packages available on the market. At https://www.capterra.com/ simulation-software/ you can find an overview of the available simulation packages (constantly updated). The most important packages that can and are used in the industry in intralogistics are (alphabetically): Anylogic, Arena, Emulate 3D, ExtendSim, FlexSim, Plant Simulation, Simio, Simul 8. It is the author's choice based on publicly available publications and Winter archives Simulation Conference (www.wintersim.org) - an excellent and accessible repository of simulation resources.

The purpose of this selection is to present trends that the author believes are relevant. Each of the producers proposes a methodology for creating simulation models that comply with the principles defined in (Law, 2007). The methodologies proposed by software producers are based on the object-oriented approach, i.e., the user must build the model himself from a set of objects (object libraries) - he does it on the screen in the so-called the working area using a computer mouse (Beaverstock *et al.,* 2017; Borschev, 2013). Usually, it is building the model from scratch, although the facilities that manufacturers develop are becoming more and more "intelligent". There are also works related to the generation of automatic models (Bergmann *et al.*, 2010; Krenczyk, 2014), but they are not commercially available - which means that they are not available to enterprises as work tools.

The simulation programs in question are primarily general-purpose software, which means that they can be used for various purposes. This puts the pressure on producers to be universal. There are software versions dedicated to special applications, e.g., for healthcare (FlexSim Healthcare), the operation of container terminals (FlexTerm) or the operation of opencast mines (Haulsim). These products are based on the FlexSim simulation engine (www.flexswim.com). Other producers, e.g., Anylogic, Simio – propose libraries of objects and processes dedicated to specific applications, e.g., Anylogic includes libraries (www.anylogic.com):

- Process Modeling Library – simulate a job shop's manufacturing processes,
- Process Modeling Library – simulate queuing in a bank,
- Rail Library – simulate a hump yard,
- Material Handling Library – simulate a production line area,
- Road Library – simulate car movement in the intersection,
- Pedestrian Library – simulate passenger flows in the subway entrance hall.

Offering libraries means development related to expanding the offer of objects, not modeling methodologies that automate the process of creating a simulation model. It still requires special skills from the user: object-oriented modeling, system analysis, programming. At the same time, each model is still built from scratch - the user can save his knowledge in libraries that can be reused, but this requires even greater IT skills. The skills necessary to create simulation models are presented in the scope of training offered by software producers. For example, training for FlexSim includes the following content:

- Basics (FlexSim terminology – model, object, flow unit, ports, action triggers, Object library, Flexsim navigation basics, Global tables, Priorities, global variables, Failures, failure handling, Timetables, Excel import / export);
- Process Flow (Introduction to Process Flow technology, Workspace and Process Flow views, Process Flow – the idea of tokens, Library of Process Flow objects, Common activities and components – shared, Connections, blocks, properties, Process Flow types: general, for permanent resources, for mobile resources, Sub-Flow, Connecting Process Flow with 3D models),
- Advanced (Advanced Flexscript Coding, Advanced Excel Collaboration with FlexSim Models, FlexSim Tree, FlexSim Functions, Dashboard – Variable Tracking, building a Task Sequence and Using the Task Performer, Using Libraries and Using Object Grouping).

In practice, this means that for simulation modeling of intralogistics (which is discussed in this article), the company should hire a new specialist - a modeler / analyst. For a production engineer, logistics, Lean specialist, it would mean the acquisition of new knowledge and experience, and the effects of work would appear only after a long time. It should be noted that this is also knowledge that is not needed in normal everyday work in these professions. At the same time, it should be borne in mind that modeling support tools (offered by simulation software producers) require the creation of the so-called abstracts that are supposed to behave like objects, processes.

Such abstracts are state diagrams (State Chart) or process diagrams (Process Flow) – usually using the notion of "token", i.e., something abstract that is supposed to reflect the process flow. This is an additional difficulty, because it forces the designer to create abstractions, that is something new – which is not in the enterprise, and which is supposed to "pretend" the processes of the enterprise. When asked where a “token” is in the enterprise process, we usually get a negative answer or a request to explain what a "token" is. This means that the terminology used in simulation programs relating to modeling, computer science, is new for engineers and factory personnel.

In order to use all the simulation possibilities, the user-engineer must master the so-called interface to the program. The software offered on the market has many types of interfaces: various types of objects, tables, scripts, tools, functions (several hundred). On the one hand it is difficult to master, but on the other hand it is universal which means it can be used in many applications. This, however, has the consequence that the time to results is long and includes problem definition, model development and testing, data collection, performance measurements. It also requires extensive knowledge from the modeler - it requires understanding simulation, statistics, simulation software, programming, etc.

This in turn makes the implementation cost high: it includes the cost of software, training, stakeholder time, data preparation, consultant for model building, etc. also note that in such a situation there are risks associated with a change in the scope of the project, project delay. These risks are high and costly.

4. Developed Solution

As mentioned earlier, the aim of the author's scientific and practical activities is to build such an approach – to enable building simulation models of factories, starting from what is happening in the factory, in the same way as processes are built (designed and implemented) in real factories. For the purposes of this article, this approach has been defined as a set of requirements in relation to the simulation program dedicated to intralogistics.

These requirements are divided into requirements concerning:

- factory layout – 3D,
- relationships,
- operations,
- token,
- Lean.

4.1 Factory Layout 3D

The layout of the factory is defined as the arrangement of all the material components that make up the factory. Usually it is a layout, i.e., a top view (plan), a 2D drawing prepared in the dwg (AutoCad) format. Layout in a macro scale – it reflects the arrangement of all elements throughout the production hall, it is a focus on guaranteeing a continuous flow, creating linear and nest forms of organization of workstations, reducing the distance between cooperating stations, thus reducing the time of transport operations.

Layout on a micro scale – it is a layout of individual workstations or areas, including all the elements necessary to perform the work; it is the entire environment of the machine and the operator's working space, including the way of moving around it. The author proposes to adopt the concept of factory topography as a configuration of the surface taking into account its shape (i.e., layout – top view) as well as the presence and mutual position of objects and characteristic points.

Such points are stations (made up of objects: locations, worktables, machines, conveyors, etc.), communication routes, transit points, logistic train stops. The key is to adopt the workstation as the basic object, which is identified by the name (given by the user), and the workstation components have reserved names adopted with a specific notation – this allows for unambiguous identification (addressing) of these elements in the factory. This order enables the definition of existing relationships in the factory (Pawlewski, 2019a). At the same time, the factory layout is created in 3D, which enables real addressing taking into account the z dimension, and the use of advanced technologies related to VR (virtual reality) and AR (Augmented reality).

4.2 Relations

The introduction of unambiguous identification (addressing) of the factory components allows for a precise recording of relations existing in the factory. Proposals for the definition of such relationships are included in the articles (Pawlewski and Anholcer, 2019). The main integrator is the PFEP database – Plan For Every part. It is a database created to collect and maintain information on all parts, components, consumables, WIP (Work In Progress) inventory, raw materials, finished products and any other materials used in the processes. PFEP definitions and requirements vary according to specific needs and industry.

Then, once a product is launched, PFEP is used to proactively maintain smooth supply chain operations by managing and optimizing inventory costs, inbound logistics costs, and parts replacement costs. Details of the use of PFEP for simulation modeling of production systems are explained (Pawlewski, 2018a).

4.3 Operations

It is essential for an industrial user to present the operator routes in simulation programs. The flow in the factory is realized by the operators. At the same time, it is not only about the human operator, but about a material object capable of independently moving parts and containers. An employee (human), robot, manipulator, forklift truck with driver, AGV (automated guided vehicle, AMR (automated mobile robot) is such an operator.

Thus, the mechanism of such routes should be transferred to the simulation program, which in turn requires the development, definition of a high-level language with which to describe the routes of operators in a manner identical to the way in which routes are prepared in a real factory (Pawlewski, 2018b,) This language should have a built-in mechanism to solve the problem of access to shared resources and synchronization, and should be able to assign value-added attributes to statements in order to be able to perform Value-Added analysis and build Yamazumi diagrams (Pawlewski, 2019b).

4.4 Token

The tools proposed by software producers use the concept of a token – an abstract object that flows through the so-called flowchart (flow process). This makes it easier to identify the course of the process and describe reality. It allows you to build abstracts whose task is to behave like processes in a factory. One may wonder whether it is worth trying a different description of the processes carried out in the factory.

A description that would be readable and understandable by the engineers in the factory. Why the achievements of Lean creators and researchers as well as the achievements of creators and researchers of the multimodal approach and multimodal processes cannot be used. If we realize that containers with parts and finished products are flowing in the factory, we will assume that the token is a container, and the flow is carried out by local cyclical processes, if we realize that the flow of containers - tokens takes place between locations, and that any operation technological facilities are implemented by objects (workstations, nests, etc.) between locations, we will get a different image of the factory and its processes (flows).

4.5 Lean

As already mentioned, Lean proposes a method of designing the internal logistics system of a factory and a method of managing it (Harris *et al.*, 2003; Conrad and Rooks, 2010). The use of these achievements in the simulation program would significantly accelerate the construction of the simulation model and would make it take place in an environment known to production engineers, logistics and Lean specialists. This would require integrating Lean mechanisms into the simulation program (Pawlewski, 2019b):

- PFEP – Plan For every part previously mentioned,
- automatic VA analyzes (Value Added Analysis) - this requires the introduction of a high-level route description language,
- Yamazumi charts – tools for balancing positions – this also requires the introduction of high-level language and thinking (and recording routes) in cycles,
- Andon mechanism – for signaling and synchronizing activities,
- KanBan mechanism – flow control based on the observations of the location status and filling of containers,
- a mechanism for generating and managing deliveries of the MilkRun type – that is, the use of the so-called logistic trains.

5. Conclusion and Further Work

The article presents an analysis of the simulation software available on the market and the requirements that this software imposes on users from the point of view of a user from the industry: production engineer, logistics, Lean specialist. Requirements for simulators dedicated to intralogistics have been defined. Taking these requirements into account would greatly facilitate the work of engineers in the factory, destroying the currently existing barriers to the implementation of simulation technologies in the practice of factory operations. First, the advantages of this approach can be summarized in the following points:

- automation of simulation model generation thanks to embedding relations in the simulation program,
- operating with engineer-friendly concepts – Lean concepts,
- automation of the generation of results in the form of value-added charts and Yamazumi charts,
- automation of the generation of ergonomic results (distance traveled and load analysis),
- separation of executive and decision-making parts – which structures decision-making and enables development based on reference processes and logistic navigators,
- 3D visualization and digital techniques of VR and AR.

Table 1 summarizes the article – the criteria for comparing (characteristics) of the simulation programs available on the market with the program dedicated to intralogistics, the features of which are defined in this article. The current work of the author focuses on the development of methodologies for the rapid creation of intralogistics simulation models based on the concept of the so-called reference processes and logistic navigators.

Table 1. *Comparison of the features of simulation programs available on the market with the required features for a simulation program dedicated to intralogistics*

Characteristic	**Other Simulation Programs**	**Program dedicated to intralogistics (LogABS)**
Implementation range	General	Dedicated to intralogistics
Types of issues	General – design and analysis of a wide variety of systems	Design and analysis of manufacturing logistics systems
The frequency of use	Often one-off	All time / reuse
User	Modelarz / Analyst	Production Engineer, Lean Specialist, Logistics
Limitations	Virtually no limitations	The specific type of problem
Basic concept	Abstract	Concentrated, extension of the user's (engineer's) work environment
Vocabulary / terminology	Modeling, computer science; often everything	Production, Logistics, Lean; mainly daily appointments for engineers and factory workers

	new for engineer and factory personnel	
Interface	Many types – objects, tools, scripts, tables etc.	First of all, tables (relationships) and language (operations)
Time to get results	Long; covers problem definition, model development and testing, data collection, performance measurements	Quick; it only applies to a specific and known system configuration system
Resources required	Many different stakeholders	Minimal, only production staff including Lean specialists
Knowledge / training required	Extensive; requires an understanding of simulation, statistics, simulation software, programming etc.	Limited; focused on user interfaces and common tools (e.g. tables and operations)
Implementation cost	Usually high; includes software, training, stakeholder time, data preparation, model building consultant, etc.	Moderate; the problem is well defined and understood, data is usually available; cheaper software
Risks: scope changes, project delays	High and expensive	Minimal; a well-defined problem and dedicated software

Source: *Own work.*

References:

Beaverstock, M., Greenwood, A., Nordgren, W. 2017. Applied Simulation. Modeling and Analysis using Flexsim, Flexsim Software Products, Inc. Canyon Park Technology Center, Orem, USA.

Bergmann, S., Strassburger, S. 2010. Challenges for the automatic generation of simulation models for production systems. Proceedings of the 2010 Summer Simulation Multiconference (SummerSim'10), July 11th-15th, Ottawa, Canada, 545-549.

Borshchev, A. 2013. The Big Book of Simulation Modeling. Anylogic North America.

Cempel, Cz. 2005. Nowoczesne zagadnienia metodologii i filozofii badań (eng. Modern issues of methodology and research philosophy). ITiE, Radom.

Conrad, T., Rooks, R. 2010. Turbo Flow: Using Plan for Every Part (PFEP) to Turbo Charge Your Supply Chain. Productivity Press.

Harel, D. 1987. Statecharts: A Visual Formalism for Complex Systems. Science of Computer Programming, 8(3), 231-274.

Harris, R., Harris, Ch., Wilson, E. 2003. Making Materials Flow. A lean material-handling guide for operations, production control, and engineering professionals. The Lean Enterprise Institute Inc.

Hompel, M., Heidenblut, V. 2008. Taschen-lexikon Logistik. Springer-Verlag.

Kartnig, G., Grosel, B., Zrnic, N. 2012. Past, state-of-the-art, and future of intralogistics in relation to megatrends. FME Transactions 40, 193-200.

Krenczyk, D., 2014. Automatic Generation Method of Simulation Model for Production Planning and Simulation Systems Integration. Advanced Materials Research, 1033-1036.
Law, A.M. 2007. Simulation Modeling and Analysis, 4th Edition. McGraw-Hill, New York.
Lee, E.A. 2006. The Problem with Threads. Computer, 39(5), 33-42.
Mierlo Van, S., Vangheluwe, H. 2018. Introduction to State charts Modeling, Simulation, Testing, and Deployment. Proceedings of the 2018 Winter Simulation Conference, 306-320.
Pawlewski, P. 2018a. Using PFEP For Simulation Modeling of Production Systems, 28th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2018), June 11-14, Columbus, OH, USA. Procedia Manufacturing, 17, 811-818.
Pawlewski, P. 2018b. Script language to describe agent's behaviors. Highlights of Practical Applications of Complex Multi-Agent Systems – Int. Workshops of PAAMS, (eds.) Javier Bajo et al., Springer.
Pawlewski, P. 2019a. Interactive Layout in the Redesign of Intralogistics Systems. In: Burduk, A., Chlebus, E., Nowakowski, T., Tubis, A. (eds.) Intelligent Systems in Production Engineering and Maintenance. ISPEM 2018. Advances in Intelligent Systems and Computing, 835. Springer, Cham.
Pawlewski, P. 2019b. Built-In Lean Management Tools in Simulation Modeling. Proceedings of the 2019 Winter Simulation Conference. N. Mustafee, K.H.G. Bae, S. Lazarova-Molnar, M. Rabe, C. Szabo, P. Haas, and Y.J. Son.
Pawlewski, P., Anholcer, M. 2019. Relational Database Template in the Simulation Modelling of Manufacturing Systems. IFAC-PapersOnLine, 52(13), 1744-1748. DOI: https://doi.org/10.1016/j.ifacol.2019.11.453.
Robinson, S., Radnor, Z.J., Burgess, N., Worthington, C. 2012. SimLean: Utilising Simulation in the Implementation of Lean in Healthcare. European Journal of Operational Research, 219(1), 188-197.
Schuhmahert, J., Hummel, V. 2019. Self-organization of changeable intralogistics systems at the ESB Logistics Learning Factory. Procedia Manufacturing, 31, 194-199.
Schwab, K. 2017. The Fourth Industrial Revolution. Crown Business.
Tokola, H., Niemi, E., Väistö, V. 2015. Lean manufacturing methods in simulation literature: Review and association analysis. Winter Simulation Conference (WSC), Huntington Beach, CA, 2239-2248.
Trott, M., Auf der Landwehr, M., von Viebahn, C. 2019. A new Simulation Approach for Scheduling Consolidation Activities in Intralogistics - Optimising Material Flow Processes in Industrial Practice. In: Simulation in Produktion Und Logistik, herausgegeben von Matthias Putz and Andreas Schlegel, 325-334. Auerbach: Verlag Wissenschaftliche Scripten.
Uriarte, A.G., Moris, M.U., Ng, A.H.C., Oscarson, J. 2015 Lean, Simulation and Optimization: A Win-Win Combination. Proceedings of the 2015 Winter Simulation Conference edited by L. Yilmaz, W.K.V. Chan, I. Moon, T.M.K. Roeder, C. Macal, and M.D. Rossetti, 2227- 2238. Piscataway, New Jersey, IEEE.
White, Jr. K.P., Ingalls R.G. 2018. The Basics of Simulation. Proceedings of the 2018 Winter Simulation Conference, 147-161.
Wilson, L. 2010. How to Implement Lean Manufacturing. New York, NY: McGraw-Hill.
Womack, J.P., Jones D.T. 1996. Lean Thinking - Banish Waste and Create Wealth in Your Corporation. New York, NY: Free Press, Simon & Schuster, Inc.
Womack, J.P., Jones D.T., Roos D. 1990. The Machine That Changed the World. Free Press.

wynright.com/intralogistics, 2021.
https://www.capterra.com/simulation-software/ 2021.
www.wintersim.org 2021.
www.anylogic.com 2021.
www.flexswim.com 2021.