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FlexSim in Academe: Teaching and Research

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Preface

Simulation is emerging as an important tool to support the decision-making and problem-solving processes that are inherent in the design, management, and improvement of numerous types of operations systems, including manufacturing, logistics, healthcare, etc. Currently, simulation is one of the key technologies within the framework of the 4.0 Industry concept. This concept defines a new organization of factories (called intelligent factories), allowing for better customer service through enormous flexibility and resource optimization. The key principles of the Industry 4.0 are as follows:

- the factory becomes digital and flexible, which means continuous and immediate communication between various workstations and tools, integrated into production lines and supply chains;
- the use of simulation tools and data processing to collect and analyze data from assembly lines that are used for modeling and testing; this is a great value for employees who want to better understand industrial conditions and processes;
- the factories become more economical in using energy and resources through the use of communication networks to exchange information in a continuous and immediate way to coordinate the needs and availability.

Simulation is a collection of methods and techniques, which includes: discrete simulation, continuous simulations (including systems dynamics), Monte Carlo method (including static simulations in a spreadsheet), managerial games, qualitative simulation, agent simulation, and others.

FlexSim is a leading simulation software; its power includes integrated 3D modeling for realistic physical representations, an open and easily customized model development environment, and process-based logic building for specifying complex system behaviors and object interactions. As a result, there is a growing need to effectively educate a wide range of students on at least the basic concepts and power of simulation and disseminate advances in research and application.

The goal of this book is to present, expand, and enhance the use of simulation in general, and FlexSim in particular, in academe through teaching and research. This book gives the opportunity to share ideas and practices.

The book consists of three parts *Introduction*, *Teaching* and *Research*. It is preceded by a chapter describing the experience obtained from many years of work with FlexSim at the Poznań University of Technology in Poznań, Poland. This chapter demonstrates how the use of FlexSim software in the specified areas contributes to the development of competences for the Industry 4.0.

Part II of the book which focuses on teaching aims to answer some important questions, which are as follows:

- How to effectively design and manage simulation course projects, both from the educator's and student's perspectives?
- How to teach with success new skills?
- How to increase high school students' interest in industrial engineering through a summer camp?

Part III of the book presents the application of the simulation software in research and it focuses mainly on:

- an implementation of 3D Discrete Event Simulation (DES) in an offshore manufacturing foundation process to increase the efficiency of the process by reducing costs and delivery times,
- an innovative parametric decision model designed by applying 3D Discrete Events Simulation (DES) concepts and customized to be applicable in offshore wind turbine foundations manufacturing plant,
- the methodology of modeling and simulation of human operators and industrial robots,
- the method of designation of the optimal number of trailers for milk-run system,
- an implementation of the calculation results about number of trains, trailers, and routes into the simulation model,
- using Constraint Satisfaction Problems solvers as alternative to simulation optimization engines.

Although not all of the received chapters appear in this book, the efforts spent and the work done by the authors are very much appreciated.

We would like to thank all reviewers whose names are not listed in the volume due to the confidentiality of the process. Their voluntary service and comments helped the authors to improve the quality of the manuscripts.

This scientific monograph has been peer-reviewed.

Poznań, Poland   Pawel Pawlewski
                                                                        Patrycja Hoffa-Dabrowska
                                                                        Paulina Golinska-Dawson
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Contents

Part I
Introduction

FlexSim Use in Didactics, Thesis, and Research in the Context of Competences for the Industry 4.0

Karolina Werner-Lewandowska, Agnieszka Grzelczak, Pawel Pawlewski and Monika Kosacka-Olejnik

1 Introduction

Nowadays, we are facing the new technology revolution, which is often referred as the fourth industrial revolution [1] defined as "Industry 4.0" or "Industrie 4.0", which is a part of German high-tech strategy [2]. In the chapter, there is used German definition of Industry 4.0 as: "the ability of ad hoc networking between intelligent machines, production facilities, components as well as storage and transportation systems via the Internet to form powerful value networks" [3]. According to the presented definition, Industry 4.0 brings new standard of value chains. The new concept has become a response to the current challenges appearing in fast-changing environments, related to the transformation of processes caused by the use of new technologies, both existing and new, which work together lead to new opportunities for companies [4]. Those technologies include Internet of things (IoT), data mining, cyber-physical systems (CPS), etc. [4–7].

As a result of those technologies, there has occurred a big amount of data, which require storage, processing, and analyzing. Another aspect of Industry 4.0 is possibility of linking the virtual and physical world, resulting in interconnection of people, objects, and systems, through the real-time data exchange [8]. It is related to issue of the smart objects. Smart machine, smart product, and augmented operator were described as paradigms of Industry 4.0 in [9]. Simulation methods have been used for several decades to describe, research, and design economic and social systems. Currently, they are one of the key technologies within the framework of the Industry 4.0 concept [10]. The presented concept is created in Germany and it has defined a new organization of factories (called intelligent factories), which allow for better customer service through enormous flexibility and resource optimization. The key principles of Industry 4.0 are as follows:

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- digital and flexible factory, what means continuous and immediate communication between various workstations and tools, integrated into production lines and supply chains;
- the use of simulation tools and data processing to collect and analyze data from assembly lines, that are used for modeling and testing. It may be perceived as a great value for employees, who want to understand industrial conditions and processes;
- more economical use of Energy and resources by factory through the utilization of communication networks in order to exchange information in a continuous and immediate way to coordinate needs and availability [11].

Considering all presented information, it was stated that Industry 4.0 may be perceived as a chance but also as a big challenge for companies, particularly in relation to humankind transformation, as Industry 4.0 has introduced changes, which have not been experienced by humanity so far [10].

With reference to the literature review on the Industry 4.0 topic, it was claimed that researchers are mainly focused on technology perspective of new concept; however, it should be noticed that human cannot work without the technology, and technology will not work without people. As a result, it was postulated to consider the role and importance of people in the Industry 4.0 concept realization, especially that the transformation of the company's business model is connected with changes in the model of work's organization. Consequently, it was stated that there have been transformations of the job's profile, in terms of managing complexity, abstraction, and problem-solving [12, p. 53].

According to experts in the Industry 4.0, repetitive operations will be performed by machines or robots, instead of people, who will integrate, manage, control work of machines, and analyze a large amount of data with the use of the newest technology [13]. Considering that, authors assumed that in the Industry 4.0, there should be not used term "Worker", but "Engineer" who should be outfitted with a wide range of new competences according to the Industry 4.0 requirements. It has been highlighted in many researches, e.g., in [14–18].

To sum up, it is stated that in order to introduce the Industry 4.0 concept into business practice, there should be hired employees with appropriate competences. As a result, it was claimed that competences of employees are one of the major challenges for the Industry 4.0 development. Consequently, authors assumed that people are key success factor for the Industry 4.0.

In the presented research, the following research problems are defined:

Does the use of FlexSim software in didactics, diploma thesis, and research projects contribute to the development of competences for Industry 4.0, referred to as C4I4.0?

With reference to the main research problem, the following research questions are defined:

RQ1   Which competences do contribute to the Industry 4.0 development?
RQ2   Which of C4I4.0 are relevant for enterprises?

RQ3 Which of C4I4.0 are developed during running a project related to the simu-
lation and optimization of business processes?

In order to answer the presented research questions, there are set out the following
research objectives:

RO1 C4I4.0 determination. The objective corresponds to RQ1.
RO2 Key C4I4.0 determination. The objective corresponds to RQ2.
RO3 To explain how the use of FlexSim software in teaching, diploma thesis, and
research projects contributes to the development of C4I4.0. The objective
corresponds to RQ3

The remainder of this paper has the following organization. Section 2 gives a brief
description of required competences for the Industry 4.0 development; however, key
competences for the Industry 4.0 were presented in Sect. 3. In Sect. 4, there are
included statistical data on the use of FlexSim in didactics, thesis, and research.
Section 5 discovered using FlexSim in didactics, thesis, and research in the C4I4.0
context. Conclusions and research limitations are set out in Sect. 6.

2   Competences for the Industry 4.0

Competences may be analyzed at different levels, including: individual, collective,
or company's level [14, p. 228; 15, pp. 1222–1224]. In the presented paper, authors
were focused on the individual competences of employees.

However, there are many definitions of the competence term in the literature,
there is a lack of clarity, what was stated, e.g., in [19]. With reference to examined
definitions of competence, authors stated that [20–24]:

- Competences create human potential, including the employee's potential (consid-
ered in the paper).
- Competences require development.
- Competences are required in order to realize the company's strategy and to achieve
established goals.
- Competences include everything what is required for tasks' realization (at work,
at private life).

Considering all presented information, it was assumed that competences include:
knowledge, skills (soft skills and technical skills) and attitude, reflected in actions
[25, p. 29] (Fig. 1).

The knowledge component may be achieved in formal or informal way, con-
sidering the following types of knowledge: know-what, know-why, know-how, and
know-who [26, p. 12]. With reference to Fig. 1, the next competence's component
is skill, determined by practical activity, including experience [25, p. 29]. Finally,
attitude expresses willingness and readiness for using the knowledge and skills in
actions [25, p. 29], what was indicated as the last element of the competence.

Fig. 1 Structure of the competence; own elaboration on the basis [25, p. 29]

In the literature may be found categorization of competences, including the following division of competences [17, p. 10]:

- technical, associated with job-related knowledge and skills;
- methodological, consisted of skills and abilities for general problem-solving and decision-making;
- social, including skills and abilities of cooperating and communication with other people;
- personal, consisted of individual's social values, motivations, and attitudes.

It is claimed, that sometimes there appears a misunderstanding between the terms: "competence" and "qualification". Authors state that there is a linkage between competences and qualifications, owing to the fact that competences' development aims to identify required competences, while qualification should close occurred gaps.

Consequently, it is stated that competences are essential issue, because of the influence on employees' work efficiency [27, p. 13]. As a result, it is pointed out that, competences are the most valuable enterprise's capital [24, p. 25], which should be well managed and developed.

The presented paper is focused on the competences for the Industry 4.0, as a new challenge for companies. In order to achieve the RO1, the need for determining a set of competences which contribute to Industry 4.0 development, has risen up. To meet the requirements, authors of the paper have used research conducted by researchers from Fraunhofer Institute for Factory Operations and Automation (IFF) on the development of competences for Industry 4.0 [12].

The scientists from Germany have examined competences development on the basis of a nonrepresentative online survey conducted among German companies, accompanied by interviews with academia and industry experts. The purpose of the research is to identify the set of required competences of employees in order to implement the Industry 4.0. As a result, there is obtained a list of employees' competences for the Industry 4.0 development, which is divided into three categories, and it is presented in Fig. 2.

With reference to Fig. 2, German researchers have arranged competences for the Industry 4.0 development, considering them in the following three areas:

(1) competences which are focused on technology that make possible to introduce and develop the Industry 4.0 concept;
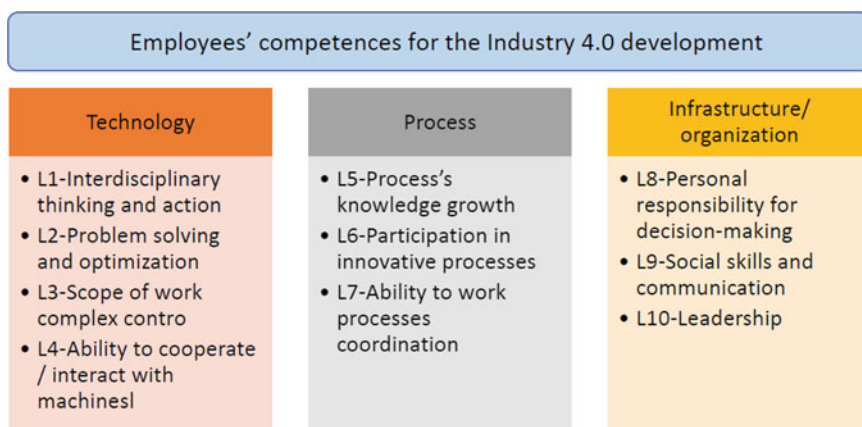
Fig. 2 Employees' competences for the Industry 4.0; own elaboration based on [12]

(2) process-oriented competences, through which there may be seen links between the processes that add value;

(3) competences which are focused on the infrastructure/organization with which there are used soft skills.

3 Key Competences for the Industry 4.0

In order to determine which of C4I4.0 are significant for enterprises, authors of the paper carried out research in 2017. The research objective is to examine which companies for Industry 4.0 are essential for Polish enterprises and employees, who work in various job positions [28, 29]. In order to achieve specified goal, there has been conducted a survey, in which there was included a question about the most relevant competence in respondent's opinion. On the basis of conducted research, there are determined key competences for enterprises, which are presented in Table 1.

Table 1 Key competences for enterprise; own elaboration on the basis [28]

Type of enterprise	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
Manufacturing company	20,00	20,00	4,00	16,00	8,00	4,00	8,00	2,00	8,00	0,00
Large enterprise	17,39	21,74	4,35	4,35	8,70	0,00	8,70	4,35	21,74	8,70
Medium enterprise	33,33	5,56	0,00	16,67	11,11	11,11	5,56	5,56	11,11	0,00
Small enterprise	11,11	33,33	0,00	0,00	0,00	0,00	11,11	33,33	11,11	0,00
Type of position	L1	L4	L9	L10	L2	L3	L8	L5	L6	L7
Worker	23,81	16,67	2,38	4,76	11,90	4,76	9,52	7,14	14,29	4,76
Manager	10,00	20,00	0,00	30,00	0,00	0,00	0,00	20,00	20,00	0,00

With reference to Table 1, the most frequently indicated competences are pointed out in italic. These competences are most often indicated, but not in the general approach, only depending on the type of enterprise and the position. Those competences are assumed by the authors of the paper as Key C4I4.0:

L1 Interdisciplinary thinking and action, the most frequently pointed out by employees of manufacturing companies (20%) medium-sized enterprises (33,33%) and workers (23,81%).
L2 Problem-solving, the most frequently indicated by employees of large companies (21,74%) and small enterprises (33,33%).
L4 Ability to cooperate/interact with machines, the most frequently pointed out by managers (30%).
L8 Personal responsibility for decision-making, the most frequently pointed out by employees of small companies (33,33%).
L9 Social skills and communication, the most frequently indicated by employees of small companies (33,33%)

It is assumed that these competences (L1, L2, L4, L8, and L9) are Key C4I4.0, owing to the fact that, they are important for the Industry 4.0 concept development and for companies, too. It is worth noting that competences with id: L1, L2, and L4, according to the adopted categorization (Fig. 2) are technology-oriented competences, while L8 and L9 are oriented on infrastructure/organization.

In the next section of the paper, there is presented the use of FlexSim software in teaching, diploma thesis, and R&D projects, as a contribution to the C4I4.0 development.

4 Using FlexSim in Didactics, Thesis, and Research—Statistical Data

From 2009 at the Poznan University of Technology (Poland), at the Faculty of Engineering Management (before 2012 to the Faculty of Computer Science and Management), as a result of cooperation with the University of Windsor (Canada), a new concept of logistics engineering teaching program has been developed, combining key Program courses of Logistics Programme. The main idea was to use courses Process Design from Level 1 (Level 1 refers first-cycle studies) and Design of Logistics Systems and Processes from Level 2 (Level 2 refers to second—cycle studies) as main foundational courses. Process-based approach allows thinking about any company or a factory as structure, where processes are performed. Students form teams (companies) and carry out some projects during two levels in continuous, integral way. Students' teams work together through the full cycle.

According to Fig. 3, the cycle is composed of four main stages:

- **Stage 1**—IPD Course—Integrative Product Development Course.
- **Stage 2**—Process Design consisted of two stages:
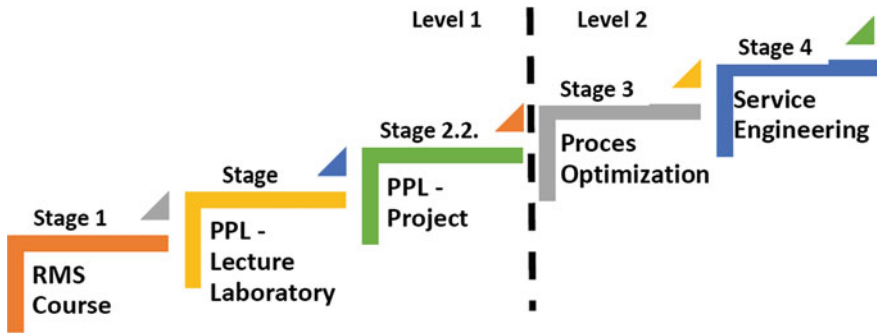
Fig. 3 The cycle skeleton based on a process approach; own elaboration on the basis [30]

- **Stage 2.1**—PPL—Lecture Laboratories. Lectures cover Process Design and students are learning hands-on fundamentals of specialized software platform(s) for process modeling and simulation.
- **Stage 2.2**—PPL Project. Based on the knowledge and experience gained in the PPL classes, in the following semester students' groups contact local companies, develop project proposals, and carry out projects according to the joint agreement. Students' teams offer design; model or map real logistics processes services.

- **Stage 3**—Design of Logistics Systems and Processes—Process Management and Optimization.
- **Stage 4**—Service Engineering.

Over the years, the course has been conducted in accordance with the presented concept (Fig. 3), resulting in many students' projects, which very often have been further developed in engineering diplomas (Bachelor of Engineering (BEng) thesis work), and master's (MSc). Researchers from the Faculty of Engineering Management have also used FlexSim software in Ph.D. thesis or in R&D projects. Statistical data, presenting a quantitative summary of the use of FlexSim software in didactics, diploma thesis, and research projects between 2010 and 2017, is presented in Table 2.

5 Using FlexSim in Didactics, Thesis, and Research in C4I4.0 Context

In order to solve the research problem determined in the Introduction, there is analyzed the use of FlexSim in didactics, diploma thesis, and R&D projects, described in detail in Subsects. 5.1, 5.2 and 5.3.

Table 2 Using FlexSim in didactics, diploma thesis, and research—statistical data

Year	PPL project	BEng thesis work	MSc thesis work	PhD thesis work	R+D project
2010	6	0	0	0	0
2011	10	1	0	0	0
2012	15	0	2	0	2
2013	10	0	2	0	1
2014	12	0	2	0	0
2015	12	1	3	1	0
2016	14	2	1	1	0
2017	14	2	0	0	1
Total	93	6	10	2	4

5.1 Using FlexSim in Didactics

With reference to Sect. 4, in the presented subsection, there are considered information about projects realized by students within studies (Fig. 3). First, the PPL projects are divided considering the range of project's subject, considering the C4I4.0 systematic areas presented in Fig. 2. Thus, there is made a reference to the classification of C4I4.0, adopted in the paper. Consequently, there are three groups of PPL projects:

- Group 1: projects which are related to simulation models building technology-oriented, e.g., designing storage technologies for the central warehouse of PKP CARGO SA;
- Group 2: projects which are related to simulation models building process-oriented, e.g., simulation of the picking process in the pallet automatic warehouse;
- Group 3: projects that are related to simulation models building infrastructure/organization-oriented, e.g., development of the concept of internal transport in the production hall and optimization of the use of transshipment ramps.

As a consequence, the knowledge about the size of each of these groups is gained as shown in Fig. 4.

According to data presented in Fig. 4, it is stated that the thematic scope of the students' projects, in terms of numbers, coincides with the area in which there

Fig. 4 PPL projects: orientation (2010–2017)
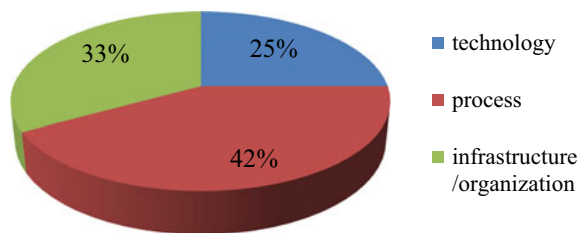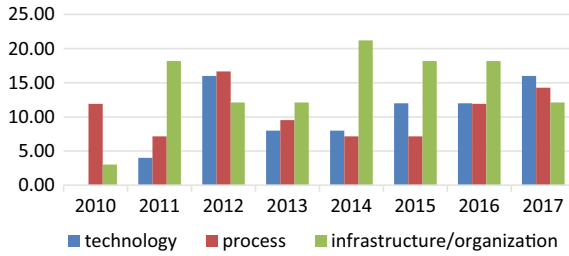
Fig. 5 PPL projects: topic's structure (2010–2017)

Table 3 Using FlexSim in didactics—statistical data [%]

Group no.: Project's focus	2010	2011	2012	2013	2014	2015	2016	2017
Group 1: Technology	0,00	5,26	*21,05*	10,53	10,53	*15,79*	15,79	*21.05*
Group 2: Process	*13,89*	8,33	19,44	*11,11*	8,33	8,33	13,89	16,67
Group 3: Infrastructure/organization	2,63	*15,79*	10,53	10,53	18,42	*15,79*	15,79	10,53

are included two of five KeyC4I4.0, namely, infrastructure/organization. By building simulation models related to the subject of enterprise's infrastructure, students develop competences related to this area, such as personal responsibility for decision-making, social skills, communication, and leadership.

Consequently, it is stated that the use of the FlexSim software in the teaching contributes to the development of Industry 4.0 competences, referred to as C4I4.0. This is a partial answer to the main research problem presented in Sect. 1.

Considering the aggregated data presented in Fig. 4, authors made a list of students' projects in particular years based on project's topic, as presented in Fig. 5.

With reference to data presented in Fig. 5, it is stated that thematic scope of students' projects is characterized by dynamics. Extensive analysis of projects is shown in Table 3, where are included percentage share of projects considered from the perspective of groups of PPL projects (at the beginning of this subsection).

According to data in Table 3, it was claimed that projects were diversified with reference to their focus; however, it may be perceived growth in the last 4 years of projects oriented on technology as well as process. The greatest growth was noticed in the first group, what may signalize growth of relevance the technology issues in companies, what is related to the context of the Industry 4.0 concept.

5.2 Using FlexSim in Thesis

Analogously to Subsect. 5.1, there was made an analysis of the diploma thesis, in which the FlexSim software was used. Between 2010 and 2018, there were developed:

six BEng theses, ten master's theses, and two PhD dissertations. Their possessive list, including the division into three areas, taking into account the subject of the work, was presented in Table 4.

where BEng—BEng thesis, MSc—master's thesis, and PhD—PhD thesis

According to Table 4, 100% BEng thesis and 100% of PhD thesis were related to the processes area. The PhD dissertations titles were:

- "Methodology of logistics process improvement in a production enterprise in the knowledge transformation context" by Karolina Werner-Lewandowska [31].
- "Methodology of modelling disturbances in logistics process", by Patrycja Hoffa-Dąbrowska [32].

With reference to Table 4, FlexSim software was very often used in master's thesis (10 master's thesis). There was made an analysis of master's thesis from the perspective of three areas related to the C4I4.0 categorization, presented in Fig. 6. However, data included in Table 4, may suggest that there were more than 10 master's theses; it should be noticed that those works are cross-sectional and multifaceted, which makes it difficult to indicate clearly one area on which research is focused on. There were a few cases, where the work is related to all three areas.

With reference to data presented in Fig. 6 it is stated that master's theses, analogously to other theses, are focused primarily on the processes; however, it does not coincide with certain Key C4I4.0. This indicates the direction of development of the FlexSim use in the area of thesis, so that they could develop key competences for the Industry 4.0.

Table 4 Using FlexSim in thesis—statistical data

Thesis focus	2010	2011	2012	2013	2014	2015	2016	2017	2018
Technology	0	0	0	1MSc	1MSc	0	3MSc	1MSc	0
Process	0	1BEng	1MSc	2MSc	3MSc	1BEng	2BEng	1MSc	2BEng
						1PhD	3MSc		
						1PhD			
Infrastructure/organization	0	0	1MSc	1MSc	2MSc	0	3MSc	1MSc	0

Fig. 6 Master's thesis: structure of topics (2010–2017)
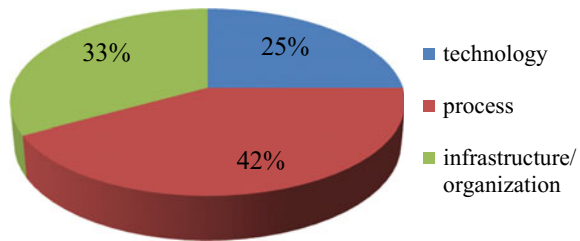
5.3 Using FlexSim in R+D Projects

Between 2010 and 2018, there have been implemented four research projects using FlexSim software, at the Faculty of the Engineering Management at the Poznań University of Technology. The characteristics of particular projects where the specified software FlexSim is used are presented in Table 5.

The scope of FlexSim use in R&D projects is presented in Table 6. It should be noted that there are analyzed only those projects, in which the implementer is at least one of the team member of the authors of this paper.

With reference to data presented in Table 6, it is claimed that 50% of projects were focused on all three areas related to C4I4.0; thus, they have developed the

Table 5 R&D projects with FlexSim use (2010–2017)

Acronym	Project's title	Duration	Range of use of FlexSim
SIRO	Sustainability in remanufacturing operations	2012–2014	The model for remanufacturing process of starters and alternators was developed, considering employees and eco-indicators as emission of CO_2 level, electricity, gas
LOGOS	Model of coordination of virtual supply chains meeting the requirements of corporate social responsibility	2012–2015	The model of supply chain coordination (impacts of the internal and external relations of the supply chain), taking into account economic, social, and environmental aspects
WATUS	Investigation of multifaceted conditions of the transformation of a production and logistics system with diversified production structure, a wide assortment of production and a multi-paradigm customer service strategy	2012–2015	The model of flow of material streams
NTWL	Development of a new type of logistic trolley and methods of collision-free and deadlock-free implementation of intralogistics processes	2017–2018	FlexSim as environment to build the simulation tool for layout and intralogistics design and redesign

Table 6 Using FlexSim in R&D projects—statistical data

B+R project's focus	2010	2011	2012	2013	2014	2015	2016	2017
Technology			SIRO					NTWL
Process			SIRO, LOGOS	WATUS				NTWL
Infrastructure/organization			SIRO					NTWL

key competences of the projects' implementers. All projects are focused on the area related to processes, what defines the direction of future research, so that they should be focused on the technology and infrastructure/organization areas, so that Key C4I4.0 could be developed by using FlexSim software.

6 Conclusions

To sum up, there should be quoted the main research problem expressed in the question: Does the use of FlexSim software in didactics, diploma work, and research projects contribute to the development of competences for Industry 4.0, referred to as C4I4.0?

The competences for the development of the Industry 4.0 have been demonstrated. As a consequence of research conducted by authors of the paper, there are defined a group of key competences for Industry 4.0, as follows:

- Interdisciplinary thinking and action,
- Problem-solving,
- Ability to cooperate/interact with machines,
- Personal responsibility for decision-making, and
- Social skills and communication.

Afterward, using the statistical data, which are analyzed and synthesized, there is demonstrated the use of FlexSim in didactics, diploma thesis, and R&D projects, which contributes or may contribute to the development of Key C4I4.0. Conducted research has shown the direction of future development in the scope of diploma thesis and R&D projects, so that by realizing those, to develop the competencies required for the Industry 4.0 development.

It is stated that considering students' education within Industry 4.0 context, the greatest attention should be paid to the growth of the thesis work number, particularly MSc and BEng. R&D projects as well as PhD thesis works are results of interests of researchers, so they do not necessarily have to relate to C4I4.0, because the university has less impact on topics of those works. However, BEng and MSc thesis works are compulsory for each of students, so their skillful management and education may prove to be more effective in acquiring considered C4I4.0, in the presented paper. Considering that, there were pointed out two the most relevant directions of future activities:

(1) Concentration on the effects of simulation technology and didactics process improvement.
(2) Building and improvement of the relationship with companies and formulating the awareness of C4I4.0 in order to create the need for BEng and MSc thesis works realization within the presented scope of research.

As a consequence of conducted research, it is stated that Key C4I4.0 are most fully developed in the didactic process. Considering that, it is assumed that students acquire competences appropriate for the current industrial revolution.

The major research limitation is related to confined scale of the research because the paper is focused on FlexSim application at one university. In the future, it is planned to expand the analysis and to compare various universities in Poland and Europe, where FlexSim is used. Moreover, it should be noticed that approach for competences for the Industry 4.0 may be changed as the industrial revolution is proceeding.

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Part II
Teaching

On the Use of Projects in Simulation Courses

Allen G. Greenwood

1 Introduction

Simulation is a process for applying modeling and analysis methods, through technology, for problem-solving and decision support. Modeling involves effectively representing the physical, logical, and data aspects of systems. The analysis involves correctly using the output from a simulation model for inference.

In this paper, simulation is applied to operations systems that are concerned with the production of goods or services. Such systems include manufacturing, logistics, transportation, health care, etc. Simulation is used to support both the design and management of operations systems. It is widely applied for process improvement and "leaning" operations. Four types of simulations are typically used in these domains—discrete-event, agent-based, continuous or systems dynamics, and Monte Carlo, with discrete-event being the most common.

Since simulation supports decision-making and problem-solving, it is fundamentally an applied technology [1]. Therefore, a key aspect of learning simulation is learning how to apply its methodologies and technologies. A common means to introduce the application of simulation is through projects.

This paper is organized as follows. Section 2 defines the basic course where simulation projects are used. Section 3 provides a brief overview of projects and project management that provide the foundation for the paper. Course projects are created and managed in three stages—Defining, Managing, and Assessing. Section 4 focuses on the Defining stage, and Sect. 5 briefly describes the Managing and Assessing stages. Section 6 provides concluding remarks.

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2   Teaching Simulation Modeling and Analysis

As computer technology becomes more powerful and commonplace, simulation has become widely used in a variety of courses and learning environments. For example, simulation is frequently used in various levels of education and training to demonstrate key concepts in science, engineering, business, etc.

While simulation is used in many types of courses, the focus of this paper is on courses that teach not just the use of simulation, but how to build simulation models and use those models for analysis. This is typically a three-credit-hour semester-long course that is required for industrial engineering and management science undergraduate and graduate degrees. It is normally an upper-division undergraduate course (oftentimes cross-listed for graduate credit) since it requires prerequisite courses in probability, statistics, and computer programming.

The course delivery mechanism may involve all lecture-type classes or a mix of lecture and laboratory hours. In a lecture environment, some of the lectures might be flipped. Flipping the classroom is a new trend where students are introduced to a topic outside of class and class time is spent practicing concepts, discussing, and performing other activities. A professor almost always delivers the lecture and a professor, instructor, or graduate student assistant with faculty oversight leads the laboratory section.

This paper deals with aspects that affect both the design and delivery (including assessment) of simulation courses. In order to avoid titles and semantics, such as teacher, professor, instructor, etc., a single term—educator—is used to refer to both the course designer and implementer roles.

Industrial engineers, operations researchers, and management scientists are the primary proponents for simulation in most organizations, and, they typically lead simulation projects. Therefore, for them to effectively use simulation to improve operations system, then any simulation course needs to include topics from each of the following categories:

- Applications, examples of how simulation supports decision-making and problem-solving.
- Methodologies, or theoretical foundations of simulation, including describing how discrete-event simulation works, defining random variables (selecting input probability distributions), designing experiments, analyzing and interpreting output from simulation models, random number generation, conceptual modeling, etc.
- Technologies, commercial simulation modeling and analysis software and supporting technologies such as spreadsheets, databases, etc.
- Practice, the notion of simulation as a process and as a project with stakeholders and a life cycle composed of activities from the definition of objectives through implementation and postmortem.

Projects provide an effective means to illustrate and demonstrate topics from each of the topical categories and to understand the relationships and interactions among them. Using projects in a course requires class time and thus means the number of

topics, the amount of time spent on certain topics, and/or course activities (tests, assignments, etc.) will be reduced or handled in a different manner, e.g., via online videos and tutorials. This presents educators with a difficult dilemma—trading off what to include, or not include, in a course, how to best cover the material, and how to assess performance.

The author believes projects should be included in every simulation course. Therefore, educators need to carefully assess and balance the topical coverage in order to enable students to gain project experience as well as obtain a basic appreciation of how simulation is applied and a fundamental understanding of salient simulation methodologies and technologies. The course should prepare all students to be advocates for the use of simulation, appreciate its power and limitations, understand what is required to use simulation, and be an effective participant in a simulation project. It needs to be recognized that in order to be a simulation specialist, students require further study and practice.

3 Projects and Project Management

While students carry out projects in a simulation course, the educator must define, manage, and assess the entire set of projects. However, before discussing each of these stages, this section provides a general overview of projects and project management, primarily from the Project Management Institute's (PMI) perspective (for information on PMI, see, for example, [7, 8]).

3.1 Projects and Project Management

According to PMI, "(a) project is temporary in that it has a defined beginning and end in time, and therefore defined scope and resources" [9]. All projects, large or small, exhibit some common characteristics. Some of these characteristics are described below in the context of a modeling and analysis project in a simulation course.

Each project has a set of **stakeholders—**people who affect, or are affected by, a project's activity or outcome. The educator and students are obvious stakeholders, but if the project is done for industry, there are likely multiple stakeholders within the client organization. In any case, stakeholders need to be identified and their **roles** in the project defined.

The primary stakeholder in any project is the **customer** since the main goal of a project is to satisfy a customer's need(s). In a simulation course project, the educator is the customer. However, if the project is done for industry, there is a second customer, referred to as the client, with a different set of needs. In any case, customer needs must be articulated and converted into clear project **objectives**.

Every project is **unique** and **dynamic**; i.e., every project is different and will **change** over its duration. These two characteristics insert **risks** and **uncertainty**. The

more types of systems and problems that are considered, and the more clients that are involved, the more uncertain the course's effectiveness becomes. As uncertainty increases, more time must be allocated, either in class or outside of class, to deal with the questions and problems. Some of this can be dealt with through electronic telecommunications, but still must be planned.

Projects are temporary, have a **life cycle** with clear start and end points, and evolve through **phases**. It is commonplace in projects for the end point or **due date** to slip due to problems and uncertainties. However, in course projects, there is very little flexibility in when a project can be completed since the course has a fixed end date. As a result, other factors besides due date must be adjusted to accommodate changes.

A project is actually a **process**; i.e., it involves a coordinated flow of related activities across time and place that collectively creates value for a customer by converting inputs into outputs. Each activity consumes a diverse set of scarce **resources**. The primary resources in a course project are educator and student time and their time become key project constraints. Therefore, course project activities must be **planned** and **managed** in order for the project to be effective and successful.

According to PMI [2], project management is a process and that process has a life cycle composed of five phases:

(1) Initiating—setting overall project direction and defining project objectives. This phase is completed by the educator before the course begins.
(2) Planning—defining a workable scheme to accomplish an objective. The educator develops an overall plan before the course begins and the students develop a plan at the start of their project.
(3) Executing—carrying out the plan. The students perform most of the execution, with the educator becoming involved as necessary, primarily as a coach and provider of technical support. In addition, the educator may assume the role of a student project's customer.
(4) Monitoring and Controlling—measuring progress and taking corrective action when necessary. Students monitor and control their projects. The educator monitors and controls the set of projects, or program. They may also become involved in controlling a specific project, at the request of a student project team, as a result of student monitoring.
(5) Closing—accepting the product of a project and bringing the project itself to an end. Students close out their project when they have completed their reports and presentations. The educator closes the projects once feedback and grades are provided to the students.

The notion of a course project is basically from the student's perspective—each student as a member of a group/team carries out a single simulation project. However, from the educator's perspective, the course project is really a program since a program encompasses "a series of projects that in aggregate achieve an overarching set of objectives" [4]. Therefore, each student project should be managed using PMI's phases, whereas the educator manages all of the projects as a program.

For course simulation projects, the program is composed of the following three stages, each of which is described in subsequent sections, Defining, Managing, and
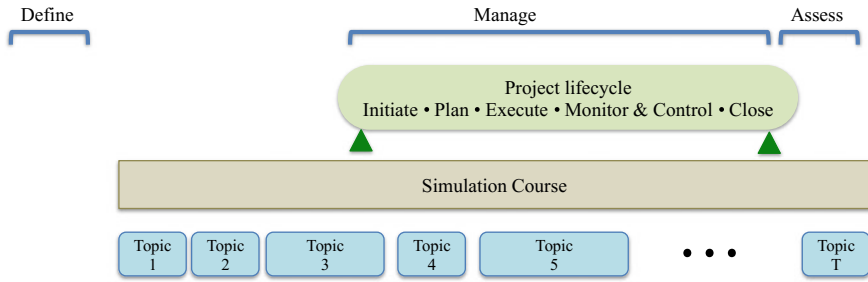
Fig. 1 Relationships between program stages and project life cycle phases

Assessing. At a minimum, the Defining stage should be completed before the course projects begin, and preferably, the stage should be concluded before the course itself begins. Much of the information about course projects should be contained within the course syllabus that is distributed at the beginning of the course. The Managing phase mostly aligns with the course project life cycle. The Assess phase is primarily conducted after the projects have concluded, but typically include some assessments that occur during the project, such as project definitions, interim status reports, preliminary results, draft recommendations, etc.

The relationships between program management stages and the project life cycle phases as it relates to a simulation course are illustrated in Fig. 1. Overlaying this information with the course's planned schedule of topical coverage enables the topics and project to be properly coordinated and integrated. This helps ensure that the topics needed for the project are covered in a timely manner and identifies where breaks in the topical coverage need to occur in order to deal with project issues. Egilmez [3] provides, via a flowchart, a good example of how to define linkages between lectures, labs, and projects in a simulation course.

4 Defining Course Projects

Using projects in a simulation course requires careful planning and management. In fact, the author considers the Defining stage to be the most important. Inadequately defined projects lead to increased management time during project executions, distractions from the purpose and value of projects, schedule changes, student and educator frustrations, etc. Some of the definitional factors that need to be addressed during the Defining stage are described by Greenwood [5]. This section defines, expands, and structures these factors. All of the factors need to be addressed and defined prior to the start of the course.

One way to structure the factors is with the proverbial 5Ws (who, what, where, when, why) and How. In the case of simulation course projects, it is important to

address these in three steps—first define *why* and last define *how*; the other four Ws are considered between these two steps. This moves the definition process from the broadest, most strategic considerations to the more detailed, tactical aspects.

4.1 The Why Question Determines Influence and Scope

Defining course projects should start with why—why is there a project component in the course? This question should be answered in the context of the degree to which the project supports the four topical categories that are defined earlier: applications, methodologies, technologies, and practice. Clearly defining the project's role is major step in establishing the project's scope within the course.

Answering the why question leads to defining the project's **influence** on the course, expressed both in terms of class time (lecture/lab) and its weight in determining student grades. While this can initially be stated as a percentage of contact hours and percentage of final course grade, these must be explicitly defined before the course begins and included in the course syllabus.

When considering class time, time needs to be allotted for definition, clarification, feedback, etc. While some of this can be handled through electronic media, some in-class time needs to be allocated to the project. It is very important to dedicate at least one class period after the project is completed for student presentations and/or discussion of results and lessons learned.

The four topical categories (applications, methodologies, technologies, and practice) also help establish the project's **scope** within the course; scope can be expressed in terms of the diversity of the systems and problems that are considered. For example, if a key role of the project is to illustrate ways simulation supports decision-making and problem-solving, then the project should involve multiple and diverse types of systems, domains, and problems. Similarly, if the role of the project is to illustrate many aspects of a simulation software package, then the project should again involve multiple and diverse types of systems and problems. On the other hand, if the intent is to illustrate the basic features of software, then much less diversity is needed.

The two scope factors—the **system**(s) and **problem**(s)—are addressed concurrently. Example systems include the operation of a discrete manufacturing cell or production line, continuous production process, distribution center, surgical suite, fast-food restaurant, etc. Example problems to address via simulation include which layout, processing rule, operator assignment, schedule, etc., is better; i.e., which option provides the most throughput, least non-value-added time, least inventory, etc. The relationships between systems and problems are represented in Table 1a, b in terms of quantity and definition responsibility, respectively.

In Table 1a, the simplest project structure is having everyone in the course address the same problem within a single system. This involves the least project time and risk. However, it can support most of the course's topical categories, including illustrating methodologies, demonstrating technologies, and providing a sense of how simulation is applied. It is not very effective in demonstrating the wide applicability

Table 1 Key components for defining course project scope

(a)				(b)			
		Number of problems addressed				Problem definition	
		One	Multiple			Faculty	Student
Number of systems	One			System definition	Faculty		
	Multiple				Student		

of simulation in terms of systems and problems, but that can be addressed through other means besides a project. Obviously, the other extreme—using multiple systems and multiple problems—requires significant educator oversight, consultation time, and management and invokes significant risk.

In Table 1b, the simplest project structure is having the faculty specify the system(s) and problem(s) to be addressed. Having students choose their own systems and problems makes the project more interesting to them and provides a very valuable learning experience. It also provides more diversity of application. However, it requires significant educator oversight, consultation time, and management and invokes significant risk. Student-defined systems oftentimes require considerable time to define and scope, which while providing good experience, may limit the extent of simulation modeling and analysis.

Risk is an important factor to consider when defining the role, influence, and mechanics of using student projects in a simulation course. Risk must be balanced and traded off against expected outcomes and impacts of using projects. We all want the best outcomes and most positive impacts from our courses, but like in finance and other areas, those things that have the highest expected rewards come with the highest risks. An honest assessment of risks needs to be addressed early in course planning. For example, it is not advisable for a new untenured assistant professor to use multiple, student-defined projects early in their academic career; the workload will be high and detract from research and risk is high to receive negative student evaluations. One way to mitigate risk is to gradually introduce projects into a course by slowly increasing the breadth and depth of projects.

4.2 The Use of What, Who, Where, and When Questions

As described above, the *why* question specifies the influence of a project on course time and assessment. It also leads to defining the project scope in terms of the number of systems and problems to consider, and it stipulates who will identify and define the systems and problems.

Therefore, at a high level, the *what* and *who* questions are driven by the responses to the *why* question. For example, the scope of a simulation course project might consist of three alternative systems—one each from manufacturing, logistics, and health care—with each student choosing which system they want to work with. In this case, the educator defines the systems, but the students decide the problems that are addressed in each system. In terms of *what*, as defined in Table 1a, this is an example of a Multiple-System Multiple-Problem project. In terms of *who*, as defined in Table 1b, this is an example of a System-Faculty, Problem-Student project.

The *what* aspect requires further definition in that each system needs to be defined in terms of its specific system boundaries, components, interactions among the components, operations logic, work hours, reliability, layout, performance measures, constraints, etc. If this is educator defined, it should be completed before the start of the course. If this is student defined, students must be provided with methodologies and tools for appropriately defining the system, including examples, templates, and diagrams. Therefore, the educator needs to gather these resources and make them available to students. The educator also needs to decide how students learn to use the resources—lecture or lab time in the simulation course, prerequisite course, self-learning, etc. Regardless of the means for defining the system, students must be provided adequate time to properly define the system.

The *who* question also involves specifying each project's customer. The educator may perform the role of customer or the students may interact with a real organization. In either case, a protocol should be established that defines the manner of student–customer interactions, including points of contacts, means of communication, data handling, etc. Some organizations require nondisclosure agreements or other types of signed legal documents or they may require a review of any material that is to be released. Obviously, such agreements should be avoided if possible since they can present a variety of complications, delays, and risks.

Related to the *what* and *who* questions is the total number of projects in a course. If the entire class addresses the same problem in the same system, there are multiple, very similar projects. This situation is obviously the easiest to define, manage, and assess. Since comparisons are quite easy, the assessment and grades are likely to be fairer. Competition may be used in order to increase quality. Also, there is the opportunity for collaborations among groups on some of the more challenging aspects of the project, e.g., modeling the arrival process, representing complex process logic in a system, constructing 3D objects, data collection for analysis, etc. By contrast, the opposite is true—diverse systems and problems may provide the richest learning environment, but will certainly be much more challenging to define, manage, and assess. This is a difficult tradeoff that the educator must make and is oftentimes driven by the *why* question.

Also related to the *what* and *who* questions is the formation and composition of the project teams/groups. The first issue is who forms the groups and by what means. For example, the educator may randomly assign each student to a group, students form their own groups, etc. Even if students form their own groups, they should be provided guidance on how to do so, e.g., not solely by whom you know, but considering skills each person brings to a project and the types of skills needed.

Group size is typically specified by the educator, possibly as a range, e.g., no fewer than three persons and no more than five. While more of a *how* issue, students should know how they will be evaluated, e.g., a portion of each student's grade is based on a peer review.

Several *where* questions should be considered during the Definition stage. If the students are to define their system, then where will they acquire the needed information? This may involve on-site visits, conference calls, web or library research, etc. Typically, client-based projects (non-educator defined) provide better learning experiences; however, they involve more coordination, and thus more time, as well as more risk. For example, client-provided information may be delayed due to shifting priorities; however, course dates have little flexibility. Another option is to base the project on a detailed case study, which involves no customer interaction—all information is supplied or assumed. Mesquita et al. [6] provide a good example of a comprehensive case study developed specifically for simulation modeling and analysis courses.

Also, *where* students will do their simulation modeling and analysis needs to be considered. This is primarily a function of software licensing—the license may restrict students to the laboratory hours or it may allow them to work anywhere anytime via university server access or individual student licenses. Another question is where the final presentations will be made—in the classroom or laboratory, in a special venue, or at the client/customer's site. It is best to require all students to attend all final presentations so they can learn from the other presentations and discussions. If a customer requires a presentation on their site, it is best to schedule that as an additional activity.

The *when* questions primarily pertain to scheduling overall due dates and milestones, such as interim reviews and final presentations. These key dates should be defined before the course begins and be included in the syllabus in order to ensure the dates coordinate with other course activities (topics, tests, holidays, etc.) and that students have the maximum lead time. Students are encouraged to build their own project plan and identify their own milestones that are needed in order to meet the course's key dates.

4.3 The How Question Determines the Ways and Means

In many curricula, students do not have formal project management training and experience prior to taking the simulation course. Therefore, for the course project to be successful, students need to have resources available to help them define and carry out the course project. These are the ways and means of the project and should be made available to students prior to the project start. Therefore, they need to be addressed during the Defining stage. Project management resources can be provided through many formats—templates, examples, video tutorials, readings and reference materials, etc.

The textbook of Beaverstock et al. [1] stresses the application of simulation and provides chapters on the professional practice of simulation and simulation project management. In addition to discussing these topics, they include examples and templates of simulation project documentation that can be customized to fit a variety of course project needs.

A few of the key means, categorized by project stage, include:

Planning—students develop a plan at the start of their project based on the educator's overall plan.

- Problem Definition—brief system description, statement of project objectives, description of key performance measures, definition of primary decision variables, and definition of scope (system boundaries, boundary assumptions and conditions, and operational assumptions).
- Operational Description—detailed description of the system (including diagrams, photos, system data, etc.), definition of key stakeholders, conceptual model, special logic to be considered, references to important documents, etc.
- Responsibility Matrix—the roles and responsibilities in a simulation project (e.g., modeling, analysis, reporting, management) and their allocation to team members, signoff by all team members.
- Project Plan—definition and timing of key activities and milestones including validation and verification plans.

Monitoring and Controlling—students measure and report progress, taking corrective action when necessary.

- Status/Progress Reports that compare actual progress with that which was planned and provide adjusted/revised plans as needed. While monitoring is a continuous activity, the reports are typically prepared at specified milestones during the project.
- Preliminary modeling reviews with the customer including model validation and verification (V&V). The V&V results are typically included in the project's final report.
- Draft reports and presentations.

Closing—students present results and recommendations, typically through both written and oral means, and contribute to project postmortem.

- Model Documentation, including simplifications and assumptions, validation and verification results, input analyses (e.g., selecting probability distributions and other data analyses), model views, special logic definition and implementation, naming convention, etc.
- Analysis and Results, including tactical information (e.g., number of replications, model run length, starting conditions), experimental design, rationale, results, and analyses, recommendations, etc.
- Feedback to the educator on pros and cons of the project, as well as suggestions for improvement.

5 Managing and Assessing Course Projects

The main emphasis of this paper is the importance of, and the means for, properly defining simulation course projects. However, to be effective, the project still must be managed and assessed. Therefore, this section briefly describes each of these stages.

5.1 Managing Course Projects

Managing course projects begins when the project is introduced into the course and ends once the projects are completed, including final presentations and postmortem.

While most of the educator's managing activities occur during project execution, especially if the course project is well defined, it is important that the student teams develop their own plans considering their customer, resources, constraints, etc. Therefore, the educator needs to ensure students have defined key activities and responsibilities, established milestones, etc., before executing their project. Some of the means for developing good plans are introduced in Sect. 4.3.

As with any project, good management means monitoring the status of projects over their life cycle. This is typically done through student-provided progress reports. Of course with today's telecommunications capabilities, more informal means for checking status and dealing with issues in a timely manner are available, e.g., email, social media, chats, and audio/video calls.

5.2 Assessing Course Projects

As discussed earlier, it is important to clearly establish early, before the course begins, the role of the course projects and their influence on course time and the determination of student grades. At a minimum, the percentage of the final course grade that is based on the project needs to be specified when the course begins via the course syllabus. Also, the weighting of the various project components should be provided as early as possible, at least when the project begins, but preferably earlier.

It is also important to specify how the project components will be assessed by both defining the evaluation criteria and identifying who will do the assessments. Example evaluation criteria include how well the system is defined, completeness of the conceptual and programmed models, correctness of analyses and interpretations, clarity of explanation of results and recommendations, quality of the content and delivery of the project presentation and response to questions, etc. Oftentimes, the educator, following a standard rubric, assesses all parts of the project. However, the project's customer or a panel of external reviewers may assess some of the components. Normally, all students in a group receive the same grade in each component.

In addition, students should assess each other's performance and contributions through a peer review. The form the author uses considers each member's: cooperativeness, quality of input, quantity of input, acceptance of workload, and overall effectiveness. Each student scores each group member, including himself or herself, using a five-point scale. The reviews are strictly confidential. The results of the peer reviews are used to convert group project grades into individual grades. The author uses peer reviews to identify outliers, those individuals who contribute significantly above and below the norm.

The educator should solicit student feedback about the project, preferably through a survey at the end of the course that is separate from the standard university-administered faculty evaluation form. Feedback can contain what the students learned linked to course objectives, e.g., how well did the project help them to understand how simulation supports decision-making, how simulation projects are carried out, the importance of planning, etc. Feedback can also be obtained on what students liked and why, what they did not like and why, general suggestions for improvement, etc.

6 Conclusions

If an educator considers simulation to be both an important means to support decision-making and problem-solving and that effectively addressing the application of simulation is an important aspect of a simulation course, then projects are likely to be a significant element in the course. While projects can be a very beneficial means of pedagogy, they require a lot of work, time, planning, and managing and can inject significant risk into a course.

This paper contains some ideas, heavily based on experience, for making projects a significant and effective part of a simulation course. The basic principles of project management must be employed both by the educator and the students. The educator needs to view course projects as a program and manage them as such. Focusing on the Definition stage increases the likelihood of success and helps to mitigate risks. Communications, as with most things, is paramount throughout the course, including setting expectations, dealing with questions and problems, and assessing performance.

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Increasing High School Students' Interest in Industrial Engineering Through a Summer Camp

Emre Tokgöz

1 Introduction

Students pursuing undergraduate engineering degrees face academic challenges that result in dropouts from engineering degrees. The retention rate of engineering students is a well-known international concern that is also reflected in peer-reviewed research that pedagogy researchers try to identify and solve the associated problems [1]. It is reported by educators/researchers of Texas A&M University at Qatar that freshmen students who join the University face significant challenges in an introductory level engineering course and thus struggle in completing their engineering degrees [2]. The academic cultural change from high school to higher education academic institutions impact many high school students ability to keep up with the engineering degrees; smoothening this transition appears to be a need at the high school level. Recognizing this need, the researcher developed and taught an online summer camp to increase high school students' interest in Industrial Engineering and simulation concepts. This online worldwide summer camp was offered for the first time during the summer of 2017. The main goals of the camp included 10th–12th grade high school students' to

- be able to understand simulation concepts and develop simulation models by using FlexSim simulation software;
- have a smooth transitioning from high school to university after gaining prior knowledge of simulation concepts;
- understand what industrial engineering degree has to offer if chosen as a career from simulation perspective.

FlexSim is a software used in various real-life applications including but not limited to transportation [3], facility allocation [4], production planning and control [5],

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logistics [6], and health care [7]. The developed summer camp was a high school student-friendly version of the simulation course taught by the author for the Industrial Engineering Program at Quinnipiac University that is located in the North-East coast of the United States of America. The participants are invited to participate in the camp via a flyer and FlexSim's website (https://www.flexsim.com/qu-summer-camp) where the requirements to participate in the summer camp are listed. The camp development explained in this work can help professors to understand the basics of high school students' simulation interests through the developed camp content and surveys. It can also guide some of the other researchers to smoothen the transition process from high school to university level education.

The rest of the article is designed as follows: The camp design components such as objectives of the camp, the objectives of the assignments that are fulfilled by the camp participants, and the content of the camp are explained in Sect. 2. Section 3 is devoted to three different types of FlexSim models developed by the camp participants as a part of the assignments and the flowchart examples developed by the participants. Section 4 is reserved to the qualitative and quantitative analysis of the camp participants' simulation learning experience; the qualitative aspect of the participants' thoughts followed through the surveys while the quantitative results consisted of the corresponding statistical results. Concluding remarks and future work are stated in the last section.

2   Camp Design

In this section, the structure of the summer camp will be briefly explained; this structure included the objectives of the camp; the assignment objectives of the camp; the lectures developed for the camp.

Objectives of the Summer Camp:

(1)   Understand and implement basic statistics concepts for using as a part of FlexSim simulation implementations.
(2)   Implement FlexSim for managing healthcare simulation.
(3)   Implement FlexSim for manufacturing simulation.
(4)   Implement FlexSim for managing service systems' simulation.

Assignment objectives of the 1st Worldwide Online Summer Camp included

- playing a game to understand the essentials of Industrial Engineering by which students are expected to submit the highest score;
- understanding flowcharts and how they work in simulation;
- understanding statistical distributions' basics for FlexSim simulation use;
- developing FlexSim models through video instructed materials and submitting these models as assignments;
- developing and improving FlexSim simulation models through instructed videos;

- explaining the development aspects of the existing simulation examples and lessons learned;
- implement manufacturing, health care, and service systems' simulation solution by using FlexSim.

  The lecture content of the camp included

- online lectures prepared by the professor explaining simulation and statistics related concepts;
- online videos available that explain applications of FlexSim;
- examples of course projects implemented in professor's simulation course by using FlexSim;
- industrial engineering basics and how simulation can be used in a variety of real-life situations.

  The assignments are related to the lecture content in the way the students

- redeveloped some of the models that the lecturer developed in the instructional videos;
- solved questions to cover the objectives of the camp;
- implemented test runs on developed models to fix problems/issues that exist in a developed model;
- fixed issues on a pre-developed simulation model for determining feasible solutions;
- determined statistical distributions for a simulation model to run without any inventory excess.

3 Camp Participants' Involvement

In this section, examples to the types of models developed, the flowcharts, and camp participants FlexSim application choices will be displayed.

3.1 Developed Models and Assessment

The participants were motivated to pay attention to the model development by using different techniques. The instructional videos for simulation model development were posted at a web-based instructional environment and students' interacted with the professor via email. Professor assessed the camp assignments based on the expectations for the corresponding developed models. Student assignments were based on three different simulation model development techniques. These three different ways of model development model and their examples are explained in this section.
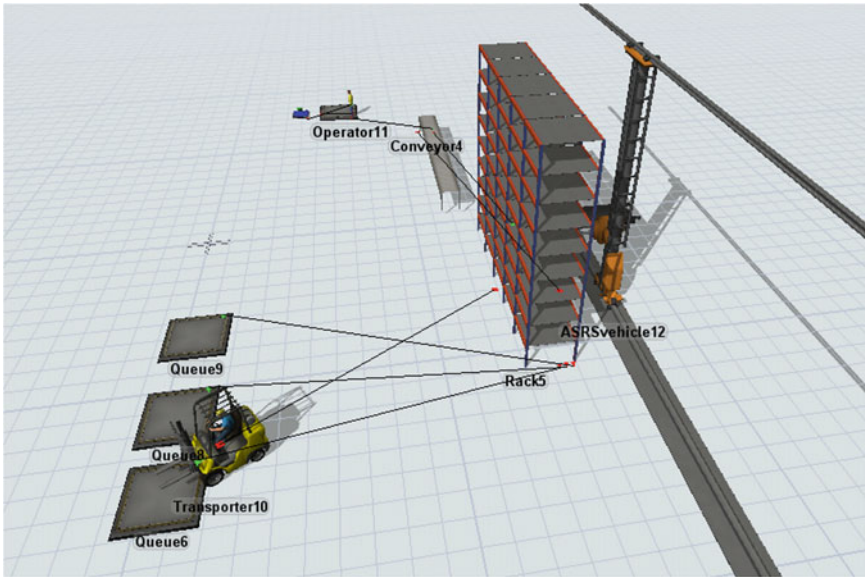
Fig. 1 A warehouse environment with automated and manual workflow

Self-developed Models

This section is reserved to display some of the work that is completed by the camp participants. Figure 1 is an image of a model that is fully developed by one of the camp participants for the second assignment of the camp. This model displays the interaction of several advanced warehouse components in FlexSim and how and where can congestion occur in a warehouse. The "ASRSvehicle" and "Transporter" task executers in FlexSim are useful for high school students to have a good start-up on understanding how task executers work in real life. Automated conveyor and operator interaction was another important aspect of the model development to display how manual and automation can interact in warehouse operations. The run of the model displays a congested conveyor belt where the "ASRSvehicle" cannot keep up with the automated conveyor feeding that results in a bottleneck.

Fully Instructed Models

The participants of the camp are asked to mimic some of the models to understand the model development essentials. The posted videos guided students' to develop the same model step-by-step. This mimicking process helped students to understand resource utilization of FlexSim tools which is a necessity for model development as stated by one of the participants:

> The best way to get practice in the program, in my opinion, is to copy all the demonstrations in the videos. With this method, you will get used to using FlexSim, and all of the different commands.
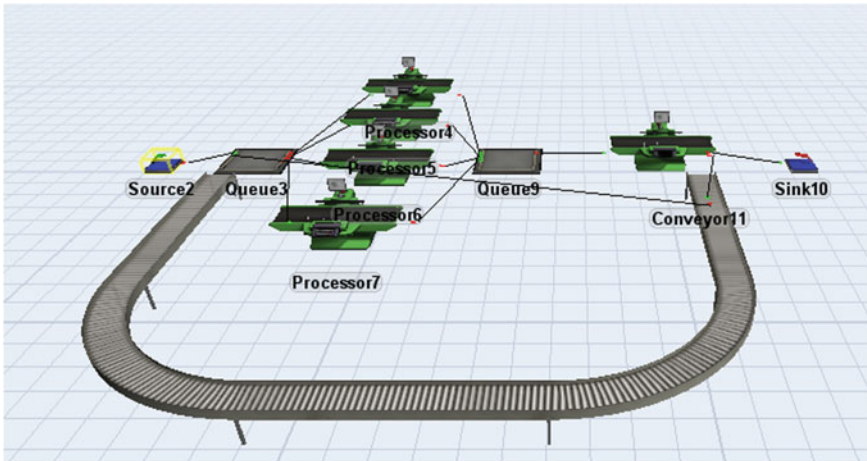
Fig. 2 The development of a manufacturing environment with several processors and a u-shaped conveyor belt

Figure 2 is an example of such a developed model by one of the participants. The same model is developed by all the other participants by using FlexSim.

All participants of the camp had a good working knowledge of how to develop the model and were capable of developing the model explained in Fig. 2.

Hybrid Models

Hybrid models are developed by the camp participants after watching the video lectures and modifying models for the job-balancing problems posed in these videos. For instance, Fig. 3 is a FlexSim model explained by the professor for how parallel processing works in a production line; however, the camp participants are asked to modify the model for the three parallel processors to keep up with the incoming raw material processing. The raw materials that are received from Source2 in the figure below are distributed to the three parallel processors with the same capability; if the raw materials are not processed by anyone of the processors then they got stored in Sink6. The items stored in Sink6 indicated inefficiency of the system in place since these raw materials were not processed throughout the system. The students were expected to determine a job-balancing solution in this simulation exercise to reduce the number of raw materials stored in Sink6. All the participants were able to implement a solution to the posed problem; however, they were not expected to find the best optimal solution to the problem.

Another example of a hybrid model was related to supermarket operations displayed in Fig. 4. Assuming all cashiers have the same capability to serve customers and customers arrive the grocery store by respecting exponential distribution and shopping in the store, the goal of the assignment was for camp students to determine the optimal number of cashiers to minimize the number of customers waiting in the line with the minimum cost to the store manager. This was a design of experiment
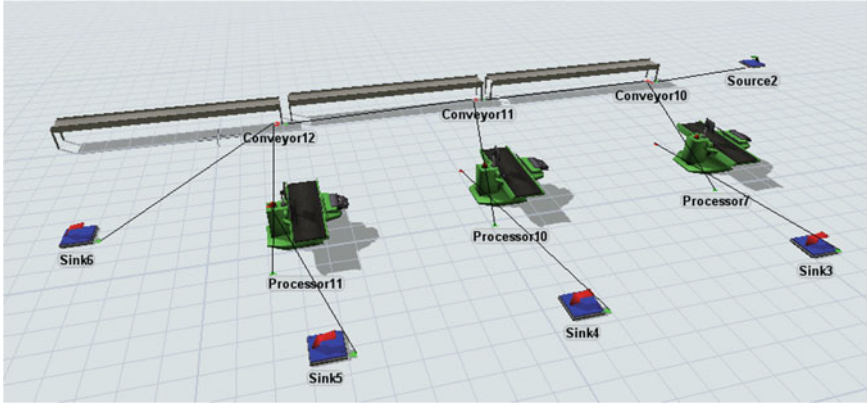
Fig. 3 A production line with three processors and automated conveyors
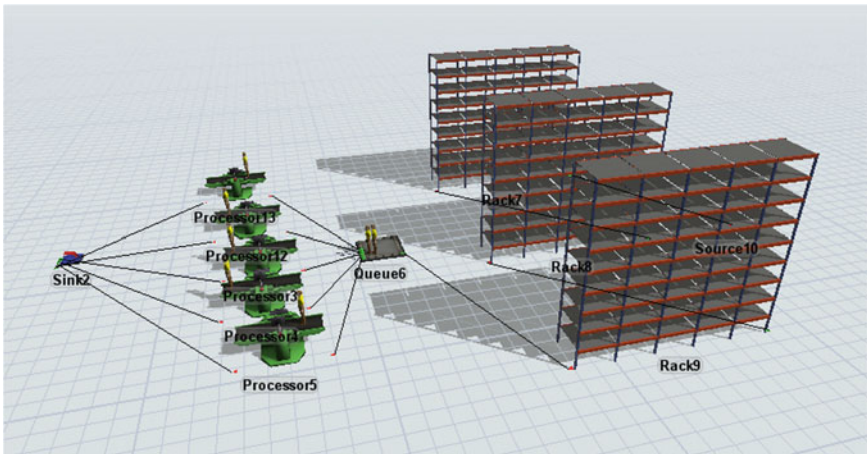
Fig. 4 A supermarket simulation model with single line and several servers

project that one of the participants particularly commented on and mentioned it to be the best exercise of the camp. All the camp participants had the ability to develop and find a solution to the posed supermarket problem that was meaningful in the context of the problem.

Flowchart Development

An essential component of simulation model development is creation of the corresponding flowchart; therefore, one of the summer camp development objectives was to structure a flowchart for a simulation model developed beforehand. The following are the flowchart examples of some of the summer camp participants for the Zombie Attack game by FlexSim [8]. Figure 5 appears to be a professionally developed

Flexsim Zombie Game Flowchart

Start:
Canisters/s= user preference
In simulation:
1 yellow worker
1 white worker
1 core charger
1 cart
1 centrifuge
Print(Initial cash
supply:$1000)
Total Money made: $0
Total Money spent:$0
Cash supply= $1000
Model view: complex

For 720 seconds

When canister is produced: cash
supply(cs)=cs-$15
Total expenditure(te)=te+ 15
When item/worker bought:
If (cs<cost): do nothing
else:
cs=cs-(cost)
te=te+(cost)

When energy cell is taken by
zombie:
Money earned(me)= 50$-(elapsed
time) x (energy loss per second)
Total income(ti)=ti+me
cs=cs+me

If (zombie>energy cell): damage
to equipment per zombie

Start when run is
pressed

Stop when time is
up

Fig. 5   An example of a flowchart developed by one of the camp participants

flowchart that contains too many details about the game for a flowchart; it does not necessarily reflect the essentials of the flowchart covered in the camp.

The two flowcharts drawn by the summer camp participants in Fig. 6 are aligning mostly well with the meaning of the flowchart during the camp; however, these two flowcharts are not containing the details of the expected answer to the question.

The following figure, Fig. 7, is an example of a hand-drawn flowchart. Even though the camp participant intended to sketch the flowchart, the outcome was only the actual graph of the Zombie Attack game layout.

Overall, about 65% of the flowcharts reflected the actual expectations of a flowchart in reality. This result is the indicator of a need for more attention to be given to the flowchart development and further information development for improving the camp participants' flowchart background.

3.2   Camp Participants' Application Choices

The summer camp participants are provided with a set of videos with FlexSim applications and asked to write a reflection essay of what they thought is the best application and why they chose this application. While about 75% of the participants like the FlexSim's restaurant applications the rest of the participants liked the dental care
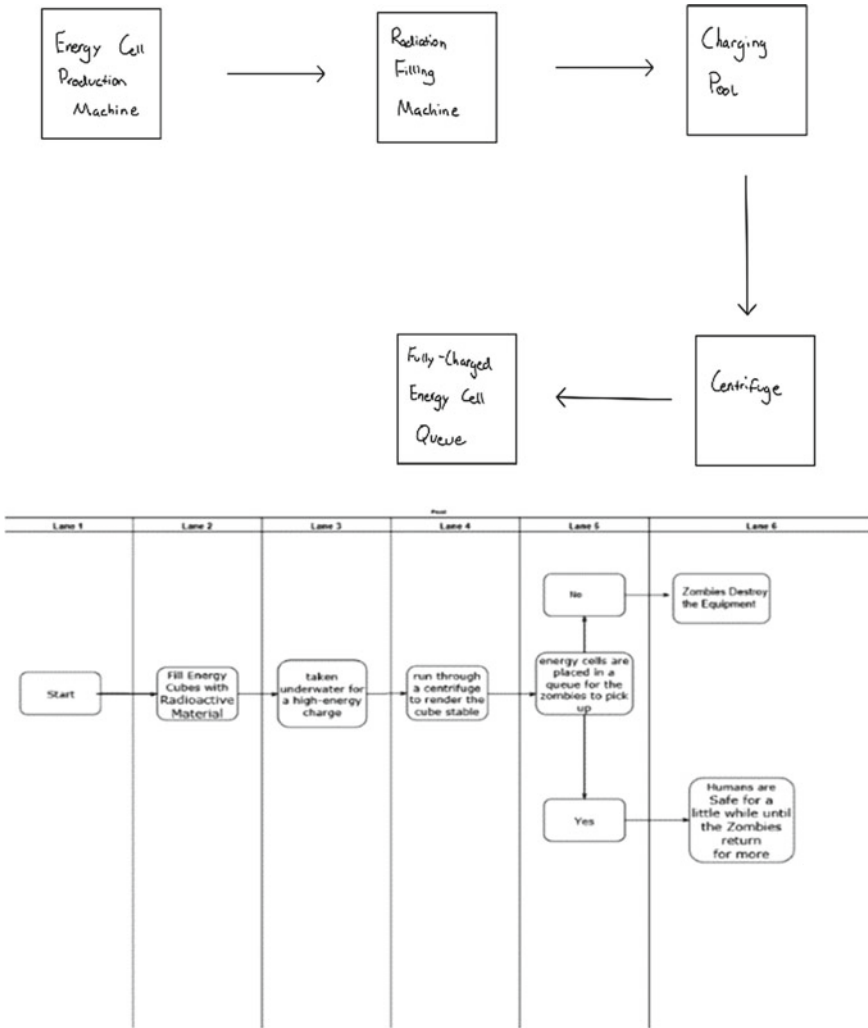
Fig. 6 Examples of two flowcharts aligning well with the definition of the flowchart

application. Some of the comments in the essays of the participants showed their interest in FlexSim and what it has to offer in applications:

…While this Flexsim application is extremely interesting it is also very beneficial to the owner of this restaurant because it can provide them with information that they may have never known. This application can also provide the user statistics on things such as cashiers or food stations. This information can also go into great detail and provide the user with influential facts. If they wanted to they could also add the money system that is seen in the zombie game with each worker costing something and each particular food costing a certain amount to make. Than as the customers move through the user can see how much profit they can make based off the model…
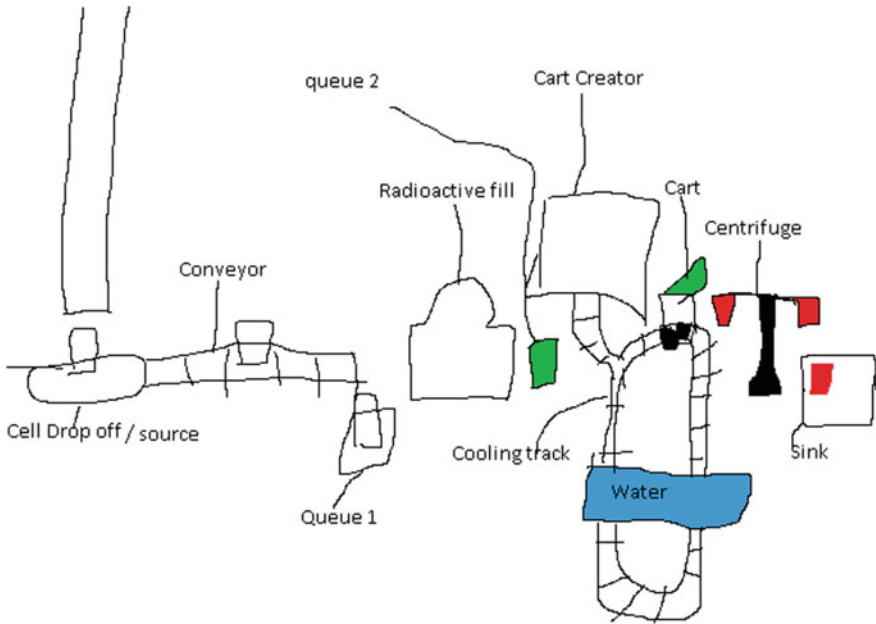
Fig. 7 One of the camp participants intended flowchart that was the drawing of the facility layout

…Out of all the different potential application areas, I chose to write about the one on dental care. Looking at each different application area made me realize how powerful FlexSim really is. At the very beginning of the program, my impressions were that FlexSim is limited to factory production examples. However, as I learned more about FlexSim throughout the program, and especially through all of the examples in Lecture 14, I recognized that FlexSim can be used to simulate so many different processes, and is able to aid in making them more efficient…

The camp content increased one of the participant's curiosity in applications:

…Also, this system only works in a hypothetical restaurant where there are only four things on the menu: cheeseburgers (without cheese), nuggets, fries, and coke. This is a bleak menu for the gluttonous modern day consumer to choose out of. It makes me wonder how actual fast food chains with a dozen different burgers and other food items prepare their food…

4   Qualitative and Quantitative Data Analysis

Five participants of the first online summer camp offered by the Industrial Engineering Program at Quinnipiac University are asked to complete a survey for immediate feedback on the camp development structure at the end of the camp period. This section is devoted to the quantitative analysis of the camp participants' comments

as well as some of the camp participants' thoughts on the camp development and participation outcomes in their own words.

Nineteen-day camp period training was enough for several participants to have the confidence of simulation knowledge and pleasure of attendance to the camp:

> …I learned the mechanical and human components of a production system and what they did. Then, I learned how to link them together in an input-output or manager-managed relationship. This alone could create a simple system, but in order to make a full, complex system capable of complex tasks, I had to learn about labels, item types, triggers, and statistical distributions. Now, I am confident that I could create a simulation upon instruction.

> …My camp experience was a really fun and unique one. Not only is this the only online camp that I have been a part of but it is also the only academic based one as well. This was a great introduction to a topic that I like and plan on pursuing in college after I graduate high school this year…

> …As the camp is now completed, all I can say is that I am extremely grateful to have been allowed to participate in the program. I have been interested in Industrial Engineering for a while now, but have not been able to gain much experience in this area. That is, until I registered for this camp. The content presented was very fascinating. Professor explained it in a way that allowed me to understand everything he taught. The concepts made sense to me, and Professor also provided video walkthroughs of what he was made in FlexSim, and it was very helpful to follow along what he created in these videos. At first, I was a bit overwhelmed … but watching the video lectures provided by the Professor… made it much easier to understand….

The increase in camp participants' confidence level is particularly important during their late high school years because this attained ability is a clear indicator for them to realize that they have the ability to understand and solve engineering problems by using simulation software. This realization of understanding and implementing simulation concepts is a motivating factor for students to choose industrial engineering as a profession.

The short camp experience also triggered students' interest on engineering applications and how simulation can be used in real-life applications:

> …overall, this was an enjoyable experience. I love learning about things that can be practically applied to real life, and this was it. I especially liked lecture 14 where I could watch different real life applications of Flexsim. I wrote a summary about the Macdonald ordering process, but I watched all the others too.

> Industrial Engineering is a broad and interesting topic that I have come to enjoy. In the summer course, I learned the basics of one of the most complex engineering's out there; Industrial Engineering. During this course I learned how to use the application, "FlexSim"…

> …In "FlexSim" I was instructed to develop several models of working systems from the real world…

> …My favorite part of the program was Lecture 13, with Lecture 14 coming in a close second. I really liked Lecture 13 because I got to develop an actual model of a supermarket, and work on solving the problem of how many cashiers should be present. This was a very cool real-life application of FlexSim and how it can be used. Lecture 14 was very similar. It showed me a huge variety of ways that FlexSim can be used, such as the dental industry, or the fast-food industry. However, I liked Lecture 13 a bit more just because I got the chance to create the FlexSim model, and worked on optimizing the way it operated…

There were comments on how the camp design structure and online content can be improved for future camp developments:

…If I had to make a few suggestions on how to make the course better, it would just be about the overall quality of the videos and the specificity of assignments. Videos like the ones in Lecture 6 were easy to watch and easy to follow because of the clear screen and narration. However, in videos like the one in lecture 10, the white noise was really loud and the screen was blurry.

The assignments appeared as a challenge for some of the camp participants which was expected by the instructor/researcher since the true ability of the students would not be recognized without challenges:

…the assignments would have been easier to do with more specific instructions- especially considering that this is a course for beginners. I found assignments 4 and 5 especially difficult because the instructions were a little vague.

The camp was very well taken by all the participants and they highly recommended the camp to other students:

I would highly recommend this course to any student interested in business management, statistics, graphics, or even computer science (as it highlights the importance of computers in the business world).

…I think that this camp was a valuable experience for my future and I think that it will give me a better understanding of what Industrial Engineering is all about…

Three of the camp participants outlined their before and after the camp experiences as follows:

In today's world, efficiency's the name of the game. It's all about maximum output in minimum time. But how are you going to assure that the system you are about to implement is the right one? Before taking this course I assumed that it was up to guesswork and mathematical projections. I had no idea that simulation had gotten to the point where they could realistically predict how a hypothetical system would run long term. Now, I can completely understand why corporations in charge of a large amount of resources would run a simulation before real life execution.

…During this camp, I learned a lot of new concepts, and it reinforced my interest in industrial engineering through the interesting lectures and hands on experience. I thoroughly enjoyed this camp, and would like to thank the Professor for allowing me to participate…

…This camp was very eye opening to me to give me a little taste of the amount of work that i will have to complete in college. However having this camp for 19 days and having all the assignments and lectures that had to be completed showed me how to manage my time between working, going to my respective sports practices and games, and then coming home and completing all of the work for the class. I loved how easy it was to access the content and lectures on the Course Sites website and how easy it was to submit the assignments, even though I did manage to submit the wrong file. The lectures were not usually too long and could be easily followed and they correlated directly with the assignments. The Zombie game was surprisingly addicting and i could not seem to close the game and stop trying to beat my high score. I do not know what it was about it but it was extremely fun and I enjoyed playing it. As for when i had questions you were always there, no matter what hour that I sent an email, to respond as fast as possible and answer my question or give me advice on my assignment. The whole flexsim process and design was interesting to me and I had a blast learning how to change all of the processes. I also enjoyed how the processes could be

connected to real life businesses and manufacturing companies to base their company of the models and the statistics given by the Flexsim model. While helping me learn a thing or two with my computer it also helped me become more familiar with it and learn how to use it in a better fashion…

All of the participants commented on their camp experience being positive, indicated how industrial engineering concepts are implemented in real life by using FlexSim, explained their positive experiences while playing the Zombie Attack game developed by FlexSim, and did not have any difficulty in developing simulation models based on the information given by the professor. 20% of the participants commented on camp development and suggested improvements while the rest of the participants had some challenges but did not have any comments on camp development. All participants agreed upon the fact that they learned new concepts and enjoyed what FlexSim had to offer them for simulating and engineering real-life situations. Only one camp participant dropped out from the camp due to health-related reasons.

5 Conclusion and Future Work

Participants of the camp were assigned tasks such as structuring flowcharts, developing simulation models, finding practical solutions to problems posed in developed simulation models and writing essays for explaining practical applications of FlexSim simulation software. The qualitative and quantitative data both indicated the success of the 1st Worldwide Online Summer Camp for high school students and the success of the developed content for the camp. The goal of the researcher/educator is to continue further developing the summer camp and providing more opportunities to high school students for learning more about industrial engineering and simulation applications by using FlexSim.

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Teaching Old Dogs New Tricks

Malcolm Beaverstock

1 Introduction

Frustration is common among educators and researchers when they wonder why the material they present to students is not always remembered and put into general practice—especially if the potential is there to greatly enhance operational activities. The issue of acceptance of new technologies has gained greater interest as computer advancements have made applying more research concepts practical. In 1978, at the Joint American Control Council conference, a full session considered the question of why advanced process control theories and techniques were not being used in the chemical industries. One paper pointed out the need for examples that showed the practical application of research theories [1].

Technology acceptance was of particular interest to the information systems world as Fred Davis and Richard Bagozzi [2] discussed a model which they felt represented how and when a user decides to use a new technology. Two issues were highlighted that affected the acceptance of technology: relevance and ease of use. Discussions indicated that, while both were influential, relevance was critical.

Impediments to using a new technology, such as simulation, can create work environments where newly hired students are discouraged from implementing their newly acquired knowledge. They also dull any interest in learning. The potential for simulation as a problem-solving and analytical tool is too great to allow it to follow the same slow acceptance process.

Educators can make a difference by reaching out to those individuals in the work environment who could benefit from simulation and thus create an environment where simulation will not only be used but will be encouraged.

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2 Old Dogs

"You can't teach old dogs new tricks" is probably one of the oldest proverbs. There are many early citations of it [3] and many of them refer to it as an "old saying". Certainly, the saying is based on problems training older dogs to pick up scents or learn new duties. Over the years it has been used to describe the difficulties with getting people to try new ways of doing things, especially if they have been doing something in a particular way for a long time. With people, it is not necessarily age-related but a product of the environment and perceived notions.

For the purpose of the present discussion, "old dogs" refers to those professionals currently working in a career position and who have developed their own ways of carrying out their assignments. In general, these professionals are part of an organization involved with some form of manufacturing, service, transportation, or other enterprises. The characteristics that describe how professionals learn new concepts are basic, but they will vary depending on the professional's technical background as well as their position within their organization.

Students and professionals are different in a number of ways that can affect the way they learn. For example, students expect to be taught and learn. They may take a simulation class as a requirement or as an elective. They have a basic knowledge of the background material through course prerequisites. Their grades are based on tests provided by the educator and the students stay in the course until it is completed.

Professionals might be interested in learning but are motivated by their desire to survive the corporate environment by contributing to improvements in operations. They are knowledgeable in the dynamic operations of their workplace. They have built a methodology for successfully carrying out their assignments in ways that are acceptable to peers and managers. Their contribution is judged against others in the organization. Although they may have a long-term commitment, they have to balance professional and personal activities.

These differences, when considered in terms of the acceptance model, can help an educator to formulate a plan that will increase the chance of simulation education being successfully accepted by professionals.

3 Methods

Teaching simulation through a typical course structure involving a series of classes, lectures, and assignments often does not attract or maintain interest from professionals. Offering standard, online classes may not be enough either. When teaching professionals, lesson plans, outlines, and structure may have to change the way a course is taught. Some examples of how to adapt simulation education to professions are provided.

3.1 Selling the Concept

Successfully teaching simulation to professionals requires more preparation than courses for students. There is usually little promotion provided to encourage students to take a simulation course. To convince professionals, however, promotion is important.

Allen Greenwood, in a paper at the 2017 Winter Simulation Conference [4], made the case for modifications to educational practice to improve the use of simulation. While not directly saying so, Prof. Greenwood strongly indicated that educators have to be "salesmen" as well as educators. The thought that "if you build it they will come" only happens in movies. Strongly believing that what is taught is important requires taking the next step: promoting it. That next step requires homework for the educator.

In addition to enhancing simulation course structure by including more projects and examples, physically taking a class directly to professionals may also be needed. Since "relevance" is a critical aspect of acceptance, courses for professionals have to be well planned.

The bad news is that making material relevant to a broad cross section of professionals is daunting. The good news is that there is much common ground for using simulation—namely, a tool for solving problems. Within organizations, many of the problems needing solutions are common (e.g., lower cost, reduced waste, faster reactions, etc.). Also, good problem-solving techniques using simulation can be used for almost all operating systems.

Individuals working in an organization have more experience with their own operations than any visiting educator—even when the educator is part of the same organization. Workers on a factory floor may not always understand the technical aspects of their equipment but they can usually define what problems they face.

Practical experience has shown that, before going to an organization's site to present information on simulation, a facility tour or chance to discuss operations can provide great insight into relevance. Observations and simple questions that elicit comments about issues and problems can be then be used during course discussions.

During the 1980s, the University of Texas, University of Maryland, University of California at Santa Barbara, and Case Western Reserve University are examples of universities that established consortiums to promote the use of advanced control technology. User companies paid between $5000 and $10,000 to be a member. Membership included access to faculty and research work as well as attendance at a two-day conference where the latest research was presented. Companies could not join if they were in a business that was in competition with another member. As a result, both members and faculty were exposed to new thinking, finding relevant topics, and networking possibilities.

Educational organizations now routinely try to advertise their programs. However, in the case of simulation, only promoting programs in technical journals or at conferences related to the technology can miss the broader audience. Professionals

who have personal improvement as part of their objectives may not read simulation journals.

Vendors have started to post advertisements and contribute papers to journals targeting decisions makers and businesses that could benefit from the technology. Presenting papers at management association meetings and industry-specific conferences is good example. A paper that explains how simulation can directly benefit the users will be eagerly accepted especially coming from an academic institution and not a vendor.

Outreach to professionals requires more effort for the educator, but the rewards in advancing the technology are significant. Not only will simulation be used more rapidly, but the entire application environment will be enhanced for future students to find acceptance in their work.

3.2 Starting Right

Teaching activities aimed at professionals must start with material that directly addresses the roadblocks to technology acceptance.

Knowing the background and responsibilities of the audience is critical to gaining interest at the beginning of a class. The textbook Advanced Simulation Modeling and Analysis (referred to as Advanced Simulation) [5] is organized by three simulation user levels: occasional, intermediate, and advanced. Based on personal experience, the percent of potential simulation users among professionals is shown in Fig. 1. These levels also relate to positions in a company's organizational chart.

Occasional users often are managers and engineers not directly involved with design or implementation activities. Intermediate users are people directly involved with operations and short-term problem-solving. They usually do not have the time to be experts in simulation but can benefit from its use. Intermediate users often have responsibilities to implement designs and include project engineers and managers. Advanced users are primarily involved with long-term improvement and problem-solving and may be internal technical consultants.
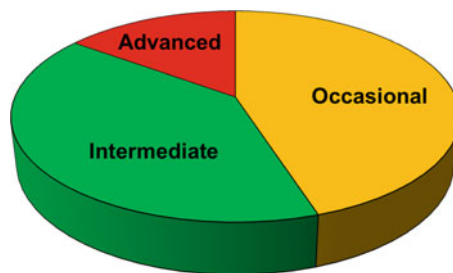

Fig. 1 Estimate of user types

For example, a simulation class for a group of project engineers and managers engaged in a packing line's design implementation started directly by addressing the group's primary function. Without any preamble, a packaging line was very quickly built by using objects that visually looked like the actual equipment found in the plants. The equipment was then connected, and the simulation run creating flow items representing familiar products. In less than 2 minutes, these packing lines were created and appeared fully operational. The impact created immediate interest and insightful questions that lasted throughout the course.

Sir Arthur Helps in 1868 [6] is credited with the phrase "Nothing succeeds like success". One of the best ways to show relevance and gain interest is through examples of simulation success. A short simulation course for managers started with examples of simulation benefits that involved issues familiar to the audience.

Examples of savings from nontraditional areas, such as identifying design issues, reducing inventory, and cost avoidance brought new interest to the audience. Figure 2 is an estimate of the percent of the time benefits were attributed to one of these areas based on projects at a major food manufacturer.

Starting with a review of projects that managers knew were successful, and where simulation supported the work, provides an increase in comfort level. Fear of failure is also a great motivator. It can help to gently remind others of projects that did not use simulation and were less than successful.

Courses to plant managers and plant technical directors should start with a focus on how simulation can improve performance measures that influence their yearly bonuses. Beginning with examples of how simulation supports decision-making and high-profile corporate activities is also important. Examples include: providing a nonpolitical means of choosing which projects should be given priority or additional funding and resolving disputes between lean working groups on changes in operations.
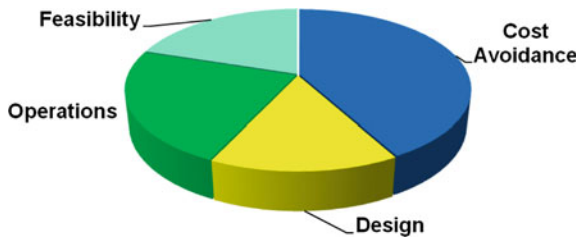

Fig. 2 Benefit areas from simulation projects

3.3   Ease of Use

Unfortunately, getting a simulation course started right does not mean that professionals will remain interested. Ease of use is a factor that affects the reception to new ideas and can help professionals retain interest.

FlexSim's graphics, consistency, and tutorials all contribute to an easier learning experience. The *Advanced Simulation* textbook leverages FlexSim's ease of use, thus allowing educators to focus more on simulation application and theory.

A paper presented at the 2011 IIE Conference [6] documented how ease of use improved teaching in the classroom. When a major food company wanted to use FlexSim as its internal standard, FlexSim engineers worked with company representatives to develop a highly friendly user interface.

The application opened with the name "Dynamo", which was created for use within the company, and a simulation model of a familiar packing line setting. When the main screen appeared, the upper toolbars contained only items that were of general use to company engineers. The changes to the main screen were made through a library that started when the application was loaded. At any time, more advanced users could go back to the more complex standard screen.

Additionally, an art school graduate student was hired during the summer to build 3D representations of major pieces of equipment familiar to engineers in the company. When a piece of equipment was opened, the parameters and other tabs were modified to present a simplified structure using nomenclature familiar to the engineers. For example, machine cycle time, which was not a term normally used, was replaced by the more common expression to define a machine speed: "units per min". Custom code changed the familiar entries into standard FlexSim values. Figure 3 shows an example of a simplified "operation" tab and a "design" tab that contained pertinent information for the user in familiar terms.

At any point, users could access the standard FlexSim interface by clicking on an "Advanced" button at the bottom of the screen. While these changes were significant
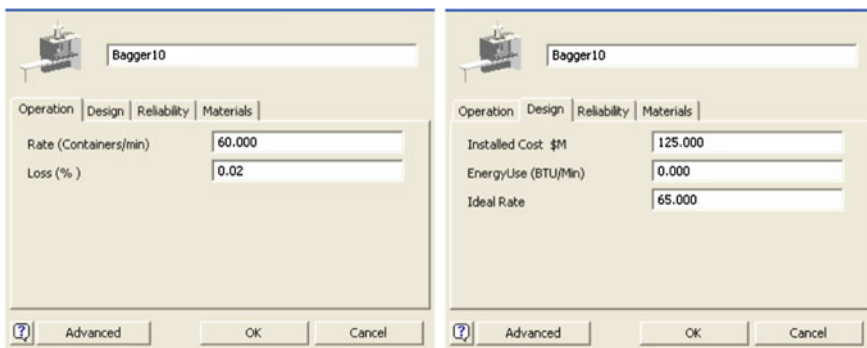

Fig. 3   Examples of simplified equipment tabs

in obtaining acceptance of the software, the application was still standard FlexSim. As a result, engineers found it much easier to learn simulation techniques when the visuals and vocabulary matched their everyday experience.

3.4 Theory Follows Application

A solid background in statistics and other basic theories is critical to successfully applying and understanding the results of simulation. Giving university students a solid base of theory first, then following it by the application of simulation makes sense. However, when considering the importance of relevance to learning, the opposite often is needed when teaching professionals.

For example, the excitement of getting a result from a first model has to be tempered with a discussion of why randomness may mean that results from a single run can be deceiving. The *Advanced Simulation* textbook uses prebuilt models to bring this point forward. Additional theory may also be needed to explain why management's desire for a plant to maintain a production average that always equals the highest value run on a particular day may not be possible. Understanding random events and statistics would show that such a high average would require machines operating at speeds not physically possible.

In these cases, as in the following examples, the approach is to provide application examples first that then lead to a discussion of the relevant theory. This approach can be iterative in that more application can be introduced followed by additional theory.

Implementing machine failures in a simulation leads directly to a discussion of reliability, mean time to failure, and time to repair. Simple models can demonstrate how failure modes may differ by specific machine operations such as loading, running, or idle states. Additional statistical theory may be added to discuss appropriate distributions for failure and repair modes. Concepts such as the need to collect information about machine failures using exclusive downtime data now become more relevant.

Once users are comfortable with building simple simulations, then the need for running a model more than one time can be introduced, which leads to a discussion of design of experiments. Basic theory for choosing variables, ranges, scenarios, and replications now makes sense.

These small "doses" of application followed by theory work well for the casual and intermediate user. Hopefully, at this point, those wanting to become advanced users will recognize the need for in-depth education in both theory and practice which may be found in a more traditional classroom setting.

3.5 Coach Versus Teach

There are times when more than the standard classroom approach is needed. Small groups of professionals, who are immersed in their daily activities, may be attracted to using simulation on their current problems rather than being taught the general technology.

This approach starts with a short introduction to simulation focusing on its application to the type of problems the group may be facing. The introduction is followed by exercises building simple models. Time is spent with each professional to provide enough information for them to begin formulating a plan for their project.

Participants are then given time to return to their daily routine but encouraged to continue trying to build a simulation. The educator must be available to discuss the activity via email or phone. The next session for the group starts with discussions about each project. Simulation questions that come up are used to focus the course presentation materials. This approach of using "teachable moments" to structure lectures can be very effective.

An example of one such training effort involved a model that was built along with the engineer trying to determine why a batch mixing process could not keep up with the production rates. While discussing how the steps of the operation could be simulated, the engineer recognized a flaw in the transfer logic of the batches—this solved the problem. As a result, the engineer became a believer in using simulation as a problem-solving tool. This model is now incorporated in the *Advanced Simulation* textbook.

Becoming a coach as well as teacher requires more effort from the educator. However, since the professional is more familiar with the operating process, the educator's contribution is to help direct a logical thought methodology—which is something that is inherent in any simulation development activity.

3.6 Continuous Teaching

The coaching approach, described above, might imply that educating professionals requires continuous effort—and to some extent it does. Since much of the interest in simulation is driven by need, application details and theory may be forgotten once the lessons are over and a simulation has served its purpose. At a later time, when simulation could once again be used, going through textbooks looking for concepts is not always easy and can lead to dismissing the use of simulation.

Short videos are effective as teaching and reference tools for both FlexSim and the *Advanced Simulation* textbook. However, this is a challenge because of continuous changes to the application software. FlexSim has found that its blog, Facebook, and YouTube provide effective means for users to find help with software concepts. Similarly, a means for finding information about applying simulation would be beneficial to professionals.

A tool from the lean manufacturing domain that addresses this need for easy references is the use of "one-point lessons" [7]. These serve as simple reminders of important concepts. Such lessons, each described on a single page and easily referenced, would make remembering aspects of the simulation approach much easier.

One of the best methods for continuously reminding professionals of the steps involved in applying simulation is to introduce them to a structured approach. Professionals, and especially managers within an organization, recognize the benefit that structure provides to an organization and its work. The *Advanced Simulation* textbook provides such a methodology for working on simulation projects that have proved successful.

4   Summary

This paper shows that "older dogs can learn new tricks". A recent study by the Messerli Research Institute, which is part of the University of Vienna [8], provided results from a study showing that training older dogs may be even easier than working with excitable young dogs. Unfortunately, there are other issues involved with teaching people.

The major difference in educating university students and professionals in the practice of simulation is in the need to provide relevance to the material. The ease of use provided by FlexSim is also important, not only for those learning the software but for the educator who can then spend more time focusing on teaching the application of simulation.

The methods suggested in this paper have been used by the author during his career. While not always perfect, they have been found to improve the acceptance of simulation as well as other new concepts. This has been true even with individuals who are more inclined not to spend the time or energy to consider simulation, and who see it as a distraction from their well-worn, comfortable approaches to problem-solving.

The commitment of an educator to teaching professionals involves a commitment that goes beyond the duration of a course. However, there are at least two major benefits that can result from the effort:

(1) Professionals, knowing that simulation can benefit them in their careers, will be anxious to put it to immediate use.
(2) Being successful with simulation will carry forward, not only with the individuals involved but to others through word of mouth.

As a result of these benefits, a receptive environment is built within an organization. Even if through attrition the excitement wains, the concepts will still be welcomed to try again. This improved environment benefits not only the organization but future university students as they pursue their careers.

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Part III
Research

DES as Tool for the Decision-Making in an Offshore Manufacturing Foundation Process

Jose Antonio Muiña Dono, Adolfo Lamas Rodríguez and David Chas Álvarez

1 Introduction

World demand for energy is rising and the global resources are not limitless; therefore, the research and development of more efficient and environmentally friendly methods to obtain energy is necessary. Nowadays, nobody has any doubt about the promising future in the wind energy generation between renewable energies. However, it is difficult to find continental places, with high wind speed rates, without being exploited in some developed areas like Europe.

Wind industry has continuously reduced cost, making the onshore wind energy the cheapest new energy in Europe but it has been proven that offshore wind energy can be in the same cost range [5]. Offshore wind is also undergoing an increasing cost reduction and technology improvements [14]. For this reason, the motivation to develop the offshore energy methods has increased.

Europe is involved in this process, increasing its installed capacity to 15.780 MW in 2017. This corresponds to 4149 wind turbines across 11 countries [15] (Fig. 1).

Offshore wind is one of the most dynamic renewable energies, in terms of installed capacity and technology development since 2010 [14]. The higher wind speed rate at sea (around 1 m/s) and the absence of obstacles that hinder the airflow improve the offshore energy production by 20% compared with onshore production.

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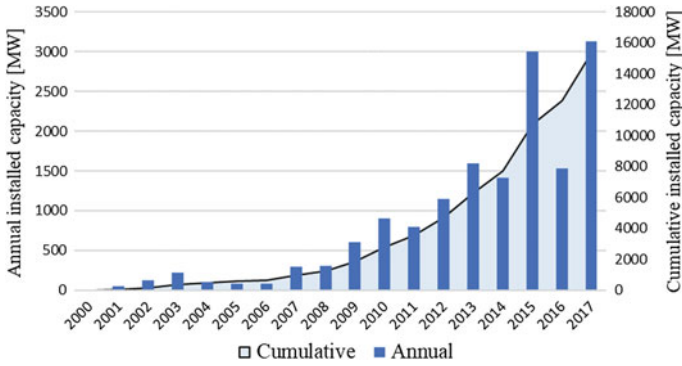
Fig. 1 Cumulative and annual offshore wind energy installation. Own elaboration based on [15]

WindEurope expects a total European offshore wind capacity of 25 GW (planned and confirmed projects) in 2020. The increase will be linked to the largest wind turbines capacity (5.9 MW average capacity in 2017) and situated in deeper (27.5 m average deep in 2017) and further away to shore areas (41 km average distance in 2017).

The wind farm depth is linked to the selected structure type (see at Fig. 2). This trend means a promising future by the jackets market, representing the 6.9% of all foundations installed in 2017 [15].

In search of this aim, Jan Kjærsgaard (CEO of Bladt Industries) proposes the jacket design standardization to contribute to offshore wind cost reduction. It is important to mention that costs derived from this kind of structures represent 28% of the cost of the whole wind turbine. As reported by [13], a substantial cost reduction can be expected over the long term through economies of scale, learning effects, and R&D efforts. The experience curve concept has been widely applied to predict the future
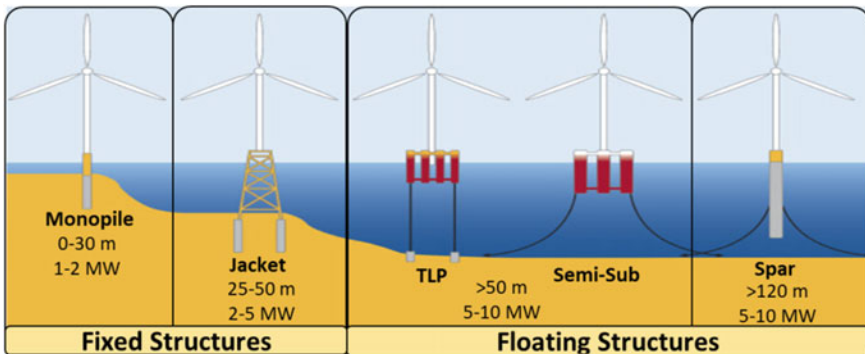
Fig. 2 Types of offshore wind foundations. Own elaboration based on www.windpowerengineering.com

trend of offshore wind energy costs, which expresses cost reduction as a function of increased cumulative installed capacity.

Not only a reduction in cost is necessary but also a reduction in the manufacturing process time. Nowadays, market establishes a challenging lead time, which can mean the fabrication of around 50 structures in little more than a year.

These objectives will undoubtedly be reached using new technology, process optimization, standardization, and big volumes in supply chain as well as maintain supplier cost-out.

As a result, a 3D Discrete Event Simulation (DES) model is developed in order to represent and optimize the jackets construction strategy. The case study is referred to the construction of these structures and substructures in the jackets fabrication yard. DES will be used to minimize the cycle time per jacket, identify bottlenecks, and define the number of workstations, resources, elevation, and transportation means needed for accomplishing the delivery milestones and minimizing the costs and the probability of their noncompliance, which are the main goals of this study.

2   Related Works

The simulation is considered one of the basic nine technological advances of the fourth industrial revolution or Industry 4.0 [10] (Fig. 3).

Examples of simulation applied to a problem optimization process can be easily found [3]. However, finding studies where it applies to a process of this magnitude is difficult: relatively few units and a long manufacturing time.

An example of the importance of simulation in projects of these projects can be found in [4]. They stand out in their work the importance of simulation-based design technologies in order to achieve higher efficiency in terms of work strategy planning.

Autonomous robots	The cloud	Additive manufacturing
Simulation	Cybersecurity	Augmented reality
Horizontal and vertcal system integration	The IIoT	Big data and analytics

Fig. 3 Technologies of the Industry 4.0. Own elaboration based on [10]

Without a doubt, an efficient communication is and will be the key to the good development of any project [9].

An interesting application of simulation to study the transmission of information is [9]. This study tries to identify areas that can be improved in the communication aspect of a project.
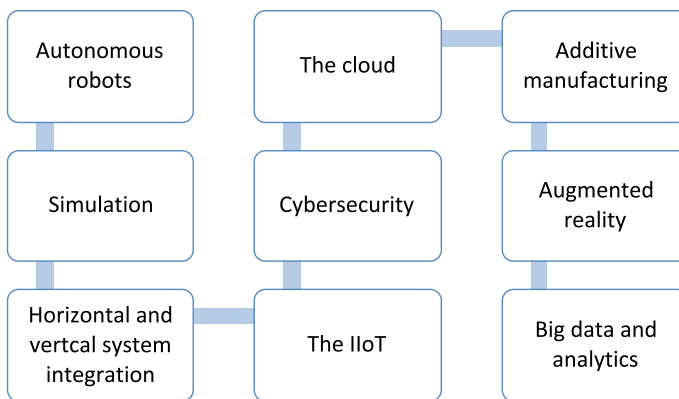
A recently published survey in logistic decision-making can be found in [12]. The majority of applications have been reported in production plant design and production evaluation (especially in automotive and semiconductor industries).

In [11], a case study of an example of DES applied in a biopharmaceutical manufacturing process is presented. DES helps in the decision-making process, analyzing different scenarios, and providing information to select the best option.

Another important application can be the use of 3D tools to share and validate the results obtained from the simulation.

In [1], an interesting comparison between the advantages and disadvantages of the 3D DES and 2D DES is presented. Early problem detection and solution is seen as a particular advantage of 3D DES. On the other hand, highlight the difficult and time needed to develop these 3D simulation models.

In [2], authors synthesize the benefits and cost associated with the 3D simulation and the Virtual Reality (VR) techniques through an extensive bibliographical review (2000–2016). They conclude in their work the significant benefits of 3D/VR on the model development, experimentation and analysis, model validation, and verification.

FlexSim is one of the most popular DES software used by its 3D visualization/animation capacities [7]. These skills are essential when space and buffer is a problem, especially in layout problems [8].

3   Jacket Manufacturing Process: Description

Jacket term defines, in the offshore wind industry, a fixed offshore steel platform. The wind turbine at sea is supported by this structure, which certain sections placed below the waterline.

Jacket can be generally divided into three main parts (see at Fig. 4):

- Transition Piece (TP).
- Substructure Upper Block (SUB).
- Substructure Lower Block (SLB).

There are different ways to fabricate this lattice structures and it will depend on the resource capacity, technical development, welding techniques applied, and of course, the construction strategy used by the company (point to point or fabrication based on nodes).

Jackets manufacturing process has experienced important changes from the conceptualization and manufacturing phase of the first offshore wind farms until today: slender and high structures, standardization, and shorter delivery times are the bases
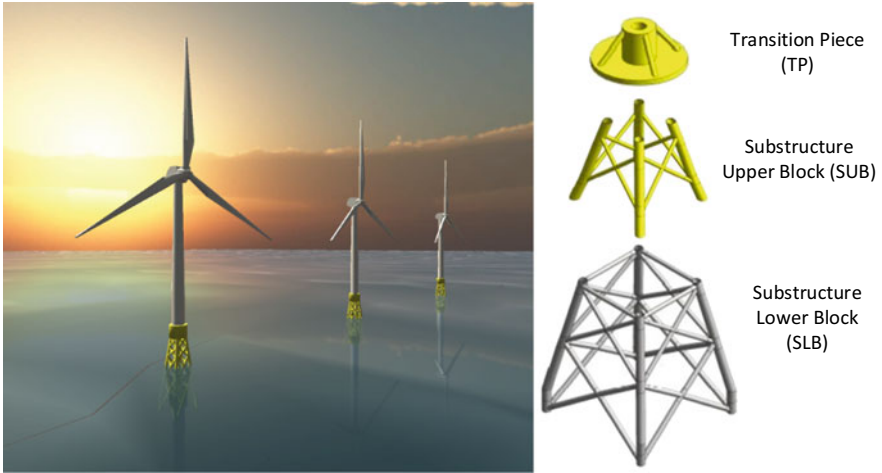
Fig. 4 Representation of wind turbines at sea, and main parts in a jacket

Table 1 Example of the jackets' dimensions and weight

Deep (m)	50
Length (m)	75
Total weight (t)	850
Footprint (m)	25

in the today market. Studying how to reduce fabrication costs taking into account these market trends will be a challenge (Table 1).

In this chapter, the main stages in the jackets manufacturing process are studied in detail (see at Fig. 5). To sum up, the fabrication process includes the following sequence:
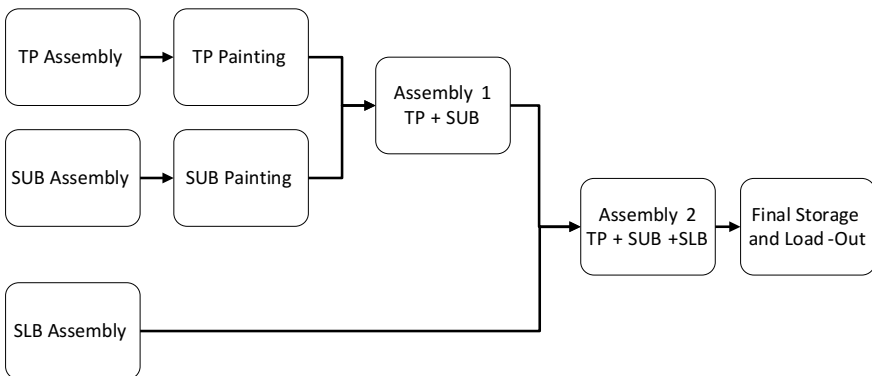
Fig. 5 Flowchart of the simulation model

(1) Assembly of TPs, SUBs, and SLBs in different workshops.
(2) TPs and SUBs are painted in special painting cabs (some of them shared).
(3) After that, the TPs and SUB are assembled (Assembly 1).
(4) Finally, the SLB is assembled with the TP + SUB (Assembly 2).
(5) Jacket is transported to the buffer area or moved directly to the Load-Out area.

This chapter is based on the feasibility study of a new offshore wind project that will consist of a fabrication of 40 jackets in 18 months. Intermediate milestones are established by the customer and noncompliance will have an important economic penalty (100,000€ per jacket and day).

The magnitude of the project, the delivery dates, unforeseen events, and production costs make it necessary to monitor all fabrication stages, from the material supply phase to the final stage: the Load-Out process.

4 Model Development

4.1 Problem Description

According to the description given above, an assembly and storage problem in an offshore wind manufacturing project is studied. The logic of the problem allows classifying it as a job shop problem, since its completion requires a series of previous activities to be completed.

This chapter study is based on a real problem, so it should be noted that real challenges must be represented:

- Available resources during the project: painting cabins, operators, etc.
- Risk and their impact on the project: accidents, strikes, delays in materials procurement, etc.
- Theoretical production time and its variability, learning curves, etc.
- New projects overlap.
- Adverse weather conditions depending on the season.
- Internal and external logistic.
- Layout problematic: storage areas, transports capacity.

The demanding business requirements (time and cost) force to have any parameter under control to guarantee the viability and profitability of the project. For this reason, the study of the current and planned situation should be carried out during the project progress.

All the information generated during this activity should be shared among different experts and departments from the company or clients. The model should facilitate the feedback, improving the transmission and validation of this information.

For this study, the expert advice and historic company database are used to estimate duration process, to study and to propose different scenarios and finally, to validate the results (Fig. 6).
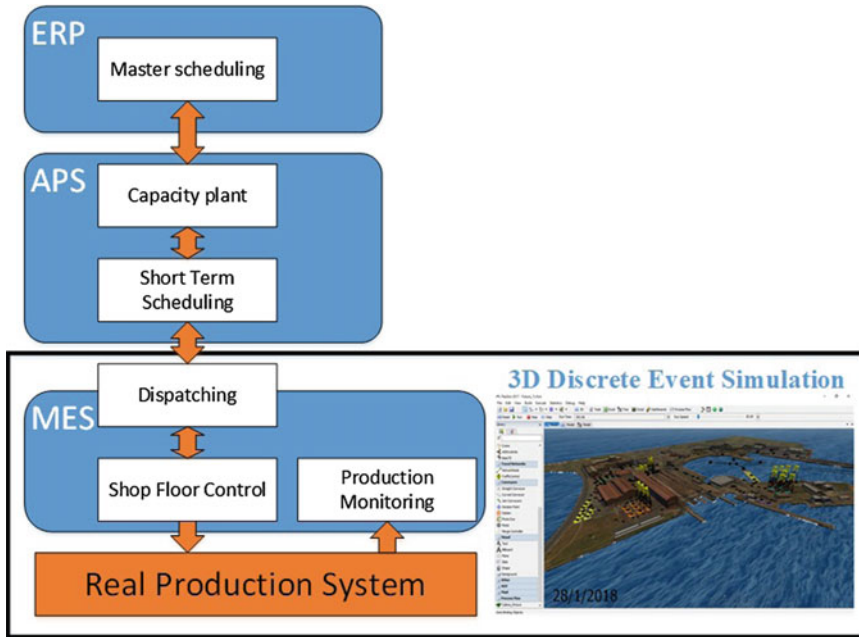
Fig. 6 Applying the simulation for schedule evaluation. Figure based on [6]

The simulation allows identifying bottlenecks, quantifying the buffers area, studying the variability of the fabrication task durations, etc. These will be the key performance indicators used to take into account when implementing measures to optimize this manufacturing process and reducing the waste activities.

The use of the model is not restricted to this conceptual process. During the project, model will receive real information as input and it will be capable to analyze future scenarios (identify bottlenecks activities, risks, overlaps with new projects, etc.).

4.2 Simulation Model: Discrete Event Simulation

Discrete event simulation method is selected to develop a simulation model by its characteristics:

- Discrete: state of system changes in discrete points in time.
- Dynamic.
- Stochastic: random magnitudes.
- Parametric: linked to a database.
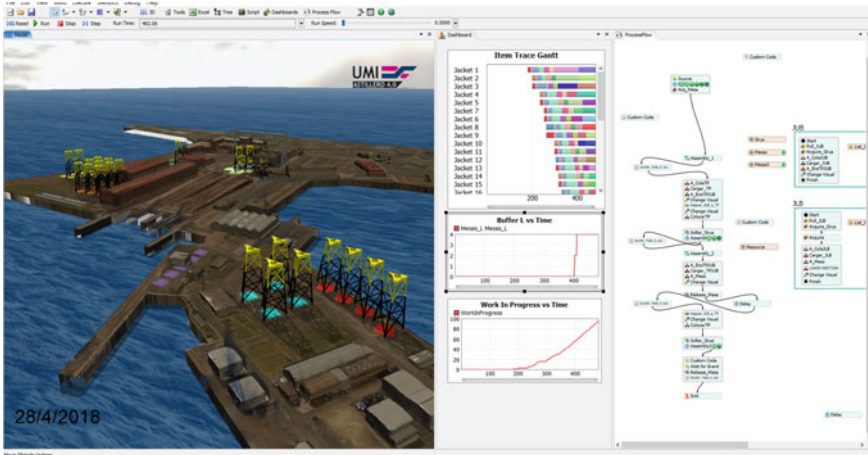
Fig. 7 Screenshot: FlexSim 3D view, Dashboard, and ProcessFlow

FlexSim simulation software has been selected by its versatility to represent any process, from the simplest to the most complex one. This software is used in other industries (food, healthcare, etc.) but especially in manufacturing processes.

This simulation tool includes predefined simulation blocks that make the job easier and faster, having a fast learning curve. However, using only these predefined blocks is difficult to represent a model as complex as the one studied, so it is necessary for the use of specific language coding and the ProcessFlow.

An important advantage is its possibility to connect with other programs. For example, it has a predefined connection with Excel files, sharing information with other people in the way they need. In any case, using VBA programming is simple to improve the connection.

On the other hand, it has an important versatility with 3D models formats and direct connection with Virtuality Reality (VR) devices (Oculus Rift or HTC Vive). This helps to validate model and to share result with company and customer, having an important commercial advantage (Fig. 7).

4.3 Digital Twin and the 3D Simulation

The word "Digital Factory" has existed for 20 years. However, today its use is again popular, thanks to the new technological revolution: the Industry 4.0.

The Digital Factory is the representation and study in a virtual environment of the lifecycle design of manufacturing processes and manufacturing systems using simulation [10]. The objective is to achieve an improving performance, productivity, etc.

This Digital Factory aims to support the daily work, monitoring and analyzing in parallel the real situation of the factory.

In this study, having a Digital Twin from our factory is essential to achieve the objectives: absolute process control and information sharing. The 3D representation in a virtual environment of the process and state of the factory allows us to share information in a way that is understandable to any user.

The 3D model of the jackets fabrication yard has been modeled, including resources and workshops.

5   Experimental Results

5.1   *Conceptual Phase*

The development of a model during the conceptual or commercial phase is complex. These projects have usually public bidding procedures, being a worldwide competition with particular requirements of each area.

The great challenge to have quickly a realistic commercial offer must be added to the difficulty of not having real data of the same project already done. For this reason, experts' experience and department information (Engineering, Production, Inspection, etc.) are so important.

During this activity, these isolated work teams expose different proposals and each one requires a continuous rework activity. Simulation is used to canalize this information and achieve knowledge to validate or not these ideas.

Different scenarios are proposed during this commercial phase to quantify workstations, lead time, costs, and other parameters. For example, simulation model quantifies the necessary assembly workstations and the painting cabin to accomplish the customer milestone.

The available resources in the factory and the milestones force to start the project long before the first Load-Out, having to store up to 16 units (see at Fig. 8).

During this stage, the simulation offers important advantages, processing a lot of information in a short period. This way of solving the questions "what if…" has meant an important saving of time and cost for the company (Fig. 9).

The information generated is exposed in an interdepartmental meeting to make a well-considered decision.

Fig. 8 Satellite image (left) and 3D model (right)
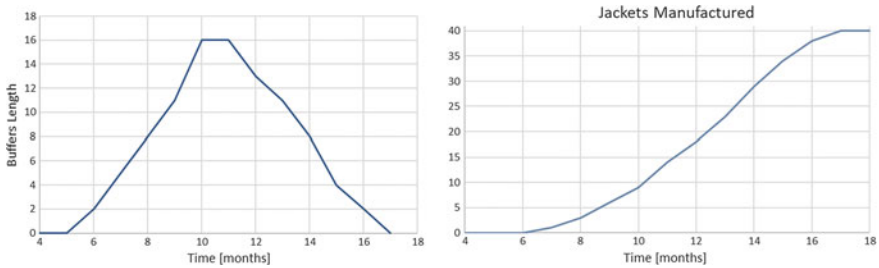
Fig. 9 Jacket production planning (right) and final buffers' length (left)

Undoubtedly, 3D possibilities achieve a full collaboration and involvement of the staff, without necessity of simulation knowledge. The 3D animation helps to explain in detail to the final client how the project will be developed and the problems that may arise.

Having detailed and complete information requires a significant amount of modeling time. However, acceptable results can be achieved in a brief time, being the information available to the rest of the project team to continue their work.

5.2 *Monitoring Project Progress*

DES advantages are not limited to the design of the project. The capacity to monitoring the project progress is an important benefit of this powerful tool. However, several applications of these techniques forget these possibilities.

DES helps to understand the current situation of the factory and to estimate the future situation.

In this study, many drawbacks have happened during the project progress (material nonconformities, delays related in the reception of design drawing, accidents, new requirements, etc.).
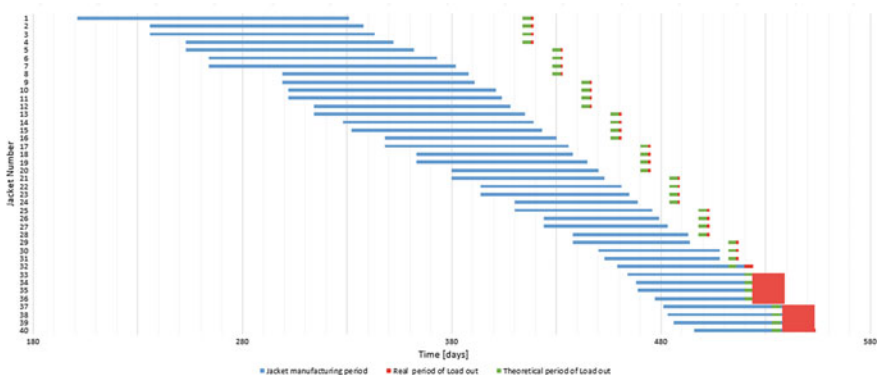
Fig. 10 Gantt chart of the project progress

All these issues compromise the objectives of the company, both in time and cost. If there is no change, there will be a delay of 22 days in the delivery of some jackets that will suppose approximately 8M€ in penalties.

In fact, the project progress changes completely the system behavior. New bottleneck activities and important work time fluctuations are part of this new situation.

The Gantt chart (see at Fig. 10) confirms the new bottleneck activity: Assembly. Increasing the Assembly workstation is not easy (welders, scaffolding, area available, etc.).

This limit is establishing in a new one workstation for Assembly 1 or Assembly 2, but not in both cases. Simulation shows that the best option is to increase Assembly 1 workstation but in this case, a faster production of TPs, SUBs, and SLBs is necessary.

Improving the productivity could be possible hiring more operators. However, the increment of operators is not fully exploited because, in this new situation, the activity that limits our capacity is once again the painting.

Increasing the number of painting cabins could be a solution, but the near-deadline date and the time necessary to have it available not make it feasible.

As an alternative, during a risk management meeting, simulation supports in the decision-making process. New logic for the painting cabin use is studied and with some minor modifications in TPs and SUBs painting flow, Load-Out dates are achieved and the penalties decrease to zero.

It should be noted that the development of mitigation plans requires at least a couple of weeks. When deadline is too close, having tools that facilitate or automate the process is so important. It is really attractive to the company the use of simulation during these meetings, being able to carry out these modifications directly in the simulation model in a few seconds (Fig. 11).

The 3D simulation support helps to explain the clients the "future" of the project, improving the capacity to explain the changes which will affect the time and/or cost.
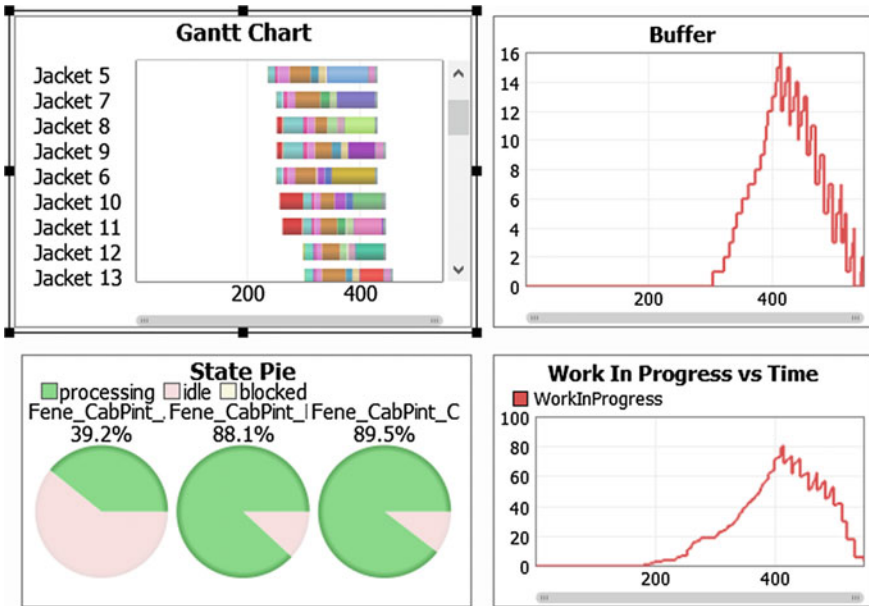
Fig. 11 Dashboard results using FlexSim

6   Conclusions

The viability of offshore wind is based on the cost reduction per KWh and manufacturing process has an important power for this objective.

The DES tools have been used for this purpose in other industries and their use is now expanding, but not especially in this sector. This study demonstrates the viability of the application of these simulation tools during the complete project development in the jackets fabrication yard.

In this case, the simulation is presented as an integrating tool, allowing the detail process study and improving it. For this purpose, alternative scenarios are proposed by the different isolated working teams. They are analyzed based on the information offered by the simulation output.

On the one hand, the DES tools have allowed the analysis of different scenarios during the conceptual phase of the Project, allowing correcting design errors, improving internal logistic, and optimizing the project.

On the other hand, the model has also been very useful during the monitoring of the project, since with the updating of information inputs, valuable outputs are automatically generated and easily shared between workers and clients.

These sorts of problems have not an optimum; there is a compromise between time and cost, so the study of alternatives is so important. Having quick answers to the problem of "what if…?" means an important saving in time and cost for the company, increasing their efficiency.

The 3D possibilities to validate and visualize the results have been especially important in this activity. It allows to share information without specific need for simulation knowledge and to "see" what is happening and the need to apply changes. In addition, this is undoubtedly an important commercial advantage as it significantly improves communication with the customer when a negotiation or renegotiation is necessary.

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3D Discrete Events Simulation to Evaluate the Internal Logistic Strategies in a Shipyard

**Adolfo Lamas Rodríguez, David Chas Álvarez
and Jose Antonio Muiña Dono**

1 Introduction

Nowadays, onshore wind power is the cheapest power generation in Europe. The offshore version of this energy is proving that it can be in the same cost range. As reported by [4], the 2016 offshore tenders in the Netherlands and Denmark evidence that under a regulatory framework fit for the national wind potential, significant cost reductions can be achieved.

By 2020, offshore wind is projected to grow to a total installed capacity of 24.6 GW, which means doubling the current capacity. The trend is to build offshore wind farms with more installed capacity (379.5 MW in 2016 to 1.2 TW in projected farms), located in deeper and further areas from the coast. In terms of the substructure market, according to [10], the current situation highlights a clear domain of monopile, with 9.840 MW installed at the end of 2016. However, there is expected market increase for jackets substructure, for which it is foreseen a market share of 22% in 2022.

Under this trend, it is important to mention that costs derived from this kind of structures represent 28% of the cost of the whole wind turbine. According to [12], a substantial cost reduction can be expected over the long-term through economies of scale, learning effects, and R&D efforts.

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To reduce the manufacture costs of these structures, transports take an important role. Last projects demand yards with big storage capacity and the ability to act as marshaling port. As staged by [9], the future of wind power will depend on the industry's ability to continue achieving reductions in the cost of energy.

In this point, it is important to place each activity in a specific zone and in a specific moment in the project timeline to optimize the company resources. As staged by [11], in discrete event simulation, only the points in time at which the state of the system changes are represented. In other words, the system is modeled as a series of events, that is, instants in time when a state change occurs.

To achieve the market requirements, a 3D simulation model has been developed to represent the real manufacturing system and the internal logistic strategy in the jackets manufacturing project. The 3D model designed can check different manufacturing strategies, taking into account the transport available resources to transport the jackets to the storage zone or load the jackets in the barge for their transport at the wind farm. As well as, the 3D model respects the space needed for maneuvers, real transport speed in the shipyard, and the estimated times for load and unload processes.

As a result of this work, a representation of the shipyard status has been achieved using different manufacturing strategies respecting the jacket load dates imposed by customer. Thus, it is possible to evaluate the necessary number of storage supports, as well as the power to calculate the later dates to load the manufactured jacket and do not exceed the supports available having to stop the manufacturing due to lack of space in the storage zones.

2   Related Works

The problem associated with internal logistics in a jacket project could be treated as a scheduling problem. Moreover, to this work, the simulation model has been designed with a 3D simulation software, in order to bring realism to the model and improve the results' interpretation. The following paragraphs present a brief summary of the most relevant studies related to the problem considered.

Discrete event process is used in [6] to do the schedule and cost estimation for transport and installation of a floating hybrid generator platform. In this research, Project viewer and Google Earth viewer have been integrated for showing the results.

Through the study of user surveys, the advantages and disadvantages of the 3D discrete event simulation in front of 2D discrete events simulation are presented in [1]. This study remarks as advantage the possibility of the earlier error detection and resolution, and regarding the disadvantages, it is remarkable the greatest difficulty and needed time to develop the simulation models.

In [2], the authors studied the facility and quickness to detect errors in simulation models through the design of two models about car's basic assembly line. They designed a 2D and 2.5D (3D components are situated above a plane) simulation models and give 10 min to detect errors to 62 people belonging to the Lancaster University. They conclude that it is more easy and quick to detect errors in the 2.5D

simulation model and also explain that the sampling is reduced; therefore, the result may not be significant.

A comparative study between the 3D simulation software and the 3D visualization advanced techniques applied by game engines is presented in [3]. As a conclusion, the authors note that the current level of 3D simulation software is enough to represent the simulation environment, but their use as marketing tool is improved by the game engines.

In [1], the benefits and cost associated with the 3D simulation and the virtual reality techniques are synthesized through an extensive bibliographical review which covers the period 2000–2016. Authors conclude in their work the significant benefits of 3D/VR on the model development, experimentation and analysis, and model validation and verification.

As was described in the previous references, the use of 3D simulation models brings important benefits at the hour of interpreting the results of the model. For this reason, FlexSim simulation software is used to represent the jackets manufacturing and internal logistic process, due to its comfortable interface to design 3D simulation models and to use the VR techniques.

Moreover, it is remarkable the use of FlexSim software by other authors to design parametric simulation models. These authors propose in their works similar aims to those proposed in this article, as the improvement of the layout or the use of the simulation model to generate schedules.

3D simulation is used in [8] in order to optimize the layout of a manufacturing plant. Authors used the FlexSim software to design the simulation model in their work, first building and simulating the existing layout, and then through the proposal of new layouts based on various alternatives to avoid the bottlenecks.

Finally, FlexSim software and the KBR planning software are used in [7] to generate automatically simulation models in order to check the viability of the production schedules subject to the material handling limitations. Authors justify the use of FlexSim simulation software due to which it is a simulation software that integrates modeling, simulation, and 3D visualization and animation in 3D object-oriented drag–drop–connect environment.

3 Description of the Internal Logistics in a Jackets Manufacturing Plan

The storage of any fully assembled jacket ready to be delivered to the customer is the result of a non-just in time process which needs to define storage areas needed in the shipyard as soon as the first jackets have been fabricated. For this reason, it is necessary to define storage areas and internal logistic strategies.
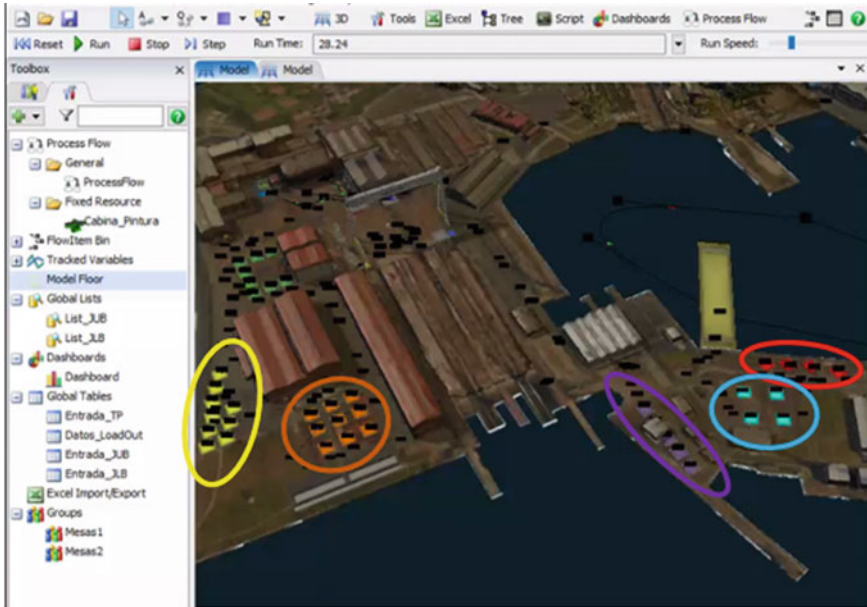
Fig. 1 Location of the storage areas

3.1 Definition of Storage Areas

With the aim to minimize the load movements to the barge, the complete jackets should be stored close to the Load-Out area, which could be used also as storage area. Figure 1 represents the distribution of the storage areas in the shipyard where the Load-Out area is marked in red color, and the other four zones are marked in color blue, purple, orange, and yellow. The four storage areas define 30 buffer potential positions in total. According to the manufacturing strategy, not all of them have to be used.

3.2 Elements of the Process

The main elements to represent the manufacturing process and the internal logistics are the following:

- Jacket (Fig. 2): the final product of the manufacturing process and needed a space of 265 m^2 for its storage in the shipyard. At the same time, the economic impact of break any Load-Out milestone in a typical contract for jackets manufacturing represents a penalty about 100.000 €/[jacket and day].
- Self-Propelled Modular Transport (SPMT) Fig. 3: the resource in charge of the transportation of jackets, which have to be moved from the last manufacturing stage
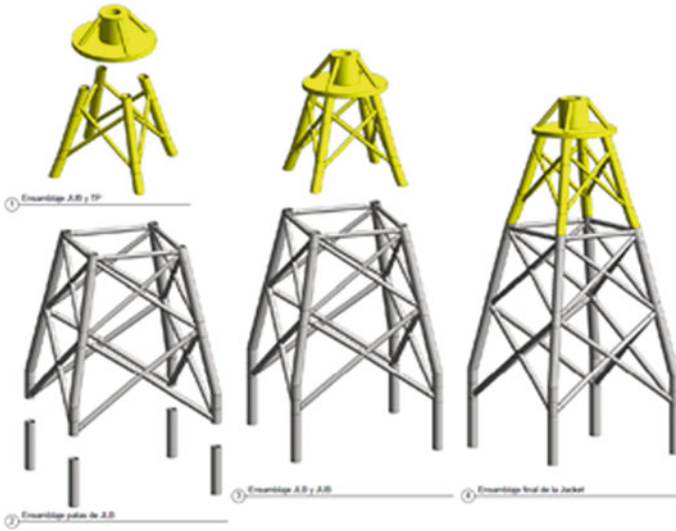
Fig. 2 Jacket

Fig. 3 Self-Propelled Modular Transport

to the storage areas. SPMTs also are the internal logistic resources destined to the
Load-Out operations. In case of use rental SPMTs, their price is usually closed
and applicable for a certain period with restrictions about the weekly movements,
i.e., if the weekly limit is exceeded, the price of extra movements will be added as
an extra cost.

- Support elements (Fig. 4): concrete structures to distribute the weight of the jacket
  on the floor. For each jacket, leg is necessary one support element, and thus each

Fig. 4 Support element
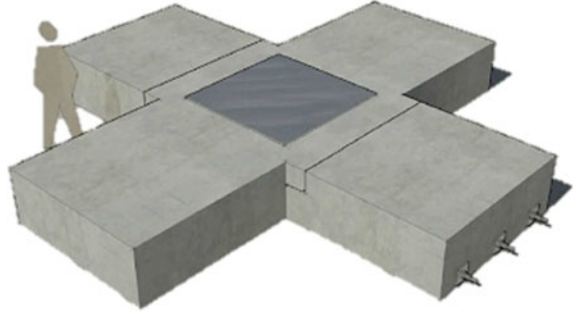
jacket needs four supports element. On the other hand, its fabrication must be anticipated to the jacket manufacturing that takes place, because it is necessary for a drying time of 35 days to be used. Besides, the fabrication cost of one of these concrete structures is about 5.000 €/support, i.e., 15.000 €/jacket.

4   Methodology

The analysis process is based on checking all possible scenarios with the 3D discrete events model developed. For each scenario, the simulation model represents the status of the shipyard along the jackets manufacturing period, allowing to see the buffers occupation along the project, as well as the transport dates, the internal logistic strategy, and the maximum storage space needed.

The use of the 3D simulation model is represented in Fig. 5, using as reference the starting dates present in the master scheduling, as well as the unforeseen circumstances that can appear along the project, and the strategies applied to manufacture and internal logistics.

As a result, the model makes a new Load-Out schedule, calculating the maximum buffer positions required, and the cost associated with the internal logistic process.

4.1   3D Simulation Model

To design the 3D simulation, model FlexSim software has been used. FlexSim is an object-oriented simulation software that allows the importation of 3D objects in different formats, such as .obj, .fbx, etc. These imported objects should be representative of the shipyard, and in this case, representative of the jackets manufacturing process. Besides, the use of 3D realistic models contributes to a better interpretation of the model. On the other hand, the simulation software used has predefined simulation blocks that allow a model to develop quickly.
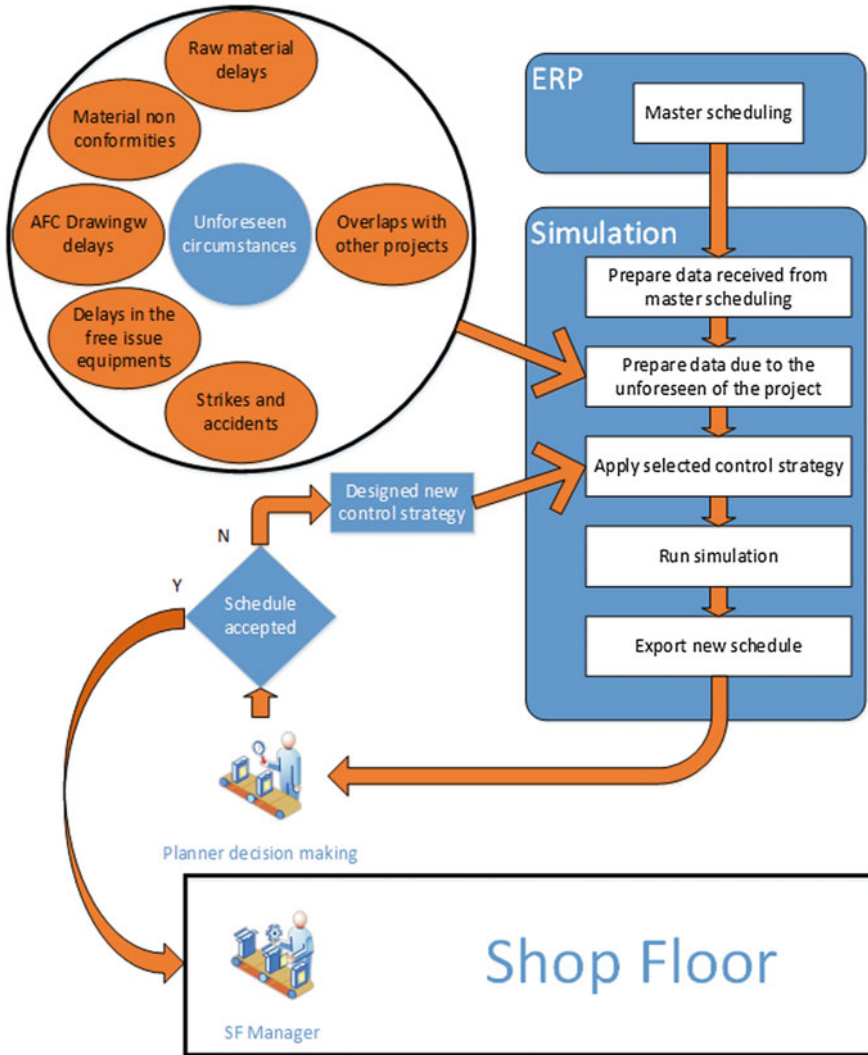
Fig. 5 Process flow to use the simulation model

FlexSim software also has the possibility to customize simulation blocks using the ProcessFlow tool. These customized blocks allow the users to award at the workstations, the needed properties to represent the real process, whether at visualization level or to integrate the time of different jobs that occur in the same workstation.

In this work, the 3D simulation model is used to represent the real manufacturing system. Here, the developed simulator is used as a component of a higher level system taking the role of the real production system and acting as a "quasi-emulator" [5].

The process flow represented in Fig. 6 has been developed in order to represent the role of the 3D simulation model designed in planning chain, where the control logic of the simulator ensures that the schedule is executed in the same way as it was passed by the short-term scheduler [5].

At the same time, the simulation model apart to represent the storage and Load-Out operations and calculate the cost for each scenario is used to propose and check new construction strategies if the customer milestones are not met with the current strategy. This can be done because the simulation model does a monitoring of the resources in the process, showing the periods with more workload, allowing to modify the construction strategy in key points for better use of the resources.

The model developed to this work takes the aspect of Fig. 7. This model has three main parts: the left part represents the 3D model of the shipyard, the central part shows one of the result sheets, and the right part represents the aspect of one ProcessFlow designed to represent the assembly works executed under the gantry crane.

Thus, besides the analytic value present in all discrete events of simulation models, the 3D model developed brings high commercial value in order to show the manufacturing process to the customer and, on the other hand, the 3D component transforms the model into an innovative tool to be used as learning tool.
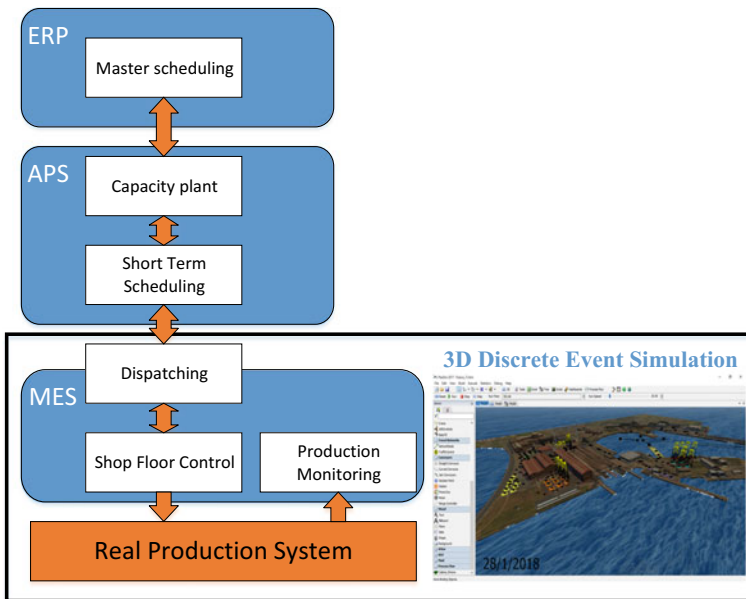
Fig. 6 Simulation model role

4.2   Problem Description

This problem applies to internal logistic operations in a shipyard when the resources for those activities are limited. Because the customer is in charge of the transportation of the jacket from the shipyard to the offshore wind farm site, the Load-Out dates and duration are defined at the beginning of the project. The noncompliance of the Load-Out dates implies penalties in the contract. At the same time, it is important to present the project timeline to the customer showing the shipyard capacities, and that the shipyard has the resources needed to the project exigencies. It is also useful to evaluate the possible mitigation actions under any unforeseen circumstances that may arise through the project, and which may oblige the shipyard to store the jackets more time than expected in the master schedule.

Moreover, in the shipyard represented in this work, other projects are developed at the same time that is the objective project of this paper. For this reason, it is essential to represent the space busy by these projects, and their iteration with the work zones and the storage areas used by the studied manufacturing project.

On the other hand, the simulation model developed will be used in different stages of the project from the tender phase until the last Load-Out. For this reason, the 3D simulation model should be parametric allowing the user to start the simulation in the current point of the project, and locating each jacket in this specific location in the shipyard when the simulation runs.

Finally, the problem caused by the material raw delays or the free issue equipment delays should be taken into account, because these delays can have effects in the manufacturing strategy, forcing the project team to design new construction strategies that are implied to make secondary steel assemblies outside the assembly zones.
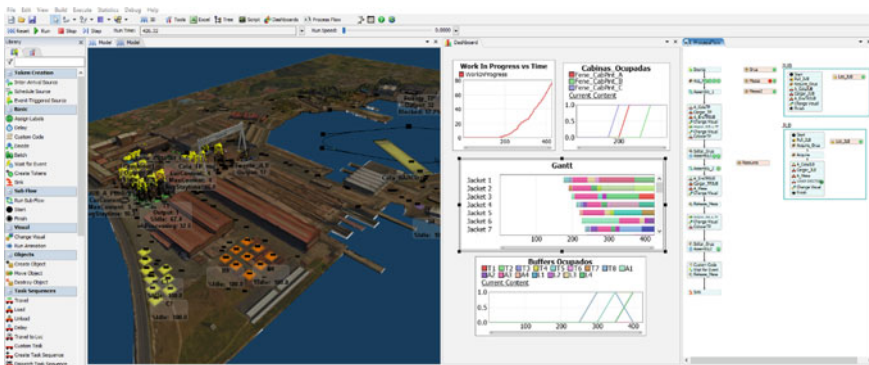
Fig. 7   Simulation model developed

5 Case Study

Two case studies based on a real manufacturing project of jackets are presented. First case study has been made to represent the manufacturing strategy adopted to elaborate the master scheduling, as well as represents the occupation along the project of the total storage zones available in the shipyard. Second case study based on a delay in the secondary equipment is presented, evaluating different changes in the manufacturing strategy in order to avoid the delays generated in the manufacturing process.

5.1 Base Line 3D Representation and Study

First case study is used as validation of the 3D simulation model developed. To achieve this, the case study is used to represent the manufacturing strategy used to elaborate the master scheduling. The model validation has been made through the comparison of start and finish manufacturing dates presented in the master scheduling with the dates obtained from the 3D simulation model. At the same time, this case study has been used to show the manufacturing strategy at the customer, even with the use of virtual reality glasses or the iteration in the first person with the model through the visualization in the CAVE. This immersive method of visualization is useful to design new manufacturer strategies through the iteration between simulation model and experienced staff. The iteration between both components adds value in decision-making and detects nonviable strategies proposed by the simulation model.

On the other hand, through the case study presented, it studied the occupation of the storage zones along with the project timeline when the master schedule is applied. The storage zone's occupation for this case study is represented in Fig. 8, with a maximum buffer of 14 jackets and with the yellow storage zone completely free along the project.

Finally, Table 1 represents the baseline internal logistic cost, including the cost of main factors involved in the internal logistic strategy. These factors are as follows:

- SPMT rent,
- Supports manufacturing, and
- Additional movements of the SPMT.

5.2 Delay in the Secondary Equipment

Second case study represents the influence in the internal logistics of a delay in the secondary jacket equipment. The secondary equipment delayed should be assembled in the assembly areas under the gantry crane, because this component is situated in
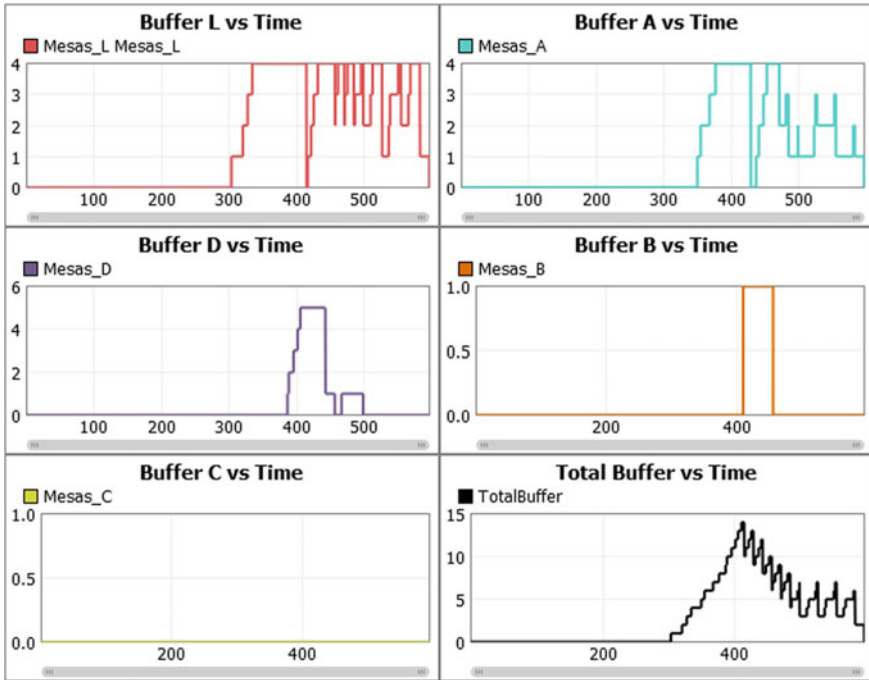
Fig. 8 Buffers occupation along the project timeline

the upper part of the jacket. In this case, study will be evaluated by the possibility of incorporating a new assembly zone, where the secondary equipment assembly could be made through a mobile crane, Fig. 9.

The secondary equipment arrives at the shipyard in batches of 10 equipment, being the delay studied in 60 natural days in the first batch and 30 natural days in the second batch.

Once defined the delays, the 3D simulation model has been used to calculate the effect of these delays if the secondary equipment assembly strategy is maintained. Keeping the initial secondary assembly strategy implies to move a certain group of jacket to the storage areas without the secondary equipment, and once its equipment arrives, the shipyard comes back with the jackets at the assembly zone. Thus, the

Table 1 Internal logistic cost to master scheduling

Description	Cost
SPMT rent along 5 months	1.250.000 €
Supports to 14 Jackets (4 supports per jacket)	280.000 €
Additional movements	0 €
Total	**1.530.000 €**

Fig. 9 New assembly zone location

Table 2 Effect of delays in the customer Load-Out milestones

	Milestone				
Delay (days)	M1–M7 (%)	M8 (%)	M9 (%)	M10 (%)	M11 (%)
0	98	12	2	0	1
0 to 5	2	74	46	7	33
5 to 10	0	14	51	25	54
10 to 15	0	0	1	68	12

SPMT movements are increment meaningfully, and, on the other hand, keep the secondary equipment strategy implies delays in the delivery of the jacket, breaking que customer Load-Out milestones according to Table 2, and assuming a penalty to the project.

The results presented in Tables 2 and 3 guarantee a confidence interval of 95%.

In order to avoid these delays, the utilization and sizing of new assembly zone are studied; in this case, the simulation model developed has been used to evaluate the project results if new secondary equipment assembly zone is implemented. Table 3 represents the simulation model results with a capacity to the new storage zone from four to seven jackets.

According to Table 3, an assembly zone capacity of six jackets is enough to avoid the delays in the delivery of jackets derivatives of the electrical and mechanical equipment delays. In addition, an important internal logistic cost reduction is achieved with this assembly zone, because half of a month reduction in the SPMT rental and a reduction of nine SPMT extra movements are achieved.

Table 3 Effect of the new secondary equipment assembly zone in the customer Load-Out milestones

Assembly zone capacity	Delay (days)	Milestone				
		M1–M7 (%)	M8 (%)	M9 (%)	M10 (%)	M11 (%)
4	0	100	95	21	0	0
	0–5	0	5	75	3	18
	5–10	0	0	4	58	54
	10–15	0	0	0	39	28
5	0	100	100	64	15	23
	0–5	0	0	36	82	77
	5–10	0	0	0	3	0
	10–15	0	0	0	0	0
6	0	100	100	98	87	96
	0–5	0	0	2	13	4
	5–10	0	0	0	0	0
	10–15	0	0	0	0	0
7	0	100	100	100	99	100
	0–5	0	0	0	1	0
	5–10	0	0	0	0	0
	10–15	0	0	0	0	0

6   Conclusions

The logistics internal problem in a jacket's manufacturing project is not a trivial problem, and often little studied by the project manager, although this problem can mean about the 5% of contract budget.

For this reason, this paper presents a tool based on 3D Discrete Events Simulation that allows evaluating the internal logistic strategy in terms of costs and resources in charge of the transportation to the storage area and Load-Out operations.

In addition, the simulation tool developed calculates the storage area required during the project, allowing evaluating the interferences with other projects and the supplier delays. At the same time, the simulation model situates each storage movement in the project timeline and places each jacket in its storage position throughout the project showing the dates of entry and exit in each buffer place.

Furthermore, this paper highlights how useful the 3D Simulation model is to evaluate costs, develop storage strategies, and bring commercial value at the project, allowing the company to verify the feasibility of the project, define new assembly strategies, and show the manufacturing strategies to hire new projects.

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The Methodology of Modeling and Simulation of Human Resources and Industrial Robots in FlexSim

Grzegorz Gołda, Adrian Kampa and Damian Krenczyk

1 Introduction

Currently, in the manufacturing industry, one can observe the increasing use of automation and robotization, which replaces human labor. Industrial robots have mobility similar to that of the human arm and can perform various complex actions similarly to a human. In addition, they do not get tired and bored. Therefore, many industrial robots are used these days, especially for repetitive and high precision tasks (e.g., welding) or activities of monotonous and demanding physical exertion (e.g., machine tending). Also, the manufacturing processes become more complex and challenging to analyze. The research on real manufacturing systems is usually not possible, because of common production and excessive cost related with every delay [6].

Therefore, the computer simulation and especially Discrete Event Simulation (DES) method [2] is widely used for the design of manufacturing systems [10], solving scheduling problems [34], for efficiency [20] and stability analysis [5] of production systems and the design of transportation systems with Automated Guided Vehicles (AGVs) [32]. These are problems that are related to operational research that also involves the conceptual design of the systems [29], generation of computer models for different scenarios [24], production planning, and control [25]. These problems also involve bottleneck detection, simulation parameter selection (deterministic or stochastic), and the impact of different parameters on results (control

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factors and noise factors). Also, these problems are about computational complexity, NP-completeness of certain problems, congestion, deadlock and delay in the system, design of experiments, and the statistical analysis of results [2]. There are many DES software tools dedicated to production process simulation, including ARENA, Enterprise Dynamics, FlexSim, Plant Simulation, GPenSim, and others [4, 7].

The main advantage of DES is the ability to conduct experiments that cannot be performed on real manufacturing systems and designing a simulation model helps in gaining knowledge that could lead to the improvement of the real system. The disadvantages of DES include the following [30]:

- special training is required to build simulation models;
- very often, attempt to gain insights through simulation turns futile due to ambiguous models;
- since so much randomness is associated with simulation (random inputs), it can be hard to distinguish whether an observation is a result of system interrelationships or due to randomness; and
- simulation modeling and analysis can be time-consuming and expensive.

Therefore, it is important to effectively educate a wide range of students on at least the basic concepts and power of simulation and disseminate advances in research and application development using simulation software like FlexSim.

2   The Problem Description

The main problem at the design stage of manufacturing systems is how to establish a real difference in the work efficiency between improved or reengineered manufacturing systems, for example, ones that is manually operated and other that is fully automated. The aim of the current study is to develop a methodology that allows us to clearly define the production efficiency growth associated with an improvement of manufacturing systems, for example, the replacement of human operators with industrial robots. Moreover, the next question is what parameters are important for the evaluation of this problem. That question involves factors related to human–machine interaction. There are many human factors that are difficult to model because of human individuality. In addition, factors related to machine parameters, machine tending, machine and robot reliability and failures, the transportation system, storage system, and quality control system should be taken into consideration [22, 26].

Manufacturing systems consist of different numbers of specialized machines and human operators or robots for material handling. In industry, there are diverse types of machine tools used, and presses are commonly robotized. The schema of a typical hydraulic press workstation is presented in Fig. 1. Usually, an operator is required for loading and unloading the machine and for transferring the product from one machine to the next production stage. Robots can undertake the same work faster and more consistently than human operators, as is presented in the industrial example of robotized press line [27].
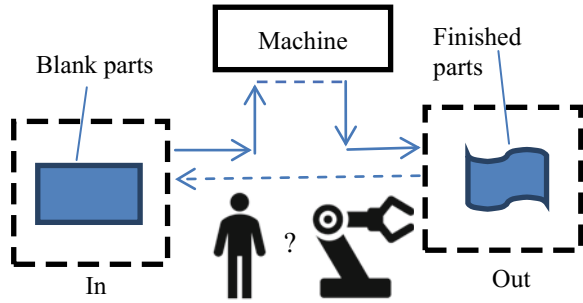
The workstations can be organized as cells or lines. Fully automated and robotized lines typically work very well, but some problems with failures can occur. Failure of any element of the line causes production stoppage of the whole manufacturing line. Therefore, the reliability of the components plays a key role in the productivity and utilization of the manufacturing system.

2.1 Machine Availability and Reliability

The term availability pertains to planned work time and unplanned events, e.g., disturbances at work and random machine failures. Certain unplanned events cause machines to become unavailable, decreasing production efficiency. The reliability of objects, such as machines, is defined as the probability that they will work correctly for a given time under defined conditions of work. The most popular method for estimating reliability parameters uses the theory of probability to forecast value of any failure-free time and repair time parameters, under the condition that a trend based on historical observations is possible to notice.

In practice, for describing machine reliability, in most cases, the parameter Mean Time to Failure (MTTF) is used, which is the expected value of the time to failure of a machine or system component. For example, if that time is an exponentially distributed random variable with failure rate λ [31], we have

$$\text{MTTF} = \int_0^\infty t f(t) \mathrm{d}t = \int_0^\infty t \lambda \mathrm{e}^{-\lambda t} \mathrm{d}t = \frac{1}{\lambda} \tag{1}$$

In the case of repairable objects, the parameters Mean Time Between Failures (MTBF), and the Mean Time to Repair (MTTR) are used:

$$\text{MTBF} = \text{MTTF} + \text{MTTR} \tag{2}$$

For complex systems, consisting of n serially linked objects, each of which has exponential failure times with rates λ_i, $i = 1,2,\ldots, n$, the resultant overall failure rate λ_S of the system is the sum of the failure rates of each element λ_i:

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \qquad (3)$$

Moreover, the system MTBF_S is the sum of inverse MTBF_i of linked objects:

$$\frac{1}{\text{MTBF}_s} = \sum_{i=1}^{n} \frac{1}{\text{MTBF}_i} \qquad (4)$$

For the example of the manufacturing line, we can use formula four with different failure parameters for machines, robots, and also for human operators.

2.2 Human Factors in Manufacturing

Regarding the production flow process, people are characterized by a high variability of behaviors [19], e.g., when tired, they work with lower efficiency. Moreover, people can cause disturbances in the production process (human errors). Also, accidents at work may be the result of human errors or equipment failures. These accidents may cause an inability to perform future works in production processes.

Since people are very different, there is no universal method for describing the interaction between an operator and a machine. Most often, methods based on mathematical statistics, e.g., Methods Time Measurement (MTM), are used to determine working time standards [16].

Also, in computer software intended for production process simulation, human factors are not sufficiently utilized. When building a computer model, people are treated as a quasi-technical element of the production system, and they should operate in the same way as a machine. In practice, human behavior is unpredictable, which might help to explain why simulation models do not respond to the reality as it would be expected [1].

Knowing the categories of human errors can help to simulate human behavior more realistically. The planned working time of a human operator can be represented by using a schedule, including the planned interruption of work, such as preparation of workstation, set up, testing of products, cleaning after work completion and meal breaks, and rest pause. Planned vacations and excused absences can be omitted because replacements can be arranged [14].

We can also take into consideration unplanned interruptions at work such as short-term interruption resulting from a variety of psychophysical conditions, physiological needs, and long-term interruptions associated with sudden disease or accident at work. We can model them as machine failures and describe them

using exponential distribution with a constant failure rate. Considering the average length of human absence because of health problems is 2×5 days per year with 250 working days per year, the probability of an employee absence can be described using the parameters MTBF = 125 days and MTTR = 40 h. In turn, short breaks are difficult to estimate because of human individuality and can be approximated using the parameters MTBF = 4–8 h and MTTR = 5–10 min.

For example, assuming human unreliability basing on Human Error Assessment and Reduction Technique (HEART) for "routine and highly practiced rapid tasks involving a relatively low level of skill," the nominal value of human error equals to 0.01 [33]. Therefore, the human error rate can be described by parameters: $MTBF_h$ = 8 h and $MTTR_h$ = 5 min.

2.3　Robotic Factors in Manufacturing

Modern industrial robots are characterized by a high precision of operation, high speed of motion, and high reliability of work. They can be equipped with various tools and used for different works that are traditionally performed by human workers. It is important that robots can work in conditions that are harmful to human health [12].

Theoretically, robots can work 24 h per day without any breaks, but human supervision of the production process as well as precise planning and scheduling of robot work is necessary for better performance [23]. Changes of tools and reprogramming, which are conducted from time to time, require the participation of an operator. Moreover, a robot requires periodic maintenance service and inspection before each automatic run.

There are some methods for robot motion planning described in [11, 28]. These methods are based on the MTM or on the traditional time study concept and can be used for comparing the relative abilities of robots and humans. Dedicated computer software for robot movement planning can also be used. The outcome of each technique is a set of time values that can be used to compare human and robot productivity. Nowadays, robot manufacturers declare an average of MTBF = 50000–60000 h or 20–100 million cycles of work [17]. However, the robot's equipment is often custom made and has lower reliability. Therefore, the most common range of the experienced MTBF is 500–1000 h, and most of the companies need about 4–8 h for the MTTR of their robots [9].

3　Building a Model

The methodology of the modeling and simulation process (Fig. 2) includes the analysis of the real problem, conceptual design and model synthesis, a simulation experiment, and implementation of the obtained solution [10, 29].
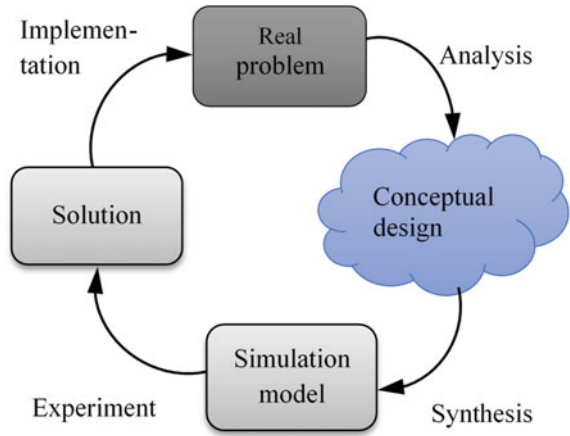
The first step includes conceptual design of the model with the use of graphical diagrams methods [21], e.g., Object Flow Diagram (OFD) [15]. The example of the workstation diagram is presented in Fig. 3.

In the next step, we can build workstation model in FlexSim using predefined fixed resources (Source, Queue, Processor, Queue, Sink) that are linked with A-connections. Then, we should add an operator (or robot) and connect them with Queue1 and Processor1 with S-connections, as presented in Fig. 4 (and check the option "Use Transport" in Flow menu).

The data of robotic press line were based on the industrial example described in [27], and the human operator data were taken from experimental time study [13]. The parameters include constant machine process time $Tm = 10$ s, average operator cycle time $Top = 10$ s, and constant robot cycle time $Tr = 6$ s, which results in different
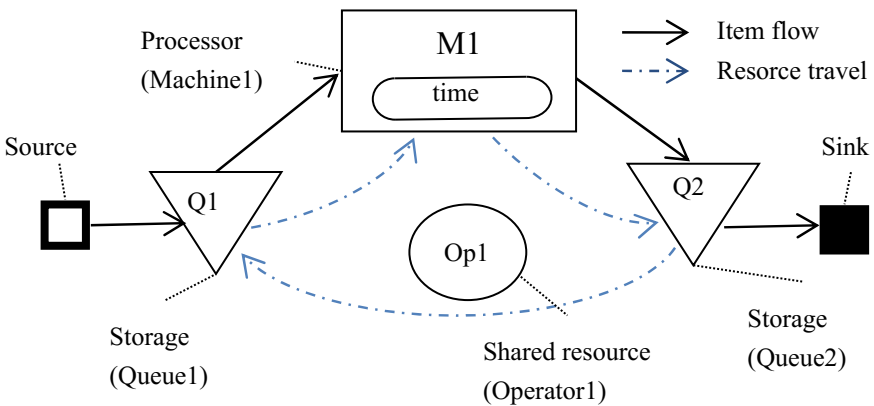
Fig. 3 The conceptual design of the workstation model using OFD
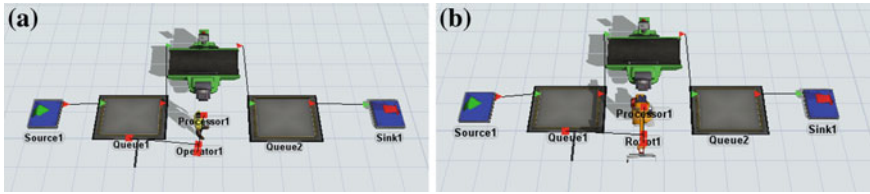
Fig. 4 Model of (**a**) human-operated workstation (**b**) robot-operated workstation

throughputs: about 180 items/hour for human-operated workstations and about 220 items/hour for robot-operated workstation.

In order to achieve the desired throughput in the model, we should put the object near each other and modify operator parameters:

- Do not travel offset for load/unload task,
- Machine setup time: normal distribution with 4 s meantime and 1 s standard deviation, and
- Check the option "use operator for setup."

And also modify the robot parameters:

- Use simple motion method,
- X rotation speed $= 180°/s$,
- Z rotation speed $= 180°/s$,
- Extension speed $= 2$ m/s, and
- Load/unload time $= 1$ s.

In the next step, we should build a model of manufacturing line with four serially connected workstations as presented in Fig. 5.

Because of unstable speed of work of different operators, the changes of queue contents can be observed as presented in Fig. 6.

On the other hand, a very regular work of industrial robots and only slight changes in queue content can be observed, as presented in Fig. 7.

As a result, we can observe throughput increase of about 25% for robot-operated line comparing to the human-operated line. The next questions appear: Is it enough? Is it possible to achieve greater robot performance?
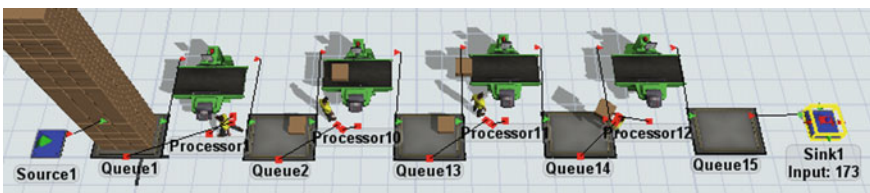
Fig. 5 Human-operated line after 1 h of work
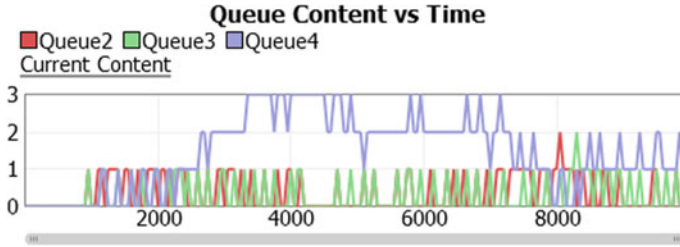
Fig. 6 Queue content changes with time [s]
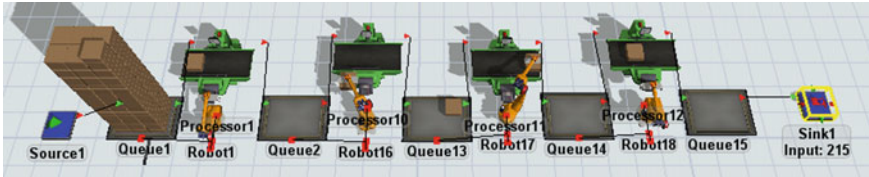
Fig. 7 Robot-operated line after 1 h of work

When we observe a real robotized manufacturing process, for example, a movie from Comau Robotics [8], we can see that there are not any storage buffers between machines. Because of robot regularity, the queue is unnecessary, and robots can transfer products directly from one machine to the next machine. This requires system reconfiguration and adding one additional robot, as presented in Fig. 8.

In order to synchronize robots and machines, it is suggested to add trigger action, "On Unload" to all robots, including command "Travel to an Object", which causes the robots to not wait motionless for next item, and already after unload, they begin the movement to the loading position.

That reorganization will improve the production throughput for above 40%, comparing to the human-operated line, and is one of the reasons that industrial robots are widely used in industry.
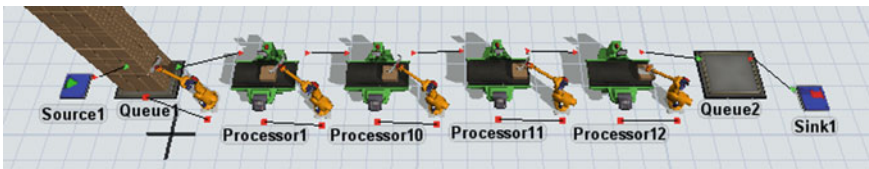
Fig. 8 Modified robot-operated line after 8 h of work

4 Production Efficiency and Key Performance Indicators

In order to evaluate results from simulation experiments, some Key Performance Indicators (KPI) can be used, including [18]

- Production throughput,
- Manufacturing lead time (MLT),
- The average waiting time of ready parts,
- Queue length,
- Work in progress (WIP),
- The number of deadlock situations, and
- Mean tardiness and rate of tardy parts (relative to the number of parts produced on-time), and
- OEE—Overall Equipment Effectiveness.

Work efficiency and the use of the means of production can be expressed using the OEE metric that depends on three factors: availability, performance, and quality.

$$OEE = (\text{Availability}) \times (\text{Performance}) \times (\text{Quality}) \tag{5}$$

Availability is the ratio of the time spent on the realization of a task to the scheduled time. Availability is reduced by disruptions at work and machine failures.

$$\text{Availability} = \frac{\text{available time} - \text{failure time}}{\text{scheduled time}} \tag{6}$$

Performance is the ratio of the time to complete a task under ideal conditions compared to the realization in real conditions or the ratio of the products obtained in reality to the number of possible products to obtain under ideal conditions. Performance is reduced (loss of working speed) by the occurrence of any disturbances, e.g., human errors.

$$\text{Performance} = \frac{\text{ideal cycle time}}{\text{real cycle time}} \tag{7}$$

Quality is expressed by the ratio of the number of good products and the total number of products.

$$\text{Quality} = \frac{\text{good products}}{\text{overall products}} \tag{8}$$

The number of good quality products is a random variable, which can be described by a normal distribution with standard deviation sigma. Quality levels are determined for ranges of the standard deviation sigma. In traditional production systems, level of 3 sigmas is considered to be sufficient. However, in the modern automated and robotic systems, the level of 5–6 sigmas is possible to achieve [3].

The OEE metric is widely used in industrial practice, and it can also be used for modeling of manufacturing systems [22], which requires implementation of planned work schedule and breakdowns into model. For operators, the human error rate can be described by parameters: MTBFh = 8 h and MTTRh = 3–5 min. In FlexSim, it can be easily defined in object breakdown menu: "First Failure Time" and "Uptime" as exponential distribution, "exponential (0, 28,800, 1)" and "Downtime" as uniform distribution "uniform (180, 300, 1)" [in seconds].

The planned schedule of an operator can be defined as "TimeTable", and the example is presented in Table 1. It includes preparing to work = 10 min (600 s), meal and rest pause = 15 min (900 s), and machine cleaning at the end of the shift = 5 min (300 s). The scheduled work time of the operator is equal 7.5 h. However, some human errors can occur and real work time will be shortened.

The robot failure rate can be described by the following parameters: MTBFh = 1000 h and MTTRh = 4–8 h, and robot schedule is presented in Table 2. The robotic line is typically set up once per shift, and that takes about 15 min (900 s).

The performance ratio is related to the time needed to load and unload the machine by operator or robot (do not require any change as we have it already defined).

The quality ratio can be defined as the output of good quality products and bad quality products, which requires additional inspection station and sink for bad quality products and random flow distribution at the last queue, including percentage separation of items between output ports, for example, 99.7% for Port 1 (good products) and 0.3% for Port 2 (bad products). For robotic line, it can be defined as 99.99% for Port 1 (good products) and 0.01% for Port 2 (bad products) as presented in Fig. 9.

Table 1 Human operator schedule (Time table with custom repeat = 28,800 s)

Row no	Time (s)	State	Duration (s)
1	0	12-scheduled down	600
2	12,600	12-scheduled down	900
3	28,500	12-scheduled down	300

Table 2 Robot schedule (Time table with custom repeat = 28,800 s)

Row no	Time (s)	State	Duration (s)
1	0	12-scheduled down	900
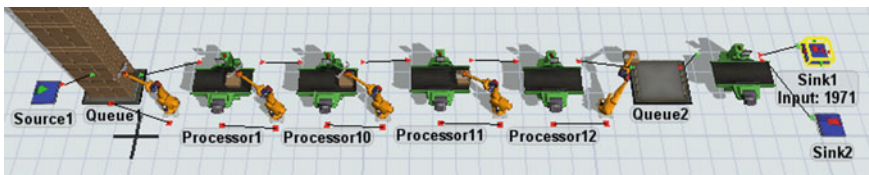
Fig. 9 Modified robot-operated line with outputs for good and bad quality products

Presented way lead to sophisticated models of manufacturing lines that enable better representation of real manufacturing processes. However, it is time-consuming and the interpretation of results is difficult because of many stochastic parameters. Therefore, proper simulation experiment is needed, and statistical analysis of the results is required.

5   Conclusions and Further Work

The advanced computer simulation software like FlexSim enables to build the sophisticated models of the production systems with machines, operators, and robots with stochastic (short-time and long-time) reliability parameters, which allows better representation and understanding of a real production process. As it was predicted, the experiments confirm the advantage of the application of robotic manufacturing line compared to manually operated line. However, this is one of the best examples of robotic improvement in manufacturing, and in other cases of machine tending, the difference between human operator and robot is not so clear to see.

This approach is universal because the use of OEE indicator in modeling allows the direct comparison of results from simulation with other manufacturing systems. Results obtained with presented methodology can be used for detailed designing of a manufacturing system and for economic analysis, regarding labor costs and costs associated with the investments in robotization.

The further work is related also with the use of simulation software like FlexSim in other areas including

- Automatic model generation,
- Production planning and scheduling,
- Assembly processes,
- Logistic processes,
- Flexible manufacturing systems, and
- Automated guided vehicles.

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Determination of the Optimal Number of Trailers for Milk-run Intralogistics System

Kamila Kluska

1 Introduction

Company X produces metal seats. Due to the dynamic development, the company has decided to implement a new production line. This investment is intended to meet the growing demand for SDW seats. To make it possible, the company designed a production line and decided that the tact time is 18 s.

Due to the innovation of the project, the specificity of the new line, and the desire to achieve a number of benefits, the company decided to design an intralogistics system based on the milk-run concept. Due to the high risk and difficulty in designing the milk-run system, company decided to initially design such a system only for the new SDW chair production area, which requires cyclical delivery of 16 material items. The company intends to implement deliveries based on this concept for all production lines in the future.

The goal of the article is to describe a methodology that allows to designate a set of orders for materials (for logistics train) and the number of transport trailers necessary to handle it. This methodology includes the following:

- Collection and preparation of the necessary materials data,
- Determination of orders and its frequency, taking into account the quantity and type of containers transported to individual bus stops, and
- Determination of the demand for specific quantities of transport trailers to serve the orders.

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This methodology is the basis for the development of technology in the FlexSim simulation software, which will allow for automatic calculations and analyzes in the simulation program, and thus to quickly build the intralogistics systems in simulation models.

The article consists of five sections. This section defines the goal and scope of the article. Section 2 provides literature review and description of milk-run concept. Sections 3 and 4 describe the methodology on the example of the described company, taking into account all the most important stages. The summary and plans of further research are presented in Sect. 5.

2   Milk-run Concept

The milk-run is an internal logistic system. Its main idea is to replace traditional means of transport with logistic trains. The logistic train (in Japanese Mizusumashi) consists of a tugger and trailers operated by the train operator. Each logistic train can contain different numbers of trailers, which may additionally differ in shape, size, number of shelfs and configuration (storage arrangement), and thus weight and capacity. Large capacity of logistics train allows the transport various types of materials, and carries out many loading and unloading operations in one cycle.

The logistic train moves on the transport routes. It is necessary to enable the train to reach the source locations (e.g., supermarket), locations of material consumption, and the parking zone. The milk-run idea assumes delivering materials to the use locations in small batches. A milk-run can be organized based on a fixed route or on a fixed schedule, but a second option is less popular [5].

Greenwood et al. [2] identify a series of flows in intralogistics systems. First flow concerns the transport of production materials to workstations. The second one is the flow of finished products from workstations to designated storage area. The other two flows concern transport of work-in-progress materials between workstations and delivery of empty containers from workstations to their storage areas. The flow of information could also be taken into account.

Milk-run systems are based on multiple deliveries, thanks to which they allow to achieve a number of operational benefits, including the following:

- Improvement of load factors [4],
- Increasing the efficiency of the internal transport system [8],
- Better fulfillment of transport demand and timely deliveries of materials in the system [8],
- More effective use of working time of internal transport employees [9],
- Lower incidences of collisions due to reduction of traffic in a given area. In addition, the driver in the logistics train has a better view of the space than in the forklift, so in case of any danger, he can react faster.
- Shorter route traveled by means of transport and thus shorter shipment distances [1],

- Less energy consumption, consolidated distribution, and collection of goods as well as empty containers, resulting in lower transportation costs [1],
- Increasing the reliability of deliveries by the synchronization of means of transport and minimization of empty runs [7],
- Lower level of work-in-progress materials [7],
- Process transparency [6],
- repetitive processes lead to learning effects and thus to a high level of reliability [6],
- Reduction of the total area of transport routes, which provides additional space for new investments, and gives the opportunity to better organize the production space [4],
- Prevention of overproduction, and better throughput of the production system.

Milk-run systems also have some disadvantages as follows:

- Designer needs to have a wide knowledge of the demand (distribution and volumes), the source and use locations, the characteristics of the containers and of the parts being transported, the specificities of the production process, the topography of the analyzed area, the towing capacity of the trailers, the capacity of the tuggers, etc.
- Necessity of adapting order policies [6].
- High complexity for tactical planning [6].
- Need for good planning of transport volumes, because the big transport lot sizes cause high inventories [6].
- Risk of inefficient tours [6].
- All activities of operator should be standardized to prevent errors and ensure efficient flow.
- Milk-run system is appropriate only for systems with stable frequencies of demand and approximately stable volumes of orders [6].
- During the design of transport routes and the selection of means of transport, it is necessary to take into account the tugger attributes, for example, its power and size. An important issue is the possibility of cutting corners by trailers during the route.
- There is no possibility of making any mistakes. The train has to deliver to workstation exactly as many materials as needed, which can be risky in case of mistakes of employees, deviations in demand, or train breakdown.
- Difficulties in arranging a cyclical route, which would be well founded and based on the real needs of the production line.
- Usually, in companies, logistic trains do not allow to serve the entire intralogistics. Therefore, it is necessary to use forklift trucks that are irreplaceable in placing goods on racks and in loading and unloading delivery trucks.

Furthermore, to achieve mentioned benefits, it is necessary to determine the optimal number of means of transport, i.e., specified types of trailers. Too many trailers cause the waste of money associated with the purchase and maintenance of the transport fleet, and also causes reduction of available space. On the other hand, too few trailers do not allow efficient and timely satisfaction of material needs.

Therefore, in this case, the term "optimal" means the smallest number of trailers that ensures efficient work of the internal logistics system.

In the analyzed literature sources, no method was found to determine the optimal number of trailers for the logistics train. Greenwood et al. [2] developed a framework for simulation modeling of milk-run system; however, it does not take into account the problem of separating orders for materials, appearing at a certain frequency. It also does not take into account the issue of the allocation of materials to transport containers as well as their location on individual types of trailers and on shelves. The pattern assumes building a model based on information that is difficult to determine, which is why it was applied to the described methodology. It will allow not only to determine the necessary data for the design of the milk-run system but also to develop the mentioned methodology of simulation modeling with additional analytical and computational mechanisms.

3 Designation of Orders for the Milk-run System

The methodology consists of many stages, however, due to the issues and the goal of the project, the computational part of the methodology is described in more detail. Methodology uses a calculation mechanism "CalculatorForMR" built in MS Excel and assumes the implementation of calculation results in a simulation model built with the use of FlexSim simulation software. It includes designation of orders and determining the number of trailers. Current section describes designation of orders and consists of following stages:

- Preparation of layout and the list of workstations, which will be fed in parts by the logistics train.
- Specification of locations of bus stops on the layout of analyzed space.
- Definition of possible routes to individual bus stops.
- Preparing the PFEP table.
- Filling the table "Orders" which includes data about orders.
- Filling the table "Calculator_for_Orders."

3.1 Preparation of Layout and the List of Workstations, Which Will Be Fed in Parts by the Logistics Train

This stage involves the preparation of the topography of the factory, taking into account the location of workstations, supermarket, and all spatial limitations that may disrupt the material transport process. The topography has to include the names, shapes and sizes of all machines, and storage locations within each specified workstation, buffer, or warehouse. The assigned names are necessary for the subsequent definition of addresses for the containers transported by the logistic train. They should

be consistent and understandable both for the employees (the client) and for the person designing the system. Therefore, it is necessary to develop a proper notation. The designed supermarket and locations for containers should have a sufficiently large capacity in relation to the adopted assumptions as well as enable efficient, safe access of the logistics train operator to supported locations.

3.2 Specification of Locations of Bus Stops on the Layout of Analyzed Space

The prepared layout should determine the location of bus stops for the logistic train, taking into account its potential length and method of train positioning. It is necessary to decide if a material delivery requires train relocation in order to reduce the burden of train operators. The most important criteria that are taken into account are the available space, size, and weight of transport containers and the number of train operators. The space for the bus stop must guarantee safe work of the operator and a safe stop of the logistics train, taking into account the assumed logic of its positioning and service.

3.3 Definition of Possible Routes to Individual Bus Stops

On the basis of the collected data and constraints, it is necessary to design transport routes which enables fast and collision-free movement of logistics trains between bus stops. Definition of transport routes should include layout, width, turning radius, directions (one- or two-way road), locations, and the rules of movement at intersections.

3.4 Preparing the PFEP Table

PFEP is Plan For Every Part. It should be filled with data on all materials transported by the logistics train. In the described case, the classic form of PFEP was simplified to include only the data relevant for the methodology. Figure 1 shows the PFEP table in calculator in MS Excel, prepared for described case. PFEP table takes into account the ID of the part and the container, the dimensions of the container, the assumed number of containers at the workstation, and the source and use location of parts. A container assigned to parts should be adjusted to their specificity and special requirements, but due to the subject of the publication and the issues raised in it, this issue has been omitted.

Part ID	Container ID	Length	Width	Height	Capacity	At Station	Use Point	Warehouse
PGE1001	Plastic_tray	600	400	150	24	2	WKS_01	SMarket_01
PGE1002	SLC280	600	400	280	30	2	WKS_02	SMarket_01
PGE1003	SLC280	600	400	280	30	2	WKS_03	SMarket_01
PGE1004	Carton_2	400	300	150	1000	2	WKS_03	SMarket_01
PGE1005	Carton_1	600	400	300	800	2	WKS_03	SMarket_01
PGE1006	Plastic_tray	600	400	150	24	2	WKS_03	SMarket_01
PGE1007	Plastic_tray	600	400	150	24	2	WKS_03	SMarket_01
PGE1008	Carton_2	400	300	150	1000	2	WKS_01	SMarket_01
PGE1009	Wozek_1	1200	800	900	200	2	WKS_03	SMarket_01
PGE1010	Carton_3	600	400	150	2000	2	WKS_03	SMarket_01
PGE1011	Carton_2	400	300	150	2000	2	WKS_03	SMarket_01
PGE1012	Plastic_tray	600	400	150	24	2	WKS_03	SMarket_01
PGE1013	SB	250	148	130	400	2	WKS_03	SMarket_01
PGE1014	SB	250	148	130	400	2	WKS_01	SMarket_01
PGE1015	SB	250	148	130	400	2	WKS_02	SMarket_01
PGE1016	Carton_2	400	300	150	1000	2	WKS_04	SMarket_01

Fig. 1 The PFEP table in "CalculatorForMR." *Source* Own study with use MS Excel

3.5 Filling the Gray Columns in Table "Orders" Which Includes Data About Orders

On the basis of the PFEP table, the user should fill with data the columns marked in the table "Orders" at Fig. 2. The first column contains the material ID, the "Source" column specifies the exact source location, and the "Destination" column defines the workstation and the name of the storage field. The "Type of act" column defines the type of activity performed by the train operator. There are five available types of activities, which allow for a proper indication of the train operator's work as given below:

- 0—load empty container and transport to destination,
- 1—load container with parts and transport to destination,
- 2—load container with parts, transport to destination, take an empty container and transport to supermarket,
- 3—only take an empty container from destination and transport to supermarket, and
- 4—only take full container from destination and transport to supermarket.

Distinguishing the types of activities is important for simulation modeling of logistics train movement and work of train operator. This is the basis for further calculations. The preparation of it requires a thorough analysis of the system as well as knowledge about its specificity and future requirements.

In the "BusNR for unload" column, user can enter the name of the bus stop at which the logistic train stops in order to deliver the container with the material to the designated storage field (Destination). The values in the other columns will be determined in the next steps of the proceedings. It concerns the following:

What	How many	Source	Destination	OrderNR	Type of act	TrailerNR	BusNR for unload
PGE1001		SMarket_01/P_11	WKS_01/P_01		2		1
PGE1002		SMarket_01/P_05	WKS_02/P_01		3		3
PGE1003		SMarket_01/P_12	WKS_03/P_01		1		4
PGE1004		SMarket_01/P_13	WKS_03/P_04		1		5
PGE1005		SMarket_01/P_06	WKS_03/P_05		3		5
PGE1006		SMarket_01/P_01	WKS_03/P_06		2		5
PGE1007		SMarket_01/P_02	WKS_03/P_07		2		5
PGE1008		SMarket_01/P_15	WKS_01/P_02		2		2
PGE1009		SMarket_01/P_03	WKS_03/P_02		2		4
PGE1010		SMarket_01/P_10	WKS_03/P_03		2		4
PGE1011		SMarket_01/P_04	WKS_03/P_07		2		5
PGE1012		SMarket_01/P_07	WKS_03/P_08		2		5
PGE1013		SMarket_01/P_08	WKS_03/P_09		2		5
PGE1014		SMarket_01/P_14	WKS_01/P_03		2		2
PGE1015		SMarket_01/P_16	WKS_02/P_02		2		3
PGE1016		SMarket_01/P_09	WKS_04/P_01		2		5

Fig. 2 The table "Orders" in "CalculatorForMR." *Source* Own study with use MS Excel

- "How many"—the quantity of containers to deliver,
- "TrailerNR"—on the designated trailer number in the logistic train, and
- "OrderNR"—within the designated order number, which will be generated automatically according to the calculated frequency.

3.6 Filling the Gray Columns in Table "Calculator_for_Orders"

Next stage is filling the following columns in "Calculator for Orders"table presented at Fig. 3:

- "Tact [s]"—designated tact time,
- "How many parts per unit"—number of parts used in operations in designated location, per one piece of finished product.

After entering the abovementioned values, the calculator automatically determines the time of emptying one container and the number of containers used within 1 h.

The "Frequency of deliveries [h]" column requires entering how often the containers should be delivered to the workstation. The decision on the frequency of deliveries should be made on the basis of the values displayed in the "Nr of containers" column, which are automatically calculated. "Nr of containers" means the number of containers that must be delivered to the workstation in order to meet the demand for the analyzed type of part.

Part	Capacity	Use Point	Nr of BusSTOP	Warehouse	Nr of full totes at station	Tact [s]	How many parts per 1 unit	Emtying time/1 container	How many containers/ 1 h?	Frequency of deliveries [h]	Nr of containers	NR of order
PGE1001	24	WKS_01	1	SMarket_01	1	18	1	0,120	8,333	0,5	5	1
PGE1002	30	WKS_02	1	SMarket_01	1	18	1	0,150	6,667	0,5	4	1
PGE1003	30	WKS_03	2	SMarket_01	1	18	1	0,150	6,667	0,5	4	1
PGE1004	1000	WKS_03	2	SMarket_01	1	18	1	5,000	0,200	5	1	4
PGE1005	800	WKS_03	2	SMarket_01	1	18	1	4,000	0,250	4	1	3
PGE1006	24	WKS_03	1	SMarket_01	1	18	1	0,120	8,333	0,5	5	1
PGE1007	24	WKS_03	1	SMarket_01	1	18	1	0,120	8,333	0,5	5	1
PGE1008	1000	WKS_01	1	SMarket_01	1	18	1	5,000	0,200	5	1	4
PGE1009	200	WKS_03	2	SMarket_01	1	18	1	1,000	1,000	2	2	2
PGE1010	2000	WKS_03	2	SMarket_01	1	18	1	10,000	0,100	10	1	5
PGE1011	2000	WKS_03	2	SMarket_01	1	18	1	10,000	0,100	10	1	5
PGE1012	24	WKS_03	3	SMarket_01	1	18	1	0,120	8,333	0,5	5	1
PGE1013	400	WKS_03	3	SMarket_01	1	18	1	2,000	0,500	2	1	2
PGE1014	400	WKS_01	3	SMarket_01	1	18	1	2,000	0,500	2	1	2
PGE1015	400	WKS_02	3	SMarket_01	1	18	1	2,000	0,500	2	1	2
PGE1016	1000	WKS_04	2	SMarket_01	1	18	1	5,000	0,200	5	1	4

Fig. 3 Table "Calculation_for_Orders" in "CalculatorForMR." *Source* Own study with use MS Excel

Next step is grouping and assigning individual parts to order numbers according to the frequency of delivery (e.g., parts PGE1010 and PGE1011 are delivered every 10 h, so they will be delivered under the same order).

The data obtained from this step of calculation can be also used for filling the columns "How many" and "OrderNR" in table "Orders."

4 Determining the Number of Trailers

The challenge of determining the optimal number of trailers is the second part of calculation procedure. Current section describes how to determine the number of trailers that guarantees efficient work of the internal logistics system. It consists of following stages:

- 4.1 Collecting and preparation of data about trailers.
- 4.2 Analysis of the possibilities of loading trailers.
- 4.3 Calculation of the required number of trailers for the milk-run system.

4.1 Collecting and Preparation of Data About Trailers

The next step is to determine the IDs, the maximum number of shelves, dimensions and distances between the shelves on each trailer in table Trailers shown at Fig. 4. It enables to determine the available space for containers with materials on each type of trailer.

Trailers				
	Maximum number of shelfs	Length [mm]	Width[mm]	Distance between shelves
X	2	1200	800	300
Y	3	1000	600	500
Z	1	1500	800	400

Fig. 4 The table "Trailers" in "CalculatorForMR." *Source* Own study with use MS Excel

4.2 Analysis of the Possibilities of Loading Trailers

Next step is entering data to the "Calculator for trailers" table, shown in Figs. 5, 6, and 7. It automatically calculates the possibilities of using individual types of trailers and the filling level of their shelves' load spaces in the "POSSIBILITIES" table area.

The second part of the table "CHOICE" allows the user to manually assign a specific number of containers to individual types of trailers, based on subjective preferences and knowledge about the specificity of materials. In the columns "How many of shelfs?", the calculator will show the level of filling the single shelf by containers with or without parts.

Data				
Part	Frequency of deliveries [h]	Container ID	Capacity	Nr of containers per delivery
PGE1001	0,5	Plastic_tray	24	5
PGE1002	0,5	SLC280	30	4
PGE1003	0,5	SLC280	30	4
PGE1004	5	Carton_2	1000	1
PGE1005	4	Carton_1	800	1
PGE1006	0,5	Plastic_tray	24	5
PGE1007	0,5	Plastic_tray	24	5
PGE1008	5	Carton_2	1000	1
PGE1009	2	Wozek_1	200	2
PGE1010	10	Carton_3	2000	1
PGE1011	10	Carton_2	2000	1
PGE1012	0,5	Plastic_tray	24	5
PGE1013	2	SB	400	1
PGE1014	2	SB	400	1
PGE1015	2	SB	400	1
PGE1016	5	Carton_2	1000	1

Fig. 5 First part of table "Calculator for trailers" in "CalculatorForMR." *Source* Own study with use MS Excel

POSSIBILITIES											
Trailer X				Trailer Y				Trailer Z			
length	width	heihgt	Nr of shelfs	length	width	heihgt	Nr of shelfs	length	width	heihgt	Nr of shelfs
2	2	2	0,625	1	1	3	1,667	2	2	2	0,625
2	2	1	1,000	1	1	1	4,000	2	2	1	1,000
2	2	1	1,000	1	1	1	4,000	2	2	1	1,000
3	2	2	0,083	2	2	3	0,083	3	2	2	0,083
2	2	1	0,250	1	1	1	1,000	2	2	1	0,250
2	2	2	0,625	1	1	3	1,667	2	2	2	0,625
2	2	2	0,625	1	1	3	1,667	2	2	2	0,625
3	2	2	0,083	2	2	3	0,083	3	2	2	0,083
1	1	0	IMPOSSIBLE	0	0	0	IMPOSSIBLE	1	1	0	IMPOSSIBLE
2	2	2	0,125	1	1	3	0,333	2	2	2	0,125
3	2	2	0,083	2	2	3	0,083	3	2	2	0,083
2	2	2	0,625	1	1	3	1,667	2	2	2	0,625
4	5	2	0,025	4	4	3	0,021	6	5	3	0,011
4	5	2	0,025	4	4	3	0,021	6	5	3	0,011
4	5	2	0,025	4	4	3	0,021	6	5	3	0,011
3	2	2	0,083	2	2	3	0,083	3	2	2	0,083

Fig. 6 The part "POSSIBILITIES" of table "Calculator for trailers" in "CalculatorForMR." *Source* Own study with use MS Excel

CHOICE					
Trailer X		Trailer Y		Trailer Z	
How many containers?	How many shelfs?	How many containers?	How many shelfs?	How many containers?	How many shelfs?
5	0,625		0		0,000
4	1,000		0		0,000
4	1,000		0		0,000
	0,000		0	1	0,083
	0,000		0	1	0,250
	0,000		0	5	0,625
	0,000		0	5	0,625
	0,000		0	1	0,083
	0,000		0		0,000
	0,000		0	1	0,125
	0,000		0	1	0,083
5	0,625		0		0,000
	0,000		0	1	0,011
	0,000		0	1	0,011
	0,000		0	1	0,011
1	0,083		0		0,000

Fig. 7 The part "CHOICE" of table "Calculator for trailers" in "CalculatorForMR." *Source* Own study with use MS Excel

After the assignment of trailers to parts, user can also fill with data the column "TrailerNR" in table "Orders." It is an important source of information for the organization of work of logistic trains. The completed table is shown in Fig. 8.

What	How many	Source	Destination	OrderNR	Type of act	TrailerNR	BusNR for unload
PGE1001	5	Smarket_01/P_11	WKS_01/P_01	1	2	1	1
PGE1002	4	Smarket_01/P_05	WKS_02/P_01	1	3	1	3
PGE1003	4	Smarket_01/P_12	WKS_03/P_01	1	1	1	4
PGE1004	1	Smarket_01/P_13	WKS_03/P_04	4	1	2	5
PGE1005	1	Smarket_01/P_06	WKS_03/P_05	3	3	2	5
PGE1006	5	Smarket_01/P_01	WKS_03/P_06	1	2	2	5
PGE1007	5	Smarket_01/P_02	WKS_03/P_07	1	2	2	5
PGE1008	1	Smarket_01/P_15	WKS_01/P_02	4	2	2	2
PGE1009	2	Smarket_01/P_03	WKS_03/P_02	2	2	2	4
PGE1010	1	Smarket_01/P_10	WKS_03/P_03	5	2	2	4
PGE1011	1	Smarket_01/P_04	WKS_03/P_07	5	2	2	5
PGE1012	5	Smarket_01/P_07	WKS_03/P_08	1	2	1	5
PGE1013	1	Smarket_01/P_08	WKS_03/P_09	2	2	2	5
PGE1014	1	Smarket_01/P_14	WKS_01/P_03	2	2	2	2
PGE1015	1	Smarket_01/P_16	WKS_02/P_02	2	2	2	3
PGE1016	1	Smarket_01/P_09	WKS_04/P_01	4	2	1	5

Fig. 8 The final version of table "Orders" in "CalculatorForMR." *Source* Own study with use MS Excel

4.3 Calculation of the Required Number of Trailers for the Milk-run System

On the basis of data in the table "Calculator for trailers", the table "Calculator for the train" is filled. This table is shown in Fig. 9. It shows the exact and final number of shelves and transport trailers based on the specificity of these trailers described in the table "Trailers."

The designated total number of trailers will allow simultaneous execution of all orders. Due to the cyclical nature of the orders generation, it is necessary to consider

Fig. 9 The table "Calculator for train" in "CalculatorForMR." *Source* Own study with use MS Excel

	Total number of shelfs	Final number of shelfs	Total number of trailers	Final number of trailers
Trailer X	3,25	4	2,00	2
Trailer Y	0,00	0	0,00	0
Trailer Z	1,90	2	2,00	2

overlapping orders over time. This means: If order 1 appears every 0.5 h, order 2 every 1.5 h, then when order number 2 appears, order number 1 will also appear. Therefore, it is also necessary to list emerging orders in time and use the tables to determine the needed number of several trailers regularly, based on the demand for materials and their current availability.

5 Summary and Further Research

The presented methodology is based on theoretical considerations. Further research assumes its development to take into account the limitations related to the maximum capacity of storage locations at workstations as well as the weight of the logistic set (containers with/without materials and logistic trailers) in relation to the towing capacity of tugger. It is the basis for the construction of simulation technology, which initial version is described in paper of Greenwood et al. [3]. Next version of technology will take into account the issues raised in the publication and described calculation mechanisms. Functions of technology are as follows:

- Automatic determination of orders for a logistic train, including their composition and frequency,
- Determination of the optimal number of resources (operator, tugger, and trailers), based on their availability and attributes,
- Generation of milk-run objects and support of the building of transport paths related to specific relations with the production system in a simulation model, and
- Enabling modeling of train movement and operational activities performed by the logistics train operator.

All these functions are needed for simulation experiments to verify the calculation results and evaluate the possible alternatives.

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Implementation of Calculation for Simulation of Milk-run Intralogistics System

Kamila Kluska and Patrycja Hoffa-Dąbrowska

1 Introduction

Aspects of design the intralogistics system based on milk-run are actually important and popular. In many companies, traditional transport—based on forklift—is changed for using milk-run systems, in which goods are transported using trains that consist of tugger and trailers. The main challenge in milk-run system is to define right number of trains (with number of trailers) and route for them. Every part has to be delivered in right place, in right time (not to late), and right quantity (calculated for period time) including economic aspects. The big challenge is to define the route for each train and driving schedule.

Kluska, in previous chapter, in this manuscript presents how to calculate appropriate number of trains with all details. In this article, authors present next step—the implementation of calculation results into the simulation software. In described methodology, the calculation mechanism "CalculatorForMR" is used. This mechanism was built in MS Excel. In next step, calculation results are implemented into a simulation model, which is built using FlexSim simulation software. It includes designation of orders, determining the number of trailers, and verification of calculation results in simulation model. The simulation model has implemented mechanisms, which allows for automatic transformation of data from tables.

The goal of chapter is to present how to implement the calculated data for creating milk-run intralogistics system into simulation model. It is the next step from developed methodology. First step is preparing data into "CalculatorForMR" calculator, what is exactly described in the chapter "Determining of the optimal number of

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trailers for milk-run intralogistics system." Next step is implementation of calculating results into simulation model, what is the main goal of this article. In presented methodology, authors described the mechanism of transformation of data from calculator. The obtained results from created simulation model are described too.

2   Simulation Modeling of Milk-run Systems in Literature

Many literature positions focus on the design and modeling of milk-run intralogistics systems. However, literature describes built mechanisms for individual cases, solving specific problems of selected enterprises, or focusing on a chosen aspect of designing the internal transport system.

Wang et al. [15] search the optimal layout of routes in milk-run system. The tool is the discrete firefly algorithm, tested with case study. The goal is to find the optimal route, where objective is the minimization of the transportation cost.

Kitamura and Okamoto [10] prepared the automated route planner for milk-run systems, which uses framework that adopts linear temporal logic and NuSMV model checker. The framework is used for searching the optimal truck routes in a route map, which will satisfy delivery requirements.

Bae et al. [2] described milk-run delivery system, analyzed based on three experiments. The goal of the study is to analyze the results of implementation of milk-run system in automotive company, based on many variables, e.g., number of supply trains, load and unload times, and travel speeds. The experiments were conducted in order to find the best combination of model input parameters.

Alnahhal [1] described the simulation model for an efficient material flow design using tugger trains as modes of transport. Logistics trains are used to transport parts in bins to the locations at assembly lines. Internal logistic transport uses e-kanban system. The simulation is one of the tools of methodology.

Issue related with the design of the milk-run system in assembly plant is also described by Korytkowski and Karkoszka [11]. Paper presents the discrete event simulation model of the workstations and milk-run internal transport system. The model is a tool for the evaluation of interactions, efficiency analysis, and also for examining the impact of logistics train operator on assembly line with taking into account disturbances occurring in the production environment. Authors used Arena software.

Hao and Shen [7] developed a prototype software system based on hybrid simulation approach that uses both agent-based and discrete event simulation. Simulation tool is used to analyze "what-if" scenarios, improve internal transport system performance, and to find the optimal solutions for material handling processes serving assembly lines. Material handling system is, in this case, a kanban-based milk-run system.

Greenwood et al. [6] also described the hybrid simulation approach, which in this case is used for simulating milk-run logistic systems with use FlexSim simulation software. This approach uses discrete event simulation and agent-based simulation in order to model milk-run system with novel objects. These objects have built-in

intelligence that allows for implementation of complex decision-making processes. The initial simulation model was built with the use of the framework for simulating milk-run in-plant logistics systems [5].

Vieira et al. [14] described the development of one main Simio model. The simulation model analyzes the internal transport system in warehouse, served by milk-runs and pickers.

Costa et al. [4] used simulation experiments in Arena software to analyze the milk-run material delivery system serving the workstations transport in electronics company.

Chee et al. [3] used a simulation technique to analyze the kanban-based milk-run transport system in an electronics company. Authors used value stream mapping and prepared model of system to test its various performances.

Kilic et al. [9] describe the models for one of the main categories "determined time periods assignment problem." The models are built in order to minimize the total distance traveled by internal transport vehicles and reduce their number.

Hosseini et al. [8] developed an integer programming model in order to designate a solution, which minimizes the total shipping cost in the consolidation network, which consists of direct shipment, milk-runs, and cross-dock.

Staab et al. [13] developed a generic simulation model in order to model the traffic situations in internal transportation network. An important issue is definition of all important dependencies between the logistics trains.

Due to limited literature and insufficient amount of tools on marked, a methodology was created. Methodology uses a calculation mechanism "CalculatorForMR" built in MS Excel and assumes the implementation of calculation results in a simulation model built with the use of FlexSim simulation software. It includes designation of orders, determining the number of trailers, and verification of calculation results. Simulation modeling of milk-run systems enables verification, improvement, and visualization of projects. The methodology consists of many stages. One of them is the calculation of data on orders and train components for logistic trains in production system.

3 Determining the List of Orders and Optimal Number of Trailers for Milk-run Intralogistics System

The most important source of information in the described methodology is the list of orders and the quantities of trailers of a specific type. To designate this data, use the CalculatorForMR tool built in MS Excel. The calculator's operating procedure consists of two stages. The first stage is aimed at determining the list of orders, based on demand data and material flow in the system. The goal of second stage is to determine the optimal number of logistic trailers and tuggers, based on selected and defined vehicles (by user). In this case, the "optimal number of trailers" means the smallest number of trailers that guarantee the efficient work of the internal logistics system. At this stage of the analysis, calculations do not take into account any disturbances.

The distinguished stages consist of many steps that require entering data into designated columns and analyzing the obtained results which are as follows:

(1) Designation of orders for the milk-run system

    (a) Preparation of layout and the list of workstations, which will be fed in parts by the logistics train.
    (b) Specification of locations of bus stops on the layout of analyzed space.
    (c) Definition of possible routes to individual bus stops.
    (d) Preparing the PFEP table, which contains information about every parts, source and use locations, containers, sizes, and weight.
    (e) Filling the table "Orders" which includes data about orders.
    (f) Filling the table "Calculator_for_Orders."

(2) Determination of optimal number of trailers

    (a) 4.1 Collecting and preparation data about trailers.
    (b) 4.2 Analysis of the possibilities of loading trailers.
    (c) 4.3 Calculation of the required number of trailers for the milk-run system.

The results of working with CalculatorForMR are specific data collected in tables. These data can be adapted to the model. Tables that should be prepared by user are given below:

- "Orders" that contains all information about all orders for logistics train. Table consists of the material ID, the source location, the use location (the name of workstation and the storage field), the type of activity performed by the train operator, the name of the bus stop, the number of containers with parts to transport, the number of trailer (it is numerical value of trailer type), and number of order. An important issue to organize the orders in table "Orders" based on the sequence of stops and direction of train movement. The result of the arrangement of orders is the "Orders" table shown in Fig. 1.

In presented methodology, five available types of activities are defined. They describe a proper activity for the train's operator as follows:

- 0—load empty container and transport to destination,
- 1—load container with parts and transport to destination,
- 2—load container with parts, transport to destination, take an empty container, and transport to supermarket,
- 3—take an empty container from destination and transport to supermarket, and
- 4—take full container from destination and transport to supermarket.

Determining the types of activities is necessary for proper programming of the operator's activities by the mechanisms in simulation model. It is described in the further part of the publication.

- "Train data" that contains the data about sizes and specification of available tuggers and trailers, presented at Fig. 2.

What	How many	Source	Destination	OrderNR	Type of act	Trailer Type	BusNR for unload
PGE1001	5	Smarket_01/P_11	WKS_01/P_01	1	2	1	1
PGE1002	4	Smarket_01/P_05	WKS_02/P_01	1	3	1	3
PGE1003	4	Smarket_01/P_12	WKS_03/P_01	1	1	1	4
PGE1006	5	Smarket_01/P_01	WKS_03/P_06	1	2	2	5
PGE1007	5	Smarket_01/P_02	WKS_03/P_07	1	2	2	5
PGE1012	5	Smarket_01/P_07	WKS_03/P_08	1	2	1	5
PGE1014	1	Smarket_01/P_14	WKS_01/P_03	2	2	2	2
PGE1015	1	Smarket_01/P_16	WKS_02/P_02	2	2	2	3
PGE1009	2	Smarket_01/P_03	WKS_03/P_02	2	2	2	4
PGE1013	1	Smarket_01/P_08	WKS_03/P_09	2	2	2	5
PGE1005	1	Smarket_01/P_06	WKS_03/P_05	3	3	2	5
PGE1008	1	Smarket_01/P_15	WKS_01/P_02	4	2	2	2
PGE1004	1	Smarket_01/P_13	WKS_03/P_04	4	1	2	5
PGE1016	1	Smarket_01/P_09	WKS_04/P_01	4	2	1	5
PGE1010	1	Smarket_01/P_10	WKS_03/P_03	5	2	2	4
PGE1011	1	Smarket_01/P_04	WKS_03/P_07	5	2	2	5

Fig. 1 The table "Orders" in "CalculatorForMR." *Source* Own study with use MS Excel

Trailers			
	Maximum number of shelfs	Length [mm]	Width[mm]	Distance between shelves
X	2	1200	800	300
Y	3	1000	600	500
Z	1	1200	800	400
Tuggers			
Tugger_ID	Name	Type	Length	Availables
1	Tugg_01	Toyota BT TSE 3	1,2	1
2	Tugg_02	Linde P30	1,2	1

Fig. 2 The table "Train data" in "CalculatorForMR." *Source* Own study with use MS Excel

Fig. 3 The table "Calculator for train" in "CalculatorForMR." *Source* Own study with use MS Excel

	Total number of shelfs	Final number of shelfs	Total number of trailers	Final number of trailers
Trailer X	3,25	4	2,00	2
Trailer Y	0,00	0	0,00	0
Trailer Z	1,90	2	2,00	2

- "Calculator for train" with information about optimal number of designated types of trailers, presented at Fig. 3.
- "Orders_Data" with information about frequency of deliveries, presented at Fig. 4.

Fig. 4 The table
"Orders_Data" in
"CalculatorForMR" built in
MS Excel. *Source* Own
study with use MS Excel

Frequency of deliveries [h]	Frequency of deliveries [s]	OrderNR
0,5	1800	1
2	7200	2
4	14400	3
5	18000	4
10	36000	5

4 Procedure for Entering Data into the Simulation Model

The simulation model has implemented mechanisms, which allows for automatic transformation of data from tables. It is transforming data into ready-made formulas that are used to program the work of the train operator and logistic train movement. The work of operator and train allows to execute orders assigned to operators at specific points of time. The introduced mechanisms also allow to

- take into account the specifics of the logistic train operator's work,
- including the specifics of the trailers (size, shape, number of shelves, and a dedication to transport individual types of containers) and adjusting the logic of placing containers at individual trailers,
- introduce synchronized movement of all train elements,
- maintaining the procedures of moving logistics train along transport routes, rules of behavior at corners and intersections, and
- implementing the appropriate visualization of the system operation.

Milk-run system in the current version of technology consists of

- parking for trailers and tuggers,
- area for logistics trains formation,
- logistics network with bus stops and reference points,
- global table "Path_Base,"
- intralogistics cell, and
- supermarket.

All listed structures are shown in Figs. 5 and 6.

Parking for tuggers and logistic trailers sets their default locations. It means that after resetting the model or deforming the logistic train (when the order is completed), the objects will return to these locations.

The area of logistics train formation is necessary to form a train consisting of the operator, tugger, and trailers (treated as individual objects in model).

Trailers are selected based on the demand for defined number of specific truck types. The operator of the train is responsible for the initiation of the train's movement. He sends signals to the tugger and trailers in order to start synchronized movement on the routes.
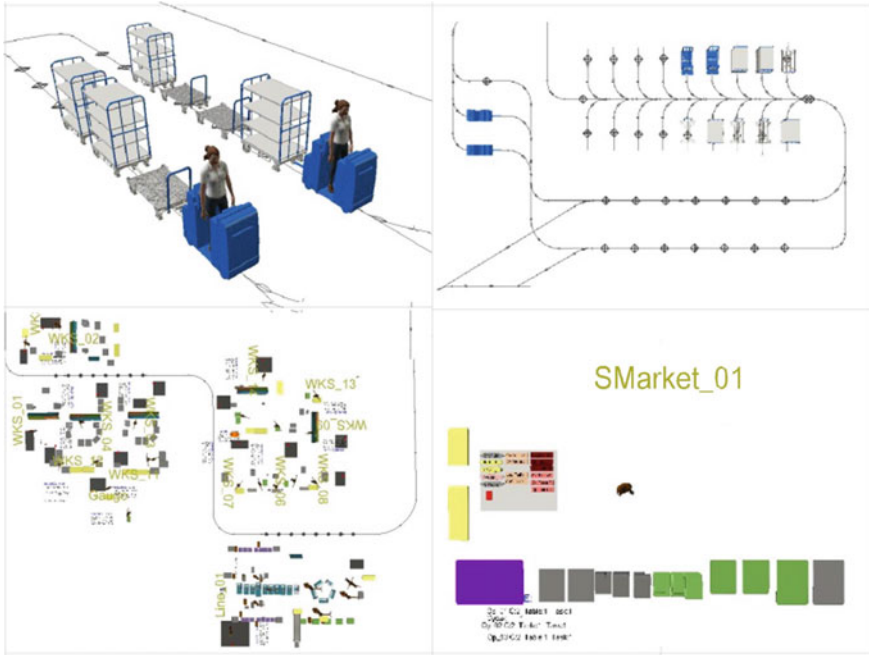
Fig. 5 Milk-run system elements in simulation model. *Source* Own study with use simulation model

The logistics network includes roads with a specific arrangement in the model space, including possible traffic directions (one- and two-way roads), corners, and intersections. The basis for their designation is the layout of the production space. The logistics network enables the train to reach the place of formation and all necessary locations, featured in the list of orders. Near to these locations, bus stops and reference points are created. The reference points are located on transport routes and enable control of the route covered by the train during the execution of orders. These points are saved in the global table "Path_Base", which is described at point 4.1 of paper.

The intralogistics cell is the basic structure containing the manipulator, logistic train operators, and function buttons. The manipulator loads the list of orders and cyclically generates signals initiating the work of train operators. Generation of a signal means the appearance of the order. Initiation of the operator's work means accepting the order by him and starting to perform the list of tasks generated for the given order.

Order can only be allocated to an operator who is free, thus does not perform any other action and does not perform another order. The top view on the intralogistics cell is shown in Fig. 6.

The buttons are divided into two groups. The first group is buttons that allow for opening a series of tables intended for the implementation of data on the organization of work of logistics trains. The second group of buttons allows to open automatically

Fig. 6 Intralogistics cell.
Source Own study with use
simulation model

generated tables containing a list of activities for logistic operators. A separate table
is generated for each order.

The data implementation consists of the following stages:

- 4.1 Filling the global table "Path_Base" based on designated logistics network by
  global points at logistics network.
- 4.2 Implementation of data to the simulation model (filling up the tables in logistics
  cell) "Orders."
- 4.3 Reset model and see the list of tasks for intralogistics operator.

4.1 Filling the Global Table "Path_Base" Based on Designated Logistics Network by Global Points at Logistics Network

The first column of the table contains the numbers of the paths. In subsequent
columns, user can define the names of reference points on the logistics network,
according to the order in which the train arrives to them. Each table row describes a

	Path_NR	GG_001	GG_008	Loc3	Loc4	Loc5	Loc6	Loc7	Loc8	0
Row 1	1	GG_001	GG_bus_00	0	0	0	0	0	0	0
Row 2	2	GG_008	GG_002	GG_003	GG_004	GG_005	GG_009	GG_011	GG_006	GG_bus_01
Row 3	3	GG_008	GG_002	GG_003	GG_004	GG_005	GG_009	GG_011	GG_006	GG_bus_01
Row 4	4	GG_001	0	0	0	0	0	0	0	0
Row 5	5	GG_013	GG_014	GG_008	GG_bus_00	0	0	0	0	0

Fig. 7 "Path_Base" table in simulation model. *Source* Own study with use simulation model

separate path for logistic trains. Each individual path refers to a selected part of the route that allows for

- passing the train from the parking area to the bus stop near the supermarket (LT –> SM),
- passing the train from supermarket to production line (SM –> LINE),
- passing the train from production line to supermarket in order to deliver the empty containers (LINE –> SM), or
- passing the train from supermarket to parking area (SM –> Parking).

In this table, user should create as many paths as many possibilities can be defined for the train movement between locations on logistics network. If the train can use two ways for passing from parking area to the supermarket, user should create two separate paths (Fig. 7).

4.2 Implementation of Data to the Simulation Model (Filling up the Tables in Logistics Cell)

The "Orders" table can be opened using one of the function buttons. This button is called "Orders" and opens the table shown in Fig. 8. The table should contain the order data specified in CalculatorForMR.

	What	How many	Source	Destination	OrderNR	Type of act	TrailerNR	BusNR for unload
Row 1	PGE1001	5	Smarket_01/P_11	WKS_01/P_01	1	2	1	1
Row 2	PGE1002	4	Smarket_01/P_05	WKS_02/P_01	1	3	1	3
Row 3	PGE1003	4	Smarket_01/P_12	WKS_03/P_01	1	1	1	4
Row 4	PGE1006	5	Smarket_01/P_01	WKS_03/P_06	1	2	2	5
Row 5	PGE1007	5	Smarket_01/P_02	WKS_03/P_07	1	2	2	5
Row 6	PGE1012	5	Smarket_01/P_07	WKS_03/P_08	1	2	1	5
Row 7	PGE1014	1	Smarket_01/P_14	WKS_01/P_03	2	2	2	2
Row 8	PGE1015	1	Smarket_01/P_16	WKS_02/P_02	2	2	2	3
Row 9	PGE1009	2	Smarket_01/P_03	WKS_03/P_02	2	2	2	4
Row 10	PGE1013	1	Smarket_01/P_08	WKS_03/P_09	2	2	2	5
Row 11	PGE1005	1	Smarket_01/P_06	WKS_03/P_05	3	3	2	5
Row 12	PGE1008	1	Smarket_01/P_15	WKS_01/P_02	4	2	2	2
Row 13	PGE1004	1	Smarket_01/P_13	WKS_03/P_04	4	1	2	5
Row 14	PGE1016	1	Smarket_01/P_09	WKS_04/P_01	4	2	1	5
Row 15	PGE1010	1	Smarket_01/P_10	WKS_03/P_03	5	2	2	4
Row 16	PGE1011	1	Smarket_01/P_04	WKS_03/P_07	5	2	2	5

Fig. 8 "Orders" table in simulation model *Source* Own study with use simulation model

Implementation of data to "Path_Select" table in logistics cell in simulation model is assignment of defined in "Path_Base" paths to specified stages of order fulfillment.

Path numbers for individual route segments are assigned to individual order numbers. In each of the rows, the order number is defined in the first column, while in the following columns defines path numbers. The four fragments of the path form the route covered by the train. The "LT –>SM" column specifies the path from the parking area (of logistics team) to the supermarket.

The "SM –>LINE" column defines the path from the supermarket to the production line, similarly the "LINE –>SM" column. The "SM –>Parking" column indicates the path number uses for arriving from the supermarket to the parking area of tuggers and trailers.

The way of logistics train movement within the production line is not described, because it relies on the movement of train between individual stops and the sequence of arriving to them depends on the list of orders. The "Path_Select" table is presented in Fig. 9. The table is opened using the function key named "Path_Select" in the intralogistics cell.

The next step is to fill the tables containing information about trailers and tuggers. They are presented in Figs. 10 and 11. Tables are opened using the function keys called "Trailers" and "Tuggers."

In these tables, user should enter data from CalculatorForMR about ID, name, type (expressed by number or name), length, and number of shelves (for trailers). The "Availables" column informs about the availability of the tugger. The value "1"

	Ord_NR	LT -> SM	SM -> LINE	LINE -> SM	SM -> Parking
Row 1	1	1	2	5	4
Row 2	2	1	4	3	4
Row 3	3	1	2	3	4
Row 4	4	1	2	3	4
Row 5	5	1	2	5	4

Fig. 9 "Path_Select" table in simulation model. *Source* Own study with use simulation model

	Trailer_ID	Name	TrailerNR	Length	Shelves_NR
Row 1	1	Trailer_01	1	1.200	2
Row 2	2	Trailer_02	1	1.200	2
Row 3	3	Trailer_03	2	1.200	1
Row 4	4	Trailer_04	2	1.200	1

Fig. 10 "Trailers_Base" table in simulation model. *Source* Own study with use simulation model

	Tugger_ID	Name	Type	Length	Availables
Row 1	1	Tugg_01	Toyota BT TSE 300	1.200	1
Row 2	2	Tugg_02	Linde P30	1.200	1

Fig. 11 "Tuggers_Base" table in simulation model. *Source* Own study with use simulation model

means that the tugger is available for work. The value "0" means that the tugger is not available, due to order fulfillment, loading, maintenance, or tugger failure.

It is also necessary to enter data on the frequency of generation orders in system. Manipulator is the object which will generate these orders in simulation model (at appropriate intervals) and manage the orders appearing at the same time.

Currently, entering orders data consists in preparing a list of tasks for the manipulator. The cyclical implementation of list of tasks will result in the allocation of orders to the specific operators of logistic trains, taking into account the designated distribution over time.

The preparation of the mechanism of automatic generation and intelligent allocation of orders is one of the challenges for the development of methodology in the future.

4.3   Reset Model and Open the List of Tasks Created for Intralogistics Operator

On the reset, the model reads the data and transforms it into task lists for logistic train operators. For each designated order, a separate task list is generated.

Every task list takes into account the following:

- Which tugger operator will pick,
- What path logistics train will use to arrive at the supermarket (taking into account the traffic rules defined for the logistics network),
- How many empty and full containers transport from the supermarket (from which locations in the supermarket) and how to pick them (to which location in the space come in order to collect the container),
- Where to allocate the specific types of containers—on which trailer, on which shelf,
- What path logistics train will use to arrive at the production line (keeping the traffic rules defined for the transport routes),
- To which bus stops the train should arrive,
- Which containers, in what sequence and quantity, should be delivered to workstations (to which locations on the workstations) and how to deliver them (to which location in the space come in order to put down the container),
- Which containers, in what sequence and quantity, should be picked up from workstations (form which locations on the workstations) and how to pick them (to which location in the space come in order to collect the container), and where to allocate these containers (on which trailer, on which shelf),
- What path logistics train will use to arrive at the supermarket (keeping the traffic rules defined for the transport routes),
- In what order and number operator will deliver empty containers to the supermarket (to which locations in the supermarket) and how to deliver them (to which location in the space come in order to put down the container), and
- What path logistics train will use to arrive at the parking area.

Mechanism of preparation of the list of tasks is based on the original programming language for activities of logistics train operator. Language uses commands executed by the operator in simulation model. These commands form lists that are implemented cyclically in order to ensure the continuity of the operator's work, taking into account implementation of decision-making processes. Mentioned language includes activities carried out both by production and logistics operators. Due to the subject of publication, Table 1 describes only commands dedicated to the logistics train operator.

Using the commands and data, the program generates separate task lists for the specific orders. These task lists are executed by the logistics train operator. Task list includes the ID of the activity, the exact location of its execution, the name of the command, and a parameter specifying the time [s] or quantity. The parameter type depends on the type of command being called. A fragment of the exemplary task list is shown in Fig. 12.

Simulation model has a built-in mechanism. It reads the commands from the lists of tasks and controls the operator's work. For each command, a logic is written using the source code, according to which the command is executed by the object. The user has access to the generated lists of tasks, so he can analyze every list and in case of irregularities, correct the data.

The program will also use data on the composition of trains (how many trailers are needed for the execution of a given order) and the availability of objects. It is the basis for the automatic formation of a logistics train.

Table 1 Commands for logistics train operator

Command	Description
Travel	Operator is moving to a specific location in model space
GrabTugger	Taking a logistic tugger by an operator—an operation dedicated only for intralogistics operators
ReleaseTugger	Leaving a logistic tugger by an operator in order to carrying out transport operations—an operation dedicated only for intralogistics operators
DriveTugger	Move a logistic tugger by an operator in order to drive the logistics train—an operation dedicated only for intralogistics operators
GrabTote	Picking up the tote
ReleaseTote	Unload the tote to location
WaitForEmptyTote	Checking by operator if the one empty container is in the shelf—if not operator will wait for empty container
GrabEmptyTote	Load an empty tote from shelf
Ready4Task	End work and wait for new tasks
CheckTrolleyWait	Checking if the one blocked container is in the shelf—if not operator will wait for blocked container

Source Pawlewski [12]

	ID	Where	Activity	Duration [s] / How many
Row 1	1	G_Tugger_01	Travel	0
	2	G_Tugger_01	GrabTugger	0
	3	GG_001	DriveTugger	0
	4	GG_bus_00	DriveTugger	0
	5	G_Tugger_01	ReleaseTugger	0
	6	Smarket_01/I_11	Travel	0
	7	Smarket_01/P_11	GrabTote	0
	8	LT03/G_Tugger_01/P_01	Travel	0
	9	LT03/G_Tugger_01/P_01	ReleaseTote	0
	10	Smarket_01/I_11	Travel	0
	11	Smarket_01/P_11	GrabTote	0
	12	LT03/G_Tugger_01/P_01	Travel	0

Fig. 12 A fragment of the task list for the logistics train operator. *Source* Pawlewski [12]

After completing the order, the program will automatically deform the train and guide the train elements to their default locations in the parking area.

4.4 Run the Simulation and Observe the Work of System

After resetting the model, all the mechanisms are ready for work, so user can start simulation. Using simulation model, in this case, consists in observing the visualization and analyzing the reasons for displaying possible errors that may result from incorrectly entered data, errors in data, or system reaction to inefficiency of the internal transport system as a result of disturbances and deviations in the system (not included while making calculations in the calculator in MS Excel).

5 Conclusions and Further Research

Designing milk-run intralogistics systems using simulation technology has many advantages. One of them is, of course, the visualization of system, which in many cases help in the analysis of different considered scenarios. The big advantages of using simulation technology are also visualization of train and operator movement, what is presented in Fig. 13.

Analysis of milk-run intralogistics system using simulation technology has the additional positive aspects such as the possibility of including randomness, the possibility of designing activities to minimize losses (effects of random events), and verifying them during the simulation model. The ability to observe the conduct of the experiment and the ability to make changes during the experiment is the main advantage over the calculations in MS Excel.

Of course, simulation has also disadvantages—one of them is the time needed for building the simulation model. But, preparing appropriate tools (calculator or

Fig. 13 Visualization of train and operator movements. *Source* Own study with use simulation model

mechanism for creating objects in model) and defining understandable programming language, significantly reduces the time needed for built the model.

The presented methodology is still developed. The next steps in simulation model are as follows:

- Adding automatic generation of basic results and Yamazumi analysis (load balancing graphs),
- Adding the mechanisms informing about lack of parts and the reason of lack of them,
- Adding the mechanism of operators reactions for lack of parts—changing the list of tasks for operators,
- Adding the mechanism of transportation system's reaction in case of notification of lack of parts,
- Development of visualization mechanism—more detailed.

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Using CSP Solvers as Alternative to Simulation Optimization Engines

Pawel Pawlewski and Marcin Anholcer

1 Introduction

The article presents the results of research carried out in recent years in the area of modeling and simulation of production and assembly systems. In the automotive industry, mixed model assembly line [5] is widely employed to deal with a variety of auto-body products. It allows the assembly of different variants of the common based product on the same assembly line.

Our research was performed in plants where the main process was focused on assembly process of car seats.

The paper focuses on presenting the preliminary results of the research joining two approaches—simulation and constrained programming—to optimize the processing of orders in an assembly plant by tugger trains.

Some acronyms are used in the paper which are as follows:

DES Discrete Event Simulation—is a dynamic system with discrete states of transitions which are triggered by events. This provides a general framework for many man-made systems where the system dynamics not only follow physical laws but also the man-made rules.

CSP Constraint Satisfaction Problems—are mathematical questions defined as a set of objects whose state must satisfy a number of constraints or limitations. CSPs represent the entities in a problem as a homogeneous collection of finite constraints over variables, which is solved by constraint satisfaction methods.

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VRP   Vehicle Routing Problems—is a combinatorial optimization and integer programming problem which asks "What is the optimal set of routes for a fleet
      of vehicles to traverse in order to deliver to a given set to customers?" It
      generalizes the well-known traveling salesman problem (TSP).

The paper is organized as follows. Section 2 reviews the literature. Section 3
presents problem definition and motivation. Section 4 discusses the hybrid modeling
approach, using simulation and optimization. Section 5 presents an example of application of methodology and describes framework which supports the model building
process. Section 6 concludes and discusses future research directions.

2   Literature Background

2.1   Simulation Optimization

Simulation gives limitless power to try various what-if scenarios. If we can try to
check some scenarios we have to change decision variable (set them to new values)
and repeat simulation experiments. Simulation software packages available on the
market offer the tool that help to prepare many scenarios and to start experiments
automatically. How to find the best set of model specifications, i.e. input parameters
and structural assumptions to obtain the goal function is the challenge. This process
is called simulation-based optimization [10, 16]. The performance is the output of
a simulation model, and the problem setting thus contains the usual optimization
components:

- decision variables,
- objective function, and
- constraints.

Depend on the nature of these components various simulation optimization
techniques can be classified [2, 6, 15]. Ranking and selection algorithms are
classified as discrete and metaheuristics as discrete and continuous. Both focus on
global optimization. Other algorithms that on discrete variables are direct search
and model-based. These algorithm are classified as local optimization. Algorithms:
response surface methodology, gradient based methods, and Lipschitian are applicable to continuous variables, local oprimization (Lipschitian can be used for global
optoimization too).

Our research focus on following applications: manufacturing systems, project
management, operations scheduling, inventory systems and supply chain. To solve
problems in these areas simulation packages based on Discrete Event System (DES).
On the market many of commercial simulation packages are available. In the Table 1
the list of Optimization packages available in simulation software is presented. This
list contains also the search strategy developed in optimization packages.

Table 1 Optimization packages available in commercial simulation software

Optimization package	Vendor	Simulation software	Search strategy
AutoStat	Brooks automation	AutoMod, AutoSched	Evolution strategies
Extend optimizer	Imagine That	Extend	Evolution strategies
OptQuest	OpTek, Inc.	AnyLogic, Arena, Delmia/Simulia, Enterprise dynamics Flexsim, Promodel, Quest, Simio, SimProcess, Simul8	Scatter search, tabu search, and neural networks
SimRunner2	ProModel Corp.	ProModel	Evolution strategies, genetic algorithms
Tecnomatix optimizer	Siemens AG	Plan simulation	Hill climbing, simulated annealing, tabu search, genetic algorithms
Witness optimizer	Lanner Group Inc.	Witness	Simulated annealing and tabu search

Based on Fu [11] and Law [15] Simul8 changed the optimization package from Optimiz to Optquest.

2.2 Optimization Solvers

As we have already mentioned in the previous section, one of the solvers that one could use to optimize the arising problems with constraints is OptQuest. It uses three heuristic search methods such as scatter search, tabu search, and neural networks. It is capable to work with both linear and nonlinear constraints, also including uncertainty/risk.

Probably the most popular is the Solver of Frontline, attached to MS Excel. This one uses both exact and heuristic methods (simplex, generalized reduced gradient, branch and bound, genetic algorithms, and available multi-start option that can be applied in case of non-convex problems). An interesting feature is the ability to solve nonlinear problems with integer or binary variables. Also the method of setting the problem is very user friendly. Unfortunately, this add-in has significant limitations regarding the size of the input.

Another very popular commercial software is CPLEX/ILOG. It can be used as a library and called from user's own application. It solves large-scale problems, although has some limitations with respect to the possible problems forms (e.g., nonlinear problems with integer/binary variables).

Yet another quite popular (also commercial) software is SAS/OR. Also this one has limited list of possible problems to solve, but large-scale instances are acceptable.

The possible problem would be merging it with the software already developed during the research.

The above list is not complete and we only wanted to show that it is difficult to find a solver that would be able to solve problems of many forms and at the same time of large scale. For that reason, we decided to use an open-source optimization tool—GeCode. It is a constraint programming (CP) solver that can be used for free and freely developed by the user. Since it is, in fact, a set of C++ libraries, it is compatible with the software developed already during the research.

We want to highlight that constraint programming techniques are not well explored as far as DES models are concerned. It seems that using CP techniques should be quite natural in the context of these models since the formulation of DES models is quite close to the formulation of scheduling problems. On the other hand, CP algorithms require the statement of optimization problem in the way very similar to that used in scheduling. Several CP codes accept the formulation of optimization problems as mathematical programming problems.

3 Problem Definition and Motivation

The research works have been implemented in a car industry enterprise. The process is performed on several welding stations, where welding operations are carried out successively and then the assembly and packaging operation of the product are carried out—Fig. 1. It is a pipeline production. The goal of the research has been to organize and maintain a management system for parts, components, subassemblies, and other materials that are delivered to the enterprise from suppliers.
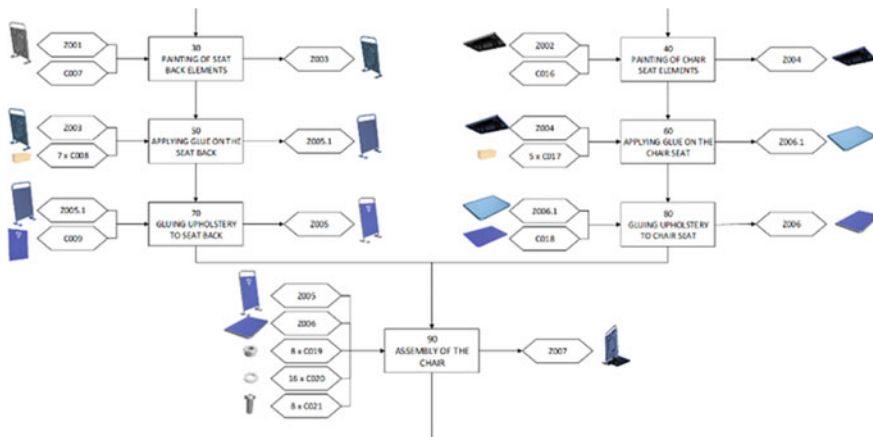

Fig. 1 The part of the assembly diagram of an example seat

The challenge is to find the answer to the question of how to design (redesign) such a logistic system, which will eliminate a much waste as possible, and it will ensure the most effective flow of materials inside the factory. The word "flow" has a special meaning here—it can be compared to the bloodstream of a living organism. The internal logistics system, with its delivery routes, is like the cardiovascular system of an organism. There are arteries (supply routes) supplying nutrients (purchased parts) and veins—taking away contaminants (empty containers for parts), so as to keep the cells of the body (production nests) healthy and provided with what they need and when they need it. The arteries and veins of this system (supply routes) are also used to transfer signals from cells (production sockets) to the nervous system (production control department) with the level of nutrient demand (materials and purchased parts).

We are looking for answers to questions given below:

- How to submit a logistic train—(depending on one or more needs for operating the production hall)—i.e., choose a tugger, trolleys, and containers (their number, capacity, and type)?
- How to determine the number and location of stops for a logistic train (e.g., one stop serving one stand or production cell or one stop serving multiple locations)?
- What is the size of the buffer—i.e., what is the minimum and maximum capacity of the buffer at the station to be used so as to ensure the availability of materials and parts for the machine operator (including the type of containers used and their capacity)?
- How to choose a route on a previously defined layout—a logistic structure plan and how to set a timetable for logistic train journeys (consider two variants: schedule and Kanban) so that the whole system works without collisions and without blocking?

The layout of analyzed production line is presented in Fig. 2, where

- MRStop_xx—means a stop for logistic train,
- GG_xx—signs the point of passage of transportation network, and
- L2_Wks_xx—means the workstation where assembly operation is performed according to assembly diagram—xx—number of operation.

The following proposition was adopted on the first approach to the task being solved:

- The smallest functional unit is the production unit (PU), which can consist of many workstations and locations. Location is an area where containers can be stored. It may be the case that one PU is served from several stops. Each location, however, is always served from one stop. From the modeling point of view, this can be described in such a way that PUs are sometimes broken down into smaller units, which can be described by means of a pair (PU, liner_id).
- There are two containers in each location—delivery of a new one must take place between emptying the first one and the second one—this means that there are three containers in circulation—two on the site and the third on the move.
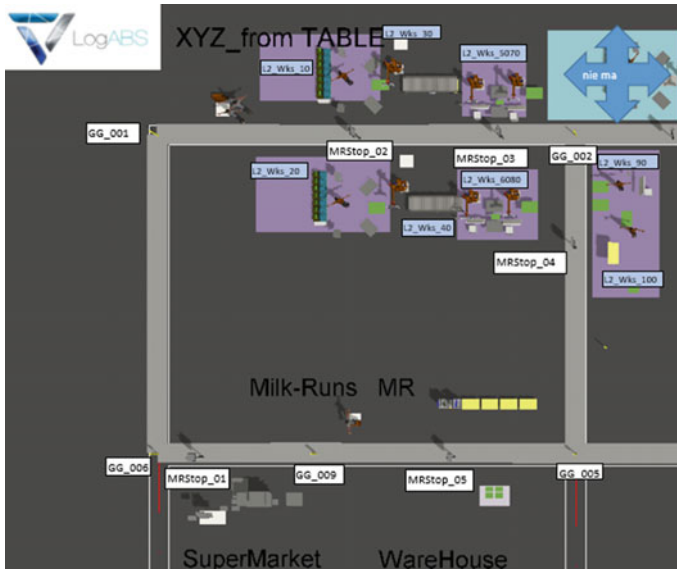
Fig. 2 The layout of the analyzed assembly system—screen from FlexSim simulation model

The analysis framework is defined as follows: "Supermarket"—the place to collect containers with parts and return empty containers to parts; it is assumed that there are always available full-on-demand containers (unlimited availability) and you can always give away any number of empty containers; PU (and in principle: a stop)—full containers with parts are delivered, empty containers are removed for parts, empty containers for finished products are delivered, full containers with ready products are removed; Buffer—the place of accepting full containers with finished products and dispensing empty containers for them; it is assumed that the possibilities of issuing and accepting are unlimited. The capacity of the wagons is determined by the number of containers, regardless of whether they are full or empty.

4 The Concept of Workflow Using Simulation and CSP

To solve the task defined in previous section, the following workflow was designed in Fig. 3. Data collection at the factory is the first step. Following data are necessary:

Types of tuggers described by means of parameters, in particular, the following:

- Maximum number of trolleys that a given tugger can pull,
- Maximum speed at which the tugger can move (possible generalization: different maximum speeds can be defined for the same tugger depending on the number of trolleys that actually pulls—not exceeding its maximum capacity—and depending on the sector in which it moves).

Fig. 3 The designed
workflow using simulation
with CSP solver
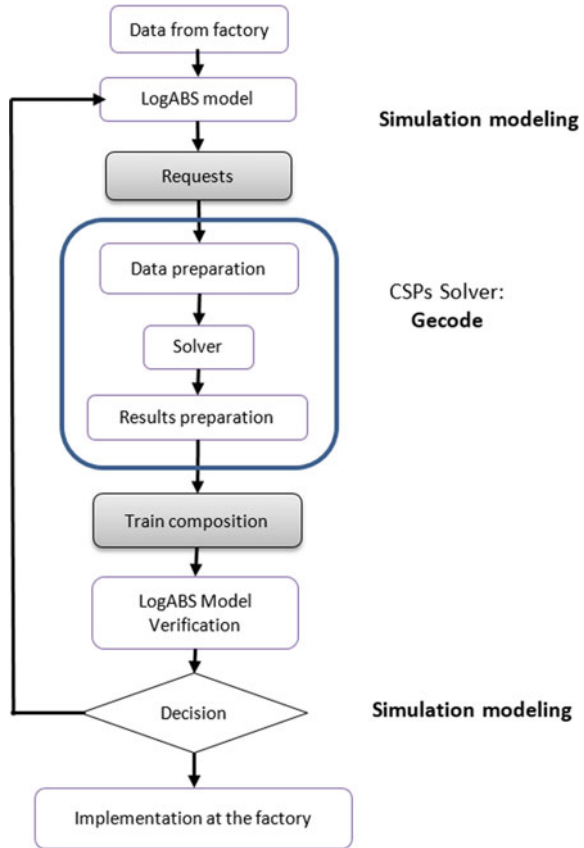
Types of trolleys described by means of parameters, in particular, such as given below:

- How many containers can be transported (assuming for today: there are only two types of container: for parts and for finished products),
- Possible generalization in the future: how many containers of different types can be transported.

List of sectors described using appropriate parameters, in particular, such as given below:

- The minimum journey time per sector for each type of train,
- Maximum speed in a given sector (possible generalization: depending on the type and length of the train).

Minimum stop times for trains at individual stops (as a function of the number of containers unloaded/picked up).

To build the simulation model special module called LogABS [3] based on FlexSim simulation software was used. FlexSim simulation environment was chosen due to the following features [4]:

- Ease of use in a real size with drag and drop technology,
- Loading a .dwg file from the layout directly to a model,
- Objects ASRS vehicle, crane, robot, elevator,
- Extended possibilities to model conveyors,
- Fitting the shape of trucks and their parameters—in real values,
- Integrating built-in experimenter tool with OptQuest,
- Including task sequence technology.

LogABS is the technology developed by Atres Intralogistics that answers the question of how to organize data in a company to build the simulation model without deep knowledge of simulation modeling in very short time. LogABS enables to build simulation model using the designed script language that is similar to the language used by the employees of the company, due to the absorption of the language of the production engineers, and is dedicated to rapid simulation modeling of intralogistics processes. This technology enables to obtain the distribution of demand for new containers in time (for each location) generated by simulation, assuming that the containers are topped up automatically. The distribution is given as a list of moments in which another container is emptied—block "Requests" from Fig. 3.

Next step is the data preparation for solver. Generic constraint development environment (Gecode) was chosen as the first CSP solver (https://www.gecode. org). It is the toolkit for developing constraint-based systems and applications. The main argument to choose this solver was its opening for programming and easily interfacing to FlexSim. Both environments are implemented in C++.

Following definitions of constraints were designed:

- Trains cannot collide.
- Trains arrive at stops in such a moment that:

  - for a container with new parts—exactly one was emptied (the train arrives before emptying the other),
  - when it comes to a container with finished products—at least one was full.

- The same wagon cannot be used on two different trains at the same time.
- The stop time of the train at the bus stop cannot be shorter than the time required to unpack and pack the containers.
- Travel time through the sector cannot be shorter than the defined minimum time.
- Trains are in motion, i.e., they do not perform any other stops than at the designated stop—e.g., they do not wait 5 min before the stop to be on time at the designated stop.

The following results are obtained in the form of:

- List of various trains (tractor + a list of potentially different types of wagons) that meet all the assumptions and limitations. Tractors and wagons can be present in

different trains (when the train ends, it can be "disassembled" and its elements are designed for the construction of subsequent trains).

- Routes of individual trains, which are lists of successively visited sectors and stops.
- "Timetable" of all trains on the list, including exact information on the moment of entry to each sector and departure from it, the average speed that must be maintained in each sector and the time to spend at each stop.

5 Developing the Mathematical Model

As we want to use a solver to find the solution to the problem, first it is necessary to define a mathematical model. The most important thing is the choice of the decision variables, so that the equations and inequalities are as simple as possible, but, on the other hand, describe the constraints listed in the previous section in the best possible way.

In recent years, several authors presented the models for similar problems. Kilic and Durmusoglu [13] considered a situation, where the vehicles have equal cycle times. Moreover, the vehicles are identical, their speed is constant, and no traffic problems can occur. The authors also assumed that a finite number of possible routes were generated in advance. Because of these simplifications, they were able to use the binary variables indexed with routes and periods, taking value 1, e.g., when some area belongs to a route, when a stock point was assigned to a route, or when a route is used in given period. Similar approach was presented by Kilic et al. [14].

Satoglu and Sahin [17] considered a problem for one period, which resulted in a model similar to the classical formulations of the VRP with additional capacity constraints, so they were able to use the variables indexed only with the numbers of start and end points and number of vehicle. Similar approach was used by Vaidyanathan et al. [19].

Alnahhal and Noche [1] assume that train cycles and station cycles are defined and so can be enumerated, which allows them to index the binary decision variables taking the value 1 if and only if there is a train cycle covering the station cycles between the two corresponding with the variable's indices.

Golz et al. [12] used the binary variables indexed with the sets of drivers, predefined paths and tours, taking value 1 if and only if the respective driver during the given tour visits the given path. Another set of binary variables informs whether one order is processed directly after another on a tour taken by a given driver. Since they also use continuous variables representing the starting and ending times of the tours, this model is the closest to the one that we need in our research. The problem is that one of the assumptions is that no traffic problems occur, while we do not assume that but define the respective constraint. It suffices, however, to introduce some modifications to the model, so that the traffic conflicts will be forbidden.

Also the formulations of Emde et al. [5, 7–9, 20] are similar to the one that we need. In the case of the listed papers, the main idea is to use, among others, binary variables taking value 1 if and only if given tour takes place at given moment or at

given cycle and integer or continuous variables informing how many items of each type are taken by a train processing given tour at given time (or at given cycle). Also, in this case, the tours are treated as predefined.

As we can observe, in most cases, the authors assume that the tours are defined in the first stage of the problem-solving. During the second stage, the tours are scheduled (and this is the moment, where the respective mathematical models are used).

In the remainder of this section, we are going to present the mathematical model that uses somehow the ideas described above. In our formulation, we assume that traffic problems cannot occur. This is the first approximation of the final model, where we plan not to make such an assumption, but to guarantee that by introducing respective constraint. Moreover, we do not assume the existence of any cycles, i.e., we allow the trains to start and end the tour at any moment.

We will solve the problem in two steps. In the first step, the orders are assigned to tours. This way, the tour set is defined. In order to do that, we apply a simple greedy procedure.

We consider one tour at time. Given the list of orders ordered by times, we choose the first order from the list and append it to the tour. We continue the process while the following conditions hold:

(1) The next order from the same point does not appear before the tour can end (in such a situation the second bin would be emptied and so the delivery would be late). We can estimate the tour time using any heuristic for TSP.
(2) Adding the next order to the tour would not exceed the train's capacity.

This way the set of tours is defined. Of course, it may happen that for a given tour the capacity of a train is not fully used.

On the contrary to many formulations mentioned in this section, in our model, we consider continuous time. In the future work, when we add the constraint excluding train collisions, we will need to use discrete time, i.e., we will assume that every moment is defined as an integer

$$t \in [0, T], \tag{1}$$

where T is the length of the working day.

The topology of the assembling plant will be described as a network with edges (arcs) representing sectors of the plant and nodes being either the sector joints or the delivery points. In the latter case, it may happen that in the network there will be a need to add some edges and nodes (if a delivery point is placed inside some sector, then we will divide it into two parts). All the edges are directed. If the traffic is allowed in both directions, then one sector is represented by two opposite arcs.

Since the tours are already defined, we want to optimize them in order to make the train routes as short as possible. As one can easily see, we may apply the mathematical model of the TSP with time windows, since for each tour all the serviced orders, so also the demands, are defined.

Each tour can be represented by a network having the following form. For each order, its location corresponds with one node of the network, denoted $v_1, v_2, \ldots, v_n$,

where n is the number of orders processed during the tour (which means, in particular, that some points of the plant may appear more than once in the network representing the tour). The Supermarket and the Buffer are two additional nodes with labels v_0 and v_{n+1}, respectively. We will use the notation similar to the one from [18]. For every node i, the following parameters are defined:

s_i service time of order i (loading and unloading time),
e_i the earliest arrival time to node i,
l_i the latest arrival time to node i.

For every pair of nodes (v_i, v_j), the traveling time t_{ij} is defined. In the model, we use the following variables:

x_{ij} the binary variables taking value 1 if and only if the train processes the order v_j directly after the order v_i,
y_i the continuous variable representing the starting moment of processing order v_i.

We assume that our goal is the minimization of the processing time of the whole tour. The mathematical model looks as follows. The objective function has the form

$$\min(y_{n+1} - y_0) \tag{2}$$

The constraints are given in the following. Each order must be processed

$$\sum_{j=1}^{n+1} x_{ij} = 1, \quad i = 1, \ldots, n. \tag{3}$$

The tour must start at the Supermarket

$$\sum_{j=1}^{n+1} x_{0j} = 1. \tag{4}$$

When train enters some location, it must also leave it

$$\sum_{i=0}^{n} x_{ij} - \sum_{i=1}^{n+1} x_{ij} = 0, \quad j = 1, \ldots, n. \tag{5}$$

The time interval between starting two consecutive orders cannot be shorter than the service time plus traveling time (M is a large constant)

$$y_j - y_i + M(1 - x_{ij}) \geq t_{ij} + s_i, \quad i = 0, \ldots, n+1, \quad j = 0, \ldots, n+1, \quad i \neq j. \tag{6}$$

The service time must fall into the time window

$$e_i \leq y_i \leq l_i, \quad i = 0, \ldots, n + 1. \tag{7}$$

Here, the common time window for Supermarket and Buffer (the time horizon for the tour) is defined by

$$e_0 = e_{n+1} = \min\{e_i | i = 1, \ldots, n\}, \tag{8}$$

$$l_0 = l_{n+1} = \max\{l_i | i = 1, \ldots, n\}. \tag{9}$$

Solving the above problem allows to minimize the duration of every tour.

One can also solve the problem in one stage by introducing the tour index to the model and adding capacity constraint (see, e.g., [18]). However, it would increase significantly its complexity and so in practical applications could be used only in relatively small settings. Moreover, in such a situation the number of tours should be known in advance. This could be estimated from above by the number of tours generated by the heuristic used by us in the first stage of the procedure described above.

6   Conclusion and Further Research

This paper presents an approach for simulating and optimizing the operation of milk-run, in-plant logistics systems. The hybrid approach—simulation and optimization—allows to make such systems more efficient.

The initial implementation of the approach is in FlexSim simulation software. The basic task executer objects are extended to include agent-based capabilities. For example, the operator executes its own work, rather than being driven by tasks sent by other objects, trailers are independent task executers, but follow the lead and path of the tugger, and positioning at a source/use point is coordinate among several objects.

The proposed approach for implementing the framework leverages the existing modeling capability in FlexSim and thus does not require special agent-focused software to be linked with, or integrated into, the DES software, nor does it require links to sophisticated algorithms written in other languages, such as C++.

Also the mathematical formulation of the train scheduling should be treated as an initial one, mostly because of the assumption that the trains cannot collide. This simplification allowed us to model the optimization problem as the TSP with time windows. In the future work, we want to use the formulation similar to the one of Golz et al. [12].

Since this paper provides initial results, future work will further develop and expand both the mathematical model and the simulation part of the research.

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