РАЗРАБОТКА НА ЦИФРОВИ ДВОЙНИЦИ С ПОМОЩТА НА ИНСТРУМЕНТА ЗА МОДЕЛИРАНЕ И СИМУЛАЦИЯ ANYLOGIC

DIGITAL TWINS' DEVELOPMENT USING MODELING AND SIMULATION TOOL ANYLOGIC

Radoslav Hrischev, Nikola Shakev, Donna Stoyanova, Denis Kulev
Technical University of Sofia, Branch Plovdiv, Control Systems Department

Abstract

AnyLogic is a powerful modeling and simulation platform suitable for Digital Twin development of processes and systems. This software tool integrates modeling methods into one multi-method approach, which allows models to be designed, built, dynamically simulated, and optimized. AnyLogic can build models using external databases and simulation can generates an information for effective process control. Examples of effective use AnyLogic for the development and deployment Digital Twins of business processes for educational purposes are presented.

Keywords: Digital Twin, modeling, simulation, AnyLogic, education.

INTRODUCTION

The development of Digital Twin of a real object is a modern approach not only for the investigate of systems and objects but also increasingly for the effective management and optimization of complex technical objects, systems, and business processes. One of the methods for building Digital Twins is the use of specialized modeling and simulation software platforms. The models are build using data for the objects, and also in the process of simulation created data, which are on the base of the effective management.

Billions of sensors collect information for the functioning of the real objects and using new communication technologies transfer them to the cloud databases. Big data generated by IoT devices has many utilities. This includes data on physical and virtual objects with a variety of uses, from smart products such as autonomous cars and spacecraft, manufacturing systems to smart cities. Common for all of them is that management goes through the creation of models of managed objects.

Modeling and simulation are one of the ways to investigate real objects, their interaction with their surroundings and attempts to solve problems that arise when they exist in the real world. Especially when we can't afford to experiment with real objects to find the right solutions. Sometimes creating, researching, and making changes can be too impossible, or just too expensive [1]. It is often necessary to study the behavior of systems under conditions that will lead to their destruction. In these cases, models come to the rescue, from simple models, product prototypes to Digital Twins of real objects. Modern science and powerful computer technology allow building a twin of a real system by representing it using specialized modeling languages and with the help of specialized software tools. This process implies a certain level of abstraction, which means that we must reduce the details that are not essential to the study of the object for a specific purpose, but we retain the important elements for our study [2].

Digital Twin is a simulation and executable model; running it builds a

*Проект **BG05M20P001-1.002-0023 - Център за компетентност „ Интелигентни мехатронни, еко- и енергоспестяващи системи и технологии“,** финансиран от Оперативна програма „Наука и образование за интелигентен растеж“, съфинансирана от Европейския съюз чрез Европейските структурни и инвестиционни фондове.*

trajectory of system state changes. Operating rules can be described by complex mathematical methods, including systems of differential equations, experimental state diagrams of observed or generated databases of real objects and processes. The twin's outputs are produced and observed as the model runs [3]. Simulation modeling requires special software tools that use simulation-specific languages [3]. The training to build Digital Twin of real object, time and effort are rewarded when the model offers a high-quality dynamic system analysis and opportunity for optimization. Therefore, the development and deployment of Digital Twin of a real system are important knowledge and skills for scientists and engineers.

Any Logic platform as an intelligent tool for process modeling and optimization is a perfect tool for student education because it integrates most modern modeling approaches and provide opportunity to use external databases.

MODELING AND SIMULATION APROARCH

The simulation model gives the opportunity to analyze complex objects and systems and find optimization solutions when the methods used to, for example, analytical calculations and linear programming due to the complexity of the systems, do not give the necessary results.

Knowing the modeling methods and specialized tools for this and having specific skills, it is usually not so difficult to develop a simulation model of the studied object. As a rule, the capabilities built into specialized platforms require less thinking but more skill, and the development process is predictable, scalable, incremental, and modular [4]. The structure of the simulation model reflects the structure of the system at certain levels of abstraction. In the simulation model, we can observe and measure key parameters of the object, add new measurements, accumulate data internally of in external database, and conduct statistical analyses when it’s necessary.

Simulation models developed with modern tools such as AnyLogic allow the creation of 2D and 3D models and the ability to reproduce and animate the behavior of the modeling object over time. This is a key advantage of simulation over the use of typical mathematical models [4]. Animation is useful for object observation, behavior demonstrations, checking and debugging of object design errors.

In simulation modeling, the modeling method is the framework which use to map a real-world object to its model [5]. Modeling tools are software platforms, but they are not only a programming language; they offer rules and conditions for building a model and simulating the behavior of the object in real-world conditions. On the base of this process is a information for the object. Last years thanks of computer and communication technologies growing this information is represent as Big Data and modern data analysis approaches.

Simulation modeling tools are usually based on three main methods - System Dynamics, Discrete Event Modelling, and Agent-Based Modeling. Modern platforms increasingly offer tools that combine these three methods in one additional mix - a Multi-method approach.

Each method reflects a certain range of abstraction levels. System dynamics implies a very high level of abstraction and is typically used for strategic modeling. Discrete event modeling supports medium and medium-low abstraction, such as for small businesses or simple control systems. In the middle are agent-based models, which can range from very detailed models where agents represent physical objects to highly abstract models. Often, this is subjective because it also depends on the user's knowledge and skills with the modeling and simulation tools.

Agent-based modeling is a newer and more modern method compared to system

Проект ***BG05M20P001-1.002-0023 - Център за компетентност „ Интелигентни мехатронни, еко- и енергоспестяващи системи и технологии“,*** *финансиран от Оперативна програма „Наука и образование за интелигентен растеж“, съфинансирана от Европейския съюз чрез Европейските структурни и инвестиционни фондове.*

dynamics and discrete event modeling. In fact, agent-based modeling was largely an academic topic until software tool developers made practical simulations possible 20 years ago.

It was driven by advances in modeling technology made possible by computer science, such as object-oriented modeling, and the rapid growth in processing power and memory capacity of computing systems.

There is no standard language for agent-based modeling, and the structure of an agent-based model comes from graphical editors or scripts [3]. There are many ways to define the behavior of an agent. When we have an idea of the actions and state of the model, then the behavior is best defined with state diagrams. In these cases, the internal dynamics of the agent are important and a system dynamics or discrete event approach is used and then a stock-flow diagram or process diagram is constructed in the agent. This is why many agent-based models are multi-method models.

Agents in an agent-based model can represent many different objects - real and virtual: people, vehicles, units of equipment, projects, products, ideas, companies, and organizations.

System dynamics is a methodology for studying dynamic systems, as the name implies.

The system dynamics method was created in the 1950s by MIT professor Jay Forrester and is the first known modeling method. Forrester applies the laws of physics to study economic, financial, and social systems. Today, many software systems enable the application of the method without special mathematical and computer skills, for example, Vensim.

Discrete event modeling emerged shortly after system dynamics. In 1961, IBM engineer Jeffrey Gordon introduced the GPSS software system, considered the first software tool for discrete event modeling using this method. Many different discrete event modeling programs are in use today, including modern versions of GPSS.

This type of model is defined graphically as a process flowchart, where the blocks represent different sequential operations. As a typical flowchart, the model usually starts with source blocks that generate agents and implement them in the process and ends with sink blocks that remove them.

Agents, originally named transactions in GPSS or entities in other simulation software, can represent customers, employees, physical and electronic documents, parts, products, and more. Resources are groups of agents, for example staff, libraries, servers, warehouses, equipment, etc. Agent service times and arrival times are typically stochastic, and since they are drawn from a probability distribution, discrete event models are themselves stochastic. Or, to have a result, the model must run for a certain period of time or complete a certain number of iterations of the cycles of operations. This type of modeling and simulation provides information useful for optimizing the operation of the real facility, such as resource usage time, waiting time, queue lengths, system throughput and identifying process bottlenecks.

The multi-method modeling is a mix of abovementioned modeling paradigms. There's a significant synergy between different simulation methods, and this means the capabilities of multi-method models are greater than the sum of their parts. Often the "hybrid modeling" is interchangeably with multi-method modeling.

Combining the three modeling methods and the use of a programming language creates a hybrid model, which allows the sienites and engineers to model different aspects of a system at different levels of detail. This multi-method simulation modeling was first introduced by Any Logic and, till today, remains the only software that has that capability on the market.

Проект ***BG05M20P001-1.002-0023 - Център за компетентност „ Интелигентни мехатронни, еко- и енергоспестяващи системи и технологии“,*** *финансиран от Оперативна програма „Наука и образование за интелигентен растеж“, съфинансирана от Европейския съюз чрез Европейските структурни и инвестиционни фондове.*

THE PLATFORM ANYLOGIC

Any Logic platform is a versatile tool for process modeling and optimization. It has been used in many fields like supply chain management, cargo terminal optimization, automated packing systems, unit-assembly production, etc. The software is widely used in simulation and optimization experiments like unit-assembly production and technological lines. One of the key factors allowing Any Logic to be used worldwide is its capability for hybrid modeling [6].

What makes the software such a powerful tool for the industry is that for more than 20 years after its release, the platform proved its potential among 40% of Fortune 100 companies [6]. The software was designed by The Any Logic Company to support all the most common situation methodologies, including system dynamics, process centricity, and agent-based modeling. The interface of the software is designed so it's user-friendly with drag-and-drop functionality, thinking about both beginners and experienced modelers. Claiming its position as a one-of-a-kind tool and operating from the United States and Europe, the company has gained a global network of partners [6].

The software enables users to develop models using all three simulation methodologies [6]. They can be used in combination with other software to create complex simulations to optimize business processes and improve decision-making. Additionally, the software Any Logic supports the use of common programming languages like Java.

Any Logic is built and optimized in such a way that users can have a hands-on, unique suite of industry-specific tools called "Process Modeling Libraries". Each library is a powerful instrument for developers to model at a detailed level in logistics, banking, manufacturing, and many other businesses and services [6]. With the modeling library, any user can visualize every kind of business process easily. The results of business processes can also be validated using Any Logic's animation capabilities.

The platform also offers a wide range of 2D and 3D visualization options, including charts, animation, and GIS mapping capabilities. An important part of Any Logic is that the software incorporates optimization and experimentation capabilities, allowing modelers to analyze multiple scenarios and identify optimal solutions. By running different experiments with the best possible outcome, users can evaluate different factors and make informed decisions to improve efficiency and productivity.

Knowing modeling capabilities, Any Logic supports real-time data to improve the realism and accuracy of simulations. The platform allows users to import data from different resources, such as databases and external applications. Any Logic's flexibility and scalability have made it a leading tool for problem-solving in diverse industries. These unique capabilities of the platform make it an ideal tool for building software Digital Twin on various systems, including control systems.

The digital twin contains two different parts - a dynamic simulation model and data that reflect the current state of a living system [7], but they are two integrated elements of one object. With the model and data, it is possible to build a powerful software counterpart that serves for experimentation and analysis to understand the behavior of the system. On the Fig. 1 is illustrates the ratio between real system and Digital Twin of this system (object).

Digital twin technology helps the optimization and development of business processes, and its application is practically unlimited. Which tool to build the particular twin is a complex question due to the combination of personal approach and choice of software tool, which in turn is determined by the knowledge and skills

Проект ***BG05M20P001-1.002-0023 - Център за компетентност „ Интелигентни мехатронни, еко- и енергоспестяващи системи и технологии“,*** *финансиран от Оперативна програма „Наука и образование за интелигентен растеж“, съфинансирана от Европейския съюз чрез Европейските структурни и инвестиционни фондове.*

of the researchers and the financial costs of acquiring and maintaining the software platform.

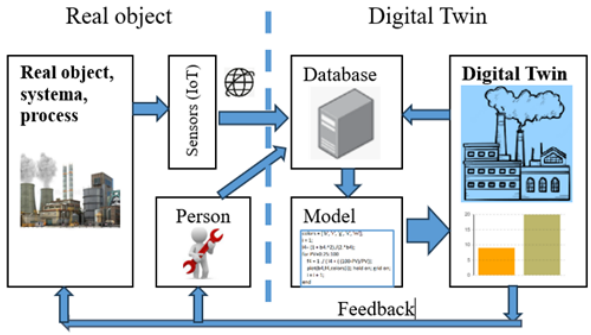

Fig. 1. *The ratio between real object and Digital Twin of this object.*

The AnyLogic platform provides multiple benefits. It provides insights that are easy to understand and communicate. In addition to being a powerful modeling tool and widely used software, the company has developed a private cloud so that users and companies can have full control over their data and processing. Any Logic's private cloud infrastructure is hosted in the user's data center by an external PaaS provider. In this way, it can be incorporated into the company's work process and the models can be implemented throughout the company.

It is good to mention the benefits of the software, which have been crucial to the business industry since its release. Some of them are:

• Leverage a risk-free environment to test and explore – The opportunity to test and explore various ideas and strategies puts forward the idea of taking advantage of situations where there are no risks involved.

• Save money and time in the real world – Allowing companies to protect themselves from unexpected expenses helps them achieve long-term financial goals. Companies save time by running simulations and benefit from being more informed when making crucial decisions.

• Ensure the quality of processes, products, and services, etc. – The companies are allowed to ensure an accurate representation of real-world systems in a simulation model, involving results based on available data or expert knowledge. This includes appropriate modeling constructs and organization, while documenting the model design and assumptions.

• Some of the suppliers of such systems (AnyLogic, Vensim) allow use of a free PLE (Personal Learning Edition) license for training purposes.

Therefore, AnyLogic is perfect tool for student education.

DIGITAL TWIN OF THE ELECTRIC VEHICLES' BATTERIES MANUFACTURING

The Green Deal is the EU's response to the ongoing climate crisis. One of the important directions for its realization is the increase in the number of electric vehicles (EV), and the most important part of an EV is the batteries.

To keep up with expanding trend of using of EV, an increasing number of automakers are investing in the research and development of electric vehicles and components.

Our student developed [8] Digital Twin of the manufacturing process of batteries for electric cars. The research and optimization of such a complex and responsible production can be carried out using a digital twin, and the advantages of this approach we have already discussed.

AnyLogic is a perfect tool for this purpose. On the Fig. 2 is present logical flowchart of manufacturing process, developed in AnyLogic.

Проект ***BG05M20P001-1.002-0023 - Център за компетентност „ Интелигентни мехатронни, еко- и енергоспестяващи системи и технологии“,*** *финансиран от Оперативна програма „Наука и образование за интелигентен растеж“, съфинансирана от Европейския съюз чрез Европейските структурни и инвестиционни фондове.*

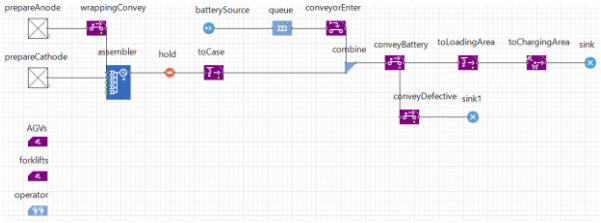

***Fig. 2**. Logical flowchart of manufacturing process.*

The proposed layout of the manufacturing shop is shown on Fig. 3 and 3-D simulation plan on Fig. 4.

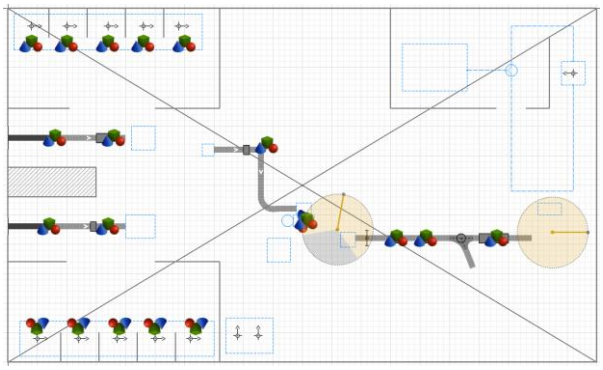

***Fig. 3.** Layout of manufacturing.*

AnyLogic allows users to construct 3D animations from a set of standard geometric shapes: rectangle, line, oval, polyline, image, text, and group. All of these shapes now support the third dimension, height, and appear in 2D and 3D presentation scenes. Standard shapes are usually used to draw simple objects (roads, walls, boxes). More complex objects (people, forklifts, airplanes, etc.) are usually not drawn in AnyLogic, but rather imported from outside using the special 3D object element. This allows the creation of realistic 3D models of objects and processes.

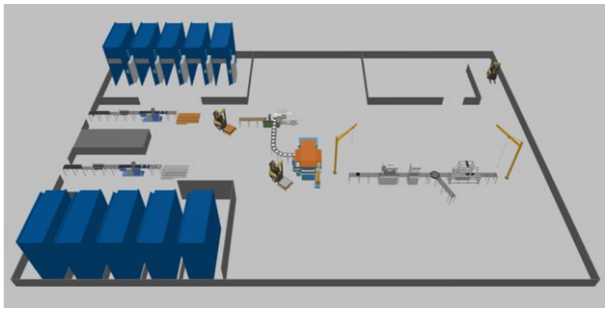

***Fig. 4.** 3-D simulation plan.*

Digital Twin is technology tool for investigating industrial processes, evaluating the effects of system changes, and producing arguments for conclusions. This minimizes the cost of testing in the real world, enables effective analysis, and provides a useful way of experimenting. AnyLogic helps to make production processes more efficient. With a specially created Material Handling Library, it is a powerful process simulation tool that makes it simpler to simulate complex manufacturing systems and processes.

DIGITAL TWIN OF THE BICYCLE ASSEMBLY FACTORY

In today's hyper-competitive business world, the preliminary research and improvement of the efficiency of companies is a key factor for their survival. Therefore, the creation of a model of small business project is extremely relevant.

Our student developed [9] Digital Twin of the manufacturing process of bicycle assembly in small factory using AnyLogic platform. The idea of researching such production is a logical continuation of the course Introduction to SAP, based on the real company Global Bikes Incorporation (GBI).

This model covered bicycles assembly area, packaging, store, and expedition processes in small, specialized assembly factory. On the Fig. 5 is shown logical flowchart of the processes.

*Проект **BG05M20P001-1.002-0023 - Център за компетентност „ Интелигентни мехатронни, еко- и енергоспестяващи системи и технологии“,** финансиран от Оперативна програма „Наука и образование за интелигентен растеж“, съфинансирана от Европейския съюз чрез Европейските структурни и инвестиционни фондове.*

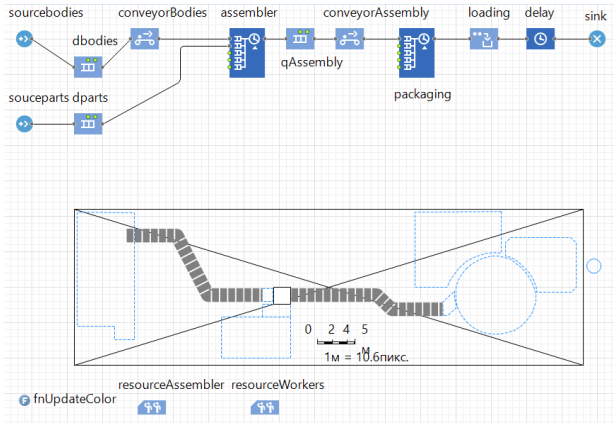

Fig. 5. *Logical flowchart and plan of bicycles assembly, packaging, and expedition.*

The simulation is present on Fig. 6.

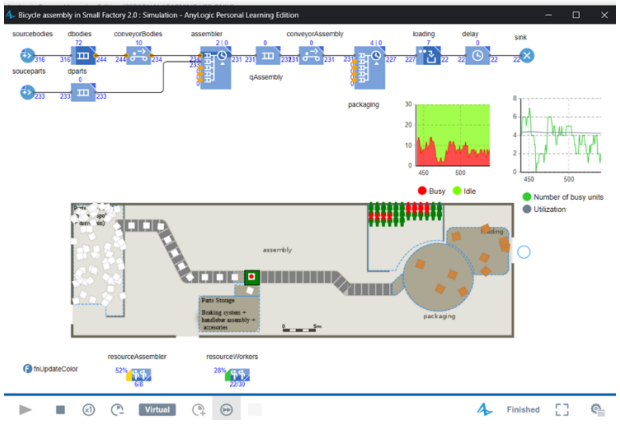

Fig. 6. *Workday simulation of the developed model.*

The development Digital Twin allows monitoring of the resources used in the small enterprise - the units (parts and bicycles) and the workload of the workers.

The results of the real time simulation in AnyLogic are presented on Fig. 7.

The obtained results in graphical view can serve to optimize production processes (assembly and packaging), resources planning and utilization, and, finally, increase the business efficiency.

Fig. 7. *Real time simulation results for resourses using in the factory.*

In this work our students are using examples of production, provided in AnyLogic cloud [10].

CONCLUSIONS

In conclusion, with the present thesis examples, we considered the possibility of developing a Digital Twin for different types of production using the AnyLogic company's modeling and simulation platform.

Any Logic is a comprehensive simulation software that enables the creation of complex and multi-method based models. The flexibility and power of the software enables the development of ideas in a wide range of fields. By providing appropriate input and guidance, this software allows us to tackle a variety of projects and tasks, expanding the boundaries of what can be achieved using known popular mathematical methods to study real systems. The user-friendly interface and intuitive features, the ability to use it for free for educational purposes, make it accessible and enjoyable for students and suitable for learning.

The use of such modern tools for modeling objects and their simulation study, learning new scientific methods, combined with the acquisition of practical skills, is an innovative approach to the training of specialists from various fields at universities.

ACKNOWLEDGMENT

This work is supported by the European Regional Development Fund within the

framework of the Operational Program \Science and Education for Smart Growth 2014-2020, project CC\ Intelligent Mechatronic, Eco- and Energy Saving Systems and Technologies, No BG05M2OP001-1.002-0023.

REFERENCES

[1] A. Borshchev, The Big Book of Simulation Modeling: Multimethod Modeling with Anylogic 6, Published by AnyLogic North America, 2013, p.612.
[2] Simulation and modeling, Study notes for Mathematical Modeling and Simulation, Online book. https://www.docsity.com/en/simulation-and-modeling-2/5894484/
[3] Ilya Grigoryev, Front cover image for AnyLogic 7 in three days : a quick course in simulation modeling AnyLogic 7 in three days : a quick course in simulation modeling. Print Book, English, 2015, p. 256.
[4] Henriette Schoen. Modeling the innovation ecosystem and development of a dynamic innovation index. Published 2018, p. 303.
[5] Ali Ertürk. System Dynamics for Aquatic Ecosystem Modelling, Istanbul University, Faculty of Aquatic Sciences. 2020. http://www.bio.bsu.by/hydrobio/files/news/seminar_models_2020/Minsk_Keynote_Lecture_2020.pptx.
[6] AnyLogic Simulation Software. Online: https://www.indx.com/en/product/anylogic-simulation-software.
[7] Arash Mahdavi, The Art of Process-Centric Modeling with AnyLogic. Online: https://www.anylogic.com/resources/books/the-art-of-process-centric-modeling-with-anylogic/
[8] Donna Stoyanova, Modeling and simulation of the manufacturing process of batteries for electric vehicles. Final year project, TU - Sofia, Plovdiv Branch, 2023.
[9] Denis Kulev, Development of model for bicycle assembly in small factory using AnyLogic platform. Final year project, TU - Sofia, Plovdiv Branch, 2023.
[10] Web platform AnyLogic Cloud, 2023, https://cloud.anylogic.com/models?public=true.