FACULTY OF MECHANICAL ENGINEERING TUL

Master Thesis

The optimization of the automated logistic system of the battery assembly line.

Study programme:	N0788A270005 Innovation and Industrial Engineering
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Master Thesis Assignment Form

The optimization of the automated logistic system of the battery assembly line.

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Rules for Elaboration:

The goal of the thesis is to optimise the automated logistic system to efficiently supply electric vehicle battery manufacturing lines at Škoda Auto a.s. The main part of the thesis is to define a number of suitable automated guided vehicles to meet the manufacturing requirements mentioned lines.
The following procedure is recommended when processing the work:
1/ Introduction to the principle of automated logistic system design using AGVs
2/ Analysis of AGVs system used in Škoda Auto.
3/ Analysis of information systems aiding automated logistic systems at Component production Unite in Mladá Boleslav (PKL).
4/ The current state analysis of the logistic supply system at battery manufacturing lines.
5/ Design and simulate supplying station at given manufacturing lines to find a suitable number of necessary AGVs.
6/ Evaluation of the designed logistic system.

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[1] TOMPKINS, James A., John A. WHITE, Yavuz A. BOZER and Jose Mario Azaña TANCHOCO. *Facilities planning*. B.m.: John Wiley & Sons, 2010. ISBN 0-470-44404-5.

[2] BANGSOW, Steffen. *Manufacturing Simulation with Plant Simulation and SimTalk* [online]. Berlin, Heidelberg: Springer, 2010 [accessed. 2023-08-14]. ISBN 978-3-642-05073-2. Available at: doi:10.1007/978-3-642-05074-9

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ABSTRACT

The thesis aims to optimize the Skoda Auto Product component logistics system's automated logistics system by evaluating and estimating the required AGVs for the assembly lines. By utilizing critical concepts of industrial engineering, such as DMAIC, layout analysis, and the use of the Tecnomatix plant simulation software, the thesis documents the analytical data of the AGVs used in Skoda Auto. The real-life working of an assembly line of Skoda Auto is simulated to simulate the problem statement and robustly achieve the goal. It provides a brief understanding of Material flow and Information flow analysis in the assembly lines. This thesis contributes to the overall growth and increasing efficiency of logistics systems and helps understand the fundamental principles of automated logistics systems.

Keywords: Automated Logistics System, AGV, Plant Simulation, Optimize, Estimate, Evaluate

ABSTRAKT

Práce si klade za cíl optimalizovat automatizovaný logistický systém systému logistiky komponentů Škoda Auto pomocí vyhodnocení a odhadu požadovaných AGV pro montážní linky. Využitím klíčových konceptů průmyslového inženýrství, jako je DMAIC, analýza rozložení a použití simulačního softwaru závodu Tecnomatix. V práci jsou zdokumentována analytická data AGV používaná ve Škoda Auto. Reálná práce na montážní lince společnosti Škoda Auto je simulována tak, aby simulovala deklaraci problému a rázně dosáhla cíle. Poskytuje stručné pochopení materiálového toku a analýzy toku informací na montážních linkách. Tato práce přispívá k celkovému růstu a zvyšování efektivity logistických systémů a pomáhá pochopit základní principy automatizovaných logistických systémů.

Klíčová slova: Automatizovaný logistický systém, AGV, simulace závodu, optimalizace, odhad, vyhodnocení

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List of Abbreviations

AGV – Automated Guiding Vehicles

ASL- Assembly line

CS- Charging Station

ERP- Enterprise Resource Planning

EV- Electric Vehicles

KPI- Key Performance Indicators

LT-Loading time

MES – Manufacturing Execution Systems

MFA- Material Flow Analysis

OEE-Overall Equipment Efficiency

PB- Portion of blocking

PC- Portion of Charging

PKL- Product component Logistics

PLUT- Portion of loading/unloading time

PNPT- Portion of non-productive time

PTT-Portion of transport time

PWT- Portion of waiting time

TB- Total blockage

TCT- Total Charging time

TNPT- Total non-productive time

TST-Total Simulation time

TTT- Total Travel time

TU: Total Utilisation

UT- Unloading time

VDI- Verein Deutscher Ingenieure

WH- Warehouse

WIP- Work in Progress

WMS-Warehouse Management Systems

1 Introduction

Industries have been at the forefront of serving as a solid base for the functioning and flourishment of society. It will be appropriate to say that logistics is the spearhead of that vitality. As the world is progressing and developing at a swift rate, the demand for evolution, efficiency, and excellence has exponentially risen in every field, and it is safe to say that logistics has not escaped that ever-escalating growth and development. With the integration of better communication systems, modern new technologies, and the implementation of the good old, tested principles, automated logistic systems have been a revolution in many industries.

With that exact intent and vision of an ever-lasting growth company, Skoda Auto has implemented Automated Logistic systems in their day-to-day functionality, and they were one of the few companies to make a switch to the fully automated assembly line of EV batteries in Mlada Boleslav, Czech Republic. Skoda Auto is the leading card manufacturer in the Czech Republic and one of the top providers in Europe and Asia. Skoda Auto is responsible for producing large volumes of EV batteries in Europe and for the partnered groups. A high-volume production and manufacturing of EV batteries is done to meet this requirement. This thesis aims to optimise the automated logistic system to meet the company's future production plans. The precise goal of this thesis is to optimise the GS 3.1 and 3.2 assembly lines, Analyse the information system aiding the automated logistic system, Design and simulate the supply at station AF020, and find the suitable number of necessary AGVs for the assembly line.

The Objective of the Thesis

- Introduction to the principle of automated logistic system design using AGVs
- Analysis of AGVs system used in Škoda Auto.
- Analysis of information systems aiding automated logistic systems at the Component production Unit in Mladá Boleslav (PKL).
- The current state analysis of the logistic supply system at battery manufacturing lines.
- Design and simulate supplying stations at given manufacturing lines to find a suitable number of necessary AGVs.
- Evaluation of the designed logistic system.

2 Literature Review

In this chapter, we analyse the collection of research on automated logistic system optimisation in assembly line settings. Automation technology integration is becoming increasingly common in modern production environments due to the constant quest for productivity and efficiency. Automated logistic systems are essential for improving overall performance on manufacturing lines, cutting costs, and simplifying procedures. To give readers a thorough understanding of the significant ideas, approaches, and developments in this area, this literature review hopes to shed light on the possibilities, difficulties, and trends now being faced.

2.1 Principle of Automated Logistics Systems

An automated logistic system implements software and machinery to ensure the smooth functioning of material flow and production. Usually, AGVs (Automatic Guided vehicles) are used in Automated logistic systems with system software. [1] Fixed-path material handling systems are also referred to as continuous-flow systems. Automated guided vehicles (AGVs) fall into this group. It involves the integration of various technologies and systems to streamline and enhance logistics operations, resulting in improved efficiency, accuracy, and responsiveness. The idea behind an automated logistics system is to use automation and cutting-edge technology to optimise and simplify different parts of the logistics process, such as distribution, transportation and warehousing. This will eliminate the human error factor to an extent and streamline the logistics system.

The main principles of automated logistics systems are:

- Enhancing Efficiency: With automation included in every sector, the principal goal has been to improve the efficiency of any system. A logistics system is one of them, and it is necessary to have solid communication and material supply. A sound logistics system must be efficient.
- Accuracy: An Automated logistics system aims for high accuracy levels in order picking, fulfilment, and inventory management, which are the goals of automated logistics systems.
- Safety: Safety is paramount in automated logistics systems, especially in settings where people and machines interact directly.
- Data exchange: Automated logistics systems are connected with other enterprise systems, including production planning, enterprise resource planning, and warehouse management systems (WMS), to facilitate smooth data interchange and synchronisation throughout the supply chain.
- Sustainability: Sustainability is becoming increasingly significant in automated logistics systems, which emphasise cutting carbon emissions, waste, and energy use. These systems use environmentally friendly technologies, such as green logistics, to ensure sustainability is prevalent.

2.2 Lean Manufacturing in High-Volume Production

Lean manufacturing, Lean production, or Lean thinking, is a philosophy and methodology that aims to minimise waste, increase efficiency, and improve overall productivity in manufacturing processes. [2] Lean focuses on eliminating waste and improving flow to enhance process efficiency. While Lean principles are commonly associated with reducing waste in various production settings, they can also be applied to high-volume production environments. Lean practices are particularly well-suited to high-volume production scenarios because they focus on efficiency and continuous improvement. Lean Management can be implemented in all fields and bring out opportunities to increase performance. Lean focuses on achieving seamless flow.

2.3 Six Sigma

Six Sigma (6σ) is a set of techniques and tools for process improvement. It was introduced by American engineer Bill Smith while working at Motorola in 1986. Six Sigma is a disciplined and highly quantitative approach to improving product or process quality. [3] The original goal, implied in the Six Sigma definition, is to reduce defects to no more than 3.4 per million opportunities. DMAIC is one of the core methodologies used within the Six Sigma framework. Six Sigma mainly focuses on lowering process variance and removing faults to increase quality and customer satisfaction. Six Sigma provides a quality philosophy and is a statistical tool to monitor process performance. It aims to reduce the variability in the process and eliminate errors. Six Sigma focuses on stability and capability.

2.3.1 DMAIC

Among many different tools of quality management that may be considered as methods of quality improvement, the main one used in the Six Sigma concept, DMAIC

DMAIC is an acronym for Define-Measure-Analyze-Improve-Control. This method is based on process improvement according to the Deming cycle [4]. It aims to improve the process using systematic methodologies. The DMAIC cycle consists of five connected stages.

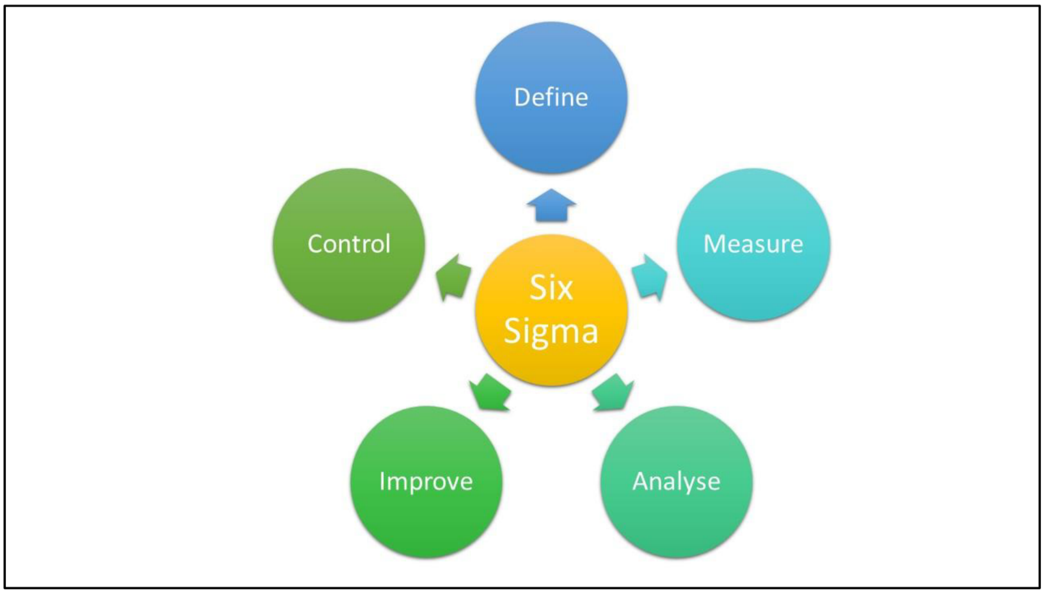

Figure 1: DMAIC [source: own]

1. DEFINE: The Primary stage involves clearly stating the problem to optimise it and defining the expected goal and its requirements. The primary purpose of this stage is to verify the actions that should be taken to solve the problems.
2. MEASURE: The Measure stage concerns gathering information about the processes that will be improved, identifying valid and reliable metrics, and documenting current performance and effectiveness. It also involves determining whether a suitable amount of data is available.
3. ANALYZE: The analysis involves analysing the measurement results and determining the causes of process imperfections and possible solutions. This stage also involves identifying critical reasons for problems and the differences between current and target performance, which helps estimate the resources required to achieve the target.
4. IMPROVE: The improvement stage aims to improve the process and implement changes that eliminate imperfections. It helps prepare the work structure, develop and test possible solutions, and select the best one. This stage aims to create and develop an action plan to improve the process's functioning.
5. CONTROL: The control stage continuously monitors the results. It also involves documenting the standardisation plan and process monitoring improvements. It confirms improved procedures. The control stage confirms that the changes implemented at the improvement stage are sufficient and continuous by verifying the quality of the improved process. It also controls the future state of the process to minimise deviation from the objectives and ensure that the correction is implemented. [4]

DMAIC allows the organisation to implement scientific methods to deliver the best value.

2.4 Layout Analysis

Layout analysis evaluates and optimises the physical arrangement of a space's amenities, workplaces, equipment, and resources. The objective is to increase productivity, streamline workflow, minimise waste, and improve efficiency.

2.4.1 Spaghetti Diagram

A Spaghetti Diagram, also called a Spaghetti Chart or a Spaghetti Model, is a visual flow of an activity or process used to identify areas for improvement. In other words, it is a visual representation that captures the basic flow of people, products, and processes. The spaghetti diagram helps understand the bottlenecks and complications in the layout by tracking and highlighting the movements.

Important traits:

1. Depicts actual paths, frequently indicated on a floor plan or layout by lines or strings.
2. Highlights the movement of individuals or objects while displaying their path.
3. Used to find locations where the flow might be improved to reduce bottlenecks and long distances traversed. [5] By using a spaghetti diagram, we are aiming to analyse the movements happening in the assembly line and layout to identify if there are any bottlenecks. Also, to include the path that will be used, the physical movement is the defining factor in the assembly line, simplified by a spaghetti diagram for analysis.

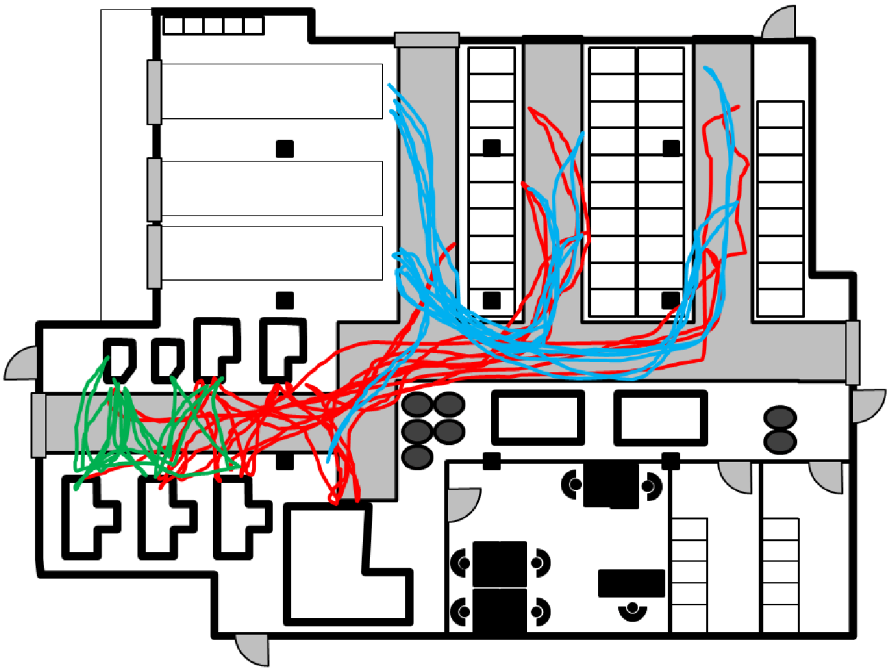

Figure 2: Spaghetti Diagram [6]

2.4.2 Principles of Process Design

The principle of process design and flow is of utmost importance in optimising the efficiency and productivity of automated logistic systems within assembly lines. This principle emphasises the creation of a streamlined, seamless workflow that minimises unnecessary delays and maximises throughput. To have better material flow, some fundamental principles are needed to be adhered which are listed down below:

1. First and foremost, the flow should adhere to the principle of being the shortest or fastest possible route from input to output, ensuring swift movement of materials and components through the production line.
2. The flow should be free from crossings, eliminating the risk of congestion and potential disruptions to the manufacturing process
3. Each step in the process should be sufficiently defined, with clear instructions and guidelines to minimise ambiguity and errors.
4. Unidirectional flow, where materials move in one direction without backtracking, maintains order and efficiency. Furthermore, the flow path should be wide enough to accommodate the size and volume of materials being transported, preventing bottlenecks and congestion.
5. The flow should be continuous, characterised by smooth transitions between process steps, minimal stoppages, and consistent movement of materials.

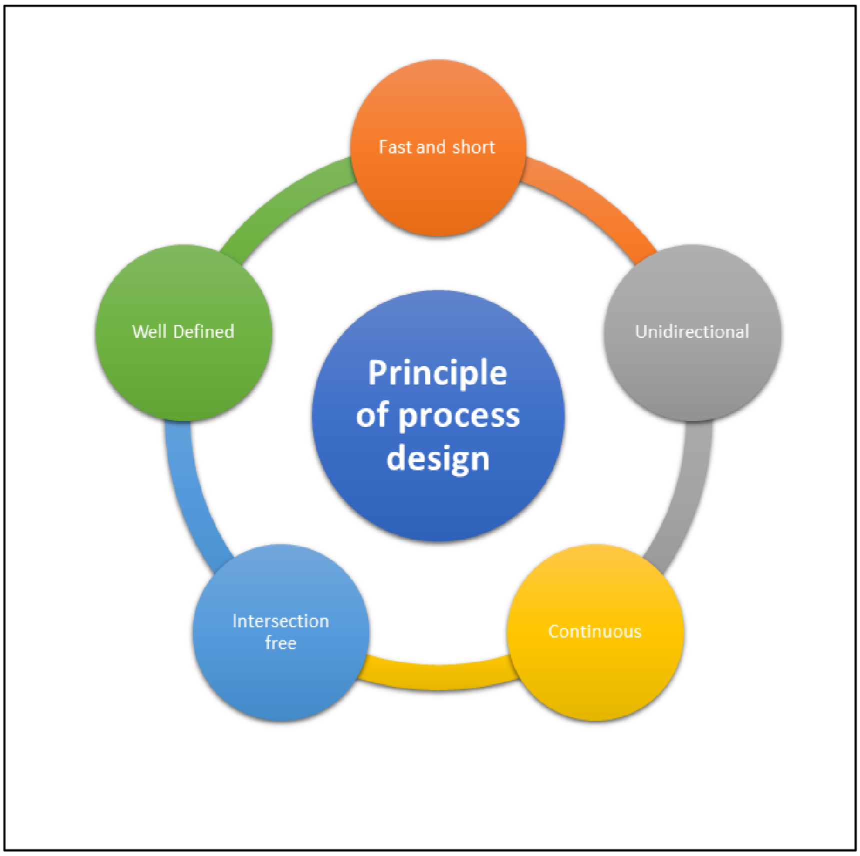

Figure 3: Principles of process design [Source: Own]

By adhering to these process design and flow principles, manufacturers can optimise their assembly line operations, enhance productivity, and achieve greater competitiveness in the market.[7]

2.4.3 Sankey Diagram

Sankey diagrams are traditionally used to visualise the flow of energy or materials in various networks and processes. They illustrate quantitative information about flows, their relationships, and their transformation.

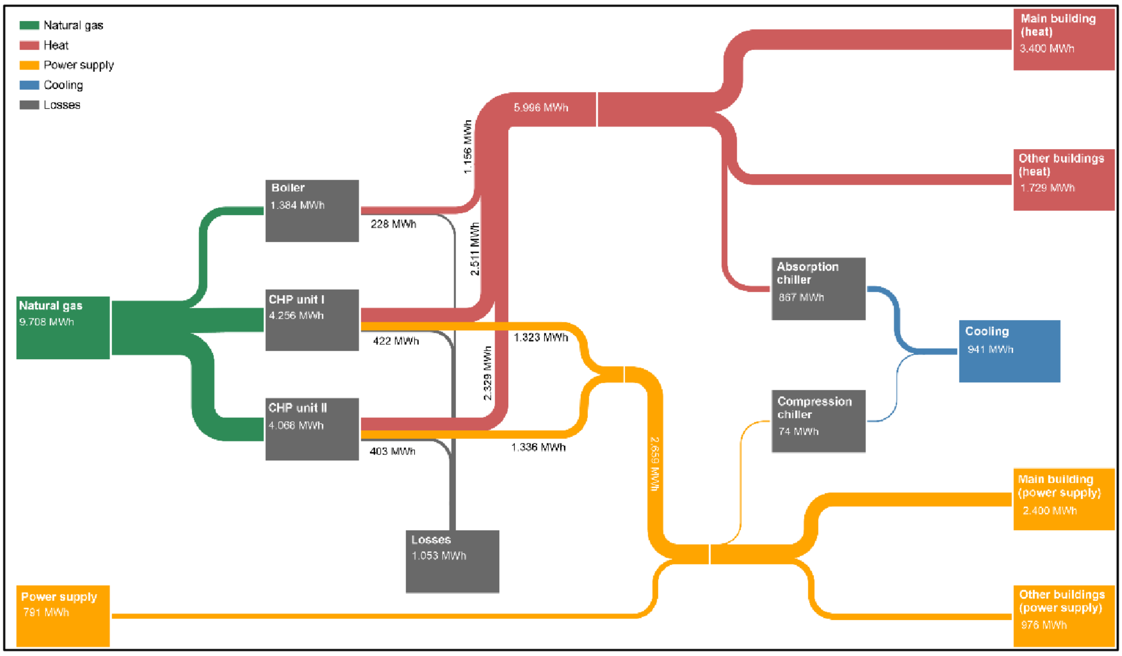

Figure 4: Sankey Diagram [8]

Sankey diagrams represent directed weighted graphs with weight functions that satisfy flow conservation: the sum of the incoming weights for each node is equal to its outgoing weights. These diagrams are often drawn by hand or generated by drawing programs. These passive illustrations are of limited use for complex flow scenarios.[9]

2.5 Simulation and Methodology

Simulation can be defined as an Imitation of a system's real-life operation. [10] It involves using real-life data to create an artificial observation and analysing the consequences of the system's workings. Simulations can help answer what-if questions and conceptualise proposed solutions. Creating a good simulation involves multiple aspects and layers. To develop an understanding of a simulation, it will be necessary to understand its types and application scenarios.

2.5.1 Type of Simulation

While performing a simulation, there will be multiple or several events that would be defined within it, and they will involve a pattern in which they are being simulated and run over time. There are different types of simulation, each suitable for a specific method, modelling needs and scenarios. The two main kinds are:

1. Continuous simulation: Continuous simulation models systems with continually changing state variables. Differential equations or other mathematical representations that explain the system's dynamics characterise these models. Dynamic systems, including physical processes like chemical reactions, fluid flow, and dynamic economic models, are studied through continuous simulation.
2. Discrete event simulation: In discrete event simulation, a system is described by a series of discrete events that happen at certain times. These events, which include the arrival of things (such as clients or orders) or the accomplishment of tasks, signify system status modifications. Systems having discrete events and interactions, such as industrial processes, queuing systems, and logistics networks, are frequently modelled using DES.

For this thesis, discrete event simulation is used as it consists of several different tasks, interactions, and updates within the processes, which is pretty helpful for such tasks and experiments.

2.5.2 Steps in Simulation Study

According to VDI guideline 3633, the following approach is recommended. :

1. Formulation of problems
2. Test of the simulation-worthiness
3. Formulation of targets
4. Data collection and data analysis
5. Modelling
6. Execute simulation runs
7. Result analysis and result interpretation
8. Documentation

To understand the guidelines in more depth, an explanation of each one is stated below:

1. Formulation of problems: This involves defining and characterising the issues or difficulties the automated system must resolve. It clarifies the goals, specifications, limitations, and requirements of all parties involved to guarantee that the automated system fulfils its intended function. This consists of stating a simulation's requirements and the simulation's outcome, which should be a written agreement.
2. Test of the simulation worthiness: Before proceeding with simulation modelling, it's crucial to determine if the simulation is the right tool for system analysis. In this stage, many criteria are assessed, including the complexity of the system, the data available, customer buy-in, and the viability of performing simulation trials.
3. Formulation of targets: Formulation is essential to achieving the goal. This may include identifying KPIs, benchmarks, and metrics for evaluating the results.
4. Data Collection and Data Analysis: Relevant data and information must be collected to develop and validate a simulation model. Historical data, system specifications, process maps, and input-output relationships can be part of this. The data must be analysed to identify patterns, trends, and dependencies that will inform the simulation modelling process.
5. Modelling: Relevant modelling techniques and software tools are used to create a simulation of the automated system. This means the system's structure,

processes, and behaviour are translated into a computational representation that accurately reflects its dynamic and interaction.

6. Execute simulation runs: Use the model to conduct simulation experiments with various scenarios, parameters, and inputs. This enables an assessment of their impact on system performance and behaviour by exploring alternative systems configurations, policies, or decision strategies.
7. Result analysis and interpretation: Analyse the simulation result to assess the system's performance against defined objectives and targets. Summarise these findings to determine the system's strengths, weaknesses, opportunities, and threats, as well as its effectiveness and potential for improvement.
8. Documentation: All aspects of the simulation study, including the model assumptions, input data, experimental design, results and conclusions, shall be documented. Clear and straightforward documentation must be provided to make the study findings more transparent, reproducible, and communicated to interested parties.

Organisations may systematically plan, implement, and evaluate simulation studies of automated systems under the guidelines set out in VDI 3633 to support decision-making, optimise system performance, and improve operational efficiency. [11]

2.6 Material Flow Analysis

Material flow analysis (MFA) systematically assesses the flows and stocks of materials within a system defined in space and time [12]. The main focus of MFA is tracking the stocks and information and their connection with associated pathways. It ensures the delivery of complete information about the flow and stocks involved in a given system.

2.6.1 Process Diagram

A process diagram visualises the processes or activities that comprise a workflow. It is often referred to as a process flowchart or process map. It displays the relationships, dependencies, and decision points across the process and how activities, actions, or information move from one stage to the next.

The process diagram can be used to depict some key components, such as:

1. Start and end point: A process diagram depicts the processes' beginning and end.
2. Type of Activity: A process diagram can classify the activities into several types, such as Operation, Manipulation, Control, delay, storage, etc., using different shapes.
3. Duration: The process diagram also specifies the activity time.

The following figure shows an example of a process diagram with the use of different shapes to specify different activities:

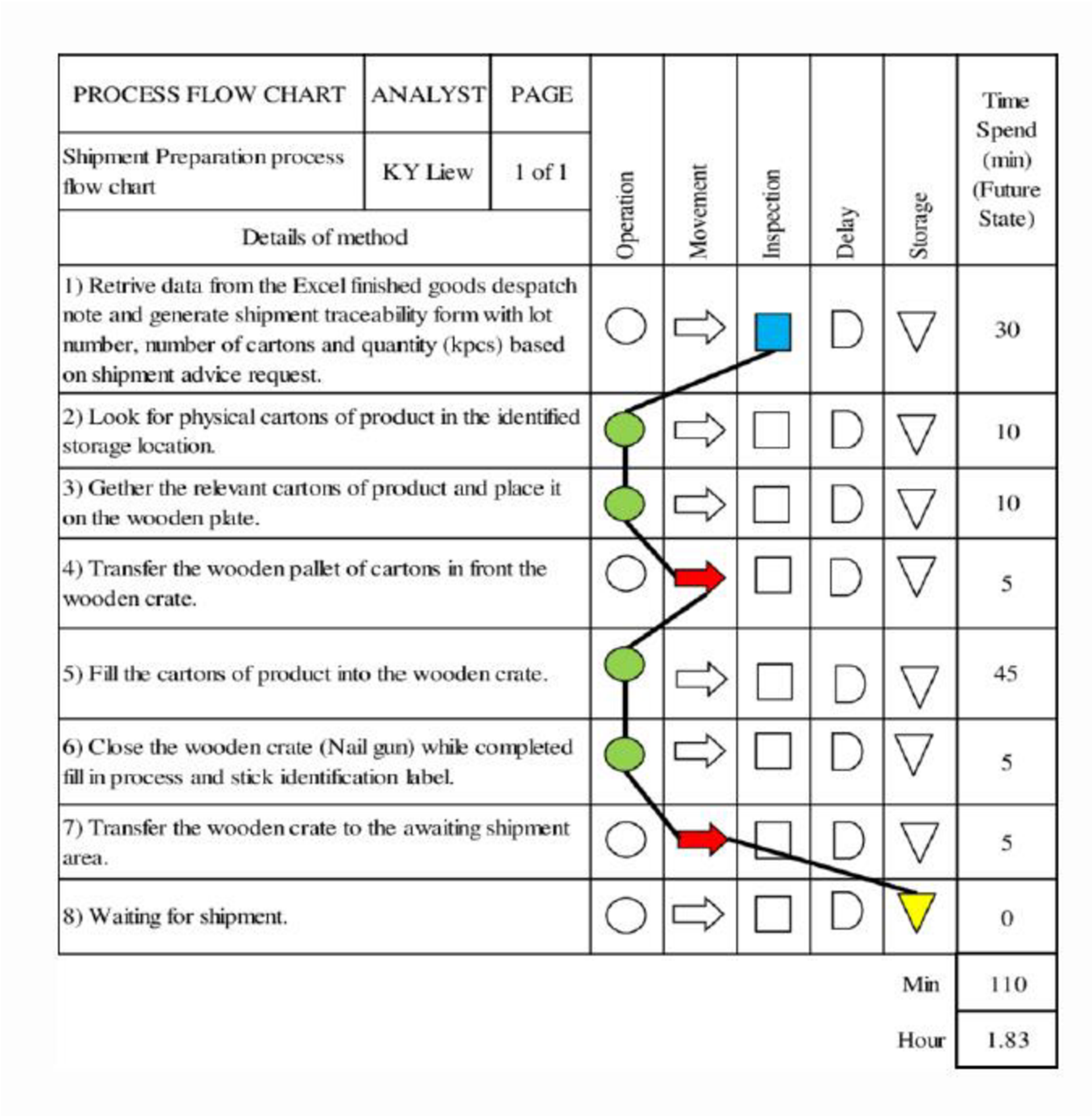

Figure 5: Process diagram [13]

From the perspective of this thesis, a process diagram would be utilised to track AGV activities and understand the supply of material in the assembly line. This would help simplify the assembly line's working algorithm, AGV behaviour, and communication within the logistics system.[13]

2.6.2 Manufacturing Execution System

A Manufacturing execution system, or MES, is a comprehensive and dynamic software system that monitors, records, documents and controls the manufacturing of goods from raw materials to final products. An MES provides the information decision-makers need to make the plant floor more efficient and optimise production by providing a functional layer between Enterprise Resource Planning ERP and the Process Control System. [14]

The Benefits of MES are listed below:

Manufacturing execution systems track considerable data, producing real-time insights that boost production efficiency and save costs. Other benefits of an MES include:

1. Improved quality control: Because quality control information is transmitted in real-time, companies with an MES can immediately halt production when issues are identified. This reduces waste, scrap, overages, and rework.

2. Increased uptime: An MES generates realistic production schedules by balancing personnel, material, and equipment resources. It integrates scheduling and maintenance to maximise product flow and asset utilisation – increasing uptime and improving overall equipment effectiveness (OEE).

3. Reduced inventory: A manufacturing execution system updates inventory records with new production, scrap, and non-conforming material so that your purchasing, shipping, and scheduling departments know exactly what material is on hand at all times. This reduces just-in-case and work-in-progress (WIP) inventory, saving money on manufacturing, transportation, storage, and inventory monitoring.

Paperless shop floor: Eliminating paperwork reduces the chance of human error. It also means that the data recorded from the shop floor is immediately available to decision-makers across all integrated systems to inform real-time decision-making.

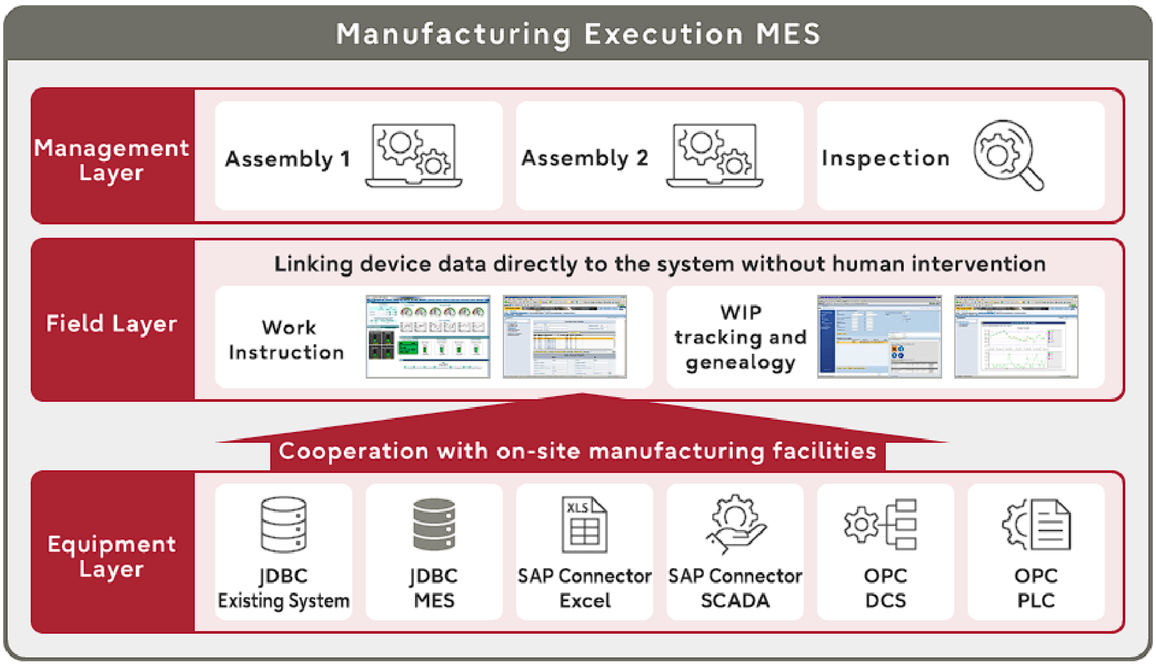

Figure 6: Schematic representation of MES [14]

Improved product tracking and genealogy: An MES follows the production cycle from beginning to end, grouping final parts or batches with the corresponding manufacturing data. This data allows for improved regulatory compliance for manufacturers that must conform to government or industry regulations [14].

2.7 Automated Guiding Vehicles

AGV is a mobile robot designed to move materials, products or other objects in an autonomous manner that does not require human intervention. AGVs can be divided into several categories based on their functionality and Shapes. Understanding them is essential as they heavily influence the assembly line's functioning. Some of the widely used AGVs are:

1. The Forklift AGV – Specially Designed: This vehicle has many uses. It's focused on containers compatible with pallets or fork trucks. Simple trips between two locations, without diverging, or even very complex taxi operations, can be straightforward logistical tasks. The vehicles can be used independently (stand-alone) or managed by an AGVS guidance control system, working in cooperation with (several) others.

Figure 7: The forklift AGV [15]

2. The Forklift AGV as Automated Serial Equipment: The serial production of vehicles from the forklift manufacturers' basic range, capable of being operated with minimal effort, is an essential use in this area. Safety equipment, guidance and navigation components are added to a serialised vehicle. The drives shall be equipped with turn angle transmitters for dead reckoning navigation. To do this, the motor's drive shaft must be extended to the outside so that an Encoder turning angle transmitter can be fitted.

Figure 8: The forklift AGV, based on serially produced equipment [10]

3. The Piggyback AGV: These vehicles may use traditional loading aids such as pallets, boxes or cages. In contrast to the two previously mentioned categories, piggyback AGVs cannot lift the loading aids directly from the floor but require a certain height, usually more than 60 cm, which has to be maintained throughout the entire plant as the standard transfer height – we will not concern ourselves here with complex mobile or stationary facilities to adjust the transfer height. [15]

Figure 9: Piggyback AGV [15]

3 Logistic System at line GS 3.1 at Skoda Auto

Skoda Auto, established in 1895, is an acclaimed automobile manufacturer headquartered in Mladá Boleslav, Czech Republic. Known for its dedication to innovation, dependability, and quality, Skoda, a Volkswagen Group affiliate since 1991, has made a name for itself as one of the world's top automotive brands.

Skoda has made significant strides in electric vehicle manufacturing in recent years, embracing sustainable mobility solutions and E-logistics to meet evolving consumer demands and regulatory requirements. Skoda has embarked on an ambitious journey towards electrification, investing in research and development to bring innovative EV models to market.

Keeping those ambitions in mind, Skoda Auto in Part Component Logistics (PKL) Mlada Boleslav manufactures 1000+ EV batteries per day and wants to increase production in the future. To meet the production demand, a new assembly line, GS 3.2, would operate along with the current one, GS 3.1. The main objective of the thesis is to estimate the requirement of AGVs for both assembly lines to meet the forecasted throughput, which will be achieved via simulation of the assembly line in the software Tecnomatix Plant Simulation. Several parameters would analyse the result. The result would ultimately comprise a balance of meeting the demand and appropriately utilising AGVs.

3.1 System Analysis

The upcoming subchapters provide an in-depth analysis of the current assembly line system involving GS 3.1. The primary focus of these chapters is to comprehend the critical components of the system that contribute towards the consistent production output. This information is crucial for comprehensively understanding the assembly line process.

3.1.1 Material Flow at Line GS 3.1

Material flow at line GS 3.1 is a periodic cyclic flow scheduled and timed according to the need for production. The flow begins from the warehouse, where the full battery module housing (Bath) pallets are stored in pallets. Each pallet comprises 7 Battery module housings supplied in the assembly line. These battery module housings are housing for the battery modules used in several EVs produced by Skoda Auto and deployed to the partnered groups. The takt time at the GS 3.1 line is around 66 seconds. i.e., each battery module housing takes around 66 seconds between two exits of the initial operation to be used by the robotic arm and is further passed on to the next operation in an assembly line.

GS 3.1 is a high-volume assembly line, and its approximate throughput goal for each day is around 1000+ batteries. The assembly line involves a continuous flow of battery module housing parts. To better understand the material flow, the following figure gives an overview of the assembly line alongside crucial elements involved in material handling and transport.

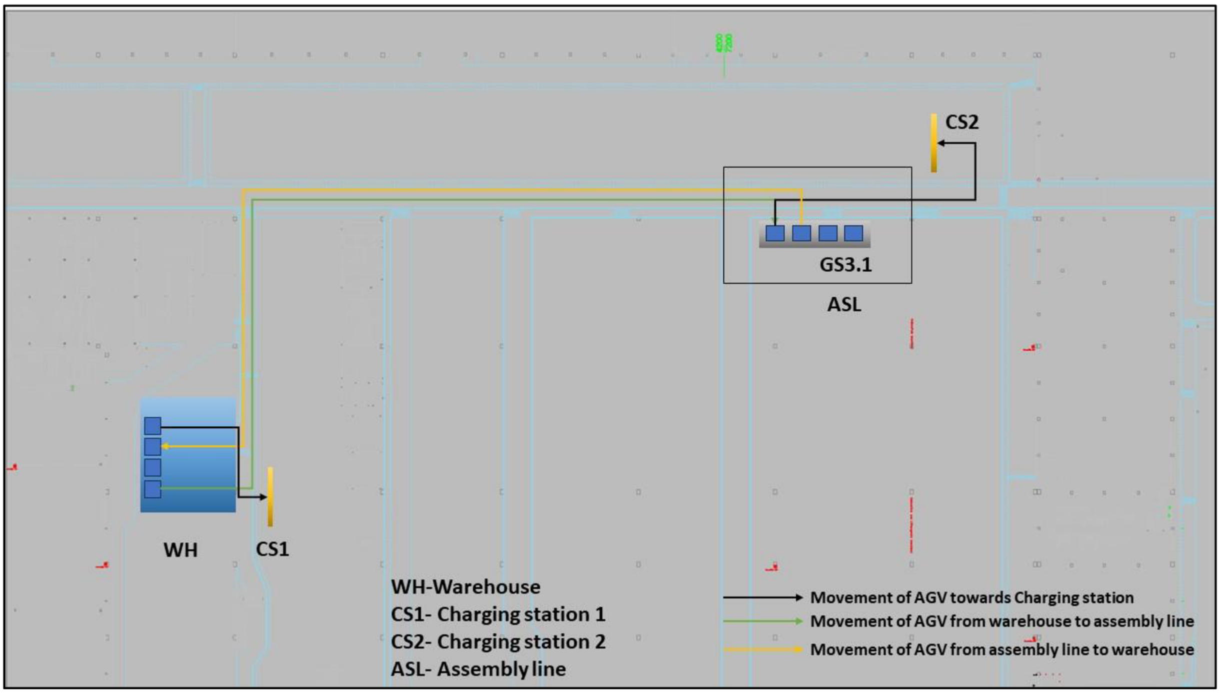

Figure 10: Overview of the Current State of assembly line [source: own]

The current state of the assembly line and warehouse is pictorially depicted in Figure 7, where only GS 3.1 exists, and the critical components of the assembly line are highlighted. The warehouse comprises 4 stations designated for the full and empty pallets and charging points for AGVs. The assembly line has designated waiting points for AGVs to avoid collision and ensure the smooth transfer of materials. GS 3.1 comprises 4 work stations where the pallets are transported and collected. The Battery module housing is consumed in these stations, and as a result, the pallets are emptied, which are later collected by the AGVs present at the charging point in the assembly line. To understand the flow of transportation, it's necessary to understand the purpose of each station. The stations in the warehouse are responsible for holding and collecting full and empty pallets, respectively. The stations in the warehouse are responsible for consuming and returning the full and empty pallets, respectively. The nearest charging points are assigned positions for AGVs when they are not transporting the pallets or are in line for the following call-off from the ERP system. The waiting points in the assembly line ensure the control of several AGVs in an assembly line during a particular production time. Unless the AGV carrying empty pallets does not cross the parallel track of waiting points, the AGV with full pallets will wait at the waiting point. The flow of transportation is shown in Figure 9 above. The figure above tries to simplify the understanding of the flow, with black arrows depicting the flow of AGV towards the charging station, green arrows representing the flow direction from the warehouse to the assembly line and yellow ones depicting the flow from the assembly line to the warehouse. The current layout described in the above pictures operates with 5 AGVs outputting 1000+ batteries per day. To understand the material flow, a process diagram can illustrate the activities the AGV and MES executed to supply the materials to station GS 3.1 from the warehouse.

Process flow Chart: Pallet delivery process flow chart (Page 1 of 1) — Details of method	Operation	Movement	Inspection	Waiting	Storage	Time spent (mins)
1. MES sends a call-off to AGV based on the requirement of the full pallet in the assembly line request.	○	⇨	■	D	▽	1
2. AGV in the warehouse moves towards the pallet holders	●	⇨	□	D	▽	2
3. AGV loads the full pallets from the warehouse.	○	➡	□	D	▽	1.5
4. AGV waits before the assembly line for AGVs from the assembly line to cross.	○	⇨	□	◗	▽	7
5. The AGV reaches the front of the Station and interacts with the optocoupler on the door to open the station.	○	⇨	■	D	▽	15
6. The Optocoupler receives the message to open the door, and AGV unloads the full pallet in the assembly station.	○	⇨	□	D	▼	3.5
						30

Table 1: Process flow chart of pallet delivery at GS 3.1 [source: own]

The process flow chart above explains the activities required to execute one pallet delivery at the assembly line GS 3.1. Several repetitions of such activities are required to deliver the pallets back and forth.

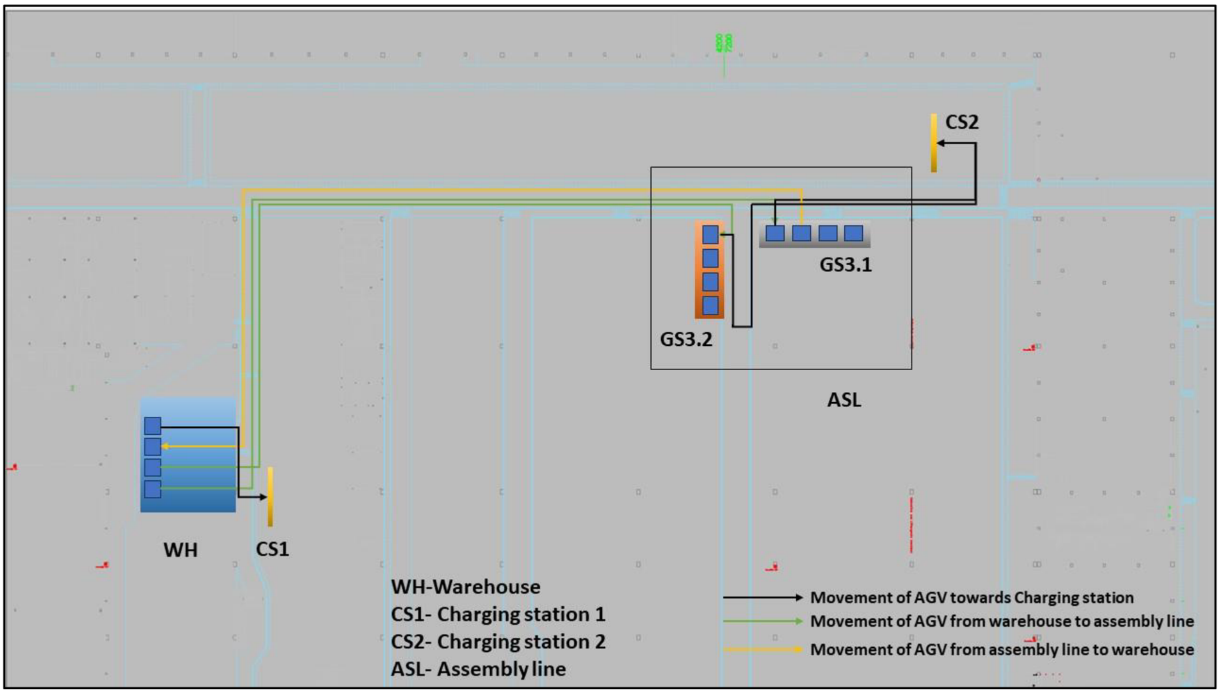

Figure 11: Overview of Material flow in the future state [source: own]

Figure 10 depicts the future state or the state simulated in the simulation. The following consists of two assembly lines running simultaneously with an output of 1500 batteries per day with tact times of 66 seconds and 132 seconds at GS 3.1 and 3.2, respectively.

3.1.2 AGV System Analysis

The AGV system used in Skoda Auto is Technologically advanced and equipped with various safety functionalities to ensure the uninterrupted flow of material and safe material handling of the battery parts. The modules and parts of EV batteries are incredibly delicate and expensive, so it is essential to have a well-equipped AGV system that handles it with care and, at the same time, ensures safe transportation in a given time. This subchapter will provide an in-depth analysis of the AGV used for the current system and an overview of other AGVs used in Skoda Auto.

1. AGV 1500FES: CEIT provides the AGV system used in Part component Logistics in Mlada Boleslav. The model number of AGV is AGV 1500FES. The AGV type is a Fork trolley with support, and the critical parameters are specified in the following table.

Basic Information about the device	
Product name	AGV 1500FES
Direction of Travel	Forward and Backward
Max Speed in the direction of travel (m/s)	1.2
Turning radius (m)	2.2 (Manipulative depending on the size of the pallet)
Navigation method	Contour Navigation
Load Capacity (kg)	1500
Total weight (equipment +cargo) in kg	2600
Lift (mm)	1500
Dimensions (L, W, H in mm)	2,968x1,598x2,555
Max Pallet size (L, W, H in mm)	1,800x2,300x1,500
Battery type	LiFePO4 (lithium-ion)
Charging type	Inductive/Automatic
Control	Manual control, touchscreen, steering handle
Safety scanners	Safety PLC, safety laser
Colour of device	Yellow-Black

Table 2: Specification of AGV 1500FES [16]

The dimensional drawings of the AGV have been depicted in the following figures.

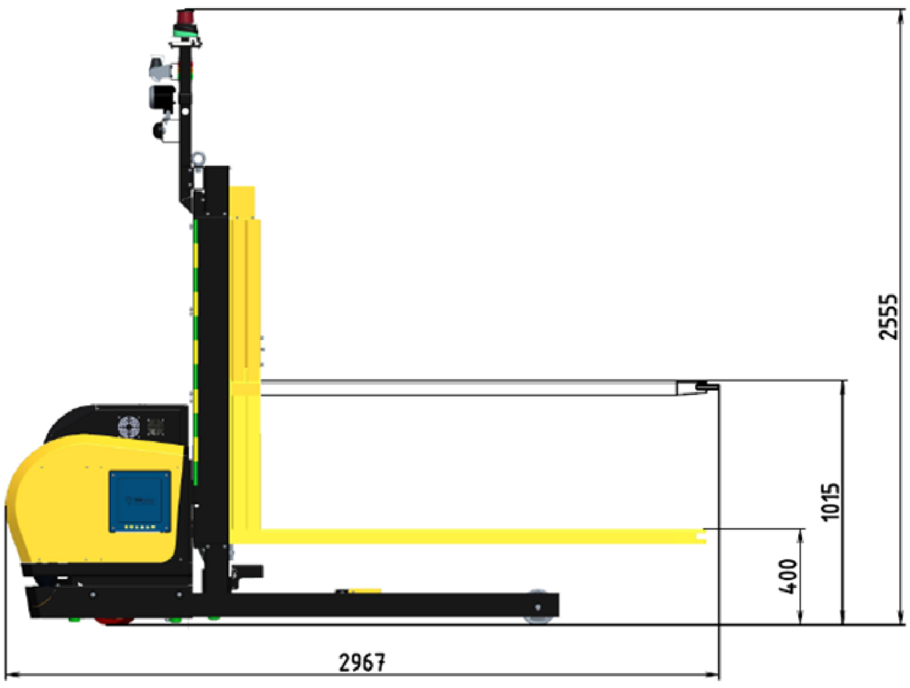

Figure 12: Side view of AGV 1500FES [16]

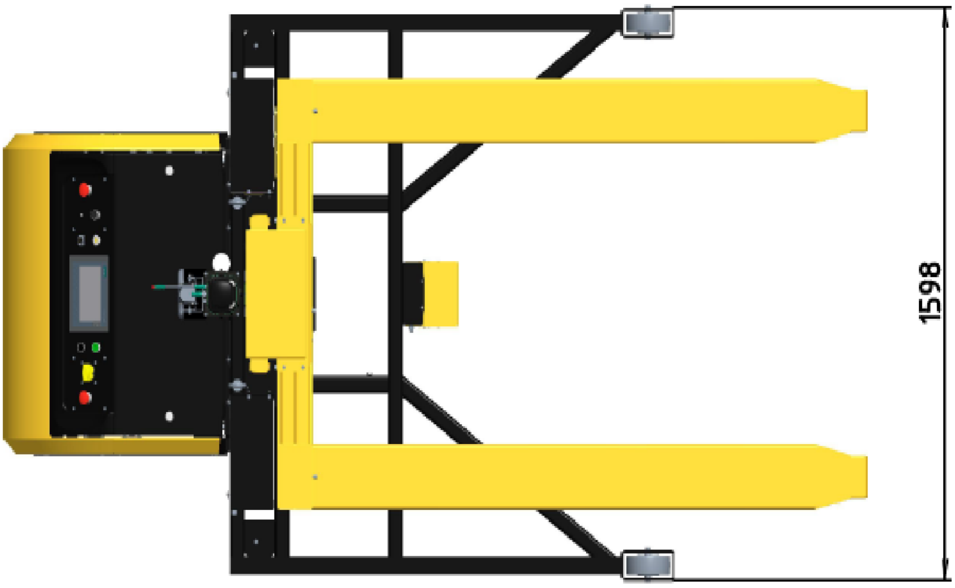

Figure 13: Top view of AGV 1500FES [16]

The total height of the equipment is 2555mm, with a lift of around 1500mm. The width of the equipment is 1598mm and comprises a length of 2967mm. The clearance between the fork and the ground is around 400mm.

Characteristics and Use of the Equipment:

The AGV 1500FES, the forklift system used in Skoda Auto, can transport loads and handle material without a driver. The device runs on a predetermined path defined by the contour navigation system. It is intended only for transporting cargo placed on the equipment's forks.

The following are the operations carried out by the AGV daily:

1) Automatic transport of the pallets from warehouse to assembly line and from assembly line to warehouse back and forth.
2) Automatic lifting and lowering of the pallets.

The average number of pallets transported in the current assembly line in one day is 140, which consists of 7 battery module housing to meet the current throughput of 1000 batteries per day.

The batteries serve as the energy supply and must be charged at the charging station while in operation. Charging occurs automatically during circuit pauses or manually by attaching the battery connector to the charger. The gadget's lifting portion is fastened by a hydraulic system housed inside. The AGV is not intended for outdoor use. The Load placement on the equipment is shown in the figure below.

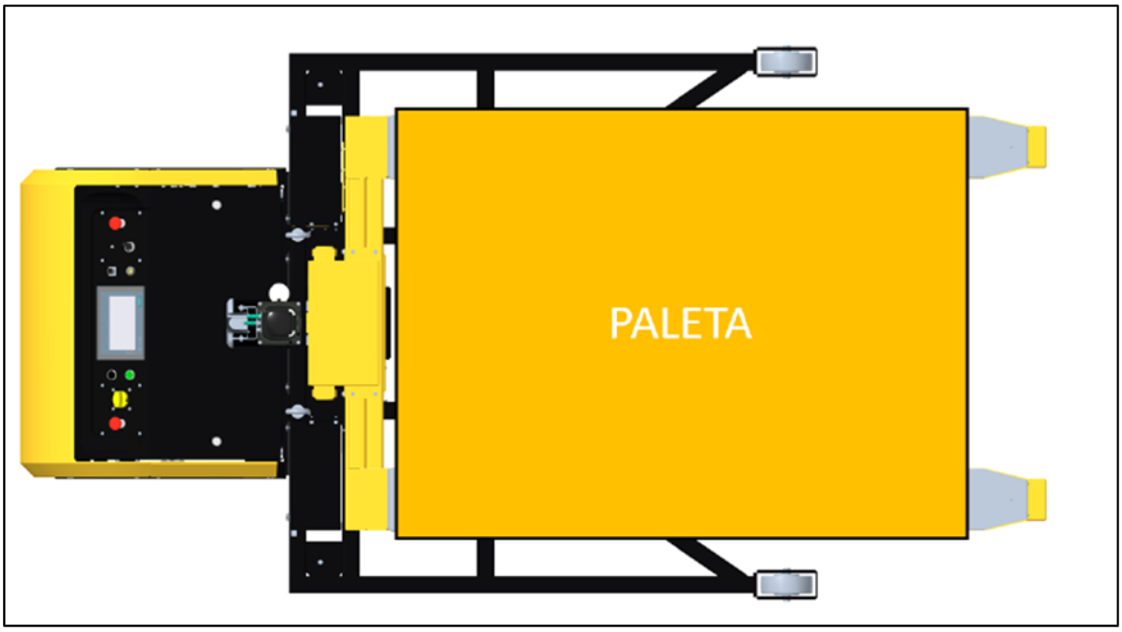

Figure 14: Position of the pallet on AGV 1500FES [16]

The pallets should be placed appropriately in the centre to avoid any case of damage or mishandling during transportation.

Charging and Charging station of AGV 1500FES:

The charging of the AGV in the Skoda Auto utilises a non-contact Inductive charging mechanism. It is an automatic charging station which can also be handled manually. The AGV and charging station have a charging plate that is responsible for charging the AGV. The following figure indicates the location of the charging plate on the AGV,

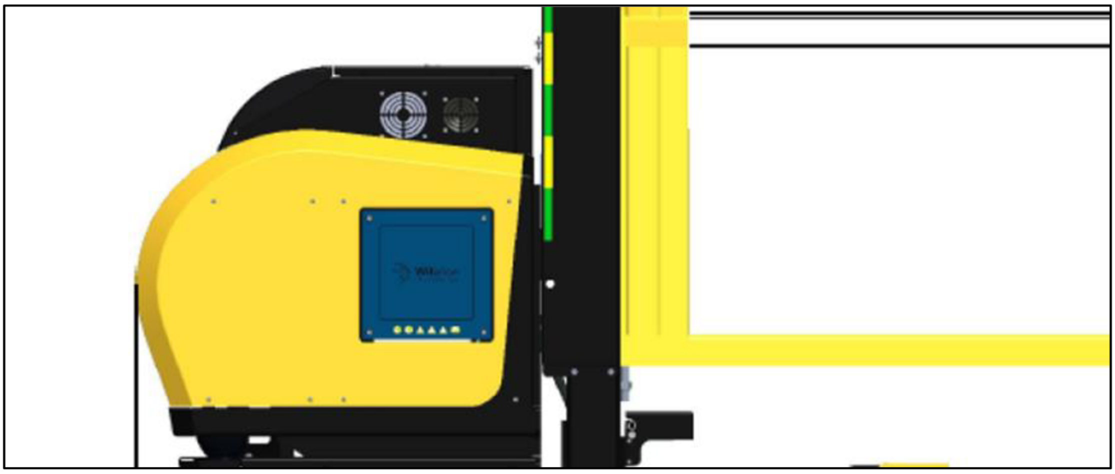

Figure 15: Charging plate on AGV 1500FES [16]

The critical component of the charging system on AGV is the mobile charging plate, which is responsible for receiving the charge from the static charging plate in the charging station and passing it on to the mobile electronic system inside the AGV.

Following is the figure of the charger at the charging station:

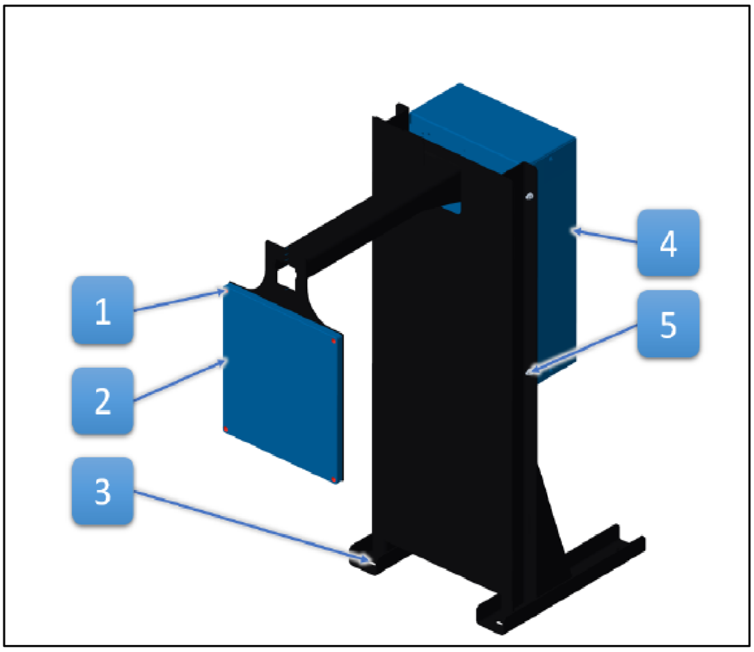

Figure 16: Charging station for AGV 1500FES [16]

1. Screws connecting the charger to console
2. Inductive charger of the static part
3. Attachment of the mount to the floor
4. Source of the static part of the charger
5. Charger source bracket

The dimensional diagrams of the charger are depicted in the following figures:

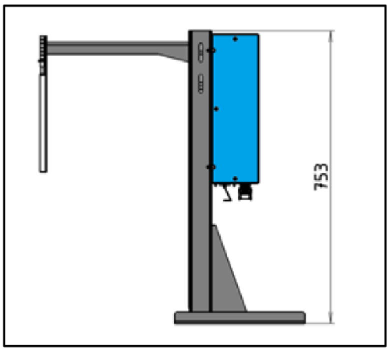

Figure 17: Front view of the charger [16]

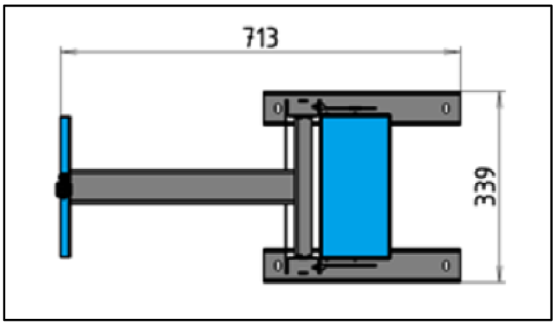

Figure 18: Figure 19 Top view of the charger [16]

2. AGV 1000LC-F:

The CEIT 1000LC-F is a certified device equipped with 5G technology. It is designed to manipulate various loads such as pallets, racks, trolleys, automotive trolleys, and customised items. It features a bi-directional drive system capable of manoeuvring forward and reverse directions and on-the-spot rotation functionality.

Basic Information about the device	
Product name	AGV 1000LC-F
Direction of Travel	Forward and Backward
Max Speed in the direction of travel (m/s)	1.2
Turning radius (m)	0.7
Navigation method	Contour Navigation
Load Capacity (kg)	1000
Weight (kg)	220
Lift height (mm)	50
Dimensions (L, W, H in mm)	1214x917x294
Battery type	LiFePO4 (lithium-ion)
Charging type	Inductive/Automatic
Control	Manual control, Touchscreen, Remote control
Safety scanners	SICK 2x 180° (optional 2D scanner)
Colour of device	Yellow-Black

Table 3: Specifications for AGV 1000LC-F [17]

Following are the figures for AGV 1000LC-F:

Figure 19: AGV 1000LC-F [17]

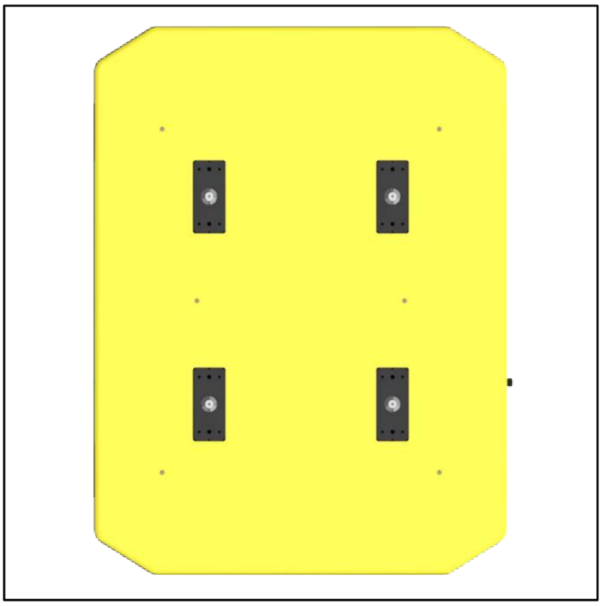

Figure 20: Top view of AGV 1000LC-F [17]

3. AGV 1500FSP:

The AGV 1500FSP is an advanced AGV used to streamline material handling and logistic operations in industrial environments. It has a compact design, heavy-duty construction, and advanced features. The critical parameters are specified in the following table.

Basic Information about the device	
Product name	AGV 1500FSP
Direction of Travel	Forward and Backward
Max Speed in the direction of travel (m/s)	2
Turning radius (m)	1.8
Navigation method	Contour Navigation
Load Capacity (kg)	1500
Max. pallet size (L, Win mm)	1,200x800
Lift height (mm)	300
Dimensions (L, W, H in mm)	2,438x900x920
Battery type	LiFePO4 (lithium-ion)
Charging type	Inductive/Automatic
Control	Manual control, touchscreen, steering handle
Safety scanners	Safety PLC, safety laser
Colour of device	Yellow-Black

Table 4: Specifications for AGV 1500FSP [18]

Following are the pictures of AGV 1500FSP:

Figure 21: AGV 1500FSP [18]

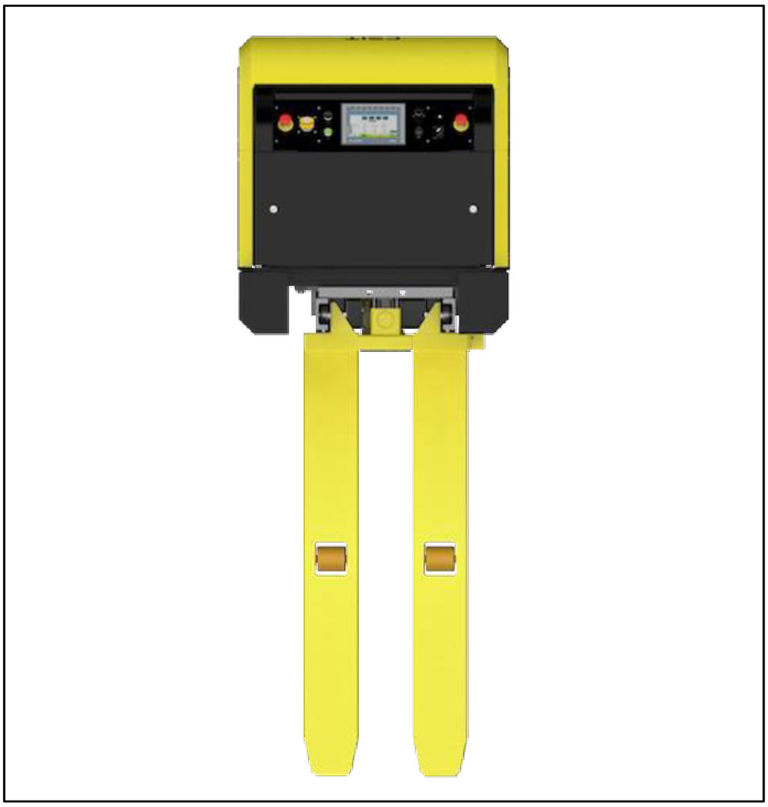

Figure 22: Top view of AGV 1500FSP [18]

4. AGV 1500FS:

The AGV 1500FS is another AGV belonging to CITE. It is an autonomous lift device with support under the forks and lifting height. The AGV is built for specific functions that operate in low-lift conditions. The comprehensive specifications of AGV 1500FS are listed below.

Basic Information about the device	
Product name	AGV 1500FS
Direction of Travel	Forward and Backward
Max Speed in the direction of travel (m/s)	2
Turning radius (m)	1.8(Depends on the size of the pallet)
Navigation method	Contour Navigation
Load Capacity (kg)	1500
Max. pallet size (L, W in mm)	1500x1400
Lift height (mm)	1500
Dimensions (L, W, H in mm)	2,386x937x2,554
Battery type	LiFePO4 (lithium-ion)
Charging type	Inductive/Automatic
Control	Manual control, touchscreen, steering handle
Safety scanners	Safety PLC, safety laser
Colour of device	Yellow-Black

Table 5: Specifications for AGV 1500FS [18]

Following are the pictures of AGV 1500FS:

Figure 23: AGV 1500FS [18]

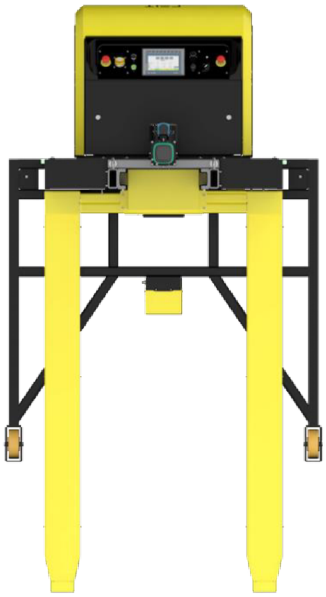

Figure 24: Top view of AGV 1500FS [18]

A comparative analysis of the specifications is necessary to obtain a complete overview of the AGV's uniquity and understand and conclude which AGV would suit transportation purposes. The following table documents and highlights some critical parameters for a Comparative analysis of the AGVs:

AGV / Parameter	1500 FES	1000 LCF	1500FSP	1500FS
Direction of Travel	Forward and Backwards	Forward and Backwards	Forward and Backwards	Forward and Backwards
Max Speed in the direction of travel (m/s)	1.2	1.2	1.8	2
Turning radius (m)	2.2	0.7	1.8	1.8
Navigation method	Contour Navigation	Contour Navigation	Contour Navigation	Contour Navigation
Dimensions (L, W, H in mm)	2,968x1,598x2,555	1214x917x294	2,438x900x920	2,386x937x2,554
Load Capacity (kg)	1500	1000	1500	1500
Max. pallet size (L, Win mm)	1,800x2,300x1,500	NA	1,200x800	1500x1400
Lift height (mm)	1500	50	300	1500

Table 6: Comparative analysis of the AGVs

The above table reflects the comparisons and similarities in specifications of the AGV used in Skoda Auto. It also helps us understand how the vehicles are so similar yet different and unique for their respective purposes. Considering that point, the battery housing part has specific dimensions that cannot be disclosed concerning the NDA. It is vital to select the appropriate AGV to ensure suitable pallets are used to hold those parts and that they are transported safely.

The AGV 1500FES has been more friendly to flexibility in terms of manipulation. Its large turning radius helps smooth transport and provides more room for adjustments. Its large dimensions are suitable for holding the specific pallets used for the battery housing parts. These crucial parameters make AGV 1500FES a perfect transport AGV for the current assembly lines.

3.1.3 Information Flow at Line GS 3.1

The information system used in Skoda Auto is a fluent communication system that generates automated call-offs based on forecasted and specified production plans for the assembly line. The flow ensures fluent communication concerning material delivery, and the appropriate course of action is in the proper sequence. The Information system used in Skoda Auto to aid the automated logistics system is pretty advanced and modern. It is responsible for the high-volume delivery of materials to the assembly line and ensuring availability in the warehouse.

Several elements make up the information system. The components will be explained below, but what makes this information system modern is the interaction between elements and how directly the information is passed further in moments. This sub-chapter will enunciate the aspects of information systems alongside their functionalities, and eventually, what part of information flow is prominently used in the simulation to replicate the real-life functionality and simulate GS 3.2 will be depicted.

The Key Elements of the Information are mentioned below:

- Assembly line
- Manufacturing Execution system
- ERP system
- AGV
- Interface
- Optocoupler
- Communication server

The information flow results from the continuous flow of information between the above elements. The back-and-forth exchange of Information ensures the availability and confirmation of empty materials and the fulfilment of the requirements. The information system has specific information sets that need to be verified before the next set of actions is executed.

The information exchanges in the system are:

- Production plan
- Movement on the assembly line
- Information about the consumption of the material
- Requirements to remove/bring the residual quantity
- Information about Loading/Unloading of empty or full pallets
- Communication with the optocoupler to open/close the gate of the station
- Availability of positions for empty and full pallets
- Material requirement
- Request of Transportation
- Request of Cancellation
- Position of Material

The schematic representation of the information flow is given in the figure below.

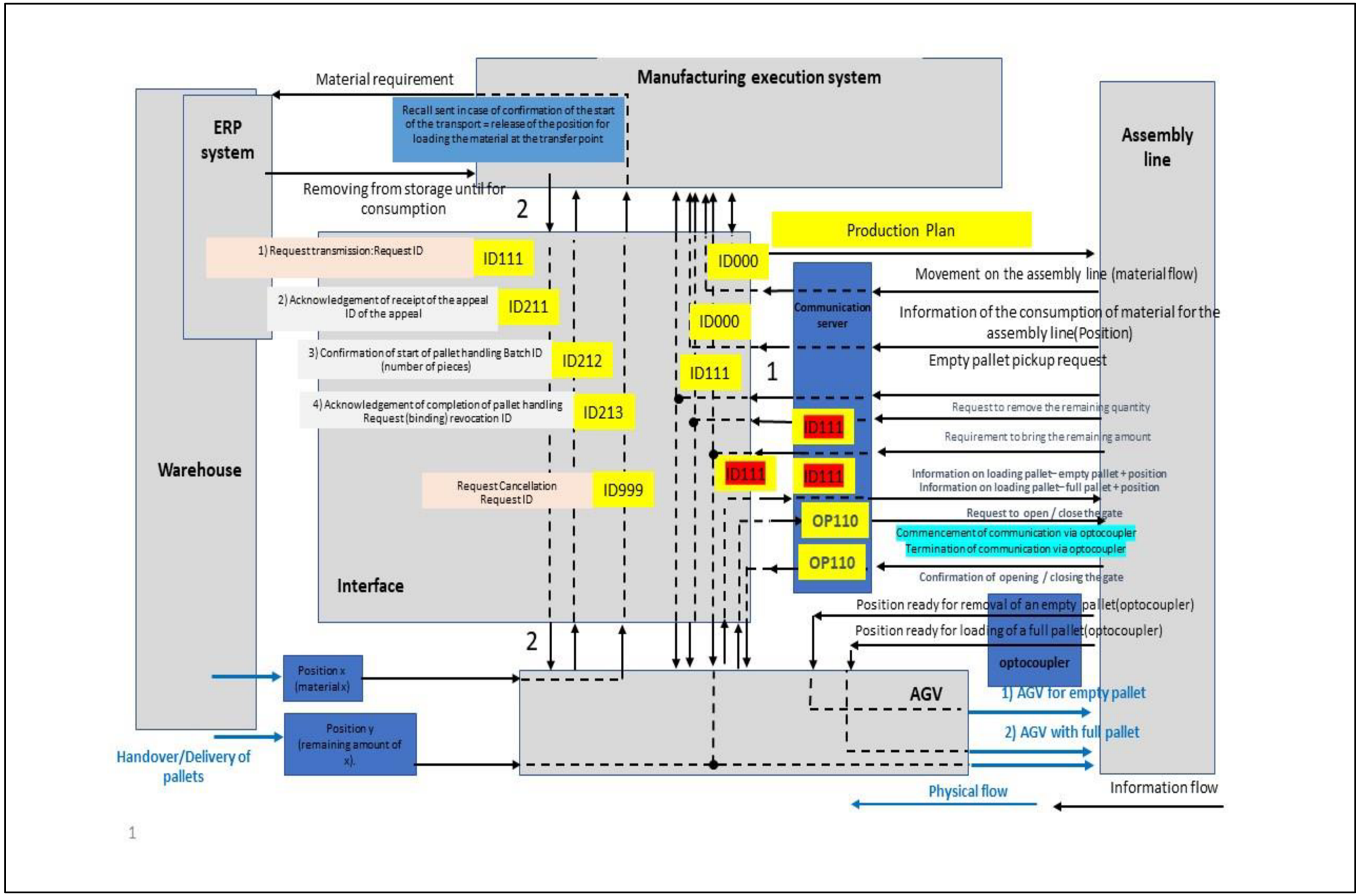

Figure 25: Information flow [source: own and Skoda Auto]

Breaking down the information system to develop a better understanding is essential.

- MES is the brain of the entire system, which is crucial in generating call-offs according to the production plan for AGVs. It initially sends the production plan to the Assembly line, which shares information about the current state of movement of material flow on the assembly line to MES through the communication server and Interface.
- The following Information updated and exchanged by the assembly line concerns the request to remove empty pallets and information about loading/unloading pallets (empty/full pallets and their position) in the assembly line. This information is shared simultaneously with the AGV and MES systems. The MES forwards the information to the warehouse, which the ERP system manages and prepares the material for the next set of transport.
- The assembly line also interacts with the optocoupler when AGV arrives with full pallets or for collecting empty pallets to open or close the gate of stations in an assembly line.
- The ERP system managing the warehouse ensures the material fulfilment requests from the assembly line and material cancellations when they occur.
- The ERP system also consistently updates the position and availability of material to AGV to ensure immediate transportation by the available AGV.

In conclusion, some information flow has been implemented in the simulation to replicate the current state. Which are enlisted below:

- The communication between AGV and assembly line via Optocoupler.
- A pre-defined production plan given to the assembly line.
- Call-offs for the AGVs for collection and supplying the material in an assembly line.
- Verification of AGV availability.
- Communication of Material position AGV in the warehouse.

4 Model Definition

This subchapter will focus on the Simulation software, the basic setup, goals, selection of KPIs, evaluation criteria, simulation model structure, essential elements, and model logic. The aim is to simplify the understanding of the Simulation model and execution of the practical aspect of the thesis.

4.1 Introduction to Tecnomatix Plant Simulation

Tecnomatix plant simulation is a powerful software developed by Siemens. It helps to simulate, visualise, and analyse complex manufacturing systems and processes. The simulation software was implemented to simulate another assembly line, GS 3.2, which runs on different takt times but simultaneously alongside GS 3.1. By simulating the assembly lines, it would provide an overview of plans that are to be implemented. The expected throughput with two assembly lines combined would be 1500+ batteries daily.

The stations, tracks, warehouse, and other essential elements of Simulation must be set up to simulate the two-assembly-line system.

4.2 KPIs Used in Plant Simulation

Key Performance Indicators (KPIs) are vital for assessing a production facility's efficiency, productivity, and overall performance in plant simulation and manufacturing operations. To ensure that necessary goals are met, the KPIs must be selected. They will help evaluate the experiment's outcomes and serve the purpose of reaching the objective goals. KPIs facilitate data-driven decision-making, enabling us to identify areas for improvement and implement targeted strategies to enhance performance during the experiment.

In the context of an experiment focused on plant simulation, the evaluation of obtained results relies heavily on selecting and analysing relevant KPIs. The KPIs used in this experiment are used in two different ways. Initially, the KPIs are used to set up the experiment, define the parameters, and so on. This ensures the experiment is as close to real-life scenarios of actual working assembly lines in Skoda Auto. Moving further, the KPIs are also used to evaluate the results of experiments, which will help us evaluate the results and be crucial in further decision-making for the thesis.

The KPIs used for setting up the plant simulation experiments are listed below with their use case specifications:

1) Takt time: The takt time of two assembly lines, GS 3.1 and 3.2, is important in setting the assembly lines. To ensure the replication of real-life scenarios of assembly lines, the two lines had different takt times. GS 3.1 had a takt time of 66 seconds, whereas GS 3.2 had a takt time of 132 seconds. As the takt times were defined, the arrival, waiting, and leaving scheduling of AGVs was done concerning the takt times of two assembly lines.
2) Throughput: The throughput is an important KPI in a high-volume assembly line. It is necessary to ensure that the assembly of battery components fulfils the customer's requirements. This KPI also significantly impacted the creation of the assembly line in the way it is defined in the experiment. The throughput at GS 3.1 is approximately 1000 batteries per day, and to achieve the new throughput goal of 1500 batteries per day, this number needed to be fulfilled in the simulation.
3) Speed of AGVs: The speed of AGVs influences the rate at which materials or products are transported within the facility. While higher AGV speeds can improve operational efficiency, they may also lead to increased energy consumption. Monitoring AGV speed as a KPI allows for optimising speed settings to balance productivity with energy efficiency and cost-effectiveness.

The KPIs used for evaluating the results of the plant simulation experiments are listed below with their use case specifications:

1) Percentage of Transport time: This KPI measures the proportion of simulation time spent transporting materials or products by AGVs. By analysing this KPI, we can assess the impact of different configurations, scheduling algorithms, or layout designs on transportation efficiency and identify opportunities for optimisation.
2) Percentage of Blocking Time: This KPI measures the time AGVs are blocked or unable to move due to obstacles, congestion, or other factors. Blocking time directly affects AGV productivity and system throughput. A high percentage of blocking time indicates inefficiencies in the layout, routing, or operation of the AGV system. This KPI can identify bottlenecks, congestion points, or areas of improvement in the plant layout and operational procedures.
3) Percentage of Waiting Time: This KPI measures when AGVs are idle or waiting for loading, unloading, or path clearance tasks. It can be used to optimise task sequencing, resource utilisation, and AGV dispatching rules to minimise waiting time and improve system efficiency.
4) Percentage of AGV Utilization: This KPI represents the Utilization of AGVs, including the timings of Transport, Loading/Unloading, Charging, and waiting. This KPI needs to be balanced, as AGVs are prone to failure if they are overused, and if utilised, they might not fulfil the production plan.

4.3 Model Structure

The simulation model consists of AGVs, warehouse, waiting points, charging stations, and assembly lines GS 3.1 and GS 3.2, respectively, with takt times of 66 and 132 seconds. The real-life case has only one assembly line, GS 3.1, and soon, Skoda Auto plans to implement the second assembly line; thus, The Simulation model is designed in a way where it is intended to simulate the supply of battery module housing to the current assembly line and future assembly line. The simulation aims to estimate the necessary AGVs for the assembly lines when functioning simultaneously.

The overview of the components of the simulation model is described below:

1) Assembly line GS 3.1: Assembly line GS 3.1 consists of 4 stations for receiving pallets. The pallets consisting of Battery module housing are consumed at this station. The consumption of one battery module housing takes around 66 seconds. The figure below shows the GS 3.1 station in plant simulation. The assembly line is set up using 4 buffer stations and a source for simulating the consumption of pallets.

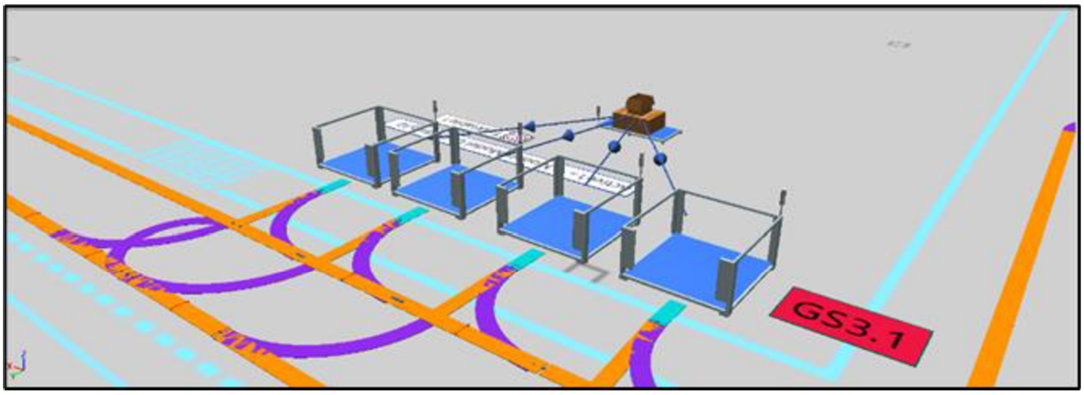

Figure 26: Assembly line GS 3.1 [source: own]

2) Assembly line GS 3.2: Assembly line GS 3.2 also consists of 4 stations for receiving pallets. The pallets consisting of Battery module housing are consumed at this station. The consumption of one battery module housing takes around 132 seconds. This assembly line does not exist in reality but is simulated in plant simulation using the parameters to estimate the requirements for this setup to run simultaneously alongside GS 3.1. Below are figures showing GS 3.2 and its arrangement with GS 3.1.

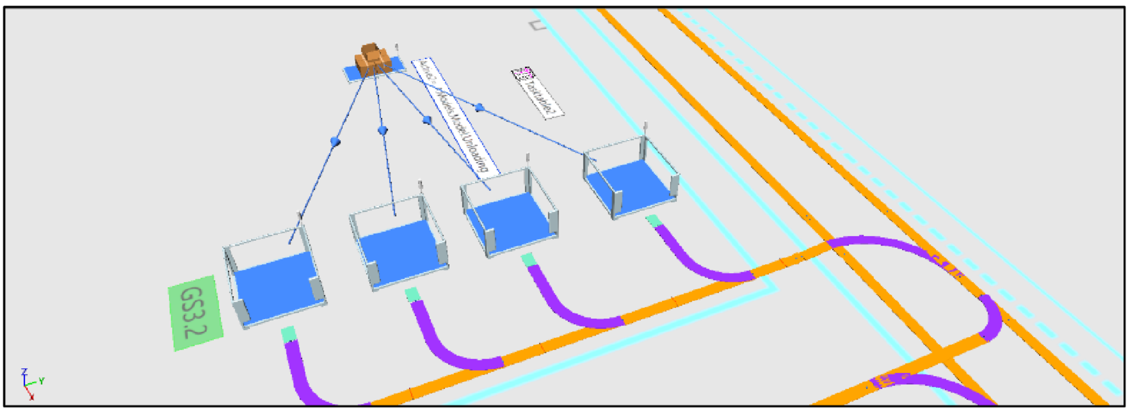

Figure 27: Assembly line GS 3.2 [source: own]

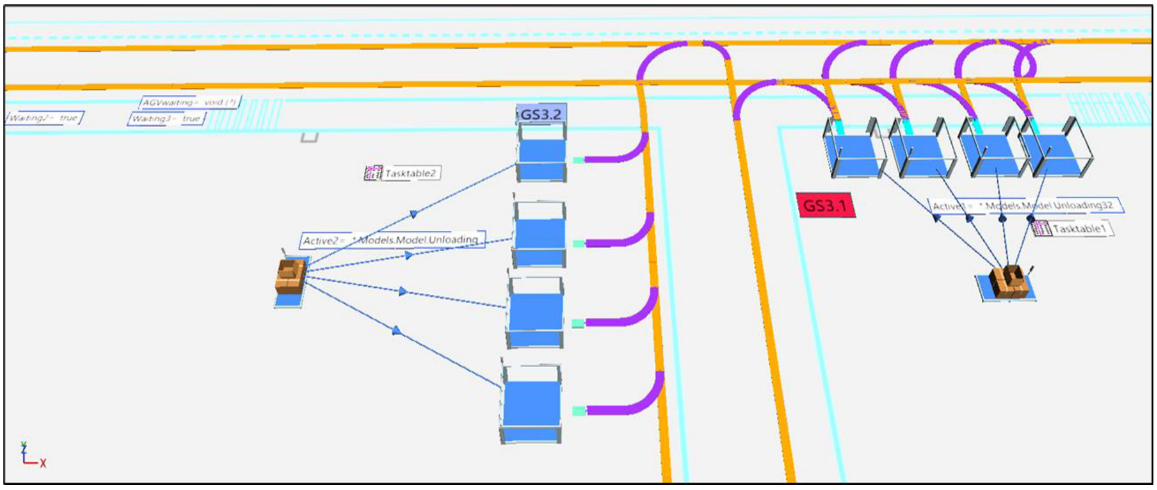

Figure 28: Arrangement of assembly line GS 3.1 and 3.2 [source: own]

3) Warehouse: The warehouse consists of 4 positions assigned for pallets, two positions for full pallets, and 2 for empty pallets. Charge stations for AGVs are also present in the warehouse. There is also a source for generating the AGVs in simulation. The warehouse is a crucial component as the material required for the assembly line is located there. The following figure shows the warehouse in simulation.

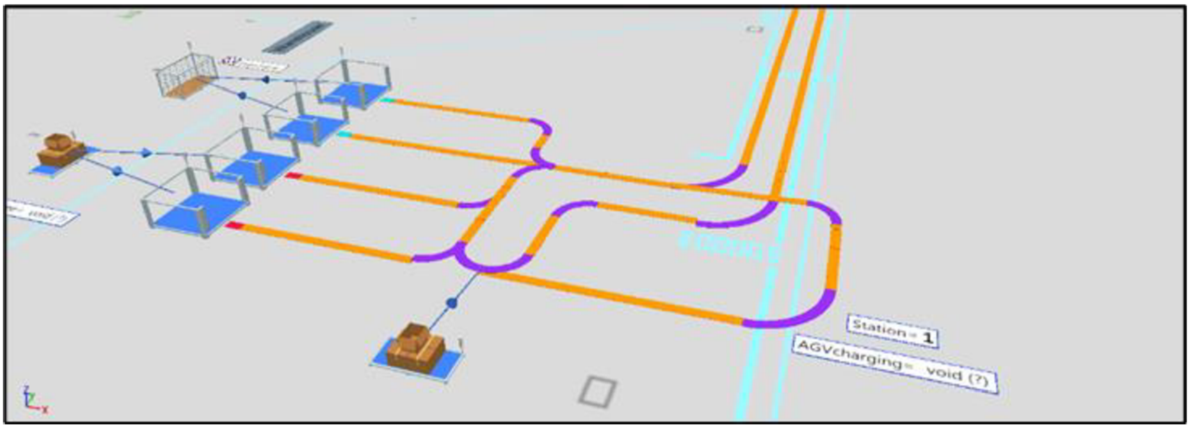

Figure 29: Warehouse [source: own]

4) Charging stations: These are the points where AGVs are charged. The simulation is designed to follow real-life movement. That is, when there is no movement or transport of AGVs, they are charging at the nearest charging station. The Charging stations are located in the warehouse and assembly line. The following figure shows the locations of the stations at the warehouse and assembly line.

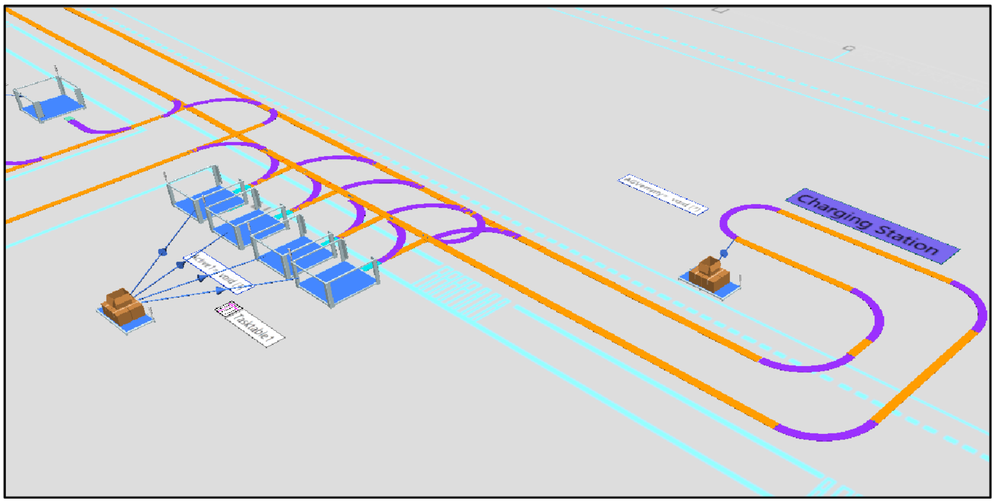

Figure 30: Charging station at assembly line [source: own]

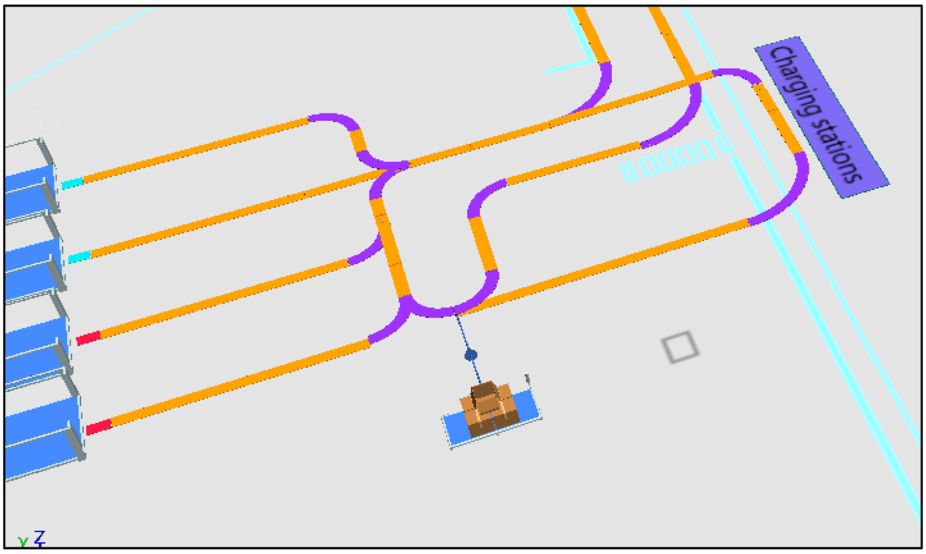

Figure 31: Charging station at warehouse [source: own]

4.3.1 Elements Used

This sub-chapter will include a comprehensive overview of the elements and attributes used to set up the simulation.

1) Source: The source creates AGVs and the battery parts. The source can produce different parts in a row or mixed order. The Source produces the necessary parts for the simulation.

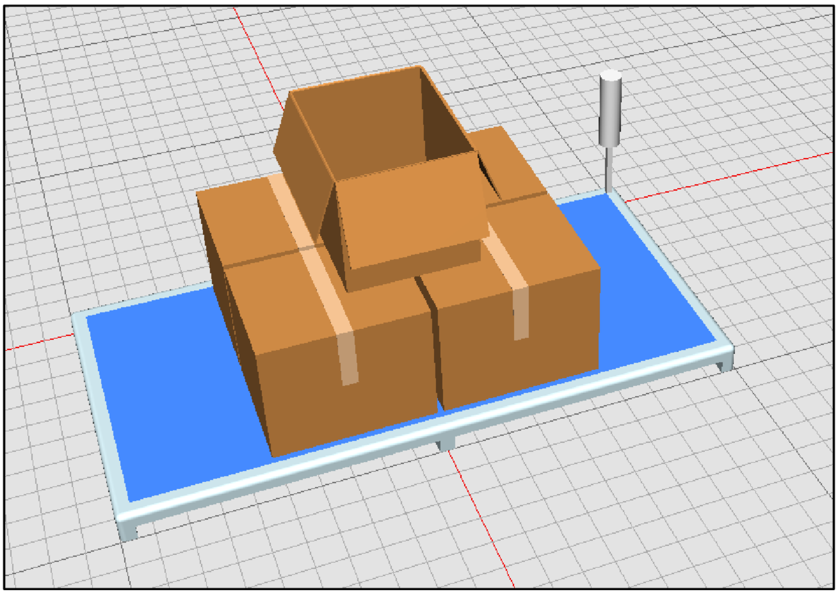

Figure 32: Source [source: own]

2) Drain: A drain is a designated location or endpoint where entities, such as products or materials, are directed to leave the simulated system. In this simulation, the drain is an exit point for empty pallets.

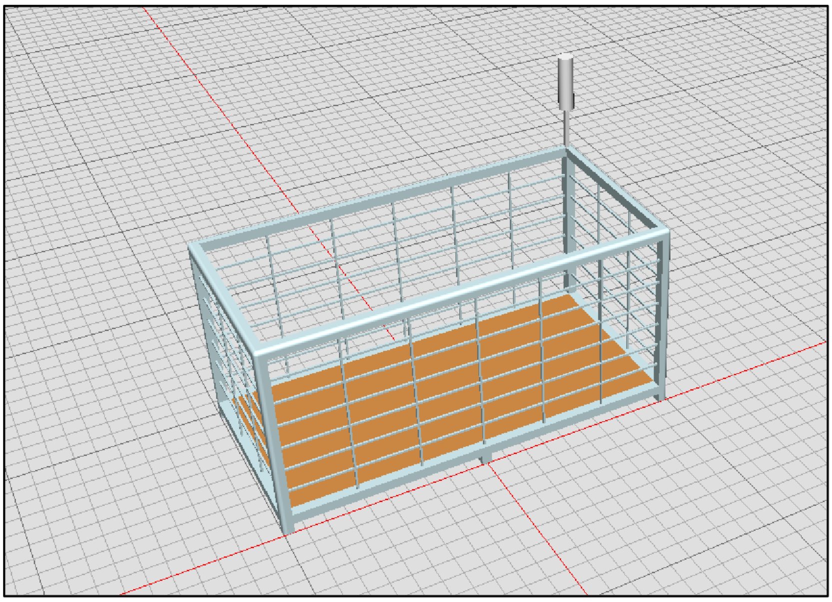

Figure 33: Drain [source: own]

3) Buffer: A buffer refers to a designated area or storage location within a manufacturing facility where materials, work-in-progress (WIP), or finished goods are temporarily stored or held to manage variability in production processes and to facilitate smooth flow of materials through the system. Buffer in this simulation simulates pallet holders in the warehouse and stations in GS 3.1 and 3.2.

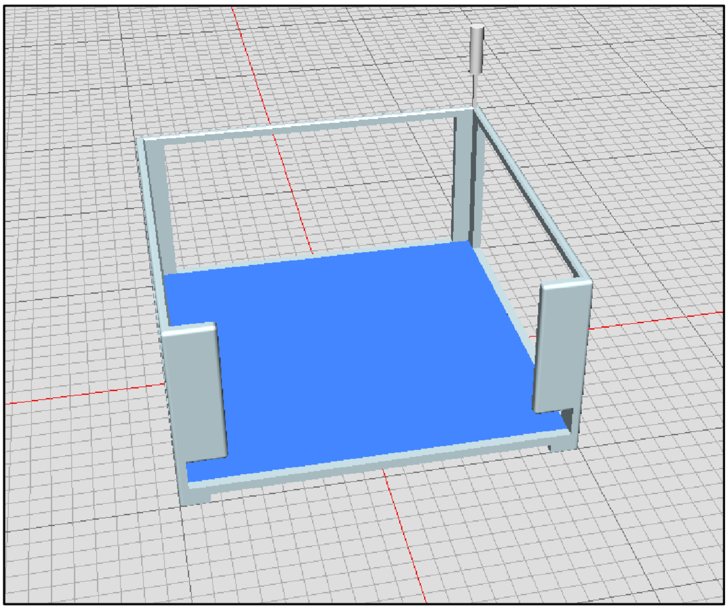

Figure 34: Buffer [source: own]

4) Mobile Unit: Mobile units can represent various types of equipment, vehicles, or resources that can transport materials, perform tasks, or interact with other components in the system. These units are typically characterised by mobility, allowing them to navigate the simulation model and execute predefined actions based on specified rules or logic. Mobile units in the current simulation represent AGVs, autonomous vehicles equipped with sensors and navigation systems that enable them to transport materials between different locations within a manufacturing facility.

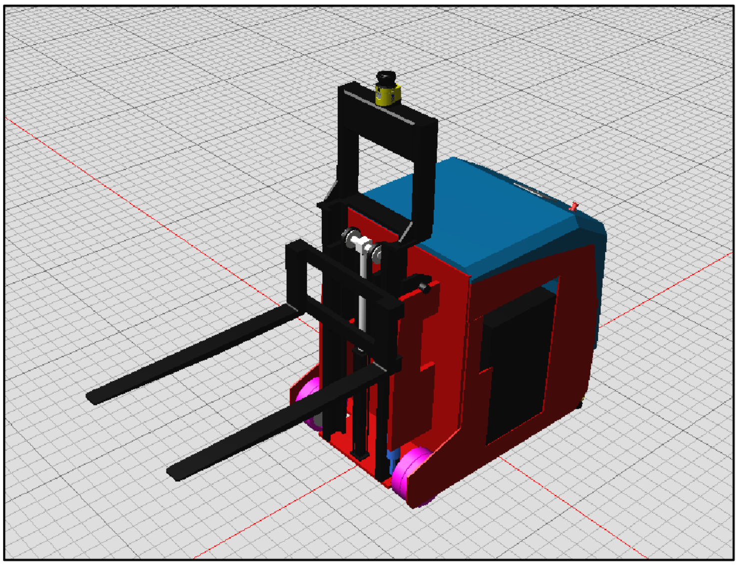

Figure 35: Automated guiding vehicle [source: own]

5) Tracks: The Tracks are the paths on which the AGVs travel and transport the material. They are well-defined paths with different colours indicating different purposes. Orange is Straight tracks, Purple is used for curves, and Red and turquoise is used for loading/unloading, respectively.

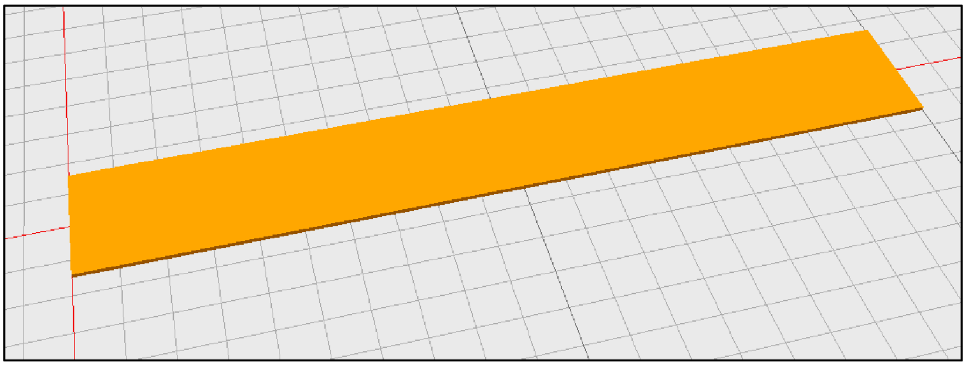

Figure 36: Tracks [Source: own]

6) Variable: A variable refers to a data item that can change in value during the execution of the simulation model. Variables represent dynamic aspects of the modelled system, such as quantities, states, or conditions. They are manipulated by the simulation logic to simulate the system's behaviour over time.

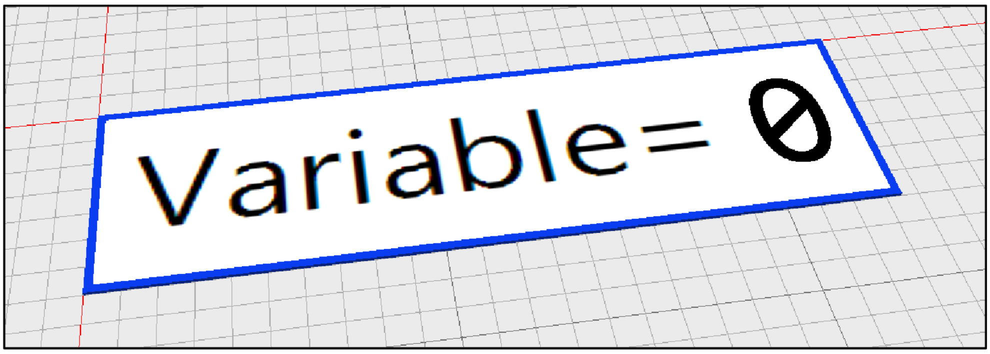

Figure 37: Variable [source: own]

7) Data table: A Data table is a structured data collection organised in rows and columns within the simulation model. Data tables are commonly used to store and manage various types of information, such as input parameters, model settings, experimental results, and statistical data.

	object 0	time 10	time 11	time 12	time 13	time 14
string	.UserObjects.Transporter:1	loading time	unloading time	Total blockage	Total travel time	Total non productive time
1	.UserObjects.Transporter:1	7:48:00.0000	7:47:00.0000	38:23.5203	2:21:52:20.0829	10:00:00.0000
2	.UserObjects.Transporter:2	7:47:00.0000	7:47:00.0000	38:09.5695	2:21:48:02.9955	10:00:00.0000
3	.UserObjects.Transporter:3	7:47:00.0000	7:47:00.0000	41:44.9160	2:21:49:20.5295	10:00:00.0000
4	.UserObjects.Transporter:4	7:48:00.0000	7:47:00.0000	38:23.5203	2:21:52:01.9006	10:00:00.0000
5	.UserObjects.Transporter:5	7:47:00.0000	7:46:00.0000	41:28.7757	2:21:40:49.3098	10:00:00.0000
6	.UserObjects.Transporter:6	7:47:00.0000	7:47:00.0000	41:24.0764	2:21:46:12.8579	10:00:00.0000

Figure 38: data table in simulation [source: own]

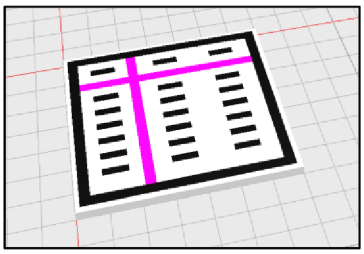

Figure 39: data table icon [source: own]

8) Method: A Method refers to a predefined procedure or instructions for performing a specific task or operation within the simulation model. Methods encapsulate reusable logic or functionality that can be invoked by other components in the model to achieve desired outcomes. This simulation method has been used several times for different purposes, such as crossroad management, charging stations, and recording the data of AGV movements.

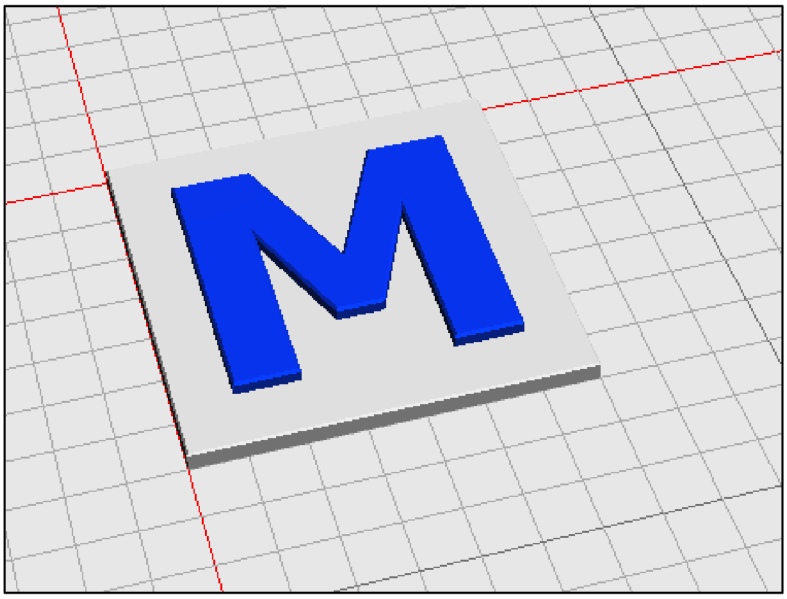

Figure 40: Method [source: own]

4.3.2 Model Logic

The simulation focuses primarily on optimising the battery line's automated logistics system. It is a discrete event simulation where systems' behaviour evolves through discrete events. The main entities involved in the simulation are AGVs, assembly lines, and stations in the warehouse.

The pallets enter the simulation through a source in the warehouse and the assembly line, which is transported using the AGVs. As no simulation starts from the absolute beginning to simulate the scenario where the assembly line is already running, the source in the assembly also generates pallets, which simulate their utilisation in the assembly station. The simulation has no warm-up time; the pallets in stations are pre-generated. When the pallets in the assembly line are utilised, a call-off is made to pick them up and transport them back to the warehouse. This is a simulation of returning empty pallets from the assembly line to the warehouse when the assembly line has an empty station. Are AGVs ready at the waiting point to supply the full pallets to the assembly line? After supplying the full pallets, AGVs return to the nearest charging point or the charging point in the warehouse, depending on the availability of the charging station. This cyclic flow is characterised by timely call-offs created by the production plan.

The AGVs operate in a way that replicates the real-life crossroads and waiting patterns scenario. For instance, when the AGVs return from the assembly line with empty pallets, the AGVs with full pallets will stay at the waiting point unless the AGVs from the assembly line pass them on a parallel track. This creates a systematic and safe travel of AGVs, eliminating any collision risk between them.

Understanding how the AGV's movements and actions have been controlled is crucial to developing a broader perspective of the logic behind the model. The simulation explanation will be divided into movements, call-offs, loading/unloading, and waiting codes. This will help us simplify the understanding of the workings and controls of simulation.

1) Loading/Unloading code:

```
if @.load = true // - it needs to unload unloading
    @.cont.move(?.assignedstation) //attribute - assigned station
    @.load := false
    AGVStats["Unloading time",@]:=agvStats["Unloading time",@]+60
    @.destination := Straight32
else ?.assignedstation.cont.move(@) //loading
    @.load := true
    AGVStats["Loading time",@]:=agvStats["Loading time",@]+60
    @.destination := Straight2
end
@.backwards := true
@.stopped := false
AGVStats["Travel time start",@] := EventController.abssimtime // Starting time of the transport (records the start time)
```

Figure 41: Loading/unloading code [source: own]

The above code ensures that the few key details are verified and executed. The key details are:

- Conditional statement
- AGV movement
- Updating Load status
- Updating AGV statistics
- Destination

- if @.load = true.

  In Tecnomatix Plant Simulation, this conditional statement checks whether the AGV is currently loaded with a pallet. If the AGV is loaded (@.load = true), it indicates that the pallet needs to be unloaded at its assigned destination. Here, @ represents the AGV.

- @.cont.move(?assignedstation) and @.load:= false

  If the AGV needs to unload, this line moves the carried container (@.cont) to the station referenced by the ?.assignedstation attribute. This attribute likely points to the designated unloading station. After unloading, the @.load attribute is false, indicating the AGV is now empty. If loading is successful, the @.load attribute is true, indicating the AGV is now carrying a load.

- @.destination:= Straight32.

  This line sets the AGV's destination. The specific destination depends on the loading/unloading state. If unloaded (@.load = false), the destination is Straight32.

Overall, this code defines the behaviour of an AGV that alternates between loading and unloading tasks at designated stations. It also tracks loading/unloading times and travel start times for further analysis in the simulation model.

2) Code responsible for the control of the sequence of action on Assembly line GS 3.1:

```
waituntil Active1 = void
Active1 := ?
wait 462
Active1 := void
Tasktable1[1,Tasktable1.ydim+1] := ?.Assignedtrack
@._3D.materialdiffusecolor := 10592673 // 16711680

//empty pallet
waituntil AGVempty /= void
AGVempty.destination := ?.Assignedtrack // empty pallet
AGVempty.batcharging := false
AGVempty.stopped := false // It will start the vehicle
AGVStats["Travel time start",AGVempty] := EventController.abssimtime // Starting time of the transport (records the start time)
AGVempty.move // Command to just start the movement

//full pallet
waituntil ?.empty = true // when station is empty we will wait 60 seconds to not call next AGV at empty pallet
wait 60
waituntil AGVwaiting /= void
AGVwaiting.destination := ?.Assignedtrack // full new pallet
AGVwaiting.stopped := false
AGVStats["Travel time start",AGVempty] := EventController.abssimtime // Starting time of the transport (records the start time)
AGVwaiting.move
AGVwaiting := void
Waiting3 := true // True means empty
AGVincoming := AGVincoming-1
```

Figure 42: Code used in GS 3.1 [source: own]

The code of GS 3.1 involves different functions within the simulation. To understand the code, the further explanation is divided into a few steps:

1. Initialisation of Active stations:

   - waituntil Active1 = void

     This line waits until the condition "Active1" becomes void. "Active1" is a variable or condition that controls the activation status of some process or activity.

   - Active1 := ?

     After the condition becomes void, the value of "Active1" is set to "?" which is typically used as a null value.

   - wait 462

     This line introduces a delay of 462 seconds.

   - Active1 := void

     After the delay, the value of "Active1" is set back to void, possibly indicating the completion of a task or process.

2. Sending Empty AGV:

- Tasktable1[1,Tasktable1.ydim+1] := ?.Assignedtrack

  This line assigns the value of the variable "Assignedtrack" to a specific cell in "Tasktable1", for tracking purposes or to update task-related data.

- @._3D.materialdiffusecolor := 10592673

  This line changes the diffuse colour of a 3D object in the simulation environment to the specified RGB colour value.

- waituntil AGVempty /= void

  This line waits until the condition "AGVempty" is not equal to void, indicating that an AGV is not empty.

- AGVempty.destination := ?.Assignedtrack

  Sets the destination of the AGV to the value of "Assignedtrack", specifying the location where the AGV needs to deliver the pallet.

- AGVempty.batcharging := false

  This indicates that the AGV is not currently undergoing battery charging.

- AGVempty.stopped := false

  Starts the AGV movement by setting the "stopped" attribute to false.

- AGVStats["Travel time start",AGVempty] := EventController.abssimtime

  Records the start time of the transport operation for statistical analysis.

- AGVempty.move

  Initiates the movement of the AGV to deliver the pallet to its destination.

3. Sending the full AGV:

- waituntil ?.empty = true

  This line waits until the station becomes empty, likely indicating that the AGV has completed its delivery and the station is ready to receive another pallet.

- wait 60

  Introduces a delay of 60 seconds before proceeding to the next step.

- AGVwaiting.destination := ?.Assignedtrack

  Sets the destination of the waiting AGV to the value of "Assignedtrack" to pick up a new pallet.

- AGVwaiting.stopped := false

  Initiates the movement of the waiting AGV by setting the "stopped" attribute to false.

- AGVStats["Travel time start",AGVempty] := EventController.abssimtime

  Records the start time of the transport operation for statistical analysis.

- AGVwaiting.move

  Initiates the movement of the waiting AGV to pick up the new pallet.

- AGVwaiting := void

  Resets the value of AGVwaiting to void after the AGV completes its task.

- Waiting3 := true

  Indicates that the station is empty and waiting for the next pallet to arrive.

- AGVincoming := AGVincoming-1

  Decrements the variable AGVincoming, representing the count of incoming AGVs.

The above code generally simulates the functioning of AGVs in a production setting, including pallet delivery, movement control, and work scheduling. During the simulation, it tracks relevant statistics and models the behaviour of AGVs using a variety of conditions, delays, and attribute assignments. The code controls the sequence of actions in GS 3.2 and uses similar coding attributes, but the waiting parameters differ according to the assembly line requirements.

4.4 Simulation Experiment

This sub-chapter will provide a comprehensive overview and description of the simulation experiment. It will also explain the parameters used for the experiment and discuss different case scenarios. The statistics obtained from the experiments will be illustrated and compared to estimate the required number of AGVs for the two assembly lines.

4.4.1 Experiment Overview

The experiment follows an iterative approach, as the primary goal of the simulation is to narrow down an optimal number of AGVs necessary for supplying the materials at both assembly lines. The simulation starts from 4 AGV systems to 7 AGV systems, so the results of all 4 systems would be compared to get a conclusive reasoning. The expected outcome would be a combination of the fulfilment of throughput and optimal utilisation of all the AGVs. This is crucial to ensure that AGVs are not over-utilized or under-utilized to affect production and their lifespan. The following picture depicts the simulation of the pallet collection from the warehouse.

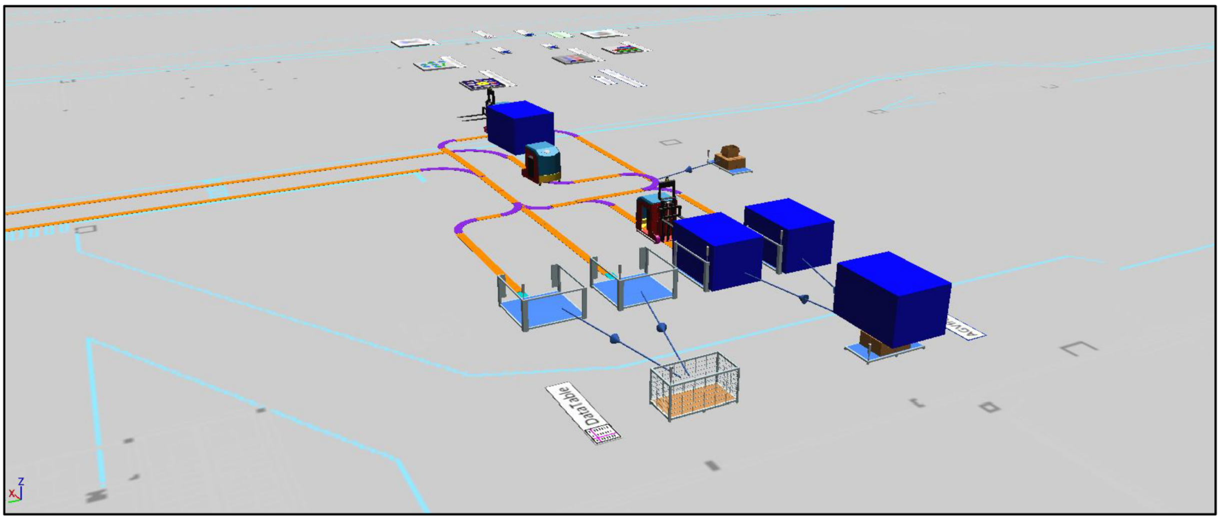

Figure 43: Simulation of the material supply from warehouse [source: own]

After collecting the full pallets from the warehouse, the AGVs follow a pattern of operation where they always wait near the assembly line for the AGVs from the assembly line to leave so they can enter the assembly line. The following picture depicts the simulation of waiting for the AGVs near the assembly line.

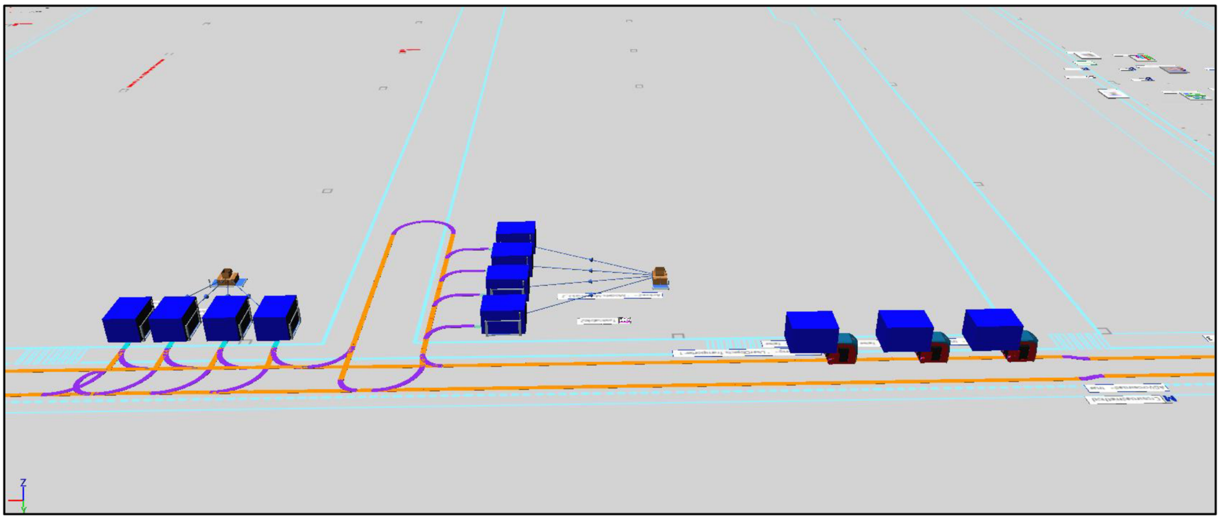

Figure 44: Simulation of waiting of AGVs near assembly line [source: own]

When the pallets in the assembly line become empty, when every battery housing module is used, the ERP calls the nearest AGVs, in this case, the AGVs from the assembly line, to collect the empty pallets and deliver them to the warehouse. The following figure shows the collection of empty pallets from the assembly line.

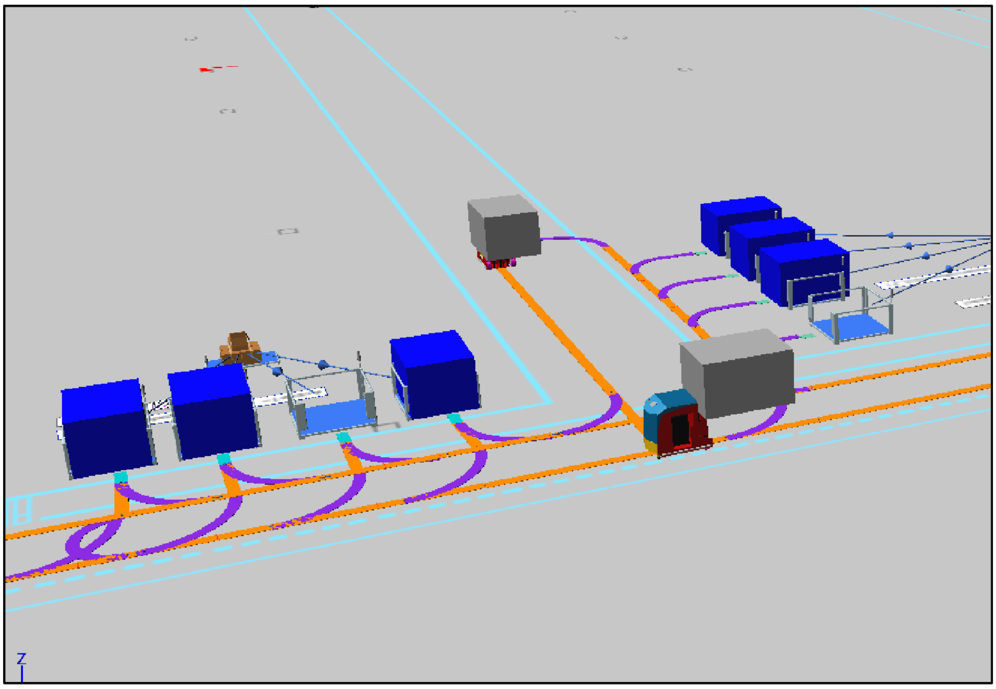

Figure 45: Simulation of delivery of empty pallets from the assembly line to the warehouse [source: own]

This is followed by the delivery of the full pallets from the waiting point in the assembly line to the assembly stations in GS 3.1 and GS 3.2, respectively. The following picture depicts the simulation of supplying the full pallets in the assembly stations.

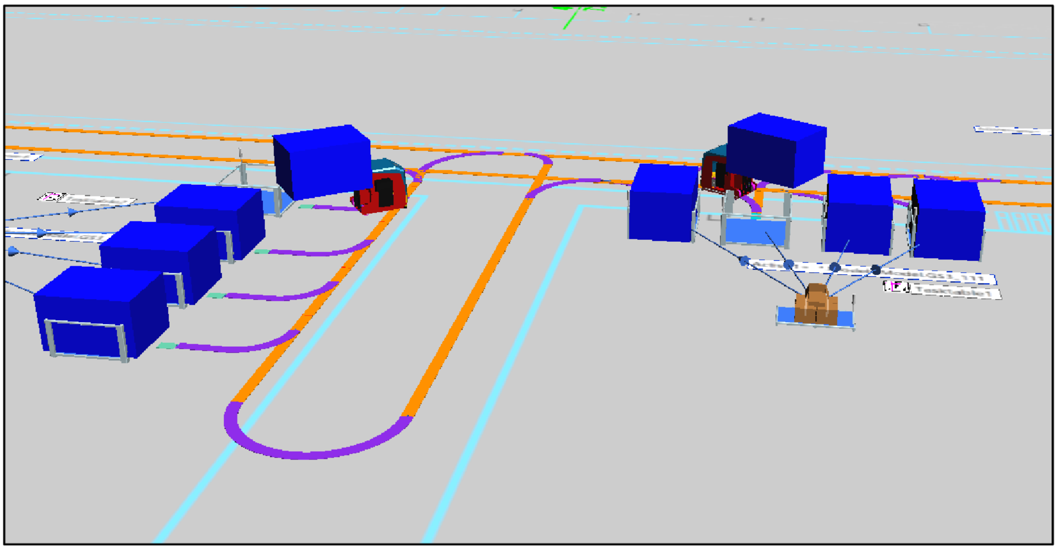

Figure 46: Simulation of delivery of full pallets to the assembly line [source: own]

The AGVs carrying the empty pallets from the assembly line to the warehouse deliver them at the respective empty stations, shown below.

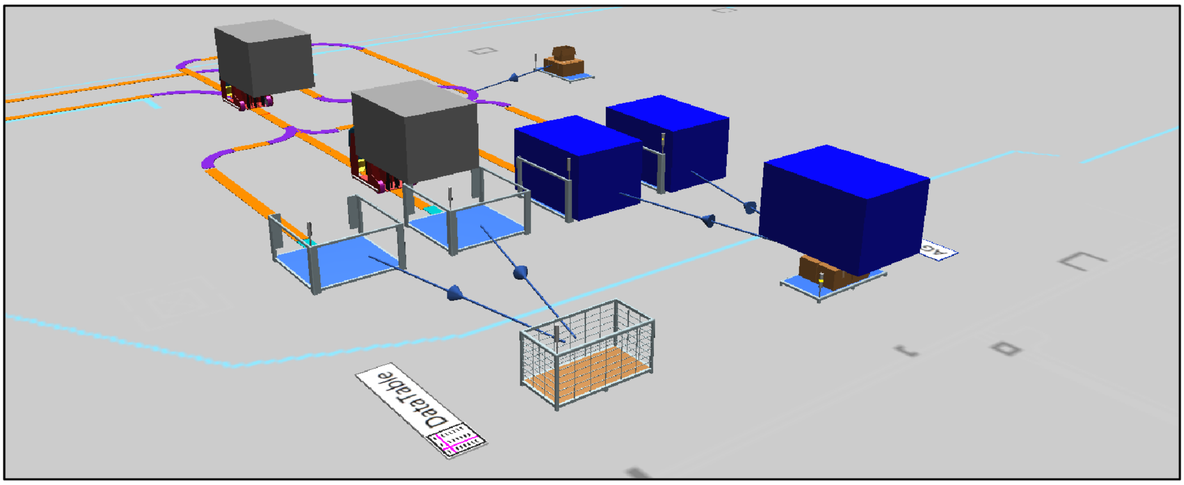

Figure 47: Simulation of delivery of empty pallets to the warehouse [source: own]

The flow analysis of the layout is done using the built Sankey diagram tool available in the Tecnomatix plant simulation. The tool highlights the tracks with the most incoming and outgoing AGVs. This helps us highlight the safety and precautionary zones to prevent any disruption in the supply of the materials to the assembly line.

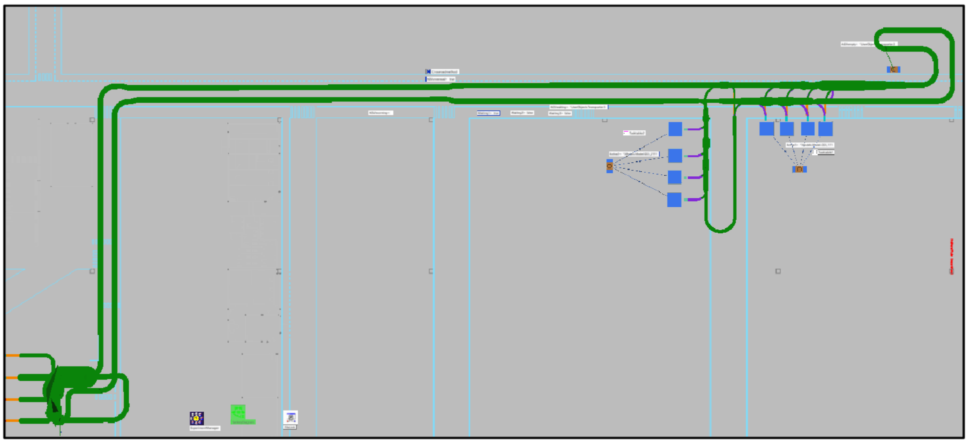

Figure 48: Sankey diagram of the simulation [source: own]

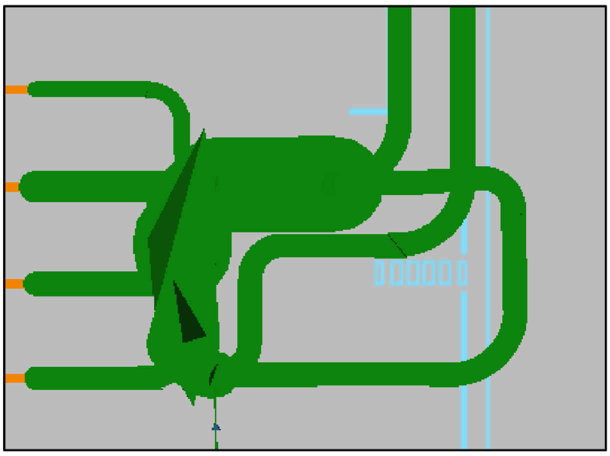

Figure 49: Sankey diagram Closeup (Warehouse) [source: own]

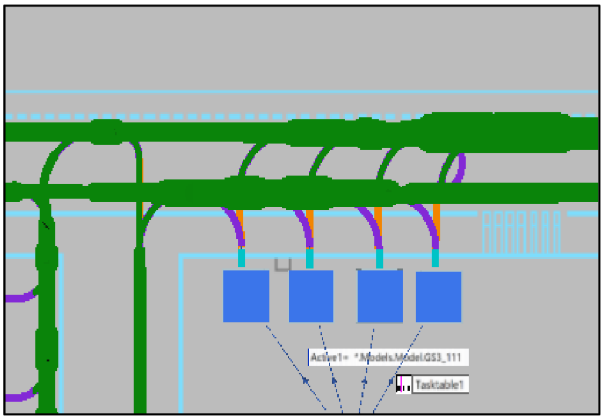

Figure 50: Sankey diagram Closeup (Assembly line) [source: own]

The above figure highlights the routes most utilised or the volume in which they are employed. The warehouse and assembly line GS 3.1 are the most used tracks, as there is a constant supply of empty pallets towards the warehouse and a collection of full pallets. The tact time of the GS 3.1 is relatively lower than 3.2, producing more batteries than GS 3.2. This is one of the critical reasons for the Sankey diagram of 3.1 being thicker compared to 3.2.

4.4.2 Methodology

The Simulation for each AGV system 4 to 7 runs for 5 days. This production time is to replicate the real-life case scenario of production. The total number of shifts is 15, with 40-minute breaks each shift. This ensures keeping track of non-productive time as well, which will be counted for calculating the total utilisation of the AGV. The Simulation experiment is also structured to simulate the crossroad, which will account for the interrupted movement of the AGV in the statistics. The main criteria for the evaluation of AGVs would be their utilisation. The data analysis will also highlight a Sankey diagram, which will help us understand the AGVs' movement in two assembly line systems. The estimated throughput in the simulation is 1070 pallets, i.e., 7500 batteries per week.

The estimation would depend on the results following factors

1. Portion of Transport time
2. Portion of Loading/Unloading time
3. Portion of Charging time
4. Portion of Blocking time
5. Portion of non-productive time
6. Portion of the waiting time

All of the parameters above are calculated in percentages. Due to the plant simulation limits in data delivery, the values are directly provided in percentage instead of time. Still, the method to calculate the percentage of time is given below.

1. Portion of Transport time:

   The following equation can calculate the Portion of Transport time:

   $$PTT = \frac{TTT}{TST} * 100 \qquad (1)$$

   Where,
   PTT: Portion of transport time
   TTT: Total Travel time
   TST: Total Simulation time

2. Portion of Loading/Unloading time:

   The following equation gives the portion of Loading/unloading time:

   $$PLUT = \frac{LT + UT}{TST} * 100 \qquad (2)$$

   Where,
   PLUT: Portion of loading/unloading time
   LT: Loading time
   UT: Unloading time
   TST: Total Simulation time

3. Portion of Charging time:

The following formula calculates the Portion of Charging time:

$$PC = \frac{TCT}{TST} * 100 \tag{3}$$

Where,
PC: Portion of Charging
TCT: Total Charging time
TST: Total Simulation time

4. Portion of Blocking time:

The portion of Blocking time is calculated by:

$$PB = \frac{TB}{TST} * 100 \tag{4}$$

Where,
PB: Portion of blocking
TB: Total blockage
TST: Total Simulation time

5. Portion of non-productive time:

The portion of non-productive time is calculated by:

$$PNPT = \frac{TNPT}{TST} * 100 \tag{5}$$

Where,
PNPT: Portion of non-productive time
TNPT: Total non-productive time
TST: Total simulation time

6. Portion of Waiting time:

The portion of waiting time is calculated by:

$$PWT = 100 - PLUT - PTT - PC - PBT - PNPT \tag{6}$$

Where,
PWT: Portion of waiting time

7. Total Utilisation:

The Total Utilisation is calculated by:

$$TU = PTT + PLUT + PC + PWT \tag{7}$$

Where,
TU: Total Utilisation

4.4.3 Additional Considerations

The Simulation is designed to simulate an ideal case scenario of material delivery where the assembly line utilises the total material within pallets. There can be a few rare cases of the battery module housing not being utilised in one pallet due to a changeover or reinsertion of a new battery type in an assembly line or a previous defective module from the Quality control department which has been fixed and ready to be inputted in an assembly line or an accidental stoppage of assembly line due to breakdown of automated machinery in assembly line etc. Several external factors, which are man-made or accidental, cannot be accounted for and simulated in the simulation.

To overcome the obstacles of the incomplete utilisation of the material in pallets, the residual pallets could be brought back to the warehouse, and 4 dedicated spaces for the residual pallets could be allotted. After every 4 call-offs, residual pallets can be periodically recalled. This will ensure no non-utilised battery housing modules and that the flow of material delivery is uninterrupted.

The visualisation of the dedicated spaced for residual pallets is depicted in the figure below:

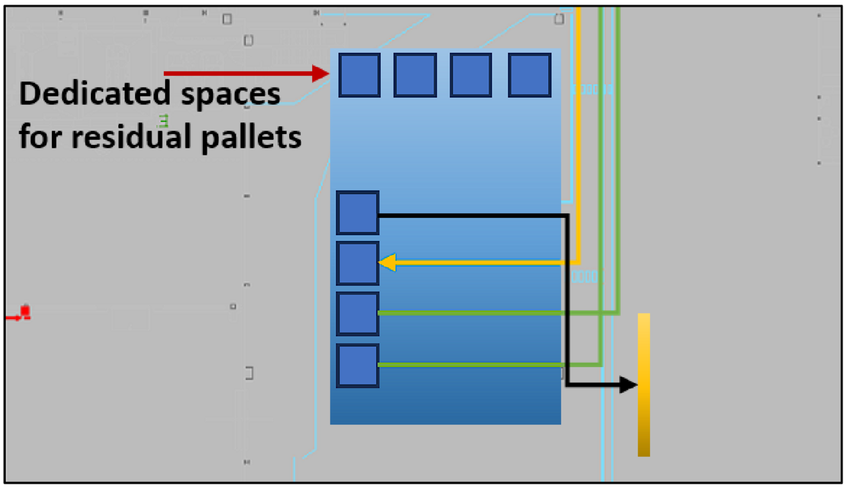

Figure 51: Warehouse with spaces for residual pallets [source: own]

The 4 extra spots are allocated in the warehouse to synchronise with 4 call-offs for the residual pallets. The duration between each call-off for residual pallets is set to 4, so if residual pallets occur frequently by chance, they will always be picked up by the frequent call-off. This will ensure the accumulation of residual pallets is not more than 4. This solution aims to counter any non-ideal behaviour occurring at the assembly lines and ensure the supply of materials to the assembly line without any delays.

4.4.4 Simulation Parameters

The following sub-chapter will highlight the data collected from the simulation, and a comparative analysis will provide an insightful overview and reasoning for the conclusions. Before analysing the results, it's necessary to understand the parameters used to rate them and their significance, showcased in the graphs below.

- Portion of Transport: This parameter measures the percentage of time the AGVs are transporting the full and empty pallets during the entire simulation. It is represented by the colour blue in the graph.
- Portion of Loading/Unloading: This parameter showcases the time AGVs were involved in loading and unloading action during the simulation. It is represented by the colour turquoise in the graph.
- Portion of Charging: This parameter gives the total time the AGV was involved in charging action during the simulation. It is represented by the colour green.
- Portion of Blocking: Portion of blocking expresses the percentage of time in which the unwanted and unscheduled waiting of the AGVs occurred in the simulation. It is represented by the colour red in the graphs.
- Portion of Waiting: This parameter expresses the waiting times that are scheduled, accounted for, and managed and are part of the AGV running mechanisms. They are represented by the colour yellow.
- Portion of Non-productive time: A portion of non-productive time is when breaks are scheduled in shifts, and simulation is halted briefly during this time to replicate the real-life scenario of the assembly lines. It is represented using the colour grey.

The AGV system tested in the simulation needs to fulfil specific requirements to be recommended. Those requirements are listed below:

1. AGV should meet the throughput of 1500 batteries daily, which would be 214 pallets in one day and 1070 pallets outputted in one 5-day run.
2. AGVs should have transportation values between 50 to 60%
3. AGVs should have loading/unloading times below 15%
4. AGVs should have an even distribution of timings for the above-described parameters.
5. The overall utilisation of AGVs should be between 80% to 90%.

Unfortunately, the 4AGV system does not fulfil the first condition, but it is still analysed to define the starting point for selecting an AGV system for analysis. The picture below illustrates the maximum pallets each AGV system delivers in one simulation run.

Experiment	Used AGV+2	Empty pallets reached the warehouse
Estimation of AGVs	1	
Estimation of AGVs	2	944
Estimation of AGVs	3	1400
Estimation of AGVs	4	1400
Estimation of AGVs	5	1400
Estimation of AGVs	6	1400

Figure 52: Maximum pallets delivered by the AGV systems [source: own]

The above picture shows the maximum number of pallets delivered by the AGV systems starting from 4 AGV systems. The second column illustrates the total number of AGVs, which is added by +2 as there are two AGV sources, one in the Warehouse and the other in the Assembly line.

The total number of pallets to be delivered is 1070 in 5 days, consisting of 7490 batteries in a week, accounting for a throughput of approximately 1500 batteries per day, around 214 pallets per day. By accounting for the total number, the experiment begins with 4 AGV systems, which deliver 944 pallets in 5 days of simulation run, which will be 188 pallets in 1 day and a total throughput of 1320 batteries, which is pretty low from the required value. Whereas the other systems are capable of delivering 1400 pallets at maximum, the simulation is set in a way that aims to output 1070 pallets in one run to calculate the efficiency of the system.

The results obtained for the 4 AGV system are outputted for 944 pallet delivery instead of 1070 pallets, so it automatically rules out the 4 AGV system for recommendation. But for the sake of experimentation and proper documentation, the results for 4 AGV systems are documented and explained briefly. The results for each simulated and tested AGV system are demonstrated, explained appropriately, and discussed in the following sub-chapters.

4.5 4 AGV system:

The 4 AGV system, as the name suggests, is the logistic system with 4 AGVs used for supplying the materials at assembly lines GS 3.1 and 3.2 to fulfil the throughput of 1500 batteries per day that is 214 pallets in one day and 1070 pallets in 5 days. However, the 4 AGV system can only provide 944 pallets in 5 days. i.e. 188 pallets in a day, which would be approximately 1320 batteries per day, which fails to fulfil the throughput requirement. The Graphical visualisation and statistics of the 4 AGV system are shown below:

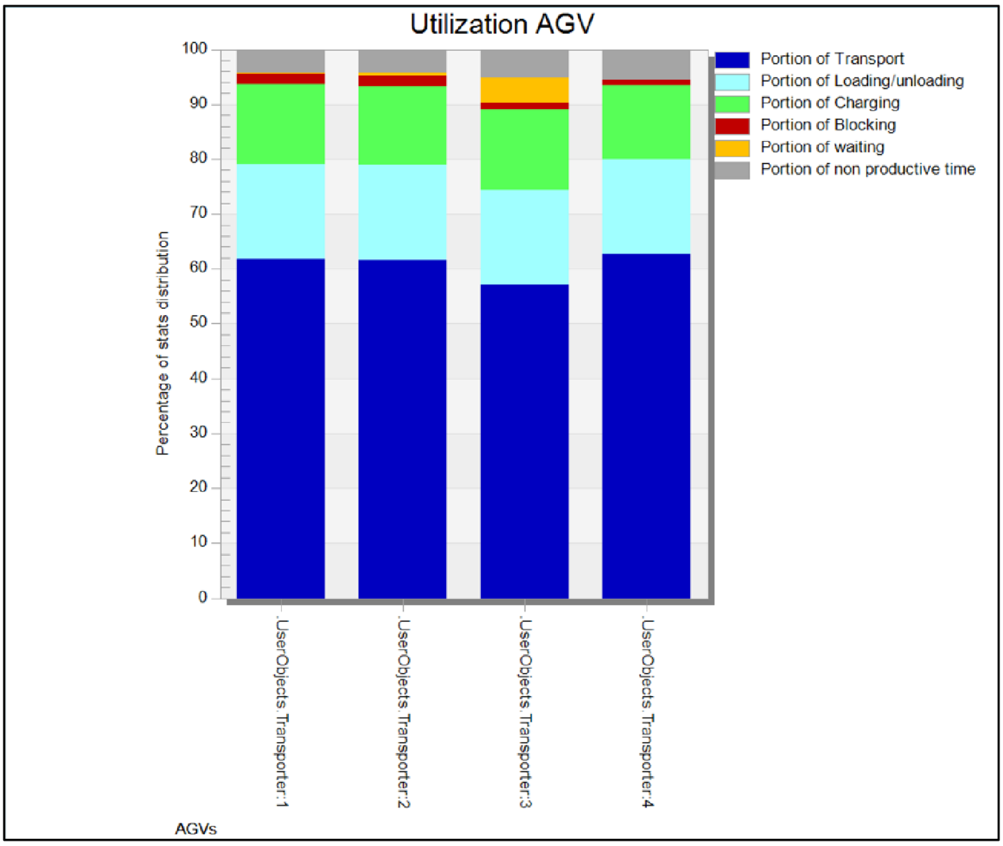

Figure 53: Graphical representation of time Utilization of 4 AGV system in percentage

Parameters	Values in Percentage			
	AGV 1	AGV 2	AGV 3	AGV 4
Transport	61.62	61.61	57.1	62.6
Loading/unloading	16.1	16.2	17.2	17.2
Charging	14	14.1	14.6	13.5
Blocking	1.9	1.98	1.1	1
Waiting	0.17	0.4	4.6	0
Non-Productive time	8.3	8.3	8.3	8.3
Total Utilisation	91.89	92.31	93.5	93.3

Table 7: Time Utilisation of 4 AGV system [source: own]

Result analysis:

- The above system fails to meet the Throughput of 1500 batteries/day.
- The Total transportation time of the AGV is above 60% for all of them, which is higher than the standard value for the throughput of 1300 batteries.
- The loading/unloading times also have a higher value than expected.
- The waiting time is pretty low. There are only 4 AGVs and plenty of material to be transported, so the routing and scheduling of AGVs are more manageable due to their low numbers. Still, the fourth AGV has no waiting time, implying its continuous run in the shift, which is unsuitable for machines.
- The Blocking time is pretty low, which is ideal overall and is a good thing for any AGV system; overall, The Total Utilisation of the above system is over 90% for each AGV

Conclusion:

- The 4 AGV system does not manage to deliver the throughput.
- The high transportation and loading/unloading time is a bit concerning for the machines' life spans as they are equipped with sensors and delicate systems for continuous use.
- The Low waiting time for AGVs proves that machines are constantly running, which is not ideal.
- Utilization above 90% is not ideal, as the machines are over-utilised, affecting their life span.

In conclusion, the 4 AGV system is unsuitable for the 2-assembly line logistic system.

4.6 5 AGV system:

The 5 AGV system is currently used in the assembly line to supply the materials at the single assembly line GS 3.1. The 5 AGV system used here would supply the materials at 2 assembly lines, GS 3.1 and GS 3.2. The Graphical visualisation and statistics of the 5 AGV system are shown below:

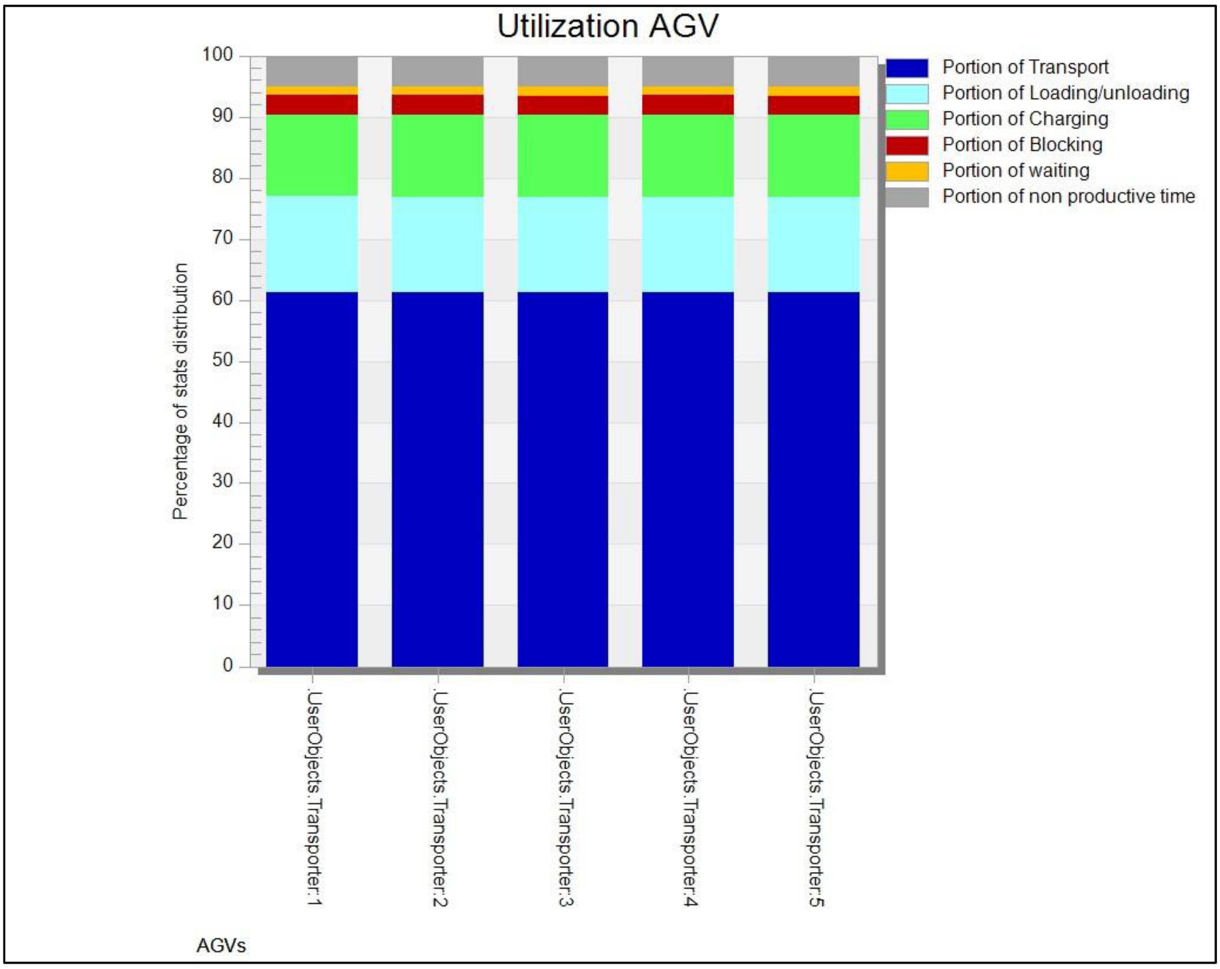

Figure 54: Graphical representation of time Utilization of 5 AGV system in percentage

Parameters	Values in Percentage				
	AGV 1	AGV 2	AGV 3	AGV 4	AGV 5
Transport	61.3	61.2	61.3	61.3	61.2
Loading/unloading	15.5	15.4	15.6	15.5	15.4
Charging	13.4	13.4	13.4	13.4	13.4
Blocking	3.2	3.3	3.2	3.2	3.2
Waiting	1.3	1.4	1.4	1.4	1.63
Non-Productive time	8.3	8.3	8.3	8.3	8.3
Total Utilisation	91.5	91.4	91.7	91.6	91.63

Table 8: Time Utilisation of 5 AGV system

Result analysis:

- The Total transportation time of the AGV is above 60% for all of them, which is higher than the standard value.
- The loading/unloading times are over 15%, a higher value than expected.
- The waiting time is low.
- The Blocking time is low, which is ideal overall and is a good thing for any AGV system; overall, The Total Utilisation of the above system is over 90% for each AGV

Conclusion:

- The 5 AGV system does manage to deliver the throughput. Still, the high transportation and loading/unloading time is higher in this case as well, which is unsuitable for the life span of machines as they are equipped with sensors and delicate systems for continuous use.
- Utilization above 90% is not ideal, as the machines are being over-utilised, affecting their life span.

In conclusion, the 5-AGV system is unsuitable for the 2-assembly-line logistic system. The above system's total utilisation is over 90% for each AGV.

4.7 6 AGV system:

The 6 AGV system is simulated to supply 1500 batteries per day. With 4 AGVs stationed at the warehouse and 2 AGVs at the assembly line, the setup aims to provide materials at both lines GS 3.1 and 3.2. The following graph and table show the simulation's results throughout a 5-day shift.

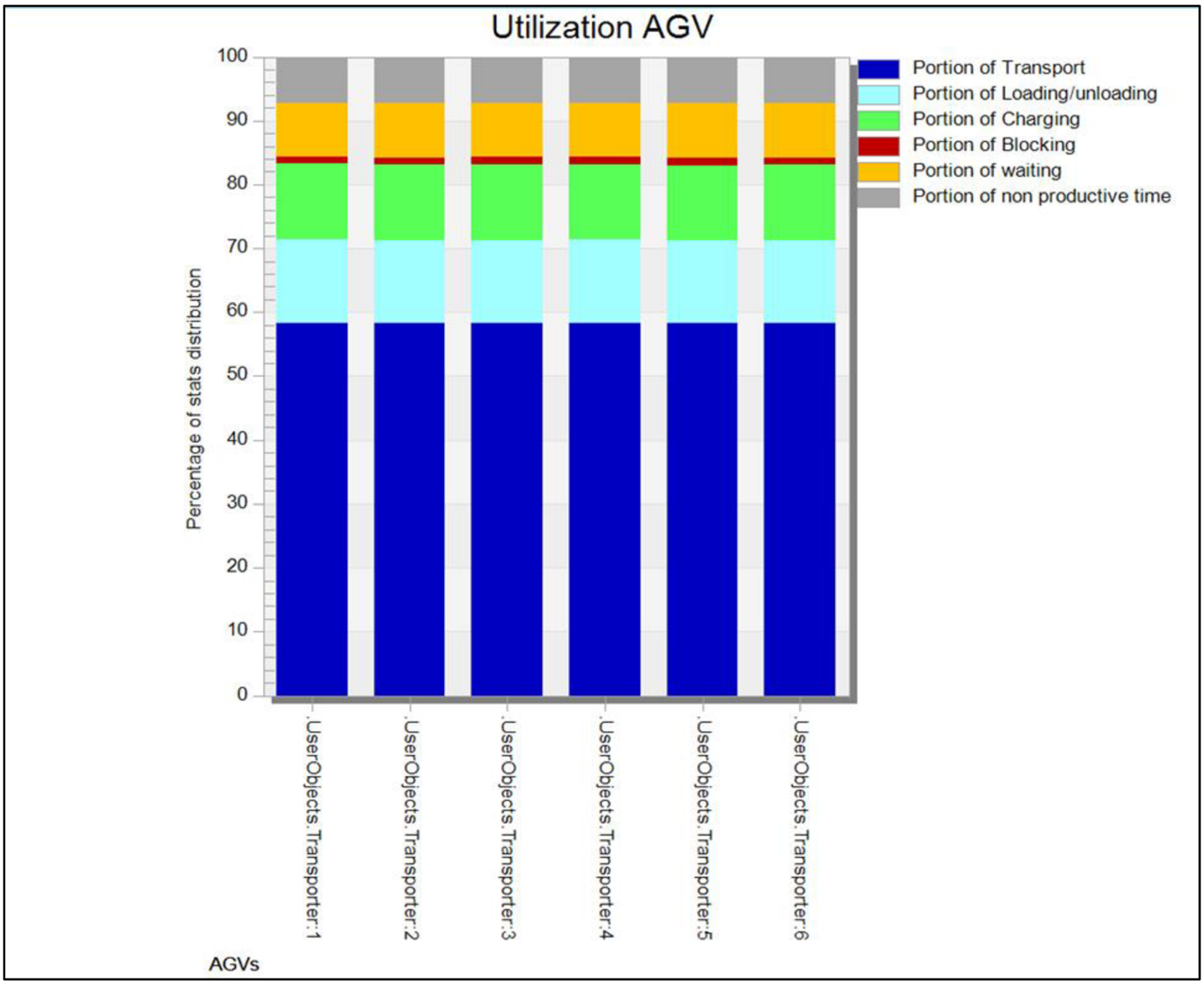

Figure 55: Graphical representation of time Utilization of 6 AGV system in percentage [source: own]

Parameters	Values in Percentage					
	AGV 1	AGV 2	AGV 3	AGV 4	AGV 5	AGV 6
Transport	53.3	54.3	55.3	56.3	54.3	56.3
Loading/unloading	10.9	10.9	10.9	10.9	10.9	10.9
Charging	11.8	11.8	11.8	11.8	11.8	11.8
Blocking	1	1.1	1.1	1	1.1	1.1
Waiting	7.4	7.5	7.6	7.6	7.5	7.6
Non-Productive time	8.3	8.3	8.3	8.3	8.3	8.3
Total Utilisation	83.4	84.5	85.6	83.6	83.5	84.6

Table 9: Time Utilisation of 6 AGV system [source: own]

Result analysis:

- The total transportation time of each AGV is around 55-56%, which is an optimal value.
- The Transportation is distributed evenly among the AGVs.
- The Blocking time is pretty low.
- The waiting time is higher comparatively.
- The Loading/Unloading time is below 15% for every AGV, which is optimal.

Conclusion:

- The 6 AGV system delivers throughput with optimal transportation and loading/unloading time, which is good for the AGVs' lifespan.
- The blocking time is pretty low for this system.
- Due to even numbers, the routing of AGV is relatively more straightforward.
- The Total Utilisation of the above system is around 84% for each AGV, which is lower than the threshold value.

In conclusion, the 6 AGV system is suitable for supplying the material for 2 assembly line logistic systems.

4.8 7 AGV system:

The 7 AGV system is simulated to supply 1500 batteries per day. With 5 AGVs stationed at the warehouse and 2 AGVs at the assembly line, the setup aims to provide materials at both lines GS 3.1 and 3.2. The following graph and table show the simulation's results over a 5-day shift.

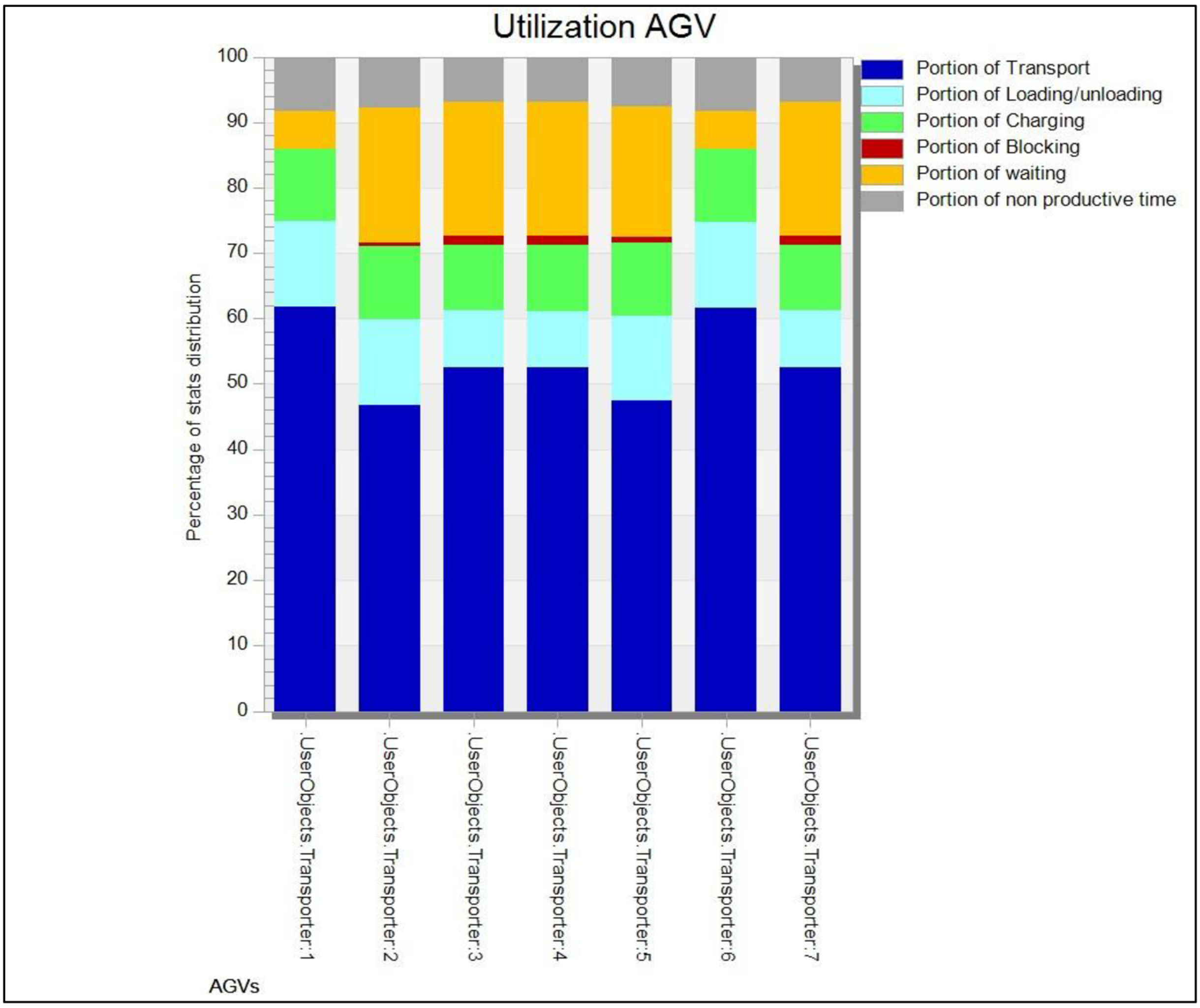

Figure 56: Graphical representation of time Utilization of 7 AGV system in percentage [source: own]

Parameters	Values in Percentage						
	AGV 1	AGV 2	AGV 3	AGV 4	AGV 5	AGV 6	AGV 7
Transport	61.8	46.8	52.5	52.5	47.5	61.7	52.5
Loading/unloading	13	12.9	8.6	8.6	12.9	12.9	8.6
Charging	11.1	11.1	10.1	11.1	11.1	11.2	10
Blocking	0	0.6	1.4	1.4	0.7	0.1	1.4
Waiting	5.56	20.6	20.3	20.4	20	5.7	20.2
Non-Productive time	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Total Utilisation	91.46	91.4	91.5	92.6	91.5	91.46	91.6

Table 10: Time Utilisation of 7 AGV system [source: own]

Result Analysis:

- The total transportation time for each AGV is unevenly distributed.
- The AGV transportation time is sometimes lower than the standard utilisation values.
- The Loading/Unloading time is lower but uneven due to uneven utilisation.
- The Waiting time is much higher than all the systems and higher than standard acceptable Values.
- The blocking time is low.

Conclusion:

- The 7 AGV system does manage to deliver the throughput, but the transportation times are uneven.
- Waiting times are quite high, which results in the under-utilisation of AGVs in terms of transportation.
- The uneven wait times make the routing of AGVs difficult.
- The higher wait times result in AGV utilisation crossing the 90% mark, which is higher than the standard value.

In conclusion, the unevenness of the 7 AGV system makes it unsuitable for supplying the material for 2 assembly-line logistic systems.

5 Conclusion

This thesis's approach is in tandem with Skoda Auto's "Simply clever" motto and the pursuit of excellence. Its purpose was to optimize the automated logistics system to meet the requirements of the two assembly line systems, which aims to increase the production of EV batteries. The primary approach for understanding the problem was DMAIC. With the implementation of the Simulation software Tecnomatix plant Simulation, the simulation of the lines became more intuitive.

The essential concepts of Logistics were vital in defining and understanding the reasoning behind the problems. Concepts such as the spaghetti diagram, principle of process design, and Sankey diagram helped me understand the flow, set some base benchmarks and rules, and understand the quantitative information of the layout. Alongside the material exchange, it was equally important to understand how the intel exchange occurs regularly and how efficient the flow is, which enables seamless assembly and production in massive manufacturing units. These were understood using process diagrams and achieved using the combination of modern logistics aiding systems such as MES, etc.

The last but not least piece of the puzzle was AGV, which included understanding, analysing, and evaluating the AGVs. This was done using a comparative study of the specifications and individual assessments of each AGV for specific purposes. After the comparative analysis, it was straightforward to conclude that AGV 1500FES was the best suited for the current assembly line. Its dimensional capacity and versatile movement gave it a clear advantage over the other AGVs.

The simulation approach is deterministic and discrete. Simply put, Simulation works under specific timings and a set of tasks necessary to achieve the goal of a throughput of 1500 batteries per day in this case. The number of AGVs is crucial in meeting the throughput efficiently, completing the production plan, and ensuring the safety and appropriate utilisation of the AGVs. Four simulation scenarios were run multiple times to achieve the goal of throughput. Those 4 scenarios were 4 AGV setup, 5 AGV setup, 6 AGV setup and 7 AGV setup. Of the 4 scenarios, 1 had a hardware safety and logistical edge. Before discussing that scenario, it would be appropriate to discuss each system's results briefly. The 4 AGV system does not meet the required throughput requirements, which quickly rules it out for consideration. 5 AGV system had a significant flaw in that its transportation time and loading/unloading times were higher than optimal values, which resulted in their total utilisation being above 90%, which is pretty high for types of machinery involved in high volume production. The 6 AGV system had optimal transport and loading/unloading times. However, the waiting times were slightly higher than previous systems but still within the optimal value, resulting in total utilisation of about 84% on average, below the threshold value. The final scenario, which has a 7 AGV system, was pretty uneven regarding transportation times. At times, the transportation times were below the optimal values. Despite the transportation times being low, the system had total utilisation above 90% as well, and this was due to the high waiting times, which were also uneven, making it challenging to plan and manage.

In conclusion, it would be safe to say that the 6 AGV system has optimum utilisation, and its ease of scheduling gives it a clear edge over other systems. The 6 AGV system embodies a distinct balance of utilisation and routing, which makes it easier to recommend for implementation in Skoda Auto's plans.

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