THE REPUBLIC OF KAZAKHSTAN
MINISTRY OF SCIENCE AND HIGHER EDUCATION

Non-profit Joint Stock Company "Kazakh National Research Technical University named after K. I. Satpayev"

School of transport engineering and logistics named after M. Tynyshbayev
Direction of the educational program" logistics"

Amantay Daryn Nurlanuly

Simulation modeling of production processes at the Astana Motors Manufacturing plant

THESIS WORK

6B11301 - Transport services

Almaty 2025

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THESIS WORK

Theme: Simulation modeling of production processes at the Astana Motors Manufacturing plant

6B11301 - Transport services

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ASSIGNMENT
thesis assignment

To the student Amantay Daryn Nurlanuly
Theme: Simulation modeling of production processes at the Astana Motors Manufacturing plant
Approved by the order of the member of the management board – vice-rector for Academic Affairs R. K. Uskenbayeva dated 29.01.2025 No. 26-O / O
Deadline for submitting completed work «28» __05__ 2025 y.
The obtained data of the thesis
Summary of the thesis:
a) The thesis investigates the optimization of production and logistics processes at Astana Motors Manufacturing using simulation modeling
b) It emphasizes the importance of digital twins and AnyLogic in identifying bottlenecks and improving operational efficiency
c) In the calculation section: A detailed simulation model was developed to analyze truck unloading, internal logistics, and assembly line performance, resulting in measurable improvements in throughput and resource utilization
d) Case studies demonstrated the impact of defective parts and demand variability on production stability
e) The results confirm simulation modeling as a strategic tool for enhancing decision-making in automotive manufacturing
List of graphic material (with precise indication of mandatory drawings):
The work is presented with a presentation slide
Recommended list of references: contains 24 titles

SCHEDULE
preparation of thesis (project)

Name of sections, list of issues to be developed	Deadlines for submission to supervisor	Note
Theoretical background	11.03.2025	Done
Input data and initial analysis	25.04.2025	Done
Output data, simulation model development, and optimization cases	12.05.2025	Done

For the finished graduation work, with the indication of the sections related to it, the **signatures** of consultants and the normo-controller

Name of departments	**Consultants, (full name, surname, academic degree, title)**	**Date of signing**	**Sign**
Normo-controller	S. Bolatkyzy, c.e.s., associate professor	__.__.2025	

Scientific supervisor: __________ Mukhanova G. S.

The student was able to complete the assignment __________ Amantay D. N.

Date "03" 02 2025 y.

АҢДАТПА

Бұл дипломдық жұмыс Astana Motors Manufacturing зауытындағы өндірістік процестерді AnyLogic арқылы модельдеуге арналған. SKD-4 жинау, логистика және ішкі процестер цифрлық модельге енгізілді. Бұл тар орындарды анықтап, оңтайландыру тәсілдерін сынауға мүмкіндік береді. Дефекті бөлшектер мен сұраныс өзгерістері мысалында модельдеудің тиімділігі көрсетілді.

Кілт сөздер: имитациялық модельдеу, AnyLogic, логистика, SKD-4, Astana Motors, өндірістік процестер, цифрлық егіз, оңтайландыру, автокөлік өнеркәсібі, ішкі логистика.

АННОТАЦИЯ

Работа посвящена моделированию производственных процессов на заводе Astana Motors Manufacturing с использованием AnyLogic. Создана цифровая модель сборки автомобилей по технологии SKD-4, отражающая логистику поставок и внутренние потоки. Модель позволяет выявить узкие места и протестировать варианты оптимизации. Рассмотрены кейсы, связанные с дефектами деталей и колебаниями спроса. Имитационное моделирование подтверждено как эффективный инструмент для повышения производительности.

Ключевые слова: имитационное моделирование, AnyLogic, логистика, SKD-4, Astana Motors, производственные процессы, цифровой двойник, оптимизация, автомобильная промышленность, внутренняя логистика.

ANNOTATION

This thesis presents a simulation model of production processes at Astana Motors Manufacturing using AnyLogic. The SKD-4 assembly, logistics, and internal workflows are digitally modeled to identify bottlenecks and test optimizations. Case studies on part defects and demand fluctuations highlight the value of simulation for improving productivity and decision-making.

Keywords: simulation modeling, AnyLogic, logistics, SKD-4, Astana Motors, production processes, digital twin, optimization, automotive industry, internal logistics.

CONTENT PLAN

INTRODUCTION

The importance of simulation in modern manufacturing

Modern manufacturing is becoming increasingly complex and dynamic, requiring flexible and efficient tools for process analysis, planning, and optimization [2]. Simulation plays a key role in achieving these goals [2-7], allowing you to create virtual copies of production systems and analyze their work without risking real operations. It helps to identify bottlenecks, test various scenarios, and assess the impact of changes on enterprise performance. In the context of growing competition and accelerated digital transformation, simulation modeling is becoming an integral element of strategic production management [2].

The relevance of optimizing production and logistics processes

Optimization of production and logistics processes directly affects the competitiveness of enterprises. In modern conditions, cost reduction, minimization of downtime, improvement of resource utilization, and improvement of the overall efficiency of the enterprise are important success factors [2]. Simulation modeling allows not only to assess the current state of the system, but also to develop strategies for its improvement [2-11]. The use of such methods in logistics and production helps to increase the accuracy of forecasting, improve coordination between departments and increase the overall reliability of production processes [2].

Goals and objectives of the study

The purpose of this study is to develop and implement a simulation model of production processes at the Astana Motors Manufacturing plant in order to optimize logistics and increase the efficiency of the enterprise [2]. To achieve this goal, the following tasks were set:

– To study the theoretical foundations of simulation modeling and its application in production systems.

– Analyze the structure and features of the production process at the Astana Motors Manufacturing plant.

– Identify key parameters and performance indicators that affect the operation of the enterprise.

– To develop a detailed simulation model taking into account logistical flows and capacity utilization.

– Analyze the operation of the model, identify possible bottlenecks and propose solutions to eliminate them.

– Develop recommendations for process optimization based on simulation results.

The structure of the thesis

The thesis consists of three main sections:

1 The theoretical part – is the history and concept of Astana Motors Manufacturing.

– Principles and methods of simulation modeling.

– Application of simulation modeling in production and logistics systems.

2 Analysis and problem statement

– Description of the production processes at the factory.
– Input data and key indicators for modeling.
– Possible limitations and problems in current processes.

3 Model development and analysis

– The stages of creating a simulation model in AnyLogic.
– The process of modeling truck unloading at a factory using agent-based modeling.
– Modeling of the production process in 3D format (SKD-car assembly).
– Analysis of the results and development of proposals for improving efficiency.

The final part of the thesis contains conclusions based on the research results and recommendations for the implementation of the proposed improvements in real production.

1 THEORETICAL BACKGROUND

1.1 Overview of Astana Motors Manufacturing

1.1.1 Company Background

The history of Astana Motors

1992 – The founding of the Kazakh Motor Company Astana Motors [1], which became a pioneer of the automotive business in Kazakhstan (Figure 1).

Figure 1 – The exhibition of imported cars in the early 1990s marked the launch of Astana Motors and the rise of the automotive industry in Kazakhstan [1].
Notice – compiled by author based on the source [1]

1993 – The first contracts for the direct supply of Toyota vehicles have been signed, which has become a significant step in the development of the country's automotive market. The first specialized car dealership has been opened, providing customers with a wide range of cars and high-quality service. The iconic photo shows the President of KMK Astana Motors, Nurlan Smagulov, and the head of Toyota Motor Corporation, Mr. Toyoda, indicating the beginning of a long-term cooperation (Figure 2).

This strategic partnership marked Kazakhstan's entry into the global automotive supply chain and served as a foundation for future collaborations with leading international brands. The dealership not only introduced advanced service standards and customer experience practices but also laid the groundwork for the localization of vehicle assembly in the coming decades. It was a major milestone that boosted public confidence in foreign car brands and accelerated the modernization of Kazakhstan’s automobile retail infrastructure.

Figure 2 – Nurlan Smagulov with Mr. Toyoda
Notice – compiled by author based on the source [1]

1994 – A spare parts department has been established to provide VAZ, GAZ, KamAZ, and UAZ vehicles, which has significantly increased the level of service and availability of components. The first specialized service station (Figure 3) for maintenance and repair of Japanese cars has been opened, setting new quality standards in the field of car service.

Figure 3 – Specialized service station by Astana Motors
Notice – compiled by author based on the source [1]

1995 – The first Toyota Authorized Service Station (Figure 4) has been opened in Kazakhstan, providing car maintenance according to Toyota international standards. A distribution agreement was signed with Mobil Oil, which allowed us to offer customers world-class high-quality lubricants.

Additionally, a distribution agreement was signed with Mobil Oil, which allowed us to offer customers world-class high-quality lubricants. This partnership not only enhanced the performance and longevity of serviced vehicles but also symbolized the growing integration of Astana Motors into global automotive and service supply networks.

Figure 4 – Toyota service station by Astana Motors
Notice – compiled by author based on the source [1]

1996 – Standard Oil LLP, the official distributor of Mobil in Kazakhstan, was founded. A controlling stake in JSC 3rd Taxi Fleet has been acquired. The building has been reconstructed (Figure 5).

Figure 5 – Astana motors and partnership with 3rd Taxi Fleet
Notice – compiled by author based on the source [1]

1997 – A branch of KMK Astana Motors has been opened and the first car dealership in Astana, which was visited by President of the Republic of Kazakhstan N. A. Nazarbayev. The first batch of Tofas Sahin taxis has been delivered for the 3rd taxi fleet. Participation in the Toyota Vehicleavan Moscow– Almaty car rally. The company has sold 5,000 vehicles since its foundation.

1998 – A controlling stake in JSC Tselin-Lada (Astana) has been acquired. Participation in the second Toyota Vehicleavan Almaty–Tbilisi motor rally. Delivery of 100 Hyundai Sonata III taxis for the 3rd taxi fleet.

1999 – Supply of 20 Hyundai County buses and 70 Hyundai H-100 minibuses for urban routes.

2000 – A new car center has been opened in Astana (Figure 6).

Figure 6 – Toyota car center in Astana by Astana Motors
Notice – compiled by author based on the source [1]

2001 – Signing of a distribution agreement with Fuji Heavy Industries for the supply of Subaru vehicles.

2002 – Opening of Subaru Center Kazakhstan.

2003 – Founding of Hyundai Auto Kazakhstan, a part of Astana Motors, and obtaining the status of an official distributor of Hyundai passenger cars in Kazakhstan. Opening of the Toyota Center of Almaty.

2004 – Expansion of the dealer network with the opening of centers in Aktau, Aktobe, Atyrau, Karaganda, Ust-Kamenogorsk and Shymkent. The company's share in the automotive market of Kazakhstan has exceeded 30%.

2005 – Acquisition of Car Center-Bavaria LLP and receipt of a distribution agreement for the supply and maintenance of BMW cars. Opening of dealerships in Pavlodar, Petropavlovsk and Kostanay. Signing of a distribution agreement with Hyundai Motor Company for commercial vehicles.

2006 – The introduction of innovative banking products in the field of car loans.

2008 – The beginning of the distribution of Nissan cars.

2011 – Opening of a large-scale assembly plant for low-tonnage Hyundai trucks and buses in Almaty.

2012 – The first batch of low-tonnage Hyundai Porter (H100) trucks rolled off the assembly line at the Almaty plant.

2020 – The Hyundai Trans Kazakhstan plant for the production of passenger cars has been launched in Almaty (Figure 7).

Figure 7 – Hyundai Trans Kazakhstan plant located in industrial zone of Almaty
Notice – compiled by author based on the source [1]

2021 – Astana Motors and Hyundai Motor Company have signed a Memorandum under which Astana Motors will organize small-scale production of Hyundai Tucson at the site of the Hyundai Trans Kazakhstan plant. Investing 182 billion tenge in the construction of a multi-brand car manufacturing plant (Figure 8), the completion of which is scheduled for early 2025.

Figure 8 – Photo of the construction of the Astana Motors Manufacturing multi-brand plant in Kazakhstan
Notice – compiled by author based on the source [1]

The premium Chinese brand Haval has entered the portfolio of Astana Motors. Official importer – Haval Motor Kazakhstan. In December 2021, the company's portfolio was expanded with another Chinese brand, Chery. The distributor within Astana Motors is First Motor Group.

1.1.2 Key automotive brands manufactured at the plant

Astana Motors is actively developing car production in Kazakhstan, producing products under the following brands:

1 Hyundai Trans Kazakhstan plant, operating since October 2020, specializes in the production of Hyundai passenger cars. In 2021, the company produced 26,000 vehicles, and in 2022 – 37,205 units, of which 82% were sold on the domestic market, and the rest were exported to the CIS countries.

2 Chery, Changan and Haval. In September 2022, Astana Motors signed memoranda with Chery Automobile Company, Changan International Corporation and Great Wall Motor (owner of the Haval brand), obtaining the right to manufacture cars of these Chinese brands in Kazakhstan. To implement this project, a multi-brand plant Astana Motors Manufacturing Kazakhstan is being built with a planned capacity of 90,000 vehicles per year. It is expected that 40% of the products will be supplied to the domestic market, and 60% will be exported [13-24].

The following models are planned to be produced at the new plant:

– Chery: Tiggo 2 Pro, Tiggo 4 Pro and Tiggo 7 Pro.

– Haval: Jolion, H6 and M6 Plus.

– Changan: CS35, CS55 and CS75.

3 Foton and Golden Dragon. A subsidiary of Hyundai Trans Auto is engaged in the production and sale of commercial vehicles of the Foton brand, as well as buses of the Golden Dragon brand in Kazakhstan. These initiatives contribute to the development of the domestic automotive industry, the creation of new jobs and the strengthening of Kazakhstan's position in the international automotive market.

1.1.3 Organizational structure of the plant

Body Painting Workshops:

– Responsible for painting vehicle bodies to ensure durability, corrosion resistance, and aesthetic quality.

– Uses automated and manual painting processes, including primer, base coat, and clear coat application.

Plastic Coloring Shop:

– Specializes in painting plastic components such as bumpers, side mirrors, and trims.

– Ensures color matching with the vehicle body for a uniform appearance.

3 Welding Workshops:

– Handles the welding and assembly of car body structures.

– Uses robotic welding and manual processes to ensure precision and structural integrity.

3 Assembly Shops:

– Conducts the final assembly of vehicles, including the installation of engines, transmissions, interiors, and electrical systems.

– Ensures quality control and testing before vehicles leave the production line.

Component Warehouse:

– Stores essential vehicle components and parts required for production.

– Manages inventory, logistics, and just-in-time (JIT) delivery to assembly and welding workshops.

Warehouse:

– Stores finished vehicles or semi-assembled units before distribution.

– Manages packaging and logistics for shipping to dealerships or export markets.

Treatment Plants:

– Handles waste management and water treatment to ensure environmental compliance.

– Treats wastewater and emissions from the production process to minimize pollution.

Engineering Networks:

– Supports the factory's infrastructure, including electricity, water supply, and ventilation systems.

– Ensures the proper functioning of all technical and mechanical facilities.

Each department plays a crucial role in the efficient and high-quality production of vehicles at Astana Motors Manufacturing (Figure 9) [2].

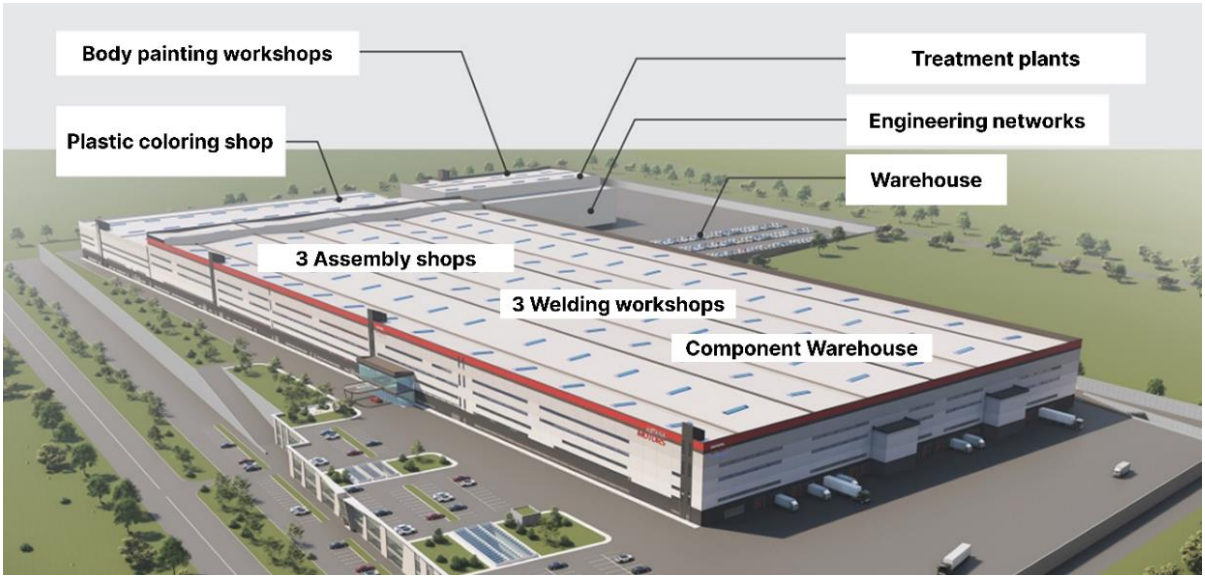

Figure 9 – Multi-brand plant [2]
Notice – created by author

The layout of the Astana Motors Manufacturing plant, as shown in Figure 9, reflects a modern and functionally integrated design tailored for SKD-4 vehicle production. The building is divided into key operational areas that support a smooth production flow.

1.2 Manufacturing and Logistics Processes at the Plant

1.2.1 Supply chain and material flow

Large – scale assembly or SKD assembly (from the English Semi Knocked Down – "semi-disassembled", also ironically "screwdriver assembly") is a car assembly technology in which fully ready-to-assemble components (Figure 10) are supplied to the assembly site from the manufacturer, often in the form of large assemblies. A machine kit or normo is a set consisting of separate units, assemblies and parts for one assembly unit of equipment supplied from abroad in special containers to the factory for subsequent assembly. Large-scale assembly is the simplest car assembly technology, which is used at the initial stage by almost all assembly plants [13].

Figure 10 – Raw car body from plant in China
Notice – created by author

A large-scale assembly includes four subcategories with an index from 0 to 4. Moreover, the higher the number, the more complex the assembly technology and the smaller the units supplied. SKD 0 is the simplest and most primitive (fully finished cars are disassembled into a small number of large components, various elements and parts like seats, interior upholstery, lighting equipment, bumpers, engine, gearbox, etc. are somehow removed, and brought to the assembly site and reassembled. With the SKD 4, "naked" painted bodies and all the necessary parts are supplied, and an untrained person may confuse such production with ordinary production. Nevertheless, SKD4 should not be confused with small-unit assembly (CKD), in which not only parts are assembled on site, but also bodies are welded and then painted, and several components are often purchased from local manufacturers. To maximize shipping efficiency and reduce transportation costs, three car bodies are strategically positioned within a single container, utilizing customized racks and secure mounting systems to ensure stability and protection during transit (Figure 11).

Figure 11 – Car bodies for one container (3 pieces)
Notice – created by author

Manufacturing Process at Astana Motors: SKD-4 Assembly

Astana Motors operates a modern vehicle manufacturing facility that follows SKD-4 (Semi-Knocked Down) assembly technology, ensuring high localization while maintaining international quality standards. This advanced approach allows the company to assemble vehicles from painted body shells and a full set of necessary components, bringing the process as close as possible to complete production while still classifying as SKD. Key Stages of SKD-4 Assembly at Astana Motors:

1 Receiving and Storing Components (Figure 12)

– SKD parts, including fully painted body shells, engines, transmissions, chassis components, electrical wiring, interior elements, and other vehicle systems, are sourced from global suppliers and delivered to the factory.

– Upon arrival, components are stored in a Component Warehouse, where they are categorized and prepared for just-in-time distribution to assembly lines.

Figure 12 – Unloaded car body in logistic zone at plant.
Notice – created by author

2 Assembly Shops: Vehicle Construction

– In the Assembly Shops, the vehicle undergoes sequential assembly, where key systems such as the drivetrain, suspension, exhaust, and electrical wiring are installed (Figure 13).

– Interior components, including seats, dashboard, upholstery, and multimedia systems, are mounted and connected.

– The final stages involve the installation of exterior elements, such as bumpers, mirrors, lighting systems, and doors.

– The final stages involve the installation of exterior elements, such as bumpers, side mirrors, lighting systems, fenders, doors, and windows, followed by sealing and alignment checks to ensure proper fitment.

– Throughout the process, each assembly step is monitored by quality control checkpoints and supported by digital work instructions that ensure consistency and traceability. The plant follows a just-in-time (JIT) material supply strategy, where parts arrive at each workstation exactly when needed, reducing excess inventory and enhancing efficiency.

– To further streamline operations, the assembly line is integrated with Manufacturing Execution Systems (MES), which provide real-time data on production status, worker performance, and equipment utilization. This allows plant managers to quickly respond to bottlenecks, track component usage, and optimize workflow.

– Collaborative robots (cobots) are also employed in specific assembly tasks that require precision and consistency, such as applying adhesives, installing wiring harnesses, or aligning sensitive electronic components. This human-robot cooperation increases productivity while maintaining a high standard of workmanship.

Figure 13 – The “marriage”, an assembly part of a chassis and body.
Notice – created by author

3 Painting and Surface Treatment

– The Body Painting Workshops handle surface treatment and corrections, ensuring that vehicles meet aesthetic and corrosion resistance standards.

– Additional plastic coloring and refinishing are carried out in a separate Plastic Coloring Shop to maintain uniform quality across all external components.

4 Final Inspection and Quality Control

– Every assembled vehicle undergoes rigorous testing, including electrical diagnostics, engine performance checks, braking system evaluation, and safety compliance tests.

– Engineers ensure that each car meets manufacturer specifications and international safety regulations before it is approved for delivery.

5 Logistics and Distribution

– Once the quality control phase is complete, finished vehicles are moved to the warehouse and logistics area, where they are prepared for distribution to dealerships and customers across Kazakhstan and international markets.

By implementing SKD-4 assembly, Astana Motors enhances its manufacturing efficiency, reduces import duties, and supports the development of the local automotive industry. This method allows the company to produce vehicles that match the quality of fully imported models while maintaining competitive pricing and streamlined operations.

Role of the Temporary Storage Warehouse (TSW) at Astana Motors Manufacturing – at Astana Motors Manufacturing, the Temporary Storage Warehouse (TSW) plays a critical role in managing imported SKD-4 components before they are introduced into the production process. Since the plant cannot receive

and store all incoming goods directly, the TSW acts as an intermediate hub that ensures efficient customs clearance, optimized inventory management, and just-in-time delivery of essential parts.
Key Functions of the TSW:

1 Holding Imported Components Before Customs Clearance

– The TSW temporarily stores incoming shipments of SKD parts, including body shells, engines, transmissions, and other key vehicle components.

– Goods remain in the TSW until customs clearance is completed, ensuring compliance with import regulations and tax requirements before they enter the plant.

– This prevents congestion at the main manufacturing facility and allows the plant to receive only the components it needs.

2 Prioritizing Urgent Deliveries to the Plant

– After customs clearance, only urgent parts, those that are immediately required for assembly are transported to the production facility.

– This just-in-time (JIT) supply strategy reduces storage costs at the plant and ensures that production lines receive materials exactly when needed, avoiding overstocking or delays.

3 Inventory Buffer to Manage Supply Chain Disruptions

– The TSW acts as a buffer zone in case of supply chain disruptions (e.g., delayed shipments, customs issues, or unexpected production demand).

– It provides flexibility in material flow, ensuring the factory can adapt to changing production schedules.

4 Logistics and Distribution Coordination

– TSW is responsible for sorting, categorizing, and preparing components before sending them to the plant.

– It works closely with logistics teams to ensure smooth and efficient transportation of goods from the warehouse to the production lines.

How It Supports Astana Motors Manufacturing? by strategically using the TSW, Astana Motors can:

– Optimize space utilization at the main plant.

– Improve customs efficiency by processing goods in batches.

– Reduce lead times for critical components.

– Ensure uninterrupted production by delivering only what is immediately required.

This system allows Astana Motors to balance inventory management, production efficiency, and regulatory compliance, making it a crucial part of the overall SKD-4 manufacturing process. By synchronizing component delivery with real-time production needs, the system minimizes delays and material waste while ensuring that each assembly phase proceeds without interruption. Additionally, it supports compliance with international quality and safety standards by maintaining complete traceability of parts and processes. As a result, the production line remains agile and scalable, capable of adapting to changes in demand or model specifications with minimal reconfiguration.

1.2.2 Stages of SKD assembly

Efficient unloading and internal transportation of SKD-4 components at Astana Motors Manufacturing is crucial to maintaining a smooth production flow. Since the plant receives components from the Temporary Storage Warehouse (TSW), a well-coordinated logistics system ensures that the right parts arrive at the right time, preventing production delays.

Unloading Process – the unloading process starts when trucks arrive at the plant from the TSW. Given the plant's high production volume, unloading must be quick and systematic.

Truck Arrival Schedule:

– First trucks arrive at 8:00 AM.

– Regular deliveries occur from 9:00 AM to 1:00 PM and 2:00 PM to 6:00 PM, with a break from 1:00 PM to 2:00 PM.

Dock Assignment:

– The plant has 18 unloading docks, and trucks automatically move to the nearest available dock to reduce waiting times.

Unloading Time:

– Each truck takes between 20 to 45 minutes to unload, depending on the cargo type and complexity.

Forklift Operations:

– 5 forklifts handle the movement of large and heavy SKD-4 components from the unloading area to internal storage or assembly lines.

Internal Transportation. Once unloaded, SKD-4 parts must be transported internally to the correct assembly stations.

Bays and Sorting Areas:

– Unloaded parts are placed in designated storage bays, categorized by component type (e.g., chassis, engines, doors, transmission).

Urgent Deliveries:

– Parts required immediately for assembly are moved directly to production lines, bypassing storage.

Material Handling Equipment:

– Conveyor systems, forklifts, and AGVs (Automated Guided Vehicles) are used to transport materials efficiently.

Production Flow Optimization:

– The plant follows a Just-In-Time (JIT) system, ensuring that components arrive at the assembly line only when needed, reducing storage time and excess inventory.

The car assembly process at Astana Motors Manufacturing

The production process at the Astana Motors Manufacturing plant is organized according to the SKD4 principle, which means that the company receives painted bodies and all necessary parts, which are then assembled in stages into a finished car.

Body assembly – body passes through the conveyor line, new components are added to it at each stage:

– Seat installation – front and rear seats are mounted; seat belts are attached.

– Adding a front door – the doors are fixed on hinges, locks and handles are installed.

– Adding a tailgate – Similar to the front doors, the rear doors are attached and checked.

– Installation of side mirrors – mounting mirrors with adjustment mechanisms.

Chassis assembly – at this stage, the key mechanisms that ensure the movement of the car are assembled:

– Engine installation – the motor is fixed in the engine compartment; the main systems are connected.

– Installation of the gearbox – connection to the engine and installation of drive shafts.

– Wheel mounting – fixing on the hubs, checking the mounting bolts.

Connecting the body to the chassis. After separate assembly steps, the body and chassis are combined into a single structure. This is the key moment after which the car acquires its final shape.

Quality control and final operations. After the complete assembly, tests and final procedures are carried out:

– Body geometry check – the gaps and symmetry are measured.

– Water resistance test – checking the tightness of the body under water pressure.

– Installing the battery – connecting electrical equipment.

– Refueling with gasoline – preparing the car for launch and test tests.

1.2.3 Logistics within the plant

The Astana Motors Manufacturing plant uses various methods of moving materials and parts inside the production:

– Forklifts – move heavy loads and components between warehouses, temporary storage (TSW) and assembly lines. The main tool for loading and unloading trucks in warehouses and in the material acceptance area.

– Conveyors – move bodies, parts, and assembled assemblies along assembly lines. Reduce the need for manual work and increase productivity.

– Convoys are autonomous vehicles or trolleys that deliver necessary spare parts to specific assembly areas. They are used for the accurate and timely supply of materials to workplaces.

Despite automation, there are logistical constraints in production that can reduce efficiency:

– Limited capacity of TSW. Due to the need for customs clearance, some shipments are delayed in the warehouse, which can lead to a shortage of critical com-

ponents.
The solution: Prioritization of urgent goods and optimization of cargo flow.

– Overloading of unloading areas. During peak hours, the number of arriving trucks exceeds the capacity of warehouses and unloading docks.
The solution: Flexible supply planning and improved cargo arrival schedules.

– Delays in the transportation of materials to the assembly lines. If loaders or conveyors cannot handle the load, parts may not arrive online on time.
The solution: Automation and forecasting of the need for parts using digital warehouse management systems (WMS).

– Uneven loading of assembly lines. If one line is running faster than the other, this can lead to accumulation of semi-finished machines and production stoppage.

The solution: Balancing work operations and dynamic reallocation of resources.

1.3 Simulation Modeling in Manufacturing

1.3.1 Basics of simulation modeling

Simulation is a method of creating a virtual model of a real-world system to analyze its behavior under various conditions. In manufacturing and logistics, simulation helps to replicate production processes, material flows, and logistics networks without disrupting actual operations. Simulation solves real-world problems safely and intelligently. It is a convenient tool for analysis: it is clear, easy to understand and verify. In various fields of business and science, simulation modeling helps to find optimal solutions and provides a clear understanding of complex systems. Bits instead of atoms: simulation is an experiment on a reliable digital representation of any system. Unlike physical modeling, such as creating a building layout, simulation modeling is based on computer technology using algorithms and equations. The simulation model can be analyzed in dynamics, as well as viewed animations in 2D or 3D [2].

Computer modeling is used in business when conducting experiments on a real system is impossible or impractical, most often because of their cost or duration [2-9].

The ability to analyze a model in action distinguishes simulation from other methods, such as using Excel or linear programming. The user studies the processes and makes changes to the simulation model during operation, which allows for a better analysis of the system and a quick solution to the task [2]. Unlike static models, simulation offers the ability to conduct dynamic experimentation, allowing users to explore how a system behaves over time under various conditions. This approach enables the testing of multiple scenarios in a virtual environment without the need to disrupt or interfere with actual operations. As a result, organizations can gain valuable insights into potential outcomes, identify bottlenecks, and evaluate the effectiveness of different strategies before implementing changes in the real world.

1.3.2 Types of simulation modeling

The image below visually represents these three types of simulation modeling and their key characteristics (Figure 14). Each method – Discrete-Event Simulation (DES), Agent-Based Modeling (ABM), and System Dynamics (SD) – offers a unique approach to analyzing complex systems.

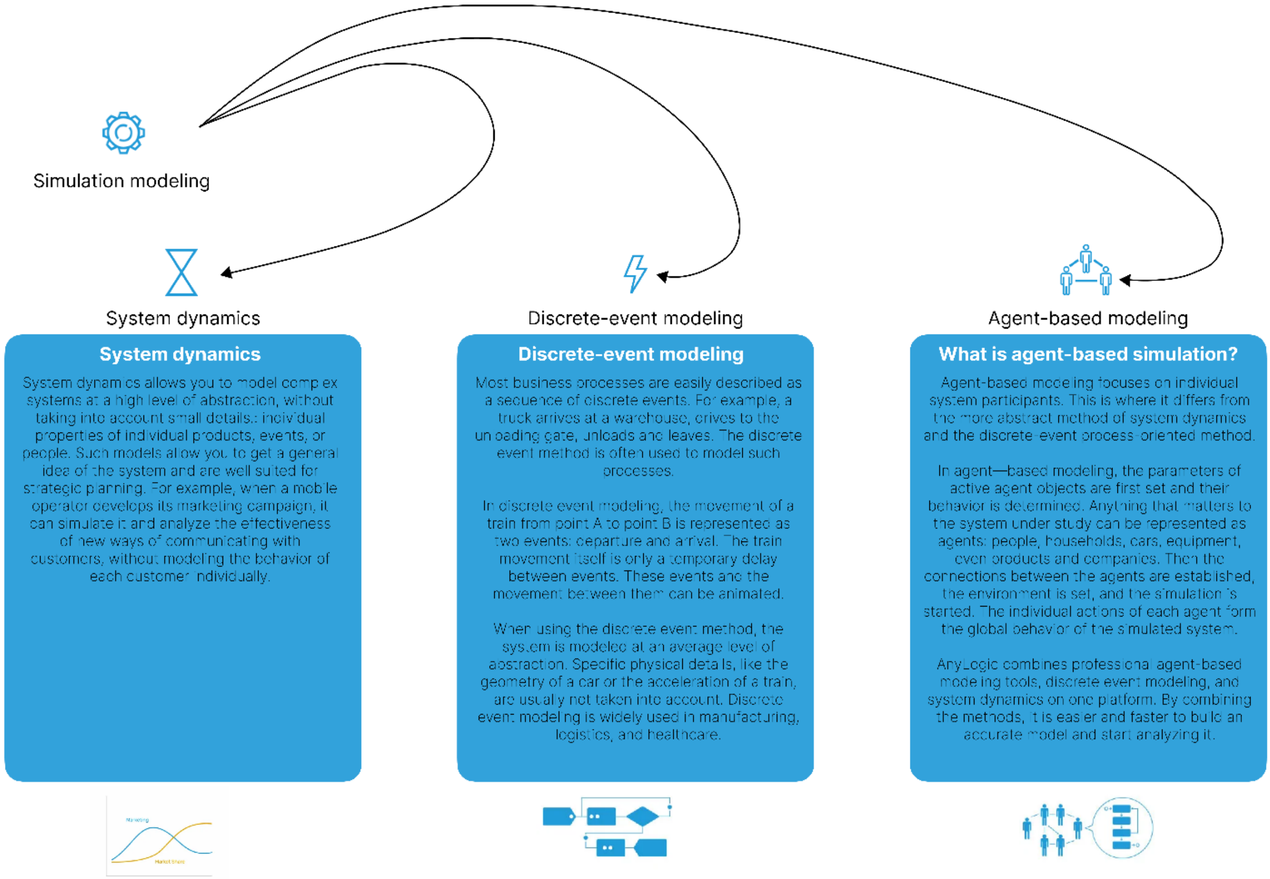

Figure 14 – Three types of modeling
Notice – compiled by author based on the source [3-5]

1.3.3 Why Anylogic for this project?

Multi-Method Modeling (Flexibility)

Project involves complex manufacturing and logistics processes at Astana Motors Manufacturing, requiring a mix of Agent-Based Modeling (ABM), Discrete-Event Simulation (DES), and System Dynamics (SD). AnyLogic is one of the few simulation tools that allow seamless integration of these three methods, which is essential for accurately capturing different aspects of your production and supply chain system.

– Agent-Based Modeling (ABM) is perfect for simulating truck unloading, worker interactions, and forklift movement [17].

– Discrete-Event Modeling (DES) is ideal for modeling loading docks, production lines, and warehouse operations.

– System Dynamics (SD) can help analyze long-term production trends and bottlenecks.

This hybrid capability is crucial because using only one method (e.g., just DES) would oversimplify important dynamics of the factory.

AnyLogic's Manufacturing and Logistics libraries make it easier to implement these features compared to general-purpose simulation tools like MATLAB or Python-based frameworks.

Scalability and Data Integration. Model involves large-scale logistics processes, truck arrival scheduling, and warehouse management. AnyLogic supports integration with databases, Excel, and even AI-based decision models [14]. This ensures:

– Scalability (handling multiple dock operations and variable truck arrivals)

– Live Data Inputs (connecting with real-time production or logistics data)

– Optimization (experimenting with different unloading strategies to reduce delays)

Other tools might require custom coding to achieve this, while AnyLogic provides built-in tools for handling dynamic logistics scenarios efficiently.

Faster Development with Java & Visual Interface. AnyLogic is based on Java, which allows custom scripting when needed, while still providing a drag-and-drop environment for faster model building. Since you want to finish the simulation quickly, this combination of visual modeling + Java coding makes it the most efficient tool compared to writing everything from scratch in Python or using slower alternatives like FlexSim.

Industry – proven for Automotive Manufacturing. Many major automotive companies like Ford, Toyota, and Volkswagen use AnyLogic for logistics and production simulation. This means your approach aligns with industry best practices.

2 INPUT DATA AND INITIAL ANALYSIS

2.1 Definition and Importance of Input Data

Input Data in Simulation Modeling. In simulation modeling, input data represents the real-world information used to define the system being modeled. This data serves as the foundation for the simulation, determining how the model behaves under different conditions [2-6]. The input data can include various parameters such as [2]:

– Operational data: Processing times, service rates, production speeds.

– Resource availability: Number of workers, machines, or vehicles.

– Demand patterns: Customer orders, market fluctuations, or supply chain variability.

– Environmental conditions: Temperature, traffic flow, or weather impact.

– Statistical distributions: Random variations in arrival times or process durations.

– Historical data: Past performance records and trends.

Properly collecting and processing input data ensures the simulation accurately reflects real-world scenarios, making it a crucial step in the modeling process [2].

Sheet 1 – Information about truck arrival [2].

Parameter	Value	Description
Number of trucks per day	20 pieces	Truck arrival rate
First truck arrival time	09:00 AM	Initial arrival
Truck speed	40 km/h	Speed from TSW to factory
Dock availability	14 docks	Number of unloading docks
Unloading time per Truck according to real experience	20-45 minutes	Time needed per truck
Working hours	(9:00-13:00,14:00-18:00)	Factory working hours
Notice – created by author		

The Role of Data Accuracy in Model Reliability. The accuracy of input data directly impacts the reliability and validity of a simulation model [2]. Key reasons why data accuracy is essential include:

– Realistic Representation: Reliable data ensures the model behaves as expected, reflecting actual system dynamics.

– Decision-Making Confidence: Accurate data leads to trustworthy simulation results, enabling better business or operational decisions.

– Predictive Power: A well-calibrated model with precise data can accurately predict future system behavior.

– Error Minimization: Inaccurate data can lead to misleading outcomes, reducing the model's credibility.

– Optimization Efficiency: High-quality input data allows for better optimization strategies, improving process efficiency and cost-effectiveness.

Ensuring data accuracy involves thorough data collection, validation, and processing. Methods such as statistical analysis, expert validation, and real-time data updates help maintain high-quality input data, enhancing the overall reliability of the simulation model.

2.2 Sources of Data collection

2.2.1 Primary sources

Production Forecast and Operational Insights [13]. As the production process at Astana Motors Manufacturing is yet to commence, direct production reports are not available. However, insights were gathered through expert interviews with factory workers and managers from Astana Motors Manufacturing Kazakhstan (AMMKZ), Hyundai Trans Kazakhstan (HTK) and manufacturers from China, providing valuable predictions regarding workflow efficiency, time allocation, and logistical challenges [2].

A time-motion study was conducted based on these expert insights, focusing on the expected cycle times for different assembly stages, truck unloading processes, and warehouse operations. These estimates serve as a foundation for simulation modeling, allowing for adjustments once real-time production data becomes available.

Additionally, potential bottlenecks were identified in areas such as truck unloading schedules, material handling, and workforce distribution. These preliminary findings will be tested and refined through simulation experiments, ultimately contributing to the optimization of production workflows at Astana Motors Manufacturing [2].

2.2.2 Secondary sources

The Semi-Knocked Down (SKD) assembly process plays a critical role in automotive manufacturing, balancing cost efficiency and production flexibility. It allows companies to import partially disassembled vehicle kits and complete final assembly locally, which helps reduce import tariffs, create local employment opportunities, and accelerate market responsiveness.

A review of academic literature highlights key strategies for optimizing SKD assembly, including lean manufacturing principles, just-in-time (JIT) logistics, and digital twin simulations to improve efficiency and minimize bottlenecks [21]. These strategies help eliminate waste, reduce unnecessary inventory, and improve coordination across production and logistics systems.

Studies also emphasize the importance of ergonomic workstation design and

material flow optimization to reduce cycle times [2]. Well-designed workstations can reduce worker fatigue and injury while increasing accuracy and assembly speed. Additionally, advanced tracking technologies such as RFID and barcode systems can further improve traceability and real-time decision-making in SKD environments.
Integration with simulation modeling tools like AnyLogic allows manufacturers to predict system performance, identify inefficiencies, and test improvement scenarios before implementation. As global supply chains become more complex, the ability to virtually simulate and optimize SKD processes becomes a critical competitive advantage for automotive companies operating in emerging markets.

2.3 Logistics and Material flow data

2.3.1 Transportation from TSW to plant

Trucks transporting SKD components arrive from the Temporary Storage Warehouses (TSW), covering a specified distance to the manufacturing plant. These trucks travel at an average speed of 40 km/h, ensuring a steady and predictable flow of materials into the facility. The travel distance, combined with potential road conditions and external factors, may slightly affect arrival accuracy, which will be considered in the simulation model [2].

Sheet 2 – duration from TSW (1) to plant [2]

TSW 1 (about 10 km)	duration (149 min)
Passing the checkpoint and the road to the container yard	00:05
Finding and removing the desired container	00:29
Loading the container onto the truck (richstacker operation)	00:06
Departure from the TSW	00:05
The road to AMMK (40 km/hr)	00:18
Unloading at the AMK	01:00
The road to the TSW (40 km/hr)	00:15
Passing the checkpoint and the road to the container yard	00:05
Removing an empty container	00:06
Notice – created by author	

The table presents a time breakdown of the logistics process between Temporary Storage Warehouse (TSW 1) and Astana Motors Manufacturing Kazakhstan (AMMK). It details each step involved in transporting a container, from retrieval at TSW to unloading at AMMK and the return trip of the truck [2].

Sheet 3 – duration from TSW (2) to plant [2]

TSW 2 (about 75 km)	duration (266 min)
Passing the checkpoint and the road to the container yard	00:06
Finding and removing the desired container	00:13
Loading the container onto the truck (richstacker operation)	00:05
Departure from the TSW	00:06
The road to AMMK (50 km/hr)	01:30
Unloading at the AMK	01:00
The road to the TSW (60 km/hr)	01:15
Passing the checkpoint and the road to the container yard	00:05
Removing an empty container	00:06
Notice – created by author	

The second table provides a detailed time breakdown of the logistics process between Temporary Storage Warehouse (TSW 2) and Astana Motors Manufacturing Kazakhstan (AMMK). It outlines each step involved in transporting a container over a longer distance (75 km) compared to TSW 1 (10 km) [2]. Representation of the facility within the AnyLogic software (Figure 15-16).

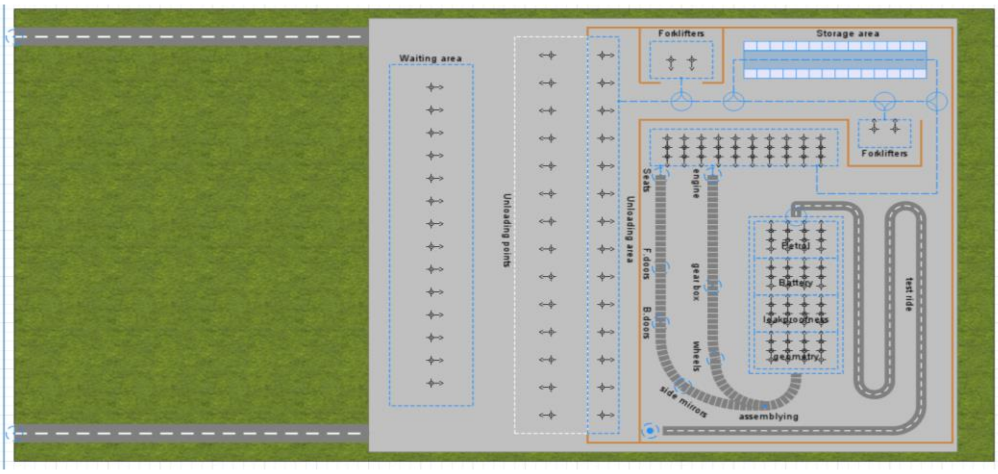

Figure 15 - Interpretation of the plant in the Anylogic program
Notice – created by author

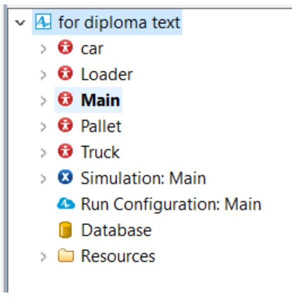

Figure 16 - List of agents needed to create interpretation
Notice – created by author

The simulation model represents the production and logistics flow at the Astana Motors Manufacturing plant. The layout is designed to simulate the key stages of semi-knocked down (SKD) vehicle assembly, starting from truck arrival and unloading to the final vehicle testing area. Below are the main components of the model [2]:

– Entrance & Waiting Area: Trucks arrive from the Temporary Storage Warehouse (TSW) and queue up in the Waiting Area before being directed to available unloading docks.

– Unloading Area: The Unloading Docks section includes 18 docks where trucks unload car parts. Trucks are assigned to the nearest available dock to ensure efficiency.

– Forklift Zones: There are designated areas for Forklifts, which transport parts from the unloading docks to the storage area and assembly lines.

– Storage Area: Components are temporarily stored here before being moved to the assembly line. It includes a bay system to optimize space usage.

– Assembly Line: This area follows a U-shaped conveyor layout where the main assembly steps take place:

– Test Ride Area: After assembly, vehicles are moved to the Test Ride area to ensure quality control before final delivery [2].

This model simulates the real-time logistics and production processes to identify bottlenecks and propose improvements for plant efficiency. Forklifts and trucks operate as agents within the AnyLogic agent-based simulation environment [2].

2.4 Assembly process data

Sheet 4 – Detailed data about duration of assembly

Body assembly	Seats	60 seconds
	Front Door	50 seconds
	Rear Door	50 seconds
	Side mirrors	40 seconds
Chassis assembly	Engine	80 seconds
	Gear box	70 seconds
	Wires	40 seconds
Final Assembly	Merging body with chassis	90 seconds
Check	Checking the geometry of body	180 seconds
	Checking for leakproofness	300 seconds
	Installation the battery	90 seconds
	Refueling with gasoline	120 conds
Notice – created by author		

2.5 The phases of creating Anylogic model

The rectangle is one of the basic shapes used to visually represent elements in your model (Figure 17) [5].

By default, when the model runs, the rectangle appears as a 2D shape in the animation and as a parallelepiped in the 3D view [5].

The base of the parallelepiped is drawn in the graphical editor, while its height is defined by the shape's Z-Height property [5].

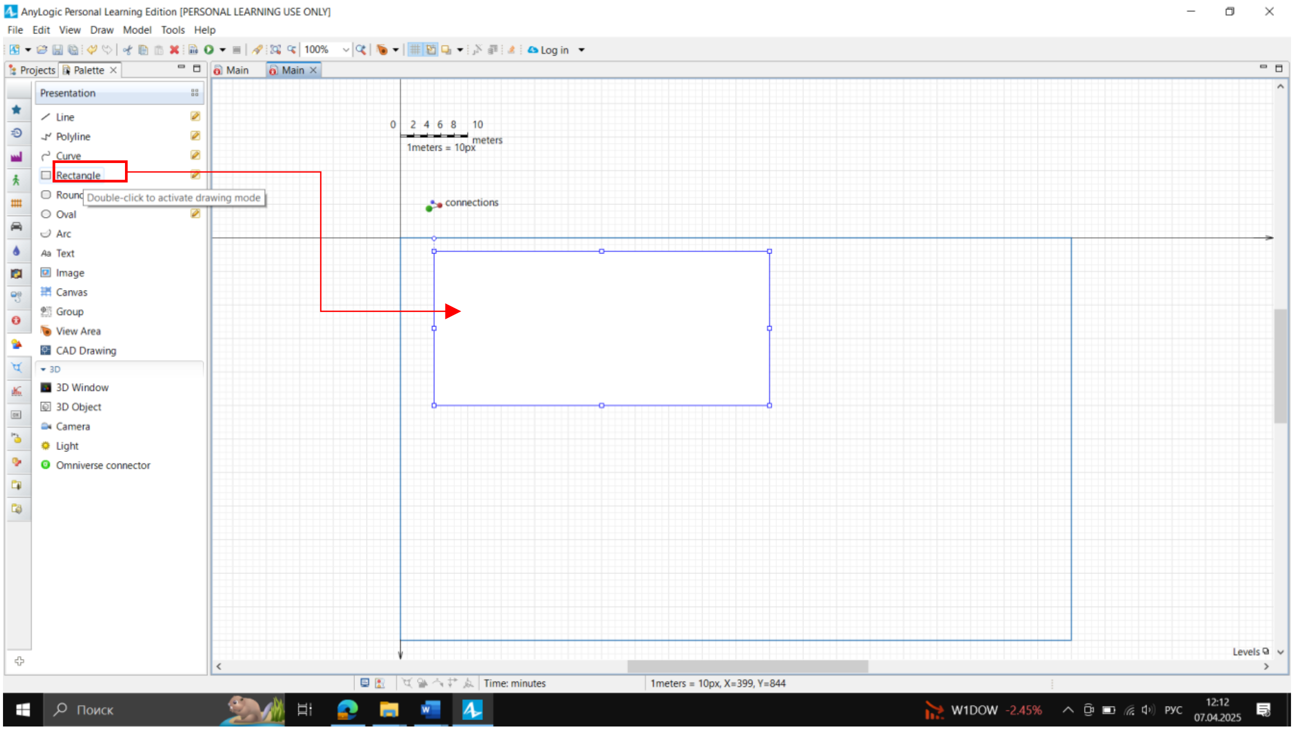

Figure 17 – Adding rectangle to main area
Notice – created by author

In AnyLogic, graphical shapes can be customized not only with solid colors and outlines but also with various textures such as grass, sand, concrete, metal, brick, wood, carpet, and water [12]. These textures are available for both 2D and 3D visualizations (Figure 18), enabling users to create realistic environments that closely resemble actual manufacturing or logistics facilities.

This feature is particularly useful when building digital twins or presentation-ready models, where visual clarity enhances understanding for stakeholders who may not be familiar with simulation logic. For instance, concrete textures can be used to represent factory floors, while metal textures can illustrate machinery or storage racks.

Furthermore, using textures helps in differentiating functional zones within the simulation – such as storage areas, pathways, assembly lines, and loading docks – thus improving the interpretability of the model. Such visual cues can also aid in identifying space constraints, traffic congestion, and inefficient layouts during scenario testing and model validation.

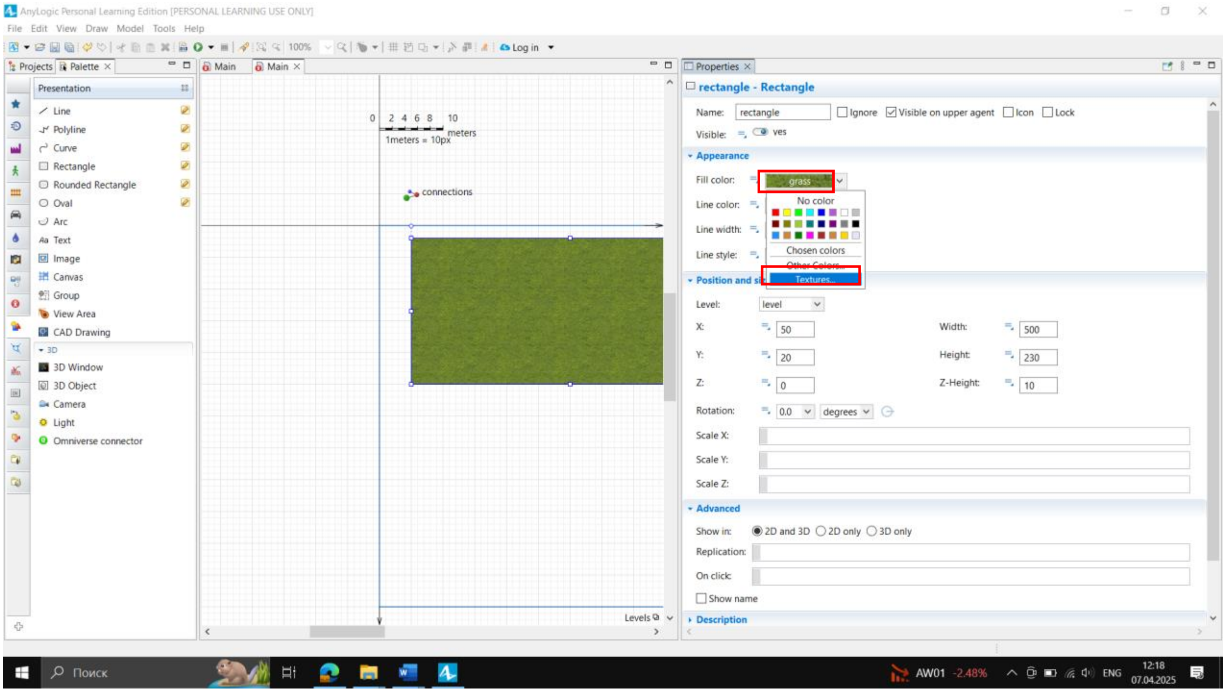

Figure 18 – Changing fill color to texture
Notice – created by author

Paths and nodes are spatial markup elements used to define agent locations within the simulation environment (Figure 19):

– A Path visually outlines the route that agents follow.
– A Node represents a specific point where agents can be located [3-4].

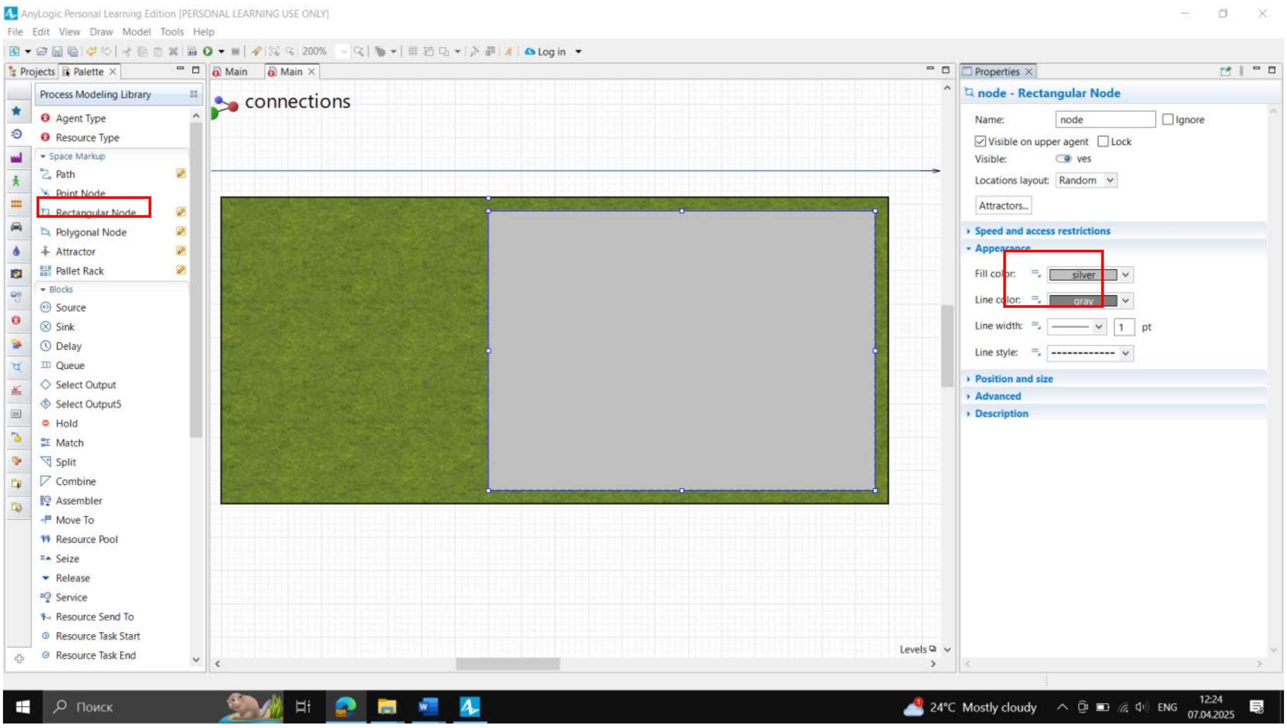

Figure 19 – Adding rectangular node with specifications shown above
Notice – created by author

Nodes can be connected with paths (Figure 20). Altogether they compose a network. AnyLogic also automatically creates a separate network for every single path element that is not connected to any nodes. In the network, a node defines a place where agents may stay, while paths connecting nodes define the routes that agents may take when moving from one node to another. Movement is always performed along the shortest path between the origin and the destination nodes. Agents and resource units may have individual speeds, moreover, those speeds may change dynamically. For example, you can set different speed for the loaded and the unloaded forklift truck. It is assumed that segments have unlimited capacity, so agents moving along a segment do not interfere [3-4].

Drag the Point node element from the Space Markup (Figure 20) palette to the graphical diagram. By default, a point node is designed to accommodate only a single agent at a time. If you need to draw an area where multiple agents can reside at the same time, we suggest using a rectangular node or polygonal node instead.

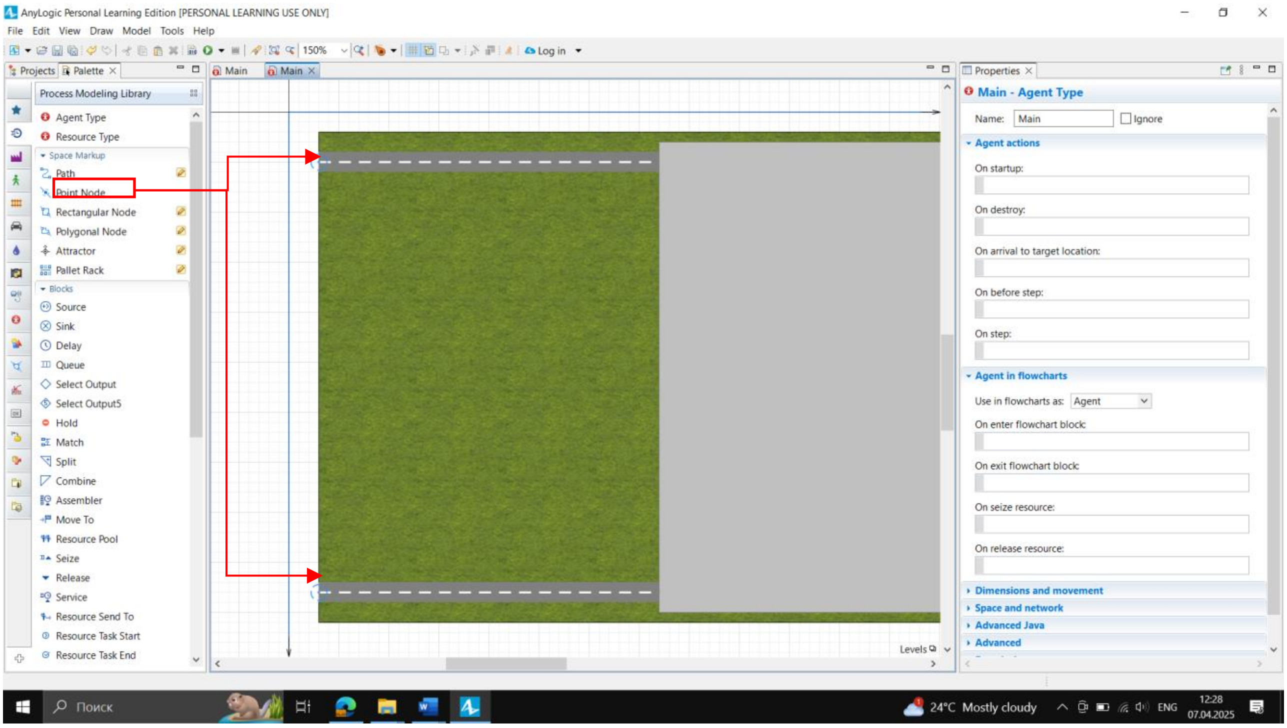

Figure 20 – Integration point nodes and path with rectangular node
Notice – created by author

1 Double-click the Path element from the Space Markup palette (Figure 21). The cursor icon will change, indicating that drawing mode is now active and you can start creating the path point by point in the graphical editor.

2 Click in the graphical editor to place the first point of the path. Continue clicking to add additional points.

3 To create a curved segment, press and hold the left mouse button at the desired turning point, then drag the mouse to shape the curve. Release the button once the segment has the desired form.

4 To finish drawing the path, double-click to place the final point [3].

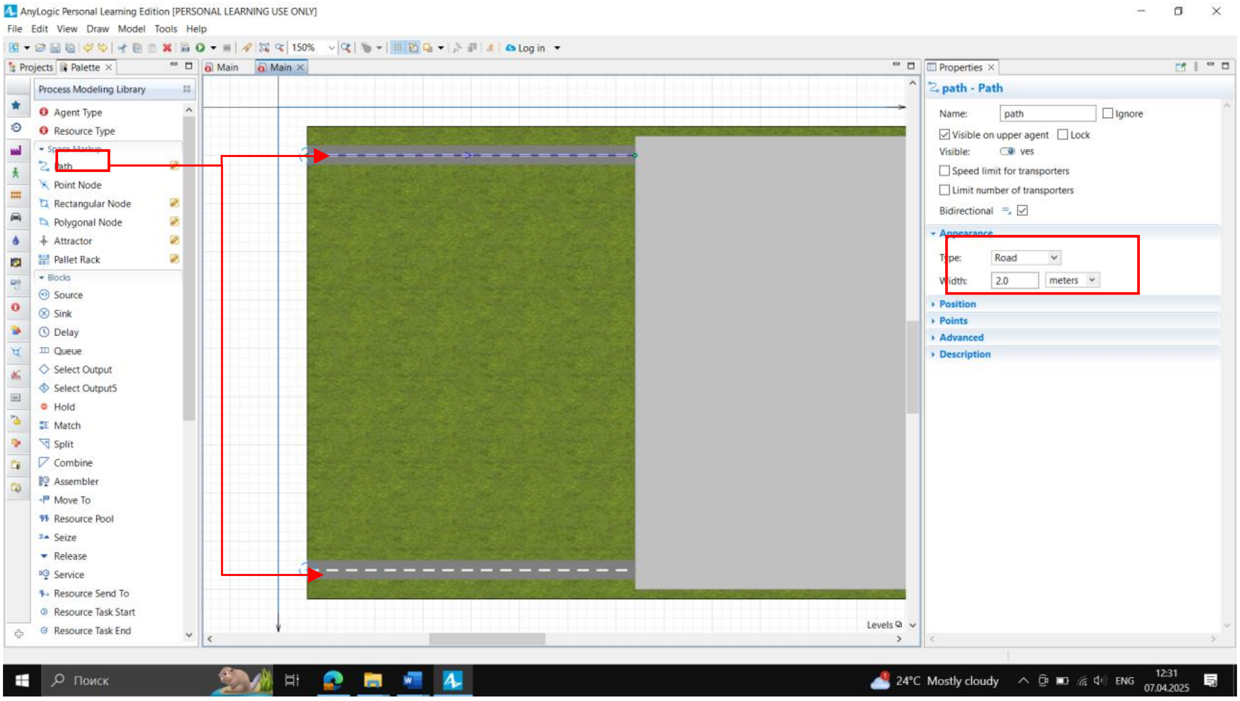

Figure 21 – Connecting point node with rectangular node by path
Notice – created by author

The direction of the attractor's arrow determines how agents are oriented when positioned within it. This is generally important when you have 2D or 3D animation and want the agent animation shapes to face the exact way (e.g. you may want customer to face ATM) (Figure 22-23).

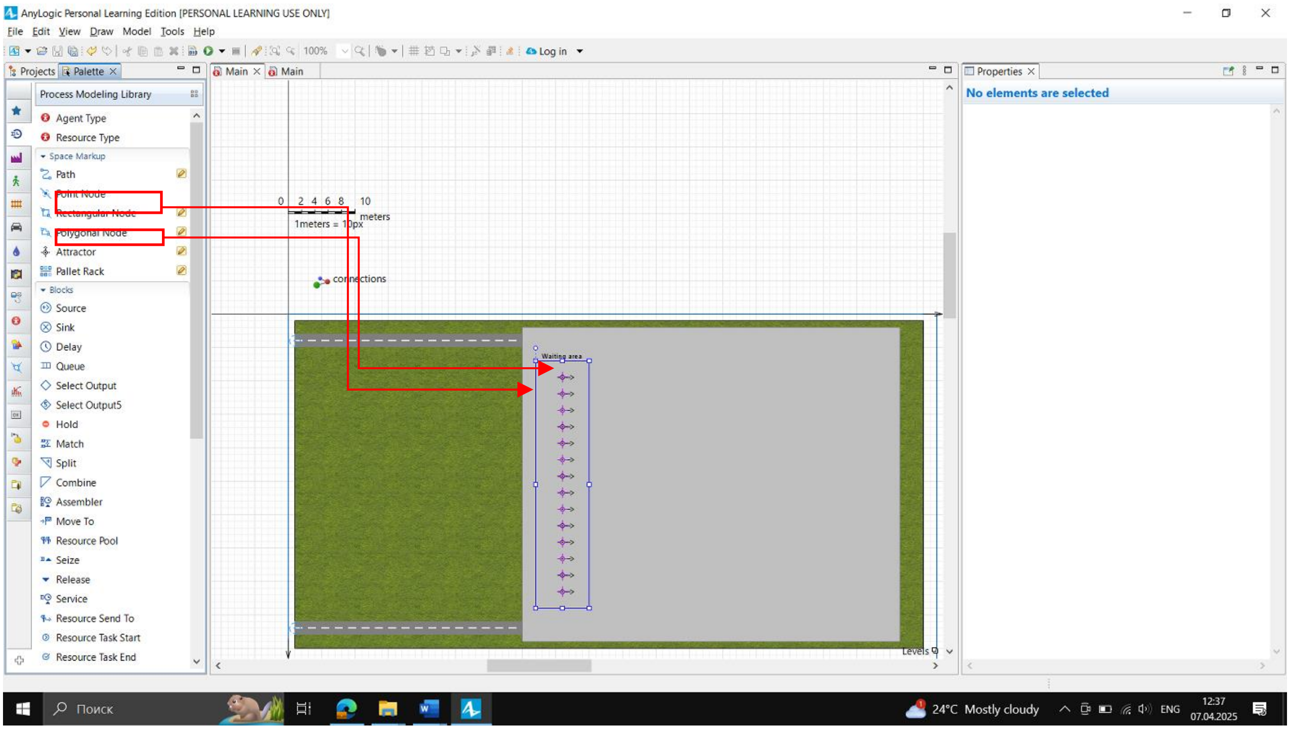

Figure 22 – Rectangular node and Attractor on gray rectangular node
Notice – created by author

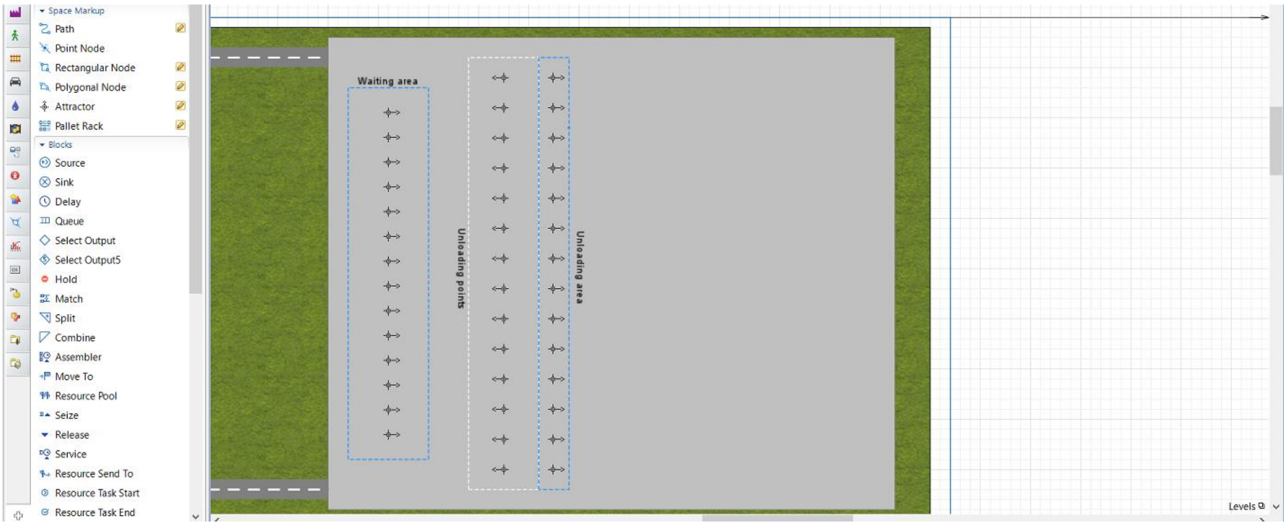

Figure 23 – Repeating the same action, and adding nodes
Notice – created by author

The Pallet Rack element in space markup visually represents shelving systems used in storage areas and warehouses (Figure 24).

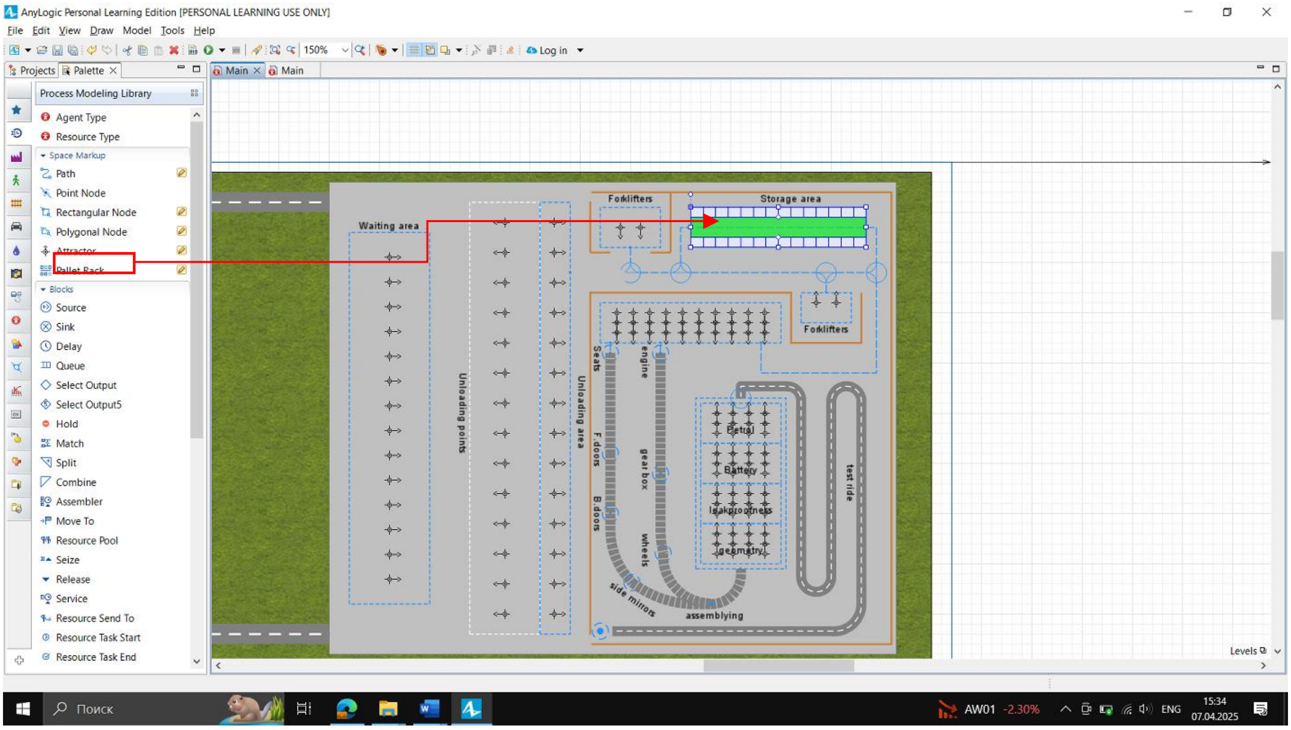

Figure 24 – Integrating pallet rack to main area of plant.
Notice – created by author

Pallet rack may have one of these three configurations:

– One aisle, one pallet rack
– Two aisles, one pallet rack
– One aisle, two pallet racks

The figures below illustrate all three cases (Figure 25):

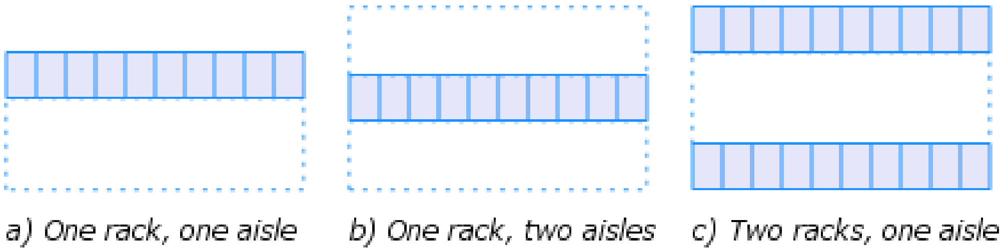

Figure 25 – Three types of pallet rack in Anylogic program
Notice – compiled by author based on the source [3-5]

A Wall is a space markup element used to represent both exterior and interior boundaries in pedestrian simulation models. To create enclosed areas within the space, you can use Rectangular Wall and Circular Wall elements [4].

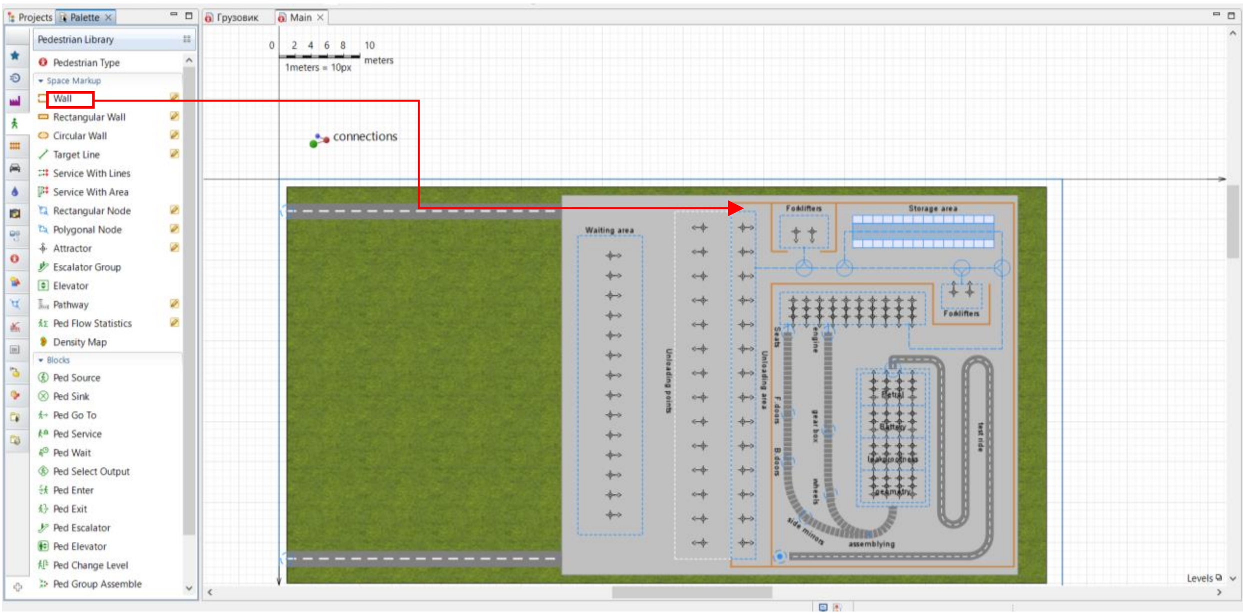

Figure 26 – Implement walls around the plant
Notice – created by author

To draw a wall (Figure 26):

1 Double–click the Wall element in the Space Markup section of the Pedestrian Library palette.

2 The cursor icon will change, indicating that drawing mode is active and you can now draw the wall point by point in the graphical editor.

3 Click in the graphical editor to place the first point of the wall. Continue clicking to add more points.

4 To create a curved segment, click and hold the left mouse button, then drag the mouse to shape the curve without releasing the button.

5 Double–click to place the final point and complete the wall [3-4].

Type – defines the visual style of the path. You can choose from Dashed Line, Line, Road, Railroad, or Conveyor [3-4]. Selecting Road, Railroad, or Conveyor changes only the appearance of the path and does not influence its functionality or behavior.

These types are generally used in highly abstract models (Figure 27).

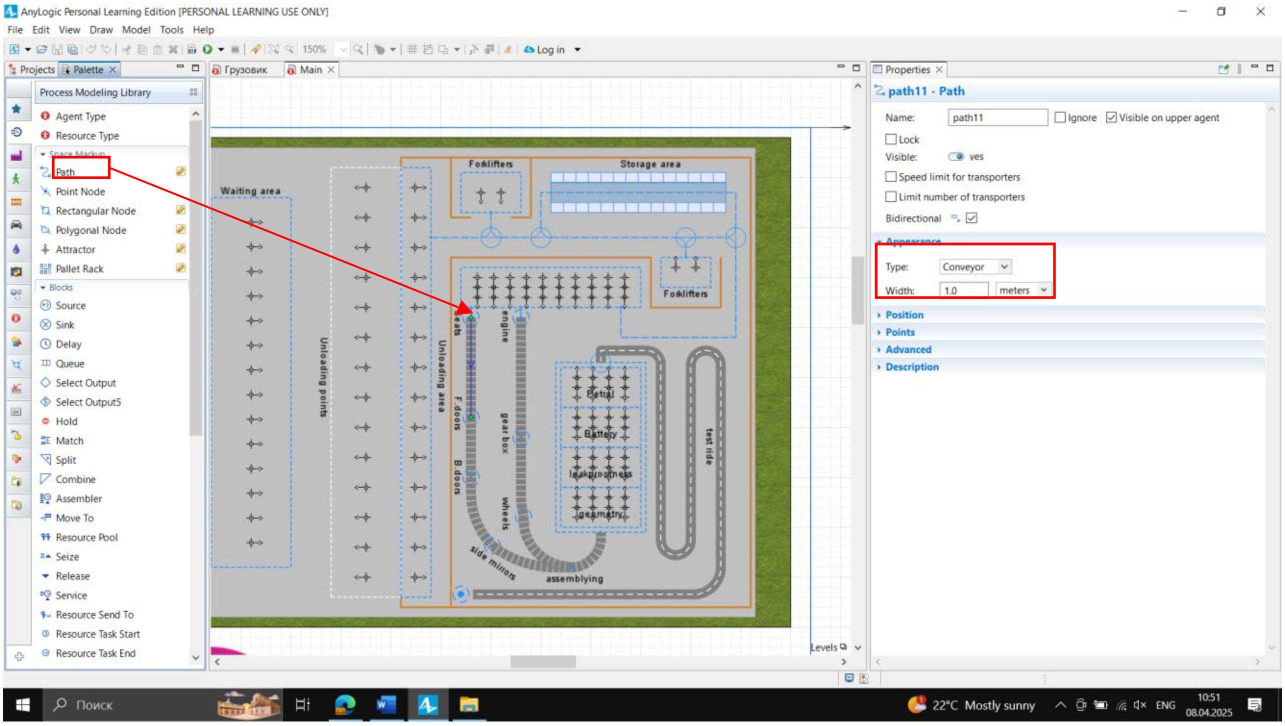

Figure 27 – Integrating path as conveyor to network

Notice – created by author

Serving as a typical starting point for process models, the Source block generates agents. The agents can be standard agents or a custom agent type. You can customize the generated agents by specifying the agent type in the new agent field, and then specifying the action to be performed before the agent exits the Source block in the On Exit action field [15].

The delay function is often used in system dynamics to model delayed effects, such as situations where decision-making or certain processes take time before actions are implemented. For instance, in the classic Bass Diffusion model, the delay function is applied to model the discard rate. In this model, individuals move from the adopter population back to the pool of potential adopters when the product they bought is discarded or consumed. Thus, the discard flow is essentially the adoption flow delayed by the average lifetime of the product.

The Hold block can pause agents traveling along a specific connection. For example, it is used when a flowchart block can accept agents but needs to temporarily block those attempting to move forward. Another scenario involves blocking the output of a particular flowchart block that merge with outputs from other blocks.

The Seize block captures a set number of resource units from a specified ResourcePool block. Optionally, it can send the captured resources to a designated location. There are various to define the resource pools and units that the agent needs to seize (Figure 28).

It is commonly used to model resource constraints, such as assigning forklifts or workers, making the simulation more realistic and helping identify potential bottlenecks.

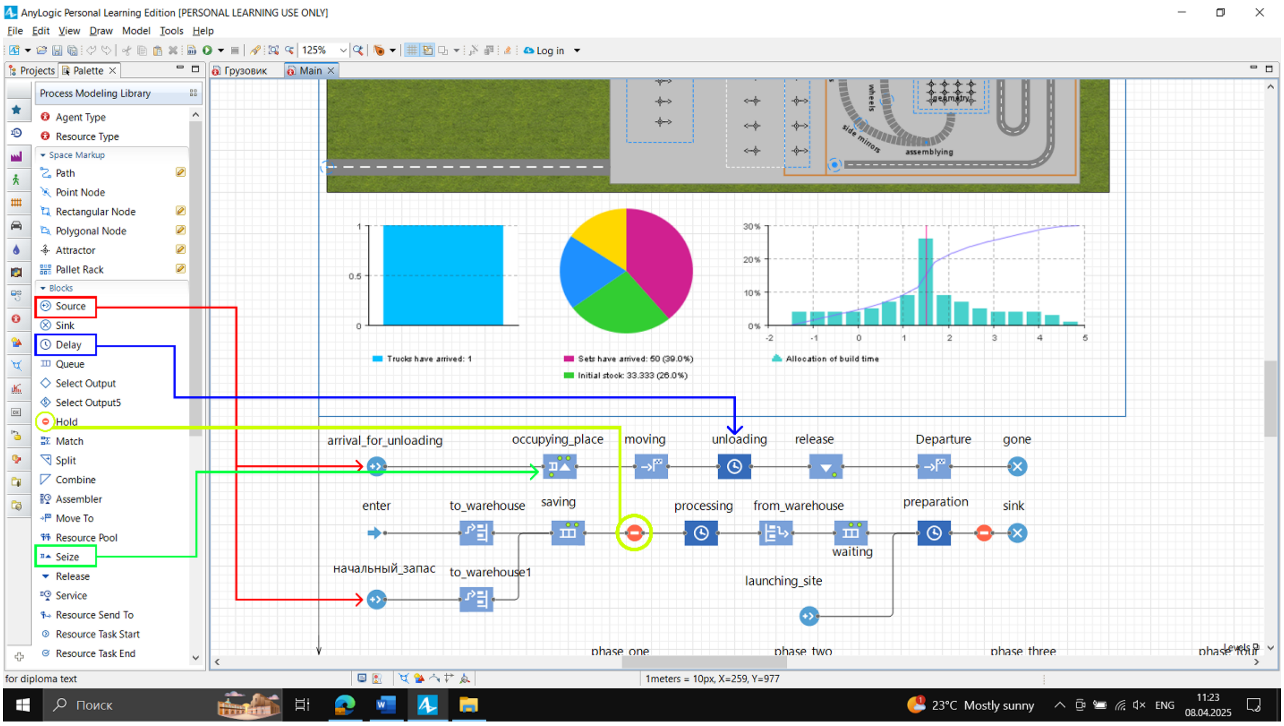

Figure 28 – Adding different types of blocks from process modeling library to Main

Notice – created by author

Phase One: Truck Arrival and Unloading (Figure 29)

1 Truck Arrival (arrival_for_unloading). Trucks arrive at the facility and enter the system using the Source block.

2 Seizing Unloading Spot (occupying_place). Each arriving truck seizes an available unloading dock using the Seize block, simulating the allocation of one of the 18 unloading docks.

3 Moving to Dock (moving). After seizing a spot, the truck moves to the unloading location, represented by the MoveTo block.

4 Unloading Process (unloading). The unloading activity is modeled using a Delay block, which simulates the unloading duration ranging from 20 to 45 minutes.

5 Releasing Dock (release). After unloading is completed, the truck releases the occupied unloading dock through the Release block.

6 Departure (Departure). The truck then moves towards the exit of the facility using another MoveTo block.

7 Truck Exit (gone). Truck exits the system using the Sink block.

The sequential logic described above is visually represented in the simulation flowchart shown below. Each block corresponds to a specific stage in the truck unloading process – from arrival to final exit – modeled using AnyLogic's process modeling library. This block-based structure provides a clear and interactive view of resource flow and time allocation, helping identify potential inefficiencies in unloading operation.

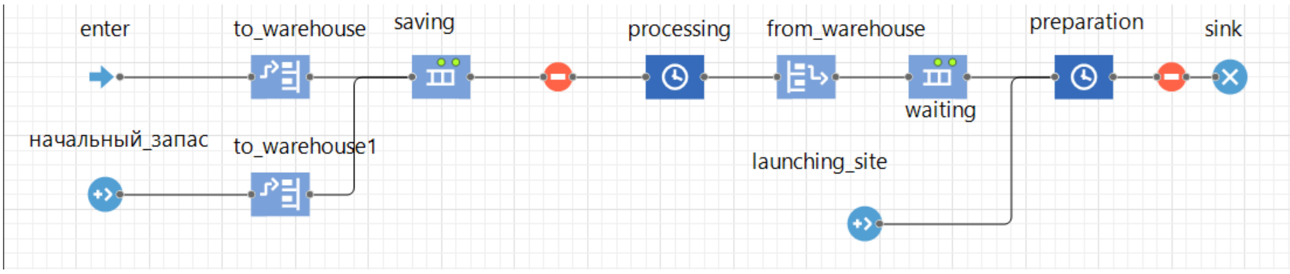

Figure 29 – Process of storaging
Notice – created by author

Phase Two: Warehouse Handling (Figure 30)

8 Entry to Warehouse (enter). Goods that have been unloaded are transferred into the warehouse system.

9 Transport to Storage (to_warehouse). The goods are moved within the warehouse using the MoveTo block.

10 Storing Process (saving). This step simulates the time taken to store goods inside the warehouse using a Delay block.

11 Preparation for Next Phase (processing). After storage, the goods are processed for further use or transport, again using a Delay block.

12 Moving to Launching Site (from_warehouse). The items are moved from storage to the next designated area through a MoveTo block.

13 Buffer Zone (waiting). A Hold block is used to simulate a buffer or waiting zone until a production signal or condition is met.

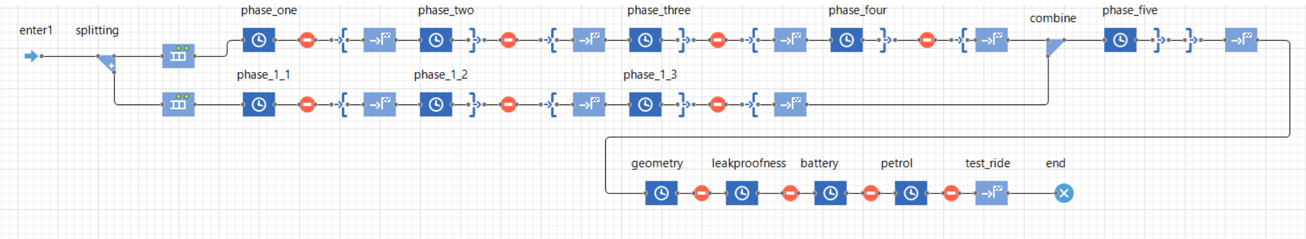

Figure 30 – 7 phases of assembling in total and 4 phases of checking the quality of assembled car in Anylogic.
Notice – created by author

Entry and Splitting

1 Initial Entry (enter1). Assembled components or vehicle parts enter the production system through the enter1 block, marking the beginning of the production process.

2 Splitting into Parallel Lines (splitting). The flow is split into two paths using a SelectOutput block:

– The upper path simulates the installation of interior and exterior elements.

– The lower path simulates the parallel installation of critical mechanical systems.

Main Assembly Line (Upper Branch)

3 Phase One – Seats Installation (phase_one). This stage involves the installation of vehicle seats.

4 Phase Two – Front Doors Installation (phase_two). Front doors are installed onto the vehicle body.

5 Phase Three – Rear Doors Installation (phase_three). Rear doors are added during this phase.

6 Phase Four – Side Mirrors Installation (phase_four). Side mirrors are mounted to the vehicle.

7 Phase Five – Final Assembly (phase_five). After completion of the above steps and merging with the lower branch using the Combine block, the vehicle undergoes final assembly, where all components are integrated.

Parallel Subassembly Line (Lower Branch)

8 Phase 1_1 – Engine Installation (phase_1_1). The engine is installed as a separate sub-process.

9 Phase 1_2 – Gearbox Installation (phase_1_2). The transmission system (gearbox) is assembled.

10 Phase 1_3 – Wheel Installation (phase_1_3). Wheels are mounted on the vehicle. These mechanical parts are later merged with the main assembly line at the Combine block.

Final Quality Control Section

11 Component Checks and Testing. Once the assembly is complete, the vehicle proceeds through a series of quality control checks:

– Geometry – Inspection of body dimensions and alignment.
– Leakproofness – Evaluation for any fluid or air leaks.
– Battery – Battery installation and performance check.
– Petrol – Fuel system testing or petrol filling.
– Test Ride – Final dynamic test to ensure full functionality and performance.

12 Completion (end). After successful inspection and testing, the vehicle exits the production system through the Sink block.

3 OUTPUT DATA, SIMULATION MODEL DEVELOPMENT, AND OPTIMIZATION CASES

3.1 Defining the output data

Below are results based on the simulation model in AnyLogic for the SKD (Semi Knocked Down) car manufacturing process at Astana Motors Manufacturing (Figure 31) [2].

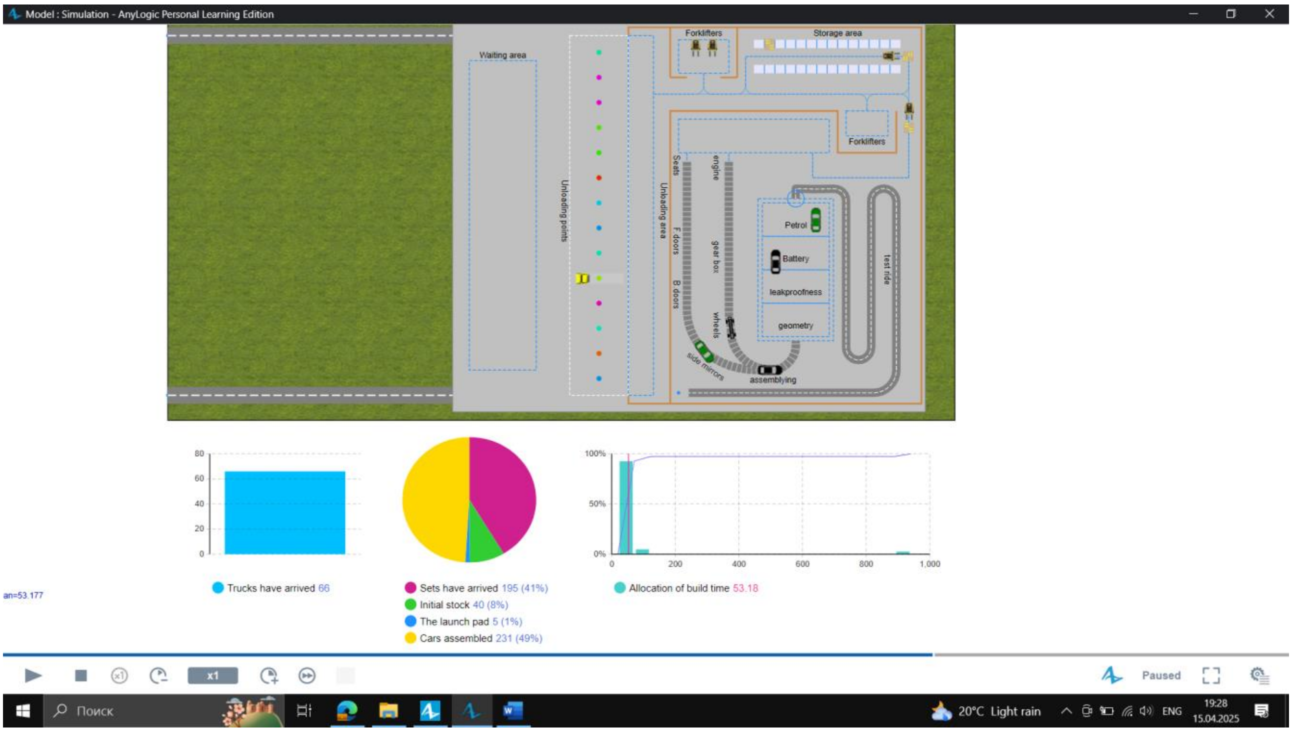

Figure 31 – Simple layout of plant Astana Motors Manufacturing Kazakhstan in simulation [2].
Notice – created by author

The simulation model successfully replicates the key logistics and production processes at the Astana Motors Manufacturing plant, focusing on truck unloading, part storage, assembly line operations, and final test rides. The results demonstrate the efficiency of the current SKD (Semi Knocked Down) workflow while identifying opportunities for further optimization [2].

Key outcomes from the simulation include (Chart 1-2):

– 219 cars assembled during the simulation period, which represents 48% of the total throughput.

– 195 sets of components arrived (42%), indicating a stable supply chain with room to increase unloading speed or storage capacity.

– A total of 65 trucks delivered goods, with unloading distributed between 18 docks and supported by 5 forklifts.

– Initial stock accounted for 9%, suggesting a lean inventory strategy.

– The launch pad used 1%, revealing low queuing and good production flow [2].

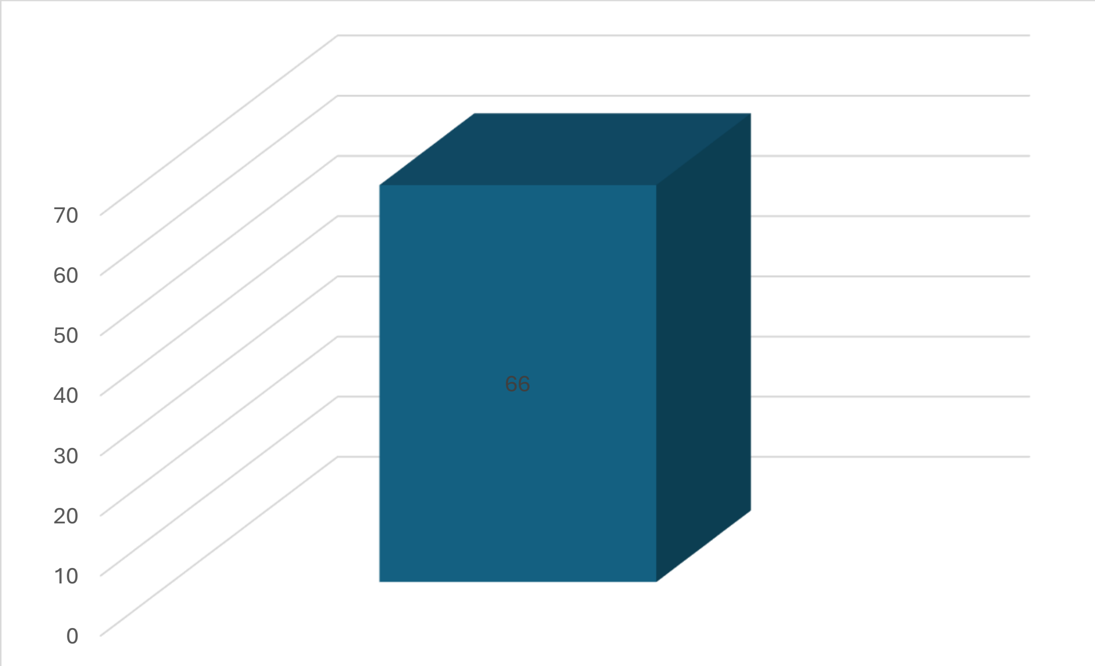

Figure 32 – Amount of Trucks arrived to site [2]
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The data presented in Figure 32 illustrates the inbound logistics performance, highlighting the number of trucks that successfully delivered SKD sets to the plant. This flow of materials is a crucial input to the assembly process.

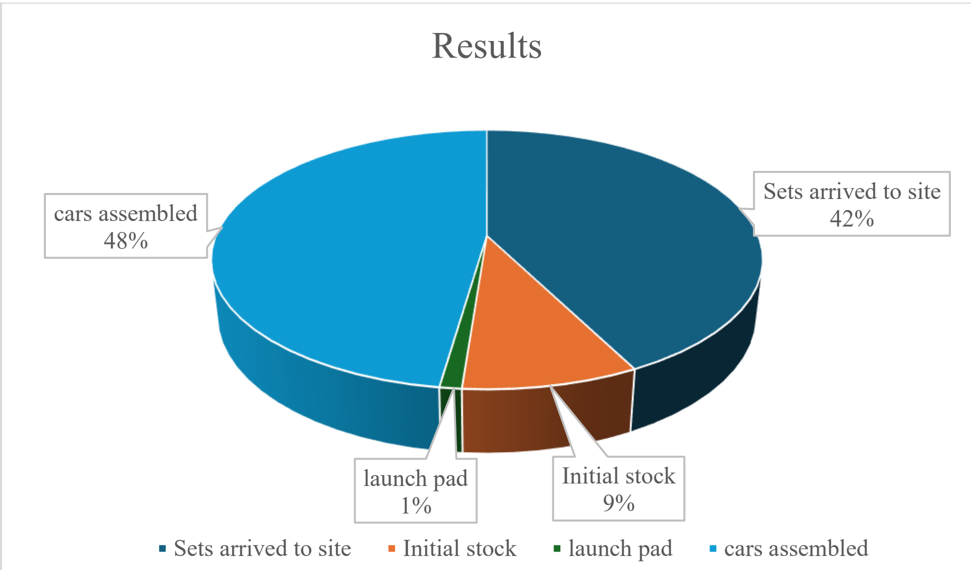

Figure 33 – The results of in three day of manufacturing [2]
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Figure 33 summarizes the outcomes of a three-day manufacturing simulation, showing how the delivered components were utilized, the number of cars assembled, and how inventory was managed. Together, these charts provide insight into the balance between incoming supply and production output.

The allocation of build time refers to the process of distributing the total available time across different stages of construction or production to ensure efficient workflow and timely completion of the project (Figure 34).

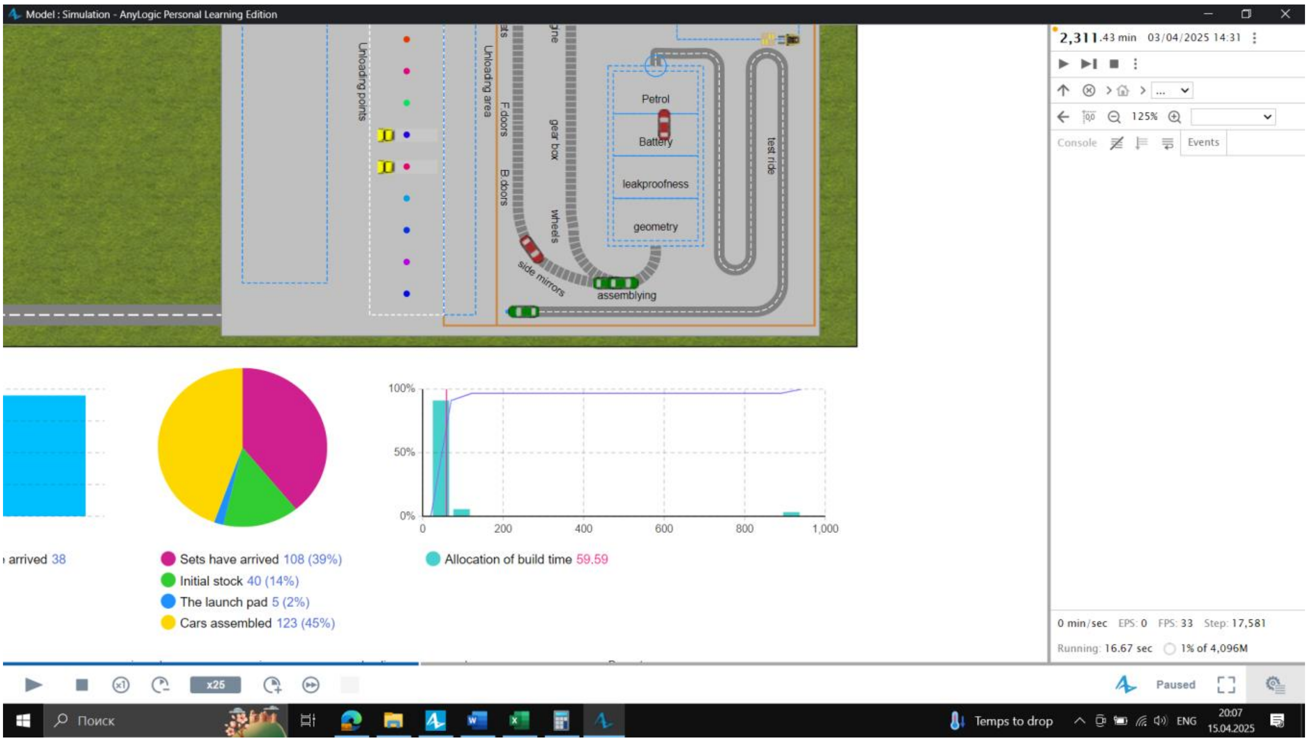

Figure 34 – Allocation of Build time

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In this simulation, the «Allocation of Build Time» refers to the percentage of total simulation time during which the assembly stations were actively engaged in building cars. Specifically, the value 59.59% indicates that more than half of the total operational time was utilized for productive assembly processes, including engine installation, gearbox mounting, wheel attachment, side mirrors, battery placement, and quality checks (geometry, leakproofness, etc.). [2]

The model illustrates the effectiveness of the current setup but also points toward potential improvements:

– Adding more forklifts or optimizing their routes could reduce idle times and increase unloading efficiency.

– Reducing bottlenecks at specific assembly stages could improve car throughput.

– Adjusting truck arrival schedules might reduce peak-time congestion at unloading docks. [2]

Overall, the simulation provides valuable insights into the factory's logistics and operational performance, serving as a powerful decision-making tool for optimizing production and supply chain activities. [2]

3.2 Case studies and efficiency analysis

Case Study 1: The Impact of Defective Incoming Parts on Manufacturing Efficiency at Astana Motors Manufacturing Kazakhstan.

Introduction In modern automotive manufacturing, production efficiency and continuous workflow are critical to meeting delivery targets and maintaining quality standards. At Astana Motors Manufacturing Kazakhstan, the assembly of vehicles depends heavily on the timely delivery of high-quality components from external suppliers. However, the presence of defective incoming parts presents a significant challenge to production stability. This case study explores how defective parts affect the assembly line and proposes mitigation strategies through simulation modeling [2-20].

Problem Statement Although Astana Motors Manufacturing Kazakhstan does not produce the components used in car assembly, it bears the consequences of receiving defective items. Faulty parts – such as engines, gearboxes, wheels, or doors – can lead to line stoppages, delayed vehicle output, and resource inefficiencies. Without an effective strategy to handle these defects, overall manufacturing performance suffers. [2]

Objectives:

- To quantify the impact of defective incoming parts on production output.
- To analyze delays and idle times caused by defective parts.
- To evaluate mitigation strategies such as safety stock and rework lines.
- To simulate the scenarios using AnyLogic modeling software [2].

Methodology The research utilizes a simulation-based approach. Using AnyLogic, a digital twin of the assembly line is developed with realistic process times and component flows [16]. Defective parts are modeled using probabilistic functions (e.g., assigning a 5% defect rate for specific parts). The simulation includes the following elements [2]:

- Quality inspection upon part arrival.
- Quarantine and rejection of defective items.
- Delay in car assembly due to missing parts.
- Use of buffer stock where available.
- Rework or wait zone for partially assembled vehicles [2].

Simulation Parameters (Chart 3)

- Number of vehicles produced per day: 100.
- Defect rate per component: 3–5%.
- Number of critical components: engine, gear box, wheels, doors, side mirrors.
- Time to detect defect: 1–2 minutes per item.
- Delay due to unavailability of replacement: 30–90 minutes.
- Safety stock: 10% of daily demand for critical parts [2].

As a results there are three types of scenarios and key findings below (Figure 36):

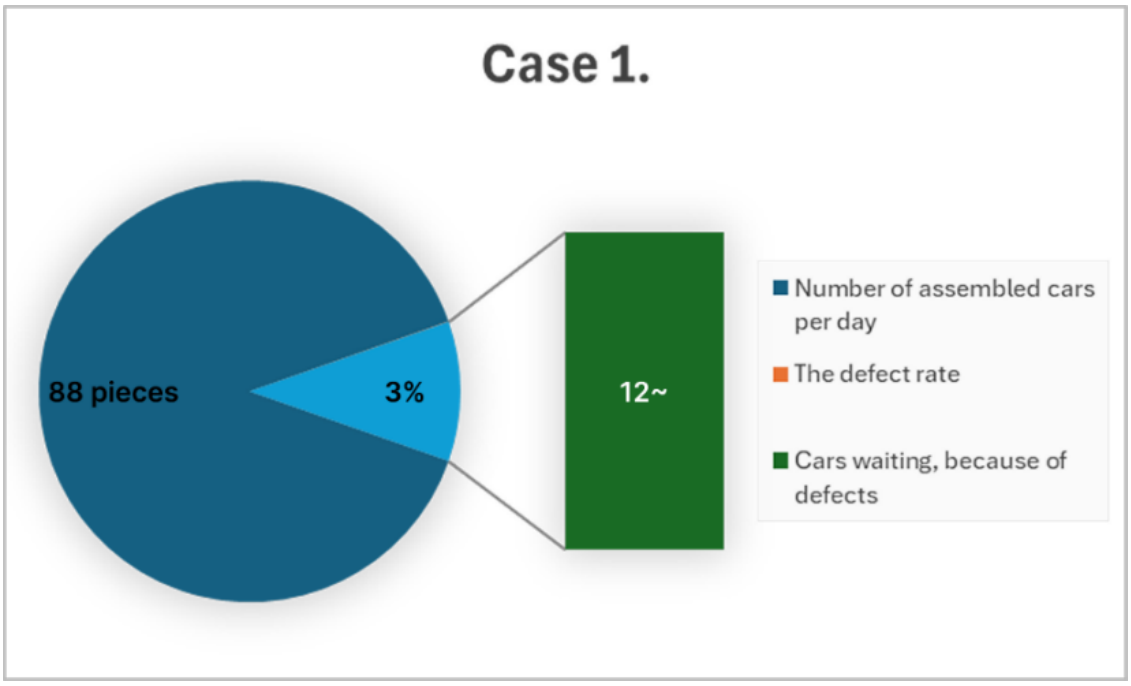

Figure 35 – case 1 [2].
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Figure 35 illustrates the distribution of outcomes in Case Study 1, highlighting how defective incoming parts significantly disrupt the production process. A notable share of total output was negatively affected due to delays caused by the absence of critical components, including engines, gearboxes, wheels, and doors. These interruptions not only reduce overall productivity but also increase resource idling, operational costs, and the risk of missed delivery deadlines. The visualization clearly demonstrates that in the absence of mitigation mechanisms, the system becomes highly sensitive to even moderate defect rates.

In response to this challenge, a set of simulation-based scenarios was developed using AnyLogic to explore the potential effectiveness of different recovery strategies. These scenarios were designed to test the system's flexibility, resilience, and performance under varying conditions of supply chain reliability and resource planning. Specifically, they simulate how the production line behaves when no safety stock is available (Scenario A), when a limited buffer is introduced (Scenario B), and when additional infrastructure such as rework lanes is added (Scenario C).

Figure 36 presents a comparative view of the simulation results under these three scenarios. Each block outlines the underlying logic, assumptions, and observed outcomes. By visually mapping the simulation logic and its implications, the diagram enables clearer insight into the trade-offs between lean inventory principles and the need for resilience.

This multi-scenario analysis supports decision-makers in selecting optimal strategies depending on operational constraints, available resources, and acceptable risk thresholds. Ultimately, such simulation-driven insights are invaluable for improving supply chain robustness, reducing lead times, and achieving more stable and predictable production outcomes in modern automotive manufacturing.

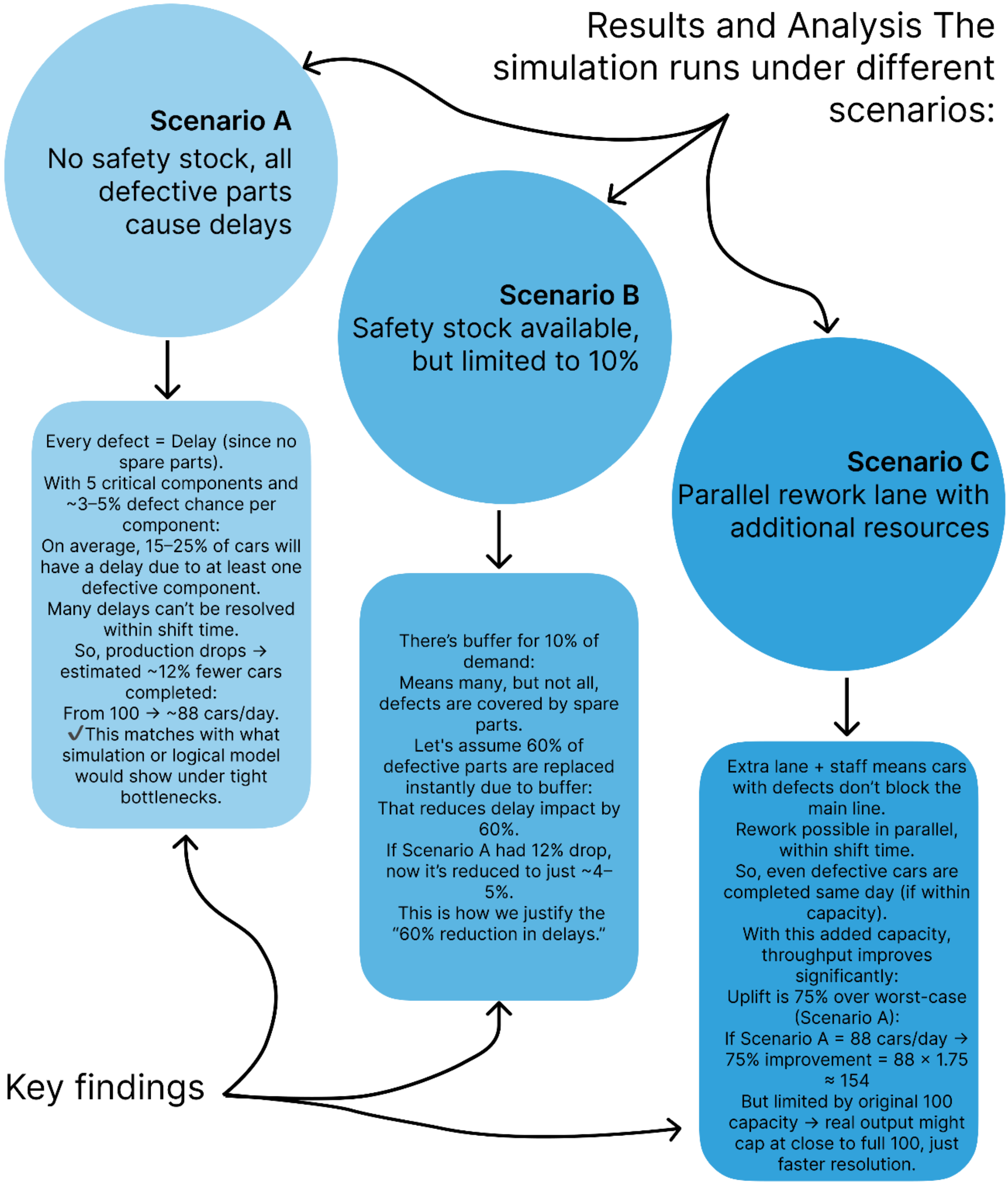

Figure 36 – Scenario A, B and C
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The analysis demonstrates that defective incoming parts significantly hinder production flow. The presence of a well-managed buffer system and a dedicated rework zone can mitigate these disruptions. However, increasing buffer size adds inventory costs, and rework lanes require additional space and personnel. Thus, a balanced strategy that includes strict supplier quality control, accurate defect prediction, and lean buffer usage is ideal.

Conclusion. Astana Motors Manufacturing Kazakhstan, while not directly reponsible for part production, must incorporate quality control mechanisms within its manufacturing operations. By leveraging simulation tools like AnyLogic, the company can forecast delays, evaluate corrective actions, and enhance operational resilience [2-10]. This case underlines the importance of anticipating supply chain issues and integrating real-time response strategies in modern automotive manufacturing [2].

Case Study 2: Production Based on Forecast vs Real Demand – A Strategic Manufacturing Dilemma.

Introduction One of the strategic challenges in modern manufacturing is aligning production with market demand. At Astana Motors Manufacturing Kazakhstan, production volumes are planned based on forecasted data provided by dealerships. However, when actual customer demand significantly deviates from forecasts, it can result in either overproduction or underproduction [22]. This case study investigates the implications of such discrepancies on manufacturing efficiency and inventory management [2].

Problem Statement Producing vehicles based on dealership forecasts assumes a level of predictive accuracy that often does not materialize. When actual sales lag behind expectations, unsold inventory accumulates, tying up resources and increasing holding costs. Conversely, if demand exceeds production, stockouts may occur, leading to customer dissatisfaction and missed sales opportunities [2].

Objectives:

– To compare forecasted versus actual demand.
– To measure the impact of demand deviation on production and inventory.
– To identify strategies for improving forecast accuracy and responsiveness.
– To simulate production responsiveness using AnyLogic [2].

Methodology A simulation model is created using AnyLogic to replicate the production process based on forecasted input. Actual sales data is then introduced with varying degrees of deviation. Key performance indicators such as stock levels, production rates, and fulfillment rates are monitored across multiple forecast accuracy scenarios [2]:

– High Accuracy (±5%).
– Medium Accuracy (±15%).
– Low Accuracy (±30%) [2].

Simulation Parameters (Figure 37). The simulation is structured to run over a three-month planning horizon, incorporating critical production variables such as lead time, maximum warehouse capacity, and safety stock levels. It evaluates how closely production aligns with forecasted and actual demand and how inventory is adjusted over time to compensate for mismatches.

Simulation Parameters, illustrated in Figure 37, include:

– A daily production rate over 50 vehicles.

– A production lead time of two weeks, meaning that any adjustments to production based on revised forecasts occur with a delay.

– A maximum warehouse capacity of 1,000 vehicles, representing a physical limit to inventory accumulation.

– A safety stock policy set at 10% above the monthly forecast to buffer against unexpected demand spikes.

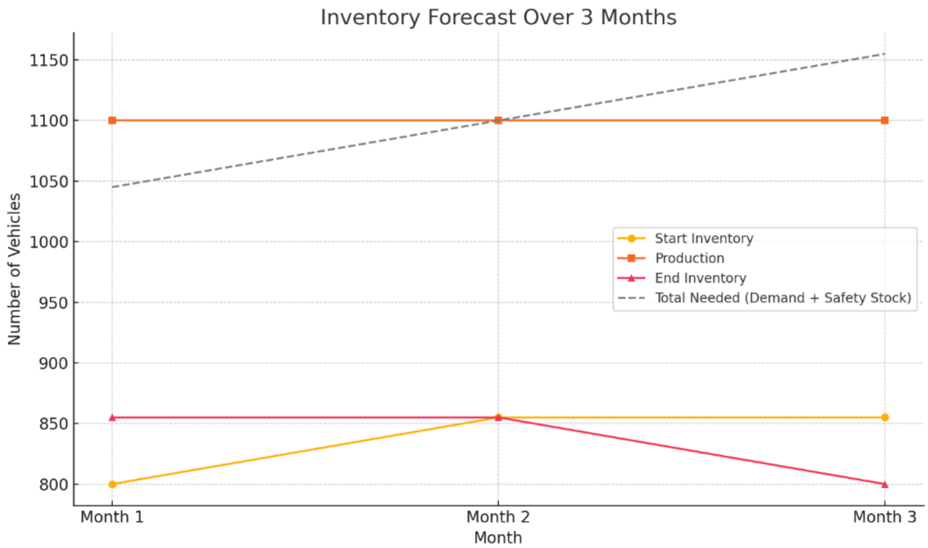

Figure 37 – Forecast for next three months [2]
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Figure 37 visualizes the forecasted production dynamics over a three-month period, comparing projected inventory, production volume, and total demand (including safety stock). The trends indicate stable production levels, but also reveal fluctuations in inventory, particularly a drop in the final month.

To complement this, Figure 38 provides a detailed numerical breakdown of the same forecast scenario, allowing for closer analysis of inventory planning, production consistency, and the balance between supply and demand.

Sheet 5 – Forecast for next three months [2]

Month	Forecasted Demand	Safety Stock (10%)	Total Needed	Projected Inventory (Start)	Production	End Inventory
Month 1	950	95	1,045	800	1,100	855
Month 2	1,000	100	1,100	855	1,100	855
Month 3	1,050	105	1,155	855	1,100	800
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– Forecast horizon: Monthly, updated quarterly
– Production lead time: 2 weeks
– Maximum warehouse capacity: 1,000 vehicles
– Average daily production: 50 vehicles
– Safety stock policy: 10% above forecast [2]

Results and Analysis The simulation revealed:

– High accuracy forecasts led to balanced inventory and efficient usage of resources.

– Medium accuracy caused 18% overproduction and 10% under-fulfillment in some months

– Low accuracy resulted in severe mismatches, including warehouse overflow and production slowdowns due to limited storage

– Dynamic forecast adjustments (monthly updates) improved alignment by 22% [2]

Forecast-driven production can be efficient when the data is reliable. However, in volatile markets, dependency on forecasts alone may expose the manufacturing system to inefficiencies. A hybrid model–combining rolling forecasts with real-time sales data–can improve responsiveness. Lean principles such as just-in-time (JIT) or build-to-order (BTO) may further reduce the risk of overproduction. There results of analysis with following recommendations (Figure 39) [2].

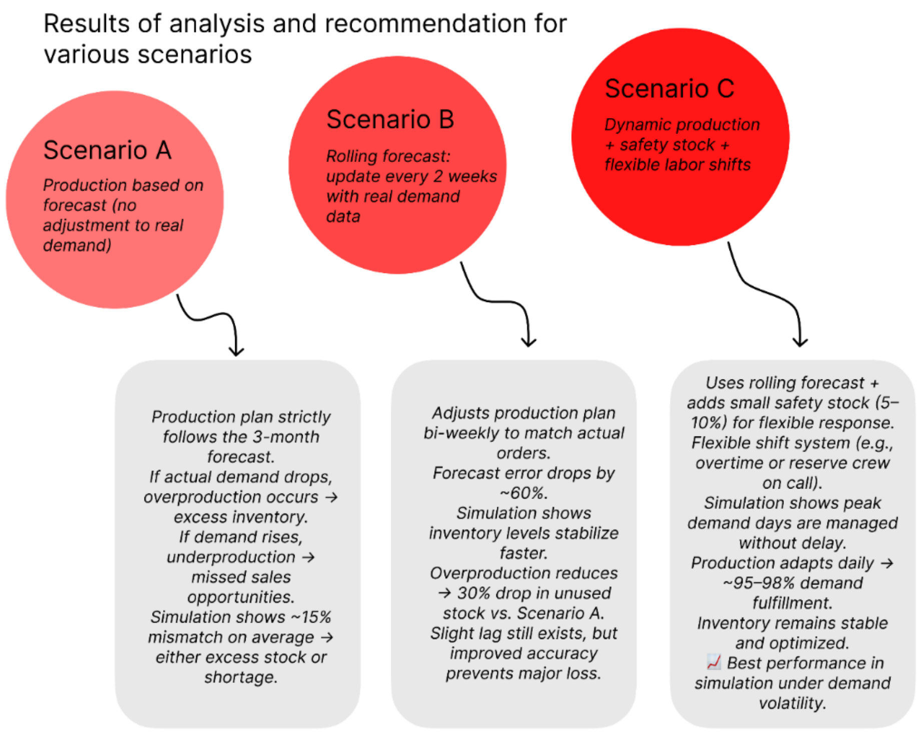

Figure 39 – Results and recommendation for scenarios A, B, C related to demand and forecast

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Conclusion. Production planning based solely on predicted demand presents risks in accuracy-sensitive manufacturing environments. By integrating demand tracking, dynamic forecast updates, and flexible production capabilities, Astana Motors Manufacturing Kazakhstan can reduce mismatches and improve overall operational performance. Simulation modeling proves to be a valuable tool in identifying optimal demand-management strategies [2].

CONCLUSION

This thesis explored the design, implementation, and analysis of a simulation model aimed at optimizing the logistics and manufacturing processes at Astana Motors Manufacturing Kazakhstan. Through a comprehensive study of the SKD-4 (Semi-Knocked Down) assembly process, logistical workflows, and the integration of a Temporary Storage Warehouse (TSW), the project demonstrated how simulation modeling can significantly enhance production planning and decision-making in automotive manufacturing.

Using AnyLogic's multi-method simulation capabilities – including agent-based, discrete-event, and system dynamics modeling – a digital twin of the factory was developed. The model accurately replicated real-world processes such as truck arrivals, part unloading, internal logistics, assembly phases, and quality control inspections [18]. Output data showed that the current setup achieves 59.59% effective build time utilization, with 219 vehicles produced during the simulation period. However, analysis also revealed potential inefficiencies and bottlenecks in forklift utilization, dock allocation, and material flow timing.

Two detailed case studies further emphasized the value of simulation for strategic planning. The first case addressed the impact of defective incoming parts, highlighting the importance of quality control and buffer stock strategies. The second explored the risks of forecast-driven production, advocating for a hybrid planning model that combines real-time data with rolling forecasts to reduce overproduction and stockouts [8].

Ultimately, the study confirms that simulation modeling is a powerful tool for optimizing complex manufacturing systems [23]. For Astana Motors, adopting recommendations such as optimizing unloading logistics, increasing forklift efficiency, and integrating real-time data – can enhance productivity, reduce costs, and improve responsiveness to market demand. The findings serve as a foundation for future digital transformation efforts in Kazakhstan's growing automotive industry.

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